

Electronics for Artists

by Bill Urmenyi

Foreword by Guy Brett

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Foreword

Foreword to *Electronics for Artists* by Bill Urmenyi
by Guy Brett [15th June 2001]

Earth, air, fire and water: the words themselves have an ancient, foundational ring about them. Electricity appears more modern, but of course it isn't. Only the formation, the familiarity, the naming, of electricity as a form and a concept is apparently more recent in human experience. The use of electricity by artists even more so! Despite the existence of some remarkable bodies of work, beginning in the 1920s with such figures as Lazlo Moholy-Nagy, Naum Gabo and Marcel Duchamp and continuing with the kinetic movements of the 1950s and 1960s, up until today's extremely diverse practices, consideration of the influx into art of a material which is also an energy has been rare. Manuals of painting and drawing abound; they have been common in Europe for centuries, and in cultures like the Chinese for millennia. But books which treat the nature and behaviour of this form of energy, with the needs of visual artists in mind, have been hard to find. Bill Urmenyi's manual on "Electronics for Artists" must be one of the first, surely the first on CD-Rom.

My own introduction to contemporary art was fundamentally influenced by two masters of electricity who I came to know in the 1960s: the Greek artist Takis and the Swiss artist Jean Tinguely. In many ways, by temperament, by vision, they were opposites. Takis seemed to seek out the pure heart of electricity. It might be manifested in the blue haze of a rectifier lamp, sending sparks running over a pool of mercury, or in the trembling of a taught wire holding a nail floating a few centimetres from a magnet, in the pulse of needles over a battery of dials, orchestrated by Takis's idiosyncratic circuitry, or in the penetrating *twang* coming from his austere wall-hung electronic harps. Takis spoke of the need to follow the "profound spontaneity" of materials. His aesthetic was so close to the elemental energy itself that when his 'Telemagnetic Sculpture' first appeared at the end of the 1950s many took it as a direct manifestation of the forces of nature, without any artistic or symbolic intervention by the artist. Takis was very partial, for example, to the forms of porcelain insulators - objects directly shaped by material necessity.

If Takis seemed to aim towards the cosmos, Jean Tinguely was firmly planted in the human world. Not that his work is any less a manifestation of energy and movement, or any less experimental and inventive in its use of electricity. Generations of technicians had channelled the raw force into the tight coils of the electric motor and its reliable, repetitive, controlled movement. Tinguely set it free again. By taking motors, mounting them in precarious instability to animate an assemblage of junk and carefully chosen trivia, he gave back to machines the

anarchic freedom of clowns and carnival dancers who know how to banish human cares by banishing the rigid and humourless. Tinguely had a rough and affectionate attitude towards his materials (“I made experiments, I beat up the motors, I put together the most incongruous things”) and his art was closely allied with his political attitudes, in which, he said, he was “against all types of force which come together and crystallise into an authority which oppresses other people”.

Both Takis and Tinguely found their own way to work with electricity. Takis in the 1960s would hide behind the door of his small room in Paris when he first wired up and switched on a new piece, just in case everything blew up. Bill Urmenyi shares this spirit, being an artist himself. Just for this reason, his manual is a practical, accessible and expert step-by-step guide to the way electricity should be handled and brought into play. His aim is to “excite the mind of the artist with the possibilities that are available”, but he imposes no aesthetic of his own. He entirely respects the imaginations of his readers.

Guy Brett
London, 2001

Introduction

This book is written using Adobe® Acrobat®, which is a powerful program with all manner of useful features including word and phrase search. The first thing to do is to use the **help** facility to learn how to use Acrobat.

This book is not intended as a textbook for electronic engineers but is for artists. No prior knowledge of mathematics or electronics is assumed. This book is specifically aimed at artists who have a need for particular types of circuits but may be of interest to hobbyists as well.

The book explains simple mathematics and electronic theory together with descriptions of common electronic components. This is to provide the artist with sufficient knowledge to understand the circuits described at a level, which should enable them to build and test them. It is assumed that it is unlikely that every circuit built will be exactly as described in this book, as mistakes in construction are common. The book therefore includes the necessary instructions in construction, faultfinding and circuit testing to ensure that the circuits will function correctly and reliably.

The circuits described in this book are in a modular form so that the reader will be able to combine a number of them to build a complete circuit. There are chapters on construction, test equipment, tools, power supplies, sensing devices, timers, control circuits, switches, amplifiers and output devices like motors, lights and loud speakers. This modular circuit design can be likened to using building bricks to construct complex structures using a number of simple component parts. Chapter 18 shows you how to do this and has a list of the circuits described in the cd. You can use this list as an index and easy way of navigating the cd

The reader will appreciate that just giving a circuit and details of how to construct it, is not going to help them very much if the final circuit does not function correctly. They will not have the knowledge to find out what is wrong with it. It is therefore essential that a small amount of technical knowledge is included in this book and the writer assumes that the reader fully understands each chapter before progressing to the next. This applies to chapters 1 to 7. The rest of the chapters deal with circuits, which perform particular types of function like sensors and timers. There are a large number of circuits described in this cd and it is unlikely that the reader will need all of them, so there is no need to read them all. Chapter 18 describes how to select which ones to use.

The cd keeps mathematical formulae to a minimum using an empirical approach wherever possible but the reader will have to understand the basic principles.

The reader should appreciate that electronic design engineers have had many years of training followed by many years of experience and that a simple book is not a substitute for that. This book is intended to give just enough knowledge to build, modify, and test the simple circuits that are most useful to artists.

The circuits described herein have been designed to allow them to be connected directly to other circuits within this cd. The effect of this is that there is a robustness of design at the expense of elegance. There will often be some simpler way of making a complete circuit but there are far too many combinations to deal with in a simple way. Some of the circuits have been designed to make them easy to test and fault find at the expense of elegance. Some of the circuits would be easier if microprocessors were used but this would mean learning how to use microprocessors within circuits (these are known as embedded circuits). This cd does not deal with this, as it would be difficult for a beginner to know whether it is computer program error or an error in the circuit, which prevents the completed design from working. There are many books available on the subject of embedded systems and microprocessors. Chapter 17 of this cd gives some advice on the use of microprocessors.

Chapter 1

Essential Mathematics

Introduction:

It is appreciated that some of the readers will have avoided mathematics at school on the grounds that it was boring. This chapter will not get involved in any complex mathematics but some knowledge of number systems and simple algebra is essential as it will be very difficult to find out why a circuit does not perform as expected if the reader has no understanding of how the circuit works. The various components (electronic bits) usually have different numeric values and the reader will have to know what that means and what effects changes in those values will have on the circuits.

The fact is that mathematics is not boring, only the teachers of it are boring.

Number systems:

Denary/Decimal:

Most people count in tens because they have five digits on each hand and have two hands. Counting in tens produces the denary number system. This is called numbers to the base 10. There are other number systems with different bases, some of which will be discussed later in this chapter.

Numbers are just numbers and have no meaning unless they are assigned to some object, value or parameter of some kind. For example 5 is just a number but 5 apples signifies a quantity of apples. It does not tell you anything about the apples except that there are 5 of them. Apples have other qualities such as size shape taste etc. We would need some different numbers and some measurement means to quantify the other parameters (qualities).

The denary number system is not limited to the numbers 0 to 9 but is extendible. The number 34 for example has two digits, a 3 and a 4. The 3 because of its position in the number means that there are 30 and the 4 means that there are an additional 4. The 3 counts in tens and the 4 in units. We can now use the same digits to give 340, which is of course 10 times bigger. There are now no units, 4 tens and three hundreds. If we keep going in this manner we can keep the same two digits in the same order but by simply changing the number of zeros, the value of the number changes.

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How about 34000000 which is a rather cumbersome number to deal with so we use a shorthand method of describing the number, we call it 34 million. There are other ways of expressing it, which are far more useful and will be used in the remainder of this book. If you count the number of zeros after the 34 you will find that there are 6 of them and we denote this by 10^6 . The 6 in this example means the number of times 10 is multiplied by itself. So 34000000 can be written 34×10^6 and 34000 can be written 34×10^3 .

You should understand that in the field of electronics, numbers tend to be either very large or very small. You will need to be able to understand and manipulate them.

Now let us consider what happens when the numbers are divided by tens instead of being multiplied by tens. We now cease to be using denary which is for whole numbers and start using decimals. Deci means one tenth and a decimal point is a full stop. The decimal point indicates the point in the number which separates the fractions of ten from the whole number.

If we start with our number 34 and divide by ten we get 3.4 which means 3 units and 4 tenths of a unit. If we divide by ten again we get .34 which is written 0.34 by convention so that it can easily be seen where the decimal point begins. In this case we have 3 tenths plus 4 hundredths. So what about the number 0.034, which is 3 hundredths plus 4 thousandths.

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IMAGE

We can make that easier to handle in the same way as the large numbers by writing it as 34×10^{-3} . You will note that it is 10^{-3} and not 10^3 . The sign of this number behaves in the same way as ordinary numbers but when you want to multiply or divide these numbers you have to add or subtract the little raised numbers, called exponents.

For example, multiply ten thousand by one thousandth. The result is ten. Now look at our way of writing the numbers. $10^4 \times 10^{-3}$. You will note that we get the same answer by adding the exponents $4 + -3 = 1$ and 10^1 is 10. If we now divide ten thousand by one thousandth, we get ten million. We get the same answer by subtracting the exponents $4 - -3 = 4+3=7$. If you subtract a negative number that is the same as adding a positive number.

You will be familiar with a few words which are used to express these exponentials. Words like deci, centi, milli, micro, Kilo and Mega are all in

common use as in deciBell for sound levels, centimetre, millimetre, micro computer, Kilometre and MegaHertz for radio frequencies. These prefixes can be used for anything you want and a complete list giving the corresponding exponent values and symbols is shown below. You will note that the positive exponents all have upper case letters and the negative exponents all have lower case letters. The classical scholars will note that they are split into Latin and Greek.

Name	Letter	Exponent
tera	T	10^{12}
giga	G	10^9
mega	M	10^6
kilo	K	10^3
hecto	H	10^2
deca	Da	10
deci	d	10^{-1}
centi	c	10^{-2}
milli	m	10^{-3}
micro	μ	10^{-6}
nano	n	10^{-9}
pico	p	10^{-12}
femto	f	10^{-15}
atto	a	10^{-18}

Now we have another means of writing down numbers. We can use the above letters in place of the exponentials. For example 34×10^6 can be written 34M and 34×10^{-3} can be written 34m. It is common practice to use the letter in place of the decimal point for ease of reading. So the number 3400 may be written as 3K4 .

Binary/Bicimal:

We have considered numbers with a base of 10. Digital electronics uses a number system to the base 2. That is because there are only two states, on and off which may also be known as true and false. A '1' is on and true, and a '0' is off and false.

When dealing with these numbers you will have to realise that AND does not mean plus. You were probably incorrectly told in your school days that it does. AND and plus are two completely separate mathematical functions and should not be confused. The AND function will be described in the chapter on digital circuits but it would be good to start using the word plus when you mean plus and not to use the word AND for the same function.

In the binary number system the rules of mathematics still apply, only the numbers appear different. The units digit can either be 1 or 0 so the next digit will represent numbers which are 2 times as big and not 10 times as they were in the denary system. The easiest way to demonstrate this is by means of the following conversion table between denary and binary.

DENARY	BINARY
00	0000
01	0001
02	0010
03	00011
04	00100
05	00101
06	00110
07	00111
08	01000
09	01001
10	01010
11	01011
12	01100
13	01101
14	01110
15	01111
16	10000
17	10001
18	10010
19	10011
20	10100
21	10101

CLICK ON
IMAGE

If you look at the way in which the digits change you should see that the mechanism by which the digits change is the same for both denary and binary. The difference is that the binary changes every other time for the least significant digit, every second time for the next significant bit (digit), every fourth time for the third significant bit and so on rather than every tenth time

for the second digit and every one hundredth time for the next digit as it does with denary.

Bicimal works in the same way with binary as decimal does with denary. The first bit after the bicimal point being one half and the second bit being one quarter and so on. You are not likely to become involved with bicimal numbers and they are only mentioned here briefly for completion and an understanding that decimals are not unique in the numbering systems.

Hexadenary/Hexadecimal:

These numbers are to the base 16 and are commonly used in digital systems as they are more easily read than binary and bicimal numbers. They count as follows: 01 02 03 04 05 06 07 08 09 0A 0B 0C 0D 0E 0F 10 11 12 13 14 15 and so on.

Basic Algebra:

Equations:

Equations are just what they say they are, no mystery at all. They are statements of equality, that is, they say that one thing is numerically equal to another. Equations are a means of finding out what we don't know by examining and formalising what we do know.

Let us say for example that I have 5 bananas. We can make a simple equation out of that by stating it in a different way i.e.

Number of bananas I have = 5

That is an equation. It is particularly useless but the principle is there. Let us say for example that I always have twice as many apples as I have bananas, then if I know how many apples I have I can calculate how many bananas I have or if I know how many bananas I have, I can calculate how many apples I have. The equation for that is:

No. of apples = 2 x No. of bananas

That looks a bit wordy and cumbersome so let us give the number of apples a name. Let us call it A and let us call the number of bananas B. A and B are called variables as they can vary and the number 2 is a constant because it can't.

Now the equation looks like this:

$$A = 2 \times B$$

It has now become convention to use * instead of x as using x can be confusing if the letter x is also used as a variable.

Manipulating Equations:

The equation as written is very convenient if we want to know how many apples we have, but not so convenient if we want to find out how many bananas we have.

The thing about equations is that whatever is to the left-hand side of the equals sign, equals whatever is to the right hand side. It follows then that if we add anything equally to both sides of the equals sign, the equation will remain true. Similarly if we perform any mathematical function to both sides of the equals sign, the equation will remain true. This is the basis for algebra and allows us to manipulate equations to our advantage.

So let us look at our equation $A = 2 * B$. We want to know what B= but we only know what A is in terms of B or what $2 * B$ is. If we divide both sides by 2 we will know what B is, as $2/2 = 1$ and $1 * B = B$. So we now get $A/2 = B$. Let us rewrite that again

$A/2 = B$ is the same as

$$B = A / 2$$

But we don't like fractions much so let us decimalize the right hand side of the equation. If we look at $A / 2$ we can see that if we multiply it by the same number as we divide it by, we will not change its value. So let us multiply and divide by 10 to give us $(10 * A) / 20$. Now let us divide and multiply by 2 which gives us $(5 * A) / 10$. We know from our look at decimals that 5 divided by 10 is 0.5 so the final equation is

$$B = 0.5 * A$$

This is clearly a very long way of doing it but after a short while it will become second nature and the process of manipulating equations will become straight forward and quick.

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That is all you need to know about algebra for the time being. Boolean algebra, which is the manipulation of truth and falsehood will be discussed briefly in the chapter on digital circuits.

Chapter 2

Electronic Theory

Current/Voltage/Resistance:

We will initially be dealing with circuits, which are battery driven and not mains driven. Batteries produce a direct voltage and the mains supply produces an alternating voltage, which will be dealt with later.

A Voltage is a force. It pushes and pulls things. What it pushes and pulls are charged particles, usually electrons, which are negatively charged particles, which form part of matter. Matter being the stuff around you like air, the floor beneath you and this cd. The unit of measurement is the Volt named after Voltaire.

Current is the rate of flow of these charged particles. It is measured in Amps, named after Ampere. An Amp is approximately 10^{19} electrons per second (A huge amount).

Resistance is the resistance to the flow of current. It is measured in Ohms named after Ohm. Everything has a resistance, a piece of metal has a low resistance and a piece of wood has a high resistance. Low resistance materials are called conductors and high resistance materials are called insulators.

It will be clear that if the force (Volts) is increased, the rate of flow (Amps) will increase accordingly and that if the resistance to that flow (Ohms) is increased that the rate of flow (Amps) will decrease accordingly. Putting it another way, if you push harder, what you are moving will move faster and if the resistance (or friction) is greater, what you are moving will move slower. Think of that and you will never forget the following formula.

$$I \text{ (Amps)} = V \text{ (Volts)} / R \text{ (Ohms)}$$

Using your knowledge of algebra you can rearrange this formula to suit your needs as below

$$R = V / I$$
$$V = I * R$$

The above formulae describe Ohm's law. You will need this for almost everything you do in electronics, so make sure that you have fully understood it.

Knowing any two of the three variables will enable you to calculate the third. This is what you need algebra for.

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Power:

Power is force times the rate of movement of matter. In electrical terms it is the Voltage multiplied by the Amperage (this only applies for direct voltages and currents) and is measured in Watts named after James Watt. The formula is therefore:

$$W \text{ (Watts)} = V \text{ (Volts)} * I \text{ (Amps)}$$

Again you can use your knowledge of algebra to rearrange the formula to suit your needs. Further more, you can use Ohm's law and combine the two equations to calculate the power if you do not know both the voltage and the current. Say for example that you do not know the current but know the voltage and resistance. You can rearrange the formula as follows:

$$W = V * I$$

$$I = V / R$$

$$\text{Therefore } W = V * (V / R)$$

$$W = V^2 / R$$

Similarly

$$W = V * I$$

$$V = I * R$$

$$\text{Therefore } W = I * R * I$$

$$W = I^2 * R$$

You will need to know this, as power makes things hot and if they get hot enough they will get permanently damaged.

Charge/Capacitance:

We have already mentioned that an electric current is a rate of flow of charged particles. Well charge is the amount of charged particles and is measured in Coulombs after Coulomb. So the Amp is a Coulomb per second.

$$Q \text{ (Coulombs)} = I \text{ (Amps)} * t \text{ (Seconds)}$$

Capacitance is the ability to store charge and is measured in Farads after Faraday. If you charge up a capacitor by making a current flow into it, a voltage will appear across it. The greater the capacitance, the more charge it holds for the same voltage.

$$C \text{ (Farads)} = Q \text{ (coulombs)} / V \text{ (Volts)}$$

$$Q = C * V$$

$$V = Q / C$$

You will note that time is in the equation for Coulombs and therefore is, by combining the equations, also a factor in capacitance. This is one of the reasons for capacitance being of special interest to the artist. A Farad is a very large unit and when dealing with capacitors you will need to use micro, nano and pico to avoid very long decimal numbers.

Inductance:

Inductance is somewhat more difficult to understand as it deals with electromagnetism. If ever you want to make something move electrically, you will be involved with induction. If an electric current passes through a conductor (a piece of wire for example) a magnetic field is produced. If that current changes, so will the magnetic field. A changing magnetic field will cause a current to flow in a conductor placed within that field. This is called an induced current. That induced current itself causes a magnetic field, which opposes the field, which produced it in the first place. These are the fundamental principles which make electric motors work. This really is too complex to explain adequately within the scope of this cd. What you need to know about inductance apart from the formula below will be explained in the chapters dealing with motors, solenoids, relays, chokes and transformers.

The unit of inductance is the Henry and is named after Joseph Henry. If a current in an inductor having an inductance of one Henry changes by one amp per second, then a voltage of one volt will appear across it.

$$L \text{ (Henrys)} = V \text{ (Volts)} * t \text{ (Seconds)} / I \text{ (Amps)}$$

The easier way to look at it is to say that the induced voltage increases with the current and the inductance and reduces with time. This gives us the formula:

$$V = L * I / t$$

The significance of this formula is that if time becomes zero, the voltage will be infinite. Time will be zero if you have a current in an inductor and then switch it off. This could seriously damage your circuits if you do not take preventative action.

This attribute can also be used to advantage. A choke, which is an inductance, is often used in power supplies to prevent current surges.

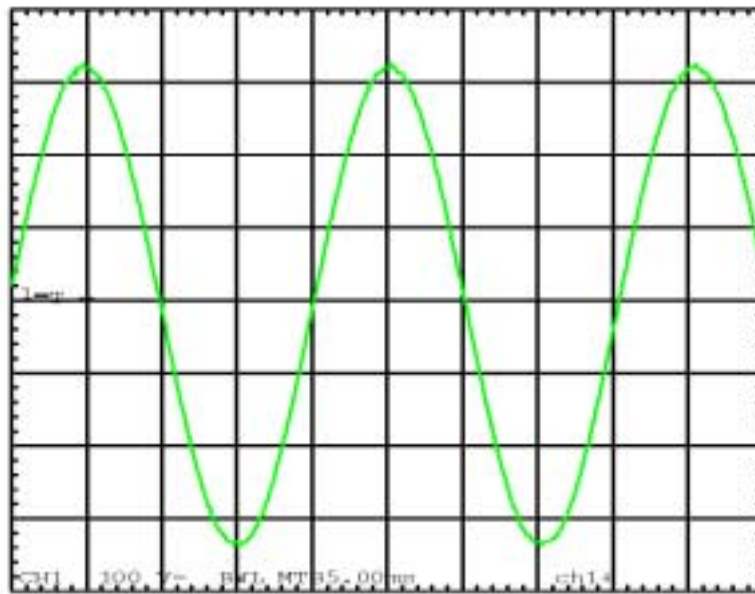
Alternating Voltages and Currents:

Here we have to consider time. Unlike direct voltages, alternating voltages change polarity in a cyclic manner. That is, they change from positive to negative and back again in a continuous cycle. The mains supply is like this. The mains supply in the UK is 240 Volts 50 Hertz. Hertz is the frequency in cycles per second and is named after Hertz. This means that the voltage changes polarity and back again 50 times per second. The 240 Volts may be a bit misleading as the peak voltage is much higher. The Voltage is measured so that if you had a purely resistive load, (one without capacitance or inductance) you could use the formulae for power in Watts and get the right answer. The 240 Volts is a kind of average known as a root mean square the description of which is beyond the scope of this cd. The complication arises because the change of polarity is not instantaneous but follows a smooth pattern, which is essentially a sine wave.

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0 Volts -----



Large divisions vertically are 100 Volts each
Large divisions horizontally are 5 mSeconds each
Oscilloscope view of UK mains supply of 240 V 50 Hz

In the picture above you can see a sine wave. The oscilloscope will be explained in the chapter on test equipment. What can be seen here is a picture, produced by making a dot of light move vertically with voltage and horizontally with time. As can be seen, it takes 20 mSeconds for the cycle to repeat itself. 20 mSec is one fiftieth of one second, which means that it will repeat itself 50 times in one second, or in other words 50 Hertz. In some countries the mains supply frequency is different. In particular 60 Hertz is used in the USA. You should note that the Voltage goes alternately positive and negative and that the peak voltages are much higher than 240 Volts. 240 Volts is a kind of average called a Root Mean Square (RMS).

Reactance:

Capacitors and inductors behave in a different way according to whether the voltages and currents are direct or alternating. As mentioned both have an element of time in their formulae.

Consider the capacitor: if you apply a voltage across it, it charges up and after that no current passes through it and it looks like an infinite resistor. If on the other hand the voltage across it is continually changing, it will be continuously charging up and discharging. We know that an electric current is a rate of flow of charge and therefore we know that a current flows in the capacitor when the voltage across it changes which it does all the time when alternating voltages are applied to it. Now the current through the capacitor does not follow the voltage across it exactly but lags behind it in time. The voltage causes the current to flow and that is why the current comes after the voltage. This is what is known as a lagging phase shift as it lags behind. The mathematics of this involves the use of complex numbers and falls outside of the scope of this cd

and although of great use to engineers is unlikely to be of great use to the artist who will use a more empirical approach.

If we have a steady state of affairs in which we have a pure sine wave voltage across a capacitor, we will also have a pure sinusoidal current passing through it albeit lagging behind. So we have a component, which has a voltage across it and a current passing through it so it would be nice if we could compare it with a resistor. Well that is what reactance is, it is the resistive equivalent. Now we know that if the capacitance increases so will the current. If we think about it, we will also know that if the frequency increases, the current will also increase. Reactance like resistance is a resistance to the flow of current so we need to invert our formula. Sine waves are derived from a circle so it is not surprising that we have π in our equation, which follows:

$$X_C = 1 / (2 * \pi * f * C)$$

Where X_C is the reactance in Ohms, π is a little over 3, f is the frequency in Hertz, and C is the capacitance in Farads.

One of the things about capacitors is that they present a low resistance to alternating currents but a high resistance to direct currents and can therefore be used to separate the two.

Well the reactance of an inductor is similar to that of a capacitance except that it is the current, which causes the voltage and not the other way round so the phase shift is in the opposite direction. The current leads the voltage and does not lag behind it. In this case the inductance presents a low resistance to direct currents and a high resistance to alternating currents. The formula for the reactance of an inductor follows:

$$X_L = 2 * \pi * f * L$$

Where X_L is the reactance of an inductor in Ohms and L is its inductance in Henrys.

You may use Reactance as though it is resistance in your approximate calculations using Ohms law but you will not get accurate answers if you mix capacitance and/or inductance with resistance because of the phase shifts. To get the right answers you would need more complex mathematics. But to get the right magnitude of component value it is quite adequate. If you really want to know what is going on you can always make the circuit and then measure it, you do not need to do the maths first. It is just that if you do some simple mathematics first you can save some expense and considerable time as well as have a better understanding.

Terminology:

When data are transmitted from one part of the circuit to another or between different systems, the electrical connections are called a bus. You have probably got a USB port on your computer. USB stands for Universal Serial Bus. The word serial, in this context, means that the data are transmitted and received one bit at a time. A character (as in a letter of the alphabet) is usually 8 bits long. Parallel ports and busses usually have 8 data connections to transmit and receive 8 bits at a time.

When power is connected to different parts of a system, it uses rails. So a 0 Volt rail is a conductor, which is used to connect the 0 Volt end of a power supply to various parts of the circuit or system. A 5 Volt rail is the same, except that it is connected to 5 Volts. A rail is just like a bus. The only difference is that a bus is used for data and a rail is used for power.

Just to confuse the issue, some manufacturers sell what they call buss bars. These are used as rails. Don't ask me why!

Chapter 3

General Electronic Components

Electronic components are divided into three main categories, active, passive and electromechanical.

The reader should be aware that there are basically three types of component depending on how they are fixed and connected to the circuit. There are the types, which are fixed using nuts and bolts, and then there are the two types, which are designed to be soldered to a printed circuit board. One type is designed to have its connections pass through a hole in the board. This is the type to use. The other type is designed to be soldered directly to the top of a board without holes. This type is called surface mount and is abbreviated in component catalogues as **SMT**. SMT devices require the use of specialist and very expensive tools, so **DON'T** use them.

Passive components:

These components are called passive because there is no amplifying effect, but without them the circuits cannot function. That was a simplification and not an accurate definition but it should suffice. In this category we find batteries resistors, capacitors and inductors/chokes.

Batteries:

These are really called cells. A battery of cells is a number of interconnected cells. However if you go to your local shop and ask for a cell, they will look at you blankly.

If you can use batteries rather than mains supplies for your works you will gain portability and not have to deal with unsightly mains leads which can also be a safety hazard if not properly installed.

There are several types of cells and batteries available and they are divided into two main types; rechargeable and non-rechargeable. The circuits in this book have been designed to use a 12 Volt supply because that is generally the most useful.

The question that needs to be answered before deciding on a choice of supply is the length of time the work will run before the battery needs to be charged or replaced. The battery will have to drive the circuit for at least the length of time it takes to survive a private view and if nobody is available to charge or change the battery it will have to last for the length of an exhibition. If a battery will last a whole days exhibition and somebody reliable and competent is there at closing time, every day, then you can arrange for the battery to be charged over night and reconnected the following day. Generally speaking it is easier not to

use rechargeable batteries and just have a plentiful supply of non-rechargeable cells unless this will prove too expensive.

There are many different kinds of cell but only three main kinds. They are **alkaline**, **nickel cadmium** (which are rechargeable) and **lead acid** (car batteries). The lead acid batteries can be purchased in smaller sizes than the car battery.

It will be clear that in order to know how long a battery will last, you will have to know the current drawn from it. The capacity of a cell is measured in **Ampere-Hours**, which is how long it will last if you draw an Amp from it.

In some cases there will be a continuous and constant current drawn from the battery and in other cases there will be a small current drain with occasional large current drain. Take for example an artwork in which there is a motor continuously on. The current drain will remain constant. If however the same motor was only turned on for one tenth of the time, the average current would be one tenth and the battery would last ten times as long.

Let us consider a typical case in which we have some kind of electronic circuit, which switches on a motor for 6 seconds every minute. If the electronic control circuit has a current drain of 10 mAmps (this is called the **quiescent current**) and the motor has a current drain of 100 mA then we divide the motor current by 10 as it is only on for one tenth of the time giving us an average motor current of 10 mA and we add to that the quiescent current of the control circuit of 10 mA we have a total average current of 20 mA. Now 20 mA is one fiftieth of 1 A so a battery of 1 Ampere Hour will last for 50 hours and a battery of 7 AHr will last 350 Hr which is long enough for most exhibitions particularly if the work is switched off when the gallery is closed.

Here is where we have to consider the difference between manufacturer's data and practice. The data given is for complete cell discharge at a discharge rate, which gives the highest value of Ampere Hours. When a cell discharges its voltage decreases and its internal resistance increases. Its internal resistance is the resistance of the cell, which limits the current that can be taken from a cell and reduces its voltage when connected to a load (the load being your circuit, a motor for example). When the cell starts to be discharged, its voltage decreases. If the voltage decreases to the value at which your load cannot function correctly (your motor can no longer turn for example) the cell is of no further use. It may still have charge in it though. As a rule of thumb, divide your calculated discharge times by two.

Here is a table of cell capacities for normal alkaline cells.

AAA	1.175	AHr
AA	2.7	AHr

C	7.75	AHr
D	18	AHr
PP3	0.55	AHr

Nickel Cadmium cells have about one third of the capacity of alkaline cells. Car batteries have capacities in the order of 35 AHr depending on their size.

The voltage of the cells varies from one type to another. Alkaline cells are 1.5 V, nickel cadmium are 1.25 V and lead acid are 2 V. To get higher voltages you connect the positive terminal of one cell to the negative terminal of the next cell and so on. This is known as a **series** connection. You will need 8 alkaline cells connected in series to make a 12 V battery. Please note that the PP3 is not a cell but is a 9 V battery. You will be pleased to know that battery holders are readily available.

Never **short** out (connect a wire directly across) a cell or battery. It will ruin the battery.

The reader will be told how to measure currents in a later chapter.

Resistors:

The reader will probably only need to use one of two kinds of resistor. Either low power resistors for general circuitry or power resistors for limiting currents in such things as lights.

I recommend that you use $\frac{1}{4}$ W metal film resistors for general use. With a supply of 12 Volts you will be quite safe using $\frac{1}{4}$ W resistors for all resistance values of 2 KOhm and above.

47K 1% 1/4W RESISTOR



Note the colour bands showing the component value.

For lower values of resistance you will have to calculate the power dissipation in the resistor and use an appropriate Wattage resistor. Please note that when the maximum Wattage of a component is specified in a catalogue, you should bear in mind that that is if the component is mounted on a large piece of metal and placed in a deep freezer. It would be better to assume a real maximum Wattage of less than $\frac{1}{2}$ of the quoted value. I tend to be even more cautious than that and use components, which have a quoted maximum power

dissipation at least 4 times higher than I have calculated that I need. As mentioned in a previous chapter, if power is dissipated in a component, it will get hot and if it gets hot enough it will fail or maybe even set fire to your work. As a general rule, if it hurts to touch a component, then it is too hot and either a component that can dissipate more power should be used or a cooling device should be used.

68 Ohm 5W RESISTOR



Note that the resistor value uses the omega symbol to indicate Ohms

180 Ohm 50W RESISTOR



Note that the resistor uses R to indicate Ohms

Now as we know, resistors have a resistance and that resistance is measured in Ohms. When you buy them they come in series of set values. You can only get other values by ordering them specially or by having precision resistors which are much more expensive. This series of values is known as the **E24** series because there are 24 values per decade. The E stands for exponential, as the difference in value from one to the next is a fixed proportion, which is approximately at 10% intervals. There are other series but this is the most common. Usually these resistors are in the range of 10 Ohms to 1 MOhm.

Here is a list of the first decade of the E24 series:

10
11
12
13
15
16
18
20
22
24
27
30
33
36
39
43
47
51
56
62
68
75
82
91

The next value will of course be 100.

Now these components are rather small so instead of writing the values on them, coloured bands are used. This can be a little confusing as sometimes there are four bands and sometimes five and you have to know which end of the components has the first band. If you end up reading the value the wrong way round it probably won't be on the E24 series. The band system works in the following way. If you have a four band coding then the first two bands give the first two digits of the value. The next band gives the number of zeros that follow that number and the last band gives the tolerance or precision of the resistor, which is normally 1% (brown) if you are using standard metal film resistors. If you have a five band resistor, which is only usually used on precision components, the first three bands give the first three digits of the value, the fourth is for the number of zeros that follow and the last is the tolerance.

Here follows the **colour code**:

Colour	Value
Black	0
Brown	1
Red	2
Orange	3
Yellow	4
Green	5
Blue	6
Mauve	7
Grey	8
White	9

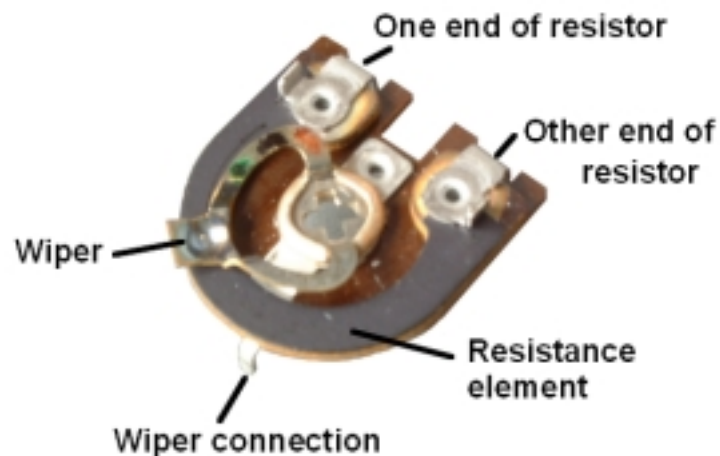
A 1% 4k7 resistor would be marked yellow mauve red brown.

The symbol for Ohms is Ω but in some catalogues it is R. So a 100 Ω resistor may be written 100R.

The reader should be aware that some times the colours are not at all clear. If in doubt check that the values exist in the E24 series and if both values are possible measure the resistance.

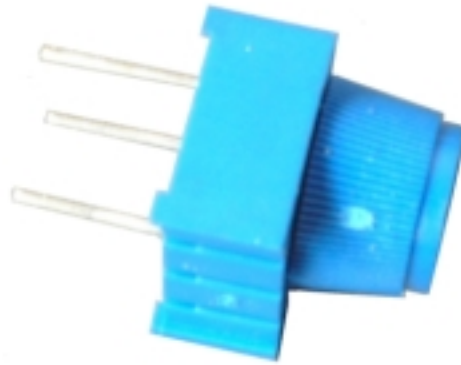
Potentiometers:

Potentiometers are resistors, which have a wiper connector to a part of the resistive element. The wiper is a mechanical contact, which wipes along the resistance element (the bit which has a resistance). The wiper can have its position on the resistance element changed. This is sometimes done with a control knob like the volume control on an audio amplifier and sometimes done with a screwdriver.



The previous image shows a poor quality potentiometer. It has been included here because it shows how potentiometers are constructed. You can see that the wiper can be rotated along the resistance element by means of a screwdriver, which can be inserted in the cross hole in the centre.

The following photograph shows a trimmer potentiometer. This type is used on a board to make semi-permanent adjustments to a circuit.



The following photo' shows a front panel mounted potentiometer. This type can be used as an external control or have its shaft attached to some moving part of a work to give a measure of how far it has moved.



To find out which of the three terminals is which on a potentiometer, set your meter to measure resistance, set the potentiometer to about half way, then measure the resistance between the three terminals. The top and bottom terminals will have the resistance of the value of the potentiometer and the wiper, which is usually the centre terminal, will have about half the resistance to either end.

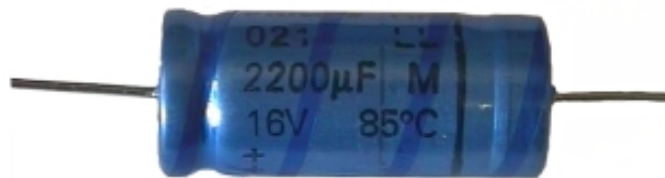
Capacitors:

There are many different types of capacitor but only three that you are likely to use. They are electrolytic, tantalum and ceramic. The choice is generally a matter of the capacitance value.

High value capacitors, that is those with a value greater than 100 μF are usually electrolytic and are polarised, that is they have a positive and a negative end. They should not be connected the wrong way round or they are likely to fail and may do so spectacularly. The metal can of these capacitors is the negative end. There are some specialist electrolytic capacitors, which are non-polarised, but these are not common.

Medium value capacitors with values between 1 μF and 100 μF may be either electrolytic or tantalum but the tantalum are generally better. Again these are polarised and if connected the wrong way round are likely to explode. They make quite a loud bang.

**2200 microFarad 16 V
ELECTROLYTIC CAPACITOR**



**Note that the positive end is to the left and that
the black line indicates the negative end.
You will note that there is a + sign under the 16V marking.**

47 microFarad 25 V TANTALUM CAPACITOR



**Note that Tantalum capacitors have the black line indicating
the positive end of the capacitor.
If you look with a magnifying glass you will always find the
polarity marked on the devices.**

Low value capacitors are usually ceramic and are not polarised and so can be connected either way round.

1 microFarad CERAMIC CAPACITOR



**Note the 105 written on the capacitor.
This is 10 followed by 5 zeros and is the value in picoFarads.
1000000 picoFarads is 1 microFarad**

Capacitors have a voltage rating instead of a wattage rating and electrolytic capacitors also have a **ripple current** rating. Always choose a voltage rating which is at least twice the maximum voltage, which can appear across the capacitor. If you take that advice, you are unlikely to be concerned with the ripple current rating. Ripple currents will be explained in the chapter on power supplies.

Electrolytic capacitors have their values written on them clearly as they are big enough. Ceramic capacitors have their value written in the form of a three-digit number. The first two digits are the first two digits of the value and the last digit is the number of zeros that follow. The complete number is in pF so a value of 224 is 220000 pF which is 220 nF or 0.22 μ F which can also be written 0 μ 22 the F is not needed as it is obvious that it is Farads because it is a capacitor. There can be some confusion as there will probably be some other numbers on the capacitor as well. These may be part numbers or batch numbers.

Inductors and Chokes:

Inductors and chokes are the same things. They are basically coils of wire, which are wound on some kind of magnetic material the most common of which is **ferrite**. Ferrite is a ceramic, which has been impregnated with iron dust. It is very fragile and shatters, so be careful.

0.47 mH INDUCTOR



**Note the markings on this component are on top and not visible in this photograph.
The marking is 474 which means 47 followed by 0000 nanoHenrys which is 470 microHenrys or 0.47 milliHenrys**

The parameters to look out for are the resistance and the current rating. The resistance value, if too high, may be a factor in your circuits but the main consideration is the maximum current rating. Again ensure that this is at least twice what you are actually going to pass through it, or it will overheat.

The inductance values are usually written quite clearly on the devices.

Active Components

Active components fall into two main categories, discrete and integrated. The discrete components are those, which are individual. Integrated components (integrated circuits or chips) are circuits comprising more than one component but packaged as one. So instead of having lots of separate components, the integrated circuit has the circuit pre-built in a single package.

Most active devices these days are **semiconductors**.

Discrete components:

Diodes:

The diode has two ends, a cathode and an anode. A current can pass through a diode from the anode to the cathode (**forward current**) but not the other way

round. It has a low resistance to currents passing one way and a high resistance to currents passing the other way. When the cathode is more positive than the anode (**reverse biased**), there is a very small current flowing. This current is called the **leakage current**.

1 A Diode



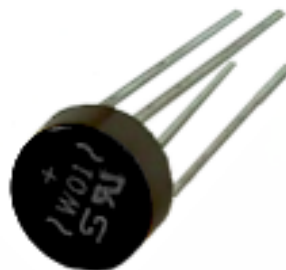
Note the line to the right of the diode indicates the cathode.

When the anode is more positive than the cathode it is known as **forward biased**. For a diode to conduct it must have a sufficient forward bias. The most common semiconductors are silicone and the forward bias on these diodes is of the order of 0.6 Volts when conducting (**Cutin Voltage**).

Diodes have a voltage rating and a current rating. The voltage rating is the maximum reverse voltage and the current rating is the maximum forward current.

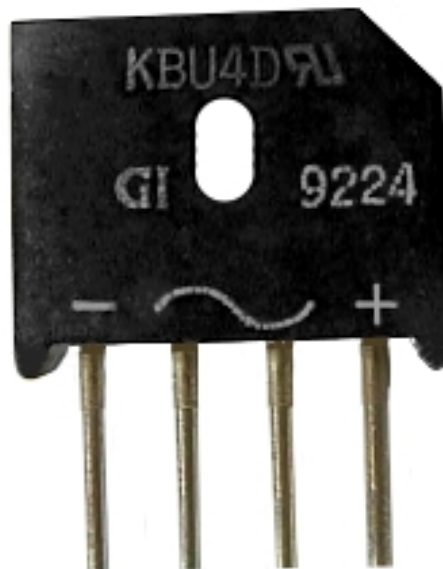
Diodes have two main purposes. One is for low current circuits and these are called **signal diodes**. The other is for high current circuits, like power supplies, and these are called **power diodes** or **rectifier diodes**. When these rectifier diodes are configured in a particular way for converting alternating currents to direct currents, they are known as **bridge rectifiers**.

1A BRIDGE RECTIFIER



Note the slow S a on their sides indicate the alternating voltage inputs and the + sign indicates the positive output.

4A BRIDGE RECTIFIER



Zener Diodes:

Briefly Zener Diodes are designed to break down under reverse voltage conditions at a particular voltage. This voltage is known as the **Zener Voltage**. When at the Zener voltage, the diode leakage current becomes very high and behaves like a forward biased device.

Zener diodes are specified in terms of Zener Voltage, on resistance (the resistance of the device at the Zener Voltage) and the Wattage, which is of course, the Zener Voltage times the current passing through it. Again it would be prudent to use devices, which are rated much higher than you intend to use.

Light Emitting Diodes (LED's):

When forward biased, some diodes emit light. These devices have a higher Cutin Voltage than ordinary diodes and they have a low reverse voltage tolerance.

The colour of the light depends on the device. Generally they come in one of the following colours. Infra red (which is of course not visible), red, orange, yellow, green, blue and white. Some devices have two or three diodes of different colours within the same package so that by varying the relative currents, different colours can be produced. The Cutin Voltages of LED's can vary considerably from one colour to another.

LED



Note the polarity of LED's needs to be checked with the catalogue data.

The reader should be aware that there are many different LED's which produce greatly differing light levels for the same current and that the angle of light produced can also vary considerably. The reader will need to choose the devices carefully according to the light levels required and the angle of projection of the light. Also some LED's have clear lenses and others are diffused. The diffused lens types are generally used as indicators and have wide angles. If you want to project light, you will need a clear lens and a narrow angle. There are some diodes which are very bright indeed and care should be taken to avoid eye damage.

Photodiodes:

Photodiodes change their leakage currents when subjected to light. Generally these are sensitive to infrared light and are used in sensors.

Their use will be explained in detail in the chapter on sensors.

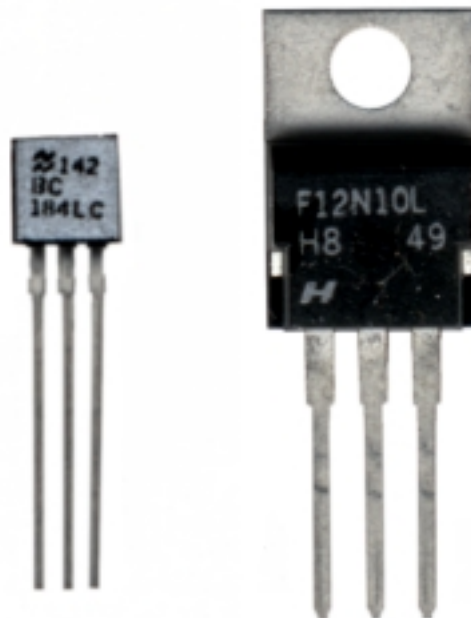
Transistors:

For simplicity, the author will only describe the types used within this book.

The transistor gets its name from trans-resistor, which basically means that the resistance of the device changes. The transistor is a three terminal device and takes two basic forms with two polarities. There are the basic transistors and field effect transistors. The explanation of how they work is beyond the scope of this book but what they do is not.

In a conventional transistor the three terminals are the **collector** the **base** and the **emitter**. The device has two diode junctions between the base and collector and the base and the emitter. If a small current is passed through the base emitter junction, a much larger current passes between the collector and emitter, none passing between the collector and the base, as it is reverse biased. The number of times the collector current is greater than the base current is called the gain of the transistor. For low power transistors, this is generally greater than 100. These transistors are called **bipolar** and come in two polarities **NPN** and **PNP**. The N stands for negative and the P for positive. The reader will note that because the base emitter junction is a diode and because most transistors are silicone, there will be a 0.6 Volt difference between base and emitter when the transistor is on (conducting, that is a current flows from collector to emitter).

TRANSISTORS



Note that there are various markings on the devices which are not part numbers. The transistor on the left is a BC184LC and the MOSFET transistor on the right is an F12N10L.

Which pin is which on the devices needs to be obtained from the supplier's catalogue if alternative devices are used as not all transistors use the same pins.

The field effect transistor has three terminals called the **drain**, **gate** and **source**. A particular type of field effect transistor is called a **MOS FET**. These devices are very sensitive to static and great care should be taken when handling them. When a voltage is applied between the gate and the source, the device turns on and there is a low resistance between the drain and the source. These devices are generally used as switches.

Integrated Circuits

Integrated circuits (IC's) are divided into two main types: **linear** and **digital**. Linear circuits are those, which are not digital, and digital circuits are those, which only have two possible states (on or off).

The use of all these devices will be described in detail by way of practical examples in latter chapters.

It should be noted that different manufacturers make components, which share the main part of the same part numbers differing only in prefix and sometimes suffix. Generally the parts are identical, but there may be subtle differences, which are unlikely to affect the performance of the devices in the circuits described in this book. The prefixes determine the manufacturer and the suffixes determine the physical package (i.e. whether the package is surface mount, plastic package or ceramic package) and the usable temperature range.

Linear:

These integrated circuits include amplifiers and regulators.

OPERATIONAL AMPLIFIER



This device is a 7101, the prefix LMC is specific to the manufacturer and the suffix BIN is the type of package, which in this case is commercial 8 pin plastic.

Note that this particular device has three different means of indicating which of the 8 pins is number 1. Pin 1 is on the bottom left. There is a small indentation in the top of the device in the middle of the left hand side, there is also a grey band on the left as well as a small indentation above pin 1.

Amplifiers are used to make signals bigger and by bigger the author means either makes them have a higher voltage or have a higher current or both. The

signal from a microphone, for example, is very small. It is only a few mVolts but if you want to hear it through a loudspeaker, it needs to be several Volts and the loudspeaker has a low resistance and will therefore need quite a lot of current, which cannot come from the microphone. An amplifier is required. The ones used in this book are mainly **operational amplifiers**, so called because they can perform mathematical operations like addition, subtraction, multiplication and division. They can add signals together, subtract signals from each other or multiply or divide the signal by a fixed amount. This multiplication or division is called the **gain** of a circuit. In the case of the microphone amplifier, a voltage gain of a few thousand will be needed to drive the loudspeakers. There are many types of operational amplifier and the reader should use the ones specified in the circuits.

Regulators are used to provide stable voltage supplies for circuits from larger unstable supplies. In most cases, a circuit needs to have a stable voltage supply for it to work properly. A battery for example has a higher voltage when no current is drawn from it than when there is a **current drain**. So if your circuit is switching a motor, for example, the battery supply voltage will be higher when the motor is off than when the motor is on. This effect can cause the circuit to malfunction, so we use a **voltage regulator** to provide a constant voltage, which does not change when the current drawn from it changes. Voltage regulators are specified in terms of their voltages and maximum currents. Again always use one with a much higher current rating than you need.

VOLTAGE REGULATOR



Note that the package is identical to a transistor. The only way of knowing that it is not is by the part number, which in this case is 7805, which is a 5 Volt regulator. The other numbers are specific to the manufacturer and include a batch number. The 0V pin is in the centre, the input is on the left and the 5 Volt output is on the right.

The power dissipated in a regulator is the difference between the voltage you supply it with and the voltage it supplies multiplied by the current drain. If for example you have a 12 Volt supply and a 5 Volt regulator and you have a current drain of 500 mA, then

the power dissipated in the device is $(12 - 5) * 0.5 \text{ Watts} = 3.5 \text{ Watts}$.

That is quite a lot of heat and the regulator will need to be cooled somehow.

There is another type of voltage regulator called a **switch mode power supply**, which is not linear. In this type of regulator the current is either on or off and the circuit includes inductors and capacitors to make it function correctly. The advantage of this type of circuit is that it does not have much power dissipated in the devices and is therefore used when high current regulation is required. Making these is not recommended. If you need one, buy one ready made.

Digital:

Digital circuits in their simplest form are just electronic switches and in their most complex form are microprocessors. This book will not deal with microprocessors but will deal with **drivers** (electronic switches) and **logic** devices.

DARLINGTON DRIVERS



Note that pin 1 is on the bottom left. The device number is 2003 and has 7 Darlington drivers in the one package.

Drivers are used to switch heavy loads with low current inputs. If for example you want to switch a small lamp on and off, or to control how bright it is, using a low current circuit, you will need some kind of switching circuit. These are called drivers. Now you could use one of the discrete devices mentioned earlier in this chapter or you could use a driver, which in this case would be made up of several devices in one package. For these kinds of application there are basically two types. A **Darlington** driver, which has for its basic circuit a pair of transistors where the current output of the input transistor feeds the base emitter junction of the second. This has the effect of multiplying the gains of the two transistors. So that if each transistor has a current gain of one hundred, the darlington's current gain would be ten thousand. These devices have a few

resistors and diodes to complete the circuit and generally there are seven or eight in one package.

Another kind of driver IC has a single field effect transistor for each circuit acting as a set of switches.

There are other drivers like **line drivers**, which will not be used in the circuits described in this book.

Logic devices describe many kinds of circuits in particular gates, latches, counters and decoders. There are two main series of these devices, the 74 series and the 4000 series. We will only be dealing with the 4000 series which can have a power supply ranging from 5 Volts to 15 Volts, use very little current and are slow. The 74 series requires a 5 Volt supply and is fast. The problem with fast logic devices is that they generate voltage spikes in the power supply and great care has to be taken to reduce them and to prevent them from causing problems.

Physically, these logic devices look identical to the picture of the Darlington drivers.

There is nothing significant in the series numbers used, they are just like names.

Logic devices are the basis for digital electronics and deal with truth and falsehood. True is called '1' and in terms of electronics is a positive Voltage, which is usually very nearly the chip supply voltage. False is called '0' and is usually very nearly zero Volts. Logic devices are usually specified in terms of a truth table. The truth table defines what output you get with different inputs.

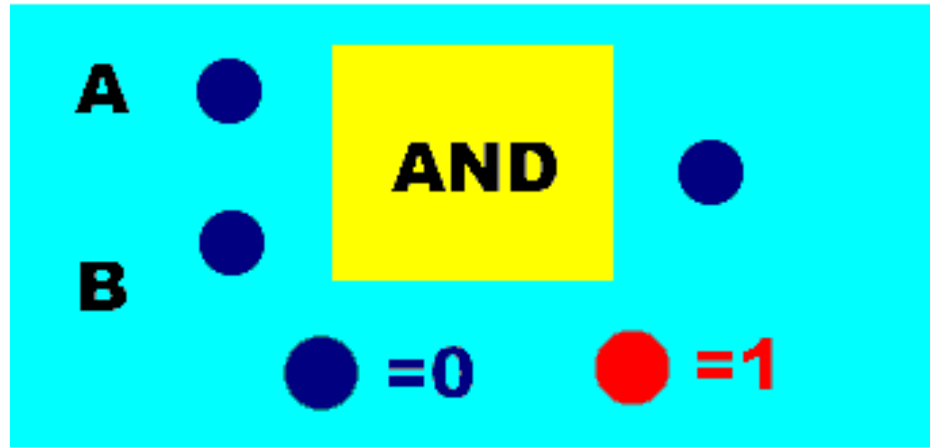
Gates are the simplest form of logic devices and perform the functions of AND, OR and NOT.

Let us consider a two input AND gate. As implied there are two inputs and one output. There will normally be four of these in each package. The output will be '0' unless both inputs are '1'. If we give the inputs names of 'A' and 'B' then the output = A and B. In Boolean algebra the notation is

$$\text{output} = A \cdot B$$

Another way of looking at the same gate is to say that if either A or B is '0', then the output is '0'. In terms of truth we can say that the output is only true if both A and B are true, otherwise it is false.

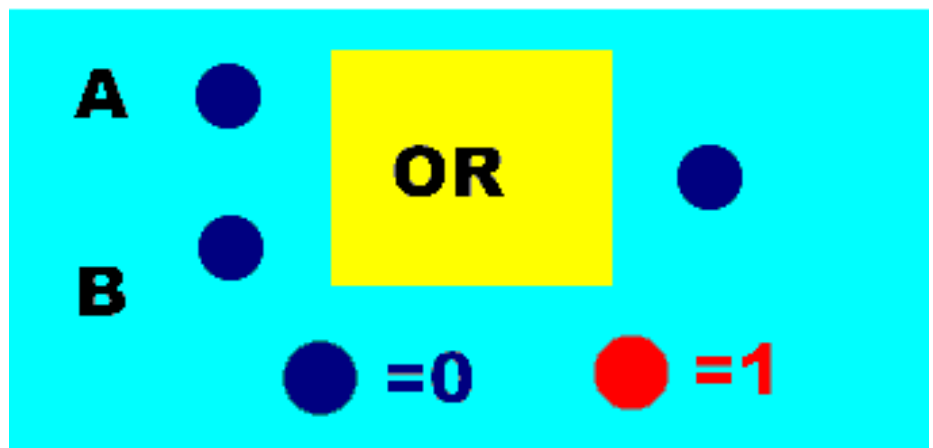
CLICK ON
IMAGE



Similarly let us look at a two input OR gate. The output is true if either or both of the inputs are true. This is called inclusive or. Let us restate this as: the output = A or B. In Boolean algebra the notation is

$$\text{Output} = A + B$$

CLICK ON
IMAGE



There is also a gate called an exclusive or, or XOR gate. In this case the output is true if either A or B is true but not if both are true.

The NOT is not a gate but is an inverter. That is to say that the output is not what the input is. A false input will give a true output and a true input will give a false output. Usually these are incorporated within the AND and OR gates to give NOT AND shortened to NAND and NOT OR shortened to NOR. The NAND gate is the most useful of all the gates as it can be configured to make any logic required. If you look at the truth tables of the AND and OR gates you will notice a similarity and that forms the basis of Boolean algebra. De Morgan's Law states that

$$\text{NOT } (A \text{ AND } B) = \text{NOT } A \text{ OR NOT } B$$

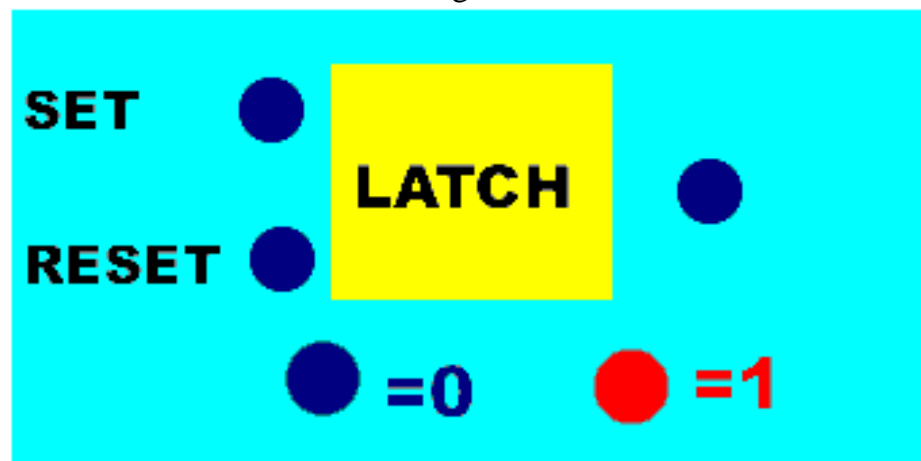
This may be useful to the reader if he designs his own logic circuits and wishes to use only one type of gate. The law can also be used to minimise the number of chips used in a circuit.

With the gates discussed so far we have only considered truth and falsehood. Let us now consider what is a '1' and what is a '0'. Well on the output of a gate it is near to the chip power supply or near to zero volts. At the inputs of the gates however we find that there is a definite voltage level at which the gate considers the input to switch from one state to the other. This is normally about half way between the chip supply voltage and zero Volts.

There is a device called a **Schmitt trigger**. With these devices the input voltage level at which the device switches from a '0' to a '1' is higher than the level at which it switches from a '1' to a '0'. These devices will be used extensively in the circuits in this book as they are very useful for making time delays, pulses and oscillators. The most useful is the 4093, which has four, two input NAND gates with Schmitt trigger inputs.

Latches are devices, which store information. They basically remember when a signal has been put on an input. The signal **sets** the output until a signal on an other input **resets** the output. Say for example you want to start a motor moving with a short signal from a movement detector and stop the motor when it has moved something to a particular point even though the movement detector does not give a long enough signal for the motor to make the required movement. You connect the movement detector to the set input and a position-sensing switch on the reset input of a latch and connect the output via a driver to the motor. You can make a latch with two NAND gates.

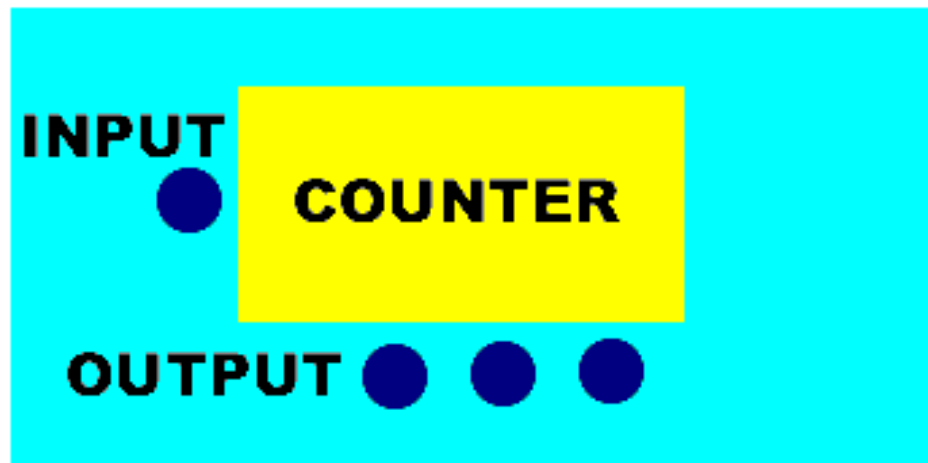
CLICK ON
IMAGE



Counters count pulses. A pulse is a signal, which temporarily changes state and then returns to its original state. For example a signal, which is a '0' becomes a '1' and then becomes a '0' is a positive pulse and a signal which is a '1' becomes a '0' and then a '1' again is a negative pulse. The counters, which are most commonly used, are binary counters and you will usually get two 4 bit counters in one chip. A 4-bit counter has four outputs and counts from zero to 15. The first bit counts in zero or one, the second in zero or two, the third bit is

zero or four and the fourth bit is zero or eight. It will be easier to see the point of having them when you see them used in a circuit.

CLICK ON
IMAGE



Decoders are usually used in conjunction with counters. They have several inputs, which are usually connected to the outputs of a counter. They also have several outputs. Consider the outputs of a four bit counter. Here is a table showing the outputs after each of 15 pulses.

Pulse number	binary counter output
1	0001
2	0010
3	0011
4	0100
5	0101
6	0110
7	0111
8	1000
9	1001
10	1010
11	1011
12	1100
13	1101
14	1110
15	1111

If however you want to switch 16 things on and off you will note that you only have four outputs and they are a little confusing at that. The decoder does that for you. It gives you 16 outputs and four inputs so you only get one of the sixteen outputs giving a signal and which output gives a signal is determined by the inputs. It decodes the four-bit binary and gives you the sixteen individual outputs.

Again it will become clearer when you see them used in an actual circuit.

CLICK ON
IMAGE

Note the animation shows a 4 bit binary output corresponding to 2 bit input. A 00 input gives a 1 in the least significant bit.

Electromechanical

Electromechanical components are those, which are partially electrical and partially mechanical. This category includes switches, solenoids, solenoid valves, relays, motors and loudspeakers. Although they do not really belong in this group, the author will include heat sinks and coolers here.

Switches are mechanical devices, which allow you to turn things on and off. They come in a large variety. Choosing a switch is not as simple as it might seem. There are four basic questions to be asked. Firstly what is being switched, secondly how many things will the switch control, thirdly do you want the switch to stay on once operated (**toggle**) or should the switch only stay on as long as there is a physical contact with it (**momentary**) and fourthly what is going to operate the switch.

Switches basically have bits of metal, which either touch each other or not. These bits of metal are called **contacts** and are specified in terms of current voltage and power. Here again make sure that you are well within the specification of the switch contacts as you will otherwise greatly reduce its working life. Many switches have three terminals and not two. In this case one terminal, called the **common** terminal, is connected to one of the other two but not both. When the switch is operated, the terminal, which was connected ceases to be connected and the other terminal becomes connected. This type of switch is called a **change over** or **double throw** switch.

Now it may be that you wish to switch more than one thing with the same switch. There are switches for that. What happens is that there are more than one switch in the same housing and operated by the same physical device so that they all switch together. The number of sets of switch contacts is called the number of **poles**. In catalogues the notation is usually abbreviated by using the first letter of each word. So a DPST switch is a double pole single throw switch.

TOGGLE SWITCH



Toggle and momentary switches are best described by way of examples. A light switch is a toggle switch. When you turn it on it stays on until you turn it off when it stays off until you turn it on. A computer keyboard switch is a momentary switch. It is only on as long as you press it. Unlike toggle switches, momentary switches have a normal and an operated state. Momentary switches have their contacts defined in terms of their state. A switch contact when touching is called **closed** and when not touching is called **open**. So if you have a momentary switch with three terminals, they will be defined as common (**C** or **COM**), **normally open** (**NO**) and **normally closed** (**NC**).

MICRO SWITCH



Note the switch is activated by pushing the lever, with the little roller, down. These are very useful for sensing positions of moved parts.

When it comes to what is going to operate the switch, there are two main categories. Either a person will operate the switch or something else will. When it is something else, a **micro switch** is usually used. Micro switches are usually momentary and have either a lever, a roller mounted on a lever or a button. If for example you had some moving object and you wanted to know when it arrived at a particular point, you could use a micro switch. Care should be taken when using micro switches. They are not designed to support heavy loads.

Solenoids are coils of wire with a movable iron core. When an electric current is passed through the coil, a magnetic field is produced. This field causes the iron core to be attracted to it. Basically we have an electromagnet with movement. These devices are useful for making small movements with low force requirements. They are specified in terms of voltage resistance and power. **When using direct voltage solenoids, always use a diode across the coil to protect the electronics from high voltage spikes.**

Solenoid



Solenoid Valve



Solenoid valves are solenoids which have valves attached. These valves are usually, either for air or water. Here you have a means of using electricity for switching air or water flow on and off. Solenoid valves are specified in the same way as solenoids. **When using direct voltage solenoids, always use a diode across the coil to protect the electronics from high voltage spikes.**

Relays are a bit like solenoids only they operate on switches. These devices are very useful for switching mains powered things as there is no electrical connection between the thing being switched and the electronics doing the switching. They are specified in terms of the switch contacts and the coil. The coil is usually specified in terms of its voltage and resistance. **When using direct voltage relays, always use a diode across the coil to protect the electronics from high voltage spikes.**

RELAY



Motors are divided into two main categories. There are mains driven motors and DC motors. This book will only consider the control of DC motors. AC motors can be easily switched on and off using relays but speed control is much more difficult and dealing with mains voltages is not safe unless done by a professional.

Electric motors come in a variety of powers so it is important to have some idea of what forces and what speed of movement are needed before buying a motor. Motors often have built in gearboxes and the faster the output shaft rotates, the less force is available. You need the same power to move a heavy object slowly as a light object quickly. There are other considerations when choosing a motor. Some small motors, particularly those for toys, are very cheap. Unfortunately they are also very inefficient and will therefore use a lot of current. It is usually better to buy a better quality motor particularly if you are going to use batteries.

I recently saw a work of art using cheap radio controlled cars. The battery life was about twenty minutes and the batteries took four hours to charge. Had the artist used better quality motors in the cars, the batteries would have lasted a few hours and the problems would have been greatly reduced.

Motors are specified in terms of voltage and power. A good quality DC motor will work at a lower voltage than its rated one. It will just go slower. The speed of the motor will be a linear function of the voltage across it. That is, if you double the voltage you will also double the speed. This is not true of cheap motors. If you load the motor by making it move something, it will move slower. When you reduce the voltage on the motor you will also reduce the available power of the motor so although it is a very simple means of speed control, it does have its drawbacks. Good speed control circuits measure the motor current as well as the voltage.

GEARED MOTOR



When a motor is free to rotate, it uses less current than when it is not. The starting current can be determined by measuring the resistance of the motor when stationary and knowing what voltage is to be applied to the motor and using Ohms Law. The starting current is the maximum current that will be taken by the motor. When considering the switching or controlling device for the motor, the user should be aware of the value of the starting current so that an appropriate controlling device can be employed.

The reader should also be aware that motors have an inductance and should have a diode in the drive circuit. Also most DC motors produce electrical interference unless they have a small capacitor connected across them to prevent it. Electrical interference may affect your circuit and will probably affect radio and TV reception.

Loudspeakers are like motors except that they only move backwards and forwards instead of round and round and do not produce electrical interference. They are specified electrically in term of their resistance and power. Generally speakers have 8 Ohm coils, but speakers for cars usually have 4 Ohm coils. These resistances are quite low so it would be prudent to ensure that the devices used to operate them are capable of coping with the power.

When it comes to audio power, the manufactures have found a way of cheating which they have managed to justify somehow. The reality is that they multiply the real power by two. The power rating is the maximum the speakers can dissipate without catastrophic damage. You should divide their figure by four.

Heat sinks are basically bits of anodised aluminium (usually black). They generally have fins on them and are used to keep components cool. The larger they are and the greater their surface area the cooler they can keep things. You fix them onto the components that would otherwise get too hot. They either have holes in them to allow the components to be screwed to them or they have some form of clip.

There is one thing that the reader should be aware of. The metal tags with holes in, that are part of some semiconductor devices, are often electrically connected to one of the device's terminals and could therefore produce an unwanted connection. So beware. Insulators, which electrically isolate the device from the heat sink are available and should be used if in doubt. Always check that you have electrical isolation where needed before you connect your circuit to its power supply.

There are some creams available, which are specially made to give a good thermal contact between the heat sink and the device. They are a bit messy but can be of help.

HEAT SINK



Heat sinks are specified in terms of degrees Celsius per Watt ($^{\circ}\text{C}/\text{W}$). This tells you how much hotter they will get for every Watt of power dissipated by the device attached to them. A simple rule of thumb is to say that the maximum temperature increase should be 30°C as the ambient (room) temperature can easily reach 25°C in temperate climates and if you touch anything that is hotter than 60°C it will burn you. Now all you need to know is the maximum power dissipated by the device. Well that is the maximum voltage multiplied by the current. You will note that if there is no current flowing when there is a voltage and no voltage when there is a current, as is the case with an ideal switch, then there is no power dissipated in the device and it won't need a heat sink. Electronic switches however are not ideal and may need a heat sink. Also not all electronic devices are used as switches and will therefore dissipate power.

The calculations are quite simple and can save time and money if performed prior to completion of the circuit construction.

You would be well advised to spend some time looking through distributor's catalogues, especially if they have colour illustrations. Electronic component distributors often sell mechanical components and tools as well.

Chapter 4

Circuit Diagrams

Circuit diagrams are symbolic drawings which tell you how the circuit functions and which components should be connected to which. They do not give any information about the physical appearance of the circuit. They are a means of describing how the circuit functions and not what it looks like. The symbols used in circuit diagrams are themselves only descriptive of function.

Another way of looking at it is to say that a circuit diagram is dealing with the general rather than the particular but can describe the particular in general terms. If for example there were such a thing as a circuit diagram to describe a spade, there would be a symbol for a flat metal blade and a symbol for a handle and there would be a line drawn to connect the two symbols together. If you recognised the two symbols you would then know that the spade had a flat metal blade connected to a handle. There is no description of what the handle or the flat metal plate should look like. Circuits cannot have such symbols, as neither a handle nor a flat metal plate, are electronic components and no electricity is involved, but the principle is the same.

Symbols

The symbols themselves are not random graphic images but have particular meanings in terms of function or physical construction but as stated before not physical appearance.

The first symbols are shown below. You will note that they are accompanied by letters and numbers. These are used to identify the particular device. C1 for example is a different capacitor to C2. A circuit will generally have more than one of the same type of component. In some circuits the value of the component is also shown on the circuit. The alternative is to show the value in a separate list. This is the authors preferred method as the values within the same circuit may change according to the user's requirements and it leaves the drawing less cluttered.



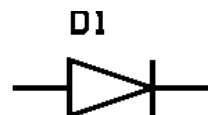
Resistor



Capacitor



Electrolytic Capacitor



Diode

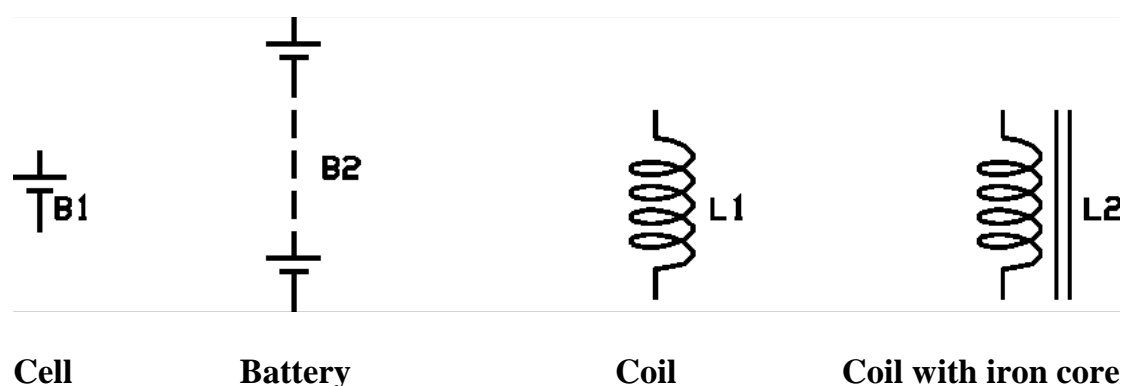
The symbols, shown above, are for two terminal devices. There are two ends to the components. These ends are usually wires and are denoted by lines going into and out of the symbols.

You will note that the symbols for the resistor and capacitor are symmetrical. This is because they can be connected either way round without any change in function. The electrolytic capacitor and the diode however are not symmetrical because there is a right and wrong way to connect them. Connecting them the wrong way round can be dramatic and expensive. In the case of the electrolytic capacitor, the positive end is shown uppermost. In the case of the diode, current passes from left to right, the anode being shown on the left and the cathode on the right. The symbol is like an arrow pointing the way the current can flow with a line blocking the flow in the other direction. The line on the symbol is usually shown on the device to indicate polarity. So in this case there is some correspondence between symbol and physical device.

Below are the symbols for cells, batteries, and coils. Coils, inductors and chokes are different names for the same devices.

The cell looks very similar to a capacitor, which is not surprising as their constructions and functions are similar. The cell as shown has its positive terminal uppermost. The battery is simply a number of cells connected in series. When the number of cells in a battery becomes large, it is convention to draw the cells at the extremes and join them with dotted lines to indicate that there are more of the same in between.

There are two basic types of coil. The first is just a coil of wire, but the second has an iron core, which is indicated by the two extra lines. The iron core will normally take the form of either a ferrite, which is iron dust embedded in ceramic, or iron laminations, which are thin layers of a special iron coated with an insulating varnish on one side.



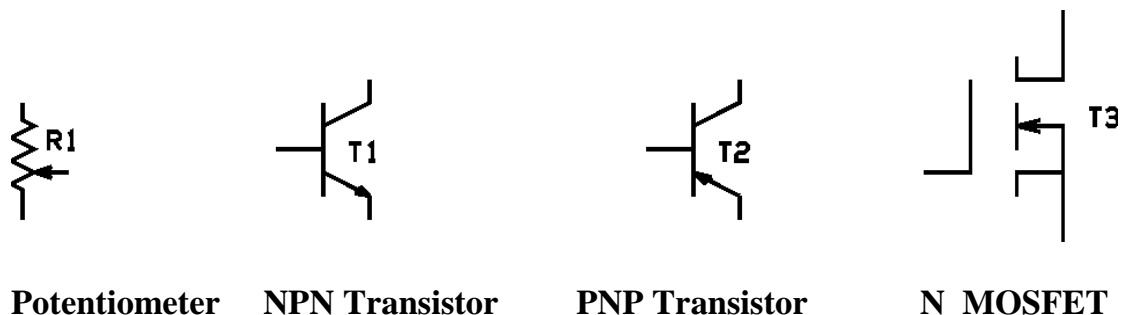
Let us now look at some three terminal devices. The first is a **potentiometer**, which is a resistor with a third connection, which is physically moveable and

can go from one end of the resistor to the other. A common use for these is as a volume control on an audio amplifier but we shall use them to make adjustments for all kinds of things like time periods for example. The part which moves is called the **wiper**. The device is called a potentiometer as it was originally used as a device for measuring potentials (voltage). Looking at the symbol it will be clear that the line with the arrow is the wiper.

In the drawing below, the transistors have their bases to the left, their collectors above and their emitters below. The direction of the arrow on the emitters denotes the polarity (whether the transistor is NPN or PNP). The arrow direction is consistent with the diode in that the current flows in the direction of the arrow.

Sometimes, particularly in amateur or very old circuits, transistors are shown with a circle around them. This is fundamentally wrong and is an historical anomaly. A circle around a device indicates that it is in a glass enclosure. If there is a dot inside the circle, then there is an inert gas, neon for example, in the glass and if not then there is a vacuum. It can be seen therefore that the circle is derived from the thermionic valve (called a tube in the USA) and makes no sense in the case of a transistor, which is a solid component, and does not have a glass enclosure with either a vacuum or an inert gas.

T3 is an N channel MOSFET and looks rather complicated. Fortunately you do not need to know how it works but only what it does. The direction the arrow denotes the polarity of the device in a similar way to the conventional transistors, which are known as **bipolar**. The gate is the terminal on the left, the drain is the terminal uppermost and the source is the lower terminal.

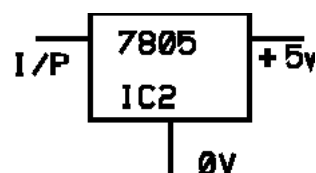
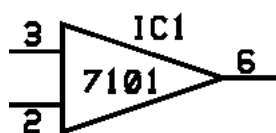


Let us now consider linear integrated circuits. Because integrated circuits can contain large numbers of individual components, microprocessors can have several million; the symbols do not show them. They tend to be just boxes with part numbers. Sometimes they show some functionality but not always. Amplifiers are usually shown as triangles as in the case of IC1 which is an operational amplifier. The main part of its part number is 7101. The main part of the part number indicates the part function and is a character set which has

been assigned to it by a manufacturer. The part number will usually have a prefix which defines which manufacturer has made it and a suffix which defines package type and other qualities like useable temperature range, speed and accuracy. A full part number for this device could be, for example, LMC7101BIN. It has two inputs and one output. The power supply terminals are not shown as this tends to clutter the drawings and does not add to their functional readability. In this particular case the pin numbers are shown. Pin 3 is the non-inverting input, pin 2 is the inverting input and pin 6 is the output. What is not shown is that the device has 8 pins and that pin 4 is the negative supply and pin 7 is the positive supply. The reader of the circuit diagram is expected to look this up in the manufacturers data book or data sheet. This information will be given together with device packaging information in the practical examples later in the book.

The voltage regulator shown is a three terminal device and is a 7805. Not all voltage regulators are three terminal devices but the most common ones are. The reader will note that the symbol is just a rectangle with three lines coming out of it. The reason for this is that there is no specific symbol for a voltage regulator. The general symbol of a box is used. The exact form of the symbol may vary from book to book as it is at the discretion of the author. The box could include the circuit diagram of the regulator but for ease of reading it does not. If the symbol were to be used in an application report on the use of the regulator then it may well be expanded to be a large box and include the internal circuit of the regulator.

The terminal to the left is marked I/P and is the input. The terminal to the right is the output, which in this particular regulator is 5 Volts. The third terminal is the 0 Volt terminal. Most circuits have inputs and outputs. In this case the input is the supply voltage which will probably be 12 volts and the output is 5 Volts. The input to these regulators needs to be 2.5 Volts higher than the output so any voltage between 7.5 Volts and 24 Volts will give 5 Volts at the output.



Operational Amplifier

Voltage Regulator

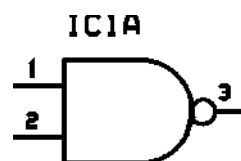
We will now look at some symbols for digital components. The most common digital components used in this book are gates. The most common of which are the NAND gate and the NOR gate. The examples shown here are for two input gates but tree input, four input and eight input are also common. The inputs are shown to the left and outputs to the right in these examples. You will note that

the component identification includes the letter 'A'. This is because there are four such gates to each integrated circuit and there is often an indication of which one of the four gates of that particular component is being referred to. The other three gates would be called 'B', 'C' and 'D'. In these particular examples the pin numbers of the integrated circuits are also shown. These are correct for 4000 series integrated circuits but not for others.

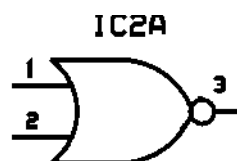
You will note that the power supply connections are not shown.

The next things you should note are the little circles on the outputs of the gates. These indicate that the outputs have been inverted. That is the outputs are NOT what they would be without the circles. If the circles were not there the symbols would be for AND and OR gates. You may sometimes see symbols, which have circles on the inputs. These also mean that the signals are inverted.

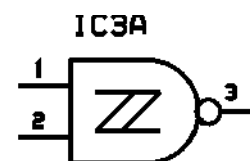
The symbol within the Schmitt triggered NAND gate, which is inside the gate, indicates that the voltage level of the inputs at which the gate responds is different for a '0' to '1' transition to a '1' to '0' transition. This is called hysteresis.



NAND



NOR

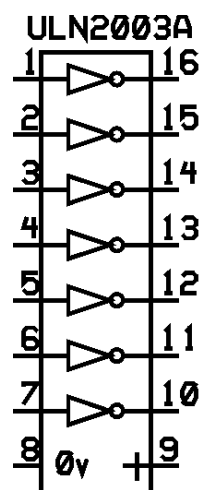


Schmitt NAND

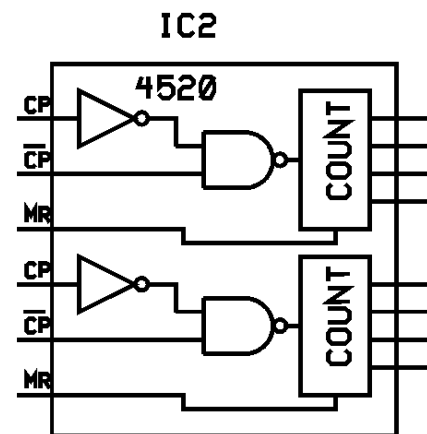
The next symbols show boxes indicating a physical package together with diagrams of their internal workings. Looking at the diagram for the Darlington driver you will see that there are seven internal circuits that are all the same. If you look at any of them you will note that there is a triangle indicating that there is an amplifier of some sort and a little circuit indicating that the output is inverted (NOTed). A Darlington is a pair of transistors, which are connected, to still have only three terminals and behave like a single transistor of enormous gain but having twice the Cutin voltage. In these particular devices, there are also a few resistors and inductive load protecting diodes to make external connections more convenient. They are used to switch things on and off. The numbers on the symbol indicate the pin numbers of the plastic package. These could be drawn as seven individual inverters in the same way as the gates but it would not be clear what to do with pin 9 for reasons which will become clear when these devices are shown in a practical circuit.

The dual four-bit binary counter symbol shows the input circuits on the left hand side in terms of the gate functions. But the boxes to the right just have the word 'count' in them to indicate that there is a counter and the four lines

coming out of the counter indicate that there are four external connections to the output of them. Instead of showing the pin numbers of the device in the diagram, the usage of the terminals is shown instead. CP stands for clock pulse and the pin below has a line drawn above the CP. This line means NOT and indicates that this input is the inverse of the CP input. MR stands for Master Reset and is used to reset the counter to zero. The advantage of showing the function rather than the pin numbers is that it is easier to understand the circuit function. But the disadvantage is that if you are trying to fault find (debug) a circuit you will have to refer to another drawing of the integrated circuit, which shows the pin numbers. In some cases both are shown on the same drawing. It is all a matter of choice and the space available for the whole drawing. If you draw a large circuit and there is not enough space then the symbols will be too small to see anyway. There are a number of conventions which need to be adhered to so that anyone can read the circuit diagrams but there is still room for individual preference.



IC1
Darlington Driver



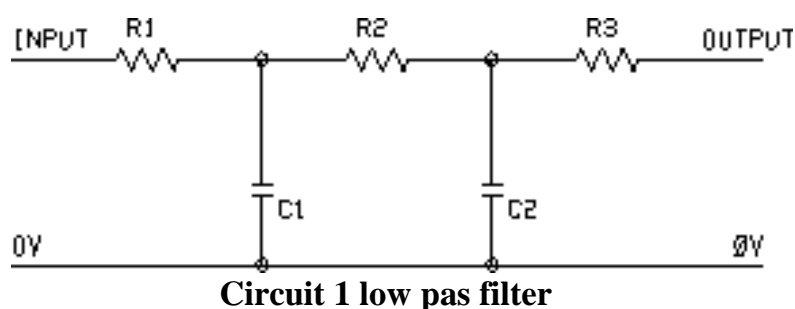
Dual Binary Counter

Circuit Diagrams

Let us now look at circuit diagrams. These are made up of symbols joined together or interconnected. The means of connecting them in practise is by electrical wires or by boards with copper glued onto them. These are known as printed circuit boards or strip boards. Printed circuits are specially made boards with particular interconnections and strip boards are general-purpose boards which have many holes and copper strips joining the holes together in strips. The reader will find that commercially made electronics usually use printed circuits and one off circuits (ones which are only made one at a time) are usually made on strip board. The artist will usually use strip board as home made printed circuit boards are difficult to make well and strip board is easier to use if only a small number of circuits are required. Strip boards can be plain

copper or can be tinned. Tinning is another word for soldering but in this instance means that the board has an even coating of solder on the copper strips. Regular, untinned boards have the disadvantage of being difficult to solder to if they have not been used shortly after manufacture as the copper gets dirty and begins to oxidize. Tinned boards will be easier to solder to and for much longer. You can easily tell the difference as tinned boards have a silvery appearance.

The types of wires used for connecting circuits will be discussed in the chapter on circuit construction.



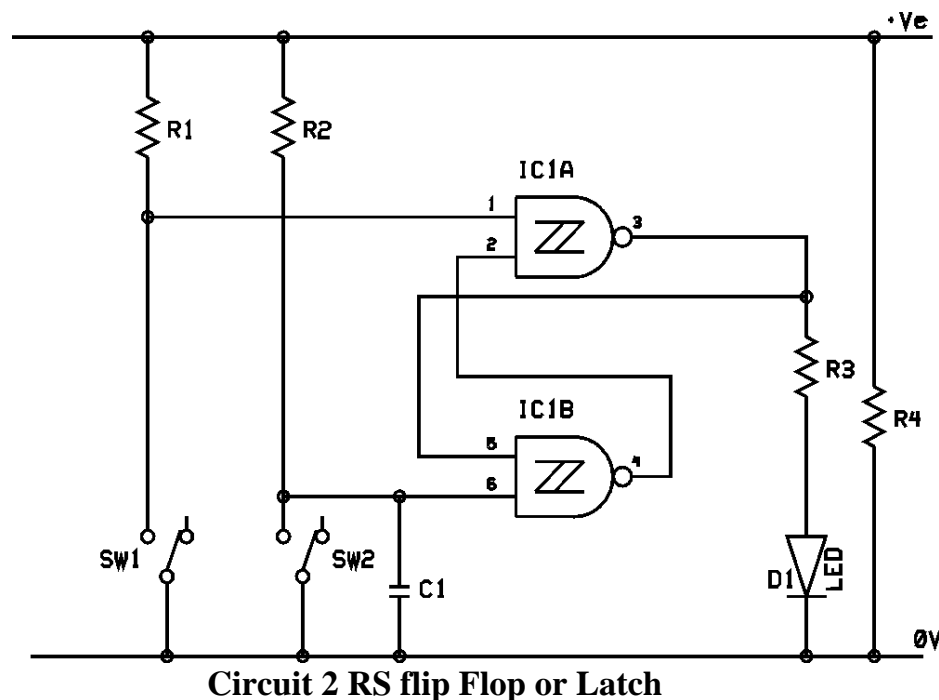
It is normal to read a circuit from left to right but it is not always possible to draw them that way. In this simple circuit of a **low pass filter**, it is read from left to right. A low pass filter allows low frequency alternating voltages and direct voltages to pass from input to output but high frequency signals will be very much reduced in amplitude (**attenuated**). Frequency is rate at which the signal changes from being positive to being negative relative to the average signal voltage and is measured in Hertz (cycles per second). In terms of sound, frequency is the pitch or note but does not tell you how loud it is or what kind of instrument is making it. So in sound terms this circuit would allow the base through but would reduce the treble. The pitch or frequency at which the signal becomes significantly reduced is the **cut off frequency** and is dependant on the resistor and capacitor values.

The reader should recognise the symbols used here. They are for resistors and capacitors. The left hand side of R1 is connected to the input which may be a microphone or some other circuit. The right hand side of R1 is connected to the left hand side of R2 and also to the top of C1. The bottom of C1 is connected to the bottom of C2 and to 0V which is zero Volts (the negative end of a battery or power supply).

In chapter 2 we considered the reactance of a capacitor. That is, its equivalent resistance, and that this went down as the frequency of the voltage across it went up. This circuit uses that fact. Consider the first part of the circuit R1 and C1. If the reactance of C1 is equal to the resistance of, R1 which it will be at a particular frequency, then the signal across C1 will be about half of the signal at the input. (It won't be exactly half because there is a phase change, which

involves complex mathematics and we will therefore ignore it.) If we now consider R2 and C2 as being the same circuit as R1 and C1 and connected to the output of the R1, C1 circuit and having the same component values, it will attenuate the signal by a factor of 2 again. The result is that at that particular frequency, the output of the circuit will be about $\frac{1}{4}$ of the input and that at much lower frequencies the signal will hardly be attenuated at all and at much higher frequencies the signal will be attenuated very much more.

It will be seen that the higher the values of the resistors and capacitors, the lower the cut-off frequency.



Now let us consider a more complex circuit. In this circuit, the LED D1 is turned on when the switch SW1 is closed and stays on when SW1 is opened again. The LED turns off again when SW2 is closed, provided that SW1 is open at the time.

The reader will note that the connection between IC1 pin 1 and R1 crosses over the connection between R2 and SW2. IC1 pin 1 is **not** connected to R2. The convention is that only lines, which go to but not cross other lines, are connected. It is impossible to draw complex circuits without having some lines crossing over others. A further convention is employed to clarify the situation. Lines, which are connected, usually have little circles or large dots to indicate the joins. In some diagrams, cross over points have a semi-circular bump in one of the lines crossing over, but this is now rather old fashioned and is difficult to read when there are a large number of lines. Sometimes interconnections are made at points where the lines cross over and are indicated by large dots or

circles but this is considered to be bad practise as a dot may not appear clearly after a circuit has been photocopied and the author never does this.

The symbol for a switch should be easily understood. When the switch is not operated (open), the lower part of the switch known as the common terminal (Com) is connected to the upper right hand side of the switch known as the normally closed terminal (N/C). When the switch is operated (closed), the common terminal is disconnected from the N/C terminal and is connected instead to the normally open (N/O) terminal shown to the upper right hand side of the symbol.

In operation, when SW1 is closed, the voltage on pin 1 of IC1 goes from being on the supply voltage, via R1, to being on 0Volts. The output of IC1A pin 3 goes positive. IC1 is a NAND Schmitt trigger so any input on zero (0) will give a positive (1) on the output. This turns the LED D1 on. R3 limits the current through the LED to an acceptable level. The output of IC1A is connected to one of the inputs of IC1B and is a '1'. The other input is also a '1' as it is connected to the positive supply via R2 and the SW2 is open. Now if both inputs to IC1B are '1's then the output of IC1B will be a '0'. The output of IC1B is connected to pin 2 of IC1A and is a '0'. If SW1 is now opened, there is still an input of IC1A on '0', pin 2. So the output of IC1A remains on '1' and the LED stays on even though SW1 is now open. Now with SW1 open let us consider what happens when SW2 is closed. Pin 6 of IC1B now becomes a '0' and therefore the output pin 4 of IC1B becomes a '1'. Now both inputs of IC1A are '1's and the LED is turned off and stays off until SW1 is closed again.

This kind of circuit is known as an RS Flip Flop. The R and S meaning Set and Reset. A Flip Flop is a bi-stable circuit meaning that it has two stable states. You will note that the circuit can be used as a memory as it remembers the last input signal after the signal has been removed until the memory is cleared by a reset signal.

Let us now consider what happens when the circuit is first switched on. At first sight it would not be clear whether the LED was on or off after switch on as both states are possible. C1 however causes the circuit to behave as though SW2 was closed for a short time directly after switch on. This turns the LED off. Prior to the connection of a supply to the circuit, C1 is discharged via R2 and R4 and the potential across it is zero. On connection of a supply, C1 charges up to the supply voltage via R2. This takes a period of time to do. The time in Seconds is approximately the resistance of R2 in Ohms multiplied by the capacitance of C1 in Farads. R4 is there so that C1 can discharge when the supply is removed. So if R4 is 10K and C1 is 0.1 μ F the time taken to reach 2/3 of the supply voltage would be $10 \times 10^3 \times 0.1 \times 10^{-6}$ Seconds, which is 1×10^{-3} or 1 mSec or one thousandth of a second. So for a thousandth of a second after switch on, the circuit behaves as though SW2 was closed.

The circuit uses Schmitt NAND gates instead of ordinary NAND gates because it has a slow moving input due to C1 and although ordinary NAND gates would work just as well in this particular application, it is good practise to use Schmitt triggered inputs when slow moving signals are employed to avoid the possibility of secondary signals due to small amounts of noise in the supply. There is no significant price difference in the components.

The circuit will function with supplies between 4 and 15 Volts and with a wide range of component values. Here is a list of reasonable values:

R1=10K

R2=10K

R3=1K

R4=10K

C1=0.1 μ F (0.1 μ F)

IC1= HEF4093BP

Note: pin 7 to be connected to 0V and pin 14 to +Ve supply

Chapter 5

Tools

Only a few tools are needed to build electronic circuits and it would be wise to buy the best quality that can be afforded. Good tools will last many decades, if they are not misused, and will be a pleasure to use for the entire time. They are a good investment. Bad tools will never work well and will not last very long.

When buying tools, always hold them in your hand in the way in which they should be used. They should feel right. If they feel awkward, don't buy them.

Your tools will become quite personal to you and you should not let anyone else use them unless you are sure that they know how to use them without causing them damage.

Electronic manufacture is generally quite delicate work and the tools required are therefore much smaller than those used by garage mechanics and home electricians.

Essential Tools List

- Small pair of snipe nose pliers
- Small pair of diagonal cutters
- Pair of heavy-duty diagonal cutters
- Pair of extra fine strong pointed tweezers
- Penknife
- Set of needle files
- Small soldering iron with stand
- Desoldering tool or solder wick
- Set of small screwdrivers
- Spy glass (magnifying glass)

The reader should note that small cutters should only be used for cutting thin component leads and copper wire. If the wire is too thick or of a hard material, the tool, which should last for years and may be quite expensive, will be ruined. If the material is heavy gauge or of a hard material, use a pair of heavy gauge cutters, which are designed for such use. Do not try to use the tweezers for anything other than picking up or holding small components or wires or the fine point will not survive. Do not use the small pliers for bending things other than thin wires or small bits of soft metal. They are not designed for that purpose and will be ruined. If you want to bend something hard, heavy or big, you should use some heavy-duty pliers.

PLIERS



SMALL CUTTERS



MEDIUM DUTY CUTTER



TWEEZERS



NEEDLE FILES



DESOLDERING TOOL



MAGNIFYING GLASS



Other useful tools

Wire strippers
Small pair of flat nose pliers
Small bench vice with ball joint mounting
Medium size soldering iron with stand
Toolmakers clamps

Using Tools

General principals

The following may seem to be a bit fussy and slow you down when you are in a hurry to get a work made, but you should find that following the advice given here will save you time and make better quality work.

Make sure that you are holding the tool comfortably. If the tool is uncomfortable, the chances are that either the tool is of poor quality or you are not using it properly. Hold the tool in the most comfortable way possible and that should be the way that the tool was designed to be held. Small soldering irons should be held like a pen, so make sure that, when you buy one, the handle is not too fat for comfort.

Whenever possible, clamp the part you are working on, so that it can't move.

Whenever you are using a cutting tool (e.g. file, saw. Chisel) make sure that you apply force in the direction of the cut and not on the backstroke. If you do not, you will blunt the tool. Take a file for example. Apply the force when pushing the file away from you and release the force when you bring it back towards you ready for the next stroke. Never use light strokes, always apply force. If you let a good tool work for you, it will. If you don't, it won't.

CLICK ON IMAGE

When using cutters on wires or component leads, keep the cutter straight. Do not twist the cutter while you are cutting or you will tear as well as cut and if you do that on a soldered component lead, you are likely to fracture the solder joint. A fractured solder joint is not easy to spot and will probably fail completely at some later time. You may be lucky or it may fail during the private view.

Try and select the most appropriate tool for the job rather than the first one that comes to hand.

Soldering

Always keep the tip of your soldering iron clean. There should be a receptacle for a sponge on the soldering iron stand. If you dampen that sponge with water, you can wipe the hot soldering iron tip on it every once in a while and that will keep it nice and clean. If the tip gets dirty, the solder joint will not be good and may fail.

It would be wise to avoid holding the iron so that the tip is above you as the molten solder may fall off the iron and burn you. A good soldering iron stand is likely to reduce the number of times you get burnt.

You would be well advised to only use the best quality low residue multicore solder. Cheap solders produce toxic and carcinogenic fumes and do not give such good results. Solder is not very expensive and a reel will last a long time so it is a false economy to use cheaper solders when you are only using small amounts. If you were in the mass production business, there may be some advantage to savings on the price of solder but, for the artist, there is no point at all.

There are three types that you will need; firstly a general purpose solder; secondly, a solder for soldering to poor solderability and oxidised components; and thirdly a low melting point solder. Low melting point solders have a small amount of silver in them and are used for soldering to silvered components and bulky components which would otherwise need a much larger soldering iron to heat up.

The principles of soldering are quite simple. When heat is applied to the solder, it melts and the **flux**, which is inside multicore solders, also melts and acts to clean the surface being soldered. If the surface does not get cleaned, the solder will not adhere to the metal surface. This is why you need different solders for different applications. The act of getting the solder to stick to a surface is called **tinning** or **wetting**. To stick two parts together and have an electrical connection, both parts need to be tinned and the molten solder needs to mix with the tinning on both parts. This process is usually just a matter of touching

both parts to be soldered together with the soldering iron tip simultaneously and then feeding in the solder to the tip so that it melts and flows over both components. When the soldering iron tip is removed, the solder cools and solidifies to leave a good mechanical and electrical joint. A small amount of the flux remains on the tip of the iron and after a while burns onto it. This needs to be removed by wiping it on a damp sponge. If the soldering iron tip is left dirty, the burnt flux will find its way into the solder joint and weaken it and in some cases produce a joint, which is not good electrically and may cause the circuit to malfunction.

If you have a small amount of solder on the tip of your iron, it will wet it and give a better heat transfer to the parts you are soldering together. If the parts you are soldering together have greatly different masses, you should wet the larger mass first and then touch the other part with the iron. This will avoid having heat applied to a small component for a long period of time, which might damage it.

If the parts you want to solder do not wet easily, then you should tin them first with the special poor solderability solder. You may even need to clean the parts first with a needle file. Make sure that both parts are wetted properly before joining them together. The parts most likely to cause problems will be old components or strip board, which have oxidised. You can see the difference quite clearly as they are dull in appearance.

CLICK ON IMAGE

When you have finished soldering, always look at every joint with a spyglass to make sure that the joint is good. It is not easy to spot a bad joint with the naked eye.

Sometimes too much solder is used, the solder joins to unwanted places or you need to remove a component. In these instances you will need to desolder (remove solder or unsolder). There are a variety of ways of doing this. Since

you are unlikely to need to do this very frequently there is no point in spending large amounts of money on desoldering equipment.

The cheapest is to use solder wick but you will need to use quite a large soldering iron as solder wick is quite massive and needs to be heated up. It works by the capillary action of copper braiding and sucks the solder up the braiding. The advantage is the price but it is awkward to use, particularly when removing components. Some people like to use this method and find it very efficient; others like the author do not. You can try it for yourself, as it is very cheap and if you find it difficult, try a desoldering pump or desoldering iron.

The desoldering irons work very well indeed but are about three or four times the price of desoldering pumps. The desoldering iron has a tip, which is hollow and a pump to suck the solder away. The pump is either similar to the desoldering pumps described below or has a rubber ball which you squeeze and let go. The author prefers the rubber ball type.

There are basically two types of desoldering pumps available. Their construction is basically a tube with a sprung loaded piston and a button operated latch. The piston has a small piece of metal attached to the end, which passes down a plastic tube usually made of PTFE, which can withstand high temperature. When the piston is depressed against the spring the tool is ready to use. You melt the solder to be removed with a soldering iron, place the PTFE tube over the molten solder and press the release button. The spring pushes the metal part up at high speed and sucks the solder away. These need constant cleaning as they get clogged with solder. The difference between the two types is that the more expensive ones have an anti-recoil design so that the desoldering tool does not bounce on your work in use. The author prefers the anti-recoil tools.

A useful thing to know is that good tweezers are made of stainless steel and solder does not stick to stainless steel. If for example you have soldered adjacent copper tracks together by mistake, you can melt the solder and use tweezers to push the solder away from the space between the tracks.

Chapter 6

Test Equipment

Multimeters

The most important piece of test equipment is a digital multimeter. Fortunately you are unlikely to need a precision meter so they are very cheap and can even be purchased at DIY stores. Make sure that the meter has an audible continuity checking facility. Most of them do. Use the current measuring facility as little as possible as they have an internal fuse, which will blow and need replacing if you exceed the current rating of the meter. This is very easy to do, so be warned. You can use Ohm's law to determine the current by measuring the voltage across a resistor.

MULTI-METER



Oscilloscopes

An oscilloscope is the next most useful piece of test equipment and although they are quite expensive. They are well worth having, as they will show you what your circuit is doing whilst it is doing it. You may well find that it is worth trying to find a few other people who would want the use of one and share one between you. Whenever appropriate, the author will include illustrations of oscilloscope screens in the circuit descriptions to aid understanding of the circuit functions and to aid fault finding.

The cheaper oscilloscopes are simple and quite easy to use despite the large numbers of knobs and switches on them. They should come with instructions on how to use them.

OSCILLOSCOPE

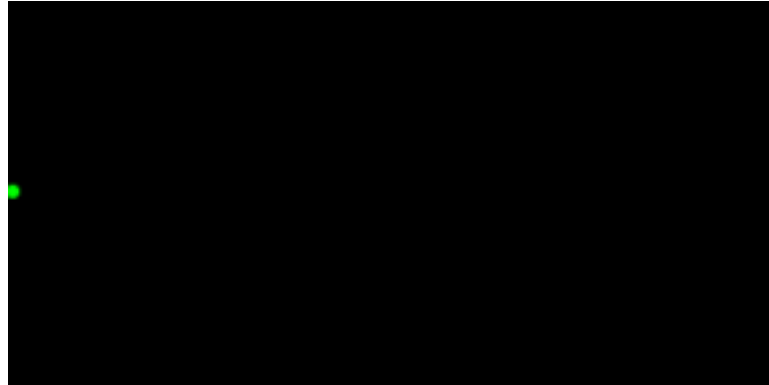


Here is a brief description of how they work which should help in using them. The author is assuming that this is a cheap, simple oscilloscope. A dot moves across the screen from left to right and when it gets there it starts from the left again. The time base controls the time that it takes for the dot to get from left to right. The time base is calibrated in terms of the time taken for the dot to travel one division of the screen and there is a control for this. If the dot moves fast enough, it will not be visible as a dot but will be seen as a line.

There are two inputs available and each one has its own dot so you will see two lines if both channels are enabled. There will be a control, which allows you to change whether you see one line or two. Each of these inputs has its own amplifier, which has a control for changing its sensitivity. This will be calibrated in Volts per division. Voltages on these inputs change the vertical position of the dot on the screen. Each input will also have a three-position switch. There will be a GND position which disconnects the input so that you can see where the dot on the screen would be if there were no signal. There will be a DC position, which makes the dot have a vertical position determined by the voltage on the input and an AC position, which only changes the vertical position if the input voltage changes but not if the voltage stays the same. Associated with these amplifiers is a vertical adjustment control. This changes the vertical position of the dot. If you set the input switch to GND you can use this control to change the vertical position of the dot, which corresponds to zero input. Oscilloscopes are supplied with probes, which connect to the input terminals. Sometimes these probes attenuate the signal by a factor of ten. Strangely they are marked with X10 although they actually divide the signal by 10. Sometimes probes have a switch on them to change from X1 to X10. If you want to have 1 Volt per division and your probe is X10 you should set the control to 0.1 Volts per division.

If your input changes with time, the dot will go up and down with time accordingly. The dot also moves from left to right with time so the result is a picture of how the input is changing with time.

CLICK ON IMAGE



The above animation shows a dot moving from left to right whilst moving up and down, producing a triangular wave. An oscilloscope joins the dots together to produce a triangle. The up and down movement is produced by the varying input voltage and the left to right movement by the scope's time base.

Let us now consider the time base again. We have a dot, which goes up and down and a time base causing the dot to go from left to right. If there is no synchronization, each time the dot starts to move vertically it will do so at a different horizontal position. There is a control, which makes the dot start to sweep across the screen just as it moves vertically. This enables a stable picture to be seen. The synchronization controls allow for changing which of the two channels will trigger the time base and a switch changing what kind of signal will do it. You can change whether it is DC AC or positive going or negative going. There may also be a switch, which changes whether the synchronization is internal or external. This should normally be set to internal.

If you see a broad line across the screen, the chances are that the dot is moving up and down too fast for the time base, so make the time base go faster and the picture will appear. If the line is straight and you are expecting it to go up and down, slow the time base down. It may be that it is going so fast that it has gone across the screen before it has had a chance to move vertically.

Power Supplies

A variable bench power supply is a useful thing to have but is not essential. An art college electronics department should really have one but the individual artist could manage without one.

A bench power supply can vary the supply voltage and limit the supply current and display the voltage



Bench Power Supply

They can be used to determine the most appropriate supply voltage for a particular work and the current it uses. This is particularly useful for battery powered works as the artist can see what happens as the battery voltage drops with time without having to wait for the battery to flatten.

The ability to limit the current supplied to a circuit is particularly useful when it is not known whether the circuit works or not. It may protect your circuit from damage whilst you are fault finding.

Chapter 7

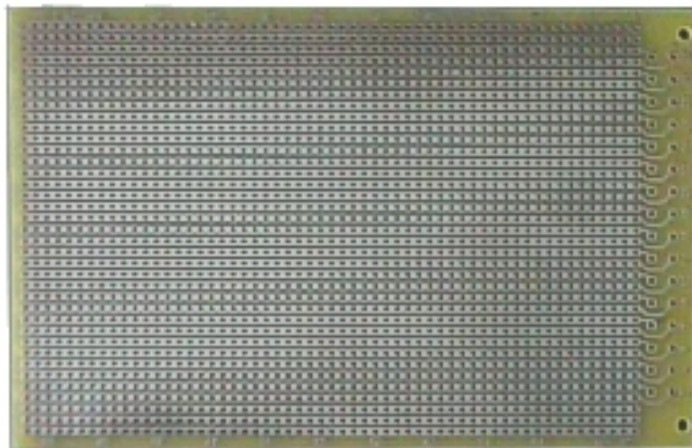
Construction

Electronic construction

The circuits need to take some physical form. The individual components should be connected together in such a way that they will stay connected in all the right places and not be connected in the wrong places. Basically they need to be robust.

In most cases the artist only needs one circuit per work. The use of dedicated printed circuit boards is not likely to be an option unless the board is to be seen by the viewer and thus becomes part of the work itself. Homemade printed circuit boards look like homemade printed circuit boards. It is better to design them and then have them made professionally. The design of printed circuit boards (PCB's) is not difficult but is best left to the professionals unless the artist is going to need lots of different ones in which case there are several CAD (Computer Aided Design) programs available. If the reader intends to design printed circuit boards, it is a good idea to visit the board makers and look at the process and the PCB masters. The PCB masters are transparent films with black markings showing which parts of the board are to be copper and which not. The process is either silkscreen or photo-resist. A visit to the board makers will clarify this.

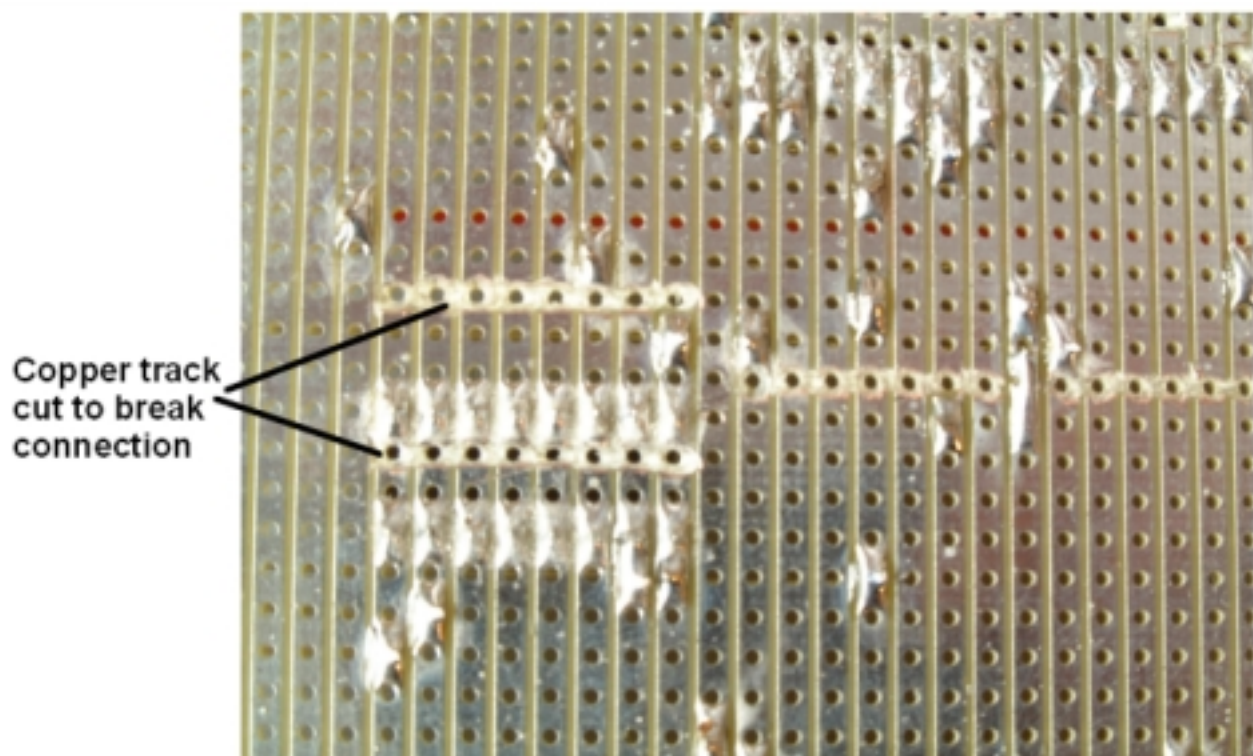
STRIP BOARD



The quick and easy way to build circuits, that are to be hidden from view, is to use strip board. This is a board made of insulating material (epoxy glass is best) with parallel strips of copper running the length of the board. There are holes drilled in the board at 1/10 th inch intervals and the strips of copper are at 1/10 th inch intervals. Most electronic components have lead spacings in multiples of 1/10 th inch. The most common strip boards are plain copper strips on a paper-based board. The easiest to use are tinned copper on glass-based boards. The tinning of the copper has a silvery appearance and being pre-tinned is

much easier to solder to, especially if the boards have been exposed to the air for some time.

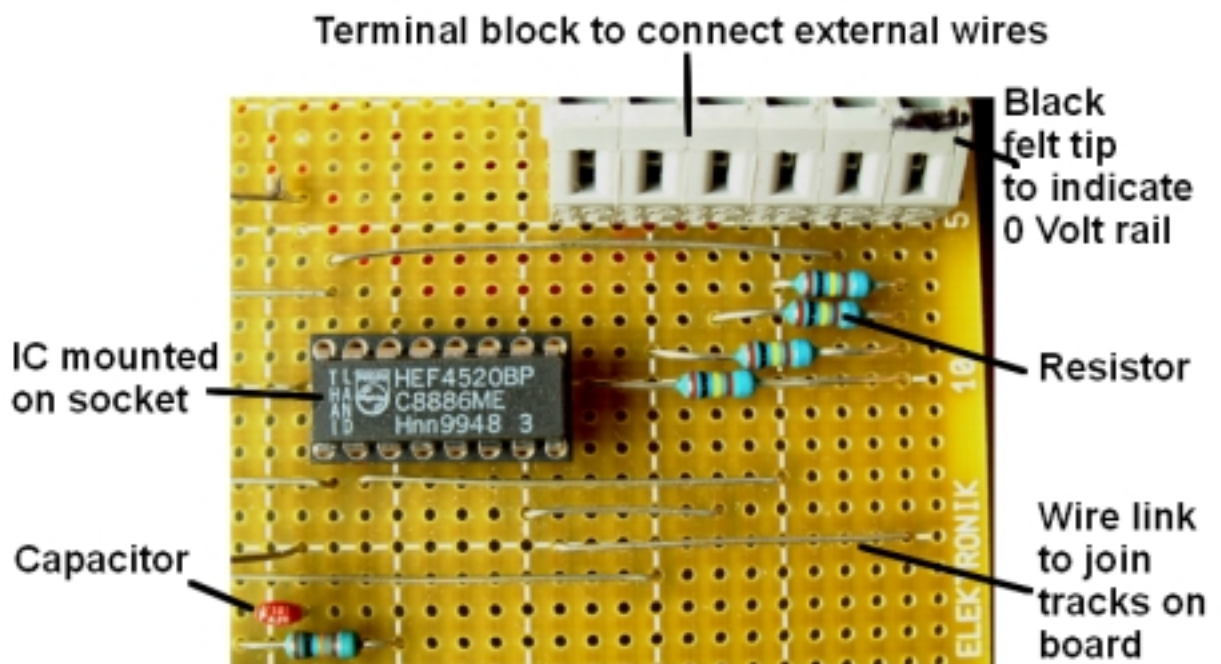
It will be obvious that if you solder the components to strip board, some of the leads will be connected to places where they should not be and some places will not be connected which should be. The way to solve these problems is to cut the copper track where you don't want a connection and to use wire links where you do. There is a special tool for cutting tracks but you can use a penknife. You should be aware that this needs to be done very carefully and that thin slivers of copper can be left which are not easy to see with the naked eye and that these slivers can cause **short circuits**. A short circuit is a connection, which should not be there and directly connects at least two parts of the circuit together. **You should always use a magnifying glass to carefully examine every break you make in the copper track to ensure that all the slivers of copper are removed.**



Wire links can be made from tinned copper wire or from single strand insulated wire. Don't use multi-strand wire for board links because it is difficult to get through the holes in the board and can leave strands, which do not go through the holes. These strands are difficult to see and may cause short circuits. You should use terminal blocks or connectors to connect external wires to boards, as external wires should be multi-stranded. **External wires should be multi-stranded as they are much less likely to fracture when moved.** Wire links on boards do not move and therefore will not fracture.

If you need to connect wires to printed circuit or strip boards you should use printed circuit terminals. These are available in many types and sizes. The picture below is of a low cost, low current and low voltage type.

Printed circuit Terminals



Board layout

The first thing to decide is what size the board should be and the next is how to mount it. You cannot just screw a board to a metal surface, as it will short out. You either need to screw it to a plastic surface or use some kind of spacer. There are various kinds of spacer available. It will be easier to drill the fixing holes in the board before putting any components onto it. The board can then be used as a jig for drilling the holes in the metal that you are going to mount it on.

Laying out a board (working out which bits go where) is a bit like doing a jigsaw puzzle. The easiest way to set about the problem is to place the bits on the

board without soldering them. In that way they are easy to move around while you experiment with the layout. The problem with that is that when you turn the board over to solder the bits to the board they will fall out. There are some jigs called work frames, which can be used to solve this problem but they are quite expensive. The way in which they work is to clamp the board onto a frame and then lower a lid with plastic foam on top of it and then clamp the lid onto the frame. When the whole thing is turned over, the foam holds the components onto the board. You can make a frame out of two sheets of chipboard, a sheet of foam and four screws but the frame to hold the board would have to have a rectangular hole cut into it to fit the board you are using so it could only ever be used to hold that size of board, which limits its use. Instead of making a frame, you can try to remember where all the bits go and then take all the bits out and solder them in place one at a time.

With practice, you should find that you can use your experience to just make the circuit without experimenting with layouts first, though a work frame will always make life easier.

Before any power is applied to any board, the board should be very carefully examined to make sure that all the components are connected the correct way round, are of the correct value, are connected to the correct places and are not connected anywhere else. This is most important as it may save you from damaging components and fault finding. It is much better to spend time looking for faults before power is connected than spending much more time finding out why the circuit does not function correctly and then having to replace damaged components.

Static

Most semiconductor components and integrated circuits are sensitive to static electricity. You should be aware that if you walk across a carpeted floor and then touch a static sensitive component, it is quite likely to damage it irrevocably, but not necessarily instantly. In other words you may damage a component without knowing it until it fails some time later. There are some simple precautions you can take to alleviate this problem. Firstly you can **use sockets for the integrated circuits** that have at least 8 pins. This allows you to **build the circuit on a board first using the sockets and then put the IC's into the sockets when you have finished**, as they are usually quite safe once they are connected to other circuits. Secondly you can earth yourself when you put the circuits into the sockets. There are several cheap ways of earthing yourself cheaply. The best is to buy an earthing strap, which you put on your wrist and connect to the mains earth. **You must be quite sure that you know which terminal on a mains plug is earth, otherwise this is a dangerous procedure.** Alternatively you can touch a water pipe with one hand and your circuit with the other. Both you and your circuit will then be earthed and provided you do this at regular intervals, you should be free to use both hands to insert the IC's into their sockets. Another advantage of using sockets is that

it is easy to replace damaged IC's. Until you have gained experience in building circuits you can expect to ruin a few IC's.

Cables and wires

There are many kinds of wires and cables. We have already stated that single strand wires should not be used except on boards where they should be used. This is most important. Wires are not perfect conductors but have a resistance. The resistance is small but, as you know, if a current passes through a resistance, there will be a volt drop across it and a power dissipation in it. If the wire you use is not thick enough, it will have a significant volt drop across it and it will get hot. Wires are defined in several ways. The total cross sectional area, the number of strands and diameter of those strands, the resistance per unit of length or the current rating of the wire. The current rating is the maximum safe current that the cable can take without getting too hot.

In general, the wires used for the electronic circuits can be thin as the currents are low and the wires used for motors lights and loudspeakers need to be much thicker. For most applications, lighting flex is ideal for connecting to these loads and what is called equipment wire can be used for the low current connections. Equipment wire is available in many thicknesses and many types of insulation. You might consider using ribbon cable for your low current connections as it has all the colours, looks quite neat and can save you from buying the colours individually. If you find that you are having to solder wires in a confined space and that the insulation keeps melting by being touched by the soldering iron, you can use high temperature insulated wire which will not melt when touched briefly with an iron. These wires are more expensive but are easier to solder to.

RIBBON CABLE



CO-AXIAL CABLE

An electric current is not aware of the colour of the insulation around the wire. However there are certain conventions. If you always follow the conventions, your life will be easier when you come to wipe the dust off an old work to put into a new show. Certainly **when it comes to mains connections you should always follow the colour convention for safety reasons.**

It is usual to use black wires for zero volts and red for positive voltages on power supplies.

When using connectors it is a good idea to use the resistor colour code so that pin 1 of the connector has a brown wire, pin 2 a red wire, pin 3 an orange wire and so on. This makes wiring and fault finding much easier, particularly if a long time has elapsed since you made the circuit.

All conductors, and that includes people, are aerials and pick up radio waves and any alternating electrical fields. The mains supply produces electrical fields and so you and any wires will pick up these signals. You can hear them for yourself if you touch an input to an audio amplifier. You will hear a hum in the speakers.

If you have sensors, which are some way away from the circuit, they should be connected using screened cable. A screened cable has a conductor, which surrounds the wires. The outside conductor is called the screen and is usually braided copper wires. If there is only one internal conductor the cable is called co-axial as the internal conductor is in the center of the cable. The screen should be connected to the zero voltage end of your power supply.

Working with mains

Always use an earth leakage circuit breaker. These are sometimes called Residual Current Circuit Breakers (RCCB). This can save your life. These work by switching the supply off, if there is a current flowing in the earth wire. There are some devices, which are generally available in hardware stores, which plug directly into the mains socket and provide a safe socket to plug your mains leads into. **It is not safe to assume that the building you are working in has been correctly wired.**

When working with high voltages you should keep one hand in your pocket or behind your back. The reason for this is that any current flowing through you will not pass through your chest and stop your heart. **This can save your life.** Any circuit that is connected to the mains, in any way, should be mounted in a separate box from the rest of the circuit and should not be connected to the mains until the box is closed so that no mains connections are exposed before the power is connected. This is for your safety and every one else's safety.

In the UK, the mains colour code was changed some time ago to try to save colour-blind people from connecting the earth to the line and the line to the earth as the earth was green and the line was red. Now the earth is green with yellow stripes, which would solve the problem. Unfortunately the people who decided which colours to use for which connections did not consider that most people are not colour blind and decided that the line should be brown, which is the colour which most people would associate with earth and that neutral

should be blue which most people would think was the line as there is no red to chose. The industry is plagued with such stupidity. Anyway the **earth is green and yellow, the neutral is blue and the line is brown**. The neutral is close to earth voltage and the line is at a high voltage.

You should not have any mains connections on the same board as the rest of your circuitry as this could be dangerous. The best way is to have the mains controlling circuit (for example Relays) on a separate board mounted in a separate box. If the box is metal, the box should be connected to earth. In this way, the low Voltage signals enter the box and the mains cables exit the box. You should have some means of strain relief on the cables going into and out of the box, so that the cables cannot become disconnected when someone trips over them during the making and installation of the work. The installation should have provision for preventing people from tripping over cables, which are laid on the ground. There are two ways of doing this. One is to use strong tape (gaffer tape). This should only be done where there are only a few people expected to walk over it and only for a short time. The other is to use a rubber moulding specially designed for that purpose and then tape the molding to the ground. These mouldings are called cable protectors.

General faultfinding procedures

The most common faults are connecting the supply the wrong way round, not cutting the copper track on boards properly if at all, forgetting to make all the connections, connecting components the wrong way round, making bad solder joints and shorting out adjacent tracks with solder.

Many of the components will get damaged if the supply is connected the wrong way round so you should make sure that the connections are correct before turning on the power supply.

Short circuits may damage components when power is applied.

Incorrect connections may also damage components.

Always thoroughly check your circuits with a spy-glass before applying power to a circuit. This is a case of more haste less speed.

Mechanical construction

Mechanics is outside the brief of this publication but here are a few simple tips anyway.

When connecting heavy objects to motors you should have separate bearings to support the weight as motor shafts and bearings are not designed for that purpose. When a separate shaft is used you should use a universal coupling to connect the shaft to the motor shaft, as it is not possible to get perfect alignment between the two shafts.

When mounting parts unto shafts you should use two screws at right angles to each other to clamp the part to the shaft and the hole in the part should not be much larger than the shaft so that a good fit is made. Most shafts will have a flat on them and the screw that clamps onto the flat should be tightened first. To ensure that the screw, which is on the flat, is tightened properly, it should be tightened in easy stages. With the screw loose, wiggle the part back and forth and then find the center of movement and tighten the screw a bit. Keep repeating this until the screw is tight and then tighten the other screw. This will ensure correct alignment of the screw against the flat on the shaft.

Since you can't have a nut on the end of the screw you will need to have a hole with a screw thread in it. The tool to do this is called a tap and the tool that holds the tap is called a tap wrench. When tapping a hole you should be aware that the tap is tighter in the hole when being unscrewed than when being screwed in and that you will need to lubricate the tap. If you do not have any cutting fluid for lubrication, you can use ordinary oil or WD40. You will note that a kit of taps has two kinds for each thread size, one is for starting the thread and is slightly tapered and the other which is not tapered is for finishing the thread. When tapping holes, cut a few turns by screwing the tap into the hole and then unscrew the tap and wipe the swarf (the bits of metal that are removed in a cutting process) off the tap. Then put some more lubricant on the tap and continue a few turns at a time. It is the swarf, which clogs the taps and makes them difficult to unscrew. Taps are brittle and break easily and are not easy to remove from holes if they break inside them.

When you have a tapped hole, you can use grub screws to clamp to the shaft. The advantage of using grub screws is that they can go right into the hole, as they do not have a screw head.

The easiest way to produce a linear (straight line) movement from a rotating one is to use an eccentric or crank. The easiest way to connect to a crank is to use what are called a rod ends.

ROD END



Another means of making moving linkages is to use nuts with nylon inserts. These nuts will not undo even if not tightened unless you use a spanner.

CLICK ON
IMAGE

Here is an example of the use of a crank and rod end to give a linear motion from a rotating shaft.

Chapter 8

Power supplies

The circuits described here will generally use a 12Volt power supply for driving the loads such as motors and lights and use a 5Volt supply for the control circuits (the circuits which control the loads which in many cases is turning them on and off).

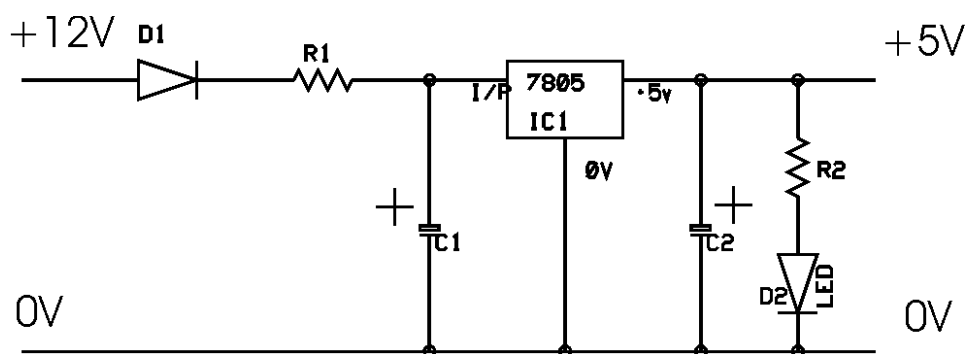
The easiest way to get a 12Volt supply is to buy one, as they are readily available and cheap. The ones, which come complete with mains plug, are usually quite adequate. **Be sure to buy the regulated type.** These come in various current ratings. The most useful is the 500mA (0.5A) type.

There are two basic types of power supply. One is the linear regulator, which is the preferred type, and the other is the switch mode regulator, which is more efficient but has the disadvantage of being more prone to electrical noise. The switch mode supplies are generally used for high current applications.

If you want a battery-powered circuit, then 8 1.5V cells connected in series will also do. Normal alkaline cells are 1.5V. Battery holders are readily available.

5 Volt power supply

The following circuit will be used in conjunction with most of the circuits on this cd to provide a 5Volt supply.



5 Volt power supply

D1 1N4002

R1 100 Ohms

C1 1000 μ F must be at least 16Volt electrolytic

IC1 7805 any prefix or suffix will do except the suffix L which is a low current version

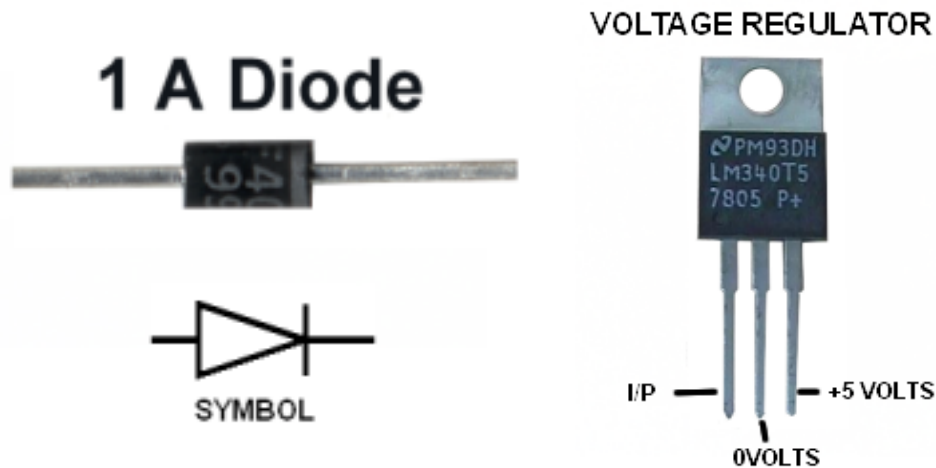
C2 4 μ 7 F must be at least 10Volt and may be electrolytic or tantalum

R2 2K2 this resistor and D2 are optional

D2 high sensitivity LED

Note: the diodes, capacitors and IC must be connected the right way round.

The plus signs on the circuit diagram by C1 and C2 indicate which way round they are to be connected. There will be markings on the capacitors indicating which are the positive or which are the negative ends.



R2 and D2 are just there to provide an indication that the power is on and do not make the circuit function better in any way and may be left out if you wish.

LED's usually have a flat on the plastic where the leads enter them. (You may need a magnifying glass to see it.) This is also the shorter of the two leads. This indicates the cathode, which is the line on the circuit diagram, which is connected to 0Volts.

Testing

The first thing to do with all circuits is to give them a thorough visual inspection with a magnifying glass. Next set your multimeter to Ohms and continuity (audible) if it has such a setting, then connect the meter leads together to check that the meter functions correctly. Connect the meter across the input (0V and +12V) points on the circuit and make sure that there is no short circuit. Do the same for the output 0V and +5V. If the circuit fails this test then check the circuit visually again. There must be a connection somewhere, which should not be there. If you can't see it, remove components one at a time and test each time until you find the part, which is causing the trouble. The most likely causes would be either a track, which is not properly cut, or a solder joint, which has joined two or three tracks together.

If you have a variable voltage supply, then connect it to the 0V and +12V inputs to the left of the diagram and connect a meter set on 20 Volts DC to the 0V and +5V outputs to the right of the diagram. Set the supply voltage to zero and switch on the supply. You should then slowly increase the supply voltage. You should begin to get a reading on the output meter when the input voltage exceeds 3Volts. The output voltage should reach 5Volts when the input reaches

8Volts and remain at 5Volts when the input voltage is increased to 12Volts. If you have connected the LED D2 and resistor R2, then the LED should be on when the supply is OK. **If you do not get these conditions, turn off the supply immediately.**

If you do not have a variable voltage supply, the use of an inline fuse should be used to protect your power source from damage. Inline fuse holders are used in car radios and so can be easily obtained. A 500mA fuse will protect your supply for this circuit but you may need a 1A fuse for some other circuits. It would be prudent to have a few spares so that you still have some if the fuse blows. Connect the fuse between the positive supply and the + 12V input to the left of the circuit diagram. Connect a meter, set to its 20 Volt DC range, across the output 0V and +5V to the right of the circuit diagram. Switch on the supply. The meter should read +5Volts and if the LED is connected, it should be on. **If you do not get these conditions, turn off the supply immediately.**

Note that the output of this circuit remains on for a while after the power has been switched off.

Circuit description

When loads are turned on, the supply will drop instantly and then probably recover. When loads are turned off, the supply will give an instant over-voltage and then recover. We want a circuit, which does not have any voltage spikes on it. Unfortunately voltage regulators cannot work instantly and a short spike would appear at the output if we did nothing to prevent it. The input circuit comprising D1, R1 and C1 reduces the effect considerably. D1 prevents currents from flowing back into the 12Volt supply, which has the additional bonus of ensuring that inadvertent reversal of the supply connection does not harm the circuit. The input voltage causes a current to flow through the diode and resistor into the capacitor, which becomes charged until it reaches the supply voltage. The rate of charge of the capacitor is reduced by R1. If the supply voltage becomes reduced, the capacitor will not discharge into the supply because the diode blocks the flow of current. The 5Volt supply is maintained by the charged capacitor for a time dependant on the current used by the regulator and the load on the 5V output. This copes with sudden drops (glitches) in the power supply. Short over-voltage spikes are converted to slow changing lower voltage increases by the resistor and capacitor. The voltage regulator easily copes with slow changing voltages. This resistor capacitor combination is called integration or smoothing. The resistor limits the current that can charge the capacitor so it takes time to charge up.

The regulator has three main components internally, which are described here for completion but which you can just consider as a three-legged device, which regulates voltages. The regulator has a voltage reference, which is nearly independent of the input voltage, a difference amplifier, which compares a proportion of the output voltage with the reference voltage and a power-

regulating transistor, which is connected between the input and output and is controlled by the difference amplifier. The difference amplifier increases the output voltage if it is too low and reduces it if it is too high. Since the amplifier cannot be infinitely quick, high-speed voltage spikes will pass straight through the regulator.

The capacitor C2 is there to reduce the effect of sudden changes in the load of the 5 Volt supply caused by other circuits connected to it.

R2 limits the current through the LED D2.

Fault finding

It is assumed that the circuit does not function correctly otherwise you would not be reading this.

If there are any short circuits, R1 could get very hot very quickly.

If the circuit did not function correctly, there are only two possible outcomes, either the output voltage was too high or it was too low.

If the output was too high, then either there is a short circuit between some part of the input circuit and the output, the regulator IC1 has been connected incorrectly or IC1 has malfunctioned. Disconnect the supply input and then use a piece of wire to short out the capacitors, which will still have some charge in them. You may notice a small spark but don't worry about that. Set the meter to continuity checking to find short circuits and connect between +5V output and input pin on IC1 then on the cathode of the diode and then on the +12V input. If there was no short circuit then check to see if IC1 was connected correctly. If there were no shorts and everything was connected to the right places, then IC1 must be malfunctioning so replace it and dispose of the old one to prevent you from using it again.

If the output was too low,

Disconnect the supply from the circuit and use a piece of wire to short out the two capacitors, which may still have some charge in them. You may notice a small spark but don't worry about it.

For faultfinding purposes, replace R1 with a 470 Ohm resistor. This will limit and current to a level which will allow you to find the fault more easily and still allow the circuit to function, provided that there is no load on the 5Volt output other than the LED.

If you were using a supply with an inline fuse, set your meter to continuity, check that the meter functions by shorting (connecting together) the leads.

Then connect the meter across the fuse. It should show a short circuit as a fuse has a very low resistance. If it does not, replace the fuse.

Reconnect the supply to the input and, with your meter set to the 20 Volts DC range, measure the input voltage making sure that it is the correct way round. A reverse voltage on the input would give zero volts output.

If the fuse blows again or you still get zero volts on the input, either there is something wrong with your supply, which can be tested by disconnecting it from the circuit and measuring the supply output with your meter on the 20 Volt DC range, or there is a short circuit on the input of your circuit or there is a short circuit between the cathode of D1 and 0V or R1 is shorted and there is still another fault.

If this is not the problem, then measure the voltage between 0V and the junction between D1 and R1. This should be about 0.5V lower than the supply voltage. If it is zero volts, then either D1 is the wrong way round or it has not been soldered properly or there is a break in the copper track between the input and the diode.

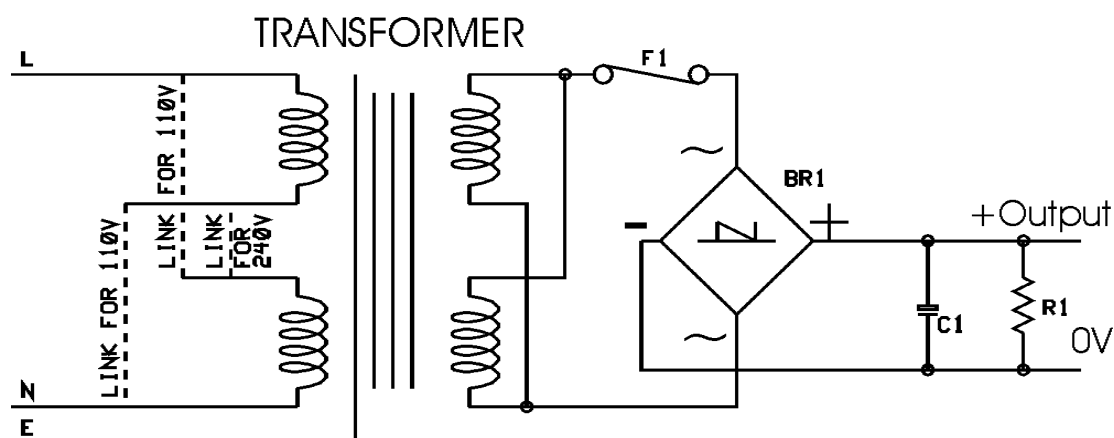
If that was OK then measure the voltage across C1, which should be about 8 Volts or more. If it is zero, then check for short circuits across the capacitor. Check that the capacitor was connected the right way round. If none of this helps, remove IC1 from the circuit and see if the voltage across C1 rises to nearly the supply voltage. If it does then that part of the circuit is OK and if not then look again at the circuit of D1, R1 and C1 and check for short circuits and open circuits (things which are not connected). You may get an open circuit if a solder joint has not been made correctly. You can use the meter on continuity checking to find the bad solder joints by putting one meter probe on the copper track and the other on the component lead, but you should discharge the capacitors first with a piece of wire.. If the voltage was OK then the fault must lie with either the IC or C2 or R2. Check the circuit again. Look for bad solder joints if necessary use the meter on continuity to check all the solder joints. See if R2 is shorted; if it was, D2 will probably be ruined and should be replaced. Replace IC1 and remove C2. If it now works, throw C2 away and replace with a new one making sure that it is connected the right way round. You should be warned that tantalum capacitors are liable to explode spectacularly if connected the wrong way round or the voltage rating is too low.

Once you have got the circuit to function correctly, don't forget to change R1 back to 100 Ohms.

Unregulated mains power supply

It would probably be easier and cheaper to buy a supply than to make one for most applications, but you may need to make one if you wanted to control a DC motor or solenoid, which takes too much current for a cheap supply.

You may need two supplies, one for the high current circuit and one for the control and sensor circuit. In this case you may use the following circuit for the high current supply and a regulated 12 Volt supply for the control, sensor and 5Volt supply circuits.



Unregulated power supply

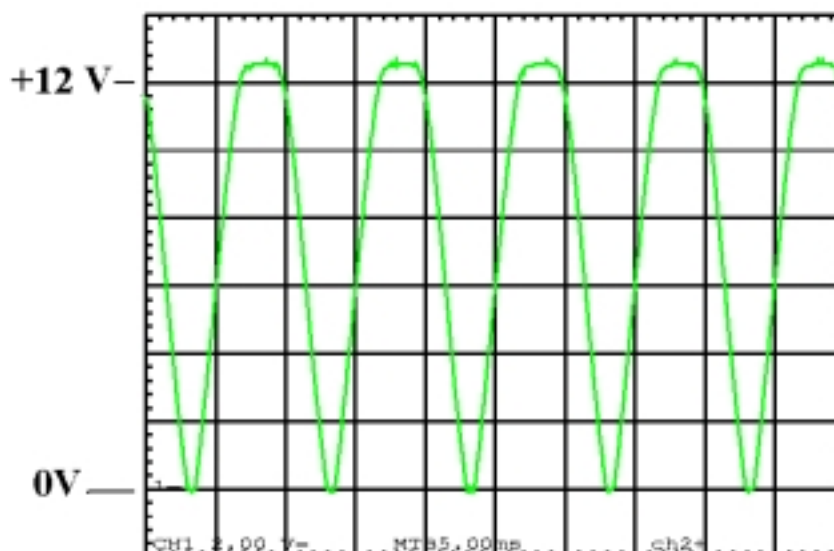
Most of the symbols will be new to you. The transformer is described using several symbols of iron-cored coils together. The transformer shown has four coils, two primary coils to the left of the diagram and two secondary coils to the right. The L, N and E are Line Neutral and Earth. There are several kinds of transformer winding configuration. The one shown is the most common. The two primary windings (coils) allow for either 110V AC mains, which is used in the USA and some other countries or 220V AC mains, which is used in most countries including Europe. In the UK the mains is 240V AC and the 220V AC windings are used there as well but the output voltage will be about 10% higher. The circuit shows some links in the primary circuit. **It is very important to get these right.** The transformer should have markings on it, which show the two primary windings as 0V and 110V. For 110V operation, the two 0V terminals should be connected together and the two 110V terminals should be connected together. **Getting this wrong is dangerous.** For 220V or 240V operation, the 110V terminal of the lower winding should be connected to the 0V terminal of the upper winding. **Getting this wrong is dangerous.** Basically the windings are in parallel for 110V operation and in series for 220V or 240V operation. Usually there are two secondary windings of equal voltage. If they are of equal voltage, they should be connected in parallel with the 0V terminals connected together and the other ends connected together. There may be a confusion here as both primary and secondary windings will both have 0V terminals. **Do not mix them up. Make sure that you know which terminals are which.** The reason for having two secondary windings is to allow for two separate outputs or for a single secondary of double the voltage if they are wired in series (the same way as the primaries for 220V operation). Usually there is another terminal marked SCR, which is a screen, but many

transformers do not have one. If your transformer has one, then it should be connected to earth.

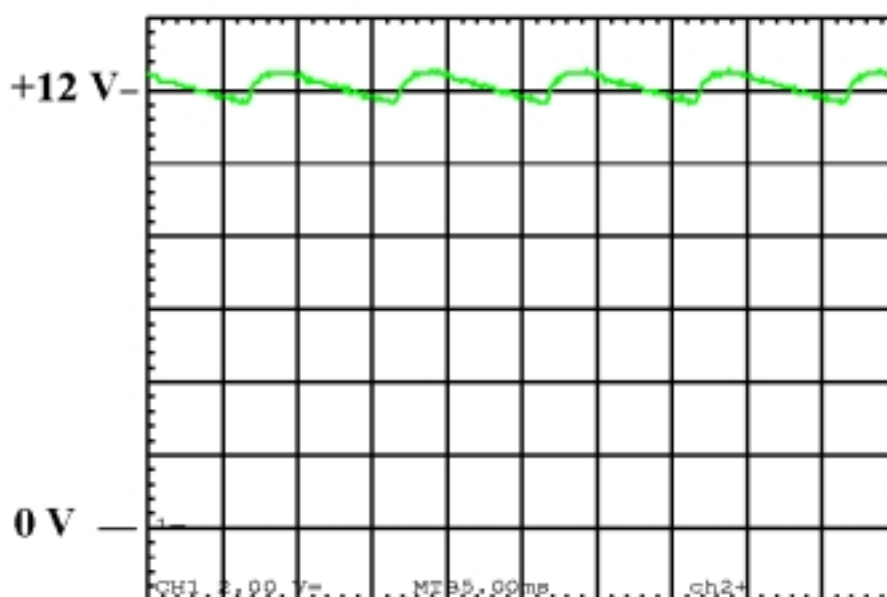
Transformers are specified in terms of output voltage and VA, which is Volts times Amps. The output Voltage that we want is after rectification and smoothing with a capacitor, but the Voltage that is given by the transformer maker is the alternating voltage at the transformer terminals and that is different. Also the manufacturer quotes the output Voltage as being the Voltage at the specified load in terms of VA. Now the output voltage drops as the output current increases. This is known as the regulation, which is specified in terms of the % Voltage drop that the output experiences when the output changes from no load to rated load. The lower this figure, the better the transformer. To make things more complicate, the capacitor only charges up when the alternating Voltage at the transformer terminals is at its peak and discharges through the output load (the motors and solenoids etc.) until the next peak comes along on the next half cycle. You will not get a smooth output Voltage when the supply is loaded but you will get a ripple at twice the mains frequency on top of your output. The size of this ripple is dependant on the load current on the output. Also there is a volt drop of about 1Volt across the bridge rectifier as there are two diodes in series with the output. **Life is not easy when it comes to transformers.** So let us try and make some sense out of all this.

If the transformer were not connected to anything then its output would look like the image of the mains in Chapter 2 except that the amplitude would be much less.

If the capacitor C1 was not connected, then the output would be as shown below. The time base (how quickly the oscilloscope dot moves from left to right) is 5 mSeconds per large division. You will note that this waveform repeats itself every 10 mS rather than the 20 mS of the mains. This is because the negative half cycles have now become positive because of the diode configuration of the bridge rectifier. This has of course doubled the frequency.



With C1 in place but with no load, the output is a straight line without ripple. When there is a load, the output has a ripple as shown below.



Let us say, for example that we want a supply for 12V DC and that our load will be 4Amps and that we can tolerate a ripple voltage drop of 2 Volts and that we are in the UK. Let us also assume that we are using a good quality transformer with a regulation of 5%. In Europe, the mains frequency is 50Hz so after the bridge rectifier, the frequency is 100Hz. If we ignore the time taken to charge the capacitor, it discharges for 100th of a second, which is 10mS. The value of the output capacitor is therefore

$$10 * 10^{-3} \text{ (Seconds)} * 4 \text{ (Amps)} / 2 \text{ (Volts)}$$

which is 20000 μ F

The nearest value to 20000 μ F is 15000 μ F, which would need to be rated at at least 16Volts and will give a bit more ripple. This is not a cheap component.

When the peak output of the transformer arrives, it has to supply the output load of 4 Amps as well as charging up the capacitor and it is at this point that one realizes that the maths is going to be too much so we will guess. Let's assume that the output current of the transformer is four times the output current i.e. 20A, when it is charging the capacitor.

We require 13 V peak at 20Amps from the transformer. This is about 13/1.4 Volts, which is 9.3 Volts rms. Transformer outputs are given not in peak voltage but an average Voltage, which is less by a factor of the square root of 2, which is approximately 1.4. Assume that we will use a 100VA transformer with a 5% regulation. We will therefore need a transformer with an output, which is 5% higher as the output is specified at 100VA and we are using about 200VA at the peak. This gives us a secondary output of 9.8 Volts rms (Root Mean Square). However in the UK the input Voltage is 240V and not 220V so

we need to reduce the winding Voltage by about 10%, which gives an output Voltage of 9Volts rms. So the transformer needs a secondary winding of about 9Volts rms. We are using a 100VA transformer and say that we are actually taking 200VA at the peak. This is OK as the average power is only 4Amps at 9Volts so the power is only 36VA. You might argue that a 50VA transformer would be adequate but if you were to use one it would get hot and the regulation would be twice as bad for the same quality of transformer.

When under load, the output of the circuit would be 12Volts peak with a ripple causing a droop of a little more than 2Volts giving an average output of about 11 Volts. When there is no load, the output voltage will rise to a bit over 13 Volts and have no ripple.

Please note that to save us losing the will to live by getting involved in difficult maths, we made some guesses and assumptions and that therefore the calculated values are very approximate.

Cheap unregulated 12 Volt supplies are only 12Volts at the stated load and can rise to over 18Volts when the load is removed. This extra Voltage can ruin your circuits.

F1 is a fuse, which should be of a slightly higher value than the required output current and should be of the **delay or semi-delay** type, as a quick blow will blow on switch on while the capacitor is charging up. For this particular example, you should use a 5Amp fuse.

BR1 is a bridge rectifier, which is just 4 diodes connected together in a particular way and put in a single package with four terminals or wires.

Note that the left wire has a – sign, the right wire has a + sign and the two in the center have a ~ sign. These correspond to the symbols on the circuit diagram. It does not matter which way round the wires with the ~ symbol are connected. Bridge rectifiers may have many different packages and this photo' is just an example but the markings are fairly universal.

4A BRIDGE RECTIFIER



R1 is there to discharge the capacitor when the power is turned off. The value is dependant on the output voltage. We do not want to waste power and we do not want to use a power resistor on the other hand too high a value would make the capacitor discharge time too long. A 1K resistor would be fine for a 12 Volt supply and a 4K7 would be about right for a 24 Volt supply. These values will make a ¼ Watt resistor warm but not hot.

These parts are too big to put on strip board so they should be bolted to a box or some sheet material. Thin equipment wire is not suitable for this circuit as the currents are too high.

Testing

The first thing to do is refer to the section on working with mains in chapter 7. Click on link to go to chapter 7.

LINK

This circuit does not use much current so it would be prudent to **use a low current fuse in the mains plug**. If you can't get a 1Amp fuse then use a 3Amp fuse but you should not use a plug with a fuse of more than 5 Amps for this circuit.

Before you connect your circuit to the mains supply you should check that it has been built correctly with special attention to the transformer connections. **If any of the components are connected incorrectly, the capacitor may explode** when the circuit is connected to the mains.

Don't forget that there is a mains connection to the transformer so you will get an electric shock if you touch the input terminals of the transformer. **This circuit should be housed in a box and should not be connected to the mains supply until the box is closed.**

Set your meter to the 20Volt DC range and connect across the output. The negative terminal should be connected to 0Volts and the positive terminal to the + output.

Connect the circuit to the mains and your meter should read about 13 Volts if you are using the example given in the text. If you get a negative reading or either a very low or very high reading you should **switch off the circuit immediately and the remove the mains plug from the mains socket**.

You should note that the circuit has a high value capacitor across the output so **the output voltage will remain for some time after the circuit has been switched off. If the output was very high, you should not touch the circuit until it has fallen to below 30 Volts. You should stand clear of it, as the capacitor may explode.**

Circuit description

In this circuit, the transformer reduces the mains voltage to the required value. A transformer works by having a primary coil and a secondary coil wound on an iron core. The iron core is laminated (thin sheets of material put together like a sandwich) and the laminations are electrically insulated from each other by being varnished. If the transformer were 100% efficient, the ratio of

secondary to primary turns on the coils would be the same as the ratio of the secondary to primary voltages. In other words, if the primary coil had twenty times the number of turns as the secondary coil, the primary voltage would be twenty times the secondary. The secondary and primary currents would also be in the same proportion. So the secondary load current would be twenty times the primary load current. Transformers are not 100% efficient so the primary current would be higher and the secondary voltage would be lower. Transformers can only work with alternating voltages and currents.

The output of the transformer is connected across a bridge rectifier BR1 via the fuse F1. The fuse protects the transformer from having too much current drawn from it. The bridge rectifier steers the current from the transformer, which produces an alternating Voltage, to the positive and negative terminals. If there were no capacitor in the circuit, the output of the bridge rectifier would look as though the negative halves of the alternating voltages had been turned upside down to make them positive as well. When the capacitor C1 is there, the output is smooth unless current is taken from the circuit in which case there will be some ripple as the capacitor discharges into the load when the transformer output is lower than the capacitor voltage and charges when the transformer output is higher than the capacitor voltage. The ripple Voltage therefore has a frequency, which is twice the mains frequency. An oscilloscope view of the ripple was shown earlier in this chapter. The resistor R1 discharges the capacitor slowly when the mains supply is switched off.

Fault finding

Since the whole circuit should be mounted in a box to make the circuit safe, there is not much that you can do if it does not function correctly. The only thing to do is to disconnect the mains from the circuit and wait a while for the capacitor to discharge. Then check that the circuit has been built according to the circuit diagram. Look for short circuits, open circuits and bad solder joints. Set your meter to continuity, remove the fuse and check that the fuse has not blown using your meter. If all else fails, try replacing the bridge rectifier and if that helps, throw the old one away. If this doesn't help, try replacing the capacitor and if that helps, throw the old one away.

Chapter 9

Sensors

There are many types of sensor. The choice of sensor is dependent on what you want to sense. You can sense heat, light, sound, position, movement, direction of movement or speed of movement. There are other things to sense but we will only consider these options.

You will have to consider which type or types of sensor are appropriate to your work.

You should note that there are circuits in the following chapters, which can be used in conjunction with sensors to control motors and lights etc. If, for example you wanted to have something operating only when someone was there to see it and it did not matter whether it continued operating for a while after the place was devoid of people, you could simply extend the operating time so that it would operate if someone had moved sometime earlier but would stop if there had not been any movement for a long time. In this case a simple movement detector would suffice and you would not need to know whether someone was definitely still there or not. This allows for a movement rather than a position sensor. Movement detectors are cheap and can sense movement over a large area

The simplest sensors to use are the ones, which you do not have to make yourself. The burglar alarm industry has several types available. The most common are the magnetic door switch, the under carpet pressure switch and PIR (Passive Infra-Red) movement detector.

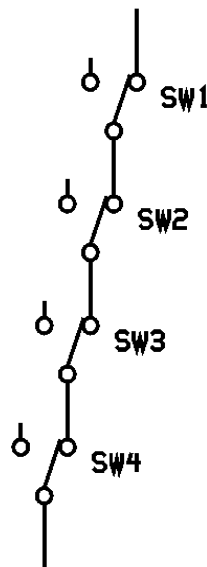
Sensors which have analogue outputs (those which are not switches or have voltage outputs which switch between 0V and 5V) will need to have some signal conditioning which is dealt with later in this chapter.

Sensors, which have switch outputs, can be connected together so that any one of the sensors giving a signal will operate the circuit but the circuit will not know which one is being operated. This is known as being **WIRED OR**. Some sensors have normally open switches (ones where there is not normally a connection but when something is detected, there is a connection) and some have normally closed switches (ones where there is normally a connection but there is not a connection when something is detected).

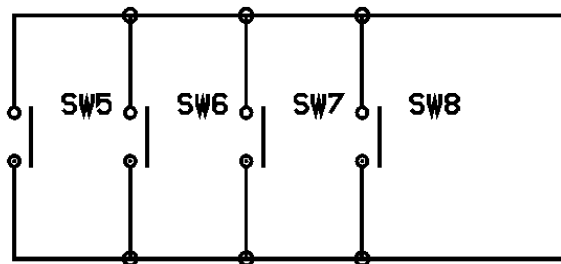
Normally open switches should be connected in parallel and normally closed switches should be connected in series.

The following circuit demonstrates these two conditions.

SW1, SW2, SW3 and SW4 connected in series



SW5, SW6, SW7 and SW8 connected in parallel



Door Switch

The magnetic door switch tells you whether a door is open or closed. It does not tell you whether anyone has passed through the door or not but just whether it is open or closed. These use a magnet and a read switch which closes when in a strong magnetic field.

Pressure Mat

Pressure mats are designed to be placed under a carpet, and if someone stands or sits on it, it will give a signal. These are simple switches and are quite useful for detecting whether someone is in a particular place like sitting in a chair for example. They can be covered with a cushion but must have their underside against a hard surface. The limitations are that the area is quite small so a large sensing area would need many of them and they are unsightly so would need to be covered somehow.

PIR detectors

PIR's detect movement by sensing body heat. They divide the sensing areas into narrow strips and look for heat changes. If you have a hot piece of metal it glows red. If it gets cooler it still radiates light but it is at a colour, which is beyond red and therefore cannot be seen by us. This colour is called infrared. The cooler the object becomes, the further into the infrared the colour becomes. The PIR sensors detect light in the far infrared, which includes the heat radiated by people.

PIR detectors come in two basic types. One is used for turning on security lights and should not be used in the circuits described in this cd as they have been designed to turn mains driven lights and therefore have the wrong kind of output. They may be used for switching mains powered devices and have the advantage of having built-in timers. The other type is for burglar alarms and that type has a relay (switch) output, which can be easily connected to anything we want. It should be noted that burglar alarms have normally closed circuits so that there is an alarm condition if the wires are cut. This means that the switch is closed if nobody moves and opens if somebody moves. This is normally the wrong way round for our purposes, but circuits in the following chapters will handle that.

As stated PIR's detect movement and not position. PIR's can tell you that somebody has moved but not if or where they are. They do have a range of about 6 meters or so, so they can sense a large area and are very useful. If the detection angle is too great, you can paint over part of the sensor. Once painted, they can not be restored to their original condition so if you intend to use this method of controlling the sensing area, you should first experiment by covering part of the sensor with tape or cardboard and only paint it when you are sure that you know which parts to paint. You should also be aware that some sensors have a viewing area directly below them so that they can be mounted above a doorway and detect people entering a room as well as people climbing in through a window. You may well want to paint over that part of the sensor.

Temperature sensors

There are several types of temperature sensors. The most common are the variable resistance types. These are available as non-precision thermistors (temperature sensitive resistors), which are available as positive temperature coefficient devices (the resistance increases with temperature) and negative temperature coefficient devices (the resistance decreases with temperature). There are also precision devices called platinum resistance thermometers, which have a positive temperature coefficient.

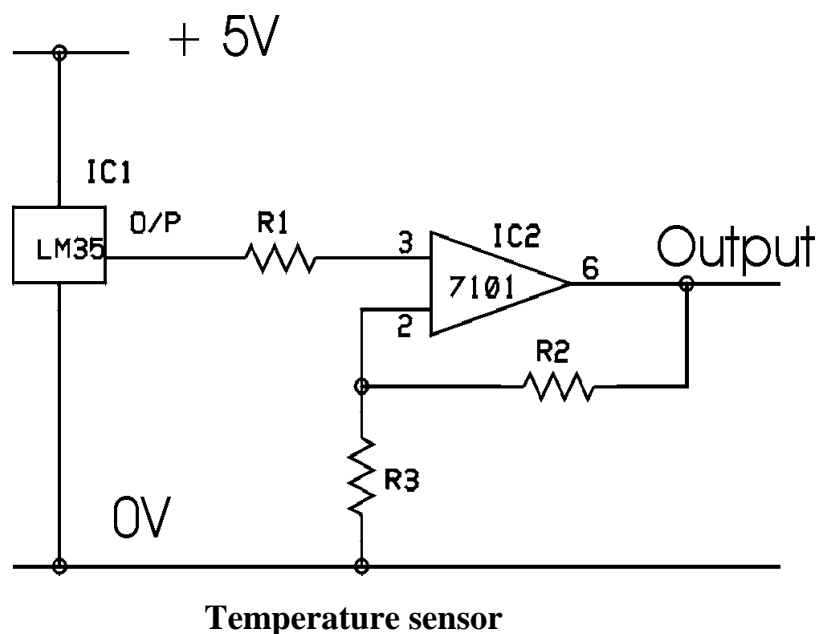
See the section on signal conditioning at the end of this chapter for circuits to provide useful signals using variable resistance sensors.

There are thermocouples, which have a very limited use for artists and will not be dealt with in this cd.

A simple and cheap way of measuring temperature is to use a temperature sensing integrated circuit. A typical device is the LM35 which will measure temperatures from 0°C to 100°C. It looks like a small transistor having three pins. One is for 0Volts one is for 5Volts supply and the third gives a signal of 10mVolts per degree C. There are several such devices available. There are remote temperature sensors using infra red technology but these are not particularly good at ambient temperatures, are expensive and their outputs are

dependent on the surface being looked at (the emissivity of the surface being measured).

The following circuit will amplify the output from an LM35 temperature sensor to make it more useful. The gain is 10 so that the output will be 100mV per deg C.



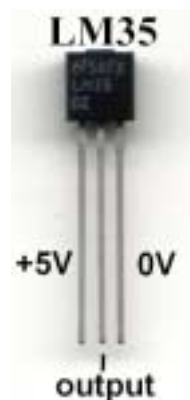
R1 2K2

R2 27K

R3 3K

IC1 LM35 temperature sensor

IC2 7101 operational amplifier, any suffix or prefix should be OK. Connect pin 4 to 0V and pin 7 to + 5V. Do not make any connections to the unused pins.



Testing

Before applying power to the circuit, inspect the circuit thoroughly using a spy glass ensuring that there are no unwanted short circuits or open circuits and that the circuit follows the diagram exactly. Ensure that the power supply is connected the right way round. Then set your meter to continuity or low Ohms range. Connect the meter across the 0V and 5V supply and make sure that the reading is not zero or near to zero. You may get a bleep or a low Ohmic value for a short time because of the capacitor in the power supply, but this should not last more than a few seconds. If it is continuous, you have a short circuit somewhere and you should follow the instructions in the fault-finding section.

Set your meter to the 20 Volt DC range and connect between the 0V supply and the output. Switch on your 5Volt supply and you should get about 2 Volts, which would be a temperature of 20°C. The output should vary with the temperature of the sensor so if the temperature is lower, so will the output Voltage. If you now warm the sensor by holding it tightly between your thumb and forefinger, the output should rise slowly to about 3 Volts. If you do not get the expected results, you should switch the circuit off immediately.

Circuit description

As mentioned, the output of the LM35 is 10 mV per °C and is zero at 0°C. At 20°C, the output will be 200 mV. This output is connected to the non-inverting input of the operational amplifier IC2 via R1. R1 could be shorted and the circuit would still function but it is there as a matter of good practice to keep the input resistances of both amplifier inputs approximately the same. It also protects both IC1 and IC2 from damage due to switch on conditions and electrical noise. Basically it is a refinement. Operational amplifiers have two inputs, an inverting input (pin 2) and a non-inverting input (pin3). They amplify the voltage difference between these two inputs. The gain can be considered as infinite for our purposes. If the Voltage on pin 3 is slightly higher than on pin 2, the output will be positive. The output of IC2 is potentially divided by R2 and R3 so that the Voltage at the junction of R2 and R3 is 1/10 th of the output voltage. $R3/(R2+R3) = 3K/(27K+3K) = 1/10$. The output of IC2 will therefore be 10 times the input. If the output of IC1 increases, the voltage at pin 3 of IC2 becomes higher than that at pin 2 so the output of IC2 increases until the Voltage on pin 2 becomes equal to the Voltage on pin 3. Similarly if the output of IC1 reduces, the output of IC2 will reduce to keep the Voltages on pins 2 and 3 equal.

Fault finding

If the supply is shorted out then either IC1 is faulty IC2 is faulty or you have a short circuit or a wrong connection. If a thorough visual inspection with a spy glass does not reveal the problem, remove IC1 and see if the short is still there, if it is not, see if the LM35 has a short by using your meter set to continuity directly across the sensor supply pins whilst it is removed from the circuit. The meter common should be connected to the 0V pin and the other meter connection to the +5Volt pin. If the meter is the other way round, the LM35 will look like a diode and your meter will probable indicate the diode voltage of about 0.6 Volts. If the LM35 proves not to be the cause, then you removed the short circuit when you removed the LM35. The short was therefore due to a sliver of solder near to the LM35. If the LM35 was the cause of the short, throw it away and get a new one. If this was not the cause, remove IC2 and go through the same procedure as with the LM35. If there is still a short circuit when neither IC1 nor IC2 are connected, then there must be a short circuit on the board. Give the board a thorough inspection with a spy glass.

If there was no short circuit of the supply but the output was zero or nearly zero then either there is a short circuit or one of the IC's is not connected the correctly. The 5 Volt power supply described in this cd has a current limiting resistor so any problem of this kind will reduce the output voltage of the power supply. With your meter set to 20 Volt DC range measure the supply voltage. If it is much less than 5 Volts, then you should first switch off the supply and then visually check the circuit again. Check that your power supply still works by disconnecting it from the circuit and then measuring the output. If the supply works correctly then carry on else read the chapter on power supplies. The most likely cause of the reduced power supply would be IC1 being connected the wrong way round. This would have had the effect of reducing the 5 Volt supply to about 0.6 Volts. If you are not sure what is causing the problem with the supply, first remove IC1 and see if the supply voltage has been restored to 5 Volts or not. If it has then the problem is with IC1 which was either incorrectly connected or is faulty. You should always throw fault components away otherwise you will use them again. Faulty components are very rare so it is much more likely that you have connected them incorrectly. Incorrect connection of components may cause them to fail. If IC1 was not the problem, then go through the same process with IC2. If you still have a problem with the power supply when neither IC1 nor IC2 are in circuit, then there must be a problem with the board itself or the resistors are both the wrong values and connected to the wrong paces.

If the output Voltage was too high, then set your meter to the 2 Volt DC range and measure the output of IC1, which should be about 0.2 Volts. If it is much higher then it is either very hot or R1 is the wrong value and connected to the wrong place or the output is incorrectly connected to some other part of the circuit or IC1 is faulty. If the output at IC1 is OK then check that the values of R2 and R3 are OK and that you have made good solder connections to R2 and IC2. IC2 may be faulty but it is more likely that there is either a bad connection or an incorrect connection.

Light sensors

There are basically three types of light sensors. There are Light Dependent Resistors, which change their resistance with the amount of light falling on them. (See the section on signal conditioning at the end of this chapter) There are photovoltaic cells which produce a voltage according to the light seen. This type was used for early forms of photographic light meter. The third type is the semiconductor type, which takes the form of either the photo diode or phototransistor.

If for example you wanted to detect changes in light level rather than just the light level itself, you will need to use a differentiator which will be described in the section on signal conditioning at the end of this chapter. This form of sensor is sometimes used in toys as a cheap movement detector but will produce false signals if the light it sees changes without anybody being there. If

your work includes lights, which change in intensity or direction, your work may cause a false signal.



LIGHT DEPENDENT RESISTOR

It will often be a good idea to insert the light sensor in an opaque tube so that it only looks at what you want.

Infrared Light Beam

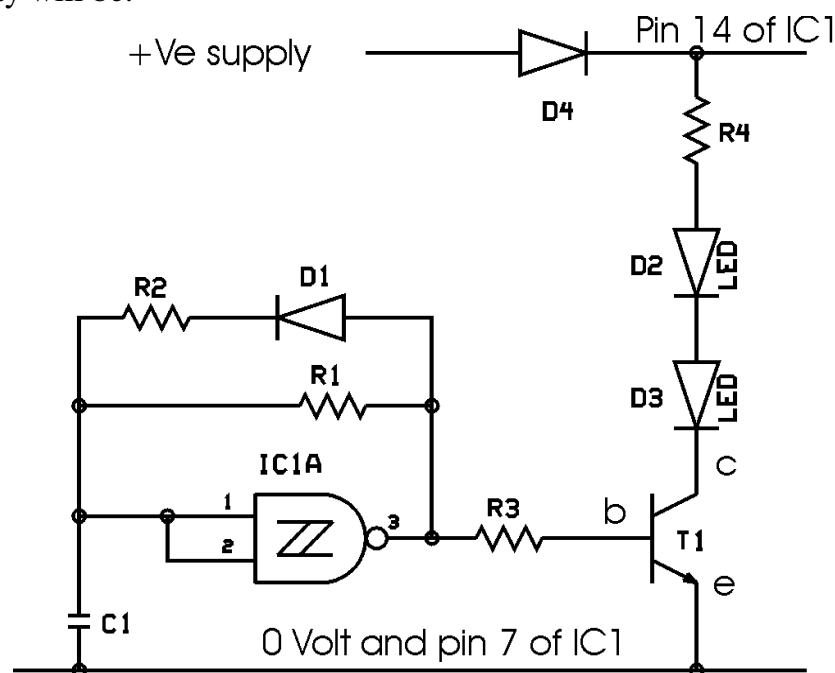
You can use pulsed infrared beams (turned on and off repeatedly and quickly) and light sensors to detect objects that break the beam. The sensor needs to have circuitry, which only responds to pulsed light and not to continuous light. You should note that incandescent lamps (ordinary light bulbs) and sunlight, produce large amounts of infrared, which can lead to trouble when using these types of sensor. Fluorescent lights do not produce much infrared and therefore do not usually cause problems. These beams with sensors are commercially available and can be used reliably for distances of up to about 10 meters. For much greater distances you would need to use lasers.

There are many photo diodes and transistors available. There are also a number of integrated circuits for amplifying the signals from photodiodes and some photodiodes have their own built-in amplifiers. There does not appear to be a particular part which is commonly available everywhere, each supplier having their own particular types. The following circuit uses commonly available components but you may be able to find a more convenient solution from your local supplier. Normally, manufacturers have application notes for use with their products but these are for professional users and do not include fault finding help.

For the purposes of infra red beams you should chose infra-red LED's which are both high intensity and have narrow angles so that they only produce light in the direction you want. If you don't use these types you will not be able to sense the light at a great distance. The greater the angle of transmitted light, the smaller the proportion of that light is seen by the sensor and therefore the distance between the light emitter and light sensor that can be sensed is less. If

you want to narrow the field of view still further and do not want to lose sensitivity, you can use a lens. Spy-glasses work quite well in such applications if you position them so that the sensor is at the focal point of the lens. You can find the focal point by moving the lens towards and away from the sensor until it appears sharp. The part to get into focus is inside the diode and not the surface of the diode.

You should also chose a photodiode, which is sensitive, has an infrared filter and has a narrow viewing angle. If you need more sensitivity, you can use a lens in the same way as for the light source. This has the effect of increasing the area of light that reaches the sensor. The bigger the lens area, the greater the sensitivity will be.



Infrared light beam source

R1 47K

R2 22K

R3 10K

R4 180 Ohms for a
12 Volt supply or
130 Ohms for a 9
Volt supply

C1 22,000 pF

D1 1N4148

D2 infrared LED, a small flat on the side indicates the cathode

D3 infrared LED, a small flat on the side indicates the cathode

D4 1N4002

IC1 4093 any prefix or suffix. Pins 5,6,8,9,12 and 13 should be connected to 0 Volts if not used by another circuit. **Note that these IC's are static sensitive.**

T1 BC184L transistor



BC184L

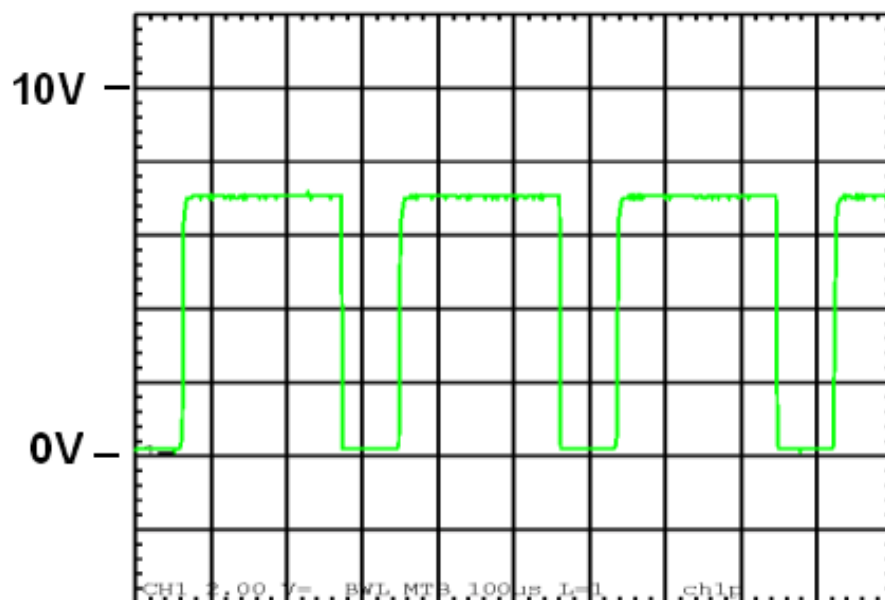


Testing

Before applying power to the circuit, inspect the circuit thoroughly using a spy glass ensuring that there are no unwanted short circuits or open circuits and that the circuit follows the diagram exactly. Ensure that the power supply is connected the right way round. Then set your meter to continuity or low Ohms range. Connect the meter across the 0V and +Ve supply both sides of D4 and make sure that the reading is not zero or near to zero. If it is continuous, you have a short circuit somewhere and you should follow the instructions in the fault finding section. If you do not get the expected results, you should switch the circuit off immediately.

Set your meter to the 20 Volt DC range and connect across the 0 Volt supply and the junction of the collector (marked 'c' on the drawing) of T1 and the LED D3. Connect the supply. The meter should read a little over 5 Volts for a 9 Volt supply and about 8 Volts for a 12 Volt supply. If you get a Voltage reading near to the expected value then the circuit is OK. If you get either a very high reading close to the supply voltage or a low reading close to zero, then switch off immediately.

If you have an oscilloscope, then connect it between 0 Volts (screen) and the collector (marked 'c' on the circuit diagram). Set the time base to 100 μ Sec per division. You should then see the image below. This is for a 9 Volt supply but a 12 Volt supply would look the same except that the Voltage would be greater by 3 Volts.



Time base 100 μ Sec per large division

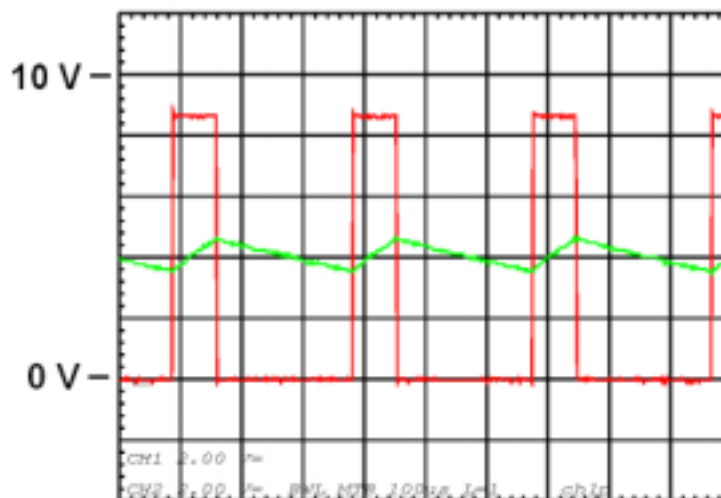
Note that the output is high for about three times the time that it is low.

If you do not have an oscilloscope but you can measure frequency with your meter, set your meter to frequency and connect between 0 Volts and the collector of T1. Your meter should read between 3KHz and 4KHz.

Circuit description

D4 protects the circuit from the wrongly connected power supplies and batteries. It is easy to accidentally touch the battery terminals to the battery clips the wrong way round.

In the oscilloscope view below, the red trace is the output of IC1 pin 3 and the green trace is the input of IC1 pins 1 and 2. The time base (horizontal direction) is 100 μ Seconds per large division and the supply is from a 9 Volt battery.



When the Voltage across C1 is low, the output of IC1 is high. This charges up C1 via R1 and R2 as D1 conducts. The Voltage across C1 quickly increases until it reaches the level at which IC1 senses that the input is high and the output then becomes low and C1 discharges through R1 but not through R2 as the diode blocks it. The discharge of C1 is therefore slower than the charging up. When C1 discharges to the level at which IC1 senses that the input is low, the output becomes high again and the process repeats itself. This circuit is called a rectangular wave oscillator. The difference in Voltage levels at which the Schmitt trigger senses a low input and a high input is called its hysteresis which in the case of a 4093 is about 1 Volt at a 9 Volt supply. You can see that the green trace is nearly triangular and that the Voltage difference between its upper and lower limits is about 1 Volt. You will note that this circuit would not work properly if IC1 was an ordinary gate, as that would not have a hysteresis.

The on period is shorter than the off period. We want this to reduce the average current drawn from the battery. A PP3 battery should last at least 24 Hours.

The output of IC1 is connected to the base (marked with a 'b' in the circuit diagram) via R3. When the output of IC1 is high, T1 is turned on and when it is low, T1 is turned off. When T1 is on, a current flows through the LED's D2 and D3 and is limited to about 50 mAmps by R4. R4 needs to dissipate the

power generated by having 50 mAmps passing through it and although this is not quite 1/2 Watt when it is on, you should use a resistor of at least 1 Watt to keep it cool. It should only be on for 1/4 of the time if the circuit works correctly, which would mean that the average power dissipated by the resistor would be 1/4 of that, but it is better to assume that it is on all of the time.

Fault finding

The first thing to do is give the circuit a thorough visual inspection with a spy glass looking for bad solder joints and short circuits. Check that the circuit you have built exactly matches the circuit diagram and that the components are the correct values and connected the right way round.

Set your meter to continuity, disconnect the power supply and check for short circuits. First check the supply side of D4 swapping over the meter leads. If it shows short circuits both ways round, then you either have a short circuit across D4 as well as a short somewhere else, D4 is faulty and you have a short circuit somewhere else or you have a short circuit between the power input and somewhere else. Since you have disconnected the power source from the circuit, there should not be any connection to the anode of D4. Look to see if there is a sliver of solder joining it to an adjacent track.

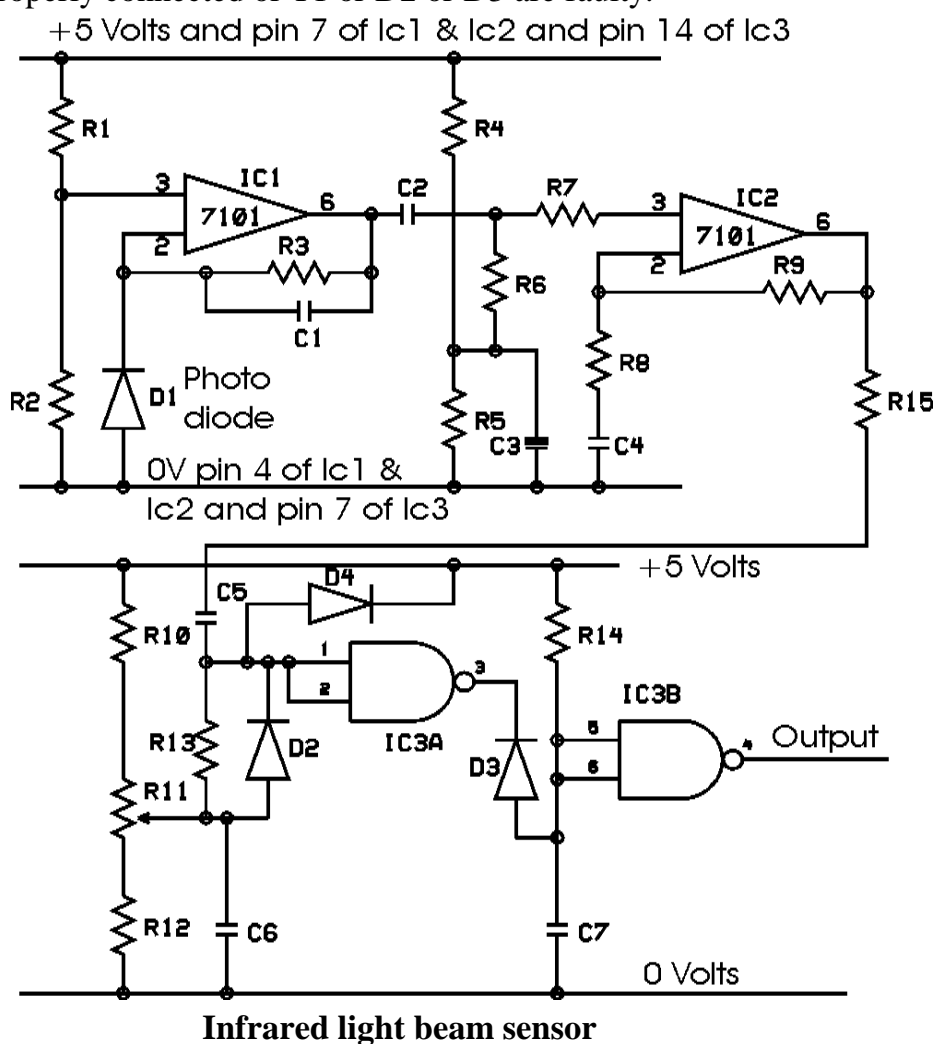
Now check the cathode side of D4 for short circuits. It should only be connected to two points of the circuit those being R4 and pin 14 of IC1. It may be easier to test if you remove IC1 being careful to protect the IC from static. You should now be able to find the short circuits quite easily and then replace IC1.

If there are no short circuits across the power supply inputs, connect the power supply. Set your meter to the 20 Volt DC range. Measure the supply Voltage and check that the supply is connected the right way round. If it is substantially lower than expected, something must be taking too much current. If this is OK, then go to the next paragraph. Disconnect the power supply and remove IC1, taking care not to damage it, as it is static sensitive, and then try again. If this has not solved the problem, R4 is probably short circuited. If R4 was short circuited, it is likely that D2, D3 and T1 will have been damaged and will probably need to be replaced. If R4 was not short circuited then the cathode of D4 is probably connected to somewhere other than where it should be. If removing IC1 cured the problem, then check the connections to the IC. If they were OK then it is just possible that you have a faulty IC.

Set your meter to the 20 Volt DC range. Connect between 0Volts and the junction of D4 and R4. Connect the power supply. The meter should read 0.5 Volts less than the power supply Voltage. If it reads nearly zero then D4 is the wrong way round.

If you have an oscilloscope, then see if you get the waveforms shown in the circuit description section, if you do, then go to the next paragraph. If you get a similar waveform but the output of IC1 pin 3 is high for much longer than it is low, then D1 is the wrong way round. If the waveform is similar but the times are very different, then you probably have the wrong component values. If you do not have an oscilloscope, set the range of your meter to 20 Volts DC and connect between 0 Volts and pin 3 of IC1. You should read 2 Volts for a 9 Volt supply and 2.5 Volts for a 12 Volt supply. If you get about 6 Volts for a 9 Volt supply or 8 Volts for a 12 Volt supply, then D1 is the wrong way round. If the output of IC1 pin 3 is about $\frac{1}{2}$ of the supply voltage, then C1 is not connected. If the output is permanently nearly zero Volts then R1 may not be connected properly or pins 1 and 2 may be connected to pin 14 or the IC may be faulty.

If the output of IC1 is OK then it is likely that T1 is not connected the right way round. Note that not all types of transistor have the same pin configuration so if you are using a different part number, it may well have a different pin configuration and you will have to find out which pin is which from your supplier. If T1 is connected correctly, then see if D2 and D3 are connected the right way round. If this is OK but the problem still persists, then either R3 or R4 is not properly connected or T1 or D2 or D3 are faulty.



R1 100K

R2 10K

R3 1M

R4 10K

R5 10K

R6 100K

R7 10K

R8 4K7

R9 1M

R10 22K

R11 10K

R12 10K

R13 100K

R14 22K

R15 1K

C1 4p7F

C2 2200pF

C3 4μF negative end to 0V

C4 10,000pF

C5 2200pF

C6 0μ1 F

C7 0μ1 F

D1 photo diode, a small flat on the side indicates the cathode

D2 1N4148

D3 1N4148

D4 1N4148

IC1 7101 any prefix or suffix

IC2 7101 any prefix or suffix

IC3 4011 any prefix but must not be unbuffered type with a U in the suffix

Note that these IC's are static sensitive

OPERATIONAL AMPLIFIER



4011



Testing

Before applying power to the circuit, inspect the circuit thoroughly using a spy glass ensuring that there are no unwanted short circuits or open circuits and that the circuit follows the diagram exactly. Ensure that the power supply is connected the right way round. Then set your meter to continuity or low Ohms range. Connect the meter across the 0V and 5V supply and make sure that the reading is not zero or near to zero. You may get a bleep or a low Ohmic value for a short time because of the capacitor in the power supply, but this should not last more than a few seconds. If it is continuous, you have a short circuit somewhere and you should follow the instructions in the fault finding section. If you do not get the expected results, you should switch the circuit off immediately.

You will need the previous circuit functioning correctly to test this circuit.

Switch on the infrared light beam source. Set your meter to the 20 Volt DC range and connect between 0 Volts and the output. Arrange the circuits so that one of the infrared emitters (LED's) is pointing directly at the photo diode D1 as in the image below.



Turn off any incandescent lamps that are pointing at the photo diode. Switch on the power supply. The output should be about 5 Volts. Now point the infra red emitter away from the photodiode, switch off the infrared light source or place an opaque material between emitter and photo diode and the output should be nearly zero. Infra red light will pass straight through paper so you will need some heavy card or plywood or some aluminium foil. If you do not get the expected results, you should switch the circuit off immediately.

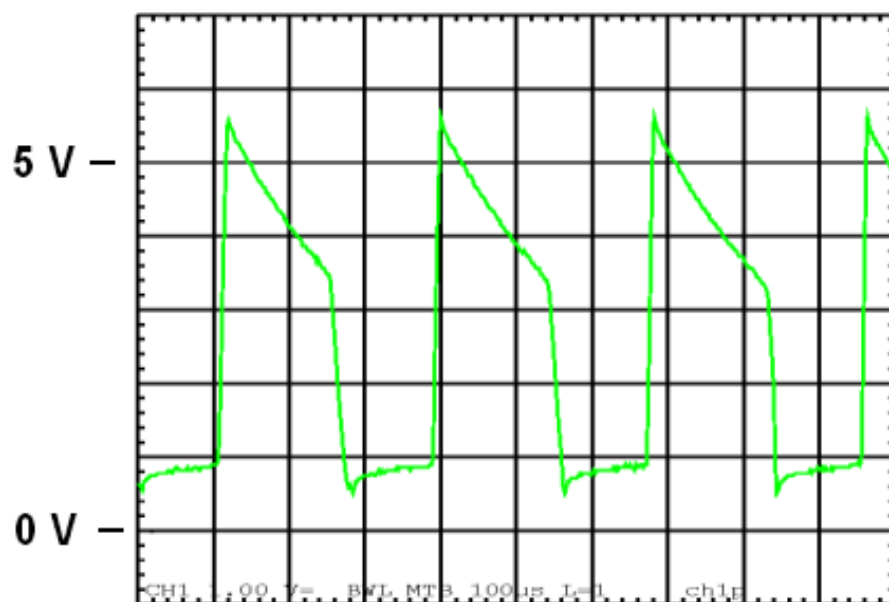
Circuit description

You will note from the circuit diagram that the photo diode D1 is reversed biased, which means that it is not conducting. There is always a very small current in a reverse biased diode. In a photo diode, this small current increases when light falls on it and it is this that we are sensing. R1 and R2 provide a bias of about 0.5 Volts for the non-inverting input of the operational amplifier IC1 on pin 3. Operational amplifiers have a very high gain and if the voltage on the non-inverting input is a little above that on the inverting input (pin 2), the output (pin 6) goes very positive. R3 is connected between the output and the inverting input of IC1 and is called a **feed back** resistor. As the output of IC1 increases, an increased current flows through R3 and increases the voltage on the inverting input of IC1. The leakage current of the photo diode determines this voltage. So you can see that the output of IC1 is a voltage, which increases according to the amount of light that falls on the photo diode. C1 is connected in parallel with R3 to prevent high frequency oscillations in the circuit and give the circuit stability. You will note that the sensitivity of this part of the circuit is determined by the value of R3. The higher the value of R3, the greater the sensitivity.

We are only interested in the amount of the pulsed light and not the actual level of light falling on D1. This is to make sure that we ignore the ambient light and only look at the light from our light beam, which is pulsed. C2 will only allow quick changing signals to pass through, as it has a low value of capacitance. This reduces the effect of mains powered lamps whilst still allowing the higher frequency pulsed light signals to pass. This is called a high pass filter. R4 and R5 provide a 2.5 Volt bias for the operational amplifier IC2. C3 removes any unwanted noise from that bias. R6 provides a connection to the bias and R7 connects the signal to the non-inverting input of IC2. R9 is a feed back resistor and R8 potentially divides the feed back to give the amplifier gain for fast

changing signals. For slow moving signals, the gain of IC2 is one, as a change in the output voltage is not reduced at the inverting input so the steady state voltage on the output of IC2 is 2.5 Volts. Fast moving signals have a much higher gain being $(R9 + R8)/R8$ which in our circuit is 214. C4 is again small so that signals from mains driven lights, is not amplified as much as the signals from the light beam. Because C4 is small and our beam pulse frequency is not high enough to ignore the value of C4, there is a reduction in the amplifier gain and its gain at the frequency of our light beam will be about 145. The effect of C4 on the circuit is to produce a further high pass filter.

The remainder of the circuit is used to convert the output of IC2 to a signal which is 5 Volts if the beam is not broken and zero Volts if it is. R10, R11 and R12 provide a bias for IC3A, which is adjusted by R11. R11 is used to vary the sensitivity of the circuit. C6 couples the bias voltage to 0 Volts for high frequency signals. The alternating signal output from IC2 is fed to the biased input of IC3A via R15 and C5. C5 is small so it acts as a further high pass filter. R13 provides a reference voltage for the alternating signal and D2 causes that signal to be always positive with respect to the bias Voltage. Without D2, the signal on R13 would alternate between positive and negative having an average value of the bias Voltage. D4 clamps the signal on pins 1 and 2 of IC3A so that it cannot be more positive than 0.6 Volt higher than the 5 Volt supply. This is to protect IC3 from damage. Most of these IC's already have such protection built in but not all of them do. R15 limits the current output of IC2 and the current in D4. R11 adjusts the minimum signal from IC2 that will cause IC3A to switch.

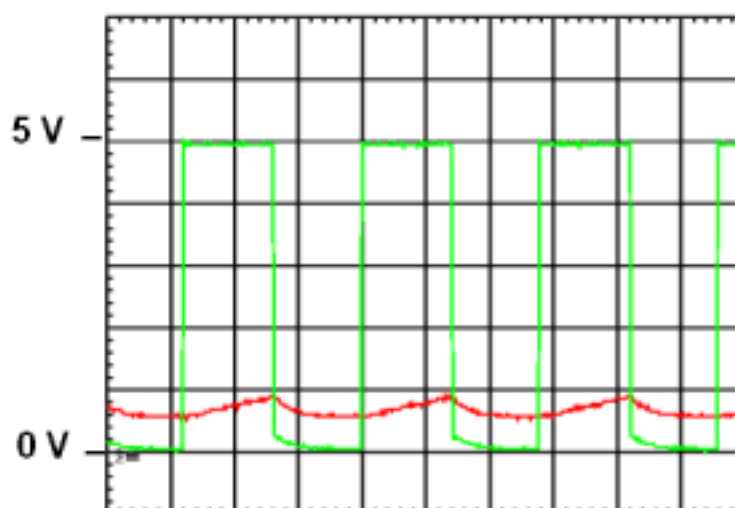


Time base is 100µSec. per large horizontal division.

In the oscilloscope image shown above, the trace shows the signal on pins 1 and 2 of IC3. The bias is set to minimum for minimum sensitivity. You will note that the high Voltage part of the signal is not flat at the top but decays

quite rapidly. This is because C5 has a low value to reduce the effect that the lower frequency signals from mains lamps has on the circuit.

When the light beam is broken, the input of IC3A is low, being the bias Voltage and the output on pin 3 is therefore high at 5 Volts. C7 charges up to 5 Volts via R14 and the output of IC3B is low. When the beam is not broken, the output of IC3A oscillates between high and low. When the output of IC3A is temporarily low, C7 discharges through D3 causing the output of IC3B to be high. When the output of IC3A is temporarily high, C7 charges up but before it has time to reach a high enough Voltage to cause the output of IC3B to become low, the output of IC3A becomes low again. The following oscilloscope image shows this. The green trace is the output of IC3A and the red trace is the input of IC3B. The time base is 100 μ Seconds per large division.



You will note that the green trace does not fall completely to 0Volts instantly but takes a short time and that the red trace follows it. This is because the output of IC3A cannot instantly discharge C7. When the green trace goes high, the red trace slowly rises but does not get very high before it comes down again.

Fault finding

The first thing to do is give the circuit a thorough visual inspection with a spy glass looking for bad solder joints and short circuits. Check that the circuit you have built exactly matches the circuit diagram and that the components are the correct values and connected the right way round.

Assuming that there are now no short circuits directly across the power supply, set your meter to the 20 Volt DC range. Connect the meter across the power supply and switch on. You should have 5 Volts. If the circuit takes too much current, the voltage will be much less. The 5 Volt power supply has a current limiting resistor in the circuit so it should not come to any harm by being short circuited. The current limiting resistor will just get hot. Do not let it get so hot

that you cannot touch it. If the Voltage is low, switch off and remove the IC's one at a time, starting with IC3 and finishing with IC1. Each time you remove an IC, switch on the power supply and see if the voltage rises to 5 Volts. If it does then check the connections to the IC and look for short circuits with a spy glass. Also check to make sure that the IC was connected the right way round and there are no unwanted connections. If everything was correct then replace the last removed IC with a new one. If that solves the problem, the IC was faulty and should be thrown away. Replace all the IC's and check the power supply Voltage again. If all is now OK then see if the circuit now functions correctly.

Assuming that the power supply is OK, set your meter to the 20 Volt DC range and connect between pins 4 and 7 of IC1 it should read 5 Volts. If it doesn't, you have not connected those pins properly. Do the same for IC2. Then connect the meter between 0 Volts and the output of IC1 (pin 6). Be careful not to touch pin 7. The best way is to connect the meter to R3 at the end, which is connected to pin 6. Switch on the power supply. The meter should read about 0.6 Volt if there is not too much light about Turn on an incandescent lamp and point it directly at the photo diode. The Voltage should increase to nearly 5 Volts if you are using a mains powered light. If it does, then this first stage of the circuit is probably working correctly, if it does not then check that part of the circuit again, paying particular attention to the polarity of the photo diode which must be the right way round. Assuming that that test is OK, you will need to see whether the circuit can detect your infrared beam. With the incandescent lamp turned off, place one of the infra red diodes of the beam source as in the illustration in the test procedure and measure the output voltage of IC1. It should be about 2.5 Volts. If it is much less then you probably have the wrong values either for R3 or C1 so check them noting that C1 should only be 4p7F and **not** 4μ7F. The latter being a million times as much as the former.

Assuming that the first stage of the circuit is OK, connect your meter between 0Volts and the output of IC2. It should read about 2.5 Volts. If it does not, connect the meter across R5 and see if that is 2.5 Volts. If it does not, then see if C3 is the right way round. Check the values of R4 and R5 and look for short circuits and make sure that the components are connected to the right places. If the Voltage across R5 is OK but the Voltage at pin 6 of IC2 is not OK then make sure that neither C2 nor C4 are short circuited, that R6 and R7 are properly connected, that the unused pins of IC2 are not connected anywhere that means to each other as well, and that you do not have a short or open circuit on any of the pins of IC2.

Assuming that you are getting the correct Voltage at the output of IC2, you now need to see if the amplifier responds to the signal from the light beam. You cannot see this with your meter on a DC range, as the amplifier does not change its average Voltage when an alternating output is present. You can use an oscilloscope to see it you get a rectangular wave going from 0 Volts to 5

Volts when the photo diode sees the beam or you can connect a 1 μ F capacitor in series with your meter and set your meter to an AC range. Some cheap meters do not have low Voltage ranges in AC mode so use the lowest you can which is greater than 2 Volts AC. Connect the capacitor on your meter probe to the output of IC6. If this is not easy to do, solder the capacitor temporarily to pin 6 of IC2 and measure from the free end of the capacitor to 0Volts. The trouble is that many cheap meters do not just read the AC Voltage when on an AC range but also measure the direct Voltage. (naughty) You should get a zero reading when the beam is not on and a reading of about 2.5 Volts when it is. You should be able to get these readings over a distance of a few meters provided the emitter and photo diode are pointing directly at each other.

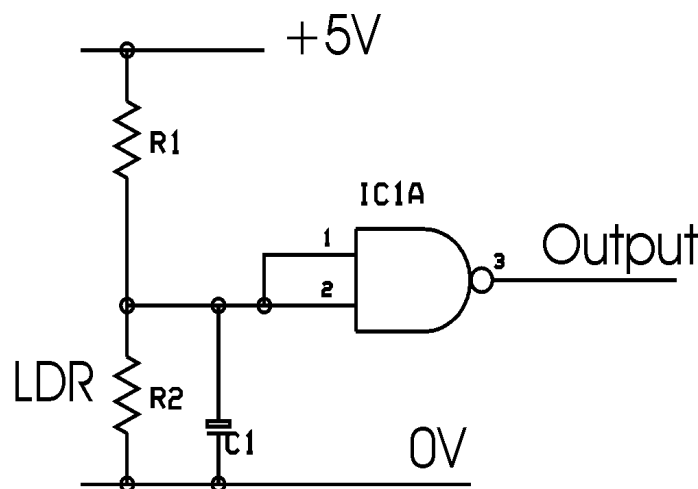
Assuming that the output of IC2 is OK, set your meter to the 20 Volt DC range. Connect the meter between pins 7 and 14 of IC3. It should read 5 Volts. If it doesn't, you have not connected those pins to the supply. Connect the meter between 0 Volts and the junction of R13 and C6. The reading should vary between about 1.2 and 2.4 Volts as you adjust R11. If it doesn't, then check R10, R11, R12 C6 R13 and D2 for values, short circuits, open circuits and against the circuit diagram. Also check that D2 is the right way round. If the Voltage readings are OK, measure the Voltage at the output of IC3A pin 3. It should be 5 Volts if the beam is not there and 0 Volts if it is. If it is permanently 5 Volts, check that R15, C5 and D2 are connected properly, have the correct values and that there are no short circuits. Also check that pin7 is connected to 0 Volts. If the output of IC3A pin 3 is permanently 0 Volts when the beam is not present, check that D4 is connected the right way round and that there is not a short circuit between pins 1 and 14 of IC3 and that pin 14 is connected to the 5 Volt supply. If you still do not get the right readings at the output of IC3A, measure the Voltages at the input pins 1 and 2 with the negative end of the meter on 0 Volts. With no beam they should be between 1.2 and 2.4 Volts according to the setting of R11. If you do not get the same readings for both pins, you have not connected pin1 to pin 2. If you do not get the correct voltage readings on pins 1 and 2 then check to see that they are not connected anywhere where they should not be and that they are connected everywhere where they should. Assuming that the input pins 1 and 2 of IC3A are between 1.2 and 2.4 Volts, measure the output on pin3. It should be 5 Volts. If it is between 0 and 5 Volts, you either have a dead IC or pins 2 and 3 are short circuited. If the output pin3 is 0 Volts, check to see if it is short circuited to 0 Volts somehow or to pin 4. If it is not shorted, see if D3 is the correct way round. If it still is not correct, you may have a faulty IC.

Assuming that the output of IC3A is Ok but the output of IC3B pin4 is not, check that D3 is the right way round. Check that C7 and R14 are the correct values and connected to the right places. Look for short circuits. Make sure that pins 5 and 6 are connected together. Connect your meter across C7. It should read 5 Volts when no beam is present and 0.6 Volts when the beam is pointing

at the photo diode. If it does not but the output of IC3A was OK, then there must be a problem either with D3, C7, R14 or IC3B pins 5,6 or IC3 is faulty.

Optical Computer Interface

If you want to use your computer and your computer program does not give you access to a parallel port or you 'thought differently' and have a computer which does not have a parallel port, you can use a light sensor as a switch output by making it look at a portion of the computer monitor. Turning that part of the monitor white or black will cause the switch to be on or off. If you wanted an input to your computer, you can obtain a spare keyboard, take it apart and connect relay contacts across a character key. Note that you should not use long wires to connect to a keyboard. The use of a relay will electrically separate (isolate) your circuitry from your computers circuitry.



Optical computer interface

R1 10K this may need to be a different value

R2 Light Dependent Resistor

C1 4 μ 7 capacitor connect negative end to 0V

IC1 4011 **do not** use the unbuffered type with a U in the suffix. Connect pin 7 to 0V and pin 14 to + 5V. Connect pins 6,7,8,9,12 and 13 to 0V if other circuits do not use these gates.

Note that these IC's are static sensitive.



The LDR should be mounted in a tube to prevent outside light reaching the sensor and should be placed very close to the computer monitor screen. The output should be +5V when looking at a light screen and 0V when looking at a dark screen.

Since monitor screens and LDR's vary, it may be necessary to use a different value for R1.

Testing

Before applying power to the circuit, inspect the circuit thoroughly using a spy glass ensuring that there are no unwanted short circuits or open circuits and that the circuit follows the diagram exactly. Ensure that the power supply is connected the right way round. Then set your meter to continuity or low Ohms range. Connect the meter across the 0V and 5V supply and make sure that the reading is not zero or near to zero. You may get a bleep or a low Ohmic value for a short time because of the capacitor in the power supply, but this should not last more than a few seconds. If it is continuous, you have a short circuit somewhere and you should follow the instructions in the fault finding section. If you do not get the expected results, you should switch the circuit off immediately.

Set your meter to the 20 Volt DC range. Connect your meter across the 5 Volt supply and switch on the supply. If the reading is much below 5 Volts, switch off immediately and go to the fault finding section.

Connect your meter between 0 Volts and the output of IC1 pin 3. When the Light Dependant Resistor is looking at light, the reading should be 5 Volts. Cover the LDR so that it is in the dark. The reading should now be 0 Volts. If you do not get these results, switch off the power supply and go to the fault finding section.

Now set up your computer so that part of the screen is dark and part of the screen is light. The LDR should be mounted in a tube to prevent outside light from reaching the sensor. Place the tube directly on the screen over the dark area. The output should be 0 Volts. Now place the tube directly over the light area of the screen. The output should be 5 Volts. If the output stayed on 0 Volts when looking at the light area of the screen, then change the value of R1 to 22K and try again. If the output was 5 Volts when looking at a dark area of the screen then either the brightness setting of your screen is too high, your tube is not touching the screen or change R1 to 4K7 and try again.

Circuit description

R1 and R2 form a potential divider. If R2 increases in value, the Voltage across it increases. If R2 decreases in value, the Voltage across it decreases. R2 has a high resistance when no light falls on it and a low resistance when light does fall on it. C1 smoothes out the Voltage across R2. Computer screens do not have a steady light output. IC1 acts as a switch, which detects whether the input is higher or lower than a Voltage of about 2.5 Volts. A low Voltage on the input of IC1 produces a 5 Volt output and a high Voltage on the input produces a 0 Volt output.

As the LDR sees more light, the Voltage at the input of IC1 reduces. When it becomes lower than about 2.5 Volts, the output switches from 0 Volts to 5 Volts.

Fault finding

The first thing to do is give the circuit a thorough visual inspection with a spy glass looking for bad solder joints and short circuits. Check that the circuit you have built exactly matches the circuit diagram and that the components are the correct values and connected the right way round.

If the power supply was short circuited or had a greatly reduced output, remove IC1 and try again. If that does not help, there must be a short circuit or misconnection. If the removal of IC1 restores the output of the power supply, check for short circuits on the pins of the IC socket, in particular any outputs of the IC (pins 3, 4, 10 and 11). Make sure that the IC was the correct way round. It is possible that the IC is faulty.

Assuming that the power supply is OK, set your meter to the 20 Volt DC range and connect across R2. If the reading is 5 Volts when the R2 is looking directly at light, check to see that R1 is not shorted and that pin 1 of IC1 is not connected to pin 14. If the Voltage across R2 is always low even when R2 is covered and no light is falling on it, check that C1 is the correct way round and that it is not short circuited and that R2 is not short circuited. The Voltage reading across R2 should be low but not zero when R2 is exposed to light and high (nearly 5 Volts) when R2 is in the dark. If this is OK but the output does not respond, then the fault must be with IC1. Check that the supply is connected to pins 7 and 14 by connecting the meter directly across the pins on the IC. If this is not the problem, replace IC1.

Sound sensors

Sound can have a variety of frequencies. There is the audible frequency range (the sound, which you can hear), the infrasound, which is at lower frequencies and the ultrasound, which is at higher frequencies. The audible frequency range, which is dependant on how good your hearing is, is in the region of between 20Hz (cycles per second) and 16KHz. Sound is a vibration. What you hear is a result of air vibrating within your ear. Sound does not only travel through the air but in any material. It travels better in some than in others.

Generally, sound sensors either work by detecting air vibrations, which is the case with ordinary microphones, or in solid materials, which is the case with contact microphones.

If you wanted to detect the sound of speech, for example you would use an ordinary microphone but if you wanted to detect the sound of an electric motor turning, or water or air in a pipe for example, you would use a contact microphone attached directly to the motor or pipe.

Contact microphones usually use piezoelectric sensors, which have very high impedances. This has the advantage that you do not need to use a mixer if you

have many of them. You can just connect them all in parallel (all the screens together and all the other leads together giving only two leads) The author has connected 50 contact mikes in parallel and connected to a single input on an audio amplifier without a mixer.

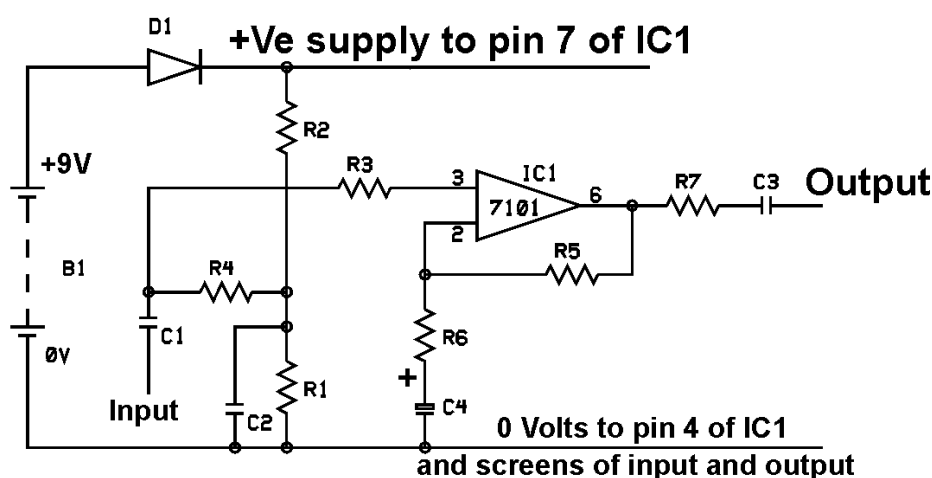
If you want to detect sudden changes in sound level, you can use a rectifier to produce a direct voltage proportional to the sound level followed by differentiator, which will be described later in this chapter. A differentiator gives an output, which is proportional to the change in a signal with time but not the actual signal itself. If the sound level suddenly got louder, there would be a signal but if it stayed at the same loudness, there would not be a signal.

If you connect a microphone to an amplifier with loudspeakers, you will get an audio feedback if the volume (gain) is too high. You can reduce this by reducing the treble on the amplifier.

You should be aware that carbon microphones need a bias, as they do not produce a Voltage output but their resistance changes. You should use a 10K resistor from the microphone input to the positive supply. Nowadays carbon microphones are rare as the sound quality is poor but they are much more sensitive.

Microphone pre-amplifier for long cables.

If you do not use screened cable or co-axial cable to connect the microphone to the amplifier, you will get mains hum. If you are using contact microphones and you cable length is long you will not only get mains hum but noise due to the cable moving. One way of reducing this is to use a battery powered amplifier near to the mike. A circuit for this is described below. This circuit will work for at least two weeks using a PP3 battery, so for shows of two weeks or less, there is no need to turn it off at night. This circuit also has a gain of 11 (the output signal is 11 times as big as the input signal) and you will therefore not have to turn the volume up so highly on your amplifier.



Microphone pre-amplifier for long cables

B1 is a PP3 9Volt battery

D1 1N4002

R1, R2 47K

R4, R5 100K

R3, R6 10K

R7 1K

C1, C2, C3 1 μ F ceramic. Do not use electrolytic capacitors here.

C4 4 μ 7 Negative end should be connected to 0 Volts.

IC1 7101 operational amplifier any prefix or suffix will do.

Note: do not make any connection to the unused pins of IC1.



Testing

Before applying power to the circuit, inspect the circuit thoroughly using a spy glass ensuring that there are no unwanted short circuits or open circuits and that the circuit follows the diagram exactly. Ensure that the battery is connected the right way round. Then set your meter to continuity or low Ohms range. Connect the meter across the 0V and 9V supply and make sure that the reading is not zero or near to zero. Then connect the meter between 0 Volts and the cathode of D1. If you have a short circuit somewhere, you should follow the instructions in the fault finding section. If you do not get the expected results, you should switch the circuit off immediately.

Set your meter to the 20 Volt DC range. Connect it between 0 Volts and the cathode of D1. Connect a new battery and read the meter, it should read about 9 Volts. If it reads substantially less, then disconnect the battery immediately and go to the fault finding section. Connect the output to your amplifier and the input to your microphone. Test for sound levels. You should find that it is much louder with the circuit in place than when the mike is connected directly to your amplifier.

Circuit description

D1 protects the circuit and battery from incorrect battery connections. It is easy to accidentally touch the battery clip with the battery the wrong way round.

R1 and R2 potentially divide the supply to provide a bias for the amplifier. C2 acts as a short circuit for alternating signals but not for direct Voltages. C1 couples the microphone input to the amplifier input and R4 connects the bias Voltage to the amplifier input. R3 protects the operational amplifier and connects the signal from the microphone to its non-inverting input pin3. R5 is a feed back resistor connecting the output of IC1 pin 6 with the inverting input of IC1 pin 2. Operational amplifiers have a very high gain and a very small difference in voltage between the inverting and non-inverting input produces a very large Voltage signal at the output. If the Voltage at pin 3 is slightly larger than that at pin 2, the output pin 6 becomes bigger, this Voltage is fed back to the input via the feed back resistor, which causes the Voltage on pin 2 to rise until the Voltages on pins 1 and 2 are equal. R6 and C4 connect the inverting

input to 0 Volts for alternating Voltages only and potentially divide the output Voltage. For direct Voltages the gain of the amplifier is unity so the output on pin 6 will equal the bias Voltage. For alternating signals, the gain is higher as the whole of the output does not get fed back to the inverting input but only a proportion of it. For high frequencies, we can assume that C4 is a short circuit and the gain of the amplifier is determined by the values of R5 and R6. The proportion of the output that reaches the input is $R6 / (R5 + R6)$ which is 1/11 th. The amplifier gain is therefore 11. R7 protects the amplifier from the load of a long cable and C3 only allows alternating signals to be passed to your audio amplifier.

Faultfinding

The first thing to do is give the circuit a thorough visual inspection with a spy glass looking for bad solder joints and short circuits. Check that the circuit you have built exactly matches the circuit diagram and that the components are the correct values and connected the right way round.

Assuming that the supply is not short circuited but that the Voltage on the cathode of D1 is 0 Volts when the battery is connected, check that D1 and the battery are connected the right way round. If this is not the problem, remove IC1 and try again. If that was the problem, ensure that IC1 was connected the right way round and that none of the unused pins are connected anywhere. If the problem persists, try another IC. If the problem still persists, you have not built the circuit correctly so examine it more carefully.

Assuming that the power supply is OK, set your meter to the 20 Volt DC range. Connect it between 0 Volts and the junction of R1 and R2. This should be about 4.5 Volts. If it isn't check the values of R1 and R2 and look for open circuits, short circuits and bad solder joints. Make sure that C2 is not a short circuit.

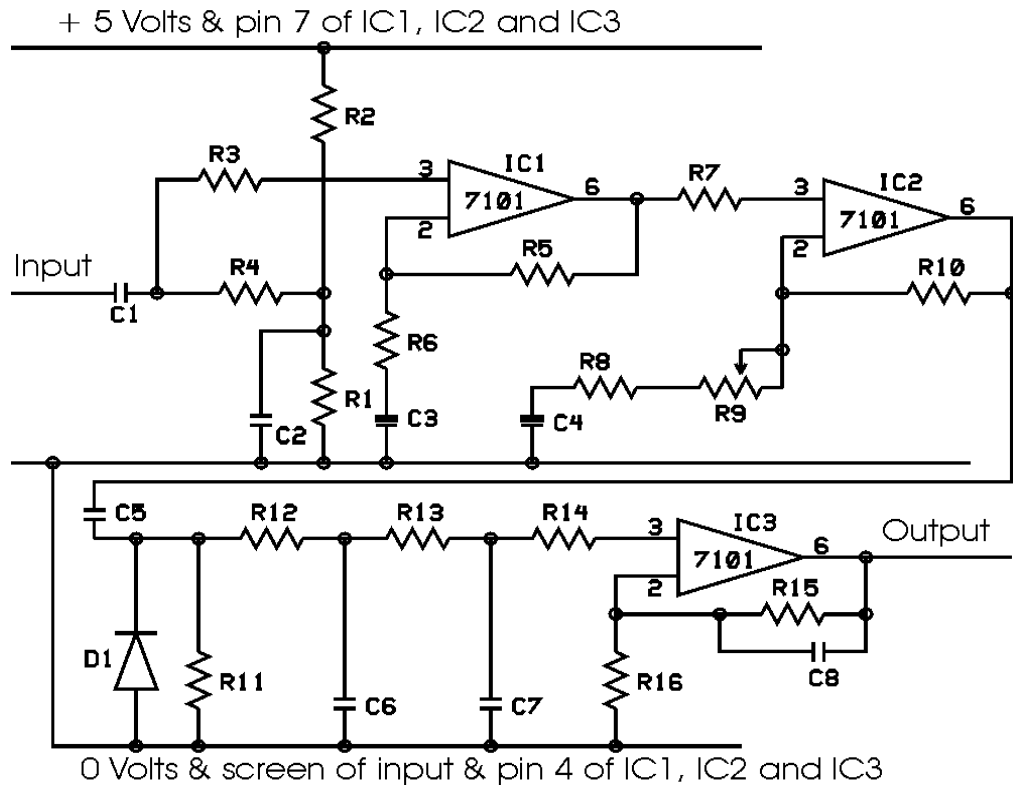
Assuming that the Voltage at the junction of R1 and R2 is OK, connect the meter between 0 Volts and pin 6 of IC1. This should also be about 4.5 Volts. If it is not make sure that pin 4 of IC1 is connected to 0 Volts and that pin 7 is connected to the cathode of D1. Make sure that C4 is the correct way round and is not shorted. Check to see that R3, R4 and R5 are connected properly and that there are no short circuits bad solder joints or open circuits.

Assuming that you are getting about 4.5 Volts at the output of IC1 pin 6, the only components left in the circuit are C1, R7 and C3. So if the amplifier does not amplify, check the values of R5 and R6.

The signal levels from the microphone are too low for cheap meters to see so unless you have an expensive meter you will have to test the circuit with an audio amplifier

Sound level detector

The following circuit has a microphone input and gives a direct Voltage output proportional to the amplitude of the detected sound. It may be used in conjunction with the signal conditioning circuits described at the end of this chapter. If you want to detect changes in sound levels rather than the sound levels themselves, you should use a differentiator.



Sound level detector

R1	22K
R2	22K
R3	10K
R4	100K
R5	100K
R6	1K
R7	10K
R8	1K
R9	10K potentiometer/trimmer
R10	100K
R11	100K
R12	4K7
R13	4K7
R14	4K7
R15	22K
R16	4K7
C1	1 μ F ceramic
C2	1 μ F ceramic

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C3 4 μ 7F negative end to 0Volts
 C4 4 μ 7F negative end to 0Volts
 C5 0 μ 1F ceramic
 C6 0 μ 1F ceramic
 C7 0 μ 1F ceramic
 C8 0 μ 1F ceramic
 D1 1N4148
 IC1 7101 any prefix or suffix. Do not make any connections to unused pins
 IC2 7101 any prefix or suffix. Do not make any connections to unused pins
 IC3 7101 any prefix or suffix. Do not make any connections to unused pins
Note: if this circuit is to be used in conjunction with the microphone pre-amplifier previously described, R6 and R8 should be increased to 3K3 and R9 should be increased to 20K This will reduce the gains of the amplifiers IC1 and IC2.

Testing

Before applying power to the circuit, inspect the circuit thoroughly using a spy glass ensuring that there are no unwanted short circuits or open circuits and that the circuit follows the diagram exactly. Ensure that the power supply is connected the right way round. Then set your meter to continuity or low Ohms range. Connect the meter across the 0V and 5V supply and make sure that the reading is not zero or near to zero. You may get a bleep or a low Ohmic value for a short time because of the capacitor in the power supply, but this should not last more than a few seconds. If it is continuous, you have a short circuit somewhere and you should follow the instructions in the fault finding section. If you do not get the expected results, you should switch the circuit off immediately.

Set your meter to the 20 Volt DC range. Connect your meter across the 5 Volt supply and switch on the supply. If the reading is much below 5 Volts, switch off immediately and go to the fault finding section.

Connect a microphone to the input (screen of cable to 0Volts). Connect your meter between 0Volts and the output. The meter should read close to zero if there is no sound. Now make a loud noise and the meter should read close to 5 Volts. If you do not get the expected Voltage readings, switch off immediately and go to the faultfinding section.

Circuit description

R1 and R2 potentially divide the supply to provide a bias for the amplifier IC1. C2 acts as a short circuit for alternating signals but not for direct Voltages. C1 couples the microphone input to the amplifier input and R4 connects the bias Voltage to the amplifier input. R3 protects the operational amplifier and connects the signal from the microphone to its non-inverting input pin3. R5 is a feed back resistor connecting the output of IC1 pin 6 with the inverting input of IC1 pin 2. Operational amplifiers have a very high gain and a very small

difference in voltage between the inverting and non-inverting input produces a very large Voltage signal at the output. If the Voltage at pin 3 is slightly larger than that at pin 2, the output pin 6 becomes bigger, this Voltage is fed back to the input via the feed back resistor, which causes the Voltage on pin 2 to rise until the Voltages on pins 1 and 2 are equal. R6 and C3 connect the inverting input to 0 Volts for alternating Voltages only and potentially divide the output Voltage. For direct Voltages the gain of the amplifier is unity so the output on pin 6 will equal the bias Voltage. For alternating signals, the gain is higher as the whole of the output does not get fed back to the inverting input but only a proportion of it. For high frequencies, we can assume that C3 is a short circuit and the gain of the amplifier is determined by the values of R5 and R6. The proportion of the output that reaches the input is $R6 / (R5 + R6)$ which is 1/101 th. The amplifier gain is therefore 101.

The output of the first amplifier IC1 is fed to a second amplifier IC2 via R7. R10 is a feedback resistor, which serves the same function as R5 of the first amplifier. R8, R9 and C4 serve the same function as R6 and C3 in the first amplifier. The gain of the second amplifier is $(R8 + R9 + R10) / (R8 + R9)$, which varies between 10 and 101 depending on the value of R9.

The output of IC2 is coupled to a rectifier, which converts the alternating voltage output of IC2 to a direct Voltage, via C5. The diode D1 acts as a low resistance to negative Voltages and a high resistance to positive Voltages. The effect of this is to prevent the most negative part of signal at the junction of C5 and D1 from being more negative than the Cutin Voltage of the diode, which for silicone diodes is about 0.5 Volts. The average Voltage at that junction will be positive and proportional to the amplitude of the signal. R11 provides a reference Voltage of zero Volts by allowing a current to flow from C5 to 0 Volts. R12, R13, C6 and C7 act as a low pass filter which converts the alternating Voltage to its average direct Voltage. C6 and C7 will have a low impedance (resistance) for high frequency signals and a high impedance for low frequency (direct) signals. As the alternating output of IC2 increases, the average Voltage at the junction of C5 and D1 increases and although the alternating Voltage across C7 is nearly zero, the average Voltage is not affected by the filter. We therefore have a direct Voltage across C7, which is proportional to the sound level.

This direct Voltage is then amplified by IC3. C8 acts as a further filter to remove the alternating part of the signal from the output. The gain of IC3 is determined by R15 and R16 and is $(R15 + R16) / R16$ which is nearly 6.

Faultfinding

The first thing to do is give the circuit a thorough visual inspection with a spy glass looking for bad solder joints and short circuits. Check that the circuit you have built exactly matches the circuit diagram and that the components are the correct values and connected the right way round.

For the first part of the fault finding procedure, do not connect the microphone as it may confuse the Voltage readings.

Make sure that the power supply is switched off. Set your meter to continuity and connect across the 5 Volt supply. There should be a short time when the meter indicates a short. This is because of the capacitor in the power supply. This should not last for long. If it is continuous, you have a short circuit somewhere. Check that the +5 Volts of the supply is only connected to R2 and pin 7 of the three IC's. If this is not the problem, remove the three IC's one at a time checking the supply each time for short circuits. If this is not the cause of the problem then the +5 Volt end of the supply must be connected somewhere where it shouldn't. If it was the cause, it is possible that you have a faulty IC.

Assuming that you do not have a short circuit across the supply, set your meter to the 20 Volt DC range, connect across the supply and switch on. You should have a reading of 5 Volts. If you do not, remove the IC's one at a time checking the Voltage. If after removing an IC the reading is correct, then look to see if the output of that IC (pin 6) is shorted to either pin 7 or pin 4. If it is not, replace the IC with a new one and try again. If that solves the problem, throw the faulty IC away so that you do not inadvertently use it again.

Assuming that the power supply is OK, set your meter to the 20 Volt DC range. Connect it between 0 Volts and the junction of R1 and R2. This should be about 2.5 Volts. If it isn't check the values of R1 and R2 and look for open circuits, short circuits and bad solder joints. Make sure that C2 is not a short circuit.

Assuming that the Voltage at the junction of R1 and R2 is OK, connect the meter between 0 Volts and pin 6 of IC1. This should also be about 2.5 Volts. If it is not make sure that pin 4 of IC1 is connected to 0 Volts and that pin 7 is connected to the + 5 Volt supply. Make sure that C3 is the correct way round and is not shorted. Check to see that R3, R4 and R5 are connected properly and that there are no short circuits bad solder joints or open circuits. If none of this helps, replace IC1 with a new one and try again. If this solves the problem, throw the IC away. If it does not solve the problem, check the circuit again.

Assuming that the output of IC1 is OK, repeat the same procedure for IC2 looking at R8, R9 R10 and C4.

Assuming that the output of IC2 is OK, measure the output of IC3. It should be nearly zero as there is no sound input. If it is not, check that there is not a short circuit between pins 2 and 3, and check that pin 4 is connected to 0 Volts. Make sure that pins 1, 5 and 8 are not connected anywhere. Assuming that that is now OK, connect a microphone to the input. Connect the meter across D1. It should give a positive Voltage if you make a loud sound. If it is a negative

Voltage when the common terminal of the meter is connected to 0 Volts, the diode D1 is the wrong way round. If that is OK and you do not get an output signal which varies with the sound, check for short circuits, open circuits and bad solder joints in the circuit around IC3 including R11, R12, R13, R14, R15, R16, C6, C7 and C8.

Vibration sensors

Vibration switches are available. They are commonly used on car alarms. It should be noted that vibration switches are not continuously on when sensing vibration but turn on and off with the frequency of the vibration. If you want a continuous signal, you should use a pulse stretcher. Pulse stretchers are described in the chapter on timers.

You can use a contact mike as a vibration sensor. You can use the sound level detector circuit for this.

Proximity/touch sensors

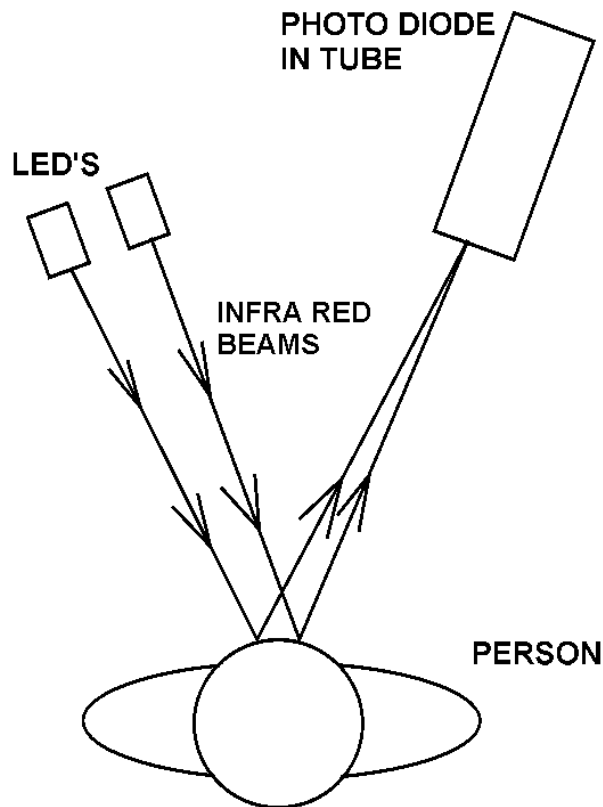
There are several ways of detecting the proximity of people. The method to use depends on the area to be detected, the closeness, the type of work and the environment in which the work is to be situated.

If you can get away with using a PIR detector mounted above the work, that would be the easiest solution. You can obscure the sensor with paint to reduce the field of view as previously described. This will of course only tell you that someone has moved into the detection area but not that they are still there. If the work is very large, you can use several PIR detectors.

For distances up to a couple of meters and small areas, you can use the ultrasonic radar distance measuring circuit described later in this chapter or the infra red light beam described previously. If you use the light beam, the photo diode will need to be mounted in a tube and the beam should be used in reflective rather than transmitted mode. That is, the photo diode looks at the light reflected from the surface of the person to be detected rather than interrupting the beam. The output signal is therefore inverted as the presence of a person will now be sensed by the presence of the light beam at the photo diode rather than the absence of the light beam. The light beam and detector will need to be at an angle so that they focus on the person to be detected. If they were to be parallel, the beam photo diode would detect white or shiny objects some distance away and the distance of people being sensed would depend largely on the clothing worn. By making the beam and detector focus at a particular distance reduces the effect of the colour or type of clothing worn by the person being detected.

The following sketch shows a plan view (as seen from above) of such an installation.

PLAN VIEW OF OPTICAL PROXIMITY SENSOR



If you want to detect touching or very close proximity, you should use a **capacitance sensor**. Using radio waves is not a good idea as it will cause interference with radios and will therefore not be described here.

Capacitive sensors are commercially available. They are expensive and have small detection areas. High sensitivity sensors, which cover a large area, can be made without too much difficulty but need to be individually set up according to the work as well as the particular location of the work. The adjustments needed require a good understanding of electronic circuitry as well as the use of an oscilloscope. In view of these complications, only a simple, low sensitivity circuit will be included here.

A brief explanation of capacitance would be helpful at this point. If you have two plates of conducting material (aluminium for example), which are not touching, they form a capacitor. The value of the capacitor increases with the area of the plates and decrease with the square of the distance between them. If you want to make a high valued capacitor you need a large area of conducting material and you need to make them very close together but not touching. The material between the plates needs to be electrically insulating and different materials will have an effect on the capacitance. You will get a low capacitance if air is used as an insulator and a high capacitance if an electrolyte is used. That is why high valued capacitors are electrolytic. Since you are a conductor

of electricity, you have a capacitance to earth and to any other conducting material. You are also an aerial, which picks up radio waves.

If you touch a metal plate, you make an electrical connection to that plate which effectively becomes bigger and therefore has a higher capacitance to earth. You are also increasing both mains hum (unwanted signals from the mains supply) and radio signals.

It will be apparent that the power supply will need to be earthed or capacitively coupled to earth for the sensors to function properly. A large metal plate or piece of aluminium foil placed on the ground and connected to the 0 Volts of your power supply will capacitively couple your circuit to earth. The area of such a plate or foil should be of a similar size or larger than the sensor. Water pipes make the best earth but the earth pin on a mains plug will also work well.

If you connect to the mains plug, you must ensure that you are not connecting to any terminal other than earth, as a mistake could be lethal. If you are in any doubt, do not do it.

If your work is to be placed outside, you can hammer a long metal stake into the ground and use that as an earth.

It will also be apparent that the sensitivity of the sensor is dependent on its surface area. If the surface area is very large, touching it will only have a small effect.

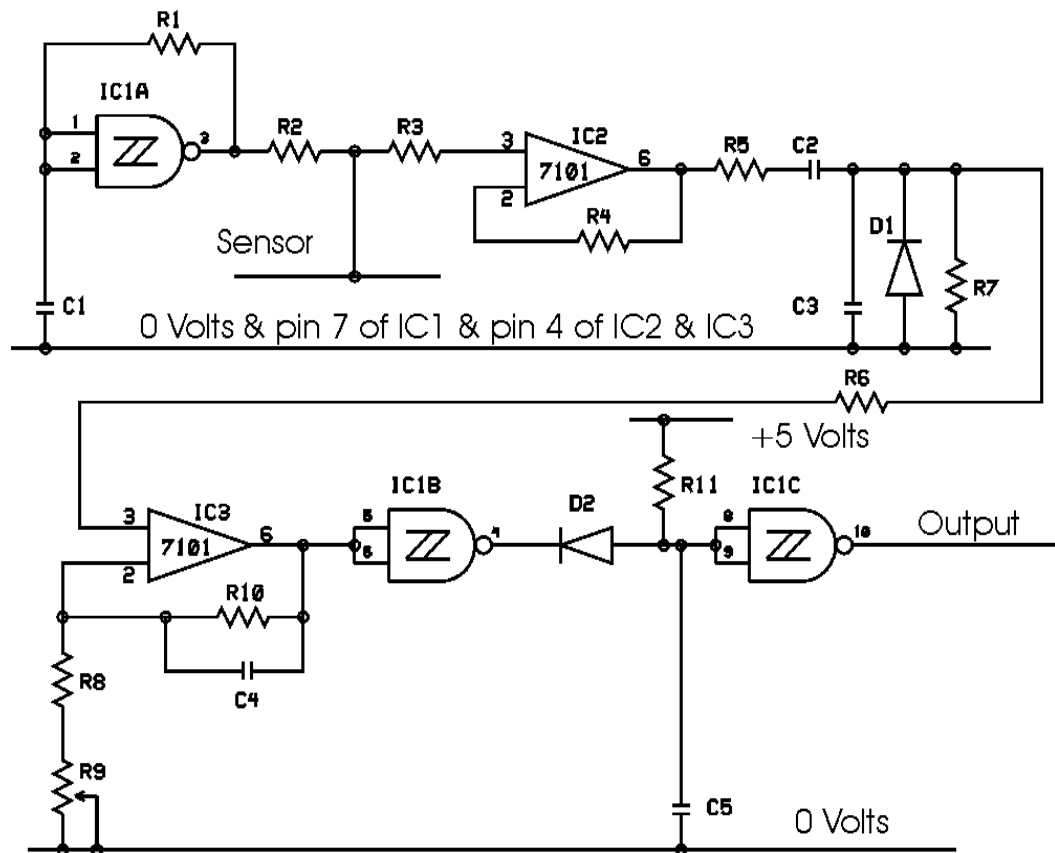
There are materials, other than metal, which conduct electricity and can therefore be used as sensors. In particular, there are some plastics, some carbonized foams and woven materials. If you look in catalogues under the headings of static protection and RFI (Radio Frequency Interference) suppression, you should be able to find a wide range of options. If you can't, you need to get some other catalogues. Some metal foils are available in adhesive backed forms, particularly aluminium and copper.

The sensor needs to be made of an electrically conductive material and could be the work itself.

In the following circuit an adjustment will have to be made on site, as the environment will affect the circuit. Adequate provision should therefore be made so that access to the circuit is possible after final installation.

This circuit is sensitive to electrical interference so may give false signals when motors or solenoids are switched near to the sensor. If you intend to switch such devices, you should inhibit the output signal whilst switching them on and off. This can easily be achieved with the use of a gate and a short pulse stretcher on the gate input. If you were to use the output of this circuit to switch a motor on when someone touched your sensor, the sensor would activate again

as soon as the motor turned off. You would need to use a circuit, which prevents the motor from turning on for a short time after it has been turned off. There is an example of such a circuit in the chapter on timers.



Pin 14 of IC1 & Pin 7 of IC2 & IC3 should be connected to +5 Volts

capacitance sensor

- R1 22K
- R2 470K
- R3 10K
- R4 10K
- R5 1K
- R6 10K
- R7 10K
- R8 10K
- R9 50K potentiometer
- R10 47K
- R11 100K
- C1 2200pF low temperature coefficient ceramic COG or NOP types
- C2 2200pF low temperature coefficient ceramic COG or NOP types
- C3 22pF
- C4 4p7F
- C5 0μ1F



OPERATIONAL AMPLIFIER



IC1 4093 any prefix or suffix. Note: these are static sensitive.
IC2 7101 any prefix or suffix
IC3 7101 any prefix or suffix

Testing

Before applying power to the circuit, inspect the circuit thoroughly using a spy glass ensuring that there are no unwanted short circuits or open circuits and that the circuit follows the diagram exactly. Ensure that the power supply is connected the right way round. Then set your meter to continuity or low Ohms range. Connect the meter across the 0V and 5V supply and make sure that the reading is not zero or near to zero. You may get a bleep or a low Ohmic value for a short time because of the capacitor in the power supply, but this should not last more than a few seconds. If it is continuous, you have a short circuit somewhere and you should follow the instructions in the fault finding section. If you do not get the expected results, you should switch the circuit off immediately.

Set your meter to the 20 Volt DC range. Connect your meter across the 5 Volt supply and switch on the supply. If the reading is much below 5 Volts, switch off immediately and go to the fault finding section.

Make sure you have connected the 0 Volts of the supply to earth or to an earthing plate, as previously described. For testing purposes, use a piece of metal or foil about the size of a letter or A4 sheet of paper, as a sensor. You can use a crocodile clip or a paper clip to make an electrical connection.

Set your meter to the 20 Volt DC range and connect between 0 Volts and the output. The output should toggle between nearly 0 Volts and nearly 5 Volts as you adjust the potentiometer R9. Set the potentiometer so that the output is 5 Volts when you are not touching the sensor but close to the point where it is 0 Volts. When you touch the sensor, the output should fall to nearly 0 Volts.

If all is well, use the sensor in your work and readjust R9. If the sensor is too large for R9 to be able to achieve a correct setting, increase the value of R10 to 220K. If this does not work, you will need to reduce the size of your sensor. You can use more than one of these circuits provided that the sensors are not connected electrically.

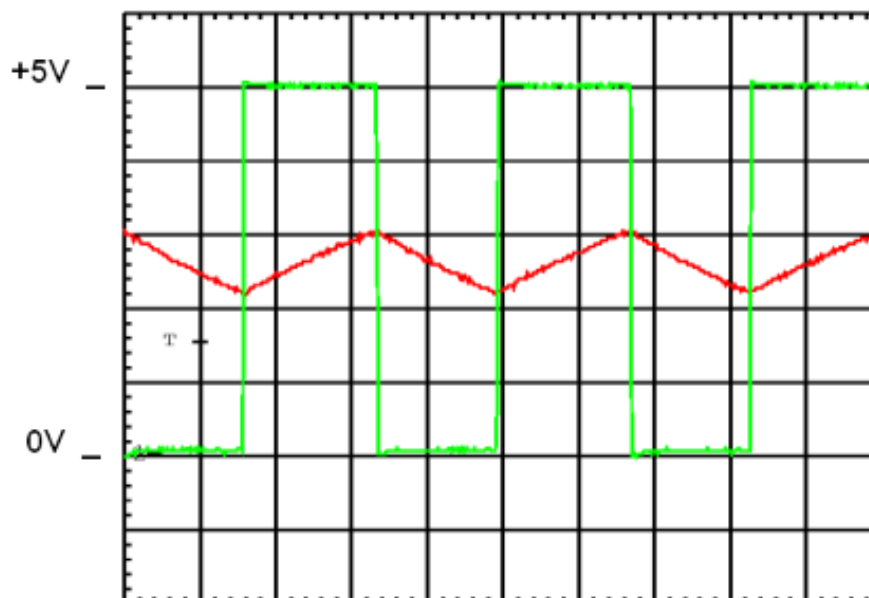
Circuit description

In the oscilloscope images, in this circuit description, the time base (horizontal direction of the trace from left to right) is 10 μ Sec per large division.

IC1A, R1 and C1 form a square wave oscillator with a frequency of about 30KHz. You will note that IC1A is a Schmitt trigger. That is, the input Voltage that is required for a '1' is higher than the input Voltage for a '0'. The difference between these Voltages is called the hysteresis or deadband.

The following oscilloscope image shows the output of IC1A in green and the input in red.

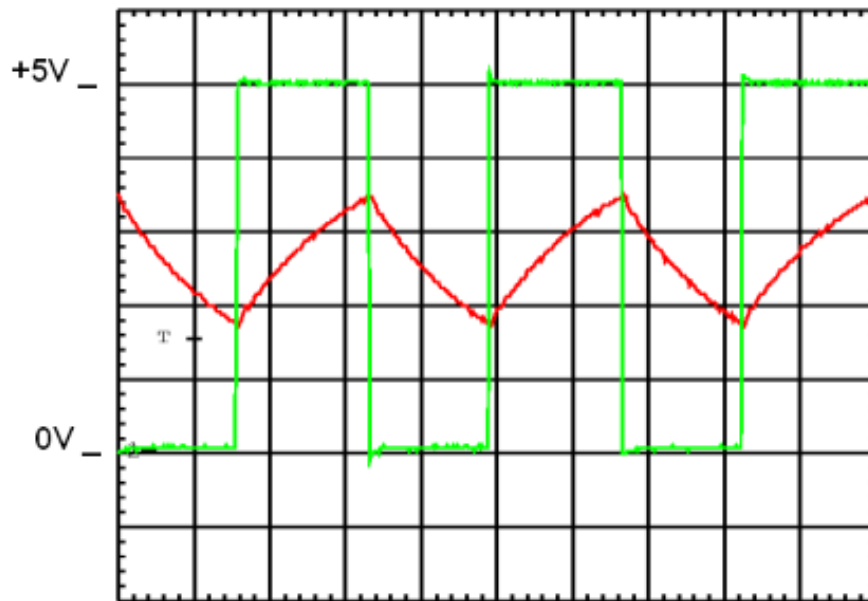
When the output is a '1' (nearly 5Volts), C1 is charged up via R1 until it reaches the Voltage level of a '1' on the input. When that happens, the output becomes a '0' (nearly 0Volts) and C1 discharges via R1 until the Voltage level of a '0' on the input is reached. When this happens the output becomes a '1' again and the process is repeated.



The output of IC1A is fed to the sensor via R2. R2 needs to be a high value so that small increases in the capacitance to earth due to touching the sensor can produce a reasonable reduction of the signal on the sensor. We need to buffer the signal on the sensor because it has a very high impedance (resistance). We use IC2 for this purpose and R3 connects the sensor to the operational amplifier IC2. This resistance is needed to allow the input protection circuitry of IC2 to function. R4 is there for the same reason as R3 and couples the output directly to the inverting input of IC2. Any small increase in the difference in Voltage between pins 2 and 3 of IC2 is amplified and appears at the output (pin 6). The output is connected to the inverting input (pin 2) via R4. So the output will be kept equal to the input on pin 3.

In the oscilloscope image below, the green trace is the output of IC1A and the red trace is the output of IC2. You will note that it is very similar to the previous oscilloscope image. The amplitude of the output of IC2 is determined by the value of R2 and the capacitance of the sensor. If you touch the sensor, the amplitude of the signal reduces.

Do not connect any measuring equipment to the sensor, as it will affect the signal on the sensor. Connecting to the output of IC2 will not affect the signal.



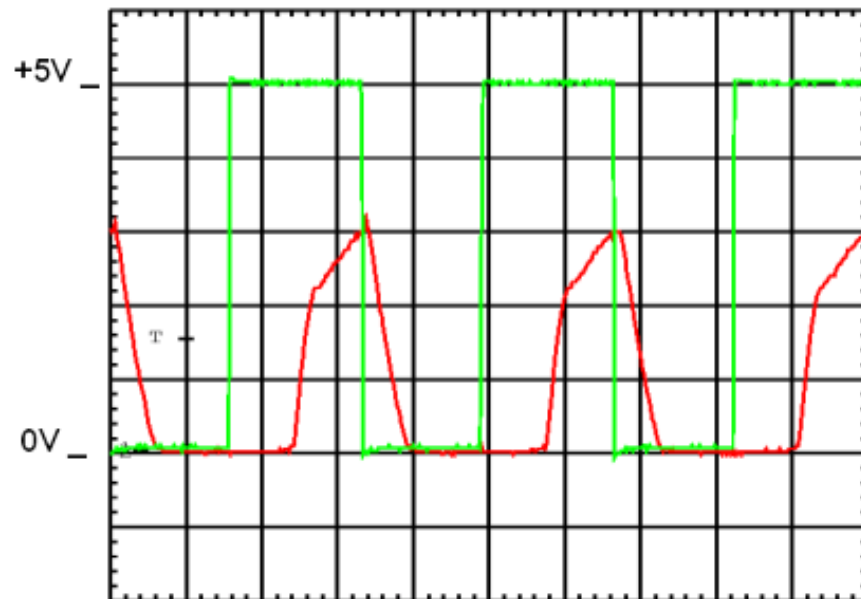
The output of IC2 has an average Voltage of about 2.5 and will have some mains hum and radio frequency (RF) interference. We need to reduce the effect of the hum and to a lesser extent the RF interference. The operational amplifiers will greatly reduce the RF, as they are not that fast. We also need to have a means of adjusting the amplitude of the signal and making the low Voltage peaks of the wave happen at 0 Volts.

R5 C2 and C3 act as a band pass filter and direct Voltage decoupler. C2 is a high pass filter as its impedance is high at mains frequencies and C3 is a low pass filter as it short circuits RF signals. R5 is needed to make C3 work. D1 and R7 hold the low peaks of the signal to -0.6Volts (the Cutin Voltage of the diode). The output of this circuit is fed to the input of IC3 via R6.

IC3 is an operational amplifier having a gain of $(R8 + R9 + R10) / (R8 + R9)$. C4 is a low value capacitor, which reduces the gain of the amplifier for high frequencies.

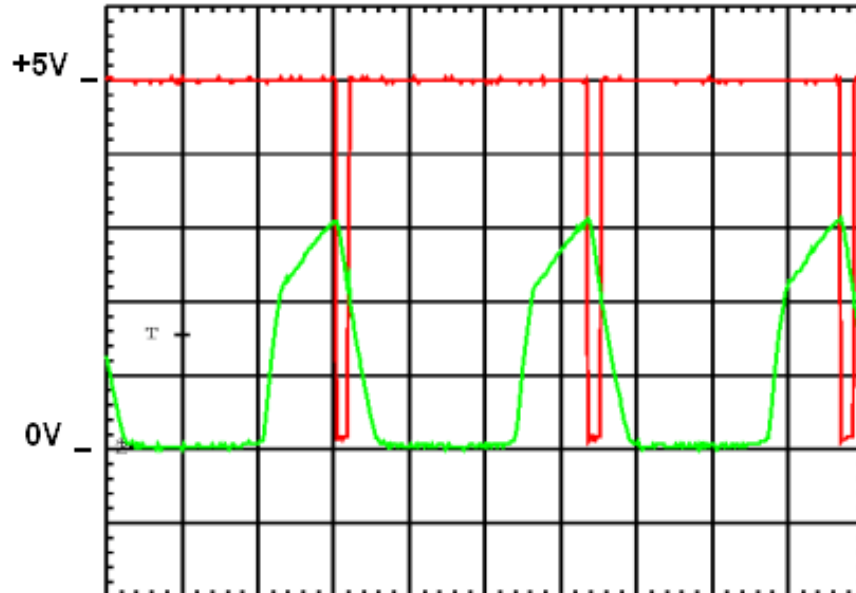
If pin 3 has a slightly higher Voltage than pin 2, the output (pin 6) goes very high. A proportion of the output Voltage is fed back to the inverting input (pin 2) via the feed back resistor R10. The feedback is reduced by R8 and R9. When the output goes high, so does the Voltage on pin 2. It can be seen that the output is kept at a Voltage, which will produce Voltages on pins 2 and 3 that are nearly equal. The proportion of the output, which is fed back to the inverting input (pin 2), defines the gain of the circuit. Changing the effective value of R9 changes the gain of the circuit.

In the following oscilloscope image, the green trace is the output of IC1A and the red trace is the output of IC3.



The output of IC3 is connected to the input of the gate IC1B. R9 is adjusted so that the peak Voltage is just high enough to reach the level of a '1' on the input of IC1B.

The oscilloscope image below shows the output of IC3 in green and the output of IC1B in red.



The output of IC1B is the inverse of the input. That is a '1' on the input produces a '0' on the output. If the sensor is touched, the output of IC3 is reduced so that it does not get high enough for the output of IC1B to go to a zero.

The output of IC1B is connected to the input of IC1C via a diode, which shorts out C5 whenever the output of IC1B is zero. C5 charges up via R11. As long as

the Output of IC1B goes to a '0' once in a while, the Voltage across C5 will be kept below the level of a '1' of the input of IC1C and the output of IC1C will be nearly +5 Volts. When the sensor is touched, C5 does not get shorted, so its Voltage rises to the level of a '1' on the input of IC1C and the output becomes a zero.

Faultfinding

The first thing to do is give the circuit a thorough visual inspection with a spy glass looking for bad solder joints and short circuits. Check that the circuit you have built exactly matches the circuit diagram and that the components are the correct values and connected the right way round.

Make sure that the power supply is switched off. Set your meter to continuity and connect across the 5 Volt supply. There should be a short time when the meter indicates a short. This is because of the capacitor in the power supply. This should not last for long. If it is continuous, you have a short circuit somewhere. Check that the +5 Volts of the supply is only connected to R11, pin 7 of IC's 2 and 3, and pin 14 of IC1. If this is not the problem, remove the three IC's one at a time checking the supply each time for short circuits. If this is not the cause of the problem then the +5 Volt end of the supply must be connected somewhere where it shouldn't. If it was the cause, it is possible that you have a faulty IC.

Assuming that you do not have a short circuit across the supply, set your meter to the 20 Volt DC range, connect across the supply and switch on. You should have a reading of 5 Volts. If you do not, remove the IC's one at a time checking the Voltage. If after removing an IC the reading is correct, then look to see if any of the pins are connected where they should not be. You should note that the unused pins of operational amplifiers should not be connected either to other unused pins or anywhere else. If all the connections are OK, replace the IC with a new one and try again. If that solves the problem, throw the faulty IC away so that you do not inadvertently use it again.

We assume that the power supply is now OK. If you have an oscilloscope, you can check that you get the waveforms shown in the circuit description. You will need to set the time base to 10 μ Sec/div. If you do not get a correct waveform, and the previous one was OK, then the fault lies with the circuit between the good waveform and the bad one. This is the easiest way to find the faults. You will need to check the frequency of the oscillator IC1A. If you get approximately the same distances horizontally on the scope as shown, then the frequency is OK. If not then check the values of R1 and C1.

If you do not have an oscilloscope then proceed as follows. Set your meter to the 20 Volt DC range. Measure the Voltage between 0 Volts and the output of IC1A (pin3). It should be about 2.5 Volts. If it is not, check that pin 7 is connected to 0 Volts and that pin 14 is connected to +5 Volts, that there are no

bad solder joints, open circuits or short circuits on pins 1, 2, 3. R1 and C1 and that the values of R1 and C1 are correct. If this does not help, try replacing IC1. If this solves the problem, throw the faulty IC away so that you do not use it again. If this has not solved the problem, look at the circuit again. If your meter can measure frequency, check that the frequency at pin 3 is about 30KHz. If the frequency differs greatly, check the values of R1 and C1.

Assuming that the output of IC1A is OK, measure the Voltage between 0 Volts and the output of IC2 pin6. It should be about 2.5 Volts. If it is not, check that there are no bad solder joints, open circuits or short circuits and that the unused pins of IC2 are not connected anywhere. Check that R2, R3 and R4 are connected properly and are the correct values. Check that pin4 is connected to 0 Volts and that pin 7 is connected to +5 Volts. If this does not solve the problem, try replacing the IC. If that solves the problem, throw the faulty IC away. If it does not solve the problem, look again.

Assuming that the output of IC2 is OK, measure the output of IC3. It should be between about 0.3 Volts and 1.3 Volts depending on the setting of the potentiometer R9. It is unfortunate that there are no intermediate points to measure in the circuit as this leaves quite a number of components, which could be incorrect. Check that D1 is the correct way round. Check that pin 4 of IC3 is connected to 0 Volts and that pin7 is connected to +5 Volts. Check that none of the unused pins of IC3 are connected anywhere and that there are no bad solder joints, short circuits or open circuits and that the component values are correct. The components to check are R5, R6, R7, R8, R9, R10, C2, C3, C4 and IC3. If this does not help, try replacing IC3. If that solves the problem, throw the faulty IC away, if not then look again.

Assuming the output of IC3 is OK, we now need to look at the output of IC1B. In order to make the signal visible, using a meter, set R9 to give maximum Voltage output on IC2. This will give a minimum output Voltage on pin 4 of IC1. When the sensor is touched, the output of IC1B should rise to nearly 5 Volts. If it doesn't, check that pins 4, 5 and 6 of IC1 are connected properly and are not connected to anywhere other than as shown in the circuit diagram. If that does not help, try replacing IC1. If that solves the problem, throw the faulty IC away and if it does not, look again.

Assuming that the output of IC1B is OK, connect the meter across C5. This should read nearly zero Volts when the sensor is not touched and nearly 5 Volts when it is. If it always reads 0 Volts, check that C5 is not short circuited, that pin 8 of IC1 is not connected to pin 7 and that R11 is connected properly. If the reading is always 5 Volts, check that D2 is the correct way round.

Assuming that the Voltage across C5 is OK, check the output, which is pin 10 of IC1. This should be 5 Volts when the sensor is not touched and 0 Volts when it is. If there is a fault, look at pins 8, 9 and 10 of IC1. If the problem

persists, try replacing IC1. If that solves the problem, throw the faulty IC away, if not, look again.

Position sensors

You can use a number of the sensors described to give a signal when anyone moves to a particular position. You can use a PIR detector with a restricted view mounted above the area. You can use under-carpet mats. You can use focused infrared beams mounted above, provided that the floor is not too reflective and the ceiling is not too high.

If you need to know where in the room someone is, the problem becomes more difficult. One easy way is to use a large number of the sensors mentioned above. There are two complex and expensive ways, which will not be described here but are mentioned for completeness. They are to use a scanning laser or video camera connected to a computer with image analysis software. If there is only one person at a time in the sensed area, you can use two ultrasonic distance measuring sensors mounted at right angles. These are described later in this chapter. They would need to be switched alternately as they would otherwise interfere with each other. They measure the distance to the nearest object. Another way is to use a number of infrared beams mounted at right angles. It would be possible to connect these signals to a computer and program it to track the positions of a number of people but you would not have to mind if it got a bit confused once in a while and you would have to have a good knowledge of computers and programming.

Distance sensors

The circuit described here **should not be attempted unless you have previously built circuits and have the use of an oscilloscope.**

This circuit uses an ultrasonic transducer (special loudspeaker) to transmit a pulse of ultrasound. It uses the time for that pulse of sound to reach the object nearest to it and be reflected back to the receiving ultrasonic transducer (special microphone) as a measure of the distance between the transducers and the object. Sound travels through air at about 330 m/Sec. It will therefore take about 6 mSecs for the sound from the transmitter to reach the receiver after being reflected from an object 1 meter away. This is effectively an ultrasonic equivalent of radar.

There are a number of siting restrictions you should be aware of. You should avoid using ultrasonics in situations where there is high frequency sound. In particular from the hitting or grinding of metal. You should avoid areas where there are strong draughts, as movements of air will affect ultrasonic transmissions. The ultrasonic beams from readily available transducers are not focused and you will get reflections from walls and floors as well as anything within a few meters of the transducers. You should mount the transducers at a height between 1 and 1.8 meters above ground level. You should also avoid a

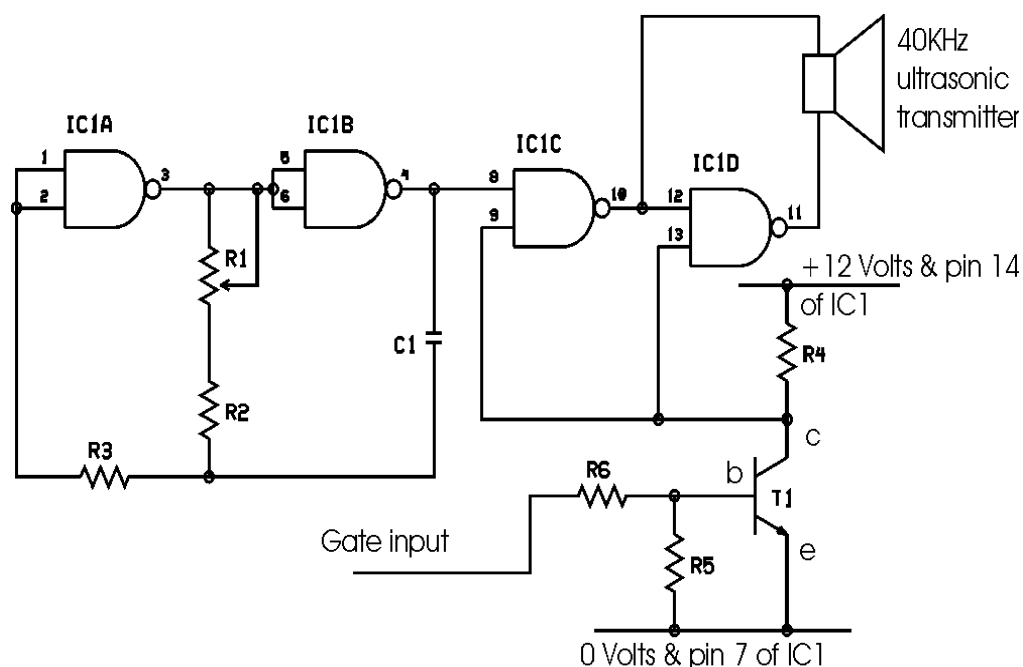
direct sound transmission from transmitter and receiver (they should preferably be about 10 cm apart and pointing in the same direction and not towards each other).

You will notice, when you are testing the circuit, that the received signal varies greatly in amplitude when the sensed object moves slightly. Sound waves are repeated pressure differences where the air pressure increases and decreases alternately. In each cycle there are two points at which there is no pressure difference as the pressure is either going from increased to decreased or from decreased to increased. If the object being sensed is exactly at that point, there is no sound to reflect. These points are called nodes. The points half way between the nodes are called antinodes. These nodes are about 4mm apart when a 40KHz sound wave is transmitted in air.

The following circuit has a range of about 3 or 4 meters.

Please note that the receiver will pick up signals from the transmitter circuit as well as from the transducer if the circuits are not physically separated. It is possible to use the same circuit board for both transmitter and receiver but beginners should consider building the circuits on separate boards and keep them a few centimeters apart.

The first circuit to be described is the transmitter which is powered by a 12 Volt supply, which may also be used as an input for the 5 Volt supply used by the receiver.



Ultrasonic transmitter

- R1 5K potentiometer/trimmer
- R2 22K
- R3 470K

R4 22K

R5 10K

R6 10K

C1 220pF ceramic COG or NOP type

IC1 4011 use HEF4011BP. Different manufacturers use different types of input static protection. The HEF4011BP has a suitable input protection for this circuit. Note: these devices are static sensitive.

T1 BC184L

Ultrasonic transmitter SCS401T or equivalent. Note: one terminal is connected to the housing, so the housing must not be allowed to make an electrical connection with any metalwork or earth.



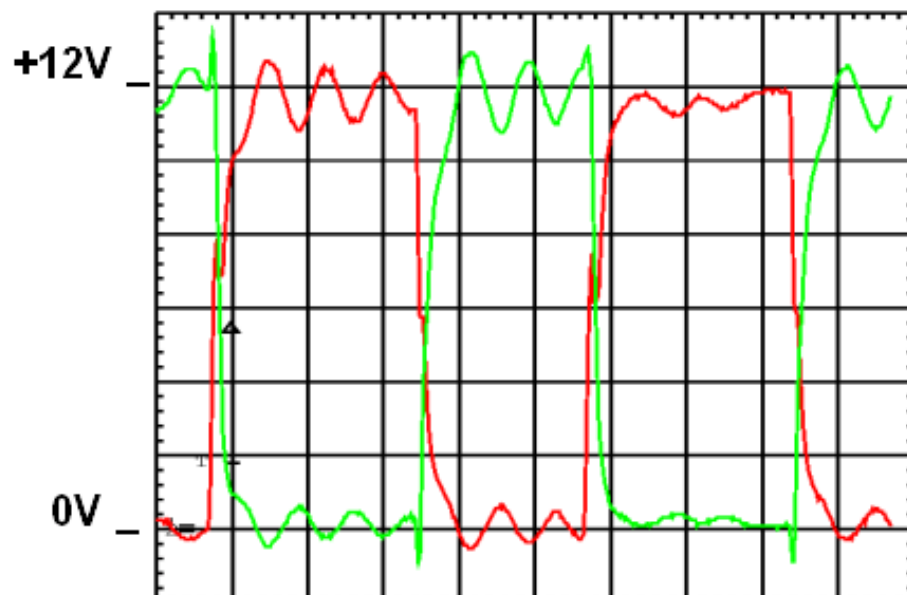
Ultrasonic transducer



Testing

Before applying power to the circuit, inspect the circuit thoroughly using a spy glass ensuring that there are no unwanted short circuits or open circuits and that the circuit follows the diagram exactly. Ensure that the power supply is connected the right way round. Then set your meter to continuity or low Ohms range. Connect the meter across the 0V and 12Volts of the circuit and make sure that the reading is not zero or near to zero. If you do not get the expected results, you should switch the circuit off immediately.

Set the time base of your oscilloscope to 5μSecs / division. Connect the screen to 0 Volts and the probes to either side of the ultrasonic transmitter. You should see the following image and the frequency should change with the adjustment of R1.



The green trace is one side of the transmitter and the red is the other. You might expect to see a clean square wave but the transducer is a tuned circuit and the ripples in the waveform are what is called ringing. You will find it easier to see what is going on if you reduce the vertical sensitivities to 5 Volts/cm and separate the traces.

If the frequency of oscillation is too high, increase the value of R2 to 27K and if it is too low, decrease the value of R2 to 18K. The frequency should be 40KHz, which is 25 μ Secs from the beginning of a cycle to the beginning of the next. A lower frequency will take longer.

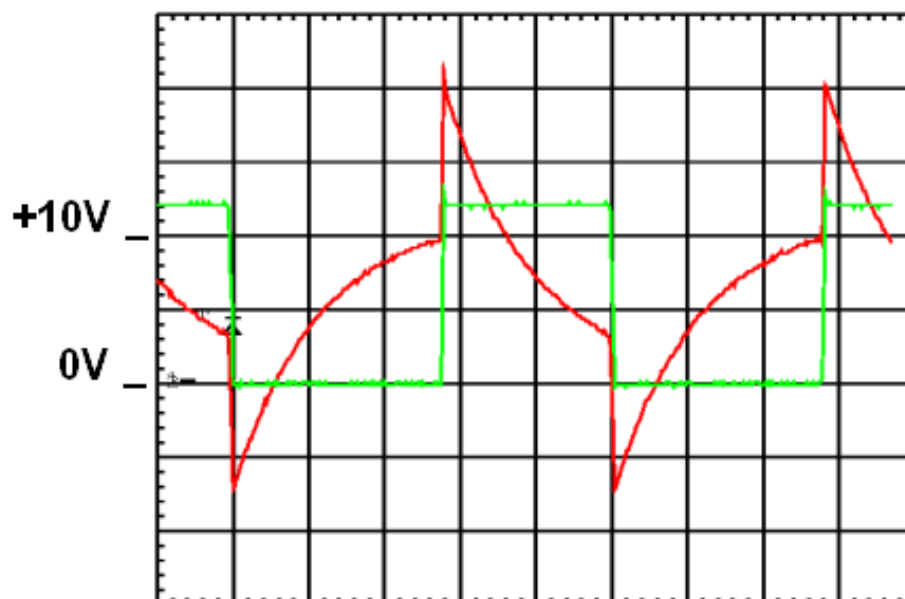
If you now connect the gate input to the + 12 Volts, both sides of the transmitter should go to the +12 Volts supply and the transmitter will not produce any sound.

Circuit description

IC1A and IC1B form a square wave oscillator. R3 needs to have a resistance, which is substantially greater than the sum of the resistances of R1 and R2. This type of circuit is called an astable relaxation oscillator.

In the following oscilloscope image, the time base (horizontal direction) is 5 μ Secs per large division. The green trace is the output of IC1B and the red trace is the other end of C1. Putting a 'scope probe on the input of IC1A adds to the capacitance of the circuit and does not correctly show the normal conditions and that trace is therefore not shown here.

You will note that the red trace greatly exceeds the supply Voltage. This will not harm the device as the input circuit of the HEF series of logic circuits includes two diodes, which clamp the inputs to 0.5 Volts more than the supply. If you use devices by another manufacturer, you may damage the devices.



When the output of IC1B goes high, The junction of R2, R3 and C1 is increased by about 12 Volts. This causes the input of IC1A to be high and its output to be low which keeps the output of IC1B high. The capacitor then discharges through R1 and R2 until the input of IC1A becomes low. At this point, the output of IC1A becomes high and the output of IC1B becomes low. This reduces the Voltage at the junction of R2, R3 and C1 by about 12 Volts and C1 is then charged up via R1 and R2 until the input of IC1A becomes high again and the cycle is repeated.

The output of IC1B is buffered and inverted by IC1C and again by IC1D. These gates then drive the ultrasonic transducer. Pins 9 and 13 need to be high for the oscillator output of IC1B to be transferred to the transducer, as these gates are NAND gates. If any input of an NAND gate is low, the output will be high irrespective of the other inputs. Pins 9 and 13 are held high by R4 as long as T1 is turned off. R5 and R6 act as a potential divider so that a Voltage of at least twice the Cutin Voltage is required at the gate input to turn the transistor on and inhibit the sound output. The Cutin Voltage for a silicone diode or transistor input is 0.5 Volts. A transistor base – emitter junction looks like a diode.

Faultfinding

The first thing to do is give the circuit a thorough visual inspection with a spy glass looking for bad solder joints and short circuits. Check that the circuit you have built exactly matches the circuit diagram and that the components are the correct values and connected the right way round.

Make sure that the power supply is switched off. Set your meter to continuity and connect across the 12 Volt supply. If you have a short circuit, remove IC1 and try again. If that does not help, check to see that the +12 Volts is only connected to R4 and pin 14 of IC1. If removing the IC helped, make sure that it was the correct way round. If it was the correct way round and still caused the problem, replace with a new one and if that solves the problem, throw the faulty one away. If it was connected the wrong way round, it was probably damaged.

Assuming that there are no short circuits, connect the screen of the 'scope probes to 0 Volts and a probe to the output of IC1B pin 4. You should get a square wave at 40 KHz. If you don't, check the circuit of IC1A, IC1B, R1, R2, R3 and C1. Look for short circuits, open circuits, bad solder joints and check the component values.

Assuming that the oscillator is functioning correctly, check that the inputs of IC1C and IC1D pins 9 and 13 are at approximately +12 Volts. If not check that T1 is connected correctly and that R5 is directly across the base and emitter. Check that there are no unwanted connections to those pins. If that does not help, replace T1. If that helps, throw the faulty transistor away.

Assuming that pins 9 and 13 are at +12 Volts, check that pin 8 is connected to pin 4, that pin 10 is connected to pin 12 and nowhere else and that the ultrasonic transducer is not shorted.

Assuming that that is OK, check that R6 is connected to the base of T1 and R5 and that T1 is connected the right way round. If

The second part of the circuit is the receiver.

In view of the complexity of the circuit it would be prudent to build it in easy stages testing each stage first before proceeding to the next. It will be assumed that the circuit will be built and tested one IC, with the accompanying passive components, at a time and in numeric order.

You may use the same 12Volt supply for both the transmitter and 5 Volt supply for the receiver. In any event the 0 Volts of the two circuits must be connected together.

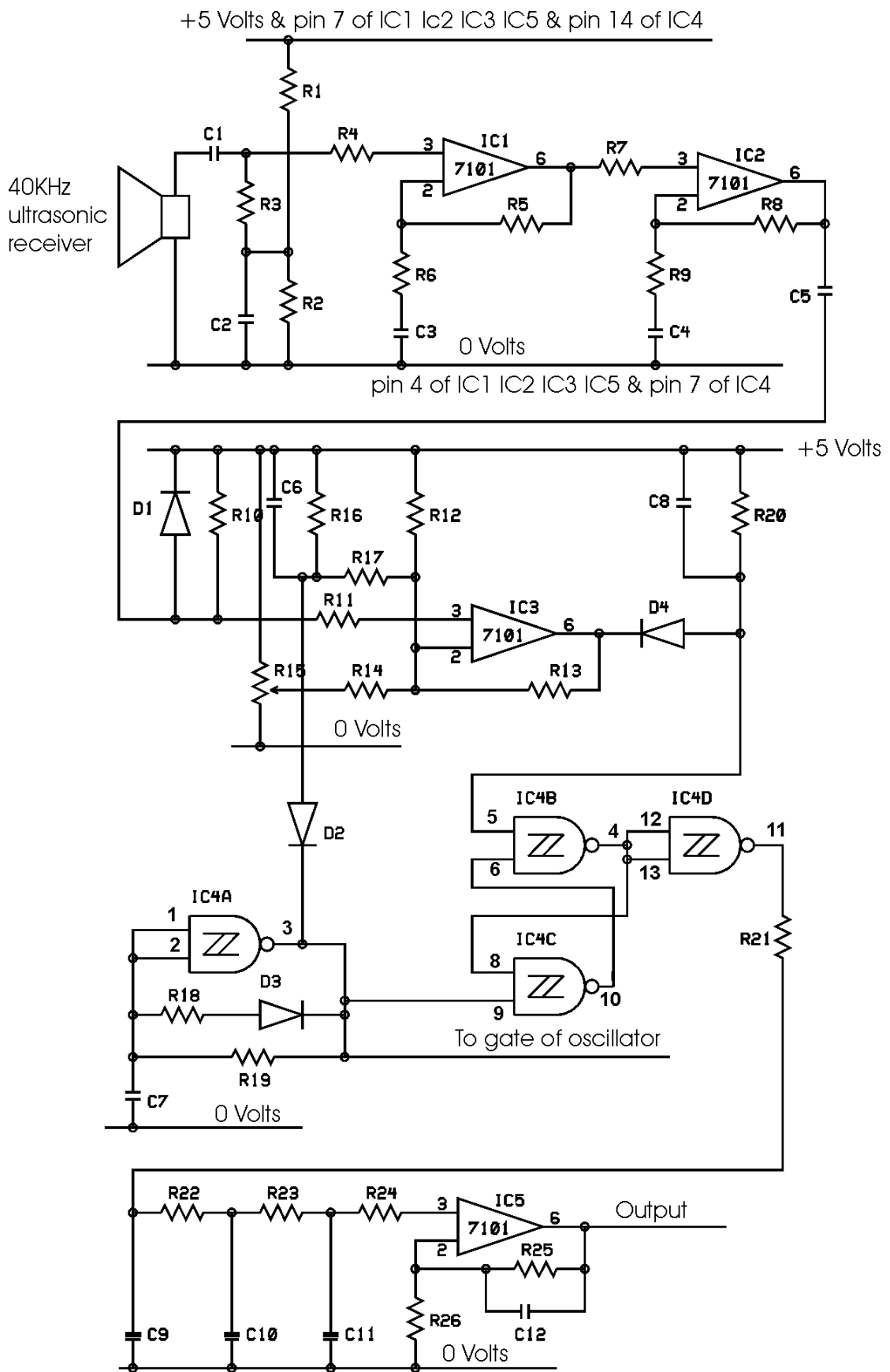
If the ultrasonic receiver is mounted away from the circuit, it should be connected using screened cable. The screen being connected to the pin which is connected to the transducer housing and to 0 Volts.

OPERATIONAL AMPLIFIER



Ultrasonic transducer





Distance sensor

R1	47K
R2	47K
R3	47K
R4	10K
R5	47K
R6	2K2
R7	10K
R8	47K
R9	4K7
R10	100K
R11	10K
R12	4K7
R13	100K
R14	10K
R15	10K potentiometer/trimmer
R16	4K7
R17	10K
R18	4K7
R19	100K
R20	22K
R21	10K
R22	10K
R23	10K
R24	10K
R25	47K
R26	47K
C1	0 μ 1F
C2	0 μ 1F
C3	0 μ 1F
C4	0 μ 1F
C5	0 μ 1F
C6	1 μ F
C7	1 μ F
C8	22000pF
C9	4 μ 7F negative end should be connected to 0 Volts
C10	4 μ 7F negative end should be connected to 0 Volts
C11	4 μ 7F negative end should be connected to 0 Volts
C12	1 μ F
D1	1N4148
D2	1N4148
D3	1N4148
D4	1N4148

IC1	7101 any prefix or suffix
IC2	7101 any prefix or suffix
IC3	7101 any prefix or suffix
IC4	4093 any prefix or suffix
IC5	7101 any prefix or suffix

all unused pins must not be connected anywhere

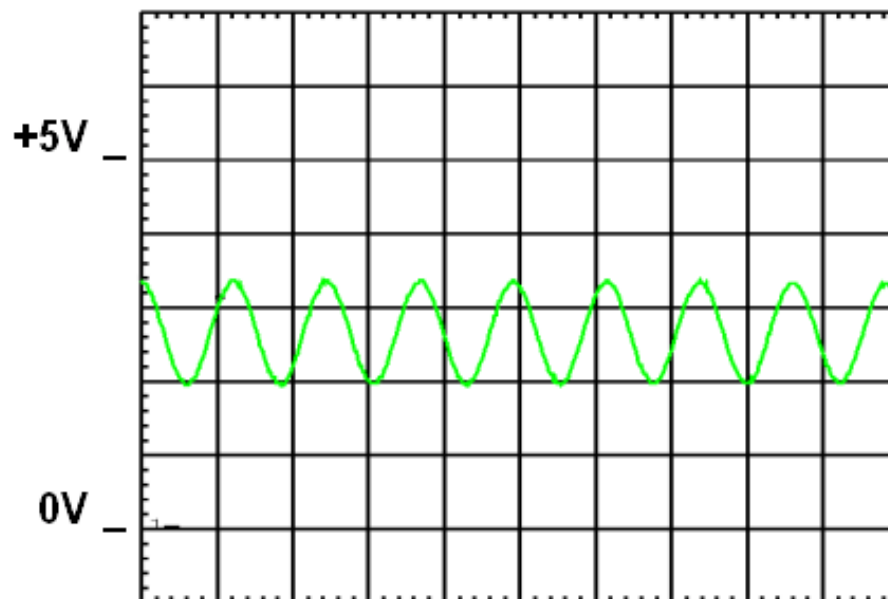
Ultrasonic receiver SCM401R or equivalent. Note that the pin connected to the housing should be connected to 0 Volts.

Testing

It will be assumed that the usual procedure of visual inspection and testing for short circuits, open circuits, bad solder joints, component orientation and value and that the circuit agrees with the diagram, will have been performed prior to the application of power in each stage of the circuit.

Point the transmitter and receiver at a wall to get a reflected signal. The example used was a ceiling about 1.5 meters away.

In all circuits, the screen of the 'scope probe should be connected to 0 Volts. Connect the probe to the output of IC1 (pin 6). Set the time base to 20 μ Secs/div. You should observe a trace similar to that shown below but probably with a reduced amplitude of the sine wave. You will need to adjust the frequency of the transmitter for maximum sine wave amplitude. This is done by adjusting R1 in the transmitter circuit. If you cannot obtain a maximum because the adjustment has reached the end stop of the potentiometer, change the value of R2 as described in the testing section of the transmitter circuit instructions.



Circuit description

R1 and R2 provide a bias Voltage for the operational amplifier IC1. Since the values of R1 and R2 are equal, the Voltage at their junction will be half the supply Voltage (2.5 Volts). C2 acts as a short circuit for 40KHz and thus removes unwanted signals in the supply from the bias. R3 connects this bias to the input from the transducer, which is capacitively coupled via C1. R4 connects the input signal and bias to the non-inverting input of IC1. R5 is a feedback resistor. C3 has a low reactance at 40KHz and can be considered as nearly a short circuit for alternating currents and as having an infinite resistance for direct currents. For direct Voltages the gain of the circuit is one so the output Voltage is the bias Voltage of 2.5. For alternating inputs the gain is

determined by the values of R5 and R6 and is $(R5 + R6) / R6$ which is approximately 22. In operational amplifiers, any small difference in Voltage between the inputs is greatly amplified. If the input on pin 3 increases, the output increases. The output is connected to the inverting input (pin 2) via R5 but not all of the output Voltage is transferred to the input, for alternating Voltages, as R6 is connected to 0 Volts via C3. Only 1/22 nd of the alternating output is transferred to the input. The output increases until the inputs are equal. The output for alternating inputs is therefore 22 times greater than the input. 40KHz is quite a high frequency for operational amplifiers so we cannot have all the gain we need from this type of operational amplifier. There are high-speed operational amplifiers but this circuit does not use them so that you can use the same type of amplifier in as many different circuits as possible. This is why we are using IC2 as well as IC1.

Fault finding

Check that the supply is 5Volts. If not make sure that the +5Volts is only connected to R1 and pin 7 of IC1 and that the 0 Volts is only connected to the transducer, C2, R2, C3 and pin 4 of IC1. If that is OK try replacing IC1. If that restores the 5 Volt supply, throw the faulty IC away.

Assuming that the supply is OK, check the Voltage at the junction of R2 and R3. It should be about 2.5 Volts. If it is not, check R1, R2 and C2.

Assuming that that is OK, check that you have 2.5 Volts at the junction of R3 and R4. The Voltage may be nearer to 2.25 Volts according the type of 'scope probe that you are using. If not see if removing IC1 restores the correct value. If it does, check for short circuits between pins 2 and 3. If not check C1 for short circuits and R3 for open circuits and bad solder joints.

Assuming that that is OK check the output Voltage on pin 6 of IC1. It should be 2.5 Volts. If it is not, look for short circuits across C2 and pins 6 and 7 of IC1.

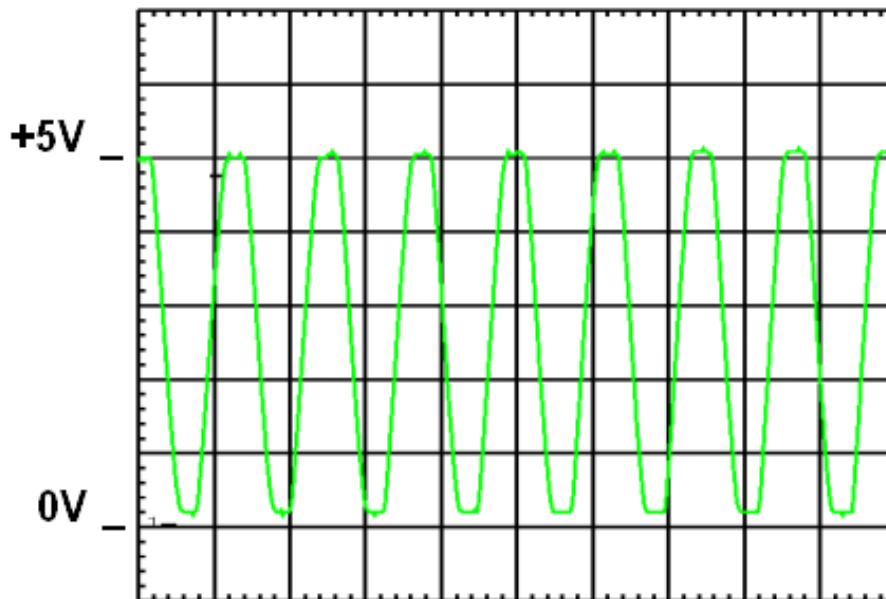
Assuming that you have 2.5 Volts at the output of IC1 pin 6, and that you are not getting a suitable alternating output and tuning the oscillator does not help, either the ultrasonic receiver is shorted, C1 is not connected, the values of R5 and R6 are incorrect or the transmitter frequency is not 40KHz.

Next stage

Now build the next part of the circuit, which is just another amplifier.

Testing

This stage of the circuit is an amplifier with a gain of about 11. The output of IC2 (pin 6) should look like the 'scope image shown below.



Circuit description

The only difference between this part of the circuit and the previous part is that the input already has the appropriate bias as it is connected directly to the output of IC1 via R7 and the gain is 11 and not 22. You will note that the amplification is so high that the amplifier is limited by the supply Voltage. The reason for this is that the sound reflections from people at 3 meters distance from the transducers is quite small and we need to be able to have a reasonable signal when people are at a node of the transmitted sound.

Fault finding

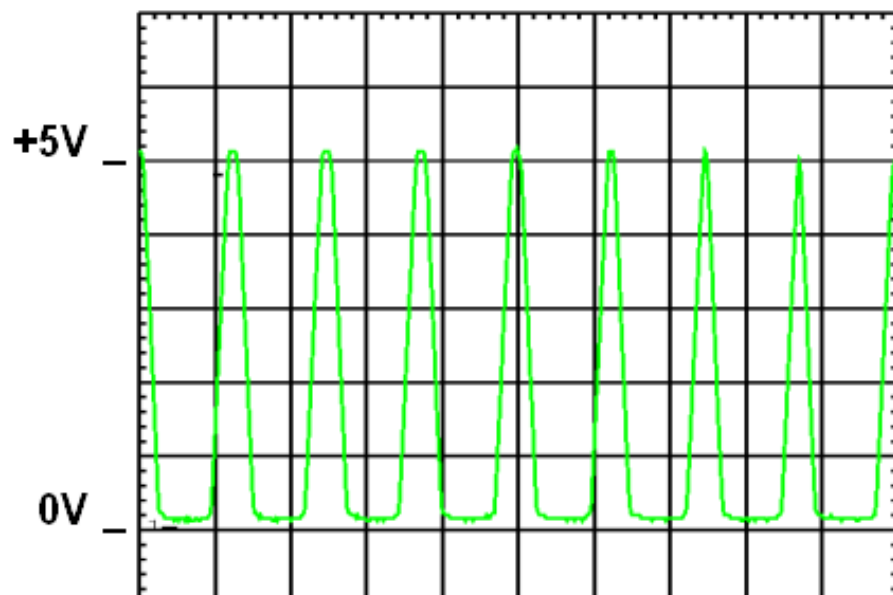
This will be similar to the previous stage.

Next stage

This comprises a rectifier, biasing and amplifier. Ensure that the diode D1 is connected the right way round. D2 may be added at the next stage.

Testing

You should observe a waveform similar to the following at the output of IC3 pin 6.



Circuit description

The signal from IC2 is coupled to the circuit by C5 and is rectified by D1 and R10. D1 clamps the positive peaks of the signal to the +5 Volts. This has the effect of making the signal always be less than +5Volts and the amount by which it is less depends on the amplitude of the signal. The reason for this will become more apparent when the next stage of the circuit is built. We want to see the difference between small signals and large signals. When the signal is small, it will be close to +5 Volts. When it is large, it will extend to the 0 Volts. In the case shown it is very large so the bottom of the 'scope trace is clamped to the 0 Volts.

The signal is connected to the non-inverting input of the operational amplifier IC3 (pin 3) via R11.

R13 is the feedback resistor and R12 acts as a +5Volt bias and gives the amplifier gain. The bias is reduced from +5 Volts according to the setting of the potentiometer R15 and the resistor R14, which also increase the amplifier gain. The function of C6, R16 and R17 will be described in the next section of the circuit. The effect of the bias adjustment is to prevent small signals from being amplified. The output of IC3 will be nearly +5 Volts unless the input signal is great enough for the peak to become more negative than the bias Voltage on pin 2 of IC3. When this circuit is used in practice there will always be some small signal from echoes, acoustic couplings between transmitter and receiver and from capacitive couplings within the circuit itself. This biasing circuit removes these unwanted signals.

Fault finding

Check that the supply Voltage is still OK. If not either the IC is faulty or you have a short circuit.

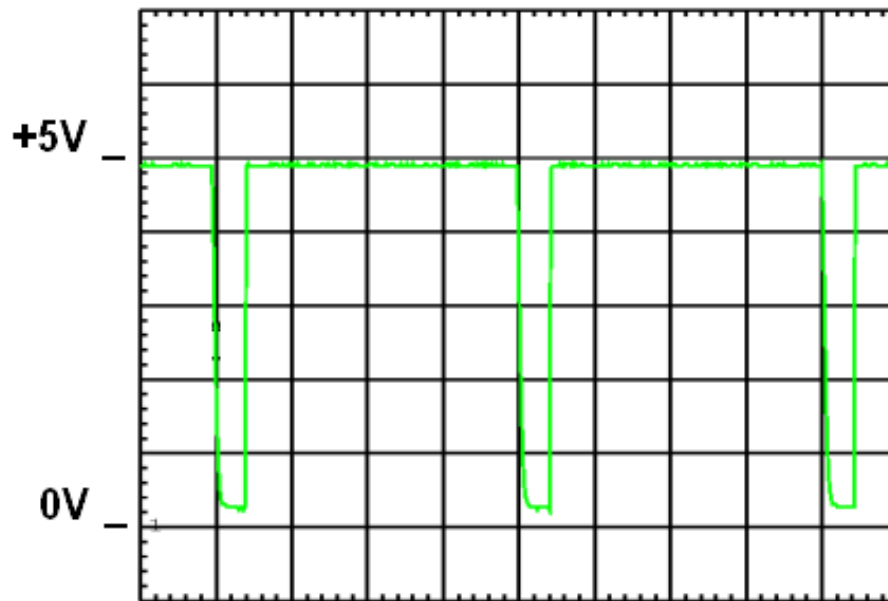
Assuming that the supply Voltage is OK, check that D1 is the correct way round. Check the component values and look for bad solder joints, short circuits and open circuits. If that does not help, try replacing the operational amplifier.

Next stage

So far the circuit has been using continuous ultrasound. This next part of the circuit pulses the sound and uses logic gates to provide a signal, which is proportional to the distance to the nearest object. D2 should also be connected at this stage. Don't forget to connect the output of IC4A (pin 3) to the gate input of the transmitter.

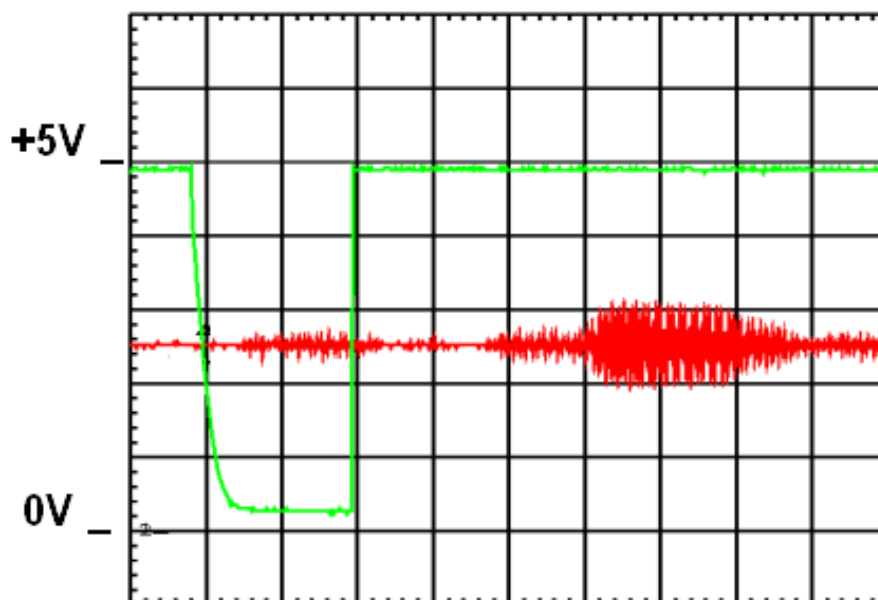
Testing

Change the time base on the 'scope to 10mSecs/div. Connect the probe to the output of IC4a (pin 3). You should see the following image.



If the trace is nearly 0 Volts for most of the time and periodically goes to nearly 5 Volts for a short period of time, you have connected D3 the wrong way round.

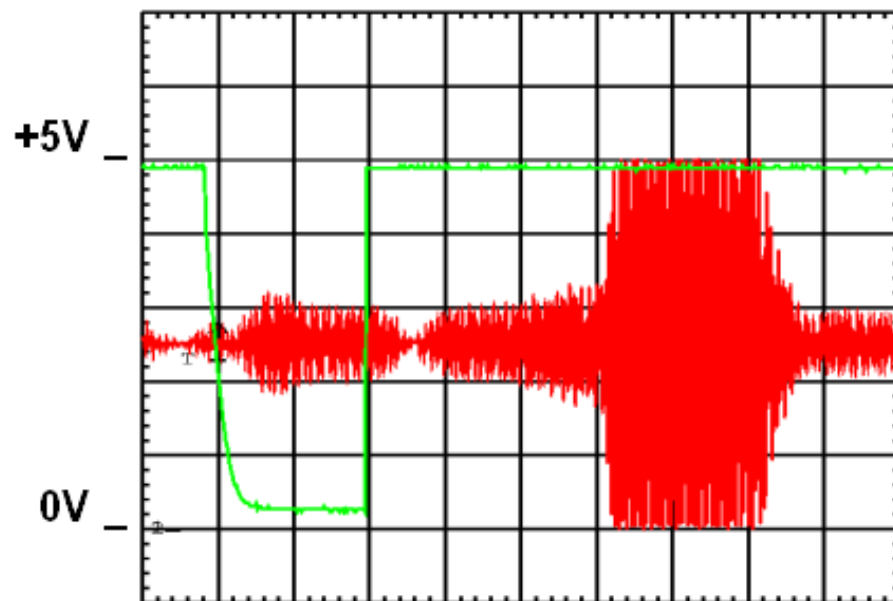
Now change the time base again to 2mSecs/div. Leave the probe connected to the output of IC4A and use that probe to synchronize the time base. Connect the other probe to the output of IC1 (pin 6). You should get something similar to the image below.



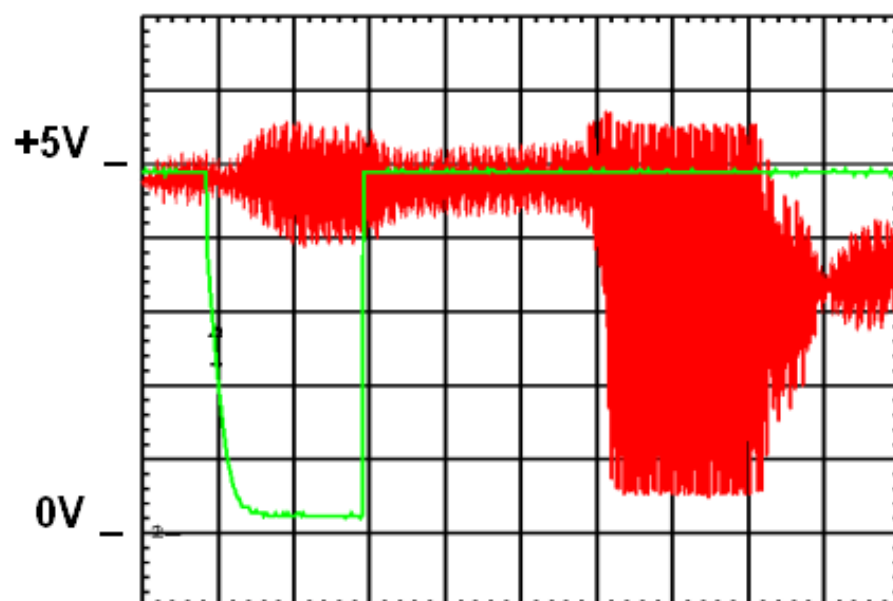
The green trace is the output of IC4A and the red trace is the output of IC1. You will note that there is a small signal that starts about 1mSec after the pulse and lasts for about 4mSecs. This is the direct coupling from the transmitter to the receiver. There is a further small signal, which starts about 7mSecs after the beginning of the pulse. This is a reflection from objects, which are to one side

of the main field of view. You can expect to get some reflections from objects, which are not the main objects. The main object produces the signal, which starts about 10mSecs from the start of the pulse.

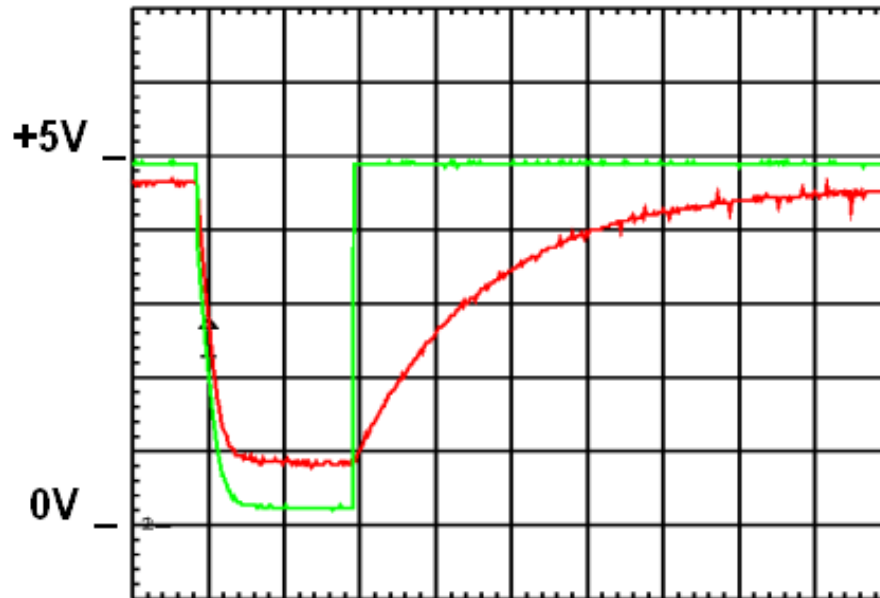
If you now move the second probe from the output of IC1 to the output of IC2, you should get a similar image to the following, which is an amplified version of the previous one.



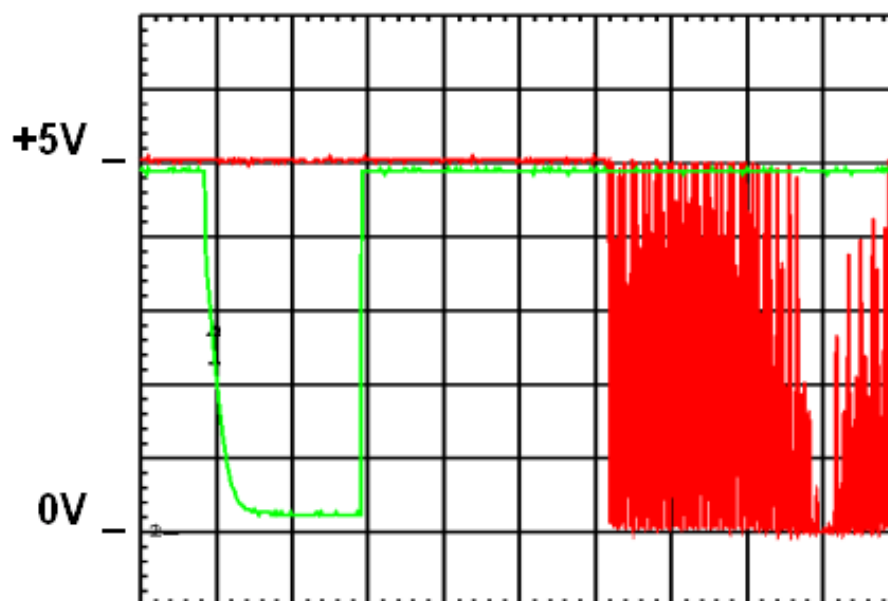
If you now move the second probe to the junction of D1 and C5 you should observe the following image. You will note that the more positive part of the signal has been clamped to a level a bit above the +5 Volts rail.



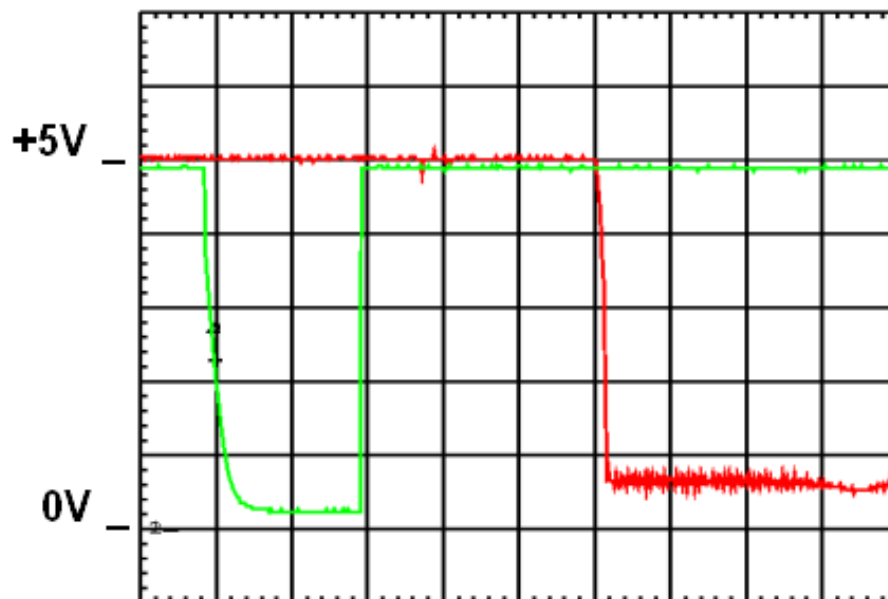
Now connect the second probe to the junction of D2 and C6. You should observe the following waveform. This shows the capacitor C6 being charged via D2 and discharging via R16 and R17. This signal is used as a further bias for IC3. The signals due to near objects will be much greater than for far objects. We impose a temporary bias, which decays over a period of about 6mSecs. The bias is a proportion of this signal. The proportion is determined by the resistor values. The effect of this is to make the circuit less sensitive for near object than for far objects.



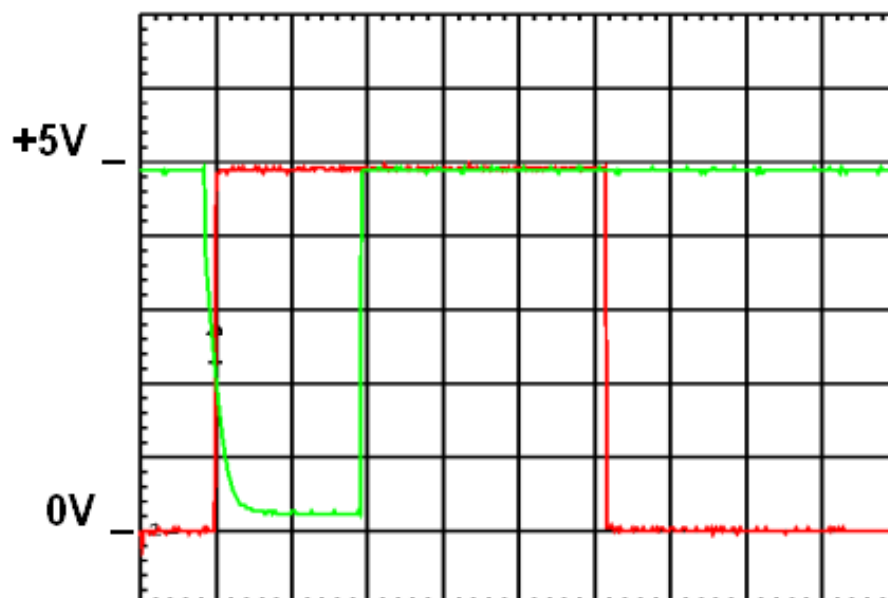
If you now connect the probe to the output of IC3 (pin 6), you should get a signal similar to the one shown below. You will need to adjust R15 to remove the unwanted signal and retain the wanted one.



Now connect the second probe to the junction of D4 and R20. You should get the image below.



Now connect the second probe to the output of IC4D (pin 11) you should get the image below. The output pulse width is directly proportional to the distance of the nearest object to the transducers.



Circuit description

IC4A is an oscillator. The gate is a NAND Schmitt trigger, which means that the input Voltage level, which causes the output to be '0' is higher than the input Voltage which causes the output to be a '1'. When the output is at 5 Volts, C7 charges up via R19 until it reaches the level at which the output goes to zero Volts. When that happens, C7 discharges through R19 and through R18

and D3. The output is therefore a '0' for a shorter period of time than a '1'. These times are about 4mSecs for a '0' and about 35mSecs for a '1'. These times may be slightly different as the components are not all identical.

IC4B and IC4C are cross coupled to form a latch. At the start of each pulse of sound, the input pin 5 of IC4B is a '1' and the input pin 9 of IC4C is a '0'. Any zero on any input of a NAND gate causes a '1' on its output. The output of IC4C is therefore a '1'. This means that both inputs of IC4B are '1's and that therefore the output of IC4B will become '0'. This output is connected to the input pin 8 of IC4C, which means that the output of IC4C will be held at '1' even if the input pin 9 of IC4C becomes a '1'. When the output of IC4B is '0', the output of IC4D is a '1'.

When the echo arrives 10mSecs later, the output of IC3 becomes zero and this zero causes C8 to be charged via D4 so that the input to IC4B pin 5 becomes '0'. C8 discharges via R20 but this is slow in comparison with the 40KHz signal, so the input to IC4B pin 5 is held low as long as there is an echo present. The '0' on the input of IC4B pin 5 causes the output of IC4B to become a '1' and the output of IC4D to become a '0'. Now this '1' on the output of IC4B will last long enough for the output of IC4A to become a '1'. The result of this is that both the inputs of IC4C will become '1's and that therefore the output of IC4C will be '0'. This will cause the output of IC4B to be a '1' and the latch will have been reset waiting for the next sound pulse to start.

Fault finding

First read the circuit description. This will tell you which part/parts of the circuit is/are not functioning correctly. When fault finding with logic gates, look at the inputs of each gate and check to see if the output corresponds to the input. In this circuit, the gates are NAND so the outputs should only be 0 Volts if both inputs are at +5 Volts otherwise the outputs should be at +5 Volts. If this is not the case, either you have short circuits, open circuits, bad solder joints or the IC is faulty. Check that the circuit that you have built corresponds with the diagram.

If you have a signal at the output of IC3 but not at pin 5 of IC4, check that D4 is the correct way round and that there are no short circuits, open circuits or bad solder joints. Similarly check the waveform on C6 with attention to the polarity of D2.

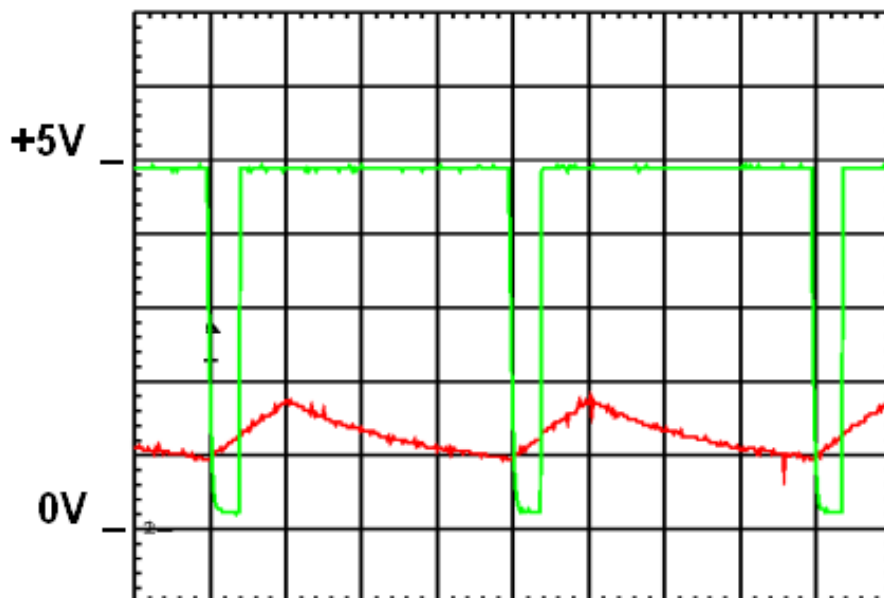
Last stage

Build the rest of the circuit bearing in mind that C9, C10 and C11 are electrolytic capacitors and must have their negative ends connected to the 0 Volt rail.

Circuit description

The last part of the circuit converts the pulse width output of IC4D to an analogue Voltage output. The pulse width is proportional to the distance of the nearest object. This pulse is repeated, approximately, every 40mSecs. All we have to do is get an average Voltage from these pulses. This process is called integration.

C9 is charged up via R21 when the pulse is present and discharged when it is not. The longer the pulse is present, the longer the capacitor will have to charge up and the shorter it will have to discharge. Set the time base of your 'scope to 10 mSecs per division and connect the second probe to the junction of R21 and C9. With the nearest object about 1.5 meters away, you should observe the following trace.



You will note that C9 charges up to about 1.8 Volts after 10mSecs and then discharges to about 1 Volts for the remaining 30 mSecs before charging up again. The low pass filter, comprising R22, R23, C10 and C11, smoothes this triangular wave out, to give a constant Voltage for a constant distance. R24 couples this signal to the non-inverting input of the operational amplifier IC5. R25 and R26 define the amplifier's gain of 2 and C12 provides a further stage of smoothing.

This circuit may be used as an input for the differentiators described latter in this chapter but the range of use is limited to less than 2 meters as the problems associated with the sound nodes become insurmountable at greater distances without the use of microprocessors. The smoothing prevents a quick acting signal. For short distances, the circuit can be made more stable by increasing the value of R6 to 4K7 and R17 to 22K, which halves the gain of the amplifier IC1 and reduces the temporary bias on IC3. Reducing the value of R19 to 47K

may also be possible provided that the unwanted echoes are not too prolonged. The differential of distance is speed as speed is distance divided by time.

Fault finding

Check that the capacitors C9, C10 and C11 are connected the correct way round. If they were not, they may well be damaged. Tantalum capacitors are more likely to get damaged than ordinary electrolytic capacitors. It would be safer to throw them away if they have had a reverse Voltage applied to them. Check that the signal appears across each of the capacitors in turn. The average direct voltage should be the same anywhere along the resistor chain comprising R21, R22, R23 and R24. The triangular waveform should diminish in amplitude the further you go along the chain.

Check to see that the output Voltage is twice the Voltage at the input pin 3 of IC5. If it is equal, you have a short circuit across R25 and C12. If it is either 0 Volts or 5 Volts, check for open circuits and bad solder joints on R25. Check that R26 is not shorted and check that none of the pins on IC5 are shorted and that the unused pins are not connected anywhere. Obviously you should check that the 0 Volt rail is connected to pin 4 and the 5 Volt rail is connected to pin 7.

Speed of movement sensors

First read the introduction to the distance sensor section.

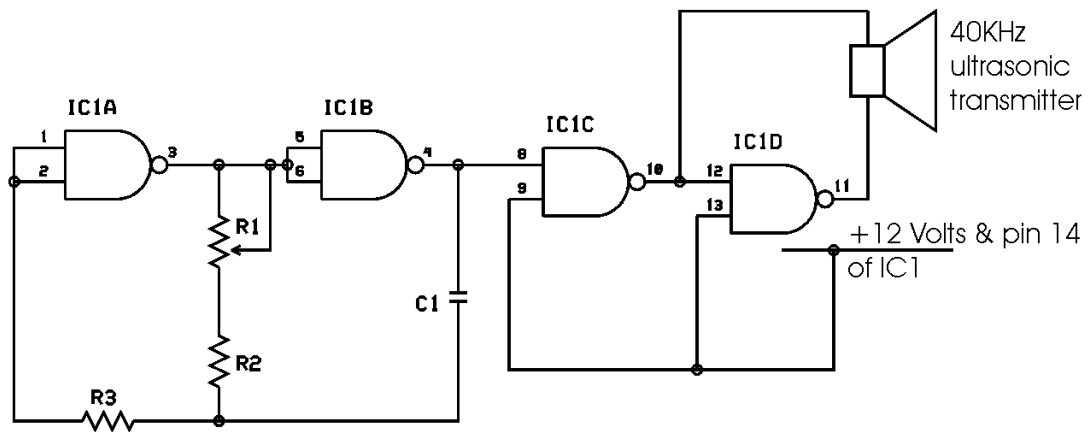
LINK

This circuit uses continuous sound rather than pulsed sound and uses the fact that the reflected sound varies in amplitude according to how close the nearest object is to the nodes of the sound wave. If you move towards or away from the sensor, you will move through these nodes. The frequency with which you move through the nodes is a measure of your speed. It will be apparent that you will get the same effect whether you move away from or towards the sensor.

This type of sensor was used for burglar alarms before PIR detectors were available at a competitive price. PIR detectors are usually slow to switch off their detection signal after the movement has ceased so if this matters to you, you can use this type of detector, which reacts quite quickly, instead.

The circuit will be divided into the transmitter circuit and the receiver circuit. The receiver circuit will be subdivided to simplify the construction, testing and fault finding.

The following transmitter circuit is nearly the same as that for the distance measurement. You should use the same component values and follow the same test procedure and fault finding except for the components, which are not present in this circuit.



0 Volts connected to pin 7 of IC1

Ultrasonic transmitter

R1 5K potentiometer/trimmer
 R2 22K
 R3 470K
 C1 220pF ceramic COG or NOP type
 IC1 4011 use HEF4011BP. Different manufacturers use different types of input static protection. The HEF4011BP has a suitable input protection for this circuit. Note: these devices are static sensitive.

Ultrasonic transmitter SCS401T or equivalent. Note: one terminal is connected to the housing, so the housing must not be allowed to make an electrical connection with any metalwork or earth.



Ultrasonic transducer

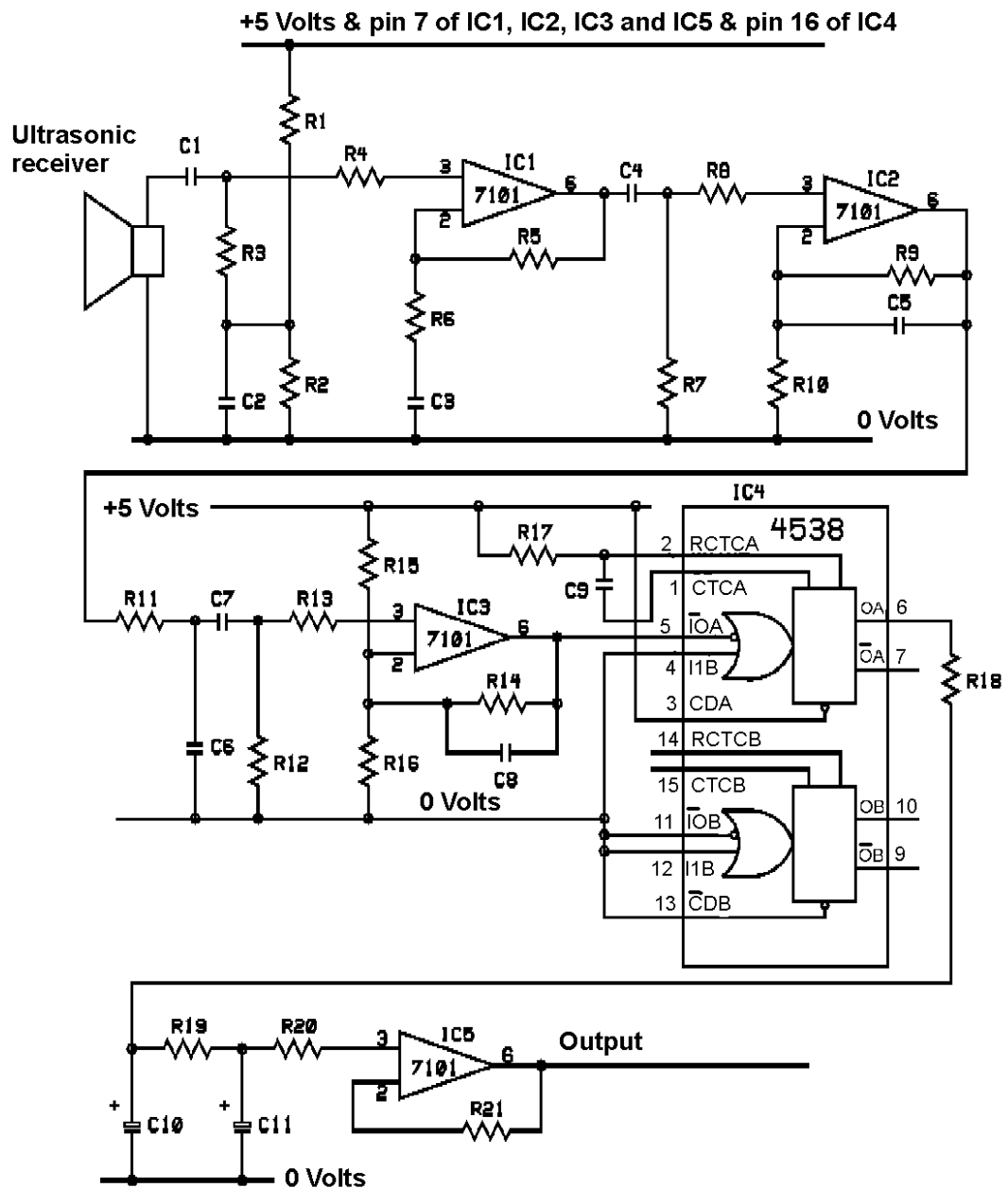


Next

The next part of the circuit is the receiver circuit. Please note that the first stage is identical to the first stage of the distance measuring circuit. Please refer to it before continuing to the next stage.

LINK

Assuming that you have built and tested the first stage and that you have tuned the transmitter, build and test the second stage.



0 Volts connected to pin 4 of IC1, IC2, IC3 and IC5 & pin 8 of IC4

Speed of movement sensor

R1	47K
R2	47K
R3	47K
R4	10K
R5	47K
R6	2K2
R7	100K
R8	10K
R9	47K
R10	1K

R11 10K
 R12 100K
 R13 10K
 R14 100K
 R15 220K
 R16 1K
 R17 27K
 R18 10K
 R19 10K
 R20 10K
 R21 10K
 C1 0 μ 1F
 C2 0 μ 1F
 C3 0 μ 1F
 C4 0 μ 1F
 C5 470pF
 C6 10000pF (10nF)
 C7 1 μ F
 C8 1000pF (1nF)
 C9 1 μ F
 C10 4 μ 7F negative end connected to 0
 Volts
 C11 4 μ 7F negative end connected to 0 Volts
 IC1 7101 any prefix or suffix
 IC2 7101 any prefix or suffix
 IC3 7101 any prefix or suffix
 IC4 4538 any prefix or suffix
 IC5 7101 any prefix or suffix

Ultrasonic receiver SCM401R or equivalent. Note that the pin connected to the housing should be connected to 0 Volts.

Dual monostable multivibrator



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Ultrasonic transducer



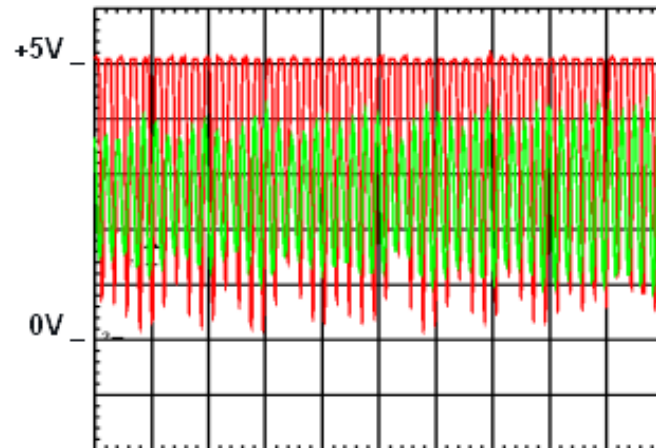
The second stage acts as a rectifier and amplifier, which has an output proportional to the amplitude of the received signal.

Testing

Set the time base of your oscilloscope to 5mSecs per division for the rest of the circuit testing. The 'scope, used for the illustrations in this cd, is a storage 'scope as this allows for a direct transfer of the image to a computer. When the time base is too long for the image to be shown, it produces an image, which is not a solid block of colour on the screen. The image you should see on an ordinary 'scope will differ in this respect. The signal amplitude profile is however faithfully reproduced. This is a case of what you see is not necessarily what you've got.

The green trace shows the output of IC1 and the red trace shows the output of IC2. These traces are showing the output when there is movement of an object

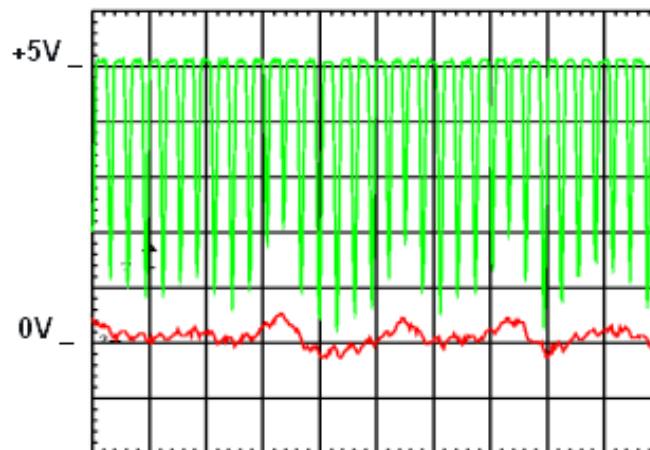
in front of the sensor. Without any movement, the traces would not have any ripple (the amplitude would be constant).



Note that the amplitude profiles correspond.

The amplitude of the waves will depend on how far the reflected object is from the sensor. In the example above, they were very close.

If you now add R11 and C6 to the circuit, you should see the following traces. The green trace is the output of IC2 and the red trace is at the junction of C6 and R11. You will note that the red trace follows the amplitude profile of the green trace.



Circuit description

C4 couples the output of IC1 to the input circuit of IC2. The signal is biased at 0 Volts by R7. The result of this is that only the positive half of the input is amplified. R8 connects the signal to the non-inverting input of the operational amplifier IC2. R9 and R10 define the amplifier's gain and C5 reduces the gain of the 40KHz signal to unity leaving the low frequency amplitude variation (modulation) at a high gain. The low pass filter comprising R11 and C6 then reduces the 40KHz signal.

Fault finding

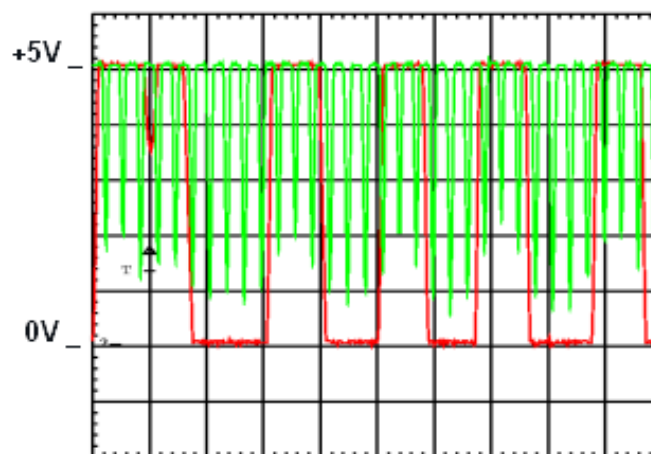
Check that the unused pins of IC2 are not connected anywhere, that pin 4 is connected to 0 Volts and that pin 7 is connected to +5 Volts. Check for short circuits, open circuits and bad solder joints. Check that the component values are correct.

Next

Build the next stage of the circuit.

Testing

The oscilloscope trace below shows the output of IC2 in green and the output of IC3 in red. The traces show the outputs when there is movement towards or away from the sensor. Without movement, the red trace would be continuously at 0 Volts and the green trace would not have any ripple.



You will note that the red trace follows the amplitude variation of the green trace.

Circuit description

The ripple signal across C6 is biased to 0 Volts by R12 and coupled to the non-inverting input (pin 3) of the operational amplifier IC3 by R13. The amplifier's gain is defined by R14 and R16 and to a lesser extent by R15. R15 puts a small bias on the inverting input (pin 2) of IC3. This is to remove unwanted signals from being amplified. There is always a small amount of residual noise and this needs to be prevented from interfering with the proper functioning of the circuit. If you find that you are getting too many false signals, you can reduce the value of R15 to 100K but this will reduce the sensitivity of the circuit, that is the distance from the sensors that a speed measurement can be made will be reduced. C8 acts as a low pass filter.

Fault finding

Check that the unused pins of IC3 are not connected anywhere, that pin 4 is connected to 0 Volts and that pin 7 is connected to +5 Volts. Check for short

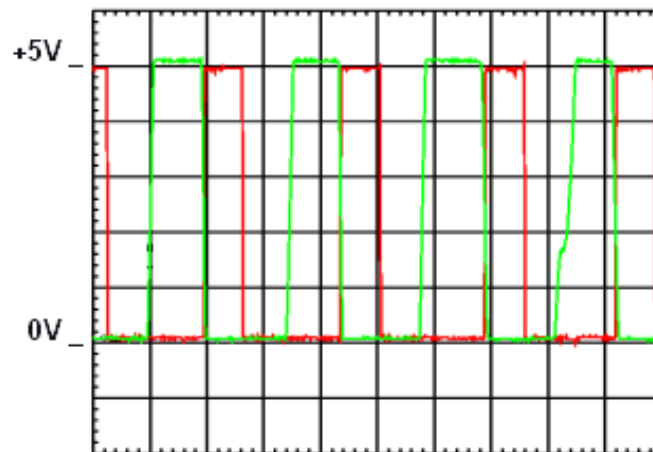
circuits, open circuits and bad solder joints. Check that the component values are correct.

Next

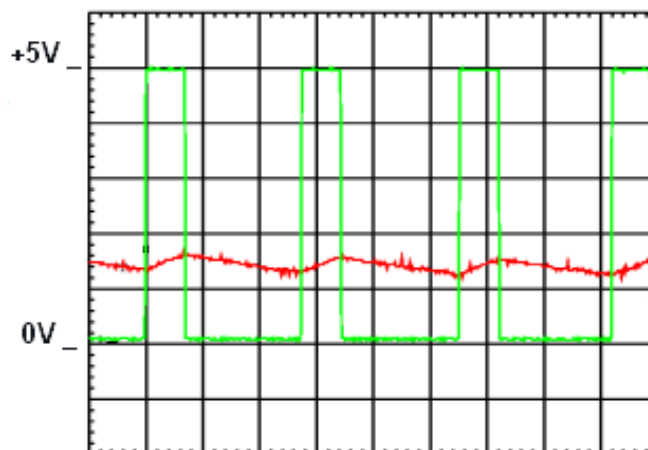
Build the next stage of the circuit

Testing

The green trace shows the output of IC3 and the red trace shows the output of IC4. If there is no movement, both traces should show 0 Volts continuously. The frequency of the pulses will be determined by the speed of movement. At high speeds, the frequency of the pulses will increase and the width of the green ones will decrease but the red ones will remain constant. The effect of increased speed of movement will be that the average Voltage of the output of IC4 will increase. You will note that the red trace goes positive when the green trace goes from +5 Volts to 0 Volts.



Now add R18 and C10 to the circuit making sure that C10 is connected the right way round. You should now see the following traces where the green trace is the output of IC4 and the red trace is the junction of R18 and C10.



Circuit description

IC4 is a dual edge triggered monostable multivibrator. This means that the IC has two circuits, which in this case are identical. The term edge triggered means that circuit only responds to inputs that change their state from '1' to '0' or from '0' to '1' but are not affected by the continuous state of the inputs. In this circuit, the IC has been connected so that it only responds to inputs that go from '1' to '0'. 'Monostable' means that the output only has one stable state. In this circuit we are using the output, which has a '0' as its stable state. After triggering it goes from its stable state '0' to its unstable stable state '1' and then returns to its stable state '0'. 'Multivibrator' is a type of oscillator. The time for the IC to be in its unstable state is defined by the values of R17 and C9. The time being approximately R17 times C9 Seconds.

Every time the output of IC3 goes from +5 Volts to 0 Volts, the output of IC4 goes from 0 Volts to +5 Volts for a few mSecs and then returns to 0 Volts.

The combination of R18 and C10 averages the output of IC4 to provide an analogue output Voltage proportional to the speed of movement towards or away from the sensors.

Fault finding

Check that the unused pins of IC4 are not connected anywhere, that pin 8 is connected to 0 Volts and that pin 16 is connected to +5 Volts. Check for short circuits, open circuits and bad solder joints. Check that the component values are correct.

Next

Build the rest of the circuit making sure that C11 is connected the right way round.

Testing

Check that the output is 0 Volts when there is no movement and that the output increases the faster you move towards or away from the sensors.

Circuit description

R19 and C11 provide a further stage of smoothing to reduce the amplitude of the triangular waveform across C10. This is connected to the non-inverting input (pin 3) of the operational amplifier IC5. R21 is the feedback resistor. Since there are no other resistors connected to the inverting input (pin 2) of IC5, the gain of the amplifier is unity. You may wonder why anyone would want to have an amplifier with a unity gain. The reason is that the output can now be loaded as small currents can be taken from the output without affecting the value of the output.

Fault finding

Check that the unused pins of IC5 are not connected anywhere, that pin 4 is connected to 0 Volts and that pin 7 is connected to +5 Volts. Check for short circuits, open circuits and bad solder joints. Check that the component values are correct.

Direction of movement sensors

You can use the ultrasonic distance measuring circuit in conjunction with a differentiator to provide a direction of movement signal. You should be aware, however, that the distance measuring circuit can produce occasional errors due to the problems associated with nodes. If the signal is reduced too much by the sensed object being at a node, there will not be a large enough reflected signal and the output will be large and your circuit will respond by giving a signal indicating that the sensed object has moved away rapidly. When the signal returns, the differentiator will give a signal indicating that the sensed object has moved rapidly nearer. This should not be too much of a problem if you only consider movements within 2 meters of the sensor. You can do this by using a signal level switch to provide a valid distance signal, pulse stretch that signal a bit and use it as one input of a NAND or AND gate and connect the other gate input to the direction of movement signal. You will need two gates, as there are two separate conditions. They are moving towards and moving away from the sensor.

If you are only concerned with a small area, (that is you want to know whether someone has moved into or out of a particular space) you can use two sensors, one inside and one outside the area, and see which signal came first. You can use a D type flip-flop for this. They are dealt with in the chapter on logic.

Link to flip-flops

[LINK](#)

Suitable sensors for this are PIR detectors and infrared beams. It should be noted that **there must be a time when both signals are on simultaneously**.

Limit and position switches/sensors

Position sensors, which sense the **position of the work rather than the position of the viewer**, will be dealt with here.

If you have a moving object, you may need to know when it has arrived at various positions, particularly the ends of movement. You will need some kind of switch to stop the movement, usually to prevent damage. In the case of the extents of movement, these are known as limit switches as they limit the movement.

The three most common types of position detecting switches are the micro switch, the optical switch and the magnetic switch.

The reed and micro switches will have a small amount of bounce so that during the switching process, the switch will close and open a few times for a couple of mSeconds or so. If this could cause problems, you can put a $0\mu\text{F}$ capacitor across the switch contacts. This is only likely to be a problem if you use them in a counting application.

The micro switch is the easiest to use as it is a mechanical switch and has both normally open and normally closed contacts.

Micro switches have a variety of different levers and rollers to activate them. The type shown here is a roller switch. There is a small wheel on the end of the metal lever. You should note that there is a diagram of the switch shown on one side of the switch, which tells you which contact is which.



Pressing down on the small wheel/roller operates the switch.

Optical switches either work using reflected light or transmitted light. The reflected light types are very distance sensitive and therefore require a high degree of precision in the making of the work. The transmitted light types have an infrared transmitter and an infrared receiver mounted in plastic. There is a gap between the transmitter and receiver. If anything is in the gap, the beam is broken. These devices will not function correctly if they are in a strongly lit environment, particularly if the ambient light source is incandescent rather than fluorescent.



Magnetic switches use a magnet and either a Hall effect device or a reed switch. When a magnet is placed near to a reed switch, the switch closes. The Hall effect devices usually have some built-in electronics to provide a digital output which changes state according to the presence or otherwise of a strong magnetic field as would be produced by the close proximity of a magnet.

The main problem with using reed switches for position sensing is that they are not very precise.

The following video clip shows a subminiature roller micro-switch used to prevent a shaft from moving too far. When the shaft passes the switch, the switch releases and switches off the drive motor. A diode across the switch allows the motor to move in the opposite direction.

CLICK ON
IMAGE

Micro switches are sprung so that the switches are released when they are not activated. This can be a disadvantage if the switch's internal spring is strong enough to move the object operating it away from the switch causing the motor to switch on again. This causes the motor to turn on and off repeatedly. This may well be an advantage from an artistic point of view but you should consider the fact that switches have a finite life span and will eventually fail. This is unlikely to happen during a temporary exhibition but will happen if the work is for permanent display. There are two ways to prevent this from happening. One is to make the mechanics in such a way that the switch cannot cause the part of the work that operates the switch to move. The other way is to use the switch to operate on logic devices that control the motor rather than the

motor directly. The logic devices should include latches, which are set by the limit switches and reset by reverse motor signals.

The following video shows a micro switch, which pushes the work away thus causing it to vibrate. The work in the video has been exhibited continuously for more than a month without failure.

CLICK ON
IMAGE

Signal conditioning

This section deals with analogue signals. Some of the sensors described in this chapter have analogue outputs. That is, they produce variable voltages or resistances rather than switch outputs (which include signals, which are either 0 Volts or +5 Volts but do not have intermediate values of Voltage).

Digital outputs (the outputs which only have the two states of either on or off) will not be dealt with here, but are dealt with in the chapter on logic.

It should be noted that some circuits will not require a digital output. In particular motor speed control, motor position control (servo's) or light level control circuits will require an analogue input.

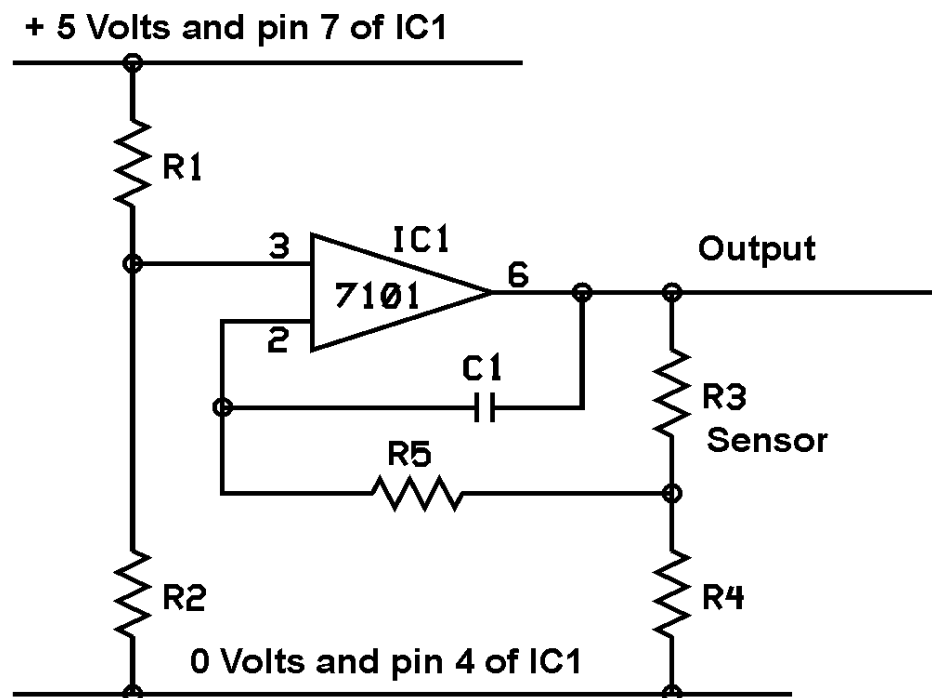
We will consider two basic types of circuit here. The one type alters the analogue signals and the other type converts them to digital signals.

Variable resistance sensors

The circuits described here convert variable resistance to variable Voltage or digital outputs.

The optical computer interface circuit described earlier in this chapter will provide a digital output with a resistive input. You may need to change R1 in the circuit depending on the resistance of your sensor. If you need to adjust the value of R1 you can use a potentiometer in series with R1.

Click on link to view the optical interface circuit [LINK](#)



Variable resistance sensor

R1 47K
R2 1K
R3 Sensor
R4 dependent on sensor
R5 10K
C1 0 μ 1F
IC1 7101 any prefix of suffix. Do not connect to any unused pins.

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R4 should be the nearest value above 1/50 th of the highest resistance that you wish to sense. For example if the highest sensor resistance is 47K then R4 should be 1K.

Testing

Before applying power to the circuit, inspect the circuit thoroughly using a spy glass ensuring that there are no unwanted short circuits or open circuits and that the circuit follows the diagram exactly. Ensure that the power supply is connected the right way round. Then set your meter to continuity or low Ohms range. Connect the meter across the 0V and 5V supply and make sure that the reading is not zero or near to zero. You may get a bleep or a low Ohmic value for a short time because of the capacitor in the power supply, but this should not last more than a few seconds. If it is continuous, you have a short circuit somewhere and you should follow the instructions in the fault finding section. If you do not get the expected results, you should switch the circuit off immediately.

Set your meter to the 20 Volt DC range. Connect your meter across the 5 Volt supply and switch on the supply. If the reading is much below 5 Volts, switch off immediately and go to the fault finding section.

Short circuit R3. Set your meter to the 2 Volt DC range. Connect your meter between 0 Volts and the output. The meter should read approximately 0.1 Volts. Now set your meter to the 20 Volt DC range and change R3 from a short circuit to about half its maximum value. The meter should read about 2.6 Volts. Now change the value of R3 to its maximum value and the meter should read about 5 Volts. If you do not get these results, switch off the power supply and go to the fault finding section.

Circuit description

This circuit is a constant current generator, which produces a current through the sensor resistor, which is independent of the value of the resistance, provided that the output Voltage is not limited by the supply Voltage. The output Voltage is therefore directly proportional to the value of that resistance plus the value of R4.

R1 and R2 provide a bias of about 100mVots. This bias is connected to the non-inverting input (pin 3) of the operational amplifier IC1. The output (pin 6) is connected to R4 via the sensor R3. R5 connects the junction of R3 and R4 to the inverting input (pin 2) of IC1. C1 reduces the output noise.

Any small difference in Voltage between pins 2 and 3 of IC1 is greatly amplified by IC1 and appears at the output (pin 6). If The Voltage on pin 3 were slightly higher than on pin 2, the output Voltage would increase. This would increase the current flowing through R4 and hence the Voltage across R4 would increase. This in turn increases the Voltage on pin 2 until it is equal to the Voltage on pin 3. If the resistance of the sensor (R3) increases, the current through R4 will decrease and so will the Voltage across it. This causes the Voltage on pin 2 to be greater than that on pin 3 and so the output Voltage increases to keep the Voltages on pins 2 and 3 equal.

Fault finding

The first thing to do is give the circuit a thorough visual inspection with a spy glass looking for bad solder joints and short circuits. Check that the circuit you have built exactly matches the circuit diagram and that the components are the correct values and connected the right way round.

Assuming that there are now no short circuits directly across the power supply, set your meter to the 20 Volt DC range. Connect the meter across the power supply and switch on. You should have 5 Volts. If the circuit takes too much current, the voltage will be much less. The 5 Volt power supply has a current limiting resistor in the circuit so it should not come to any harm by being short circuited. The current limiting resistor will just get hot. Do not let it get so hot that you cannot touch it. If the Voltage is low, switch off and remove IC1. Switch on the power supply and see if the voltage rises to 5 Volts. If it does, then check the connections to the IC and look for short circuits with a spy glass. Also check to make sure that the IC was connected the right way round and there are no unwanted connections. There should only be two connections to the 5 Volt rail and they are pin 7 of IC1 and R1. If everything was correct then replace the IC with a new one. If that solves the problem, the IC was faulty and should be thrown away. Replace the IC and check the power supply Voltage again. If all is now OK then see if the circuit now functions correctly.

Assuming that the power supply is OK, set your meter to the 2 Volt DC range and measure the Voltage across R2. It should be about 0.1 Volts. If it is not, check the values of R1 and R2. Check that the junction of R1 and R2 is connected to pin 3 of IC1 and not anywhere else. Check for bad solder joints and short circuits. If this does not solve the problem, remove IC1 and if that solves the problem, replace IC1.

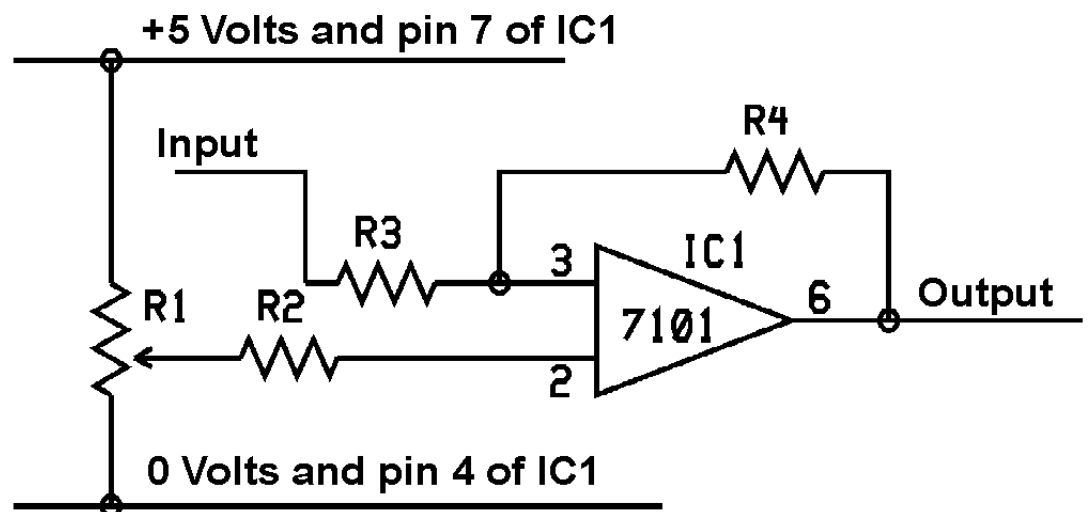
Assuming that the Voltage across R2 is OK, short circuit the sensor R3 and see if the output Voltage is about 0.1 Volts. If it is not, check R5 for bad solder

joints and short circuits. Also check for short circuits and bad solder joints on all the components connected to the output (pin 6) of IC1. If this does not solve the problem, see if replacing IC1 solves the problem.

Assuming that that is OK, set your meter to the 20 Volt DC range, open circuit the sensor R3 and see if you now get about 5 Volts at the output. If you still get about 0.1 Volts, check C1 for short circuits. Also look for short circuits across R3.

Signal level switches

These convert variable Voltage signals to digital outputs. There are two basic types. One tells you whether a signal has a higher or lower Voltage than a pre-determined level and the other has hysteresis (dead band) so that there are two outputs, one for less than and one for greater than a predetermined Voltage. In the latter case there is a signal Voltage range (the hysteresis) over which there is no output as it is neither higher than nor lower than the required Voltage but is approximately equal to it.



Signal level switch

- R1 10K potentiometer
- R2 10K
- R3 10K
- R4 1M
- IC1 7101 any prefix or suffix. Do not connect unused pins.

OPERATIONAL AMPLIFIER



Testing

Before applying power to the circuit, inspect the circuit thoroughly using a spy glass ensuring that there are no unwanted short circuits or open circuits and that the circuit follows the diagram exactly. Ensure that the power supply is connected the right way round. Then set your meter to continuity or low Ohms range. Connect the meter across the 0V and 5V supply and make sure that the reading is not zero or near to zero. You may get a bleep or a low Ohmic value for a short time because of the capacitor in the power supply, but this should not last more than a few seconds. If it is continuous, you have a short circuit somewhere and you should follow the instructions in the fault finding section. If you do not get the expected results, you should switch the circuit off immediately.

Set your meter to the 20 Volt DC range. Connect your meter across the 5 Volt supply and switch on the supply. If the reading is much below 5 Volts, switch off immediately and go to the fault finding section.

Either connect the input to the output of another circuit, which has a Voltage output between 0 and +5 Volts or connect to the wiper of a 5K or 10K potentiometer, which has one end, connected to 0 Volts and the other end to +5 Volts. This potentiometer acts as an input for test purposes. Set your meter to the 20 Volt DC range and connect between 0 Volts and the output. Set the input to have a Voltage between 1 Volt and 4 Volts. Adjust R1 and observe the output Voltage is either 0 Volts or +5 Volts and changes from one to the other according to the adjustment of R1.

If you do not get these results, switch off the power supply and go to the fault finding section.

Circuit description

R1 provides a bias/reference/comparison Voltage. R2 connects that Voltage to the inverting input (pin 2) of the operational amplifier IC1. R3 connects the input Voltage to the non-inverting input (pin 3) of IC1. R4 provides a small amount of dead-band/hysteresis to the circuit to reduce the effect of noise on the input signal.

If the Voltage on pin 3 of IC1 is slightly higher than that on pin 2, the output (pin 6) of IC1 will be + 5 Volts and if it is slightly lower, the output will be 0 Volts.

When the output of IC1 is at 5 Volts, the Voltage at pin 3 is slightly increased by R4 so the input needs to be slightly less than the bias Voltage provided by R1 to switch the output to 0 V. Conversely when the output of IC1 is at 0 Volts, the Voltage at pin 3 is slightly reduced by R4 so the input needs to be slightly higher than the bias Voltage provided by R1 to switch the output to +5 Volts. This produces a small amount of dead-band on the input.

Fault finding

The first thing to do is give the circuit a thorough visual inspection with a spy glass looking for bad solder joints and short circuits. Check that the circuit you have built exactly matches the circuit diagram and that the components are the correct values and connected the right way round.

The only connections to the 5 Volt rail should be R1 and pin 7 of IC1. If you still have a fault, try replacing IC1. If that helps, throw the old IC away.

Assuming that there are now no short circuits directly across the power supply, set your meter to the 20 Volt DC range. Connect the meter across the power supply and switch on. You should have 5 Volts. If the circuit takes too much current, the voltage will be much less. The 5 Volt power supply has a current limiting resistor in the circuit so it should not come to any harm by being short circuited. The current limiting resistor will just get hot. Do not let it get so hot that you cannot touch it. If the Voltage is low, switch off and remove IC1. Switch on the power supply and see if the voltage rises to 5 Volts. If it does, then check the connections to the IC and look for short circuits with a spy glass. Also check to make sure that the IC was connected the right way round and there are no unwanted connections. The only connections to the 5 Volt rail should be to pin 7 of IC1 and R1. If everything was correct then replace the IC with a new one. If that solves the problem, the IC was faulty and should be thrown away. Replace the IC and check the power supply Voltage again. If all is now OK then see if the circuit now functions correctly.

Assuming that the power supply is OK, set your meter to the 20 Volt DC range and connect between 0 Volts and the wiper of R1. Check that the Voltage reading varies between 0 Volts and +5 Volts as you adjust the potentiometer R1 between one end and the other and that the power supply is not affected by the adjustment either. If it does not function correctly, you either have an open circuit, a short circuit or you have not connected R1 correctly.

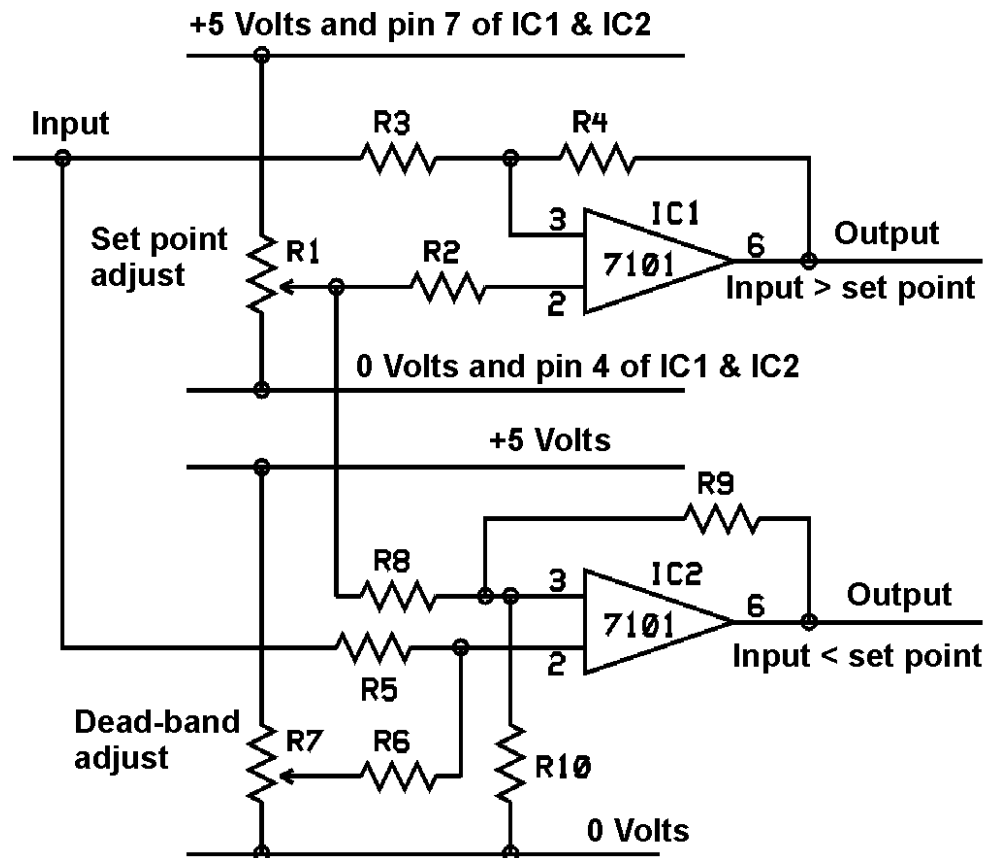
Assuming that R1 is OK, check that your input Voltage is OK.

Assuming that your input Voltage is OK, check the values of R3 and R4. Check for short circuits and open circuits on the IC and ensure that the unused pins are not connected anywhere. If none of this helps, try replacing the IC. If this helps, throw the old one away.

Signal level switch with dead-band.

This circuit has two outputs; one for signals greater than the set point and one for signals less than the set point. When the signal is nearly equal to the set point, there are no outputs.

The following circuit has two operational amplifiers. One of which has a circuit identical to the previous circuit and the other provides for an adjustable dead-band and a signal if the input is less than the set point and dead-band.



Signal level switch with dead-band

R1	10K potentiometer
R2	10K
R3	10K
R4	1M
R5	10K
R6	100K
R7	10K potentiometer
R8	10K
R9	1M
R10	100K
IC1	7101 any prefix or suffix. Do not connect unused pins.
IC2	7101 any prefix or suffix. Do not connect unused pins.

OPERATIONAL AMPLIFIER



Testing

Before applying power to the circuit, inspect the circuit thoroughly using a spy glass ensuring that there are no unwanted short circuits or open circuits and that the circuit follows the diagram exactly. Ensure that the power supply is

connected the right way round. Then set your meter to continuity or low Ohms range. Connect the meter across the 0V and 5V supply and make sure that the reading is not zero or near to zero. You may get a bleep or a low Ohmic value for a short time because of the capacitor in the power supply, but this should not last more than a few seconds. If it is continuous, you have a short circuit somewhere and you should follow the instructions in the fault finding section. If you do not get the expected results, you should switch the circuit off immediately.

Set your meter to the 20 Volt DC range. Connect your meter across the 5 Volt supply and switch on the supply. If the reading is much below 5 Volts, switch off immediately and go to the fault finding section.

Connect the input to a Voltage source of about 2.5 Volts, which could be the output of another circuit or the wiper of a 5K or 10K potentiometer, which has its ends connected across the 5 Volt supply. Set the dead-band potentiometer R7 to about half way. Set your meter to the 20 Volt DC range. Connect the meter between 0 Volts and the output of IC1. Adjust the set-point potentiometer R1 and see that the output of IC1 is 0 Volts when the wiper of R1 is at the 5 Volt end and the output of IC1 is 5 Volts when the wiper of R1 is at the 0 Volt end.

Now connect the meter to the output of IC2. The output of IC2 should be 5 Volts when the wiper of R1 is at the 5 Volt end and 0 Volts when the wiper is at the 0 Volt end.

Now set R1 so that the output only just goes to 0 Volts. The output of IC1 should now also be 0 Volts as the signal Voltage is nearly equal to the set point Voltage. If it is not, try adjusting R1 a bit. There should be a setting of R1 which gives 0 Volts at both IC outputs.

You should note that if the dead-band is set to a high value and the set point is set to a low value, it will not be possible to have an input low enough to trigger the low output (input less than set point).

Circuit description

R1 provides a bias/reference/comparison Voltage. R2 connects that Voltage to the inverting input (pin 2) of the operational amplifier IC1. R3 connects the input Voltage to the non-inverting input (pin 3) of IC1. R4 provides a small amount of dead-band/hysteresis to the circuit to reduce the effect of noise on the input signal.

If the Voltage on pin 3 of IC1 is slightly higher than that on pin 2, the output (pin 6) of IC1 will be + 5 Volts and if it is slightly lower, the output will be 0 Volts.

When the output of IC1 is at 5 Volts, the Voltage at pin 3 is slightly increased by R4 so the input needs to be slightly less than the bias Voltage provided by R1 to switch the output to 0 V. Conversely when the output of IC1 is at 0 Volts, the Voltage at pin 3 is slightly reduced by R4 so the input needs to be slightly higher than the bias Voltage provided by R1 to switch the output to +5 Volts. This produces a small amount of dead-band on the input.

The input is connected to the inverting input (pin 2) of the operational amplifier IC2 via R5. The set point potentiometer is connected to the non-inverting input (pin 3) of IC2 via R8 and the positive feedback resistor R9 produces a small amount of dead-band. R10 slightly reduces the Voltage on pin 3 of IC2 to balance the effect of R6. A bias produced by the potentiometer R7 is added to pin 2 of IC2 by R6. R6 and R10 are equal in value so the bias on pins 2 and 3 of IC2 is equal when R7 is set to zero but when R7 is set to a higher value, the bias on pin 2 is higher than the bias on pin 3. This has the effect of reducing the input Voltage required to trigger IC2. This reduction in Voltage is the dead-band.

Fault finding

The first thing to do is give the circuit a thorough visual inspection with a spy glass looking for bad solder joints and short circuits. Check that the circuit you have built exactly matches the circuit diagram and that the components are the correct values and connected the right way round.

Make sure that the power supply is switched off. Set your meter to continuity and connect across the 5 Volt supply. There should be a short time when the meter indicates a short. This is because of the capacitor in the power supply. This should not last for long. If it is continuous, you have a short circuit somewhere. Check that the +5 Volts of the supply is only connected to R1, R7 and pin 7 of the two IC's. If this is not the problem, remove the two IC's one at a time checking the supply each time for short circuits. If this is not the cause of the problem then the +5 Volt end of the supply must be connected somewhere where it shouldn't. If it was the cause, it is possible that you have a faulty IC.

Assuming that there are now no short circuits directly across the power supply, set your meter to the 20 Volt DC range. Connect the meter across the power supply and switch on. You should have 5 Volts. If the circuit takes too much current, the voltage will be much less. The 5 Volt power supply has a current limiting resistor in the circuit so it should not come to any harm by being short circuited. The current limiting resistor will just get hot. Do not let it get so hot that you cannot touch it. If the Voltage is low, switch off and remove IC1. Switch on the power supply and see if the voltage rises to 5 Volts. If it does then check the connections to the IC's and look for short circuits with a spy glass. Also check to make sure that the IC's are connected the right way round and there are no unwanted connections. The only connections to the 5 Volt rail should be to pin 7 of IC1 and IC2, R1 and R7. If everything was correct then

replace the IC's one at a time with new ones. If that solves the problem, the IC was faulty and should be thrown away. Replace the IC and check the power supply Voltage again. If all is now OK then see if the circuit now functions correctly.

Assuming that the power supply is OK, set your meter to the 20 Volt DC range and connect between 0 Volts and the wiper of R1. Check that the Voltage reading varies between 0 Volts and +5 Volts as you adjust the potentiometer R1 between one end and the other and that the power supply is not affected by the adjustment either. If it does not function correctly, you either have an open circuit, a short circuit or you have not connected R1 correctly.

Assuming that R1 is OK, check that your input Voltage is OK.

Assuming that your input Voltage is OK, check the values of R3 and R4. Check for short circuits and open circuits on the IC and ensure that the unused pins are not connected anywhere. If none of this helps, try replacing the IC. If this helps, throw the old one away.

Assuming that the output of IC1 behaves correctly, set your meter to the 20 Volt DC range and connect between 0 Volts and the wiper of R7. Check that the Voltage reading varies between 0 Volts and +5 Volts as you adjust the potentiometer R7 between one end and the other and that the power supply is not affected by the adjustment either. If it does not function correctly, you either have an open circuit, a short circuit or you have not connected R7 correctly.

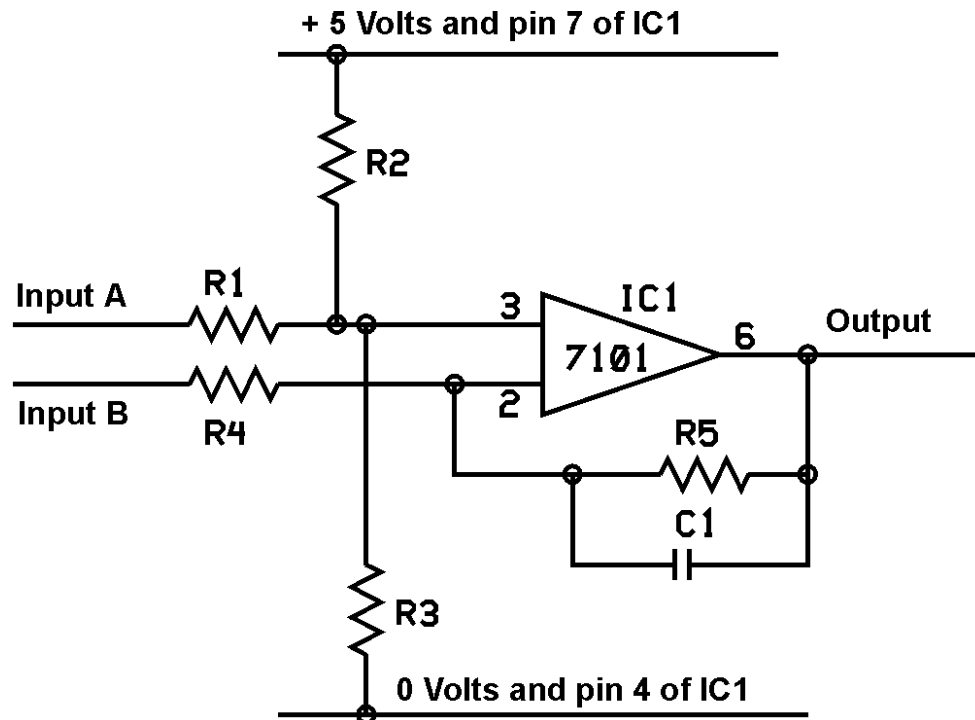
Assuming that R7 is OK, set R7 to have 0 Volts on the wiper. Check the Voltage on pin 2 of IC2. It should vary between 0 Volts and 4.5 Volts when the input varies between 0 Volts and 5 Volts. If it does not, check the values of R5 and R6, look for short circuits, open circuits and bad solder joints. See if removing IC2 solves the problem, if it does try replacing it. If that solves the problem, throw the old IC away.

Assuming that the Voltage on pin 2 of IC2 is OK, set R1 to give 5 Volts on its wiper. Measure the Voltage on pin 3 of IC2. It should be about 4.5 Volts. If it is not, check the values of R8, R9 and R10, look for short circuits, open circuits and bad solder joints. See if removing IC2 solves the problem, if it does try replacing it. If that solves the problem, throw the old IC away.

Assuming that that is OK, look for short circuits, open circuits and dry solder joint on the pins of IC2. Make sure that the unused pins are not connected anywhere. Try replacing the IC, if that helps, throw the old IC away.

Differential amplifiers

Differential amplifiers amplify the difference between two Voltages. Because the circuits shown in this cd are mainly using a single 5 Volt power supply, it is not possible to have a negative Voltage. The following circuit therefore has a bias of 2.5 Volts so that the output can respond to signals, which would otherwise try to produce negative outputs.



Differential amplifier

R1 22K
R2 22K
R3 22K
R4 22K
R5 11K
C1 0μ1F
IC1 7101 any prefix or suffix. Do not connect unused pins.

OPERATIONAL AMPLIFIER



The circuit with the component values shown performs the following mathematical formula.

$$\text{Output} = 2.5 + (A - B)/2$$

If you require more gain, you may change the values, but if you do, you will not be able to have a correct output value for the full range of input Voltages as the output is limited by the supply Voltage. The gain of the circuit as shown is $\frac{1}{2}$. The resistor values should be kept in the range of 1K to 100K. The circuit gain is $R5/R4$. R1 must equal R4. R2 and R3 must be twice the value of R5.

The following testing, circuit description and faultfinding sections assume that the component values are as shown.

Testing

Before applying power to the circuit, inspect the circuit thoroughly using a spy glass ensuring that there are no unwanted short circuits or open circuits and that the circuit follows the diagram exactly. Ensure that the power supply is connected the right way round. Then set your meter to continuity or low Ohms range. Connect the meter across the 0V and 5V supply and make sure that the reading is not zero or near to zero. You may get a bleep or a low Ohmic value for a short time because of the capacitor in the power supply, but this should not last more than a few seconds. If it is continuous, you have a short circuit somewhere and you should follow the instructions in the fault finding section. If you do not get the expected results, you should switch the circuit off immediately.

Set your meter to the 20 Volt DC range. Connect your meter across the 5 Volt supply and switch on the supply. If the reading is much below 5 Volts, switch off immediately and go to the fault finding section.

Connect both inputs to the 0 Volt rail. The output should be 2.5 Volts. Connect both inputs to the 5 Volt rail. The output should be 2.5 Volts. Connect input A to the 5 Volt rail and input B to the 0 Volt rail. The output should be 5 Volts. Connect input A to 0 Volts and input B to the 5 Volt rail. The output should be 0 Volts.

Circuit description

Since R1, R2 and R3 are of equal Value, the Voltage at the non-inverting input of the operational amplifier IC1 is the average of the Voltage at input A, 5 Volts and 0 Volts, which is $(5 + A)/3$.

Since R4 has twice the value of R11, the Voltage at the inverting input of IC1 is $(2*Output + B)/3$.

Any small difference in the Voltages between pin2 and 3 is greatly amplified, so if the non-inverting input has a slightly higher Voltage than the inverting input, the output will become more positive. This keeps the voltages on pins 2 and three equal provided that the output is within the range of the power supply. If the Voltage on pin 2 was not dependent on the value of the output Voltage, this would not be the case.

We now have the situation that the Voltage on pin 3 is equal to the Voltage on pin 2 so $(5 + A)/3 = (2*Output + B)/3$

With a little bit of algebra we can see that

$$5 + A = 2 * Output + B \text{ and}$$

therefore

$$2 * Output = 5 + A - B$$

therefore

$$Output = 2.5 + (A - B)/2$$

The capacitor C1 reduces the noise in the circuit.

Fault finding

The first thing to do is give the circuit a thorough visual inspection with a spy glass looking for bad solder joints and short circuits. Check that the circuit you have built exactly matches the circuit diagram and that the components are the correct values and connected the right way round.

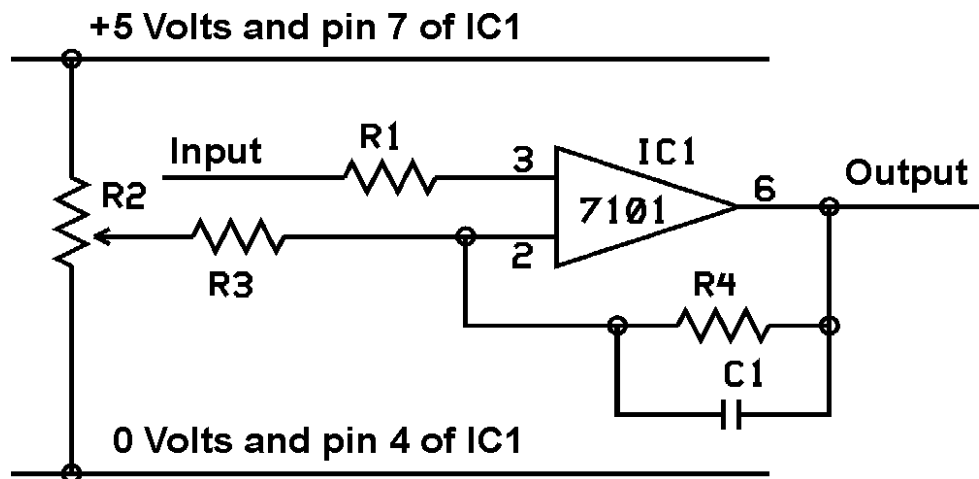
Assuming that there are now no short circuits directly across the power supply, set your meter to the 20 Volt DC range. Connect the meter across the power supply and switch on. You should have 5 Volts. If the circuit takes too much current, the voltage will be much less. The 5 Volt power supply has a current limiting resistor in the circuit so it should not come to any harm by being short circuited. The current limiting resistor will just get hot. Do not let it get so hot that you cannot touch it. If the Voltage is low, switch off and remove IC1. Switch on the power supply and see if the voltage rises to 5 Volts. If it does, then check the connections to the IC and look for short circuits with a spy glass. Also check to make sure that the IC was connected the right way round and there are no unwanted connections. The only connections to the 5 Volt rail should be R2 and pin 7 of IC1. If everything was correct then replace the IC with a new one. If that solves the problem, the IC was faulty and should be thrown away. Replace the IC and check the power supply Voltage again. If all is now OK then see if the circuit now functions correctly.

Assuming that the power supply is OK, set your meter to the 20 Volt DC range, connect input A to the 5 Volt rail, and measure the Voltage on pin 3 of IC1. The meter should read approximately 3.3 Volts. If it does not, check the values of R1, R2 and R3. Look for short circuits, open circuits and bad solder joints. If that does not help, remove IC1. If that helps, replace IC1 and if that helps, throw the old IC away.

Assuming that the Voltage on pin 3 of IC1 is OK, check the values of R4 and R5. Look for short circuits, open circuits and bad solder joints. Check that pin 4 of IC1 is connected to the 0 Volt rail and that none of the unused pins are connected anywhere. Also check C1 for short circuits. If this does not help, try replacing the IC and run through the test procedure again. If the circuit now works correctly, throw the old IC away.

Differential amplifier used to provide an offset

If for example your signal range is from 2 Volts to 3 Volts and you want to change it to 0 Volts to 5 Volts, you will need to subtract 1 Volt from the signal and then amplify it by a factor of 5. You will note that it only needs a small change to the previous circuit. The following circuit is a simple way of solving the problem.



Differential amplifier used to provide an offset

R1	10K
R2	10K potentiometer
R3	22K
R4	100K
C1	0 μ F
IC1	7101 any prefix or suffix. Do not connect unused pins.

OPERATIONAL AMPLIFIER



In operation, R2 adjusts the offset but also has a small effect on the gain of the amplifier, which is approximately 5 with the specified component values.

Testing

Before applying power to the circuit, inspect the circuit thoroughly using a spy glass ensuring that there are no unwanted short circuits or open circuits and that the circuit follows the diagram exactly. Ensure that the power supply is connected the right way round. Then set your meter to continuity or low Ohms range. Connect the meter across the 0V and 5V supply and make sure that the reading is not zero or near to zero. You may get a bleep or a low Ohmic value for a short time because of the capacitor in the power supply, but this should not last more than a few seconds. If it is continuous, you have a short circuit somewhere and you should follow the instructions in the fault finding section. If you do not get the expected results, you should switch the circuit off immediately.

Set your meter to the 20 Volt DC range. Connect your meter across the 5 Volt supply and switch on the supply. If the reading is much below 5 Volts, switch off immediately and go to the fault finding section.

Set the input Voltage to about 2.5 Volts. If you do not have a suitable input source, connect a 10K potentiometer across the 5 Volt supply and connect the wiper to the input; then adjust the potentiometer to give about 2.5 Volts on the wiper.

Connect your meter between 0 Volts and output. Adjust R2. You should note that for most of the adjustment the output is either + 5 Volts or 0 Volts but that near the middle region of adjustment, the output lies between these Voltages.

Circuit description

The input is connected to the non-inverting input (pin 3) of the operational amplifier IC1. R2 provides a bias Voltage, which is connected to the inverting input (pin 2) of IC1. R4 is a feedback resistor, which connects the output to the inverting input of IC1. C1 reduces the gain of IC1 for high frequencies and therefore reduces the noise in the circuit.

When the Voltage on pin 3 is slightly higher than that on pin2, IC1 greatly amplifies the difference so the output Voltage increases. This causes the Voltage on pin 2 to increase until it is equal to the Voltage on pin 3. The output Voltage needs to increase much more than the input Voltage to maintain equilibrium because not all of the Voltage change appears at pin 2 as it is reduced by R3 and a proportion of R2 depending on the setting of R2. The amplifier therefore has a gain of greater than one. The gain of the circuit is approximately 5 because about one fifth of the output variation appears at pin 2 as it is potentially divided by R4, R3 and to a lesser extent by R2. The Voltage on pin 2 is altered by the setting of R2. The amplifier amplifies the difference in Voltage between the input and the wiper voltage of R2. The output however is not quite mathematically correct as it can be seen that if the input Voltage becomes equal to the Voltage, the output Voltage would also equal the input Voltage. Since we are not concerned with the mathematics and this can be adjusted for using R2, this simplification of the circuit does not cause any problems.

Fault finding

The first thing to do is give the circuit a thorough visual inspection with a spy glass looking for bad solder joints and short circuits. Check that the circuit you have built exactly matches the circuit diagram and that the components are the correct values and connected the right way round.

Assuming that there are now no short circuits directly across the power supply, set your meter to the 20 Volt DC range. Connect the meter across the power supply and switch on. You should have 5 Volts. If the circuit takes too much current, the voltage will be much less. The 5 Volt power supply has a current limiting resistor in the circuit so it should not come to any harm by being short circuited. The current limiting resistor will just get hot. Do not let it get so hot that you cannot touch it. If the Voltage is low, switch off and remove IC1. Switch on the power supply and see if the voltage rises to 5 Volts. If it does, then check the connections to the IC and look for short circuits with a spy glass. The only connections to the 5 Volt rail should be R2 and pin 7 of IC1. Also check to make sure that the IC was connected the right way round and there are no unwanted connections. If everything was correct then replace the

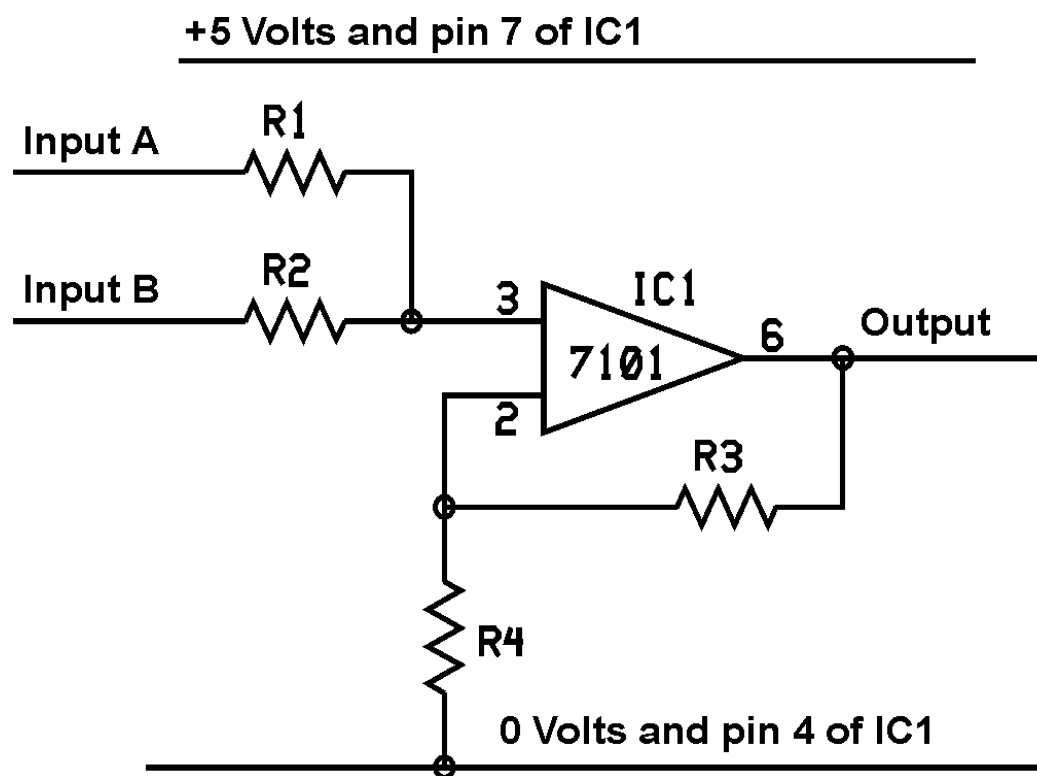
IC with a new one. If that solves the problem, the IC was faulty and should be thrown away. Replace the IC and check the power supply Voltage again. If all is now OK then see if the circuit now functions correctly.

Set your meter to the 20 Volt Dc range and connect between 0 Volts and the wiper of R2. Adjust the potentiometer from one end to the other and observe the meter reading. It should follow the adjustment between 0 Volts and 5 Volts so that at mid adjustment the meter should give a reading of about 2.5 Volts. If you do not get these results, examine the connections to R2. There is either a short circuit, an open circuit, a bad solder joint or you have not connected the potentiometer with the correct terminals going to the correct places.

Assuming that R2 is OK, check the circuit for short circuits, open circuits and bad solder joints. Check that the component values are correct and that they are connected according to the circuit diagram. Ensure that none of the unused pins of the IC are connected anywhere. If this does not help, try replacing the IC. If that helps, throw the old IC away.

Summing amplifiers

The output of the following circuit is equal to the sum of the two input Voltages A and B. You will note that if A and B are both 5 Volts, the output should be 10 Volts. The supply is only 5 Volts so the output can't be 10 Volts. If this is a problem, remove R4 so that the output is halved.



Summing amplifier

R1 10K
 R2 10K
 R3 10K
 R4 10K or leave out
 IC1 7101 any prefix or suffix. Do not connect unused pins.

OPERATIONAL AMPLIFIER



It will be assumed that R4 has not been connected as this is probably more useful. Now $\text{output} = (A + B)/2$

Testing

Before applying power to the circuit, inspect the circuit thoroughly using a spy glass ensuring that there are no unwanted short circuits or open circuits and that the circuit follows the diagram exactly. Ensure that the power supply is connected the right way round. Then set your meter to continuity or low Ohms range. Connect the meter across the 0V and 5V supply and make sure that the reading is not zero or near to zero. You may get a bleep or a low Ohmic value for a short time because of the capacitor in the power supply, but this should not last more than a few seconds. If it is continuous, you have a short circuit somewhere and you should follow the instructions in the fault finding section. If you do not get the expected results, you should switch the circuit off immediately.

Set your meter to the 20 Volt DC range. Connect your meter across the 5 Volt supply and switch on the supply. If the reading is much below 5 Volts, switch off immediately and go to the fault finding section.

Connect your meter between 0 Volts and the output. Connect inputs A and B to 5 Volts, the output should be 5 Volts. Now disconnect input B from the 5 Volt rail and connect it to 0 Volts. The output should now be 2.5 Volts. Now disconnect input A from the 5 Volt rail and connect it to the 0 Volt rail. The output should now be 0 Volts.

Circuit description

R1 and R2 connect the two inputs to be summed to the non-inverting input (pin 3) of the operational amplifier IC1. The Voltage at pin 3 of IC1 is therefore the average of the two input Voltages i.e. $(A + B)/2$.

R3 connects the output (pin 6) of IC1 to the inverting input (pin 2) of IC1. If R4 is not present, The Voltage on pin2 equals the output Voltage. If the Voltage on pin 3 is slightly greater than the Voltage on pin 2, the difference is greatly amplified by the IC and the output Voltage increases until it is equal to the Voltage on pin3. If R4 is present, the Voltage on pin 2 is half the output Voltage so the output Voltage will be twice the Voltage on pin 3.

Fault finding

The first thing to do is give the circuit a thorough visual inspection with a spy glass looking for bad solder joints and short circuits. Check that the circuit you have built exactly matches the circuit diagram and that the components are the correct values and connected the right way round.

Assuming that there are now no short circuits directly across the power supply, set your meter to the 20 Volt DC range. Connect the meter across the power supply and switch on. You should have 5 Volts. If the circuit takes too much current, the voltage will be much less. The 5 Volt power supply has a current limiting resistor in the circuit so it should not come to any harm by being short circuited. The current limiting resistor will just get hot. Do not let it get so hot that you cannot touch it. If the Voltage is low, switch off and remove IC1. Switch on the power supply and see if the voltage rises to 5 Volts. If it does, then check the connections to the IC and look for short circuits with a spy glass. Pin 7 of IC1 should be the only connection to the 5 Volt rail. Also check to make sure that the IC was connected the right way round and there are no unwanted connections. If everything was correct then replace the IC with a new one. If that solves the problem, the IC was faulty and should be thrown away. Replace the IC and check the power supply Voltage again. If all is now OK then see if the circuit now functions correctly.

Assuming that the power supply is OK, Connect your meter between 0 Volts and pin 3 of IC1. Connect input A to the 5 Volt rail and input B to the 0 Volt rail. The meter should read 2.5 Volts. If it does not, check the Values of R1 and R2. If they are OK, check R1, R2 and pin 3 of IC1 for short circuits, open circuits and bad solder joints. If this does not help, remove IC1 and see if that helps. If it does replace IC1 and if that helps, throw the old IC away. If it does not help, make sure that you have assembled the circuit correctly and that none of the unused pins of IC1 are connected anywhere and that there is not a short circuit on pin 3.

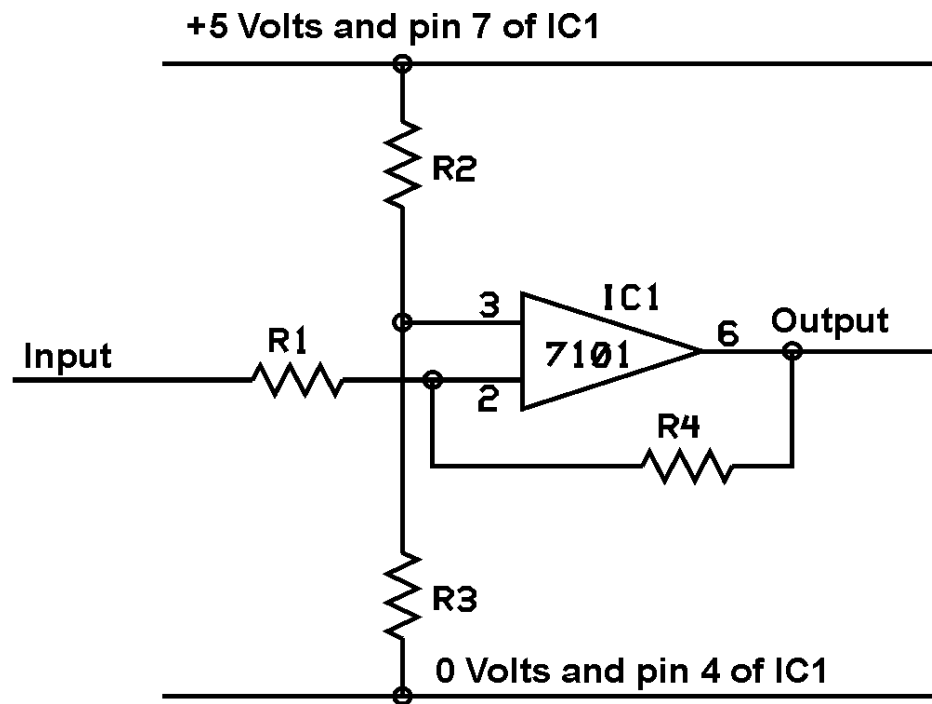
Assuming that that is OK, check R3 for open circuits and bad solder joints. If this does not help, try replacing IC1. If that helps, throw the old IC away.

Inverting amplifiers

The following circuit inverts the input signal and has an offset because there is no negative power supply. A bias is used to ensure that the required output Voltage will always remain within the power supply Voltage limits. As the input Voltage increases, the output Voltage decreases. The mathematical formula describing this is

$$\text{Output} = 5 - \text{Input}$$

Where all the values are in Volts



Inverting amplifier

R1 10K

R2 10K

R3 10K

R4 10K

IC1 7101 any prefix or suffix. Do not connect unused pins.

OPERATIONAL AMPLIFIER



Testing

Before applying power to the circuit, inspect the circuit thoroughly using a spy glass ensuring that there are no unwanted short circuits or open circuits and that the circuit follows the diagram exactly. Ensure that the power supply is connected the right way round. Then set your meter to continuity or low Ohms range. Connect the meter across the 0V and 5V supply and make sure that the reading is not zero or near to zero. You may get a bleep or a low Ohmic value for a short time because of the capacitor in the power supply, but this should not last more than a few seconds. If it is continuous, you have a short circuit somewhere and you should follow the instructions in the fault finding section. If you do not get the expected results, you should switch the circuit off immediately.

Set your meter to the 20 Volt DC range. Connect your meter across the 5 Volt supply and switch on the supply. If the reading is much below 5 Volts, switch off immediately and go to the fault finding section.

Set your meter to the 20 Volt DC range and connect between 0 Volts and the output. Connect the input to the 5 Volt rail. The meter should read 0 Volts. Now disconnect the input and connect it to the 0 Volt rail. The output should now read 5 Volts.

Circuit description

R2 and R3 potentially divide the supply Voltage to provide a 2.5 Volt bias for the non-inverting input (pin 3) of the operational amplifier IC1. R1 connects the input to the inverting input (pin 2) of IC1 and R4 is the feed back resistor connecting the output of IC1 (pin 6) to pin 2.

The Voltage on pin 2 of IC1 is the average of the output and the input.

If the input Voltage increases, the Voltage on pin 2 tries to be less than that on pin 3. This difference is greatly amplified by IC1 so the output reduces until the Voltages on pins 2 and 3 become equal.

If the input is 0 Volts, the output must be 5 Volts so that the average, which is 2.5 Volts becomes equal to the bias Voltage. Similarly if the input is 5 Volts, the output must be 0 Volts.

Fault finding

The first thing to do is give the circuit a thorough visual inspection with a spy glass looking for bad solder joints and short circuits. Check that the circuit you have built exactly matches the circuit diagram and that the components are the correct values and connected the right way round.

Assuming that there are now no short circuits directly across the power supply, set your meter to the 20 Volt DC range. Connect the meter across the power supply and switch on. You should have 5 Volts. If the circuit takes too much current, the voltage will be much less. The 5 Volt power supply has a current limiting resistor in the circuit so it should not come to any harm by being short circuited. The current limiting resistor will just get hot. Do not let it get so hot that you cannot touch it. If the Voltage is low, switch off and remove IC1. Switch on the power supply and see if the voltage rises to 5 Volts. If it does, then check the connections to the IC and look for short circuits with a spy glass. The only connections that should be made to the 5 Volt rail are R2 and pin 7 of IC1. Also check to make sure that the IC was connected the right way round and there are no unwanted connections. If everything was correct then replace the IC with a new one. If that solves the problem, the IC was faulty and should be thrown away. Replace the IC and check the power supply Voltage again. If all is now OK then see if the circuit now functions correctly.

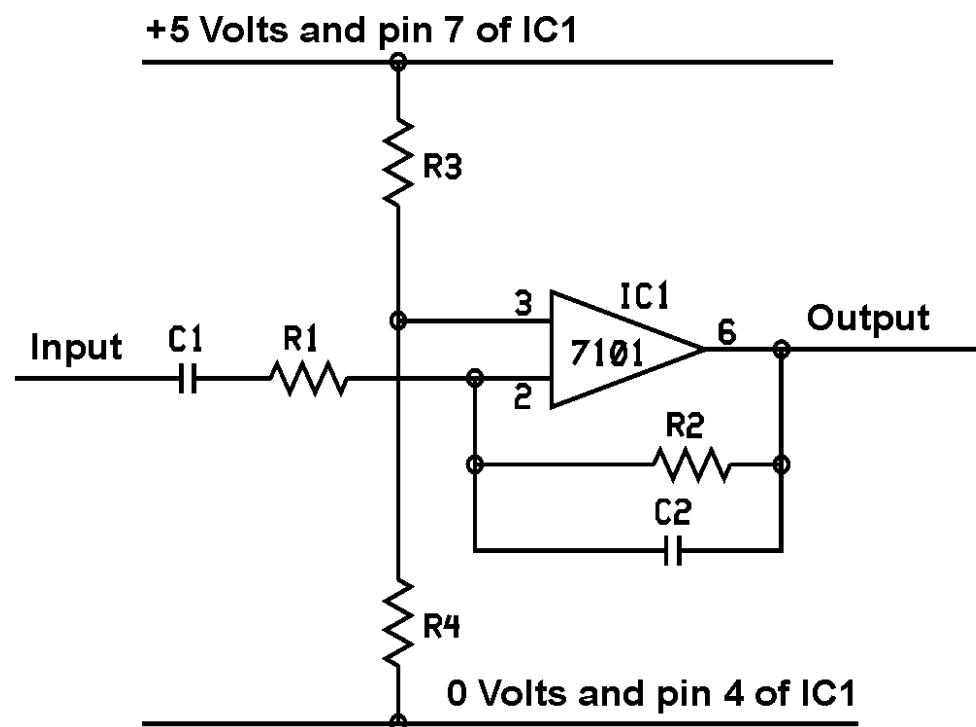
Assuming that the power supply is OK, set your meter to the 20 Volt DC range and connect between 0 Volts and pin 3 of IC1. The meter should read 2.5 Volts. If it doesn't, check the values of R2 and R3. Check for short circuits,

open circuits and bad solder joints. If that does not help, try removing the IC. If that helps, replace the IC and if that helps, throw the old IC away. If removing the IC helps but replacing it with a new one doesn't, look for short circuits on pin 3.

Assuming that that is now OK, check the values of R1 and R4. Check for short circuits, open circuits and bad solder joints. If that does not help, try replacing the IC. If that helps, throw the old IC away.

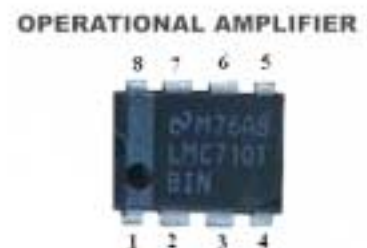
Differentiators

Differentiators give a Voltage output, which is determined by the rate of change of an analogue signal.



Differentiator

- R1 2K2
- R2 1M
- R3 10K
- R4 10K
- C1 4 μ 7F polyester or polycarbonate
- C2 0 μ 1F
- IC1 7101 any prefix or suffix. Do not connect unused pins.



In the circuit above, the input is biased so that if there is no input signal, the output will be 2.5 Volts. The input is inverting so that if the input Voltage reduces, the output will increase and if the input increases, the output will be reduced.

The circuit is very sensitive having component values suitable for very slow changes in input Voltage. If the sensitivity is too high, you should reduce the value of R4. The Value of R4 should not be lower than 10k. If you still have too much sensitivity, reduce the value of C1.

Testing

Before applying power to the circuit, inspect the circuit thoroughly using a spy glass ensuring that there are no unwanted short circuits or open circuits and that the circuit follows the diagram exactly. Ensure that the power supply is connected the right way round. Then set your meter to continuity or low Ohms range. Connect the meter across the 0V and 5V supply and make sure that the reading is not zero or near to zero. You may get a bleep or a low Ohmic value for a short time because of the capacitor in the power supply, but this should not last more than a few seconds. If it is continuous, you have a short circuit somewhere and you should follow the instructions in the fault finding section. If you do not get the expected results, you should switch the circuit off immediately.

Set your meter to the 20 Volt DC range. Connect your meter across the 5 Volt supply and switch on the supply. If the reading is much below 5 Volts, switch off immediately and go to the fault finding section.

If you have the use of an oscilloscope it will be easier to see what is happening and if you also have the use of a low frequency signal generator it will be even easier. Connect the signal generator between 0 Volts and the input. It does not matter whether the signal generator's output goes negative or not because the input to the circuit is a non-polarized capacitor. See if you get similar results to the 'scope image shown in the circuit description. If you do, then the circuit functions correctly.

If you do not have the use of an oscilloscope or a function generator, set your meter to the 20 Volt DC range and connect between 0 Volts and the output. Connect a 10K potentiometer between the 0 Volt rail and the 5 Volt rail and connect the wiper to the input.

If you do not touch the potentiometer, the output should be about 2.5 Volts. If you now very slowly adjust the potentiometer, the output should change. If you now very slowly adjust the potentiometer in the opposite direction, the output should change in the opposite direction. The output Voltage is determined by the rate of change of the input, so the faster you adjust the potentiometer the greater the output change will become.

Circuit description

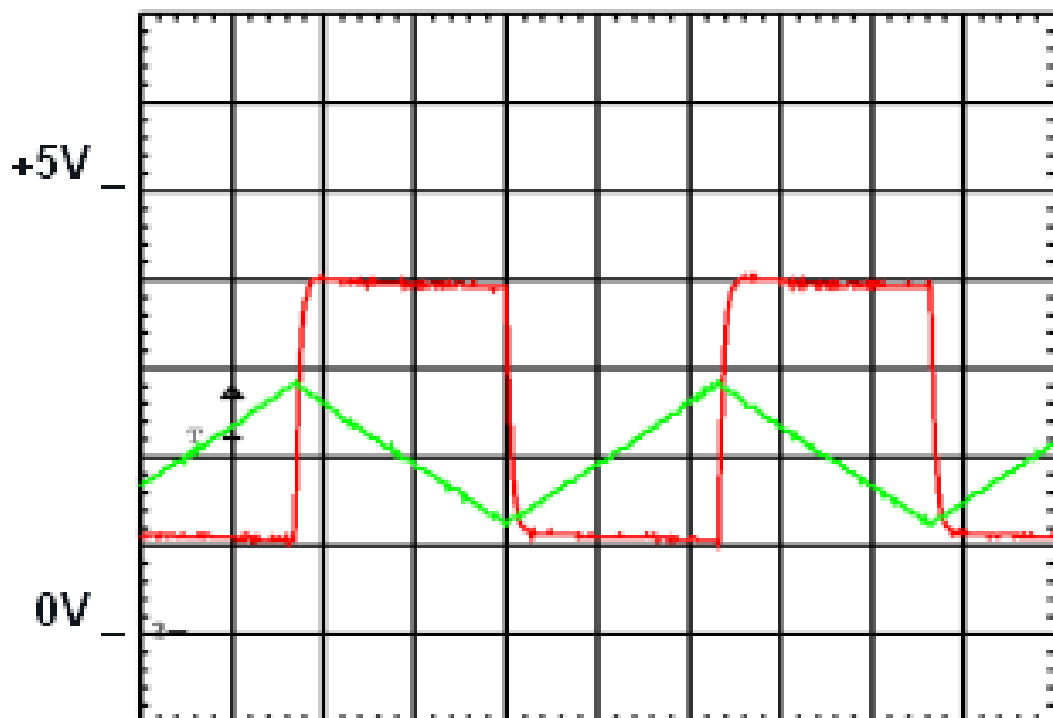
R3 and R4 provide a 2.5 Volt bias for the non-inverting input (pin 3) of the operational amplifier IC1. R2 is a feedback resistor, which connects the output (pin 6) of IC1 to the inverting input (pin 2) of IC1. C2 is connected in parallel

with R2 and acts to reduce the high frequency gain of the circuit. C1 and R1 connect the input to the inverting input (pin 2) of IC1.

When the input Voltage increases, the capacitor C1 charges up. The current to do this must pass through R2 and R1. This means that a Voltage will be generated across R2. If the Voltage on pin 2 of IC1 becomes slightly higher than the Voltage on pin3, the amplifier amplifies this greatly and the output becomes lower until the two Voltages are equal. The greater the speed with which the input Voltage increases, the greater the reduction in output Voltage, as the current flow in C1 is increased. If C2 or R1 were not present in the circuit, the circuit would have a very high gain for high frequency signals. The gain for high frequency signals is determined mainly by R1 and C2 and the gain for very low frequency signals is determined mainly by C1 and R2.

For the mathematically minded, C1 and R2 cause the circuit to act as a differentiator and R1 and C2 cause the circuit to act as an integrator.

The following oscilloscope image shows the input in green and the output in red. The time base (the horizontal direction) is 2 seconds per large division.



The 'scope image above shows that for a negatively going input signal where the signal changes its Voltage at a constant rate (a straight line), the output is a constant more positive level. In the case above, this is 4 Volts. When the input then goes positive at a constant rate, the output is a constant more negative level. As mentioned previously, the output would be constant at 2.5 Volts if the input signal remains constant.

Fault finding

The first thing to do is give the circuit a thorough visual inspection with a spy glass looking for bad solder joints and short circuits. Check that the circuit you have built exactly matches the circuit diagram and that the components are the correct values and connected the right way round.

Assuming that there are now no short circuits directly across the power supply, set your meter to the 20 Volt DC range. Connect the meter across the power supply and switch on. You should have 5 Volts. If the circuit takes too much current, the voltage will be much less. The 5 Volt power supply has a current limiting resistor in the circuit so it should not come to any harm by being short circuited. The current limiting resistor will just get hot. Do not let it get so hot that you cannot touch it. If the Voltage is low, switch off and remove IC1. Switch on the power supply and see if the voltage rises to 5 Volts. If it does, then check the connections to the IC and look for short circuits with a spy glass. The only connections to the 5 Volt rail should be R3 and pin7 of IC1. Also check to make sure that the IC was connected the right way round and there are no unwanted connections. If everything was correct then replace the IC with a new one. If that solves the problem, the IC was faulty and should be thrown away. Replace the IC and check the power supply Voltage again. If all is now OK then see if the circuit now functions correctly.

Assuming that the power supply is OK, set your meter to the 20 Volt DC range and connect between 0 Volts and pin 3 of IC1. You should have a reading of 2.5 Volts. If you do not, check the values of R3 and R4. Check for short circuits, open circuits and bad solder joints. If that does not help, remove IC1 and see if that helps. If it does, try replacing the IC. If that helps, replace the IC and if that helps, throw the old IC away. If the new IC behaves in the same way as the old one and the fault is there when the IC is in place but not when it is not, the problem is probably due to short circuits between pin 3 and another pin. Check to make sure that the only connections to pin 3 are R3 and R4.

Assuming that that is OK, check the values of the remaining components. Check for short circuits, open circuits and bad solder joints. Make sure that none of the unused pins of IC1 are connected anywhere. Check that the circuit follows the diagram exactly. If none of this helps, try replacing the IC. If that helps, throw the old one away.

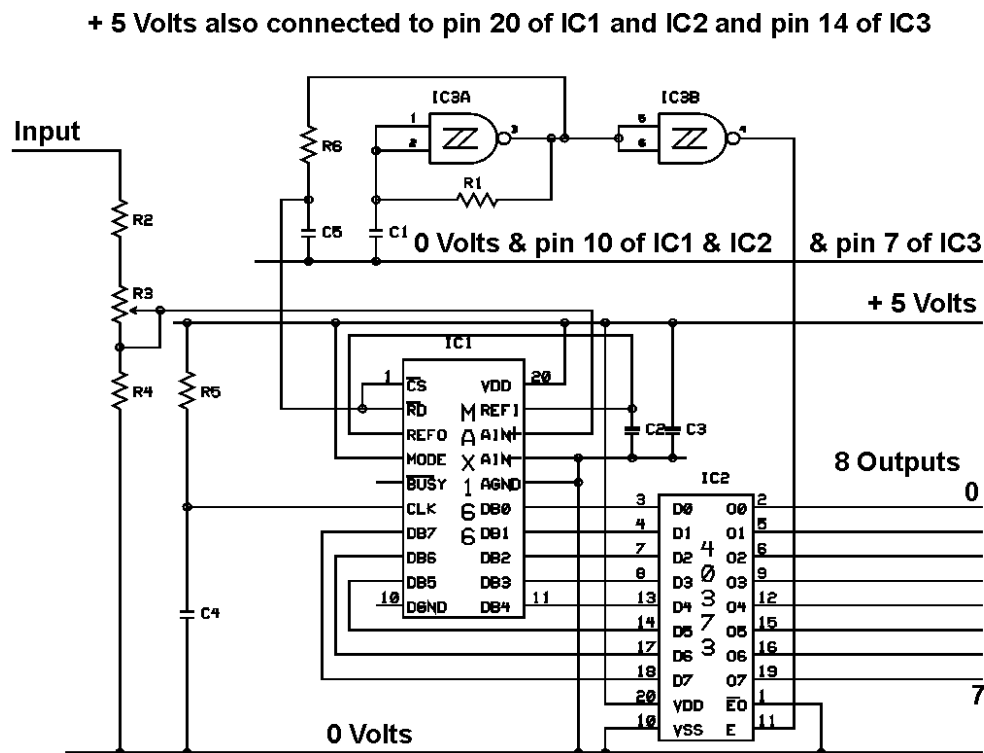
Analogue to digital converters

These convert an analogue signal to a digital number.

The commercially available analogue to digital converters (A/D converters) are designed for use either in conjunction with a microprocessor or for digital meters. The type for digital meters have built-in circuits to drive digital displays, which makes them unsuitable for our purposes. This leaves us with two alternatives, we can either make our own A/D converter or use a

microprocessor type and make a sequencing circuit to emulate a microprocessor.

The following circuit uses a microprocessor type of A/D converter, a sequencing circuit to emulate a microprocessor and an octal (8 in a single package) latch to store the resulting number. The output number will of course be in binary. These converters are 8 bit so the output will be a number between 0 and 255 corresponding to 0 to 5 Volts input.



Analogue to digital converter

- R1 100K
- R2 10K
- R3 1K potentiometer
- R4 10K
- R5 100K
- R6 10K
- C1 10000pF (10nF)
- C2 4μF Tantalum see construction notes
- C3 4μF Tantalum see construction notes
- C4 100pF
- C5 100pF
- IC1 MAX166CCPP
- IC2 HEF40373BP
- IC3 HEF4093BP see construction notes



This circuit has 8 outputs, which are binary. Here is a brief reminder of what that means. Binary means counting in twos rather than in tens. The output 0 is either 1 or 0. The output 1 is either 2 or 0. The output 2 is either 4 or 0 and so on until we reach output 7, which is either 128 or 0. To find the number in denary, all you do is add up the numbers.

The number 10110010 is $128+0+32+16+0+0+2+0$ which equals 178.

The number starts with output 7 and ends with output 0. Output 7 is known as the most significant bit MSB and output 0 is the least significant bit LSB.

Construction notes

You should not build this circuit unless you have successfully built other circuits before. The fault finding section will assume that you have the use of an oscilloscope and even then it will not be possible to give an exact cause for all problems.

Capacitors C2 and C3 are polarized and must be connected the correct way round. They will be damaged if power is applied to them the wrong way round. They should be connected as close to the appropriate pins of IC1 as possible.

The unused inputs of IC3 should be connected either to +5 Volts or 0 Volts. The pin numbers are 8 and 9 for the third gate and 12 and 13 for the fourth gate. These two gates may of course be used for other circuits.

You may wish to have some visual means of seeing what outputs are produced by the circuit. If you do you can use high sensitivity LED's with 4K7 resistors connected in series to see whether any output is 0 Volts or 5 Volts. Connect all the cathodes of the LED's to 0 Volts and the resistors to each output. This method is described in the 5 Volt power supply circuit.

Note that the symbol for IC2 is not in the order of the device's pins to make the circuit more readable.

Testing

Before applying power to the circuit, inspect the circuit thoroughly using a spy glass ensuring that there are no unwanted short circuits or open circuits and that the circuit follows the diagram exactly. Ensure that the power supply is connected the right way round. Then set your meter to continuity or low Ohms range. Connect the meter across the 0V and 5V supply and make sure that the reading is not zero or near to zero. You may get a bleep or a low Ohmic value for a short time because of the capacitor in the power supply, but this should not last more than a few seconds. If it is continuous, you have a short circuit somewhere and you should follow the instructions in the fault finding section. If you do not get the expected results, you should switch the circuit off immediately.

Set your meter to the 20 Volt DC range. Connect your meter across the 5 Volt supply and switch on the supply. If the reading is much below 5 Volts, switch off immediately and go to the fault finding section.

You can use either a scope, a meter or eight LED's to observe the state of the eight outputs which should either be 0 Volts or 5 Volts according to the input Voltage. Set the input to 0 Volts. You can do this by simply not connecting the input. Check that the outputs are all zeros. Now connect the input to +5 Volts and check that the outputs are either all 5 Volts or most of them. Now adjust R3 and you should see that the MSB's are at + 5 Volts and the LSB's change. Now adjust R3 so that you only just get all outputs at +5 Volts. Now connect the input to an intermediate Voltage source. A single cell will do. Measure the cell's Voltage with your meter and check that the outputs agree with your meter. You may be one or two bits in error. If you are, adjust R3 to get the correct outputs. You should note that the input of this circuit does not have a high resistance and that therefore the circuit will only give the correct outputs if the input is connected to a Voltage source with a low resistance. This is not a problem if this circuit is used in conjunction with the other circuits in this cd as they all have low resistance outputs.

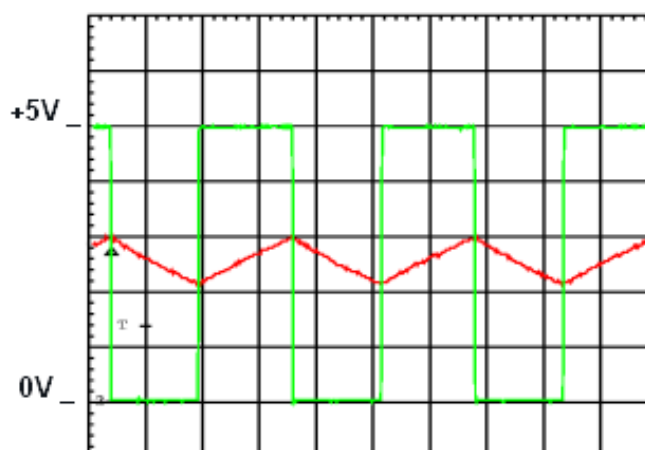
Circuit description

IC3A, R1 and C1 form a square wave oscillator with a frequency of about 1.7KHz. You will note that IC3A is a Schmitt trigger. That is, the input Voltage that is required for a '1' is higher than the input Voltage for a '0'. The difference between these Voltages is called the hysteresis or deadband.

The following oscilloscope image shows the output of IC3A in green and the input in red.

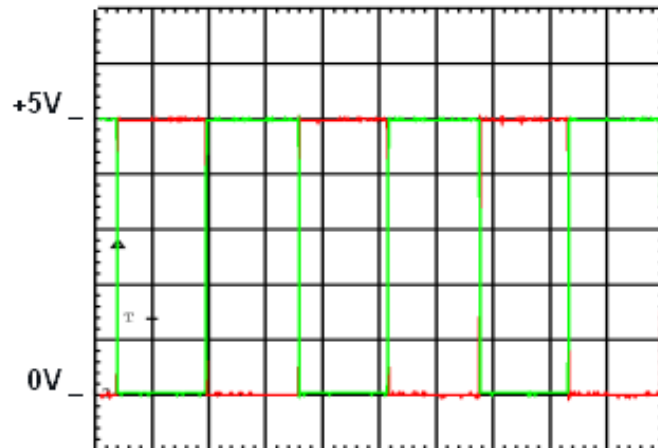
When the output is a '1' (nearly 5Volts), C1 is charged up via R1 until it reaches the Voltage level of a '1' on the input. When that happens, the output becomes a '0' (nearly 0Volts) and C1 discharges via R1 until the Voltage level of a '0' on the input is reached. When this happens the output becomes a '1' again and the process is repeated.

The time base (horizontal)
is 200 μ S per large division



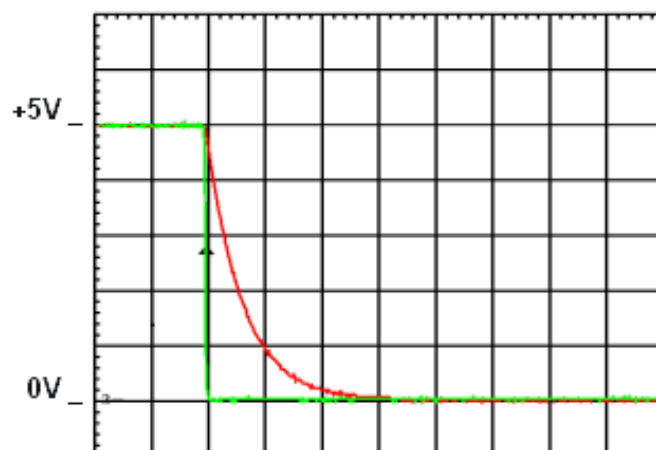
This output is inverted or NOTed by IC3B. A '1' on the input gives a '0' at the output and a '0' on the input gives a '1' at the output. In the following 'scope image, the green trace is the output of IC3A and the red trace is the output of IC3B.

The time base is 200 μ S/Div



The A/D converter IC1 starts its conversion when the NOT RD (Read) and NOT CS (Chip Select) signal go from a '1' to a '0'. It takes a few μ Secs to perform the conversion after which the NOT busy signal (pin 5) goes from a '0' to a '1'. We do not need this signal as we have given the converter plenty of time before we read the result. We need to know that the outputs are stable when we read them so we delay the RD and CS signal a little. R6 and C5 act to produce this delay. The following 'scope image shows this delay. The green trace shows the falling edge of the square wave output of IC3A and the red trace shows the NOT RD and NOT CS inputs to IC1. As can be seen we are delaying the signal by about 1 μ Sec.

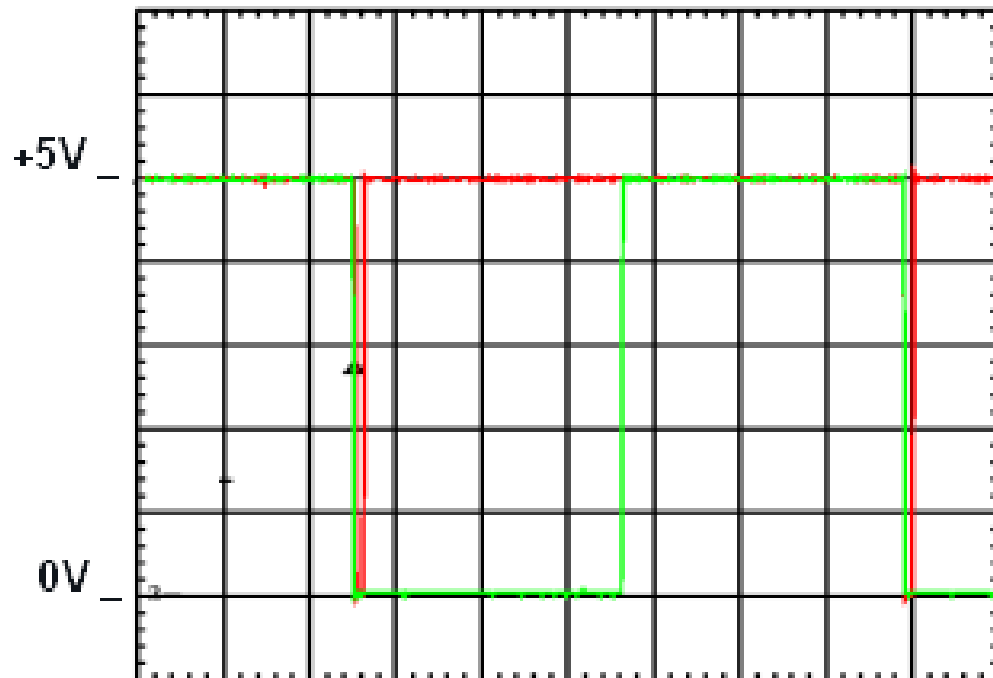
The time base is 2 μ S/Div



The outputs are stable and correct when the NOT BUSY signal is a '1'. We need to read the outputs during this period. We read the outputs when the output of IC3B is '0', which is when the output of IC3A is '1'. By delaying the

RD and CS signals a little, we ensure that the reading of the outputs has finished before the start of the next conversion.

The following 'scope trace shows the NOT BUSY signal in relation to the main oscillator. The green trace shows the output of IC3A and the red trace shows the NOT BUSY signal.



The time base is 100 μ S/Div

You will note that the red trace goes to zero shortly after the green trace and then a few μ Seconds later goes back to 5 Volts. The red trace is at 5 Volts during the time that the green trace is at 5 Volts.

As stated the output of IC3A is inverted by IC3B. The output of IC3B is therefore zero when the output of IC3A is at 5 Volts. IC2 is an octal (has 8 of them) latch. The inputs are connected to the outputs of IC1. When the Enable input (pin 11) of IC2 is a '1', the inputs are transferred to the outputs and are latched when pin 11 goes to a '0'. The outputs of IC2 are not affected by the inputs when pin 11 is a '0'. The effect of this is that the outputs of IC2 read the outputs of IC1 when they are stable and correct and remember them. They are then updated after the next conversion.

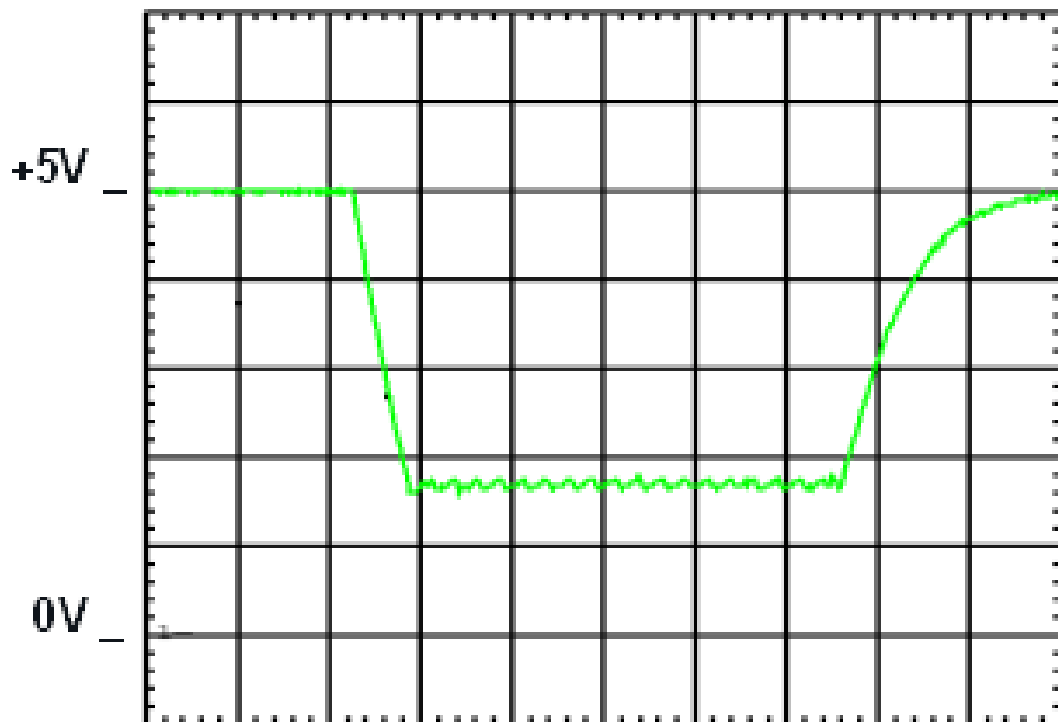
C2 and C3 are required by IC1 to keep the supply and the reference Voltage, produced by the IC stable and free of Voltage spikes. And must therefore be connected as close to the IC as possible.

IC1 has an input Voltage range of zero to 2.36 Volts. We want an input from zero to 5 Volts. R2 R3 and R4 potentially divide the input Voltage to provide

the correct input range to the IC when we have an input range of zero to 5 Volts.

IC1 has an internal clock (oscillator), which is used by the converter to perform its task. R5 and C4 are the timing components for this internal clock.

The internal clock starts when the IC receives an instruction via the NOT RD and NOT CS inputs. The following 'scope trace shows the waveform during a conversion.



The time base is $2\mu\text{S}/\text{Div}$

Note that the clock input signal reduces from 5 Volts to a bit less than 2 Volts and then has a triangular wave for a while before returning to the 5 Volt rail. This triangular wave is similar to the input of IC3A except that it has a much-reduced amplitude.

These A/D converters work by comparing the input Voltage with a proportion of the internal reference Voltage. They start by seeing whether it is greater or less than half of the full range. If it is, they set bit 7 and if not, bit 7 is cleared. They then see if it is greater or less than the first result plus bit 6. If it is, bit 6 is set and if not it is cleared. This process is continued until all the 8 bits have been processed. This process takes two clock cycles per bit.

Fault finding

First read the previous section describing the circuit. You will need to refer to the waveforms described in it.

Give the circuit a thorough visual inspection with a spy glass looking for bad solder joints and short circuits. Check that the circuit you have built exactly matches the circuit diagram and that the components are the correct values and connected the right way round.

Assuming that there are now no short circuits directly across the power supply, set your meter to the 20 Volt DC range. Connect the meter across the power supply and switch on. You should have 5 Volts. If the circuit takes too much current, the voltage will be much less. The 5 Volt power supply has a current limiting resistor in the circuit so it should not come to any harm by being short circuited. The current limiting resistor will just get hot. Do not let it get so hot that you cannot touch it. If the Voltage is low, switch off and remove the IC's one at a time. Switch on the power supply and see if the voltage rises to 5 Volts. If it does, then check the connections to the IC and look for short circuits with a spy glass. The only connections to the 5 Volt rail should be R5, C3, pin 20 of IC1, pin 4 of IC1, pin 20 of IC2 and pin 14 of IC3. Also check to make sure that the IC's are connected the right way round and there are no unwanted connections. If everything was correct then replace any IC's that caused problems with new ones. If that solves the problem, throw the faulty IC's away. Check the power supply Voltage again. Make sure that C2 and C3 are the correct way round. If they were not, they will have to be replaced, as they will have been damaged. Try replacing C3. If that helps, throw the old capacitor away. If all is now OK then see if the circuit now functions correctly.

Assuming that the power supply is OK, check that the output of IC3A is OK. If it isn't, check the values of R1 and C1. Look for open circuits, short circuits and bad solder joints. Make sure that pins 7 and 14 are connected according to the circuit diagram. If this does not help, try replacing IC3. If that helps, throw the old one away.

Assuming that the output of IC3A is OK, check the output of IC3B. If it is not OK, look for short circuits, open circuits and bad solder joints. If this does not help, try replacing IC3. If that helps, throw the old IC away.

Assuming that the output of IC3 is OK, look at the waveform at pins 1 and 2 of IC1. If that is not OK, check the values of R6 and C5. Note that the number on C5 for 100pF should be 101 being 10 followed by 1 zero. A number of 100 on the capacitor would indicate a 10pF capacitor, as it would mean 10 followed by no zeros. Look for short circuits open circuits and bad solder joints.

Assuming that that is OK, look at the NOT BUSY signal on pin 5 of IC1. If this is not OK, make sure that the MODE input on pin 4 of IC1 is connected to +5 Volts. Make sure that R5 and C4 are OK. Check the waveform at the CLK input on pin 6 is OK. If the clock input is not OK, the NOT BUSY signal can't be OK. Look for short circuits and open circuits and bad solder joints. Check

that the connections between IC1 and IC2 are OK. Check that pins 10 and 16 of IC1 are connected to 0 Volts and that pin 20 of IC1 is connected to 5 Volts. Look for short circuits. If none of this helps, try replacing IC1. If that helps, throw the old one away. Try replacing IC2. If that helps, throw the old IC away.

Assuming that the waveforms on pins 5 and 6 are OK, check that the connections between IC1 and IC2 are OK. Check that pin 10 and pin 1 of IC2 are connected to 0 Volts and that pin 20 is connected to 5 Volts. Check that the signal at the output of IC3B appears at pin 11 of IC2. Look for short circuits, open circuits and bad solder joints. If none of this helps, try replacing IC2. If that helps, throw the old IC away.

Chapter 10

Prime Movers (motors etc.)

When choosing a prime mover, you should consider the forces involved. If you can balance the moving part the forces will be reduced. You may need to isolate the moving part from your prime mover if it is very heavy. You can do this by using external bearings and shafts and couple the prime mover to that shaft with a universal or non-rigid coupling. In that way the weight of your work does not need to be supported by the shaft of your prime mover. A look at the bearings and couplings section of your distributor's catalogue would be helpful here. Many distributors of electronic components also have a mechanical section within their catalogues.

Outputs are often quoted in NewtonMeters (Nm). This is a torque or the force in Newtons at a distance of one meter. The weight of something is the force due to gravity of that thing which is why it becomes weightless when in outer space. A 1Kg weight exerts a force of about 10 Newtons on earth. So if you need to lift a 1Kg weight using a motor and the weight is attached to the end of an arm on the motor shaft and that arm is 1m long, the required torque will be 10Nm. If the arm is reduced to 10cm, the torque will be 1Nm. Torque is distance times force and force is about 10 times the weight.

Many motors come with built in gearboxes. By using gears or pulleys you can change the shaft speed whilst maintaining the same motor speed. If you use a gearbox with a high ratio you will get a high output torque and a low output speed. There is a nearly direct relationship between speed and torque as gearboxes are generally quite efficient. If you double the gearbox ratio, you will get nearly double the output torque but with a reduction in output speed.

If you load a motor, it will get slower. If you increase the gear ratio you will reduce the load on the motor and it will speed up. If a motor is very loaded so that its speed is greatly reduced, you may find that by increasing the gear ratio you can use less power for a small reduction in output speed.

You should be aware that motors, particularly geared motors, would produce sound. If your work would be affected by noise, you should take steps to reduce it. A motor on its own is not generally particularly loud but the noise may be amplified when the motor is mounted. The situation is the same as that of a tuning fork. When you use a tuning fork, it is quite quiet until you touch a surface with it. This effect will happen with mounted motors unless you take steps to prevent it. There are a great variety of anti-vibration mounts available. You should look in distributor's catalogues to find ones, which are appropriate to your work. You should be aware that if you mount a moving part on a large surface, the sound would be amplified. It is no good having a rubber gasket between moving parts and a large surface if the moving part is then rigidly fixed to the surface, as the sound will be transmitted through the fixing.

DC motors

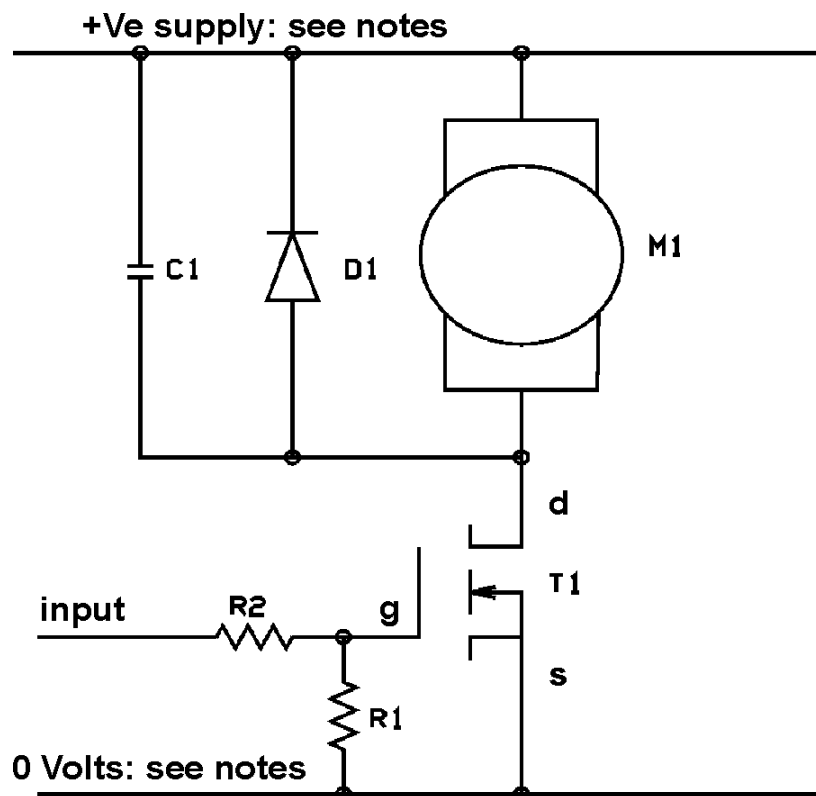
Cheap toy motors are very inefficient, noisy and are not suitable for speed control. If you use them in battery operated works, you will find that the batteries will not last very long and that you will not only have the problem of the batteries running out during your show but that it is likely to be bad economics as well, since batteries are not cheap.

When a motor is switched on, there will be an initial large current flowing through the motor. You can calculate its value by measuring the resistance of the motor and using Ohms law. Once the motor starts to move, it acts like a generator, generating a voltage opposite to that which you have connected across it. The result of this is that the current through the motor is reduced because the effective voltage across the motor is reduced. If a load is applied to the motor, the motor will slow down and therefore the current will increase. Toy motors do not make very good generators and therefore the current through the motor is not greatly reduced when the motor speed increases. You have been warned.

The direction of rotation is determined by the direction of current through the motor. If your motor is going the wrong way round, swap over the wires, which are connected to the motor terminals.

Turning motors on and off

You can of course simply use a switch, but here is a circuit, which can be used with any of the digital output circuits described in this cd.

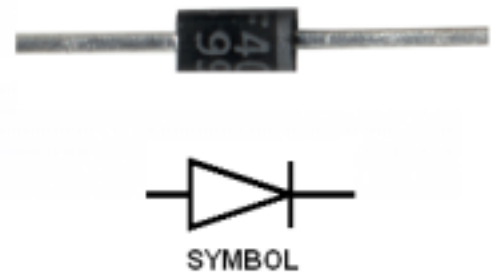


R1 100K
 R2 1K
 C1 0 μ 1F
 D1 1N4002
 T1 RFP12N10L
 M1 DC motor

RFP12N10L
N channel MOSFET



1 A Diode



Notes

The 0 Volt rail must be connected to the 0 Volt rail of your other circuits. The +Ve rail will be dependent on the motor requirements. You must not use the 5 Volt rail that is used by your other circuits. If you need 5 volts for your motor, you should have a separate supply. The 5 Volt supply circuit in this cd is not suitable for this purpose. If your motor is 12 Volts you may use a 12 Volt supply for both the motor and the 5 Volt power supply circuit. This circuit will function at low Voltages and can therefore be used for low Voltage motors. Usually, good quality small DC motors are either 6Volts, 12 Volts or 24 Volts.

The device chosen for T1 is suitable for motors up to 48 Volts but it not recommended for safety reasons. High Voltage motors should use commercially available switching devices or relays, as the Voltages are dangerous. **Earth yourself when handling T1, as it is static sensitive.**

You must ensure that the diode is connected and the correct way round before applying power to the circuit. Motors are inductive. When they are turned off, there will be a very large Voltage across them, which may cause an electric shock as well as damage to electronic components. The diode prevents this from happening. This circuit may be dangerous and T1 may fail, if the diode is not present, particularly with high Voltage motors.

The capacitor is there to prevent electrical interference with other devices. (Radios and TV for example). The capacitor should be mounted directly across the motor terminals for the greatest effect. This will cause the motor and capacitance make a tuned circuit. This may cause noise on the power supply. A compromise between best radio interference and least power supply noise can be achieved by connecting a 10 Ohm resistor in series with C1.

The MOSFET should be mounted on a heat sink if the motor current exceeds 1A under running conditions. The size of the heat sink will depend on the current taken by the motor. You should try it out and if the MOSFET gets hot, use a heat sink and if it still gets hot use a bigger heat sink. You should always use heat sink compound when mounting devices on heat sinks. This circuit is

not suitable for switching motors, which have a continuous current of more than 6 Amps. The continuous current is the current flowing when the motor is running at its normal speed. The starting current may be as much as 15 Amps without causing damage, provided that the MOSFET is mounted on an appropriate heat sink. **Note that the drain is connected to the metal tag.** You may have to use insulated washers when mounting these devices if they are being mounted on earthed metalwork. If you don't, the motor will be permanently on. After mounting the transistor, check for short circuits to the metalwork.

Testing

Before switching the power supply on, check that the supply and the diode are connected the right way round.

Check the circuit for short circuits. The motor will probably have a low resistance so using your meter on continuity and only listening to the sound will not help, you must make a resistance reading.

Set your meter to the appropriate range. This would be 20 Volts DC for a 12 Volt motor and supply. Connect the meter across the supply. Switch on the supply. Make sure that the supply Voltage is correct after switch on. If it is very low, switch off immediately and go to the fault finding section.

If the input is not connected anywhere, the motor should be off. Now connect the input to +5 Volts. The motor should now be on. If you do not get the expected results, switch off immediately.

Circuit description

The MOSFET T1 is an electronic switch. When the gate (g) is below about 2.5 Volts, the switch is off and when it is above about 2.5 Volts it is on. When T1 is off there is a very high resistance between the drain (d) and the source (s). When T1 is on there is a low resistance of about 0.2 Ohms between the drain and source.

R1 protects the gate of T1 when the circuit is not connected to other circuits. C1 is there to prevent excess radio frequency interference. D1 protects T1 and you from damage when the motor is turned off. R2 protects the circuit, which drives this circuit, from a short current pulse when the transistor is switching.

Fault finding

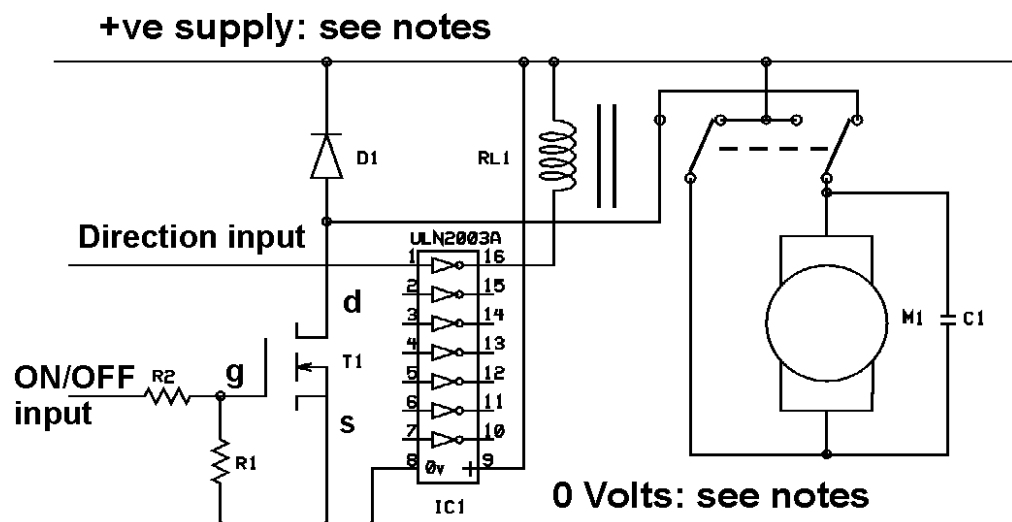
Check the circuit for open circuits, short circuits and bad solder joints. Check that D1 and T1 were connected the correct way round. If either devices were the wrong way round or the power supply was connected the wrong way round, you should replace both components and throw the old ones away.

Check to see that C1 or the motor, are not short-circuited. The motor will probably have a low resistance so using your meter on continuity and only listening to the sound will not help, you must make a resistance reading.

If you are using a heat sink, which is connected to earth or the 0 Volt supply, check that the drain of T1 is not shorted, via the heat sink, to 0 Volts or earth.

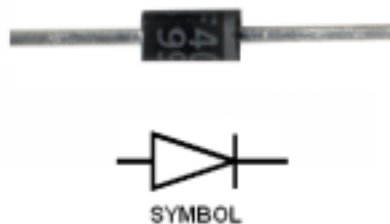
Changing direction of movement

If you reverse the current flow through a motor, it will turn the other way. There are two basic ways of doing this. The simplest is to use a relay and the other way is to use electronic switches to perform the same task.



R1 100K
R2 1K
C1 0 μ 1F
D1 1N4002
T1 RFP12N10L
IC1 ULN2003A
M1 DC motor
RL1 see notes

1 A Diode



RFP12N10L N channel MOSFET



RELAY



Darlington Drivers



Notes

See the notes on the circuit for switching motors on and off. The circuit is the same except for the addition of a relay and relay driver.

The relay needs to have the same coil Voltage rating as the power supply used for the motor. The switch contacts should be suitable for switching the starting /stall current of the motor at the power supply Voltage. The coil current should be less than 300mA otherwise the Darlington driver will fail. The relay for this circuit has two separate switches both of which are changeover. Changeover switches are now more commonly known as double throw switches even though the term changeover is a more understandable term. When there are two switches, they are known as double pole. The catalogue description of the relays will therefore be Double Pole Double Throw, which is likely to be abbreviated to DPDT.

You must check and then double check that the switch connections are made correctly before switching on. If they are wrong, you could ruin your power supply and T1. You have been warned.

The Darlington driver has built-in diode protection for switching inductive loads. These devices have 7 Darlington drivers in one package so the other 6 are available for use in other circuits. If the other circuits use a different supply, pin 9 should not be connected and a separate diode would then need to be connected across the relay coil. The diode must be connected the correct way round or the IC will suffer a catastrophic failure. The diode must be connected with the cathode connected to the positive supply. The IC may also fail if the diode is not present.

Click on link to go to the notes, testing and circuit description for the motor switching circuit.

[LINK](#)

Testing

First go to the notes and testing sections for the motor switching circuit by clicking on the link above.

With the motor on, and the direction input not connected, observe the motor direction. Now connect the direction input to +5 Volts. The motor should now turn the other way round. If the circuit does not behave as expected, switch off immediately and go to the fault finding section.

Circuit description

Half of the circuit is the same as the previous circuit describing a motor ON/OFF switch so you should read that first.

Click on link to go to the notes and circuit description for the motor switching circuit.

[LINK](#)

The symbol for the relay RL1 shows a coil with an iron core and two changeover switches. The circuit is shown without a current flowing through the relay coil. Each changeover switch has three contacts. When not operated, the lower contact (little circle in the symbol) is connected to the contact above and to the right. When the relay is operated, by passing a current through the coil, the lower contact is no longer connected to that contact but becomes connected to the contact above and to the left instead. This is the changeover action. Relays work by magnetism. When a current flows through the coil, the iron in the center of the coil becomes magnetic and attracts another piece of iron, which in turn operates the switch. When no current flows through the coil, the iron is not magnetic and a spring pulls the other piece of iron away causing the initial contact to be made instead.

Assuming that T1 is switched on by a Voltage on the ON/OFF input and the direction input is on zero Volts, The upper connection of the motor is connected to the drain of T1 and the lower connection of the motor is connected to the positive supply. When the direction input is connected to +5 Volts, IC1 switches the relay on and the upper connection of the motor becomes connected to the positive supply and the lower connection to the motor becomes connected to the drain of T1. The motor will therefore turn in the opposite direction.

Fault finding

Check the circuit for open circuits, short circuits and bad solder joints. Check that D1 and T1 were connected the correct way round. If either devices were the wrong way round or the power supply was connected the wrong way round, you should replace both components and throw the old ones away.

Check to see that C1 or the motor, are not short-circuited. The motor will probably have a low resistance so using your meter on continuity and only listening to the sound will not help, you must make a resistance reading. If C1 was short circuited, T1 will have been damaged and should be replaced.

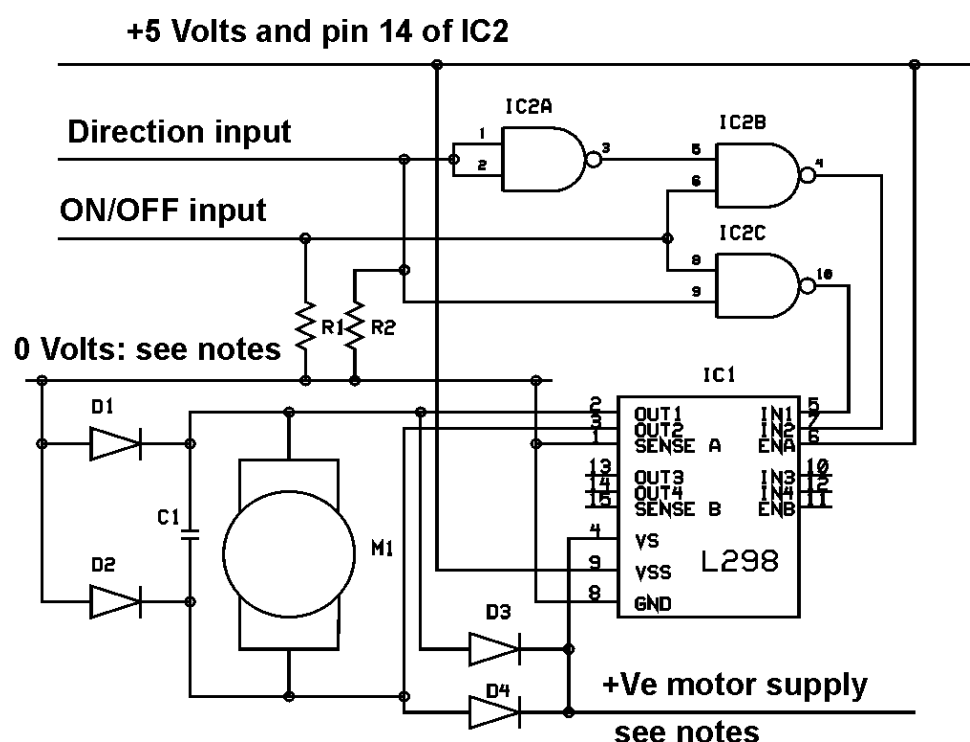
If you are using a heat sink, which is connected to earth or the 0 Volt supply, check that the drain of T1 is not shorted, via the heat sink, to 0 Volts or earth.

Check to see that relay is connected properly.

If the motor works but the direction does not change, see if the relay is operating when a direction input is applied. You should hear a small click when the relay operates but some relays are quite quiet. If you can't hear the relay being switches as you connect and disconnect the direction input. Set your meter to a range appropriate to the power supply Voltage. If you are using a 12 Volt supply for example, set your meter to the 20 Volt DC range. Connect your meter between 0 Volts and pin 16 of IC1. When there is no direction input Voltage, the meter should give a reading equal to the supply Voltage and when +5 Volts is applied to the direction input the meter should read about 1 Volt. If you do not get these readings, check your circuit again and if that does not help, try replacing IC1. If that helps, throw the old IC away.

Changing direction of movement using electronic switching

The following two circuits use a device for electronic switching instead of a relay. There are Voltage and current limitations to these circuits. They cannot be used with motors having less than a 12V supply and must have a starting current of less than 2 Amps. The two circuits are similar. The difference is that in the first circuit, the motor is shorted out when switched off and in the second circuit the motor is open circuited when switched off. A motor will act as a generator. If it is shorted out, it will have to generate a current, which dependent on its resistance and speed. The motor current acts to slow the motor down. This process is called dynamic braking. In the second circuit this does not happen so the motor will not slow down so quickly.

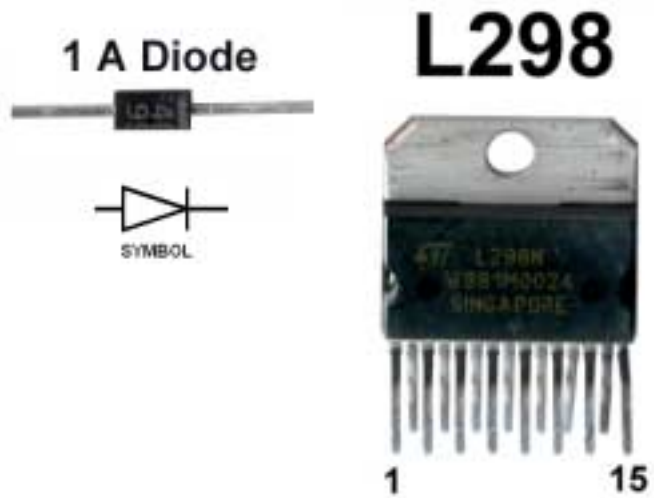


Changing direction of movement using electronic switching

R1 10K
R2 10K
C1 0 μ 1F



D1 1N4002
 D2 1N4002
 D3 1N4002
 D4 1N4002
 IC1 L298
 IC2 4011 or 4093 any prefix
 or suffix



Notes

Connect pin 7 or IC2 to the 0 Volt rail. Unused gates should have their inputs either connected to 0 Volts or 5 Volts.

The 0 Volt rail must be connected to the 0 Volt rail of your other circuits. The +Ve rail will be dependent on the motor requirements. You must not use the 5 Volt rail that is used by your other circuits. If you need 5 volts for your motor, you should have a separate supply. The 5 Volt supply circuit in this cd is not suitable for this purpose. If your motor is 12 Volts you may use a 12 Volt supply for both the motor and the 5 Volt power supply circuit. This circuit will function at low Voltages and can therefore be used for low Voltage motors. Usually, good quality small DC motors are either 6Volts, 12 Volts or 24 Volts.

IC1 is suitable for motors up to 48 Volts but it not recommended for safety reasons. High Voltage motors should use commercially available switching devices or relays, as the Voltages are dangerous. **Earth yourself when handling IC1 and IC2, as they are static sensitive.**

You must ensure that the diodes are connected and the correct way round before applying power to the circuit. Motors are inductive. When they are turned off, there will be a very large Voltage across them, which may cause an electric shock as well as damage to electronic components. The diodes prevent this from happening. This circuit may be dangerous and IC1 may fail, if the diodes are not present, particularly with high Voltage motors.

The capacitor is there to prevent electrical interference with other devices. (Radios and TV for example). The capacitor should be mounted directly across the motor terminals for the greatest effect. The motor and capacitance make a tuned circuit. This may cause noise on the power supply. A compromise

between best radio interference and least power supply noise can be achieved by connecting a 10 Ohm resistor in series with C1.

You should be aware that the metal tag on IC1 is connected to the 0 Volt rail (pin 8). You may need to mount this IC on a heat sink. If you do, make sure that the IC is either insulated from the heat sink or the heat sink is not connected to anywhere other than the 0 Volt rail.

IC1 uses transistors to perform the same task as the relay in the previous circuit. Whereas there is not appreciable Volt drop across a relay contact, there is across a transistor. The Voltage across the motor when it is switched on will therefore be less than the motor supply Voltage. The Volt drop is dependent on the current taken by the motor but it will be of the order of 2 to 3 Volts. High current motors will experience a greater Volt drop. The Voltage across the motor is the supply Voltage minus the Volt drop.

The L298 has two identical circuits so it may be used to switch two motors of the same Voltage. If you are only switching one motor, you should connect the unused inputs (pins 10, 11 and 12) to the 0 Volt rail.

There are no suitable sockets available to connect IC1 to a board so it will be extremely difficult to remove once it has been soldered. You would be well advised to make sure that the circuit has been constructed exactly as the drawing and that the power supplies are correct, before switching the circuit on. Switching the circuit on when the circuit has not been built according to the circuit diagram may destroy much of the circuit. You have been warned.

Testing

Before applying power to the circuit, inspect the circuit thoroughly using a spy glass ensuring that there are no unwanted short circuits or open circuits and that the circuit follows the diagram exactly. The motor will probably have a low resistance so using your meter on continuity and only listening to the sound will not help, you must make a resistance reading. Ensure that the power supplies are connected the right way round. Then set your meter to continuity or low Ohms range. Connect the meter across the 0V and 5V supply and make sure that the reading is not zero or near to zero. You may get a bleep or a low Ohmic value for a short time because of the capacitor in the power supply, but this should not last more than a few seconds. If it is continuous, you have a short circuit somewhere and you should follow the instructions in the fault finding section. If you do not get the expected results, you should switch the circuit off immediately. Set your meter to the appropriate range. This would be 20 Volts DC for a 12 Volt motor and supply. Connect the meter across the motor supply. Switch on the supply. Make sure that the supply Voltage is correct after switch on. If it is very low, switch off immediately and go to the fault finding section. Set your meter to the 20 Volt DC range. Connect your

meter across the 5 Volt supply and switch on the supply. If the reading is much below 5 Volts, switch off immediately and go to the fault finding section.

If both inputs are connected to 0 Volts, the motor should be off. Now disconnect the ON/OFF input and connect it to the 5 Volt rail. The motor should now be on. If you now disconnect the direction input and connect that to the 5 Volt rail, the motor should turn the other way.

Circuit description

The diodes protect IC1 from high Voltage spikes caused by switching the motor, which is an inductive load. They prevent the motor Voltage from being much greater than the motor supply Voltage and from being very negative. C1 reduces radio interference from the motor.

R1 and R2 protect the inputs to IC2 from static.

IC1 has three inputs, which determine the action of the circuit on the motor. If inputs 1 and 2 are either both '0's or '1's, the motor will be shorted out. This will produce dynamic braking and the motor will stop quickly. If the input 1 is a '0' and input 2 is a '1', the motor will turn one way and if input 1 is a '1' and input 2 is a '0', the motor will turn the other way. The enable input (pin 6) switches the motor on if it is a '1' and off if it is a '0'. In the circuit above, the enable input is connected permanently to a '1' and in the following circuit it is used as the ON/OFF input.

When the ON/OFF input is a '0', the outputs of both IC2B and IC2C (pins 4 and 10) must be '1's as the gates are NAND gates. The output of a NAND gate will only be '0' if both inputs are '1's. Since both inputs to IC1 (pins 5 and 7) are '1's, the motor will be off.

When the ON/OFF input is a '1', the outputs of IC2B and IC2C are dependent on the direction input. When the direction input is a '0', the output of IC2C is a '1' and the output of IC2B is a '0' because the output of IC2A is a '1' and therefore both inputs to IC2B are '1's. When the direction input is a '1', the output of IC2C is a '0' because both its inputs are '1's and the output of IC2B is a '1' because the output of IC2A is a '0'.

Fault finding

The first thing to do is give the circuit a thorough visual inspection with a spy glass looking for bad solder joints and short circuits. Check that the circuit you have built exactly matches the circuit diagram and that the components are the correct values and connected the right way round.

If the motor power supply was shorted by turning the power on and not shorted when the power supply was turned off, you may well find that much of the circuit was damaged. Check that the diodes are connected the right way round

and that the motor is not short circuited. Note that the motor will have a low resistance so you will need to measure the resistance rather than rely on the bleep of your meter. If the diodes were the wrong way round, they will probably be damaged, but IC1 may have survived. If the motor was short circuited, IC1 will probably be damaged. It is also possible that your power supply was also damaged.

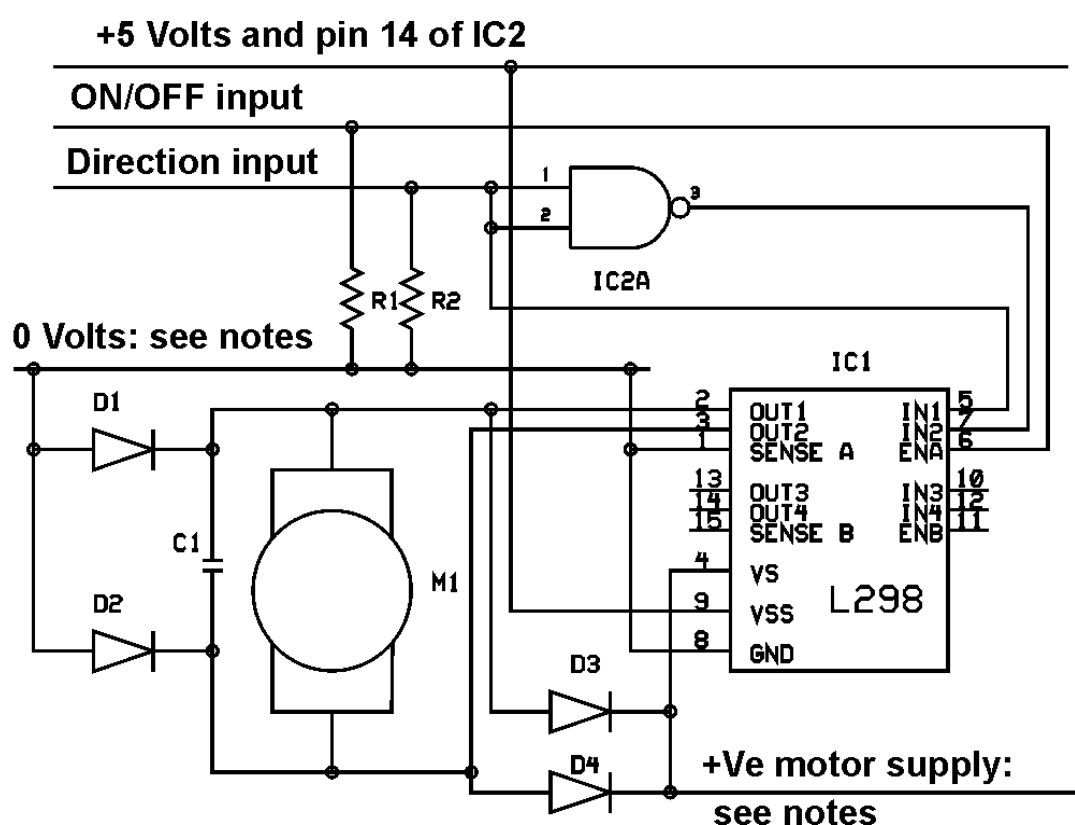
Assuming that the motor power supply is OK, check the 5 Volt supply. If it is not OK, check that the only connections to the 5 Volt rail are pin 14 of IC2 and pins 6 and 9 of IC1. Look for short circuits, open circuits and bad solder joints. If that does not help, try removing IC2. If that helps, try replacing IC2 and if that helps, throw the old IC away. Removing IC1 will be a problem but if all else fails you should try it.

Assuming that both supplies are OK, set your meter to the 20 Volt DC range and connect the common input to the 0 Volt rail and check the outputs of IC2. See if you get the correct results according to the circuit description.

If you do not, see which gates are not giving the correct outputs starting with IC1A and then check the inputs and outputs for short circuits, open circuits and bad solder joints. Make sure that the circuit you have built corresponds to the diagram. If none of this helps, try replacing the IC and if that helps, throw the old one away.

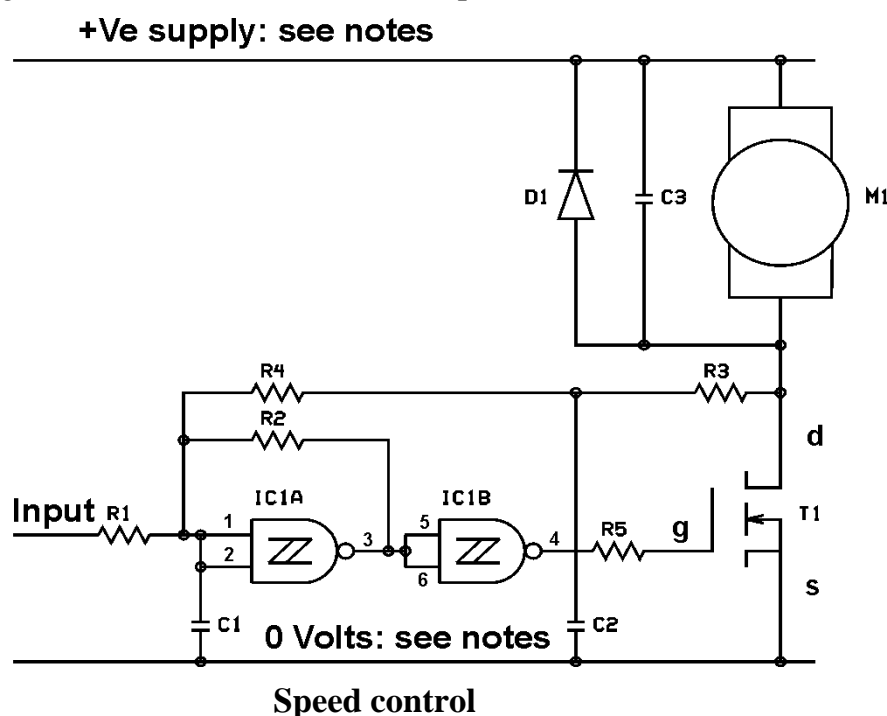
Assuming that the outputs of IC2 are OK, check that you have connected pin 1 of IC1 to 0 Volts. Check that the enable input (pin 6) of IC1 is at 5 Volts. Look for short circuits, open circuits and bad solder joints. Check again to make sure that you have built the circuit according to the diagram. If all else has failed, try replacing IC1. If that helps, throw the old one away.

Changing direction of movement using electronic switching



This circuit will not be described separately from the previous circuit other than to point out that the ON/OFF input is now connected directly to the enable input of IC1 and that Inputs 1 and 2 are always different from each other as IC1A inverts the signal.

Speed control of motors can be achieved by varying the Voltage of the motor supply. This is a reasonable way of solving the problem provided that a fixed speed is required. The problem with just having a different Voltage supply is that the motor speed is dependant on the motor load as well as the Voltage. In many cases choosing a suitable supply Voltage is quite adequate and is simple. If you need to adjust the motor speed and you need a motor speed that is less dependent on the motor load, there are many devices available commercially. The cheaper ones have a potentiometer to adjust the motor speed. If you need to vary the motor speed according to a Voltage input rather than the position of a potentiometer, the commercially available devices become quite expensive. The following circuit is a reasonable and cheap alternative.

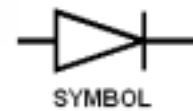


R1 33K
 R2 47K
 R3 100K
 R4 220K
 R5 1K
 C1 2200pF
 C2 1μF
 C3 0μ1F
 D1 1N4002
 T1 RFP12N10L
 IC1 HEF4093BP
 M1 motor

RFP12N10L
N channel MOSFET



1 A Diode



Notes

First read the notes for the motor switching circuit.

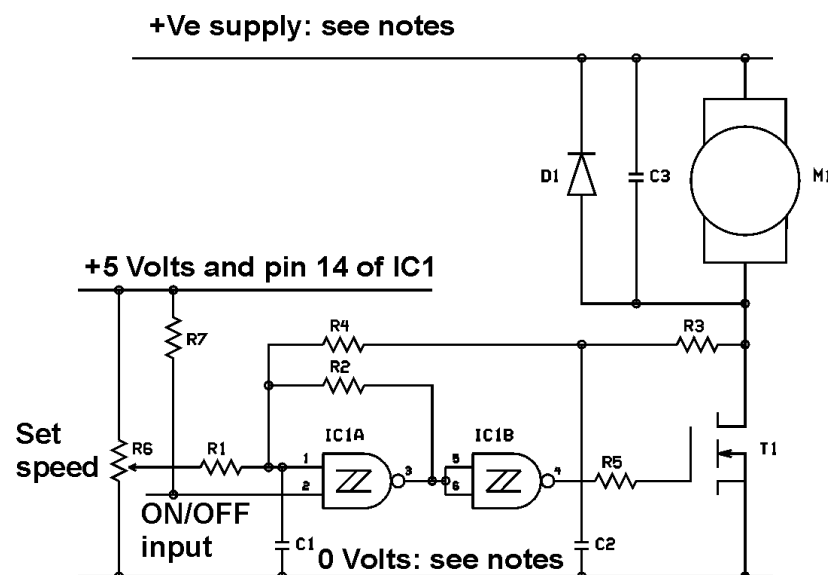
Click on link to go to the notes, testing and circuit description for the motor switching circuit.

[LINK](#)

You will need a 5 Volt supply for this circuit. The 0 Volts should be connected to the 0 Volts and the 5 Volts should be connected to pin 14 of IC1. 0 Volts should also be connected to pin 7 of IC1. The unused inputs of IC1 should either be connected to 0 Volts or +5 Volts.

The value of R4 is dependant on the motor supply Voltage. The value shown is for a 12 Volt supply. Higher Voltages will need a higher value and lower Voltages a lower value.

You may use the following circuit if you want a switchable speed controller with an adjustable but fixed speed.



R6 5K potentiometer

R7 10K

R6 provides the input Voltage and R7 holds the circuit on, if there is no input. If the input to pin 2 of IC1 is 0 Volts the motor will be turned off. Apart from these two components, the circuit is identical to the previous circuit and will not be dealt with separately.

You can of course combine these circuits with the circuit for changing direction of movement. If you do, note that R3 will remain connected to the drain of T1.

Testing

Before applying power to the circuit, inspect the circuit thoroughly using a spy glass ensuring that there are no unwanted short circuits or open circuits and that the circuit follows the diagram exactly. Ensure that the power supplies are connected the right way round. Then set your meter to continuity or low Ohms range. Connect the meter across the 0V and 5V supply and make sure that the reading is not zero or near to zero. You may get a bleep or a low Ohmic value for a short time because of the capacitor in the power supply, but this should not last more than a few seconds. If it is continuous, you have a short circuit somewhere and you should follow the instructions in the fault finding section. If you do not get the expected results, you should switch the circuit off immediately.

Set your meter to the 20 Volt DC range. Connect your meter across the 5 Volt supply and switch on the supply. If the reading is much below 5 Volts, switch off immediately and go to the fault finding section.

Connect the input to 0 Volts and switch on the supply. The motor should be off. Now connect the input to the 5 Volt supply. The motor should now be fully on. Now connect the input to a variable voltage supply (a 5K potentiometer connected as shown in the second circuit will do). Adjust the input Voltage. You should observe the motor changing its speed as you change the input Voltage.

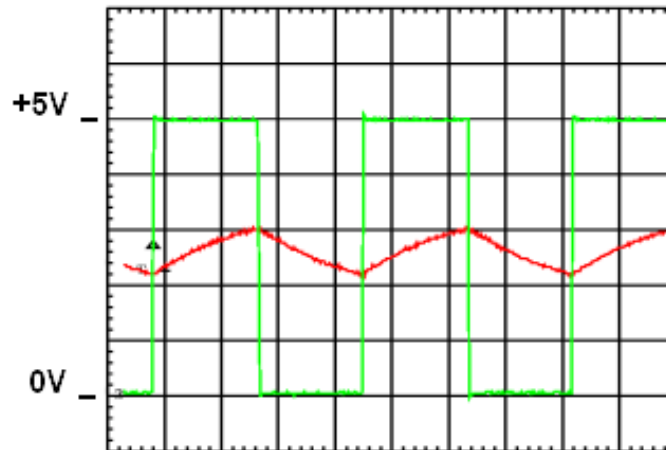
Circuit description

In the oscilloscope images, in this circuit description, the time base (horizontal direction of the trace from left to right) is 20μSec per large division.

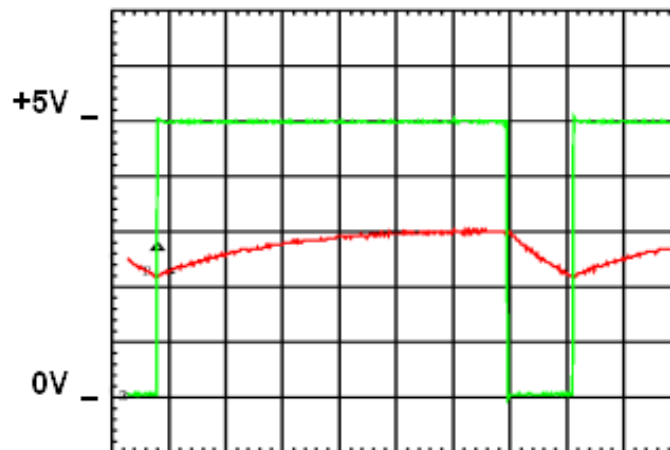
IC1A, R2 and C1 form a square wave oscillator with a frequency of about 15KHz. You will note that IC1A is a Schmitt trigger. That is, the input Voltage that is required for a '1' is higher than the input Voltage for a '0'. The difference between these Voltages is called the hysteresis or deadband.

The following oscilloscope image shows the output of IC1A in green and the input in red.

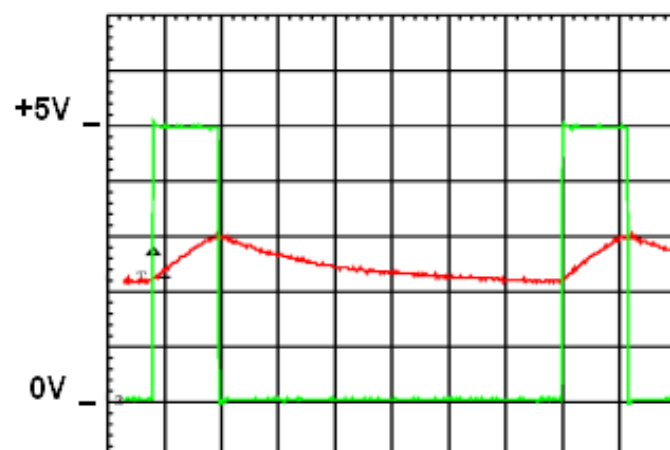
When the output is a '1' (nearly 5Volts), C1 is charged up via R2 until it reaches the Voltage level of a '1' on the input. When that happens, the output becomes a '0' (nearly 0Volts) and C1 discharges via R1 until the Voltage level of a '0' on the input is reached. When this happens the output becomes a '1' again and the process is repeated.



You will note that R1 and R4 are also connected to the input (pins 1 and 2) of IC1A. These act on the circuit to change the timing of the oscillator. First let us look at the action of R1 on the circuit. When the input Voltage is low, as shown in the following oscilloscope image, it takes much longer for C1 to charge up and it discharges more quickly. This is because R1 takes some of the current that would otherwise charge C1 and on discharge, also takes current from the capacitor so that it is not only discharging through R2 but through R1 as well.

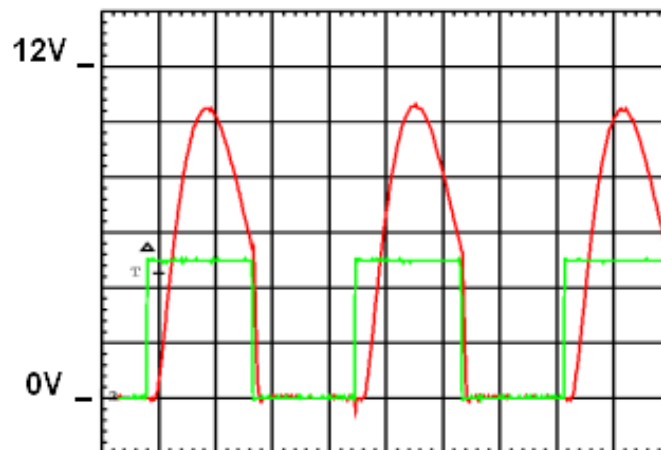


When the input Voltage is high, the reverse is true and C1 is charged up by both R1 and R2 but the discharge is much slower as it is not discharging to 0 Volts but to a higher Voltage. The following 'scope image shows this.

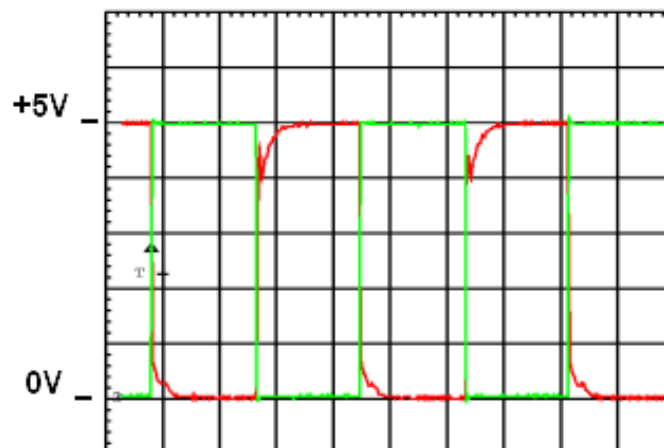


R4 acts in the same way as R1 but the Voltage on R4 is not determined by the input Voltage but by the average Voltage on the drain of T1. When a motor is turned off, the Voltage across it is dependent on the motor speed, as the motor acts as a generator. The average Voltage at the drain of T1 is therefore dependent on the motor speed. If the speed is low, the Voltage will be higher than if the speed is high. R4 therefore adds this motor speed Voltage to the input Voltage. The effect of this is to increase the current in the motor when it is running too slowly. This makes this circuit control the motor speed rather than just the power of the motor. This will have the effect of allowing the motor to run slowly whilst still being powerful.

The following 'scope image shows the output of IC1A in green and the drain (d) of T1, Voltage in red. The reason why the red trace is not more rectangular in shape is that C3 acts with the motor's inductance to make a tuned circuit. The shape of this waveform will be dependent on the particular motor you are using.



The output of IC1A is inverted by IC1B to provide the appropriate signal for the gate (g) of T1. R5 protects the output from the sudden rush of current into and out of the gate of T1 at the instant of switching. The effect of this transient current can be seen in the following 'scope image.



The green trace is the output of IC1A and the red trace is the output of IC1B.

R3 and C2 act to smooth out the signal from the drain of T1 so that the Voltage across C2 is essentially proportional to the average Voltage at the drain of T1.

Fault finding

The first thing to do is give the circuit a thorough visual inspection with a spy glass looking for bad solder joints and short circuits. Check that the circuit you have built exactly matches the circuit diagram and that the components are the correct values and connected the right way round.

If the 5 Volt power supply was short circuited or had a greatly reduced output, remove IC1 and try again. If that does not help, there must be a short circuit or misconnection. The only connection to the 5 Volt rail should be pin 14 of IC1. If the removal of IC1 restores the output of the power supply, check for short circuits on the pins of the IC socket, in particular any outputs of the IC (pins 3, 4, 10 and 11. Make sure that the IC was the correct way round. It is possible that the IC is faulty. Try replacing IC1, if that helps, throw the old IC away.

Check that D1 and T1 were connected the correct way round. If either devices were the wrong way round or the power supply was connected the wrong way round, you should replace both components and throw the old ones away.

Check to see that C3 or the motor, are not short-circuited. The motor will probably have a low resistance so using your meter on continuity and only listening to the sound will not help, you must make a resistance reading. If C3 was short circuited, T1 will have been damaged and should be replaced.

If you are using a heat sink, which is connected to earth or the 0 Volt supply, check that the drain of T1 is not shorted, via the heat sink, to 0 Volts or earth.

Assuming that the power supplies are OK, Check that pin 7 of IC1 is connected to 0 Volts and that pin 14 is connected to +5 Volts. If you have an oscilloscope, you should look at the waveforms described in the section describing the circuit, else you can use a meter. Set the input to 0 Volts. Set your meter to the 20 Volt DC range and connect the common lead to the 0 Volt rail. Measure the Voltage at the output pin 3 of IC1A. It should read 5 Volts. If it doesn't, check the Values of all the resistors. Note that the value of R4 is for a 12 Volt motor supply and that it must be increased if your motor supply Voltage is higher. Check for short circuits, open circuits and bad solder joints. Try replacing the IC. If that helps, throw the old one away. Assuming that you are getting the correct reading at the output of IC1A, check that the output of IC1B (pin 4) is 0 Volts. If it isn't, check for short circuits open circuits and bad solder joints. If none of that helps, try replacing the IC. If that helps, throw the old one away.

Assuming that that is OK, connect the input to the 5 Volt rail. The output (pin 3) of IC1A should be 0 Volts and the output (pin 4) of IC1B should be 5 Volts. If it isn't, go through the same procedure as the previous paragraph.

Assuming that the outputs of IC1 are OK, adjust the input Voltage and measure the output of IC1A. It should vary between 0 and 5 Volts as you change the input Voltage. If it doesn't, check the circuit for incorrect component values. Check that the circuit matches the diagram. Make sure that R2 is connected properly and has the correct value.

Assuming that IC1 is now working correctly, check that T1 is connected the correct way round and that R5 is connected properly. Look for short circuits, open circuits and bad solder joints. Check that D1 was connected properly. If none of this helps, try replacing T1 noting that it is static sensitive and that therefore, you must ensure that you are properly earthed when handling them, otherwise they may get damaged.

Limit switches

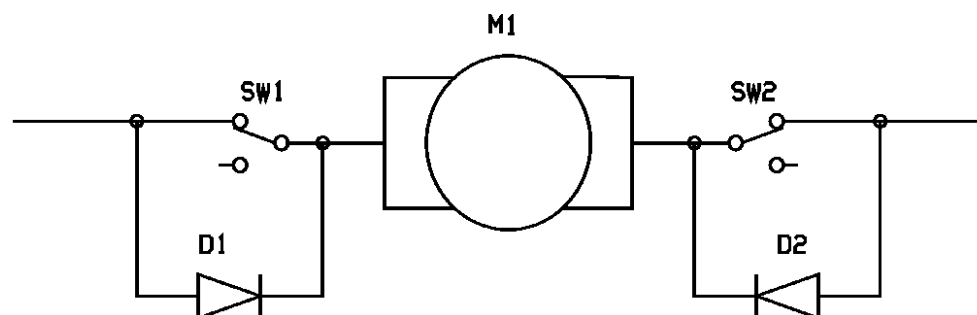
Limit switches are discussed in the chapter on sensors. To view the relevant section, [click here](#).

CLICK

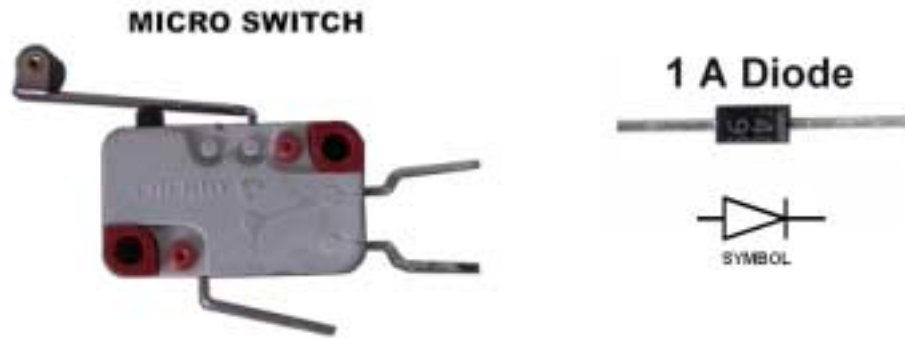
There is a complicated circuit, which solves the problem of the limit switches causing the movement in the part, which operates the switch. The best solution is to make the mechanics in such a way that this does not happen unless you want it to. If you are using microprocessors/microcontrollers to control the motor, you should use the switches to input to the interrupt inputs and solve the problem with a few lines of computer code. An example of a circuit, which will solve the problem, can be found as an exercise in the chapter on logic. [Click here](#) to go to that section.

CLICK

The following circuit should be substituted for the motor in other DC motor circuits.



Limit switches



D1 1N4002
 D2 1N4002
 SW1 microswitch
 SW2 microswitch

Notes

The direction of the diodes will need to be established during testing.

The microswitches are shown in the circuit diagram in their normal position. That is when the motor is between its limits of movement.

Testing

Get the motor to approximately its mid point of travel. Now operate the limit switch that would be operated by the motor should it continue moving in the same direction. The motor should now stop. If it does not stop, reverse the orientation of the diode, which is across that switch. Now reverse the direction of the motor and perform the same operation on the other switch and diode. If the motor did not move unless you operated at least one switch, you have connected the microswitches incorrectly.

Servos

Servos have position feed back. That is they are given a position to go to and they go to it. They need to know where they are or they cannot know when they have arrived. In this section it will be assumed that the motors are of high quality and are small 12 Volt DC motors. If you need to use other types of motor, you should choose one of the many commercially available products.

The following circuit has a Voltage input range of 0 to 5 Volts. A potentiometer is used to provide motor position information. The potentiometer should be mounted in such a way that it moves from one extreme to the other as the required movement of the work moves from one extreme to the other. There are some potentiometers, which are specially made for use on servos. You should use the type, which does not have an end stop. These can be rotated a full 360 degrees without being damaged. The potentiometer mounting is crucial to the success of the servo. There should not be any slack/play between the motor and potentiometer. This is not likely to be achievable as geared motors generally have some slack but it would be wise not to make matters any

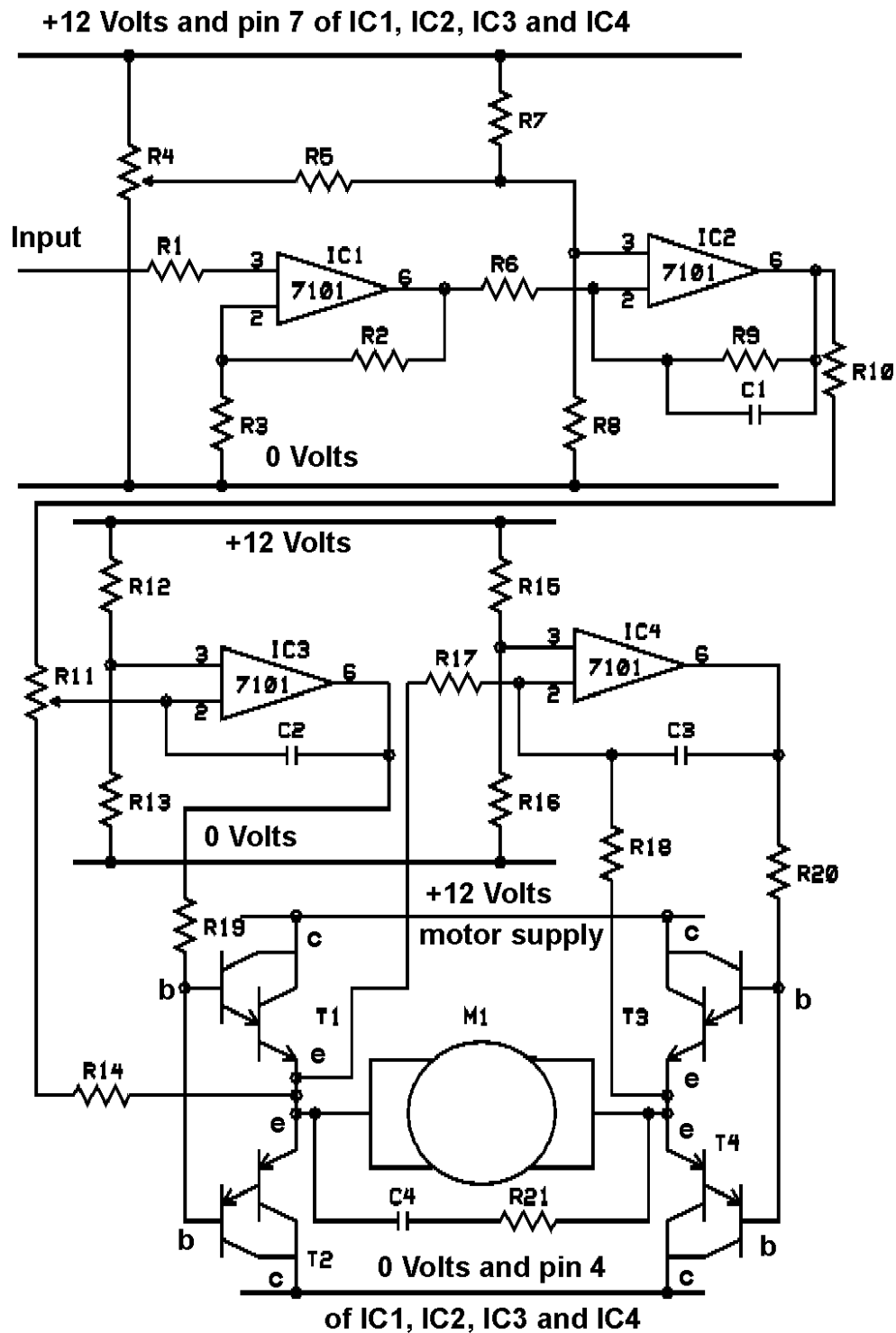
worse. You should also use limit switches, though these are not shown on the circuit diagram.

The principle of the servo is that a Voltage input is compared with the Voltage at the wiper of the feedback potentiometer. The difference between the two is amplified and drives the motor, which in turn moves the feed back potentiometer until they both have the same Voltage. There are problems however. When the motor is moving towards the correct position, it is still being driven towards that position until it goes too far, when it is driven back again. The simple solution to this problem is to reduce the gain of the amplifier so that the motor moves slowly as it approaches the correct position. A better way of solving the problem would be to use a signal derived from the motor speed. This way the motor can be traveling quite quickly as it approaches its final position and then be put into reverse just before it gets there. There are further ways of speeding up the system but these start to get more problematic and are generally only used in very high speed systems. If we rely on a reduced gain to give stability, we will also reduce the torque (rotational force) that the motor can have close to its final position. This is particularly noticeable when the motor is moving any heavy object as this increases the inertia and inertia also causes the motor to overshoot (go too far), so the gain would need to be reduced still further to give stability to the system. In spite of the reduced performance of the simple circuit without speed feedback, it is likely to prove adequate for the artists needs.

Some servo motors have tacho generators attached to them though these are generally quite expensive. A tacho generator is basically a second motor attached to the main motor shaft. This generator provides a Voltage signal proportional to the motor speed. Another way of getting a speed signal is to utilize the motor characteristics. If the motor speed is zero, the current through the motor is the Voltage across the motor divided by the resistance of the motor. When the motor rotates, it acts like a generator and the current through the motor is the difference in Voltage between the applied Voltage and the generated Voltage divided by the motor resistance. It can be seen that the motor speed can be derived from the current through the motor and the Voltage across the motor.

The main effect of the simpler circuit is that the precision would be reduced particularly if the load on the motor were uneven. If the motor were to rotate an unbalanced object vertically, gravity would need to be overcome more in some positions than in others and in different directions if the object moves either side of the vertical. The motor would have to exert a force to keep the rotated object from falling to a vertical position. This force can only be produced if there is a current flowing through the motor and that means that there must be a Voltage across the motor. The lower the system gain, the higher the difference between the desired position and the actual position of the moving part. If the

amplifier gain could be infinite, this difference would be zero. We need to keep the gain low enough for stability and this causes the error.



Servo amplifier

- | | |
|----|------------------------------|
| R1 | 10K |
| R2 | 18K |
| R3 | 13K |
| R4 | 10K potentiometer: see notes |
| R5 | 10K |

R6 10K
 R7 200K
 R8 200K
 R9 100K
 R10 10K
 R11 50K potentiometer
 R12 10K
 R13 10K
 R14 47K
 R15 10K
 R16 10K
 R17 10K
 R18 10K
 R19 1K
 R20 1K
 R21 10 Ohms
 C1 0 μ 1F
 C2 100pF
 C3 100pF
 C4 0 μ 1F
 T1 TIP121
 T2 TIP126
 T3 TIP121
 T4 TIP126
 IC1 7101 any prefix or suffix
 IC2 7101 any prefix or suffix
 IC3 7101 any prefix or suffix
 IC4 7101 any prefix or suffix

OPERATIONAL AMPLIFIER



TIP126



TIP121



Notes

You should use limit switches, though these are not shown on the circuit diagram. [Click here to go to the section on limit switches.](#)

CLICK

The 12 Volt motor supply should be a separate supply but have its 0 Volt rail connected to the 0 Volt rail of the 12 Volt supply used for the rest of the circuit. You may be able to get away with a single supply for both motor and amplifiers but this is dependent on the quality of the supply and the power of the motor. The problem is that when the motor is turned on, it takes a high current from the supply, causing the supply to have a reduced Voltage; this is then fed back into the amplifiers producing an unstable situation. If the power supply is very good and the motors do not take too much current, the problem will not arise. The problem is made worse for high amplifier gains so you may be able to use a single supply if you reduce the amplifier gain. The 5 Volt power supply used for most of the circuits in this cd will not suffer from these

problems but we need the full 12 Volts to drive the Darlington transistors in this circuit. The amplifier circuit does not take much current so a cheap, but regulated, supply will do.

R4 is the feedback potentiometer. This should be of a high quality and be suitable for servo applications and preferably not have end stops (they should be able to rotate a full 360 degrees). It must be mounted so that there is a minimum of slack/play (movement without the moving part of the work moving). The higher the precision with which it is mounted the better. This potentiometer tells the circuit where the moving part of the work is.

R11 is the gain potentiometer. If the gain is too high and cannot be adjusted to be low enough using this potentiometer, you should reduce the values of R7, R8 and R9. R7 and R8 should be double the value of R10. Try changing R10 to 51K and R7 and R8 to 100K.

The Voltage available to the motor will only be about 9 Volts as the Darlington transistors that are controlling it will have a lower output Voltage than input Voltage.

The four Darlington transistors have their tags connected to their collectors (marked with a 'c'), so you should ensure that they are not touching anything that they shouldn't. They are not likely to get hot unless the motor is continually moving. If they do get hot, you should mount them on heat sinks remembering that the tags are connected to the collectors.

You should ensure that the unused pins of the IC's are not connected anywhere.

Testing

Before applying power to the circuit, inspect the circuit thoroughly using a spy glass ensuring that there are no unwanted short circuits or open circuits and that the circuit follows the diagram exactly. Ensure that the power supply is connected the right way round. Then set your meter to continuity or low Ohms range. Connect the meter across the 0V and 12V supply and make sure that the reading is not zero or near to zero. If you get a very low reading, you have a short circuit somewhere and you should follow the instructions in the fault finding section. If you do not get the expected results, you should switch the circuit off immediately.

Set your meter to the 20 Volt DC range. Connect your meter across the supply and switch on. If the supply Voltage drops considerably, there is a fault and you should switch off immediately.

Set your input to about 2.5Volts. You may use a potentiometer connected across the 0 and 12 Volt rails and use the wiper as an input. If you find that the motor moves the work away from the correct position instead of towards it, you

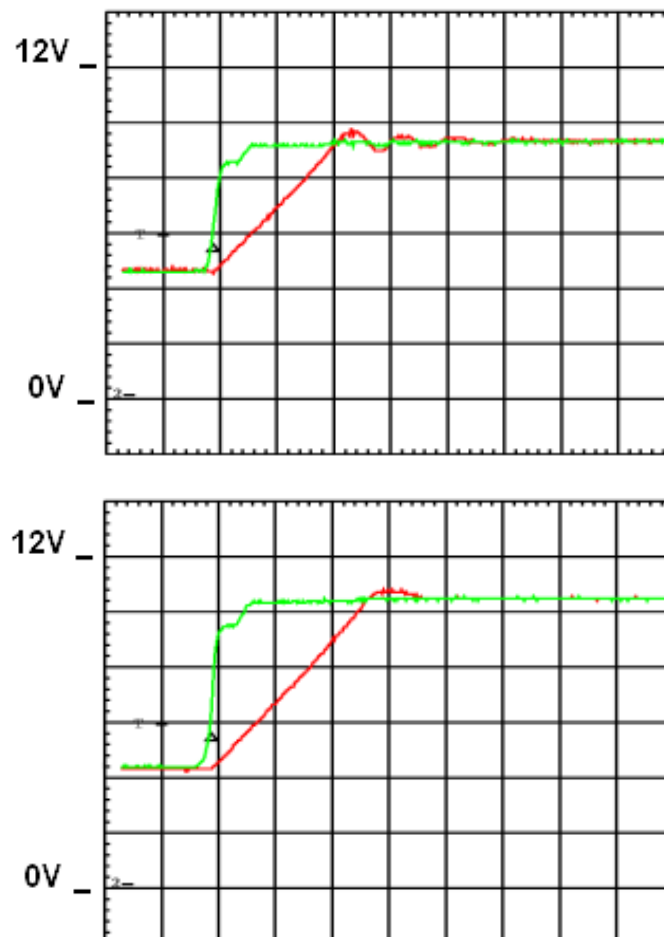
should either reverse the motor connections or swap the potentiometer leads around (the wiper lead should not be changed).

If the system hunts (goes backwards and forwards repeatedly) reduce the system gain by adjusting R11. See the notes regarding having too much gain.

In the following oscilloscope images, the time base (horizontal direction) is 500mSec per large division. The green trace is the output (pin 6) of IC1 and the red trace is the wiper of R4. The motor used for these images has a very high gear ratio so the system is very slow.

You should adjust R11 to have as much system gain as possible without hunting.

In the first image the gain is too high and you can see that servo overshoots (goes too far) and hunts. In the second image, the gain is reduced so the servo only overshoots a little and then settles down immediately.



The circuit may well behave strangely if the gain is very high.

Circuit description

The input signal is 0 to 5 Volts but our circuit is a 12 Volt circuit so we need to amplify the input to convert it to a 0 to 12 Volt signal. IC1 performs this task. R1 connects the input signal to the non-inverting input (pin 3) of IC1. R2 and R3 potentially divide the output (pin 6) of IC1. The reduced output, at the junction of R2 and R3, is connected to the inverting input (pin 2) of the operational amplifier IC1. Any small difference in Voltage between the inputs (pins 2 and 3) is greatly amplified. The effect of this is that the Voltages on these inputs are kept equal. This means that the output must have a higher Voltage than the input as it is divided by R2 and R3. The gain of the amplifier is therefore $(R2 + R3)/R3$.

IC2 is configured as a differential amplifier as discussed in the chapter on sensors. The output is biased by R7 and R8 to be half the supply Voltage. IC2 amplifies, the difference between the output of IC1 and the Voltage on the wiper of the feed back potentiometer R4, by a factor of 10. If the two Voltages are equal, the output of IC2 will be 6 Volts and if the wiper Voltage is 0.5 Volts higher than the output of IC1, the output of IC2 will be 11 Volts being 10 times 0.5 Volts plus 6 Volts. C1 reduces the gain of IC2 for high frequencies to reduce the unwanted noise in the system. [Click here](#) to go to the description of differential amplifiers.

CLICK

R12 and R13 provide a 6 Volt bias for the non-inverting input of IC3. These operational amplifiers cannot provide sufficient current to drive motors, so we are using some Darlington transistors to buffer the amplifier's output.

You can consider a Darlington transistor as being a very high gain ordinary transistor, which has twice the Cutin Voltage. The configuration of these two transistors T1 and T2 is called a totem pole emitter follower. Let us consider the action of T1. When the base (b) Voltage increases to the Cutin Voltage of the transistor, the transistor turns on and current flows through the collector (c) to the emitter (e). This causes the Voltage at the emitter to increase. The emitter Voltage then follows the base Voltage maintaining a Voltage difference between base and emitter equal to the Cutin Voltage. T2 acts in the same way except that the transistor's polarity is reversed. T1 is NPN and T2 is PNP. For T1 co conduct, the base Voltage needs to be a little over a Volt higher than the emitter and for T2 to conduct, the base voltage needs to be a little over a Volt lower than the emitter. It can be seen therefore that they cannot both be on at the same time as there is a little over 2 Volts difference between the Voltages necessary to turn them on.

R19 connects the output of IC3 to the input of the emitter follower pair T1 and T2. The emitters can now be considered as the output of IC3. Because of the 2 Volt difference between the base Voltages necessary to turn the transistors on,

IC3 would be unstable, so C2 is necessary to reduce the gain of IC3 at high frequencies.

R11 alters the gain of the amplifier. Any small difference in Voltage between the inputs (pins 2 and 3) of IC3 is greatly amplified and the output, which is now the emitters of T1 and T2, changes its Voltage greatly. This output Voltage is fed back to the inverting input (pin 2) by R14 and a proportion of R11 and the input to the amplifier is connected to the output of IC2 via R10 and the remaining proportion of R11. The amplifier inverts the output of IC2. If the output of IC2 becomes more positive than pin 3 of IC3, the output of IC3 at the emitters of T1 and T2 become more negative until the Voltage on pin 2 becomes equal to the Voltage on pin 3. The setting of R11 changes the output Voltage necessary to keep the two input Voltages equal.

IC4 and its associated circuitry is the same as IC3 except that the gain is minus 1. This means that the output is inverted. If the output of IC3 at the emitters of T1 and T2 becomes more negative than 6 Volts, the output of IC4 at the emitters of T3 and T4 will become more positive than 6 Volts by the same amount.

C4 reduces the radio interference and R21 helps to reduce the effect of C4 on the power supply, as this may be a problem if the circuit is to be powered by a single supply.

Fault finding

The first thing to do is give the circuit a thorough visual inspection with a spy glass looking for bad solder joints and short circuits. Check that the circuit you have built exactly matches the circuit diagram and that the components are the correct values and connected the right way round.

If the 12 Volt power supply was short circuited or had a greatly reduced output, remove the IC's one at a time and try again. If that does not help, there must be a short circuit or misconnection. The only connections to the 12 Volt rail should be pin 7 of the IC's and R4, R7, R12, and R15. If the removal of an IC restores the output of the power supply, check for short circuits on the pins of the IC socket. Make sure that the IC was the correct way round. It is possible that the IC is faulty. Try replacing the IC, if that helps, throw the old IC away.

If the 12 Volt motor supply is not OK, check the Darlington transistors. Make sure that the correct polarity ones are used in the correct places. That is, ensure that T1 and T3 are the TIP121 type and that T2 and T4 are the TIP126 type. Check the transistors for short circuits, open circuits and bad solder joints. Ensure that the transistors are connected the right way round and that the tags on them are not touching any part of the circuit as they are connected to the collectors.

Assuming that the power supplies are OK, set your meter to the 20 Volt DC range and connect the common input to the 0 Volt rail. Set the input to approximately 2.5 Volts. You may use a potentiometer connected between the supply rails and use the wiper as an input. Measure the voltage at the output (pin 6) of IC1. It should be about 6 Volts. If it isn't, check the Values of R1, R2 and R3. Check that pin 4 is connected to 0 Volts and that pin 7 is connected to the 12 Volt rail. Check that pins 1, 5 and 8 are not connected anywhere. Check for short circuits, open circuits and bad solder joints. If none of this helps, try replacing IC1. If that helps, throw the old IC away.

Assuming that the output of IC1 is OK, disengage R4 from the motor, disconnect the motor and adjust R4 manually to give the same Voltage at the wiper as the output of IC1, which should be about 6 Volts. If adjusting it does not change the wiper Voltage, you either have a faulty potentiometer or you have not connected it correctly. With the two Voltages (the wiper of R4 and the output of IC1) equal, the output of IC2 should be 6 Volts. If it isn't, check the values of R4, R5, R6, R7, R8 and R9. Look for short circuits, open circuits and bad solder joints. Check that pin 4 is connected to 0 Volts and that pin 7 is connected to the 12 Volt rail. Check that pins 1, 5 and 8 are not connected anywhere. Check for short circuits, open circuits and bad solder joints. If none of this helps, try replacing IC2. If that helps, throw the old IC away. Now slightly adjust R4. The output of IC2 should change 10 times as much as the input, so 0.5 Volts change in the wiper Voltage should give a 5 Volt change in the output. If it doesn't, check the resistor values again.

Assuming that IC2 is now OK, check that the circuit of IC3, T1 and T2 is OK. Adjust R4 to give 6 Volts at the output of IC2. Check the output Voltage at the emitters of T1 and T2. You should have a reading of about 6 Volts. If you don't, check the values of R10, R11, R12, R13, R14 and R19. Check that T1 and T2 are connected the right way round. Check that pin 4 is connected to 0 Volts and that pin 7 is connected to the 12 Volt rail. Check that pins 1, 5 and 8 are not connected anywhere. Check for short circuits, open circuits and bad solder joints. If none of this helps, try replacing IC3. If that helps, throw the old IC away. Now adjust R4 so that the output of IC2 is 6.5 Volts. Measure the output at the emitters of T1 and T2. Adjust R11 you should now get readings lower than 6 Volts and altering R11 should change the amount by which the output is lower. Adjust R11 to give the nearest output to 6 Volts, which should be about 5.5 Volts. This will set the system to minimum gain and maximum stability. You can increase the gain once the circuit functions correctly.

Assuming that the output of IC3 is OK, adjust R4 to give 6 Volts at the emitters of T1 and T2. Check the Voltage at the emitters of T3 and T4. It should be 6 Volts. If it isn't, check the values of R15, R16, R17, R18 and R20. Check that T3 and T4 are connected the right way round. Check that pin 4 is connected to 0 Volts and that pin 7 is connected to the 12 Volt rail. Check that pins 1, 5 and 8 are not connected anywhere. Check for short circuits, open circuits and bad

solder joints. If none of this helps, try replacing IC4. If that helps, throw the old IC away. Now adjust R4 to give 4 Volts at the emitters of T1 and T2. Now measure the Voltage at the emitters of T3 and T4. The reading should be 8 Volts.

Assuming that the circuit functions OK, reconnect the motor and reengage the feedback potentiometer R4. Now check that the motor drives the potentiometer the right way. The motor should drive the potentiometer so that the wiper Voltage becomes equal to the output Voltage of IC1. If it goes in the opposite direction, either swap the motor connections around or the ends of R4 around. You should note that changing the motor connections around at the motor terminals rather than at the limit switches will cause the diodes of the limit switches to be the wrong way round.

Now adjust R11 to give the optimum system gain.

Stepper motors

There are many commercially available drives for stepper motors that are reasonably priced.

The advantage of using stepper motors is that they give a precise movement for a given signal. The drivers need a direction signal and a pulse for every small angle of motor rotation. The motor defines the angle of rotation for each pulse. By sending a fixed number of pulses, you can instruct the motor to rotate a particular amount. This makes them particularly suitable for microprocessor applications.

Stepper motors will make a noise as they move. They move in a slightly jerky manner, which may or may not be a disadvantage according to the work. They use current just to stay where they are.

AC motors

There are many commercially available motor drives. If you simply want to switch them on and off, you can use a relay. You must ensure that any mains/high Voltage devices are made safe so that neither the maker nor anyone else can suffer an electric shock. All connections should be enclosed in a suitable box/cabinet. Always use an earth leakage (residual current) circuit breaker. To see the section on mains, in the chapter on construction, click on link.

[LINK](#)

Many motors get very hot whilst running so you will need to establish that the motor you intend to use will be suitable for the length of time it will be on. Some motors should only be on for 20 minutes every hour. You are more likely to get reliable information from the motor makers than from the motor sellers.

You can use dimmer switches as speed controls for small mains motors but the amount of control available with capacitor start motors is limited.

Synchronous motors will run at a speed, which is determined by the mains frequency so it is not possible to have a speed control for them by simple means.

Solenoids

Solenoids are inductive. You can use the circuits for switching motors to switch solenoids.

Solenoids are a convenient and cheap way of making small movements. The force is dependent on the position of the plunger within the solenoid.

There are some rotational solenoids available. You should examine the catalogues to see the range available.

If you use mains solenoids, you must follow the instructions in the mains section of the chapter on construction. You should only use relays to switch mains devices and highly inductive loads like solenoids should use a suitable snubber across the switch contacts. You should contact the maker of your solenoid for advice on snubbers.

. To see the section on mains, in the chapter on construction, click on link.

[LINK](#)

Pneumatics

Usually the interface between pneumatic devices and electronic circuits involves the use of solenoid valves. These should be treated in the same way as solenoids.

If you go to a specialist supplier of pneumatics, they should tell you exactly which parts you need for a project and how to use them.

Chapter 11

Lights

There are basically five types of lights. There are Light Emitting Diodes (LED's), incandescent lamps (light bulbs), fluorescent lamps, neon and lasers.

LED's

LED's require a direct current to make them function. They may be turned on and off as often as you like without damage or reduction in life. They will last for many years if they are not maltreated. Their colour is nearly independent of light intensity. Their intensity is easy to control. They can be very efficient, though this is largely dependent on their price. They are limited in the amount of light that they can generate, though this gets better daily with better and better devices coming onto the market. One of the problems with LED's is that the viewing angle of bright lights tends to be quite small and the wide angle LED's can only produce a wide angle by means of a built in diffuser.

There are LED's available in several colours. There are also some tri-colour LED's which are basically three LED's in one package having the colours red, blue and green. By varying the relative intensities of the three LED's, different colours can be produced. These are the same three colours that are used in television sets.

The amount of light emitted from an LED is an approximately linear function of the current passing through it. That is, if you double the current you will get approximately double the light from it. You may notice that if you pulse the current through an LED, you may increase the current through the LED. You will not, however, be able to increase the maximum light available as the maximum average current remains nearly constant and because of the linear relationship between light emitted and current. If you pass too much current through an LED, it will fail. If you work at the limit of its specification, you will note an initial dimming of the light, but after a while this reduction of light output becomes constant so that by the time you have experimented with your work for a while, the light output will become stable for many years.

LED's are diodes and will therefore only pass a current in one direction. They must be connected the right way round. The allowable reverse Voltage of LED's is not normally very high so they may well get damaged by being connected the wrong way round. You can use your meter to establish which lead is which before connecting them to your circuit. Set your meter to the diode symbol. Now connect across the LED being tested. With the leads one way round, it will indicate an open circuit and the other way round will give a reading. When the meter gives a reading, the common lead is the cathode and the other lead is the anode. The reading is the Cutin Voltage, which you should note. If you have the leads connected to your meter the correct way round, the black lead will be connected to the common (COM) terminal.

Since the LED's are always used so that a current flows, that is in a forward biased mode, the cathode should always be more negative than the anode.

The Cutin Voltage indicated by a meter is for low currents and this will increase slightly when the current is increased. It is also dependent on the temperature of the LED. The meter reading will, however, be a reasonable approximation of the value in use.

It is no good just connecting an LED across a power supply as the current taken will be too high and the LED will fail. You can use a constant current generator to drive an LED but since you should always use a regulated power supply anyway, this is unnecessary. Instead you should use a resistor in series with an LED to limit the current flow.

LED's have very different Cutin Voltages according to what type and colour they are. The Cutin Voltage for some may be 1.5 Volts and for others it may be as much as 5 Volts. The Cutin Voltage is specified in catalogues as the forward Voltage or V_F . The maximum current is usually specified as the forward current or I_F .

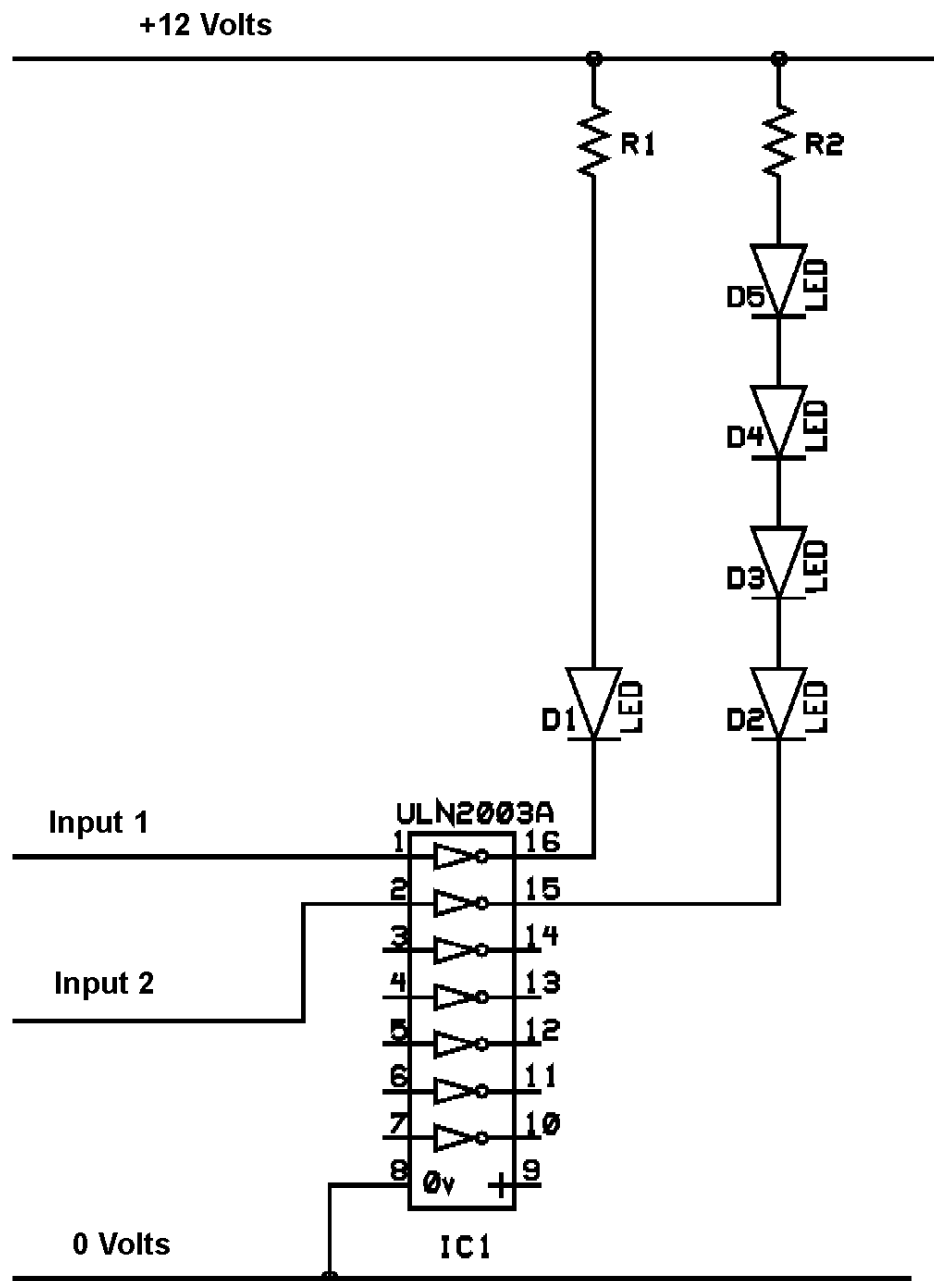
You will need to know the Cutin Voltage so that you can calculate the appropriate value of the series resistor. If you want several LED's on at the same time, you may connect them in series. If you have a 12 Volt supply and the Cutin Voltage is 2 Volts, you can connect up to 4 of them in series giving a combined Cutin Voltage of 8 Volts. This would leave 4 Volts for a switch and series resistor. Having less than 4 Volts for the series resistor and switch would not be a good idea, as the current through the LED's would vary considerably with temperature and small variations in the supply Voltage.

Most LED's have a maximum current in the range of 5mA to 100mA and are therefore ideally suited to being switched by Darlington drivers. LED's are not inductive and therefore do not require the diodes that are needed when switching inductive loads like solenoids and motors. Also they do not need the suppressor capacitors that motors need. Apart from that the switching and controlling circuits are very similar. Because the circuits are so similar, you should go to the sections on switching and speed control in the chapter on prime movers for circuit descriptions and fault finding.

LED switching circuit.

In the following circuit, a Darlington driver IC is used to switch LED's. Input 1 is used to switch a single LED and input 2 is used to switch 4 LED's in series.

The resistor values are not given as they depend on the Cutin Voltage of the LED's and the current required. Let us assume an example using some high intensity LED's with a Cutin Voltage of 2 Volts and through which we wish to pass 50mA.



LED switching circuit

IC1 ULN2003A

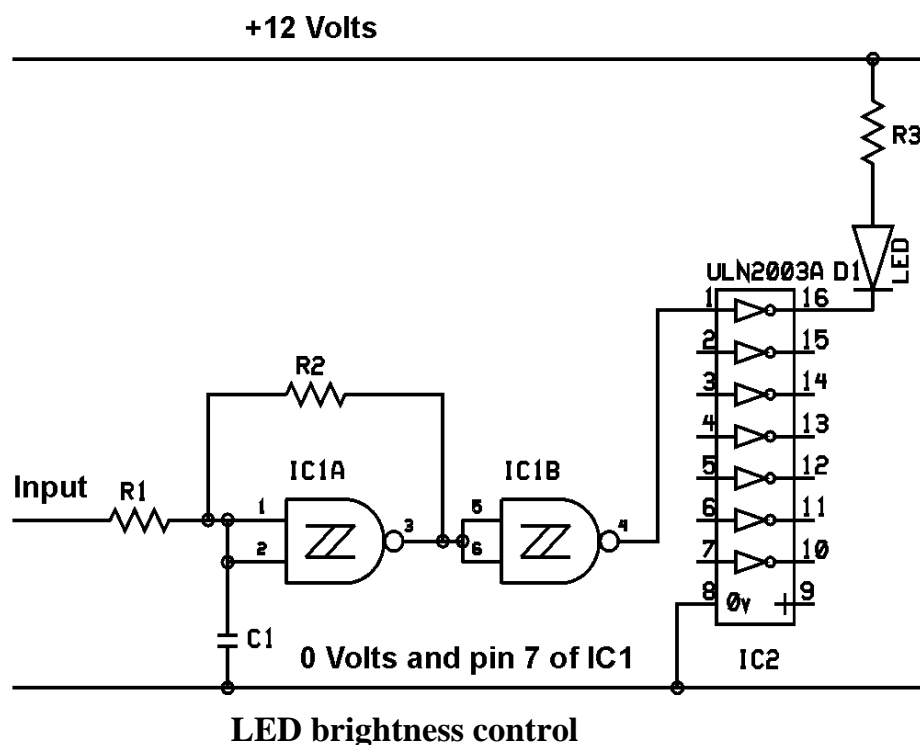
Darlington Drivers



The Darlington drivers have a Volt drop of about 1 Volt so when they art on, there are 11 Volts across the LED's and resistors. Let us consider R1 first. We have 11 Volts less the Cutin Voltage of D1, which we have decided will be 2 Volts for the sake of example. This leaves 9Volts across R1 and a current of 50mA. By Ohm's law, we can calculate the resistance, which is the Voltage

divided by the current. The Voltage is 9 and the current is 50mA or 0.05A. 9 divided by 0.05 equals 180 Ohms. This happens to be highly convenient as 180 Ohms is a standard value. We now need to know how much power the resistor, will dissipate, as if we use one, which is too small, it will get very hot and burn out. The power is the Voltage times the current, which is 9 times 50mA, which equals 450mW. Small general-purpose resistors are only rated at 250mW so we need a power resistor. It would be prudent to use one capable of dissipating at least twice the actual power dissipated as manufacturers assume that their devices will be used strapped to a railway line in a freezer. You should therefore use a resistor of at least 1Watt.

Let us now consider R2. We have 11 Volts available when input 2 is at 5 Volts. We have 4 LED's at 2 Volts each, which is 8 Volts, leaving 3 Volts across R2 when the LED's are on. If we now use the same mathematics we get a resistor value of 3 divided by 0.05, which equals 60 Ohms. You will now spot the problem, 60 Ohms is not a standard Value. We can either use a different value and have a different current flowing through the LED's or we can make a 60 Ohm resistor from other resistors either in series or in parallel. Well in this instance it would be easier to have two 120 Ohm resistors in parallel to give us the 60 Ohms we need. This also has the advantage of halving the power dissipated in each resistor. The current flowing in each resistor will now be 25mA being half of 50mA. The power dissipated in each resistor is 3 Volts times 25mA, which equals 75mW. This is well within our safety margin for standard ¼ Watt resistors.



This circuit is a combination of the previous circuit and the motor speed control circuit. The means of establishing the value of R3 is the same as the previous circuit.

The only difference between this circuit and the motor speed control is that there is no motor Voltage feedback, as there is no motor, and a Darlington driver has been substituted for a MOSFET. You should change the value of C1 to 0 μ 1F and you may like to increase the value of R1 to increase the active input Voltage range. Go to the section describing the motor speed control by clicking on the following link. Please note that R3 of this circuit is not the same as R3 on the motor speed control.

[LINK](#)

Incandescent (light bulbs)

These can be either low voltage as in torch bulbs and car bulbs or mains bulbs.

They generate light by making a filament very hot. The resistance of a filament increases with temperature so when a bulb is turned on there is a large surge of current until the bulb is fully on. **This current surge is generally of the order of ten times the normal operating current.** Light bulbs generate a lot of infrared. They change colour when they are dimmed, becoming more red or yellow. They have a limited life. This is particularly the case with high brightness lamps and it would be prudent to look at the expected life span when choosing a high brightness lamp.

Because incandescent lamps rely on getting very hot to produce light, they will have a reduced life span if they are turned on and off frequently. This is because of the thermal expansion and contraction of the filament when turned on and off. You will have observed that when light bulbs come to the end of their lives, they usually fail when turned on.

If you want to switch mains powered lights on and off using your circuits, you should use a relay, which is an electrically operated switch. Dimmer switches and power controllers are available for the control of mains powered light bulbs.

Generally speaking, incandescent lamps draw too much current for the Darlington driver IC's so you should use the same circuits for switching and brightness control as the motor control circuits except that there is no point in having the motor Voltage feedback circuit in the speed control and the protective diode and capacitors are not needed.

To go to circuits for switching and controlling low Voltage (24Volts or less) incandescent lamps, [click here](#).

[CLICK](#)

Fluorescent

Fluorescent lamps are high voltage devices and are normally mains driven. They produce a light, which is normally greenish. There are high frequency and daylight- matched types available from specialist lighting suppliers.

You should not attempt to use a dimmer switch or power controller with fluorescent lights. They may be switched on and off using relays but the amount of light cannot be controlled by simple means.

Neon

Neon lamps are high voltage devices and are normally mains driven. They should be switched using relays or professionally made controllers. They may be dimmed using an ordinary light dimmer or power controller. Other inert gasses can be similarly used to produce a variety of colours.

Lasers

These devices should be treated with great care as they can **cause severe damage to you eyes.**

You should only use professionally made controllers for these devices.

Chapter 12

Sound

This chapter will be divided into pre-recorded sound, live sound from microphones and generated sound (sound synthesizers).

Pre-recorded sound

Tape is a favoured means of playing sound because the tape can be made to travel over long distances. There are problems with this however as tape wears out and is liable to break. It would be prudent to make several copies and use the copies rather than the original.

Cd's and minidisk do not have the same visual experience but will not wear out or break. They may get dirty however.

Sound mute with pause output

It is quite common for artists to want to turn the sound on and off. When the pause input on consumer cd and minidisk players is operated, the makers have decided in their wisdom to cause a bleeping sound to be heard. There are two ways to avoid this problem. You can either not use the pause button and silence the player or you can use the pause button and silence the bleeps. Switching the output of these devices will cause a click to be heard so the silencing needs to be done by the equivalent of turning the volume control down and up. You should use players, which have pause inputs rather than just buttons. The pause inputs should be switched using relays.

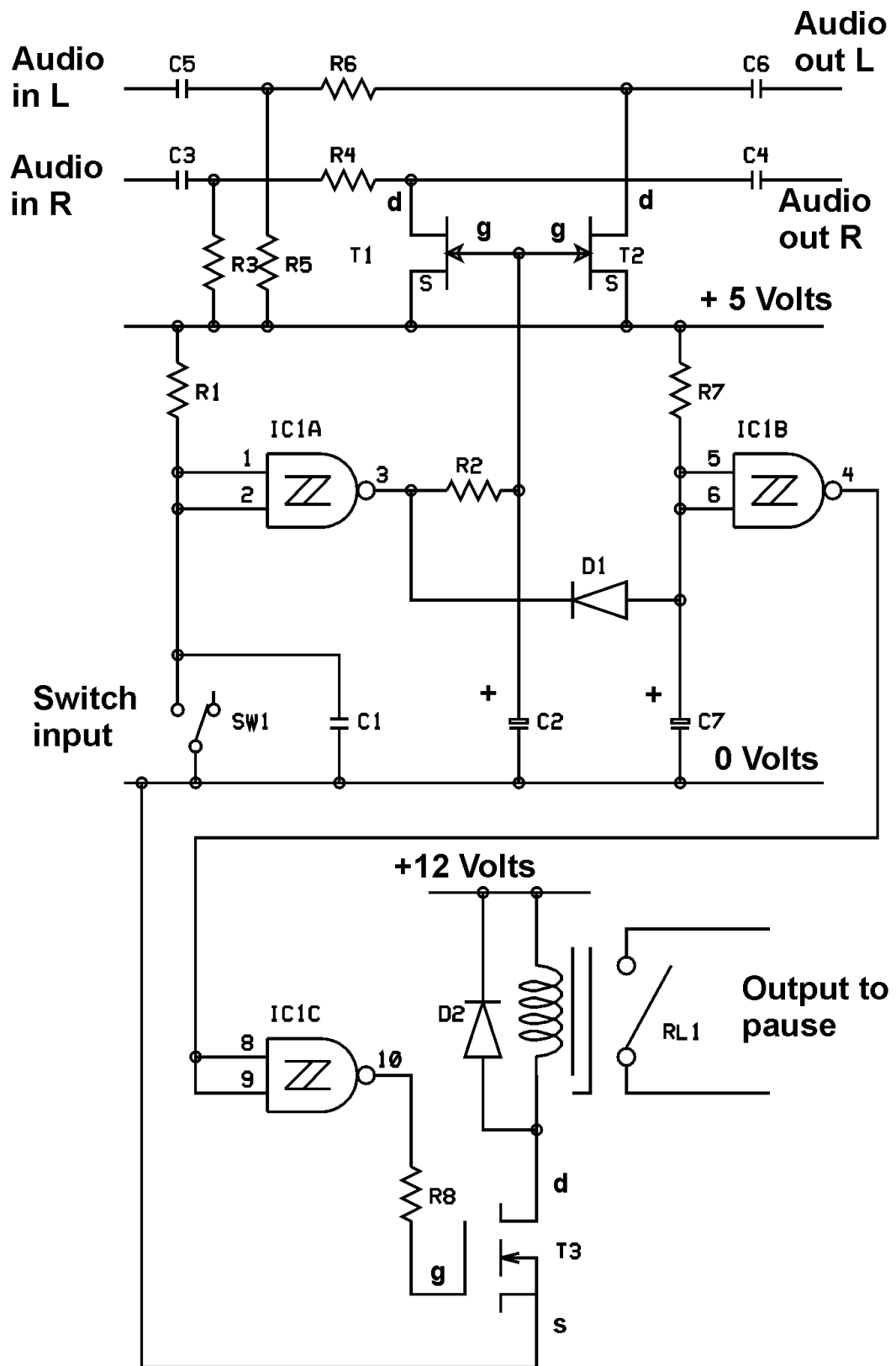
The following circuit has a switch input, which is a normally open switch. The circuit silences the sound when the input switch is closed. If you want to use this circuit with a normally closed input, you will need to invert the input with a gate. There is a spare gate available.

If you are using a digital signal other than a switch, you do not need R1, C1 or SW1. You simply use pins 1 and 2 of IC1A as an input.

The circuit has two audio inputs and two audio outputs. The inputs should be connected to the audio outputs of your cd or minidisk player and the circuit's outputs should be connected to your audio amplifier's inputs.

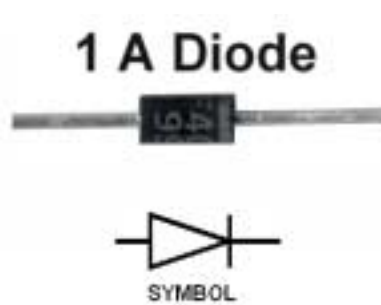
This circuit slightly reduces the volume so you will need to turn the volume up a bit. In operation the circuit normally allows the sound to go straight through. When the input is activated, the sound level is reduced significantly and then the pause is activated. When the input signal is removed again, the pause is deactivated and the sound level is then restored.

You may want the sound to be muted but still have the player continue operating. If this is the case, much of the circuit will be redundant. You will not need R7, C7 IC1B, IC1C, R8, T3, D2 or the relay RL1.



Sound mute with pause output

R1 10K
 R2 100K
 R3 100K
 R4 22K
 R5 100K
 R6 22K
 R7 220K
 R8 4K7
 C1 0 μ 1F
 C2 4 μ 7F tantalum
 C3 1 μ F ceramic
 C4 1 μ F ceramic
 C5 1 μ F ceramic
 C6 1 μ F ceramic
 C7 4 μ 7F tantalum
 D1 1N4148
 D2 1N4002
 T1 2N3819
 T2 2N3819
 T3 RFP12N10L
 IC1 HEF4093BP
 RL1 see notes



2N3819



**RFP12N10L
N channel MOSFET**



Notes

The 12 Volt supply may be the same supply that is used to provide the 5 Volt supply.

The 0 Volt rail should be connected to pin 7 of IC1 and the 5 Volt rail should be connected to pin 14 of IC1.

The tantalum capacitors are polarized and must be connected the right way round. The negative ends should be connected to the 0 Volt rail.

The transistors are static sensitive and should not be handled without first earthing yourself.

RL1 is a relay. The switching current and Voltage will be very low, so almost any relay will do. Some relays can be quite noisy, producing a loud click when they operate. The most appropriate relays to use in this application are reed relays, which are generally quiet. You will need a relay with a 12 Volt coil. The relay contacts should be connected to a suitable connector to be plugged into the pause control socket on your cd or minidisk player. The relay contacts will be isolated from the circuit so it does not matter which way round you connect them. If your relay has changeover contacts, you should use the normally open contacts.

It is very important to check that D2 is connected the right way round before applying power to the circuit. If it is the wrong way round, it will probably be destroyed along with T3 and possibly your 12 Volt power supply as well. If you have a laboratory/test/bench power supply, set the current limit to about 100mA. This should protect your circuit from damage.

The screen of the audio inputs and outputs should be connected to the 0 Volt rail.

If IC1D is not used, connect the inputs (pins 12 and 13) either to the 0 Volt rail or the 5 Volt rail.

If you need to reduce the time it takes for the circuit to react to an input signal, you can add a 220K resistor between the gates (g) of T1 and T2 and the 5 Volt rail. If you reduce the value of C2, this will also reduce the time. The time it takes needs to be long enough to inhibit any clicks heard. This is determined by the characteristics of your amplifier and speaker system and how loud a click you can tolerate. The pause output signal occurs about one second after the input signal is activated and is removed almost immediately. This is to ensure that any sound produced by your cd/minidisk player is silenced before the pause occurs to prevent any bleeps for being heard. If your player does not produce any bleeps for the first second of the pause activation, you can reduce the value of C7 to 0 μ 1F. This will have the effect of pausing the player almost immediately and then silencing the player before the bleeps occur. As you can see, this is all a matter of your particular system. The circuit as shown is a general purpose one intended to cope with any cd/minidisk player but as a consequence, is slow to react.

Testing

Before applying power to the circuit, inspect the circuit thoroughly using a spy glass ensuring that there are no unwanted short circuits or open circuits and that the circuit follows the diagram exactly. Ensure that the power supply is connected the right way round. Then set your meter to continuity or low Ohms range. Connect the meter across the 0V and 5V supply and make sure that the reading is not zero or near to zero. You may get a bleep or a low Ohmic value for a short time because of the capacitor in the power supply, but this should not last more than a few seconds. If it is continuous, you have a short circuit somewhere and you should follow the instructions in the fault finding section. If you do not get the expected results, you should switch the circuit off immediately.

Set your meter to the 20 Volt DC range. Connect your meter across the 5 Volt supply and switch on the supply. If the reading is much below 5 Volts, switch off immediately and go to the fault finding section.

Set your amplifier to a low volume in case you get some very loud sounds, which may damage your loudspeakers, from the circuit. Connect the audio inputs and outputs as well as the pause control output. Switch on the power supply. Operate the input switch and see if the sound is quietened and the pause works. You will need to see that the sound continues, from the point at which you stopped it, after the input switch is de-activated, to test that the pause control functions correctly.

Circuit description

The oscilloscope images, shown in this section, have a time base (horizontal direction) of 200mSecs. per large division.

The muting of the sound is performed by using the junction field effect transistors T1 and T2, which have a high resistance when they are turned off and a low resistance when on. They are on when the gate (g) Voltage is equal to the source (s) Voltage and turned off when the gate Voltage is a few Volts lower than the source Voltage. The devices show a variable resistance between the drain (d) and source when the source to gate Voltage lies between the on and off Voltages.

The circuit has two inputs and outputs, which are identical. Only the right (R) channel will be described here, as the left (L) is the same.

Because the gates of transistors T1 and T2 require Voltages lower than the sources to turn them off, the sources are connected to the 5 Volt rail rather than the 0 Volt rail.

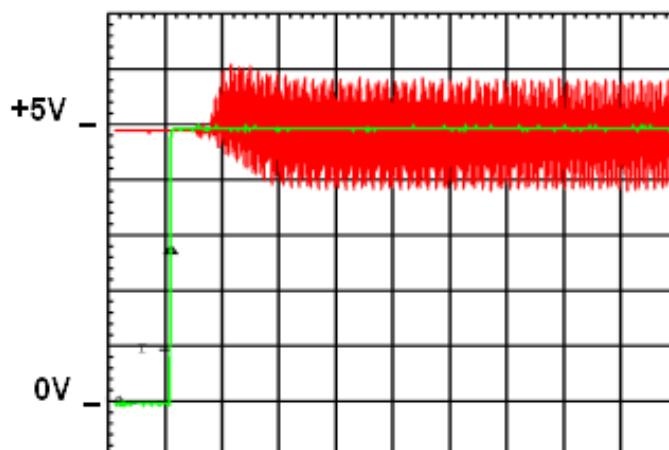
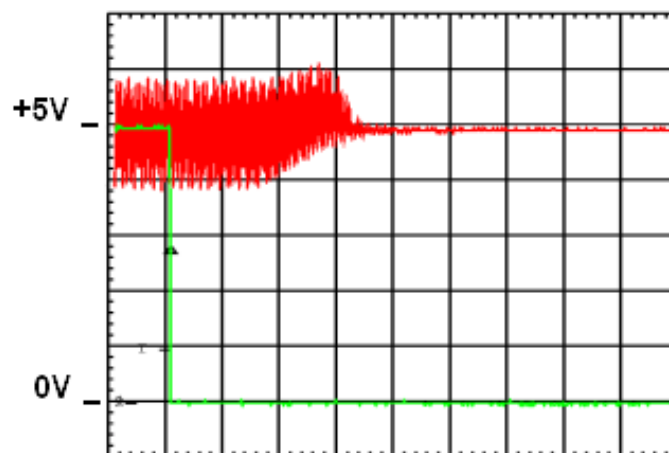
The audio signal from your cd/minidisk player is coupled to the circuit via C3, which allows the alternating Voltages to pass through but prevents the direct Voltages from passing through. This allows the alternating Voltages to be biased to any Voltage we like. In this case we choose the 5 Volt rail as a bias. This is achieved by connecting R3 between C3 and the 5 Volt rail. R4 connects the signal to the drain of T1 and the capacitor C4. C4 acts in the same way as C3. It allows the alternating signal to float for direct Voltages so that the 5 Volt bias does not affect the audio amplifier that the output is connected to. If T1 is off, the audio signal will pass through the circuit and the only reduction in the amplitude of the signal is caused by the resistor R4 and the input impedance of your audio amplifier. When the field effect transistor T1 is on, it has a low resistance compared with R4 and therefore the amplitude of the output audio signal is greatly reduced.

When the input switch SW1 is not operated, R1 puts a '1' on the input (pins 1 and 2) of IC1A and this causes a '0' at its output (pin 3). This is connected to the gates of the transistors T1 and T2 via R2. C2 acts to slow the process down. When the output of IC1A is a '0', T1 and T2 are off and the audio signal can

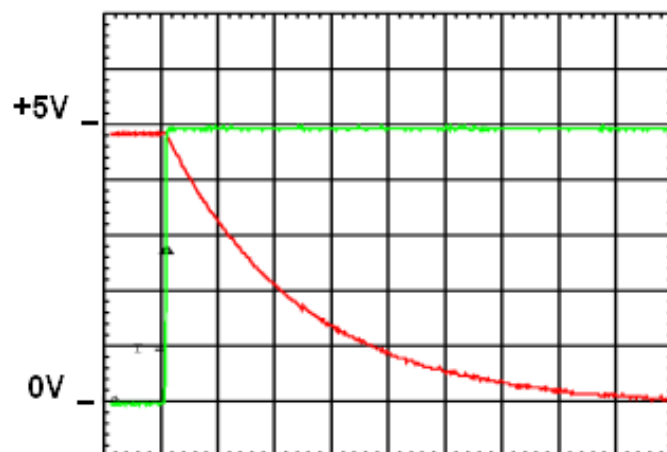
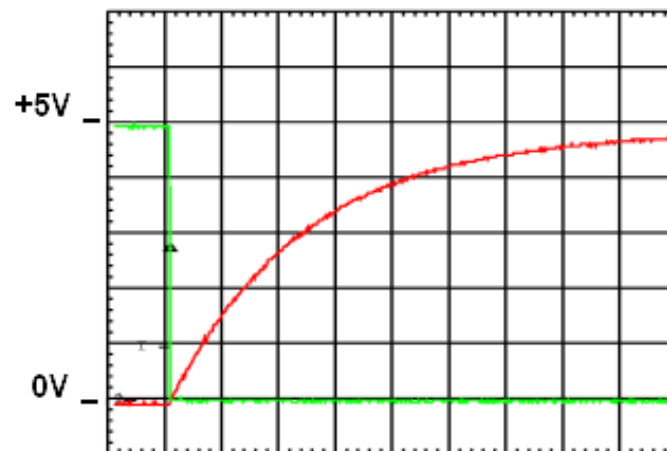
pass straight through the circuit. C1 acts to prevent noisy switch inputs from affecting the circuit.

When the input switch is operated, the input of IC1A becomes a '0' and therefore the output of IC1A becomes a '1'. The gate Voltage of T1 and T2 slowly rises to 5 Volts. When the gate Voltage reaches about 3 Volts, T1 and T2 start to conduct and the audio output signal starts to be reduced. When the gate Voltage reaches 5 Volts, the transistors are nearly fully on and the audio output signal is greatly reduced.

In the following oscilloscope images, the green trace shows the input of IC1A and the red trace shows the signal at the drain of T1. You will note that because the time base is slow, the red trace is too compressed to show the waveform of the audio signal but does show the amplitude.



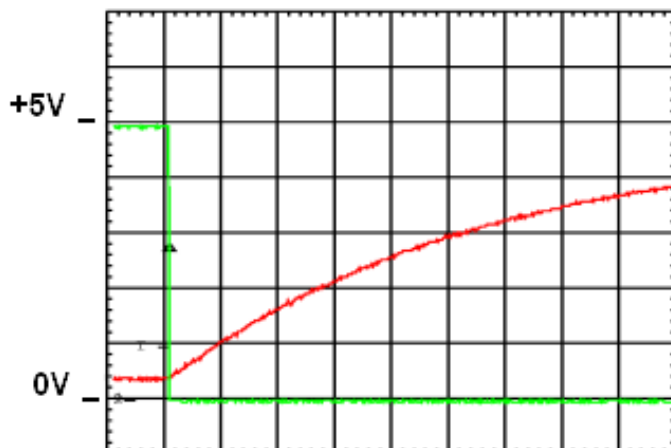
In the following 'scope images, the green trace shows the input of IC1A and the red trace shows the gates of T1 and T2.



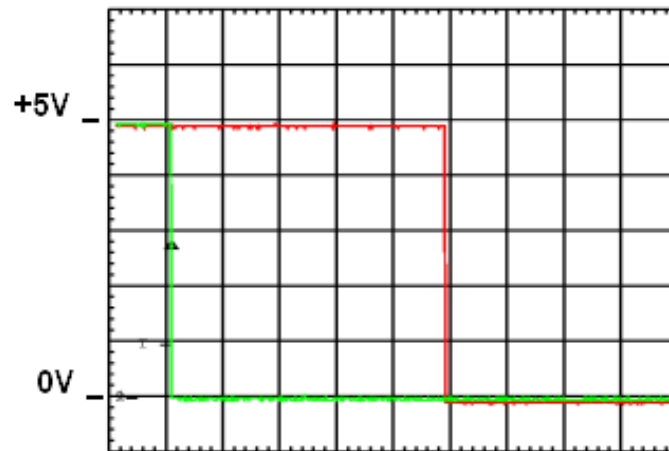
The output (pin 3) of IC1A is connected to the input (pins 5 and 6) of IC1B via D1. C7 is charged up slowly by R7. When the output of IC1A is a '0', C7 is shorted via D1 to about 0.5 Volts. When the output of IC1A is a '1', the diode does not conduct and C7 is slowly charged via R7.

In the following 'scope image, the green trace shows the input of IC1A and the red trace shows the input of IC1B.

Note that the red trace starts at about 0.5 Volts and slowly rises to 5 Volts.

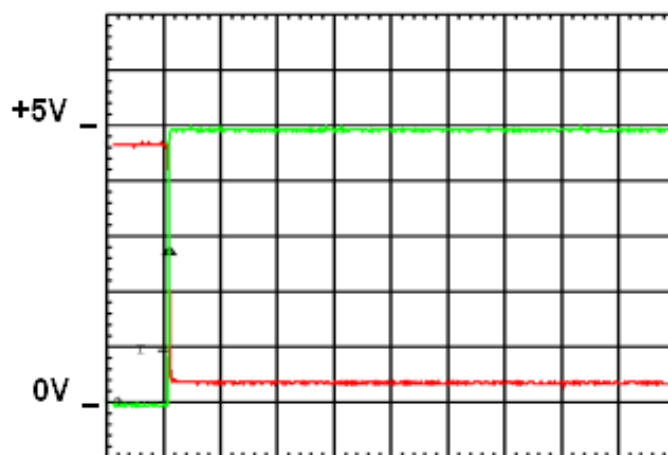


In the following 'scope image, the green trace shows the input of IC1A and the red trace shows the output of IC1B.



You will note that the output of IC1B goes to a '0' about a second after the input switch has been activated. If you look at the image of the audio signal at the drain of T1, you will note that it was silenced after about 800mSecs. So the output of IC1B goes to a '0' after the audio signal has been silenced. This is to prevent any bleeps from being heard if they should occur as soon as the pause has been activated.

When the input switch is de-activated, C7 becomes discharged quickly via D1. In the following 'scope image, the green trace shows the input of IC1A and the red trace shows the input of IC1B.



You will note that the red trace does not start at 5 Volts but is a little lower. This is due to the input resistance of the oscilloscope probe. The probe used was a X10 probe. If you were to use a X1 probe, the effect would be much greater. This is another example of a measuring instrument affecting the circuit.

The output of IC1B is connected to the input (pins 8 and 9) of IC1C and the output (pin 10) of IC1C, which is the inverse of the input (when the input is a

'0', the output is a '1' and when the input is a '1', the output is a '0'), is connected to the gate (g) of the MOSFET T3 via R8. When the output of IC1C is a '0', T3 is off and when it is a '1', T3 is on. When T3 is on, the relay RL1 is energized. D2 is there to protect T3 from the Voltage spikes across the relay coil when it is turned off, by shorting them out to the 12 Volt supply.

Faultfinding

The first thing to do is give the circuit a thorough visual inspection with a spy glass looking for bad solder joints and short circuits. Check that the circuit you have built exactly matches the circuit diagram and that the components are the correct values and connected the right way round.

If the power supply was short circuited or had a greatly reduced output, remove the IC and try again. If that does not help, there must be a short circuit or misconnection. If the removal of an IC restores the output of the power supply, check for short circuits on the pins of the IC socket, in particular any outputs of the IC. Make sure that the IC was the correct way round. It is possible that an IC is faulty. Check the connections to the 5 Volt rail. Check that none of the outputs of the IC are connected anywhere that they shouldn't. The only connections to the 5 Volt rail should be R1, R3, R5, R7, T1, T2 and pin 14 of IC1.

Assuming that the power supply is OK, set your meter to the 20 Volt DC range and connect the common (COM) input to the 0 Volt rail. When the input switch is not activated, the Voltage at the input (pins 1 and 2) of IC1A should be at 5 Volts and when it is activated, the reading should be 0 Volts. If you do not get these results, check that you are using the correct terminals of SW1. Check the value of R1. Check that pins 1 and 2 of IC1 are connected together. Look for short circuits, open circuits and bad solder joints. If none of this helps, try removing IC1. If that helps, try replacing it and if that helps, throw the old IC away.

Assuming that the input to IC1A is OK, check the output (pin 3) of IC1A. When the switch SW1 is not activated, the reading should be 0 Volts and when the switch is activated it should be 5 Volts. If you do not get these results, look for short circuits, open circuits and bad solder joints. If none of this helps, try removing IC1. If that helps, try replacing it and if that helps, throw the old IC away.

Assuming that the output of IC1A is OK, connect screen of your oscilloscope probe to the 0 Volt rail. You should use a X10 probe if you have one. Check the signal on the gates (g) of T1 and T2. The appropriate oscilloscope images can be found in the circuit description. You will not see lines on the 'scope screen unless you are using a storage 'scope, as the dots will be moving too slowly across the screen, but you will see moving dots instead. If you do not get the correct waveforms, check that the Transistors T1 and T2 have been

connected correctly. Check the values of R2 and C2. Ensure that C2 was connected the correct way round having the negative end connected to the 0 Volt rail. If C2 was connected the wrong way round, replace it and throw the old one away as it will have been damaged. Look for short circuits, open circuits and bad solder joints. It is possible that one of the transistors is fault so if all else fails, try replacing them one at a time and if that helps, throw the faulty one away.

Assuming that you are getting the correct wave-forms at the gates of T1 and T2, connect an audio signal to the Right input on C3 using co-axial cable having the screen connected to the 0 Volt rail, and check the wave-form on the drain (d) of T1. If you do not get the correct waveform, check that you are getting a signal from your player. Check the component values. Check that you have connected the transistor the correctly. Look for short circuits, open circuits and bad solder joints. It is possible that one of the transistors is fault so if all else fails, try replacing them one at a time and if that helps, throw the faulty one away.

Assuming that the signal at the drain of T1 is OK, use the same procedure to check the signal at the drain of T2.

Assuming that the signals at the drains of T1 and T2 are OK, connect the audio outputs to your audio amplifier and check that the sound is OK. If it is not, check the values of C6 and C4. Look for short circuits, open circuits and bad solder joints. Check that the screens of the output cables, which should be co-axial, are connected to the 0 Volt rail. If you experience mains hum, it may be that your audio amplifier works better if the power supply for you circuit is earthed by connecting the 0 Volt rail to earth. It may be that the hum is reduced if your power supply is not earthed. There is usually an earth terminal at the rear of audio amplifiers. If there is, you should try using that as an earth connection to the 0 Volt rail of your power supply and not using any other earth connection. Just see which way gives the best results. Hum should not really be a problem as the output signal levels of cd/minidisk players are large enough to use a low gain on your amplifier.

Assuming that the audio signals are OK, connect your 'scope probe to the input (pins 5 and 6) of IC1B and check the wave-form. If you do not get the correct result, check that D1 is the correct way round. Check the values of R7 and C7. Check that C7 is connected the correct way round. If it wasn't, replace it and throw the old one away as it will have been damaged. . Check that pins 5 and 6 of IC1 are connected together. Look for short circuits, open circuits and bad solder joints. If none of this helps, try removing IC1. If that helps, try replacing it and if that helps, throw the old IC away.

Assuming that the input of IC1B is OK, check the output (pin 4) of IC1B. If you do not get the correct results, look for short circuits, open circuits and bad

solder joints. If none of this helps, try removing IC1. If that helps, try replacing it and if that helps, throw the old IC away.

Assuming that you get the correct signal at the output of IC1B, check that the output (pin 10) of IC1C is the inverse of the output of IC1B. That is, when the output of IC1B is 0 Volts, the output of IC1C should be 5 Volts and when the output of IC1B is 5 Volts, the output of IC1C should be 0 Volts. If you do not get the expected results, check that pins 8 and 9 of IC1 are connected together and that pin 4 is connected to pin 8 or 9. Look for short circuits, open circuits and bad solder joints. If none of this helps, try removing IC1. If that helps, try replacing it and if that helps, throw the old IC away.

Assuming that the output of IC1C is OK, check the value of R8. Check that D2 is the correct way round. If it wasn't the chances are that both D2 and T3 are damaged. Check that T3 is connected correctly. Check that the relay is connected correctly. Make sure that you are using the correct terminals of the relay. Check that you have connected both relay switch terminals to the pause input of your player. Look for short circuits, open circuits and bad solder joints.

Live sound

If you need to use very long cables to connect your microphone/contact-microphone to an amplifier, you will probably get some electrical interference or noise from the cable. If this is the case, you could use the circuit described in chapter 9 to amplify the signal near to the microphone rather than at the end of the cable. This gives a significant improvement in sound quality. To go to the circuit, [click here](#).

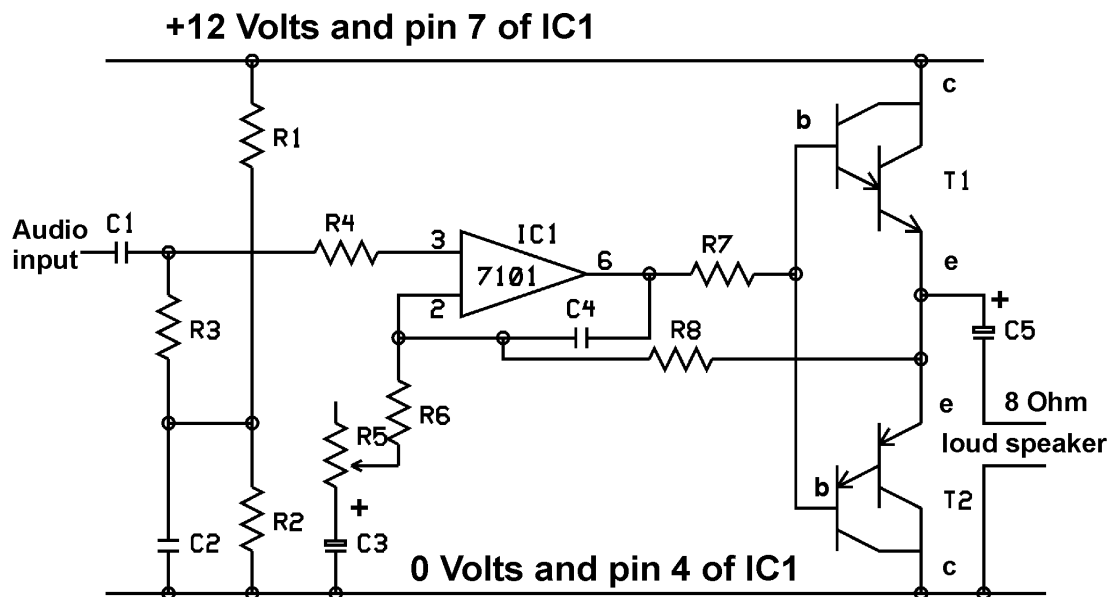
CLICK

You should always use screened/co-axial cable to connect microphones to amplifiers.

Low power audio amplifier

This amplifier is not a HI-FI amplifier but is quite adequate for speech and has the benefit of a low power consumption particularly when no sound is produced. This makes it suitable for battery operated sound works, which do not require loud outputs. Should you require higher sound levels or a better sound quality, there are plenty of commercially available products.

The problem with most HI-FI power amplifiers is that they use a substantial amount of power even when no sound is produced. This is fine if you are using a mains power supply or large batteries but is not very useful if you are using small batteries, which need to last a long time.



Low power audio amplifier

R1	10K
R2	10K
R3	100K
R4	10K
R5	20K potentiometer
R6	1K
R7	1K
R8	100K see notes
C1	1 μ F ceramic
C2	1 μ F ceramic
C3	4 μ 7F tantalum
C4	100pF
C5	2200 μ F electrolytic
T1	TIP121
T2	TIP126
IC1	7101 operational amplifier, any suffix or prefix should be OK. Connect pin 4 to 0V and pin 7 to + 5V. Do not make any connections to the unused pins.

OPERATIONAL AMPLIFIER



TIP121



TIP126



Notes

This circuit may be powered either by battery or by a stabilized mains power supply.

R5 is a volume control. If the volume is set too high, you will get severe distortion of the sound. If you cannot reduce the volume sufficiently with R5, you should reduce the value of R8. Try 22K first and if that is still too much, reduce it to 10K.

The choice of loudspeaker and mounting is important, particularly for low frequency sound. It is assumed that this circuit is to be used for speech and that therefore high frequency speakers will not help. You should choose a low frequency or mid- frequency loudspeaker. If you want to improve the low frequency characteristics of a speaker, you will need to mount the speaker in an enclosure so that the back of the speaker is in a sealed box of some sort and the front of the speaker is open to the environment. You will have to experiment with this if it is to be mounted within an art work. If it is to be a free standing speaker, you should use a commercial speaker housing.

If your audio input is from a commercial player like a tape recorder or cd player, you should connect the screen of the lead/cable to the 0 Volt rail.

Note the polarities of C3 and C5. If these are the wrong way round when power is applied to the circuit, they will get damaged. If C5 is the wrong way round when power is applied, T1 is also likely to get damaged.

Testing

Before applying power to the circuit, inspect the circuit thoroughly using a spy glass ensuring that there are no unwanted short circuits or open circuits and that the circuit follows the diagram exactly. Ensure that the power supply is connected the right way round. Then set your meter to continuity or low Ohms range. Connect the meter across the 0V and 12V supply and make sure that the reading is not zero or near to zero. You may get a bleep or a low Ohmic value for a short time because of the capacitor in the power supply, but this should not last more than a few seconds. If it is continuous, you have a short circuit somewhere and you should follow the instructions in the fault-finding section. Check that C3 and C5 are the correct way round. Ensure that T1 and T2 are the correct way round.

Connect the audio input to your signal source and switch on. Adjust the volume control R5 to the required volume. If you want the maximum volume, adjust R5 so the output is not distorted.

Circuit description

R1 and R2 provide a bias for the operational amplifier IC1. The Voltage at the junction of the two resistors will be half the supply voltage. C2 acts as a low resistance to alternating Voltages and thus reduces any noise from the power supply. C1 couples the input signal to the input of the amplifier and R3 acts to give the input signal to the amplifier a 6 Volt bias. That is the average Voltage at the junction of C1 and R3 will be 6 Volts. This biased input signal is fed to the non-inverting input (pin 3) of the operational amplifier IC1.

These operational amplifiers cannot provide sufficient current to drive loud speakers, so we are using some Darlington transistors to buffer the amplifier's output.

You can consider a Darlington transistor as being a very high gain ordinary transistor, which has twice the Cutin Voltage. The configuration of these two transistors T1 and T2 is called a totem pole emitter follower. Let us consider the action of T1. When the base (b) Voltage increases to the Cutin Voltage of the transistor, the transistor turns on and current flows through the collector (c) to the emitter (e). This causes the Voltage at the emitter to increase. The emitter Voltage then follows the base Voltage maintaining a Voltage difference between base and emitter equal to the Cutin Voltage. T2 acts in the same way except that the transistor's polarity is reversed. T1 is NPN and T2 is PNP. For T1 co conduct, the base Voltage needs to be a little over a Volt higher than the emitter and for T2 to conduct, the base voltage needs to be a little over a Volt lower than the emitter. It can be seen therefore that they cannot both be on at the same time as there is a little over 2 Volts difference between the Voltages necessary to turn them on.

R7 connects the output (pin 6) of IC1 to the input of the emitter follower pair T1 and T2. The emitters can now be considered as the output of IC3. Because of the 2 Volt difference between the base Voltages necessary to turn the transistors on, IC3 would be unstable, so C4 is necessary to reduce the gain of IC3 at high frequencies.

R5 alters the gain of the amplifier. Any small difference in Voltage between the inputs (pins 2 and 3) of IC3 is greatly amplified and the output, which is now the emitters of T1 and T2, changes its Voltage greatly. This output Voltage is fed back to the inverting input (pin 2) by R8. R6 and R5 reduce the proportion of the output Voltage that is present at the inverting input (pin 2). C3 acts as a short circuit for alternating signals and an open circuit for direct voltages. So for alternating signals, the gain of the amplifier is determined by the values of R5, R6 and R8 and the gain for non-alternating signals is unity (one). When the input on pin 3 increases, the output (pin 6) of IC1 increases greatly. This causes the emitters of T1 and T2 to have an increased Voltage. This Voltage will increase just enough to make the Voltages at the inputs of IC1 equal.

C5 couples the output of the amplifier to your loudspeaker. You need a capacitor there to prevent the direct Voltage from appearing across the speaker. You only want the alternating signal across the speaker.

Faultfinding

The first thing to do is give the circuit a thorough visual inspection with a spy glass looking for bad solder joints and short circuits. Check that the circuit you have built exactly matches the circuit diagram and that the components are the correct values and connected the right way round.

If the power supply was short circuited or had a greatly reduced output, remove the IC and try again. If that does not help, there must be a short circuit or

misconnection. If the removal of an IC restores the output of the power supply, check for short circuits on the pins of the IC socket, in particular any outputs of the IC. Make sure that the IC was the correct way round. It is possible that an IC is faulty. Check the connections to the 12 Volt rail. The only connections to the 12 Volt rail should be R1, T1, T2 and pin 7 of IC1. Check that T1, T2 and C5 are connected the correct way round. If they were not, these components may well have been damaged and need replacing.

Assuming that the power supply is OK, set your meter to the 20 Volt DC range. Connect the common (COM) terminal of the meter to the 0 Volt rail. Measure the Voltage at the junction of R1 and R2. It should be about 6 Volts. If it isn't, check the values of R1, R2, R3 and R4. Look for short circuits, open circuits and bad solder joints.

Assuming that the Voltage at the junction of R1 and R2 is OK, check the Voltage at the junction of R3 and R4. It should also be about 6 Volts. If it isn't, check the values of R3 and R4. Check that C1 is not short circuited. Look for short circuits, open circuits and bad solder joints. If none of that helps, try removing IC1 and if that helps, try replacing it and if that helps, throw the old IC away. Make sure that pins 1, 5 and 8 of IC1 are not connected anywhere.

Assuming that the Voltage at the junction of R3 and R4 is OK, check the Voltage at the emitters (e) of T1 and T2. This should also be about 6 Volts. If it isn't check that C3 is the correct way round and is not short circuited. Try replacing it and if that helps, throw the old one away. Check the component values. Check that T1, T2 and C5 are connected the correct way round. Check that C4 is not shorted out. Look for short circuits, open circuits and bad solder joints. If none of this helps, try replacing IC1 and if that helps, throw the old IC away.

Assuming that the Voltage at the emitters of T1 and T2 is OK, check that C5 is OK. Check that the resistance of the loudspeaker is about 8 Ohms. Check that you have an input signal. Check the values of R8, R6, R5, C3, C4 and C5.

Generated sound

You can use your computer to record and play sound or you can record sound on your computer and store it in a separate memory chip. To record sound on separate memory chips, you would need a computer, an EPROM burner and an EPROM eraser. You can only record a few seconds of sound on a single chip but it does give you the facility of playing it back at any speed. There are some greetings cards, which allow you to record messages and then play them back but these are not easy to alter. There are, however, some dedicated integrated circuits available, which are easier to use. If you want to use them, you should follow the instructions in the application notes available with the IC's. A typical IC for such applications is an ISD2560P, which has a microphone input, a low power amplifier for a 16 Ohm loud speaker and will record 60 seconds of

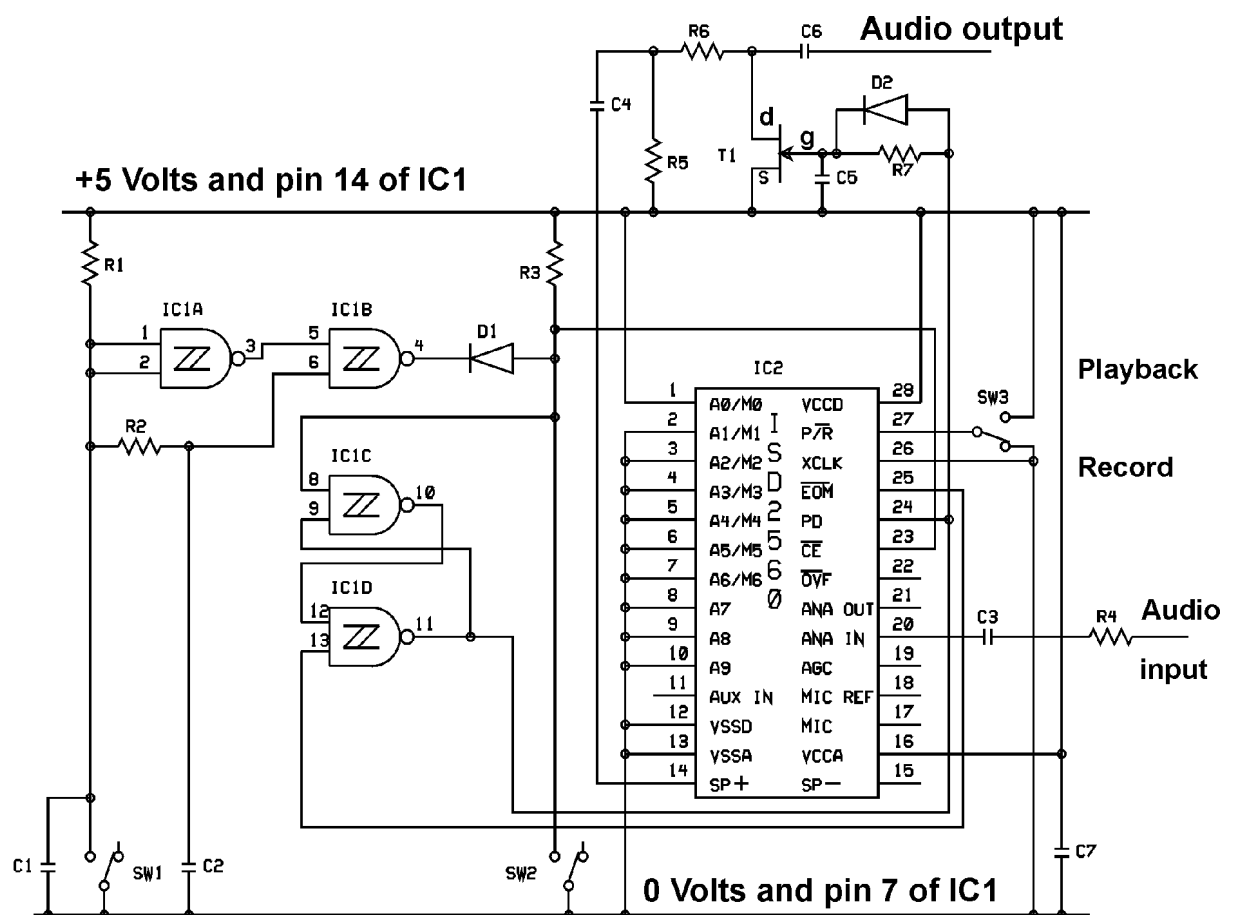
sound. The recording quality of all these devices is not of a high quality but is good enough for speech.

Speech recorder and playback.

The following circuit uses the ISD2560 to record from a computer/tape recorder/cd player/minidisk player and play back the sound whenever an input signal is present. The IC does have provision for a microphone input and very low power loudspeaker output but this circuit does not use those facilities. The IC also has the facility to record a number of different messages and play any one of them back or play a message continuously. If you wish to use these facilities, you should ask your IC supplier for a data sheet and application notes. In the circuit shown here, the audio output is intended to be connected to the input of an audio amplifier as described in the circuit notes.

This circuit can record and playback up to 60 seconds of sound.

You may need the use of an oscilloscope for fault finding.



Speech recorder and playback

- R1 10K
- R2 1M
- R3 10K
- R4 100K



R5	100K
R6	22K
R7	100K
C1	0 μ 1F
C2	0 μ 1F
C3	1 μ F
C4	1 μ F
C5	1 μ F
C6	1 μ F
C7	0 μ 1F
D1	1N1418
D2	1N1418
T1	2N3819
IC1	HEF4093BP
IC2	ISD2560P

2N3819



ISD2560P



Notes

The IC ISD2560P generates noise on the power supply. This needs to be suppressed. C7 performs this function and should be mounted as close to the IC as possible. It should be connected between pins 12 and 28.

The switch SW1 starts the playback and may be replaced by a 5 Volt digital signal if required. If SW1 is not used, C1 becomes redundant. If a digital signal is used, playback is activated every time the signal goes from 5 Volts to 0 Volts.

The switch SW2 is only used during sound recording and needs to be closed for the duration of the recording and opened again as soon as the recording is finished.

Switch SW3 determines whether the circuit is in record or playback mode.

If you are using the low power audio amplifier described earlier in this chapter, C6 will be superfluous as the audio amplifier already has an input capacitor.

The audio inputs and outputs should be connected using screened/co-axial cable. The Screen of the cables should be connected to the 0 Volt rail.

Testing

Before applying power to the circuit, inspect the circuit thoroughly using a spy glass ensuring that there are no unwanted short circuits or open circuits and that the circuit follows the diagram exactly. Ensure that the power supply is connected the right way round. Then set your meter to continuity or low Ohms range. Connect the meter across the 0V and 5V supply and make sure that the reading is not zero or near to zero. You may get a bleep or a low Ohmic value for a short time because of the capacitor in the power supply, but this should

not last more than a few seconds. If it is continuous, you have a short circuit somewhere and you should follow the instructions in the fault finding section. If you do not get the expected results, you should switch the circuit off immediately.

Set your meter to the 20 Volt DC range. Connect your meter across the 5 Volt supply and switch on the supply. If the reading is much below 5 Volts, switch off immediately and go to the fault finding section.

Switch off the power supply. Set SW3 to the record mode, which is when pin 27 of IC2 is 0 Volts. Connect a signal to the audio input. This could be from the audio output of a computer, tape recorder, cd player, radio or minidisk player. If you want to record live sound using a microphone, you can either use an amplifier or reconfigure the circuit to use the microphone input available on the IC. The circuit for this is not shown here but can be found in the application notes, which should be available from your IC supplier.

Switch the power supply on and operate SW2 for the duration of the sound recording. As soon as the recording has finished, return SW2 to its normal open circuit state.

Switch the power supply off and Switch SW3 to its playback mode, which is when pin 27 of IC2 is at 5 Volts. Connect the audio output signal to the input of an audio amplifier. Switch on the power supply and operate SW1 for a short period of time. You should now hear your recording. It may be distorted or very quiet depending on the recording level. If it is distorted, make a new recording with a reduced volume at the audio input and if it is very quiet, make a new recording with an increased volume at the audio input. The best quality sound will be achieved when the recording level is just below the level, which causes distortion.

There may be a slight click at the beginning and end of the playback but this should not be loud as there is circuitry to reduce the effect.

Circuit description

The ISD2560P IC performs most of the functions necessary for the circuit and it is only a matter of a few extra components to provide suitable inputs for record and playback and reducing the click that would otherwise be heard at the beginning and end of the message on playback.

First consider the circuit in record mode. SW3 is used to set the mode of the IC. The IC is in record mode when pin 27 is at 0 Volts. The audio input is connected to pin 20 via R4 and C3. C3 acts as a low resistance to audio signals and a high resistance to direct Voltages. R4 acts to reduce the signal level at pin 20. The audio output signals from computers and tape/cd/minidisk players are far too big for the IC.

The recording starts when the NOT Chip Enable pin 23 goes from a '1' to a '0' and continues until it goes from a '0' to a '1'. R3 holds the signal on pin 23 at 5 Volts unless SW2 is operated, when it becomes 0 Volts.

The Power Down input (pin 24) needs to be a '0' for the IC to function. At the start of a recording, the NOT End Of Message signal (pin 25) is a '1'. IC1C and IC1D are configured as a latch for reasons, which will become apparent when the playback mode is described. When SW2 is operated, pin 8 of IC1C becomes a '0', which causes the output (pin 10) of IC1C to become a '1'. This is connected to pin 12 of IC1D. Pin 13 of IC1D is also a '1' so the output (pin 11) of IC1D will be a '0'. When SW2 is switched back to its open circuit condition at the end of the recording, pin 8 of IC1C and pin 23 of IC2 become '1's. This causes a '0' at pin 25 of IC2, which is the end of message signal. The latch comprising IC1C and IC1D is then reset causing a power down signal (a '1') to appear at pin 24 of IC2

To save power, we need to have a '1' on the PD input (pin 24) when the playback is not activated. As mentioned, SW3 needs to be set so that pin 27 is at 5 Volts for the IC to be in playback mode. We also require a pulse going from a '1' to a '0' and then back to a '1' again to start playback. When the playback has finished, the IC generates a pulse going from a '1' to a '0' and then back to a '1' again on the NOT End Of Message output (pin 25).

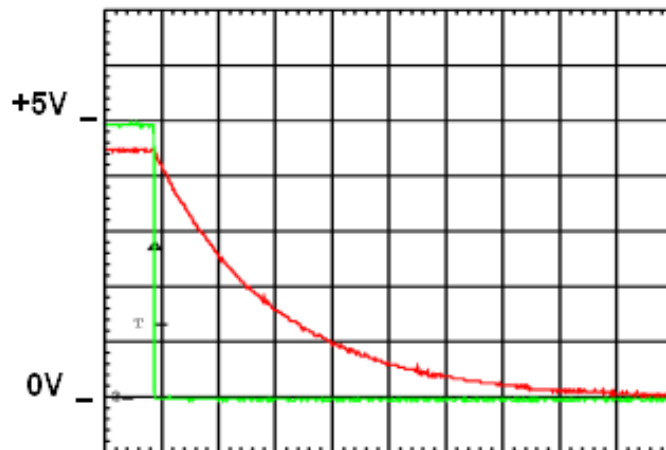
We also need a circuit to reduce the click at the start and finish of the message.

Pins 1 to 9 of IC2 are the message address lines, which determine which message is being recorded or played. Pin 1 is at 5 Volts and the rest are at 0 Volts. This has the effect of recording and playing the first message.

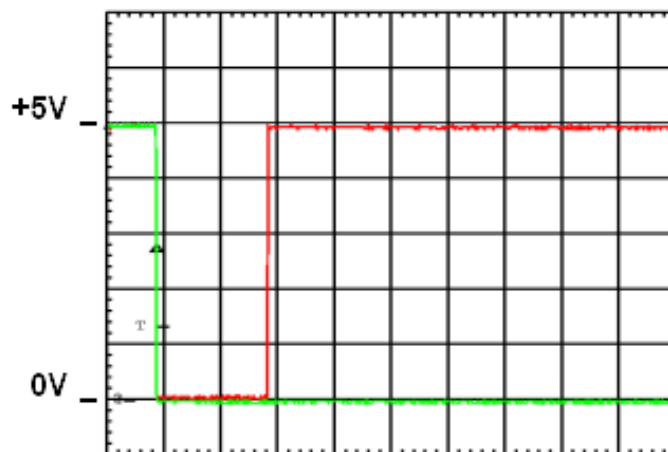
R1 causes a '1' to be present at the input (pins 1 and 2) of IC1A. This causes a '0' at the output (pin 3) of IC1A. This is connected to an input (pin 5) of IC1B causing a '1' at the output (pin 4) of IC1B. C2 is charged up via R2.

When SW1 is operated, the input of IC1A becomes a '0' and C2 discharges via R2. C1 is there to prevent the switch bounce from affecting the circuit. The '0' at the input of IC1A causes a '1' at the output (pin 3). C2 remains charged for a short period of time before it is discharged via R2 and so both inputs (pins 5 and 6) of IC1B are temporarily '1's and the output (pin 4) of IC1B becomes a '0' for this short period of time

In the following oscilloscope image, the time base (horizontal direction) is 50mSecs. per large division. The green trace shows the Voltage across SW1 and the red trace shows the Voltage across C2. The oscilloscope probe causes a Voltage drop so the trace does not start at 5 Volts but is a bit lower. The probe should be a X10 to minimize this effect.



The following 'scope image shows the Voltage across SW1 in green and the output of IC1B in red.

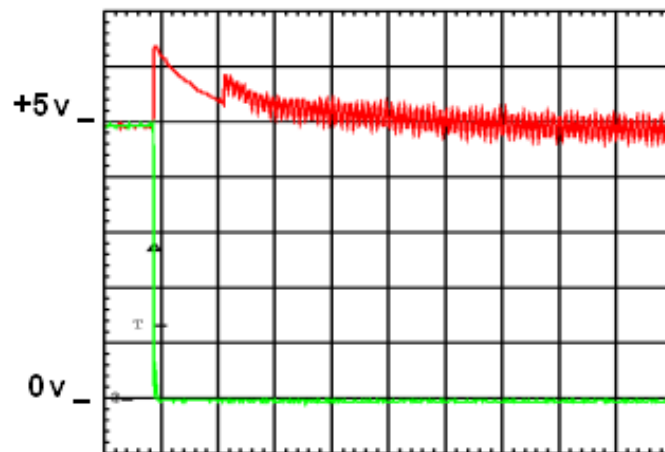


The diode D1 conducts during this pulse and causes the NOT Chip Enable (pin 23) and the input (pin 8) of IC1C to become '0' for the duration of the pulse. The diode is there so that the output of IC1B is not shorted to 0 Volts when SW2 is operated. IC2 is now enabled but we need to switch the Power Down signal off as well. We have seen that when a '0' is present at the input (pin 8) of IC1B, The output of IC1C becomes '0'. This is connected to the other input (pin 9) of IC1C so after the pulse has ended, there is still a '0' on one of the inputs of IC1C so it is latched and the output of IC1D (pin 11) remains a '0' until the input (pin 13) of IC1D becomes a '0'. This happens as soon as the message has finished as it is connected to the NOT End of Message (pin 25). IC2 is therefore in low power mode unless a message is being processed.

The audio output signal appears at pin 14 of IC2 and is connected to the click removing circuit via C4 which blocks direct Voltages but has a low resistance to audio signals. R5 provides a reference Voltage of 5 Volts for the audio signal. R6 connects this signal to the drain (d) of T1. When T1 is on, it shorts the signal to the 5 Volt rail and when it is off, it allows the signal to pass. When the gate (g) of T1 is at the same Voltage as the source (s), the field effect transistor T1 is on and when the gate Voltage is more than about 2 Volts more

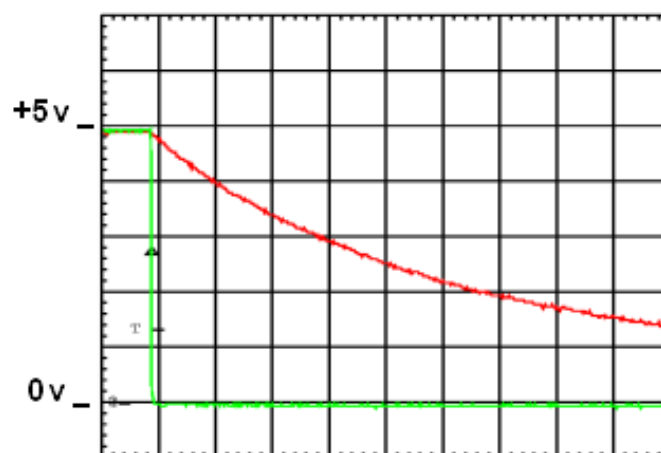
negative than the source, T1 is off. When the gate to source Voltage is between those values, T1 exhibits a resistance, which is between on and off. When the PD signal (pin 24) is a '1', T1 is on and the audio signal is shorted out and when the PD signal is a '0', T1 is off and the audio signal can pass through to the output. R7 connects the PD signal to the gate of T1 and C5 acts to slow the signal down so that the power is on for a period of time before the audio signal is allowed to pass through to the output. D2 allows C5 to charge up quickly at the end of the message when the PD signal becomes a '1' but not when it is a '0'. C6 couples the audio signal to an external amplifier.

In the following oscilloscope image, the time base is 20msecs. per large division, the green trace shows the Voltage across SW1 and the red trace shows the signal at the junction of C4 and R5.



You will note that the red trace goes positive at the beginning of the audio signal and the settles down. The thickness of the trace is the recorded audio signal.

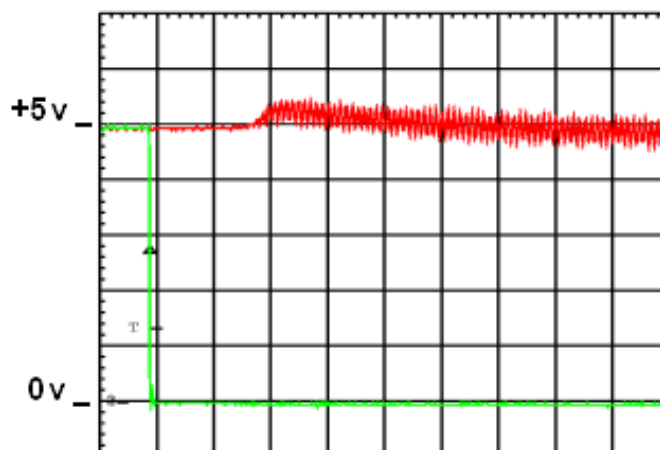
In the following 'scope image, the red trace is the gate of T1.



You will note that the gate Voltage is 5 before SW1 is operated and then starts to fall to zero. When the gate is at 5 Volts, the signal is shorted to the 5 Volt

rail and when it falls below 3 Volts, T1 is fully off and the audio signal can pass to the output.

In the following 'scope image, the red trace shows the Voltage at the drain of T1.



If you compare this 'scope image with the previous one, you will see that the initial large unwanted signal has been removed.

Faultfinding

The first thing to do is give the circuit a thorough visual inspection with a spy glass looking for bad solder joints and short circuits. Check that the circuit you have built exactly matches the circuit diagram and that the components are the correct values and connected the right way round.

If the power supply was short circuited or had a greatly reduced output, remove the IC and try again. If that does not help, there must be a short circuit or misconnection. If the removal of an IC restores the output of the power supply, check for short circuits on the pins of the IC socket, in particular any outputs of the IC. Make sure that the IC was the correct way round. It is possible that an IC is faulty. Check that SW3 is connected correctly as an incorrect connection could cause a short circuit in the power supply.

Assuming that the power supply is OK, set your meter to the 20 Volt DC range and connect the common (COM) terminal to the 0 Volt rail. Connect the meter to pin 27 of IC2. Check that it reads 0 Volts when SW3 is in the record position and 5 Volts when it is in the playback position. If this is not the case, check that the switch has been connected correctly. Check for short circuits, open circuits and bad solder joints.

Assuming that the Voltage on pin 27 of IC2 is OK, check the Voltage across C1. This should be 5 Volts when SW1 is not operated and 0 Volts when it is. If it is not, check the switch has been connected correctly. Check the values of R1 and R2. Check for short circuits, open circuits and bad solder joints. If none of

this helps, try removing IC1 and if that helps, try replacing it. If that helps, throw the old IC away.

Assuming that the Voltage across C1 is OK, check the Voltage across C2. The reading you get will depend on the input resistance of your meter because of the high value of R2. Cheap meters will give a reading of about 2.5 Volts when SW1 is not operated and better meters will give a higher reading. When the switch is operated, the reading should be 0 Volts once C2 has discharged. C2 will discharge in less than a second. If you do not get these results, look for short circuits, open circuits and bad solder joints. If none of this helps, try replacing IC1 and if that helps, throw the old IC away.

Assuming that the Voltages across C2 are OK, check the output (pin 3) of IC1A. This should be 0 Volts when SW1 is not operated and 5 Volts when it is. If you do not get these results, look for short circuits, open circuits and bad solder joints. If none of this helps, try replacing IC1 and if that helps, throw the old IC away.

Assuming that the output of IC1A is OK, check the output (pin 4) of IC1B. The best would be to use an oscilloscope and compare your results with those shown in the circuit description. If you do not have an oscilloscope, use your meter. Digital multi-meters are generally not fast enough to see the signal properly but you should notice a brief dip in the normal reading of 5 Volts when SW1 is operated. If you are using a meter, you may need to operate the switch a few times to observe the output change. You should wait for a second or two between switch operations to allow C2 to fully charge up. If you do get the expected results, check the values of R2 and C2. Check that D1 is the correct way round. Look for short circuits, open circuits and bad solder joints. If none of this helps, try replacing IC1 and if that helps, throw the old IC away.

Assuming that the output of IC1B is OK, check that you get the same results at pin 23 of IC2 and pin 8 of IC1. If you don't, check that D1 is the correct way round. Check that SW2 is correctly connected and is normally an open circuit. Check the value of R3. Look for short circuits, open circuits and bad solder joints. If none of this helps, try replacing IC1 and if that helps, throw the old IC away. . If none of this helps, try replacing IC2 and if that helps, throw the old IC away. Now check that the Voltage on those pins is normally 5 Volts and becomes zero when SW2 is operated. If it doesn't, check the connections to SW2.

Assuming that the signals at pin 23 of IC2 and pin 8 of IC1 are OK, check that pin 1 of IC2 is connected to the 5 Volt rail and that pins 2, 3, 4, 5, 6, 7, 8 and 9 of IC2 are connected to the 0 Volt rail. Check the Voltage at pin 25 of IC2 and pin 13 of IC1. This should be 5 Volts. It should drop momentarily to zero at the end of a recorded message when in playback mode. This signal drops for a very short time and may not be easily visible on your meter so an oscilloscope is

much better. If you are not in playback mode and you have not yet succeeded in recording a message, you will not get the voltage drop at the end of a message, as there is no message. **If you do not get an end of message signal because there is no message, put a short message into the circuit.** If you do not get the expected results, look for short circuits, open circuits and bad solder joints. If none of this helps, try replacing IC1 and if that helps, throw the old IC away. If none of this helps, try replacing IC2 and if that helps, throw the old IC away.

Assuming that the NOT End Of Message signal on pin 25 of IC2 and pin 13 of IC1 is OK, check the functioning of the latch circuit of IC1C and IC1D. Check the output (pin 10) of IC1C. Operate SW1. The output of IC1C should then be 5 Volts until the end of the recorded message. You may notice that it only goes to 5 Volts for a very short period of time. If this is the case, you have a fault, as the signal should last as long as the message. Check the circuit thoroughly. Look for short circuits, open circuits and bad solder joints. If none of this helps, try replacing IC1 and if that helps, throw the old IC away. Now check that the output (pin 11) of IC1D is normally 5 Volts and after SW1 is operated, it becomes 0 Volts until the end of the recorded message when it should return to 5 Volts. If you do not get this result, check the circuit thoroughly. Look for short circuits, open circuits and bad solder joints. If none of this helps, try replacing IC1 and if that helps, throw the old IC away.

Assuming that the latch circuit is OK, check the audio muting circuit. Measure the Voltage at the gate (g) of T1. It should be 5 Volts when no message is being played back and 0 Volts when it is. If you do not get this result, check that T1 has been connected the correct way round. Check the component values. Check that your circuit exactly matches the circuit diagram. Check that D2 is the correct way round. Look for short circuits, open circuits and bad solder joints. If none of this helps, try replacing T1. If that helps, throw the old one away. If the circuit still does not function correctly, you will need an oscilloscope. Check the waveforms around the circuit by comparing them with those in the circuit description. Look for short circuits, open circuits and bad solder joints.

Music synthesizer.

Music is based on harmonics. The pitch of a note is defined by its frequency (the number of times the signal goes up and down in a second) and is measured in Hertz (Hz). 1 Hz is 1 cycle per second. The note A in the treble stave is 440Hz and the C above it is 523.25Hz. Harmonics are the frequencies, which are exact multiples of the basic note. If you double the frequency you will get a note one octave higher and if you treble it you will get the major fifth above that and if you quadruple it you will get 2 octaves higher and if you go five times the frequency you will get the major third above that and so on. If you play these notes together you will get a major chord.

Using this harmonic method of generating musical scales produces a conflict with some notes as a B flat and an A sharp are not exactly the same. We take the average note between the two and call them equal. This is called the well-tempered scale.

In western music we divide the octave into 7 basic notes, the eighth being the octave (oct meaning eight) and six in-between notes. The rest of the notes in an octave belong to other scales. If you want to make music, which is melodic, you can restrict yourself to the pentatonic scale, which uses only five of the available twelve notes. Playing only on the black notes on a keyboard is a simple way of doing this.

A pure sine wave does not have any harmonics and sounds like a flute. Analogue synthesizers use square, triangle and saw-tooth waveforms to generate harmonics. By adding the different waveforms together in different proportions, you can generate different sounds because the different waveforms have different harmonics. The usual way different sounds are produced on synthesizers is to use filters to change the proportions of the harmonics present in the waveform. The most useful waveform to start with is a saw-tooth. If you start with a saw-tooth and use a high pass filter, you will get a violin like sound. If you use a low pass filter, you will get a cello like sound. If you use a band pass filter, you will get a trumpet like sound. If you use a square wave and a low pass filter, you get a clarinet like sound. The quality, tone or timbre of a sound is determined by its harmonics. Another important feature of musical instruments is the attack and decay of the sound. That is the rate at which the sound volume increases and decreases.

Modern synthesizers have a MIDI interface to control them and this requires the use of a microprocessor, which is outside the scope of this cd. In any event, it is awkward to control a modern synthesizer by simple sensors other than simply using switches connected across the keyboard. If you want to change other parameters than pitch (musical note), using sensors, it will be extremely difficult with a modern synthesizer. It is for this reason that circuits for making your own synthesizer are included here. **These circuits are not suitable for the absolute beginner.** You should have successfully built a working circuit before attempting the circuits in this section and **you should have the use of an oscilloscope for testing and fault finding.**

Some of the components need to be high stability otherwise the circuits will drift with temperature. It has already been suggested that you only use metal film resistors for all circuits, as the cost saving in using other types is not significant in small quantities. You should use metal film resistors throughout the circuits described here. You should also use good quality potentiometers in these circuits. **You should not use carbon or conductive plastic potentiometers**, as they are very sensitive to temperature changes. Use cermet (a conductive ceramic) or wire-wound potentiometers and check that the

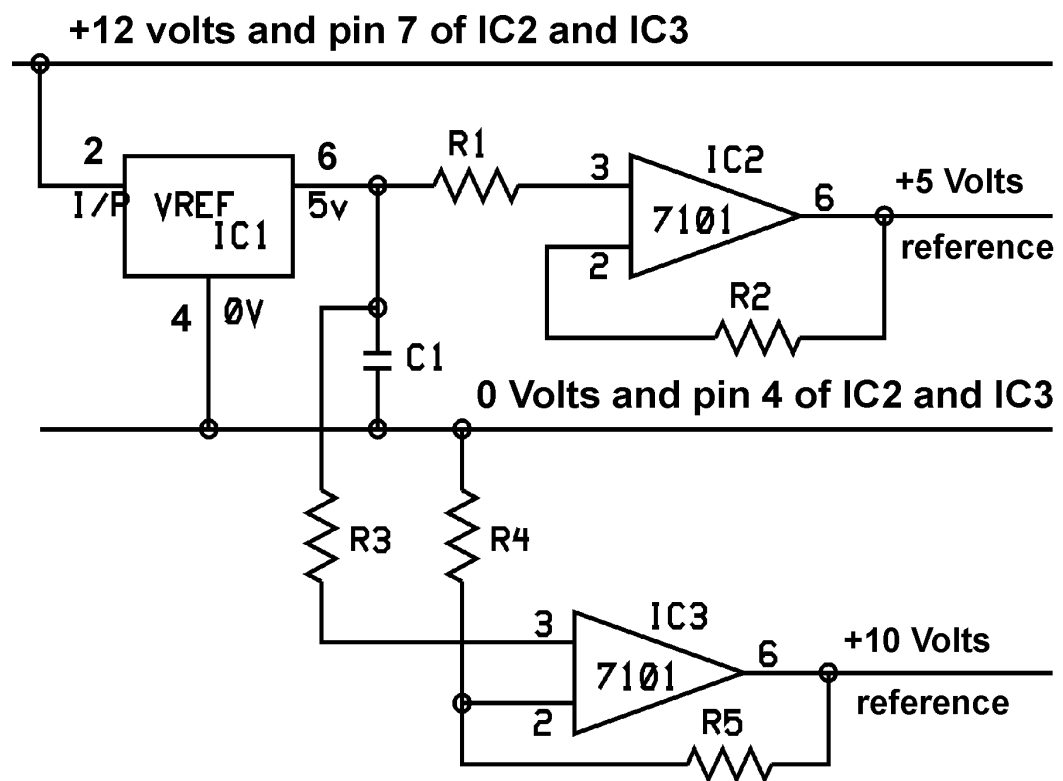
temperature coefficient is lower than or equal to 100ppm/°C (100 parts per million per degree Celsius).

The synthesizer described here is broken down into building blocks in a similar way to circuits in the rest of this cd. You may not need a complete synthesizer for your work and you should therefore decide which parts you will need and which you don't. The circuits need to have interchangeable building blocks and therefore need to have inputs and outputs, which are compatible. This has the unfortunate result that there are parts of the circuit, which are only there for the sake of compatibility and therefore make the complete circuit more complex than would otherwise be the case. When building a synthesizer, you should check each circuit before building the next part.

The synthesizer circuits use a regulated 12 Volt supply and use 5 Volt and 10 Volt references.

+5 Volt and +10 Volt reference.

Many of the circuits require both a positive and a negative supply and some also need a stable reference circuit. The circuits use the 5 Volt reference as a stable in-between Voltage as well as providing a stable reference. The 10 Volt reference is used when a reference Voltage is required, which needs to be higher than the 5 Volt reference.



+5 Volt and +10 Volt reference

R1 10K

R2 10K

R3 10K
 R4 10K
 R5 10K
 C1 0 μ 1F
 IC1 REF02AP. Do not make any connections to the unused pins.

IC2 7101 operational amplifier, any suffix or prefix should be OK. Connect pin 4 to 0V and pin 7 to + 12V. Do not make any connections to the unused pins.

OPERATIONAL AMPLIFIER



Voltage reference



Testing

Before applying power to the circuit, inspect the circuit thoroughly using a spy glass ensuring that there are no unwanted short circuits or open circuits and that the circuit follows the diagram exactly. Ensure that the power supply is connected the right way round. Then set your meter to continuity or low Ohms range. Connect the meter across the 0V and 12V supply and make sure that the reading is not zero or near to zero. You may get a bleep or a low Ohmic value for a short time because of the capacitor in the power supply, but this should not last more than a few seconds. If it is continuous, you have a short circuit somewhere and you should follow the instructions in the fault finding section. If you do not get the expected results, you should switch the circuit off immediately.

Set your meter to the 20 Volt DC range and connect the common (COM) terminal to the 0 Volt rail. Now measure the 5 Volt reference output. It should be 5 Volts. Now measure the 10 Volt reference output. It should be 10 Volts.

Circuit description

IC1 generates a precision 5 Volt reference but it can only supply current, you cannot put current into it. We therefore use a buffer amplifier IC2 so that current can be put into it as well as being taken from it. C1 is required by IC1 to reduce high frequency noise.

R1 couples the 5 Volt reference output from IC1 to the non-inverting input (pin 3) of the operational amplifier IC2. The output (pin 6) of IC2 is coupled directly to the inverting input (pin 2) by R2. Any small difference between the Voltages at the inputs is greatly amplified so if the input on pin 3 were to be slightly higher than pin 2, the output would be very much higher. The output is connected to pin 2 by R2, so if the output Voltage increases, the input on pin 2 also increase. This keeps the output Voltage equal to the Voltage on pin 3.

The circuit of IC3 is similar. The difference is that the Voltage on pin 2 is half the output Voltage, because R4 equals R5, so the output Voltage must be twice the Voltage on pin 3, which is 5 Volts. So the output is 10 Volts.

Faultfinding

The first thing to do is give the circuit a thorough visual inspection with a spy glass looking for bad solder joints and short circuits. Check that the circuit you have built exactly matches the circuit diagram and that the components are the correct values and connected the right way round.

If the power supply was short circuited or had a greatly reduced output, remove the IC's one at a time and try again. If that does not help, there must be a short circuit or misconnection. If the removal of an IC restores the output of the power supply, check for short circuits on the pins of the IC socket, in particular any outputs of the IC. Make sure that the IC was the correct way round. It is possible that an IC is faulty. The only connections to the 12 Volt rail should be pin 2 of IC1 and pin 7 of IC2 and IC3.

Assuming that the power supply is OK, set your meter to the 20 Volt DC range and connect the common (COM) terminal to the 0 Volt rail. Connect the meter to pin 6 of IC1. It should be 5 Volts. If it isn't, check that C1 is not shorted. Check the values of R1 and R3. Look for short circuits, open circuits and bad solder joints. If that does not help, try replacing IC1 and if that helps, throw the old IC away.

Assuming that the output of IC1 is OK, check the output of IC2. Check the Values of R1 and R2. Look for short circuits, open circuits and bad solder joints. If that does not help, try replacing IC2 and if that helps, throw the old IC away.

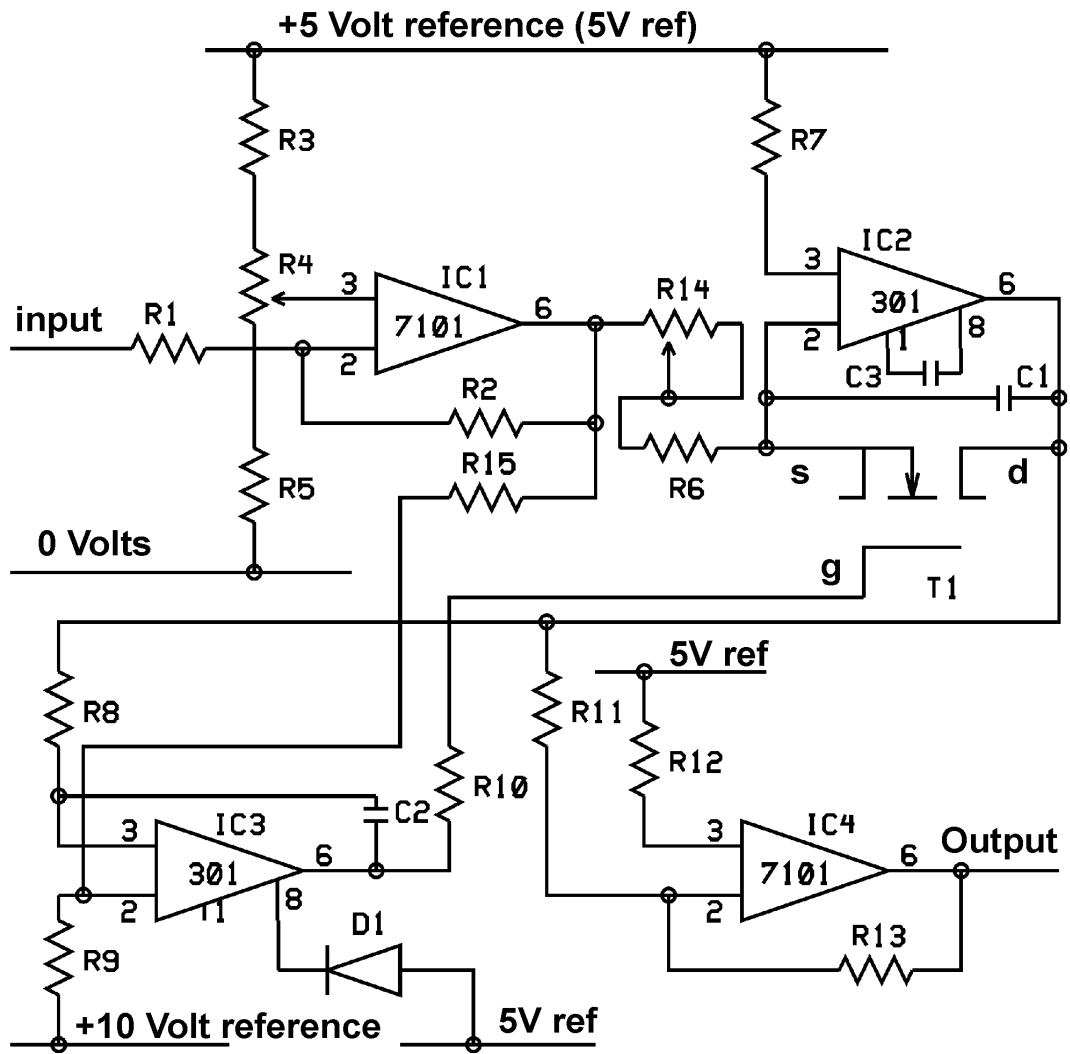
Assuming that the output of IC2 is OK, check the output of IC3. Check the values of R4 and R5. Look for short circuits, open circuits and bad solder joints. If that does not help, try replacing IC3 and if that helps, throw the old IC away.

Voltage controlled oscillator.

This is the heart of a synthesizer. It produces the fundamental waveforms, which are later modified to produce the required sounds. A second Voltage controlled oscillator (LFO), working at a much lower frequency is used to modulate such things as pitch (vibrato), amplitude (volume) and filter (timbre).

The Low frequency oscillator will be described later as it needs to be linked with the keyboard or external keyboard signal.

The Voltage controlled oscillator produces a saw-tooth waveform output. The output frequency is directly proportional to the input Voltage. Other waveforms can be generated using the saw-tooth waveform as an input. The circuits for this follow this circuit.



Voltage controlled oscillator

R1	10K
R2	10K
R3	10K
R4	500 Ohms
R5	10K
R6	8K2 see notes
R7	10K
R8	10K
R9	10K
R10	10K
R11	10K
R12	10K
R13	10K
R14	2K
R15	1M
C1	22000pF (22nF or 0μ022F) see notes
C2	4p7F
C3	10pF
D1	1N4148

VN10LP



OPERATIONAL AMPLIFIER



LM301A



T1 VN10LP see notes

IC1 7101 operational amplifier, any suffix or prefix should be OK. Connect pin 4 to 0V and pin 7 to + 12V. Do not make any connections to the unused pins.

IC2 LM301AN only use National Semiconductor devices as at least one other manufacturer makes a device called 301A, which is not a 301A. Pin 4 should be connected to the 0 Volt rail and pin 7 should be connected to the 12 Volt rail. Do not make any connection to the unused pins.

IC3 LM301AN only use National Semiconductor devices as at least one other manufacturer makes a device called 301A, which is not a 301A. Pin 4 should be connected to the 0 Volt rail and pin 7 should be connected to the 12 Volt rail. Do not make any connection to the unused pins.

IC4 7101 operational amplifier, any suffix or prefix should be OK. Connect pin 4 to 0V and pin 7 to + 12V. Do not make any connections to the unused pins.

Notes

Because capacitance tolerances can be high, you may find that you are unable to get the required oscillator frequency by adjusting R14 so you should change the value of R6 to make the adjustment possible. If the frequency is a bit too low, reduce the value to 6K8. If the frequency is a bit too high, increase the value to 10K.

C1 is a critical component from a point of view of frequency drift with temperature change. You should only use capacitors, which have a thermal drift of 100ppm per deg. C. or better. (ppm means parts per million). There are at least two types, which are suitable and these are Polycarbonate and COG type ceramic.

If you want a much lower frequency, increase the value of C1. Doubling the value will reduce the frequency by half (an octave lower). Similarly halving the value of C1 will increase the frequency by two (an octave higher). There is no limit to the value of capacitance that will work in this circuit but the circuit will become non-linear if very high frequencies are used, as the amplifiers are limited from a speed point of view.

Note that T1 is static sensitive.

The output of this circuit should not be connected directly to an audio amplifier as it may damage the amplifier. You should use the audio output circuit described later in this chapter.

Testing

Before applying power to the circuit, inspect the circuit thoroughly using a spy glass ensuring that there are no unwanted short circuits or open circuits and that the circuit follows the diagram exactly. Ensure that the power supply is

connected the right way round. Then set your meter to continuity or low Ohms range. Connect the meter across the 0V and 12V supply and make sure that the reading is not zero or near to zero. You may get a bleep or a low Ohmic value for a short time because of the capacitor in the power supply, but this should not last more than a few seconds. If it is continuous, you have a short circuit somewhere and you should follow the instructions in the fault finding section. If you do not get the expected results, you should switch the circuit off immediately.

Connect the screen of your oscilloscope to the 0 Volt rail and the probe to the output. Connect the input to the 5 Volt reference. You should have a saw-tooth waveform going from 0 Volts to 5 Volts. If you have a frequency meter you can check that it is the required frequency. If you do not have a frequency meter, connect the output to the input of the audio output circuit described later in this chapter, connect the output of the output circuit to the input of an audio amplifier using screened/co-axial cable and listen to the sound. Connect the input to 0 Volts and adjust R4 to give 5 Volts at the output (pin 6) of IC1. Connect the input to 5 Volts and adjust R14 to give the required frequency.

Circuit description

IC1 is configured as an inverting amplifier having an output of 5 Volts for an input of 0 Volts and an output of 0 Volts for an input of 5 Volts. The Voltage at the non-inverting input is adjusted by R4 to be 2.5 Volts. The average Voltage between the input and pin 6 is held at 2.5 Volts by the amplifier.

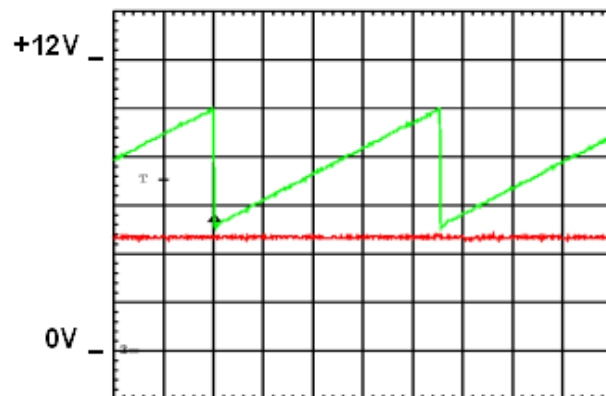
IC2 is configured as an integrator. The output of IC1 is fed to the inverting input (pin 2) of IC2. The non-inverting input (pin 3) is connected to the 5 Volt reference by R7. When T1 is off (the gate Voltage is at 5 Volts), a current will flow through C1 and the combination of R8 and R14. When a current flows through a capacitor, it charges up so there is a Voltage across it. The current flow is such that the Voltage at pin 2 is equal to the Voltage at pin 3. The difference in Voltage between the 5 Volt reference and the output of IC1 thus appears across R6 and R14. As you can see, that defines the current flowing through C1. The greater the Voltage difference or the lower the resistance of the R6 R14 combination, the greater the current through C1. The higher the current through C1, the faster it will charge up. Because the current through C1 is constant, the Voltage across C1 will increase linearly (in a straight line) with time.

You will note that IC2 is a different type of operational amplifier. The 301A is a faster amplifier than the 7101 but it has a lower input resistance, does not have an output that can reach the supply rails, cannot cope with input signals that are close to the supply rails and will not work with supply Voltages of 5 Volts. These are the reasons why it is not used in most of the circuits. It is not internally compensated and requires an external capacitor to prevent it oscillating. This has the advantage however of allowing us to control the

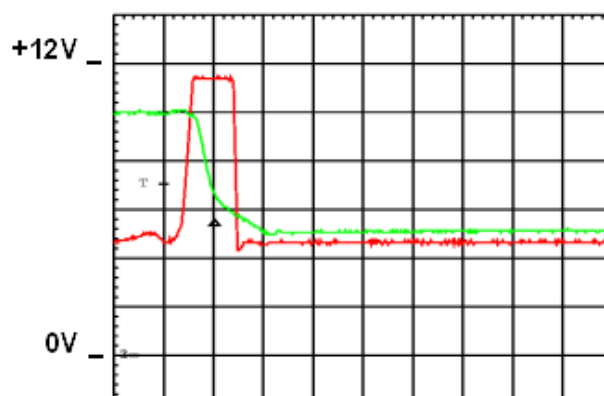
amplifier speed. In this circuit we want a fast but stable amplifier. C3 is the compensating capacitor, which sets the amplifier's speed. The 301A also allows for output clamping, which is used in IC3.

When the output (pin 6) of IC2 reaches the 10 Volt reference, the output of IC3 becomes positive and turns T1 on via R10. This shorts out C1 so the output of IC2 becomes 5 Volts. When this happens, the output of IC3 falls to 5 Volts again and T1 is turned off again and the cycle is repeated. You will note that there is no capacitor between pins 1 and 8 of IC3. This is because there is no need for stability as the output is either high or low and we need as fast a response as possible. D1 clamps the output so that it cannot go much below the 5 Volt reference. T1 is turned off at 5 Volts as the source (s) is at 5 Volts and the gate (g) needs to be at a higher Voltage than the source to turn it on. The result of this is that the output of IC3 does not have to go from 0 Volts to 12 Volts but only has to go from 5 Volts to 12 Volts and can therefore do it more quickly. C2 acts as a bit of positive feed back to speed up the amplifier a bit more and to keep T1 turned on a bit longer. This is to ensure that the output of IC3 is positive long enough for the output of IC2 to reach 5 Volts when T1 is on.

In the following oscilloscope image, the time base (horizontal direction) is 500 μ Secs. per large division. The green trace shows the output of IC2 and the red trace shows the output of IC3. The output of IC3 is so brief that you cannot see that it goes positive.



In the following 'scope image, the time base is 2 μ Secs. per large division. You can now see the falling edge of the green trace and the pulse output of IC3.

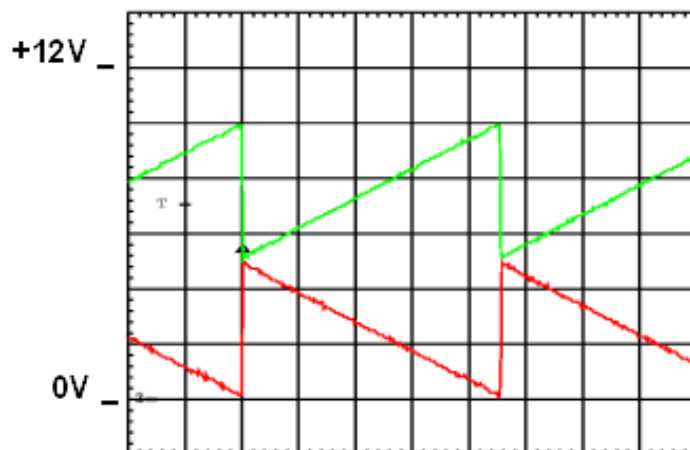


There is a slight problem with non-linearity. That is the frequency is not an exact linear function of input Voltage. As the frequency increases, the short time necessary for the output to get back to 5 Volts becomes a greater proportion of the time for each cycle. To reduce this non-linearity, we connect a high resistance between the output of IC2 to the inverting input (pin 2) of IC3. The effect of this is to reduce the Voltage that the output of IC2 has to reach before T1 turns on as the frequency increases. You will note that this happens when the output of IC1 decreases. The effect of this is to increase the frequency of oscillation more as the input voltage increases, thus making the circuit more linear.

You will note that the output of IC2 goes from 5 Volts to 10 Volts. We want an output going from 0 Volts to 5 Volts so we use IC4 to convert the signal levels. The circuit is similar to that of IC1.

In the following 'scope image, the time base is 500 μ Secs. per large division. The green trace is the output of IC2 and the red trace is the output of IC4. The oscillator frequency for this example is 440Hz.

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Faultfinding

The first thing to do is give the circuit a thorough visual inspection with a spy glass looking for bad solder joints and short circuits. Check that the circuit you have built exactly matches the circuit diagram and that the components are the correct values and connected the right way round.

If the power supply was short circuited or had a greatly reduced output, remove the IC's one at a time and try again. If that does not help, there must be a short circuit or misconnection. If the removal of an IC restores the output of the power supply, check for short circuits on the pins of the IC socket, in particular any outputs of the IC. Make sure that the IC was the correct way round. It is possible that an IC is faulty. The only connections to the 12 Volt rail should be pin 7 of IC1, IC2, IC3 and IC4.

Assuming that the 12 Volt power supply is OK, check that the reference Voltages are OK. If they are not, check your circuit against the circuit diagram looking for all the connections made to the reference supplies. Look for short circuits and bad solder joints. Check the component values.

Assuming that the reference Voltage supplies are OK, check the circuit of IC1. Connect the input to 0 Volts. The output (pin 6) of IC1 should be 5 Volts. If it is not, check the component values of R1, R2, R3, R4 and R5. Check that R4 has been correctly connected. R4 may need adjusting. Check that pin 4 is connected to the 0 Volt rail and that pin 7 is connected to the 12 Volt rail. If that does not help, look for short circuits, open circuits and bad solder joints. If none of that helps, try replacing IC1 and if that helps, throw the old IC away. Now connect the input to +5 Volts. The output of IC1 should now be nearly 0 Volts. If it is not, repeat the procedure of this paragraph.

Assuming that the output of IC1 is OK, connect the input to +5 Volts and check the waveform at the output of IC2. Check the values of the components, in particular the value of C3, which should be only 10pF and should be connected between pins 1 and 8. If you have a larger value, the IC will be slowed down. Check that T1 is connected the correct way round. It will not come to any harm if it is the wrong way round, but the circuit will not function correctly if it is. This part of the circuit can only function correctly if the circuit of IC3 is functioning correctly as well. Ensure that D1 is connected the right way round. Check that pin 4 of both IC's is connected to the 0 Volt rail and that pin 7 is connected to the 12 Volt rail. If that does not help, look for short circuits, open circuits and bad solder joints. If none of that helps, try replacing IC2 and if that helps, throw the old IC away. If none of that helps, try replacing IC3 and if that helps, throw the old IC away.

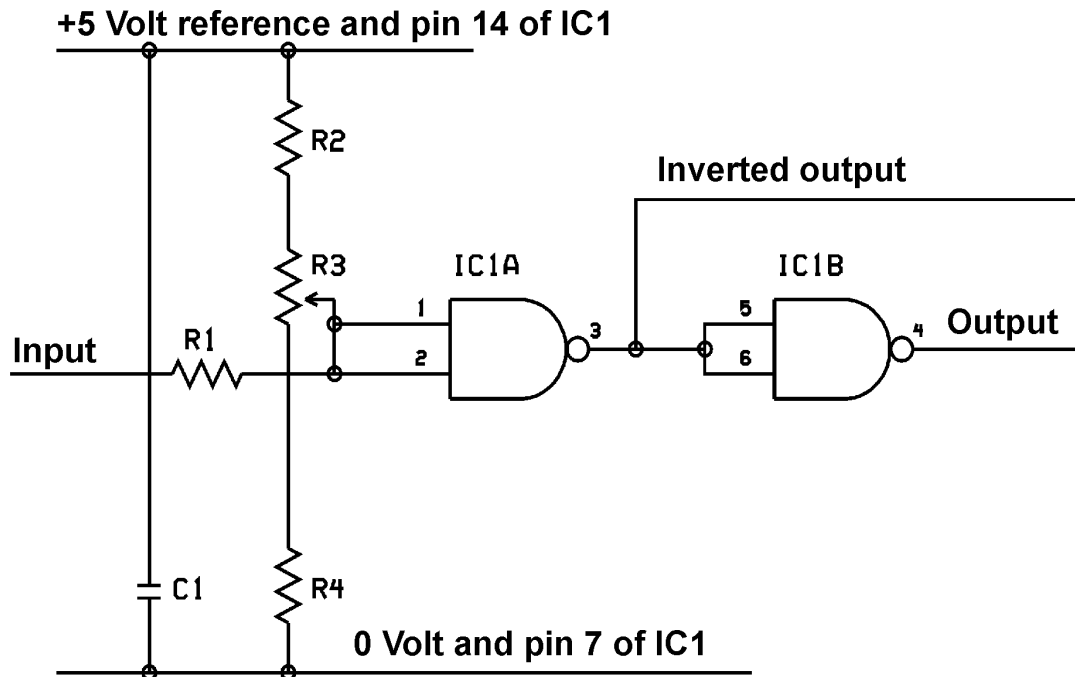
Assuming that the output of IC2 is OK, test the output of IC4. Check the component values. Check that pin 4 is connected to the 0 Volt rail and that pin 7 is connected to the 12 Volt rail. If that does not help, look for short circuits, open circuits and bad solder joints. If none of that helps, try replacing IC4 and if that helps, throw the old IC away.

Saw-tooth to square wave converter.

This circuit has as its input, the output of the previous circuit or the output of the Low Frequency Oscillator described later in this chapter.

This circuit will be needed if you are using the saw-tooth to triangle wave converter described later in this chapter.

The circuit has two square wave outputs. You will need both of them for the saw-tooth to triangle circuit and you will get different sounds according to which output you use if you mix the square and saw-tooth waves together.



Saw-tooth to square wave converter

R1	10K
R2	22K
R3	50K
R4	100K
C1	1 μ F see notes
IC1	HEF4011BP



Notes

The capacitor should be ceramic and connected as close to the supply pins 7 and 14 of IC1 as possible. This capacitor is needed to reduce the effect of the high switching speed of IC1 from interfering with the reference supply, which is being used as a power supply in this circuit.

Please note that the circuit will not work correctly if you use a 4093 as that IC has a Schmitt trigger input. All unused inputs must be connected either to 0 Volts or to the 5 Volt reference.

Testing

Before applying power to the circuit, inspect the circuit thoroughly using a spy glass ensuring that there are no unwanted short circuits or open circuits and that the circuit follows the diagram exactly. Ensure that the power supply is connected the right way round. If you do not get the expected results, you should switch the circuit off immediately.

Connect the input to the output of the Voltage controlled oscillator. Connect your oscilloscope probe to the output and check that you have a square wave output of 0 to 5 Volts.

Adjust R3 to make the positive half of the wave equal in time to the 0 Volt half of the wave.

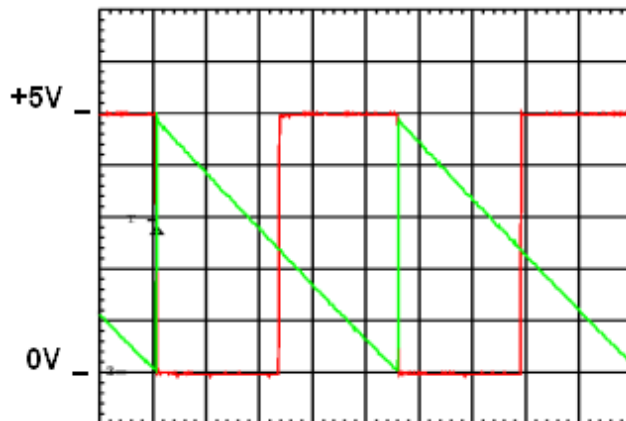
Circuit description

The IC senses when the saw-tooth input is above and below its mid Voltage of about 2.5 Volts. The output of the IC will either be 5 Volts or 0 Volts according to the voltage on the input.

R1 feeds the saw-tooth wave to the input of the NAND gate IC1A. R2, R3 and R4 bias that input to give an equal positive and 0 Volt output. A small bias is required, as the IC does not trigger at exactly half its supply Voltage. R3 adjust the amount of bias.

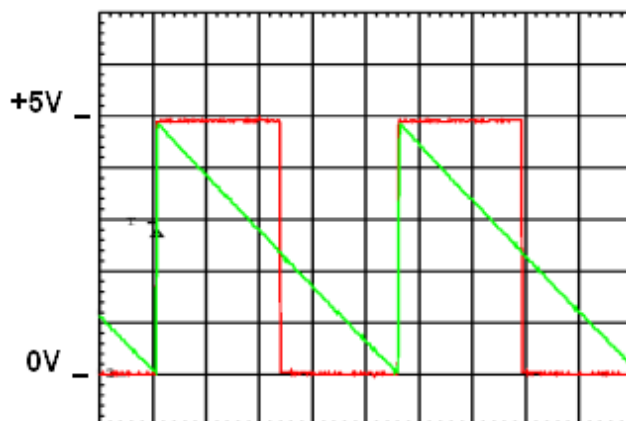
In the following oscilloscope images, the time base (horizontal direction) is 500 μ Secs. per large division. The oscillator frequency is 440Hz. The green trace is the saw-tooth input.

In the following 'scope image the red trace is the inverted output.



You will note that when the input is above 2.5Volts, the output is at 0 Volts and when the input is below 2.5 Volts, the output is at 5 Volts.

IC1B inverts the signal to give the following output as shown by the red trace in the following 'scope image.



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You will note that when the input is above 2.5Volts, the output is at 5 Volts and when the input is below 2.5 Volts, the output is at 0 Volts.

C1 is required, as the IC would otherwise produce spikes in the 5 Volt reference, which would cause a parasitic oscillation in the reference supply as the amplifier that produces the reference Voltage cannot act instantaneously.

Faultfinding

The first thing to do is give the circuit a thorough visual inspection with a spy glass looking for bad solder joints and short circuits. Check that the circuit you have built exactly matches the circuit diagram and that the components are the correct values and connected the right way round.

If the power supply was short circuited or had a greatly reduced output, remove the IC and try again. If that does not help, there must be a short circuit or misconnection. If the removal of the IC restores the output of the power supply, check for short circuits on the pins of the IC socket, in particular any outputs of the IC. Make sure that the IC was the correct way round. It is possible that an IC is faulty. There should not be any connections to the 12 Volt rail. Check that the 5 Volt reference has not been short circuited or overloaded. If it has, look for short circuits, open circuits and bad solder joints. Try replacing C1. If that helps, throw the old one away. Try replacing IC1. If that helps, throw the old one away. Look for short circuits on all the IC outputs even if they are not being used.

Assuming that the power supply and 5 Volt reference are OK, connect the input to the output of the Voltage controlled oscillator and set the oscillator frequency to about 440Hz. Check that the saw-tooth wave is present at the input. If it isn't, either you haven't connected it properly or you have a short circuit on the input. Check the component values.

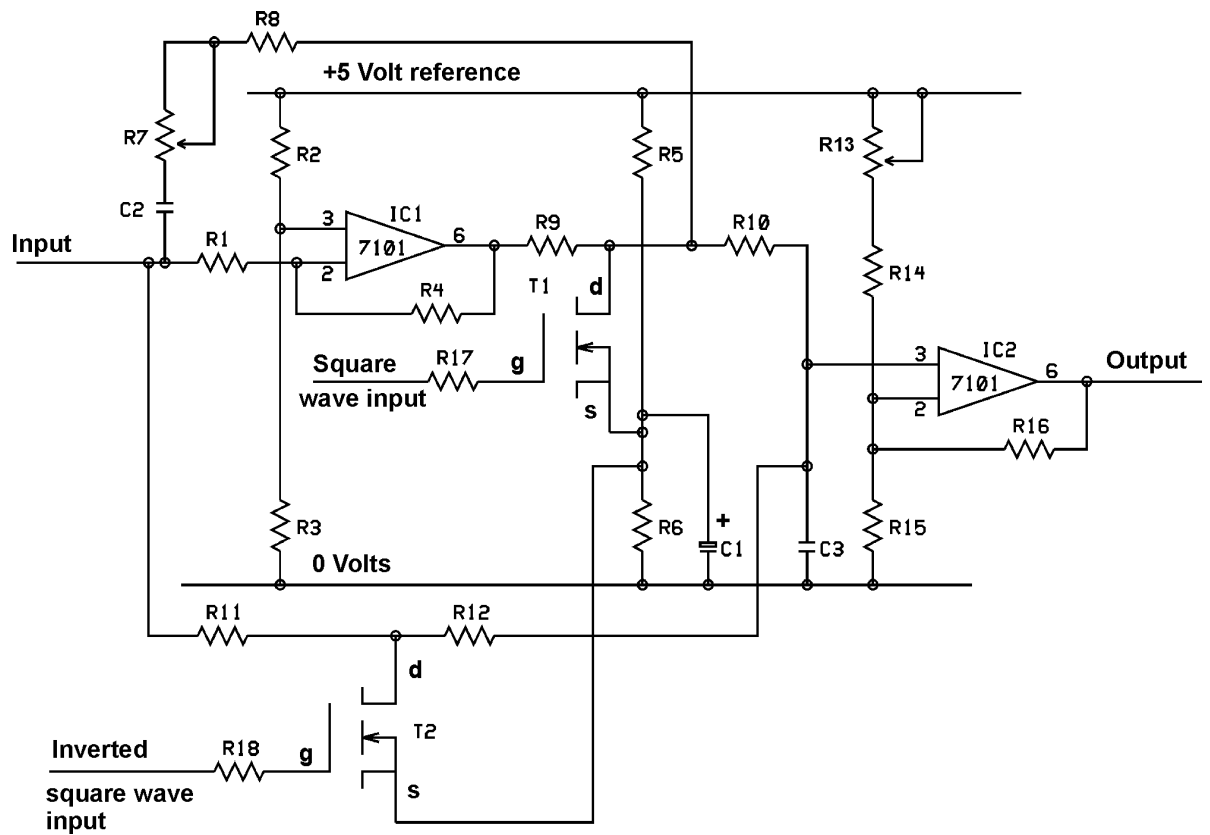
Assuming that the input signal is OK, set your meter to the 20 Volt DC range and measure the Voltage at pins 1 and 2 of IC1. It should be about 2.8 Volts. If it isn't, check the component values. Look for short circuits, open circuits and bad solder joints. If none of that helps, try replacing IC1 and if that helps, throw the old IC away.

Assuming that the input (pins 1 and 2) of IC1A are OK, check the waveform at the inverted output (pin 3) of IC1A. Look for short circuits, open circuits and bad solder joints. If none of that helps, try replacing IC1 and if that helps, throw the old IC away.

Assuming that the inverted output is OK, check the output waveform. Look for short circuits, open circuits and bad solder joints. If none of that helps, try replacing IC1 and if that helps, throw the old IC away.

Saw-tooth to triangle wave converter.

This circuit uses the outputs of the saw-tooth to square wave converter.



R1	10K
R2	10K
R3	10K
R4	10K
R5	10K
R6	10K
R7	10K potentiometer
R8	4K7
R9	10K
R10	10K
R11	10K
R12	10K
R13	10K potentiometer
R14	4K7
R15	10K
R16	18K
R17	10K
R18	10K

C1 4 μ 7F ensure that the negative end is connected to the 0 Volt rail.

C2 470pF

T1 VN10LP

VN10LP



OPERATIONAL AMPLIFIER



T2 VN10LP

IC1 IC1 7101 operational amplifier, any suffix or prefix should be OK. Connect pin 4 to 0V and pin 7 to + 12V. Do not make any connections to the unused pins.

IC2 IC1 7101 operational amplifier, any suffix or prefix should be OK. Connect pin 4 to 0V and pin 7 to + 12V. Do not make any connections to the unused pins.

Notes

The input should be connected to the output of the Voltage controlled oscillator. The two square wave inputs should be connected to the outputs of the saw-tooth to square wave converter.

If this circuit is being used in conjunction with the low frequency oscillator, you should increase the value of C1 to 1000 μ F.

Testing

Before applying power to the circuit, inspect the circuit thoroughly using a spy glass ensuring that there are no unwanted short circuits or open circuits and that the circuit follows the diagram exactly. Ensure that the power supply is connected the right way round. Then set your meter to continuity or low Ohms range. Connect the meter across the 0V and 12V supply and make sure that the reading is not zero or near to zero. You may get a bleep or a low Ohmic value for a short time because of the capacitor in the power supply, but this should not last more than a few seconds. If it is continuous, you have a short circuit somewhere and you should follow the instructions in the fault finding section. If you do not get the expected results, you should switch the circuit off immediately.

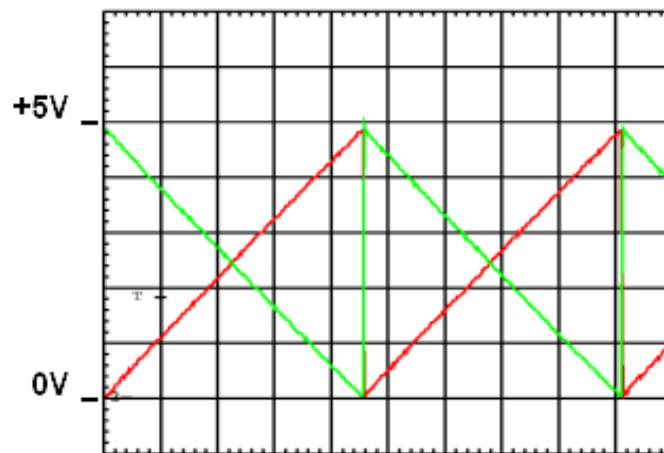
Connect the screen of your oscilloscope to the 0 Volt rail and the probe to the output. Connect the input to the output of your Voltage controlled oscillator and the square wave inputs to the saw-tooth to square wave outputs. You should get a triangular waveform. It will need some adjustments. First adjust R13 so that the bottom of the wave is just above 0 Volts. Now adjust R7 to minimize the spike at the top of the wave.

Circuit description

First we invert the saw-tooth wave so that we now have two of them as shown in the following oscilloscope image. R1 couples the input to the inverting input of the operational amplifier IC1. R2 and R3 provide a 2.5 Volt bias for the non-inverting input and R4 is the feedback resistor. This type of circuit has been described many times before.

In the following 'scope images, the time base is 500 μ Secs. per large division. The green trace is the input at 440Hz.

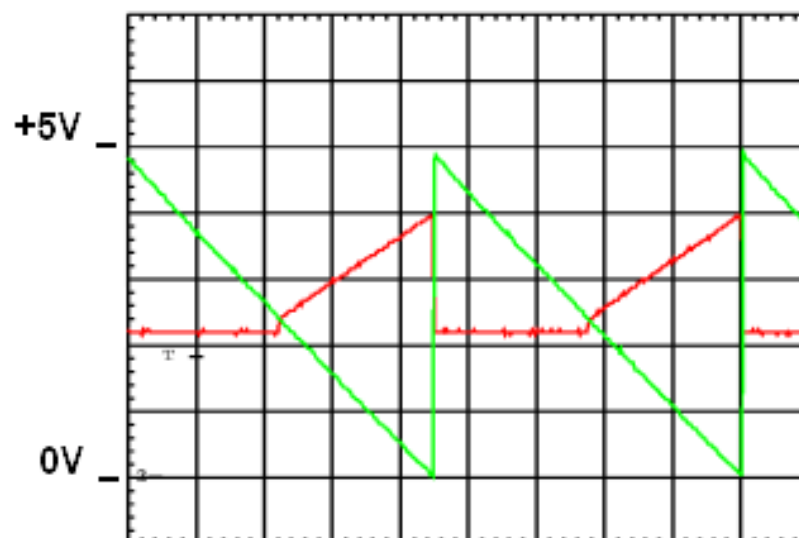
In this 'scope image the red trace shows the output of IC1.



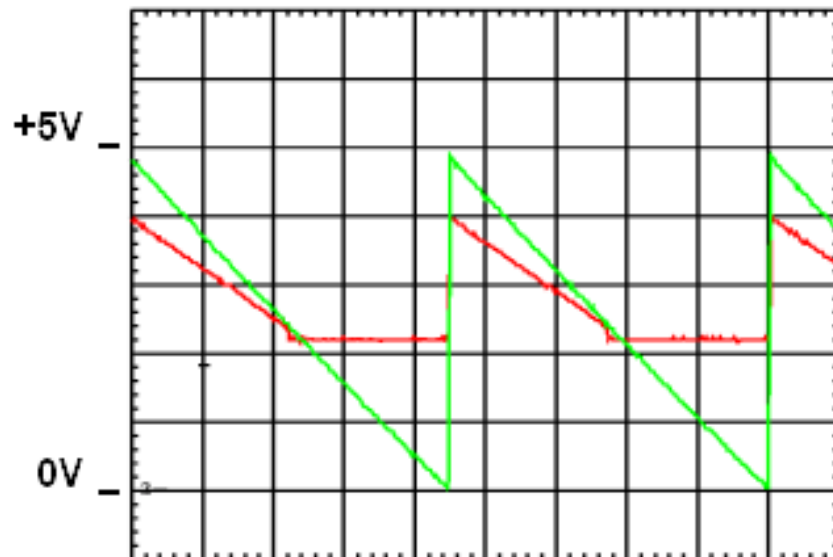
You can see that if we removed the bottom halves of the two waves and added them together, we would be left with a triangular wave. We use the square wave signals as switch inputs to short out the two bottom halves of the waves.

R5 and R6 provide a 2.5 Volt bias and C1 shorts this to ground from an AC point of view. We are using MOSFET devices as switches and the gates are connected to the square waves. First look at T1. When T1 is off, resistor R9 connected to the output of IC1 is not connected to the bias Voltage and the upper part of the wave is free to pass. When the gate of T1 is positive, T1 is turned on and the Voltage at the drain is shorted to the source, which is at the bias Voltage. The amplitude of the wave is reduced because of the loading caused by R10.

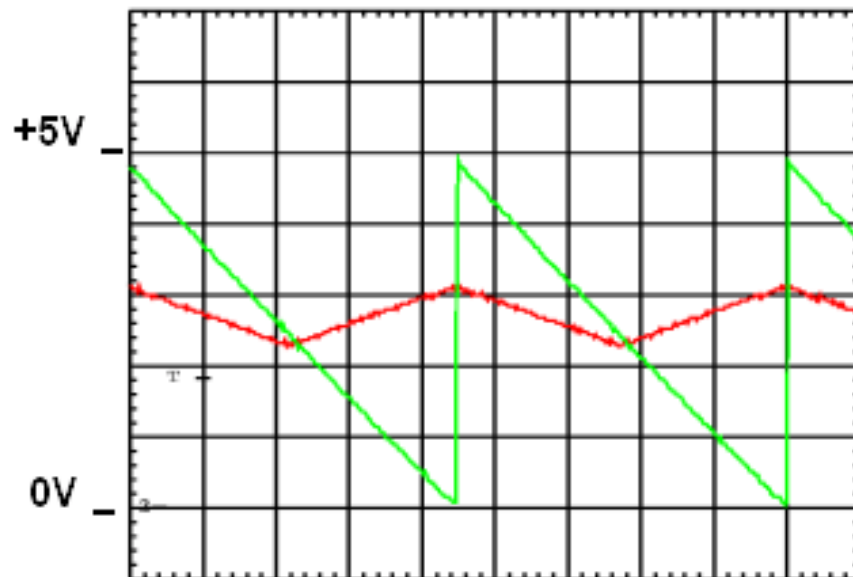
In the following image, the red trace shows the signal at the drain of T1.



In the following 'scope image the red trace shows the signal at the drain of T2.



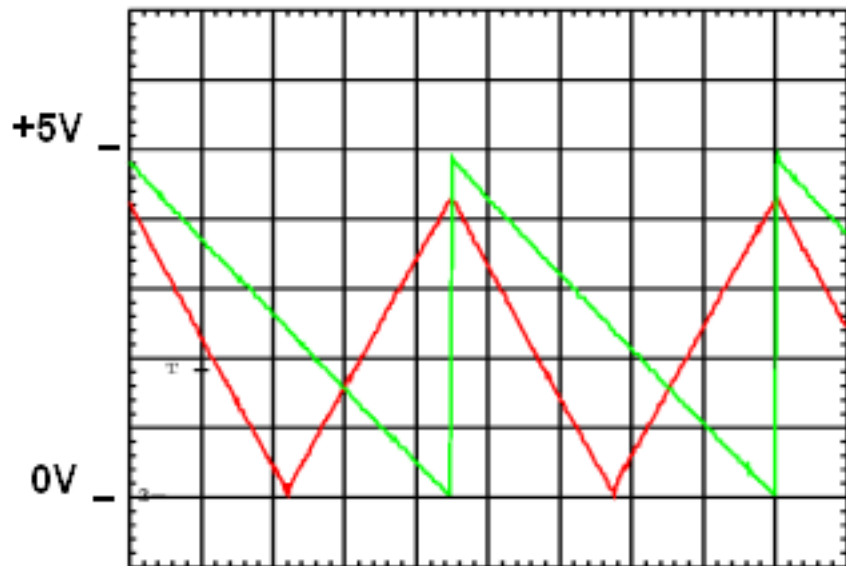
The two signals are added together by R10 and R12 and slightly smoothed by C3. The result can be seen in the following 'scope image. The red trace is the signal across C3.



IC2 amplifies the triangular wave. R13, R14 and R15 provide a bias Voltage, which can be adjusted by R13. R16 is the feedback resistor.

The following 'scope image shows the output in red.

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Faultfinding

The first thing to do is give the circuit a thorough visual inspection with a spy glass looking for bad solder joints and short circuits. Check that the circuit you have built exactly matches the circuit diagram and that the components are the correct values and connected the right way round.

If the power supply was short circuited or had a greatly reduced output, remove the IC's one at a time and try again. If that does not help, there must be a short circuit or misconnection. If the removal of an IC restores the output of the power supply, check for short circuits on the pins of the IC socket, in particular any outputs of the IC. Make sure that the IC was the correct way round. It is possible that an IC is faulty. The only connections to the 12 Volt rail should be pin 7 of IC1 and IC2

Assuming that the power supply is OK, check that the 5 Volt reference is OK. If it isn't, check that the only components connected to it are R2, R5 and R13. Check the component values. Look for short circuits, open circuits and bad solder joints.

Assuming that the 5 Volt reference is OK, check that the Voltage on pin 3 of IC1 is 2.5 Volts. If it isn't, check that pin 4 of IC1 is connected to 0 Volts and that pin 7 is connected to the 12 Volt supply. Check the values of R2 and R3. Look for short circuits, open circuits and bad solder joints. If none of this helps, try replacing IC1 and if that helps, throw the old IC away.

Assuming that the bias Voltage is OK, check that you have a saw-tooth input. Check the output waveform (pin 6) of IC1. If it is not OK, check the values of R1 and R4. Look for short circuits, open circuits and bad solder joints. If none

of this helps, try replacing IC1 and if that helps, throw the old IC away. Check the value of R9.

Measure the Voltage across C1. It should be about 2.25 Volts. It is a bit lower than 2.5 Volts because of the current flowing through the transistors when they are on. If you do not get this result, check that C1 is connected the correct way round. If it wasn't, replace it with a new one and throw the old capacitor away. Check that the transistors are connected correctly. Check the values of R5 and R6. Look for short circuits, open circuits and bad solder joints.

Assuming that the Voltage across C1 is OK, check the waveform at the drain of T1. If it isn't OK, check that you are using the correct square wave output. Check that T1 is connected correctly. Check the values of R9 and R17. Look for short circuits, open circuits and bad solder joints.

Assuming that the waveform at the drain of T1 is OK, check the waveform at the drain of T2 and follow a similar procedure to that of T1.

Assuming that the waveforms at the drains of the transistors are OK, check the waveform across C3. If it isn't OK, check the values of R9, R10, R11 R12 and C3. Look for short circuits, open circuits and bad solder joints. If none of this helps, try replacing IC2 and if that helps, throw the old IC away.

Assuming that the waveform across C3 is OK, check the values of R13, R14, R15 and R16. Check that R13 has been connected correctly. Look for short circuits, open circuits and bad solder joints. If none of this helps, try replacing IC2 and if that helps, throw the old IC away.

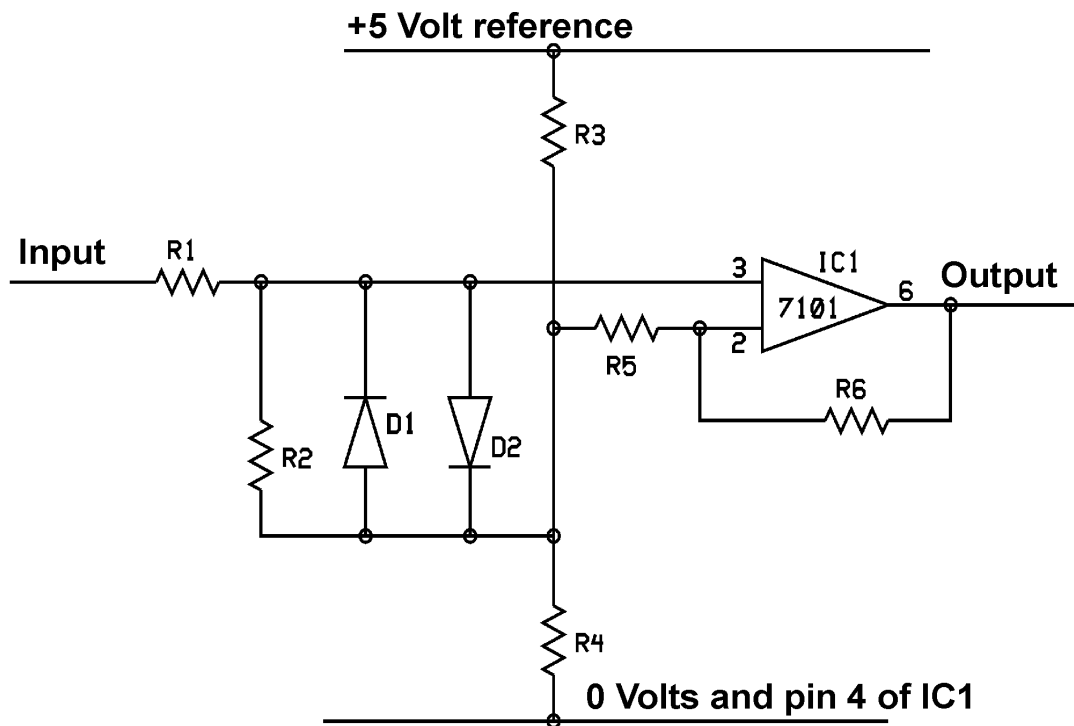
Finally check the values of C2, R7 and R8. Check that R7 has been connected correctly. Look for short circuits, open circuits and bad solder joints

Triangle to sine wave converter.

This circuit is a simple one for converting triangle waveforms to sine waves. The quality of the sine wave output is not perfect but is close enough. To get substantially better results would involve much more complex circuitry and the difference is not really worth the effort. If you are not happy with the result, you can use the Voltage controlled filter, described later in this chapter, to remove higher harmonics. You should use the low pass filter output.

The circuit uses two diodes back to back to provide a soft clamping of the waveform. This has the effect of making the waveform sides much steeper than the top and bottom, which are flattened because the diodes conduct once the Cutin Voltage has been reached.

This circuit uses the output of the saw-tooth to triangle wave circuit for its input.



Triangle to sine wave converter

R1	10K
R2	22K
R3	10K
R4	10K
R5	10K
R6	22K
D1	1N4148
D2	1N4148

IC1 IC1 IC1 7101 operational amplifier, any suffix or prefix should be OK. Connect pin 4 to 0V and pin 7 to + 12V. Do not make any connections to the unused pins.

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Testing

Before applying power to the circuit, inspect the circuit thoroughly using a spy glass ensuring that there are no unwanted short circuits or open circuits and that the circuit follows the diagram exactly. Ensure that the power supply is connected the right way round. Then set your meter to continuity or low Ohms range. Connect the meter across the 0V and 12V supply and make sure that the reading is not zero or near to zero. You may get a bleep or a low Ohmic value for a short time because of the capacitor in the power supply, but this should not last more than a few seconds. If it is continuous, you have a short circuit somewhere and you should follow the instructions in the fault finding section. If you do not get the expected results, you should switch the circuit off immediately.

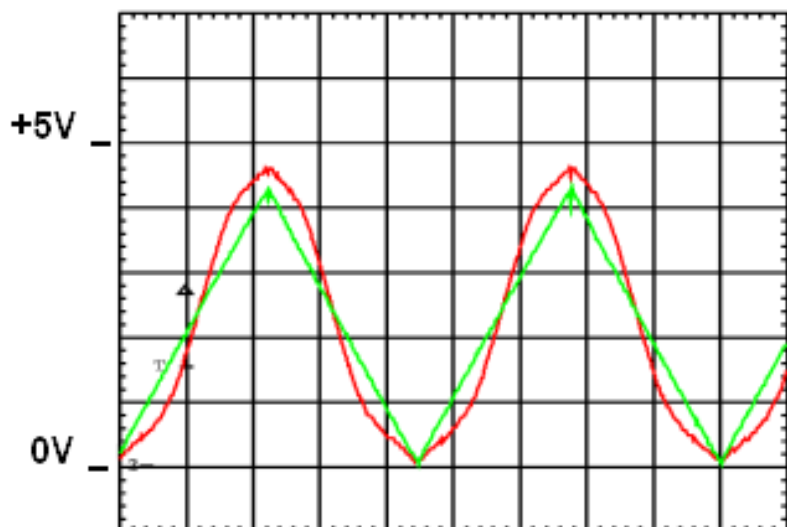
Connect the screen of your oscilloscope to the 0 Volt rail and the probe to the output. Connect the input to the output of your saw-tooth to triangle wave converter circuit. You should get a sinusoidal waveform at the output.

Circuit description

R1 connects the triangle wave input to the diode clamping circuit of D1 and D2. R3 and R4 provide a bias of 2.5 Volts. R2 reduces the signal level across the diodes. If R2 is large, the output wave will become closer to a square wave and if R2 is small, the output will become closer to a triangle. When the input is positive, D2 conducts and when it is near to 0 Volts, D1 conducts. Now the level at which the diodes start to conduct is about 0.5 Volts, being the Cutin Voltage of a silicone diode. The diodes limit the tops and bottoms of the triangle wave thus flattening the tops and bottoms. IC1 acts as a differential amplifier, which amplifies the signal across the diodes.

In the following oscilloscope image, the time base is 500 μ Secs. per large division. The green trace shows the circuit input and the red trace shows the circuit output.

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Faultfinding

The first thing to do is give the circuit a thorough visual inspection with a spy glass looking for bad solder joints and short circuits. Check that the circuit you have built exactly matches the circuit diagram and that the components are the correct values and connected the right way round.

If the power supply was short circuited or had a greatly reduced output, remove the IC's one at a time and try again. If that does not help, there must be a short circuit or misconnection. If the removal of an IC restores the output of the power supply, check for short circuits on the pins of the IC socket, in particular any outputs of the IC. Make sure that the IC was the correct way round. It is

possible that the IC is faulty. The only connections to the 12 Volt rail should be pin 7 of IC1.

Assuming that the power supply is OK, check that the 5 Volt reference is OK. If it isn't, check that the only connection to it is R3. Check the values of R3 and R4. Look for short circuits, open circuits and bad solder joints.

Assuming that the 5 Volt reference is OK, check that you have a triangle wave input. Check the values of R1 and R2. Look for short circuits, open circuits and bad solder joints.

Assuming that the triangle wave input is OK, check the voltage across R4. It should be 2.5 Volts. If it isn't, check the Values of R3 and R4. Check that the diodes are the correct way round. Check the values of R5 and R6. Check that pin 4 of IC1 is connected to the 0 Volt rail and that pin 7 is connected to the 12 Volt rail. Look for short circuits, open circuits and bad solder joints. If none of that helps, try replacing IC1 and if that helps, throw the old IC away. Note that there should not be any connections to the unused pins of the IC.

Assuming that the Voltage across R4 is OK, check the Values of R3 and R4. Check that the diodes are the correct way round. Check the values of R5 and R6. Check that pin 4 of IC1 is connected to the 0 Volt rail and that pin 7 is connected to the 12 Volt rail. Look for short circuits, open circuits and bad solder joints. If none of that helps, try replacing IC1 and if that helps, throw the old IC away. Note that there should not be any connections to the unused pins of the IC.

Voltage controlled filter.

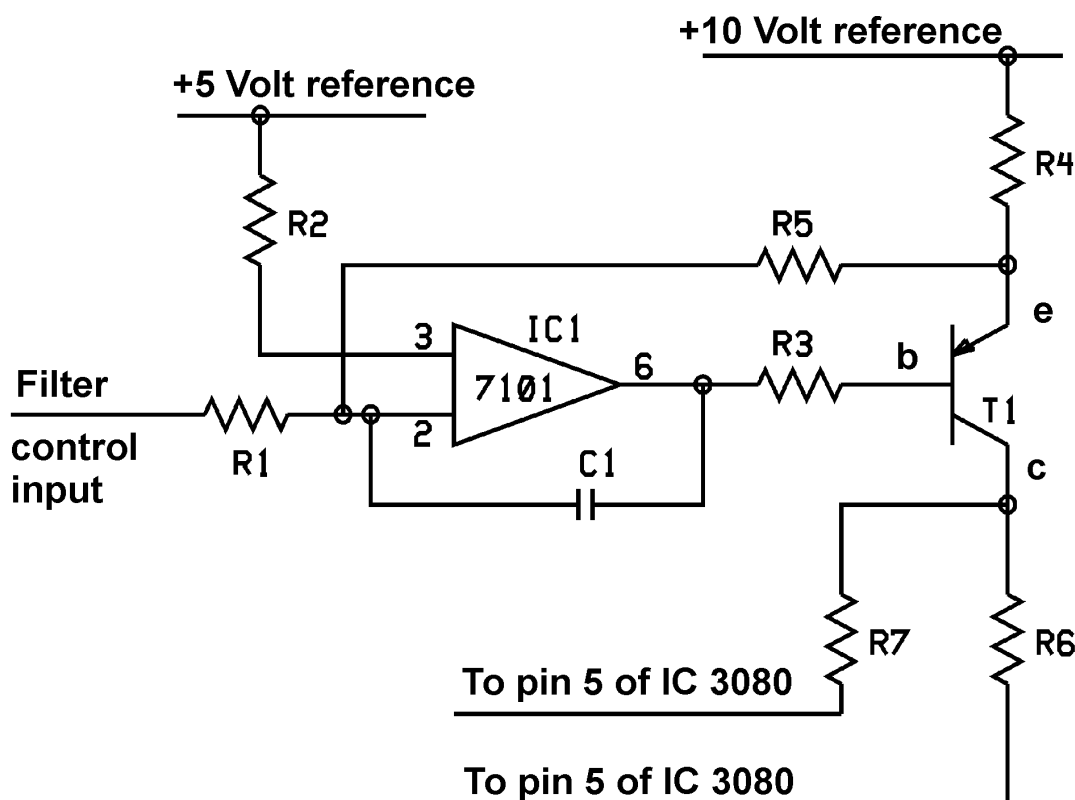
The Voltage controlled filters have three different functions. There is a low pass filter, which reduces the higher harmonics from the waveforms. There is a high pass filter, which reduces the lower frequencies. This in effect increases the upper harmonics. The third type is a band pass filter, which reduces both upper and lower frequencies, leaving the middle frequencies.

These filters can be a bit difficult to understand so they have been simplified as much as possible. The common component to these filters is a low pass filter. If you use a low pass filter as a negative feedback component, you will in effect be subtracting the low frequencies from the signal. This leaves the high frequencies, so you have a high pass filter. The effect of this is that the low pass filter has a high pass input. So the output of the low pass filter is a band pass filter.

Current converter circuit.

The filter circuit uses a transconductance amplifier. Transconductance amplifiers are bit difficult to understand. They are similar to ordinary operational amplifiers but have a current output rather than a Voltage output.

The amplifier used in these circuits (CA3080E) has an extra input on pin 5. This input controls the current at the output. In effect it acts as a multiplier, so the output current is the input times the current flowing into pin 5. We therefore need a Voltage to current converter to provide the current for this input. We will use two transconductance amplifiers so we need two current sources. The following circuit produces twice the current we want and splits this current into two halves using two resistors in the output circuit.



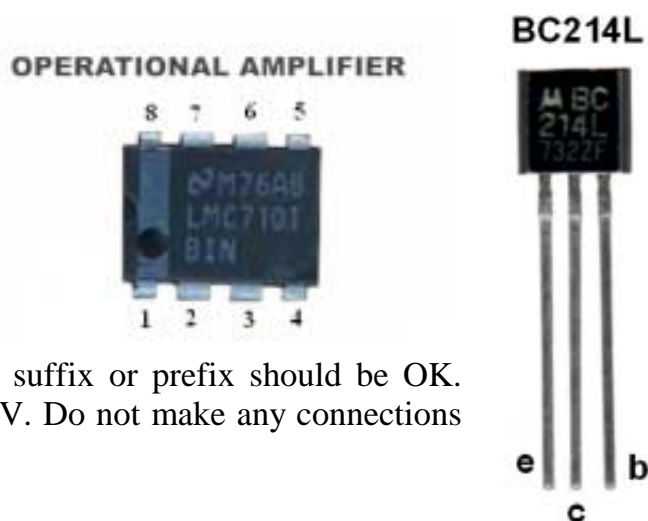
Current converter circuit

R1	150K
R2	10K
R3	10K
R4	22K
R5	100K
R6	22K
R7	22K
C1	100pF
T1	BC214L

IC1 7101 operational amplifier, any suffix or prefix should be OK. Connect pin 4 to 0V and pin 7 to + 12V. Do not make any connections to the unused pins.

Notes

R6 and R7 are to be connected to pin 5 of the CA3080E IC's used in the following filter circuits. If you are only using one filter, the unused resistor should be connected to the 0 Volt rail.



Testing

Before applying power to the circuit, inspect the circuit thoroughly using a spy glass ensuring that there are no unwanted short circuits or open circuits and that the circuit follows the diagram exactly. Ensure that the power supply is connected the right way round. Then set your meter to continuity or low Ohms range. Connect the meter across the 0V and 12V supply and make sure that the reading is not zero or near to zero. You may get a bleep or a low Ohmic value for a short time because of the capacitor in the power supply, but this should not last more than a few seconds. If it is continuous, you have a short circuit somewhere and you should follow the instructions in the fault finding section. If you do not get the expected results, you should switch the circuit off immediately.

Connect the resistors R6 and R7 to the 0 Volt rail temporarily. (The ends, which would normally go to pin 5 of the transconductance amplifiers. Set your meter to the 20 Volt DC range and measure the Voltage at the collector 'c' of T1. The Voltage should be about 0.4 Volts when the input is 0 Volts and about 2.5 Volts when the input is 5 Volts.

Circuit description

T1 acts as a constant current generator as the current flowing through the collector is not dependent on the resistance in the collector circuit. The current is defined by the voltage on the base 'b' and the resistance between the emitter 'e' and the positive supply. We are using the 10 Volt reference as a positive supply so that we have a stable supply. The transistor circuit works because the current flowing between base and emitter is negligible compared with the current flowing between collector and emitter.

The filter control input is a Voltage, which controls the frequency at which the filter cuts in. This input Voltage has a range of 0 to 5 Volts. The filter has a minimum effect when the input is 5 Volts and a maximum effect when it is at 0 Volts. The non-inverting input of the operational amplifier (pin 3) is at 5 Volts as it is connected to the 5 Volt reference via R2. R5 is the feedback resistor and C1 is there to prevent unwanted high frequency noise. R3 couples the output of IC1 to the base of T1.

When the input is at 0 Volts, the amplifier output increases, which causes the emitter Voltage to increase. This causes the Voltage at the inverting input (pin 2) of IC1 to increase until both inputs of IC1 are at 5 Volts. When the input is at 5 Volts, the emitter must also be at 5 Volts. There is therefore a 5 Volt drop across R4. Some of the current, which flows through R4 to cause the Volt drop, flows through R5 but most of it flows through the transistor.

Faultfinding

The first thing to do is give the circuit a thorough visual inspection with a spy glass looking for bad solder joints and short circuits. Check that the circuit you

have built exactly matches the circuit diagram and that the components are the correct values and connected the right way round.

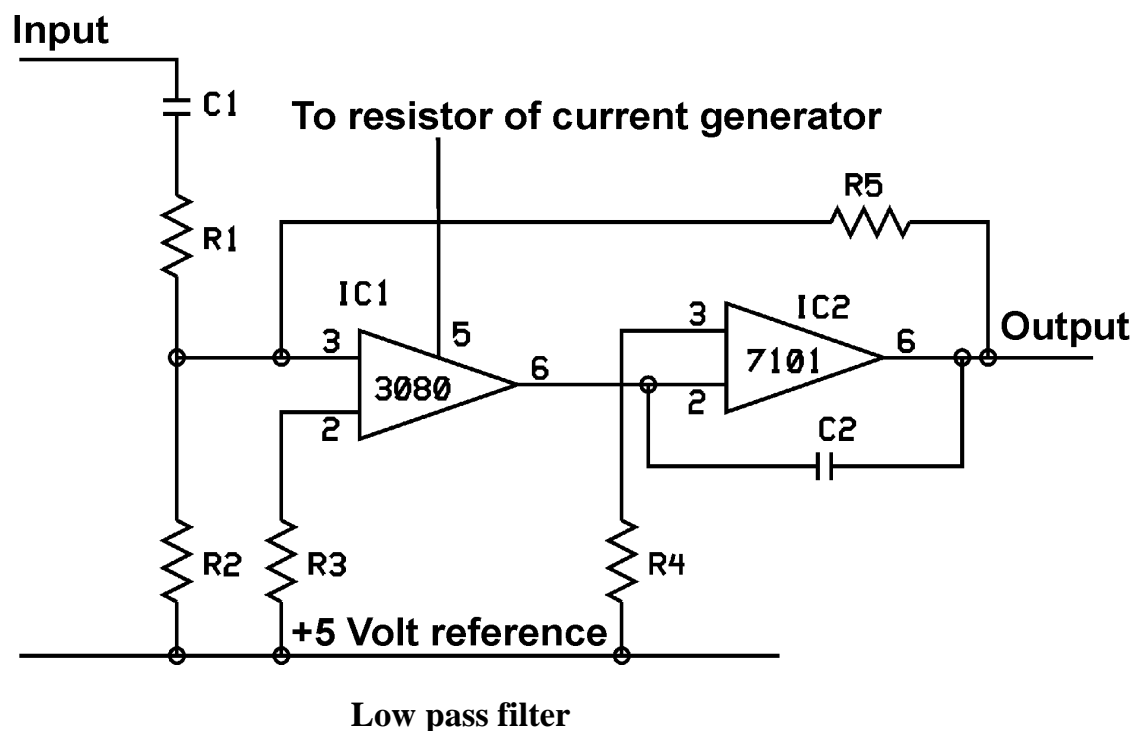
If the power supply was short circuited or had a greatly reduced output, remove the IC's one at a time and try again. If that does not help, there must be a short circuit or misconnection. If the removal of the IC restores the output of the power supply, check for short circuits on the pins of the IC socket, in particular any outputs of the IC. Make sure that the IC was the correct way round. It is possible that the IC is faulty. The only connections to the 12 Volt rail should be pin 7 of IC1.

Assuming that the power supply is OK, check that the 5 Volt reference is OK. If it isn't, check that the only connection to it is R2. Check the value of R2 and look for short circuits, open circuits and bad solder joints.

Assuming that the 5 Volt reference is OK, check that the 10 Volt reference is OK. If it isn't, check that the only connection to it is R4. Check the value of R4 and look for short circuits, open circuits and bad solder joints.

Assuming that the 10 volt reference is OK, check that pin 4 of IC1 is connected to the 0 Volt rail, that pin 7 is connected to the 12 Volt rail, that there are no connections to any of the unused pins of IC1 and that T1 is connected correctly. Check all the component values. Look for short circuits, open circuits and bad solder joints. If none of that helps, try replacing IC1 and if that helps, throw the old IC away.

Low pass filter.



R1 330K
 R2 22K
 R3 10K
 R4 10K
 R5 470K
 C1 0 μ 1F
 C2 1000pF

IC1 CA3080E connect pin 4 to the 0 Volt rail and pin 7 to the 12 Volt rail. Do not make any connections to the unused pins.

IC2 7101 operational amplifier, any suffix or prefix should be OK. Connect pin 4 to 0V and pin 7 to + 12V. Do not make any connections to the unused pins.

Notes

Pin 5 of IC1 should be connected to either R6 or R7 of the current converter circuit.

Testing

Before applying power to the circuit, inspect the circuit thoroughly using a spy glass ensuring that there are no unwanted short circuits or open circuits and that the circuit follows the diagram exactly. Ensure that the power supply is connected the right way round. Then set your meter to continuity or low Ohms range. Connect the meter across the 0V and 12V supply and make sure that the reading is not zero or near to zero. You may get a bleep or a low Ohmic value for a short time because of the capacitor in the power supply, but this should not last more than a few seconds. If it is continuous, you have a short circuit somewhere and you should follow the instructions in the fault finding section. If you do not get the expected results, you should switch the circuit off immediately.

Connect the input to the saw-tooth output of the Voltage controlled oscillator. Connect pin 5 of IC1 to the current generator circuit. Connect your oscilloscope to the input at the junction of C1 and R1, and the other probe to the output. Set the oscillator to 440 Hz. Connect the input of the current generator circuit to 5 Volts. You should get the first of the following oscilloscope image. The time base is 500 μ Secs. per large division. The green trace shows the input and the red trace shows the output. You will probably have to adjust your 'scope to see the waveforms one above the other as you are unlikely to have the use of a colour 'scope and it can be very confusing when the traces are superimposed.

Set the input of the current generator circuit to 0 Volts and see the second 'scope image.

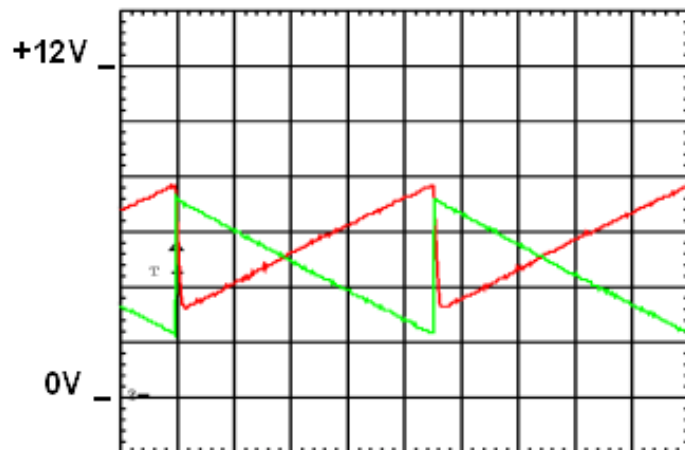
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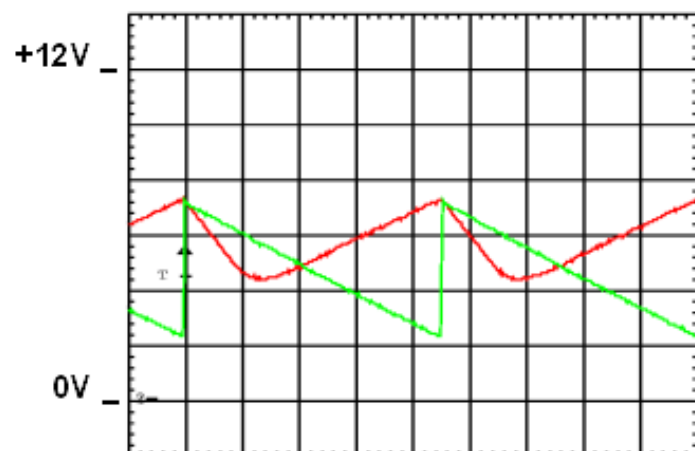
CA3080E



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Circuit description

This circuit works by controlling the current flowing into the input of IC2. This current must flow through C2 as operational amplifiers have very high input resistances. If the alternating Voltage across C2 is of a high frequency, C2 will need a high current flowing into and out of it. IC1 limits that current and so C1 cannot have high outputs at high frequencies. The effect is to reduce what is called the slew rate of the amplifier. This is the maximum rate at which the amplifier can change its output Voltage. If the slew rate is low, only the low frequencies can be amplified.

IC1 has a current output, which is dependent on both the input and the current flowing into pin 5. If the current into pin 5 is reduced, the slew rate will reduce and high frequency signals will have a reduced amplitude.

IC1 can only operate effectively in this multiplying mode if the input signals are small. C1 couples the saw-tooth input to the circuit allowing a Voltage shift. The signal is reduced by R1 and R2 and is biased at 5 Volts because R2 is connected to the 5 Volt reference instead of the 0 Volt rail. You can see that the green trace in the 'scope images above has an average Voltage of 5Volts.

The inverting input (pin 2) of IC1 is connected to the 5 Volt reference via R3. R4 biases the non-inverting input (pin 3) of IC2 to 5 Volts.

IC2 inverts the signal so the negative feedback resistor R5 needs to be connected between the output and the non-inverting input (pin 3) of IC1. This feedback resistor acts on both amplifiers at the same time and give the amplifiers a limited gain and stability.

Faultfinding

The first thing to do is give the circuit a thorough visual inspection with a spyglass looking for bad solder joints and short circuits. Check that the circuit you have built exactly matches the circuit diagram and that the components are the correct values and connected the right way round.

If the power supply was short-circuited or had a greatly reduced output, remove the IC's one at a time and try again. If that does not help, there must be a short circuit or misconnection. If the removal of an IC restores the output of the power supply, check for short circuits on the pins of the IC socket, in particular any outputs of the IC. Make sure that the IC was the correct way round. It is possible that the IC is faulty. The only connections to the 12 Volt rail should be pin 7 of IC1 and IC2.

Assuming that the power supply is OK, check the 5 Volt reference. The only connections to the 5 Volt reference should be R2, R3, and R4. Check the values of these components and look for short circuits, open circuits and bad solder joints.

Assuming that the 5 Volt reference is OK, check that you have connected the saw-tooth wave output of your oscillator to the circuit input and that you have connected pin 5 of IC1 to an output of the current generator circuit. Check the circuit against the diagram. Make sure that none of the unused pins of the IC's are connected anywhere. Make sure that pin 4 of the IC's are connected to the 0 Volt rail and that the pins 7 are connected to the 12 Volt rail and look for short circuits, open circuits and bad solder joints.

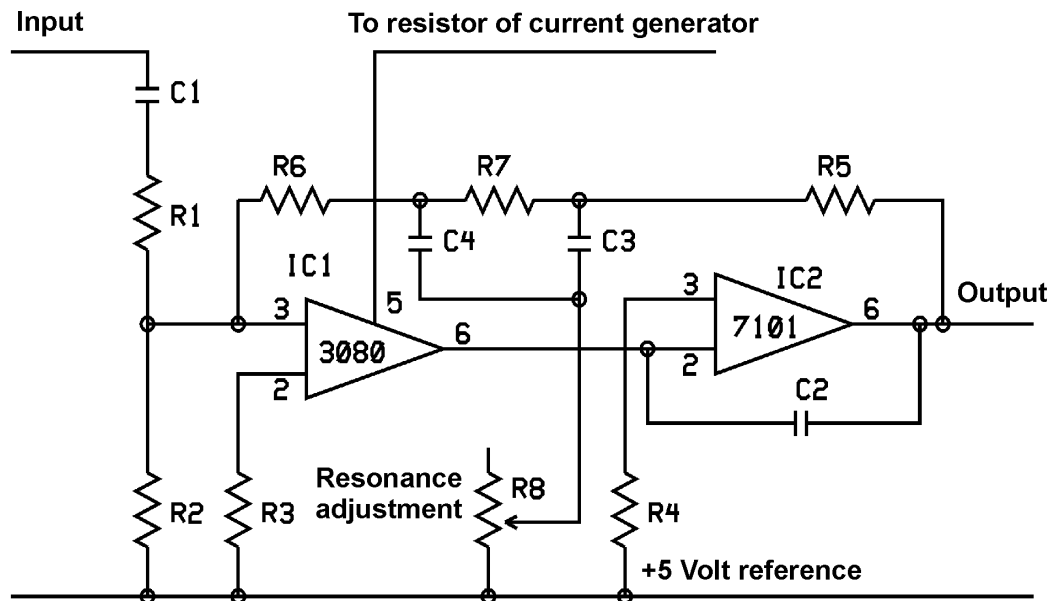
Low pass filter with resonance.

This is a minor modification to the previous circuit and causes the filter to produce a more exciting sound by introducing some instability to the circuit.

Only the circuit modifications will be described here.

[Click here to go to the circuit description of the low pass filter.](#)

CLICK



Low pass filter with resonance

Change R1 to 1M

Change R5 to 100K

R6 470K

R7 100K

R8 100K potentiometer

C3 470pF

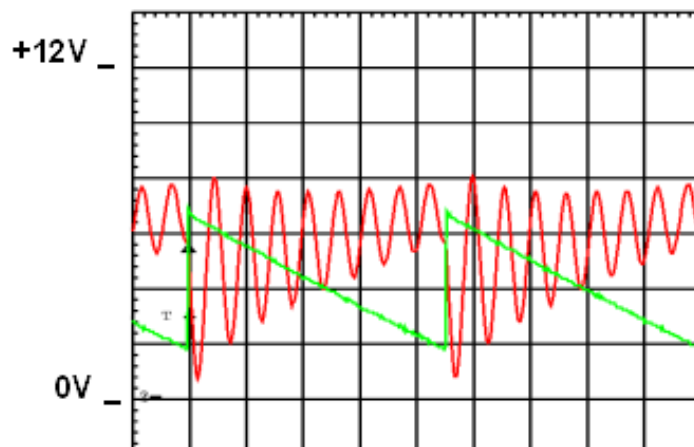
C4 470pF

Ensure that R8 is connected the correct way round.

The network comprising R5, R6, R7, C3 and C4 act to produce a phase shift between the input and output of feedback circuit. At a particular frequency, the feedback becomes much less and the circuit becomes unstable. When the input suddenly changes, the circuit oscillates at this particular frequency. This oscillation dies down over a period of time. The higher the value of R8, the less the effect of the capacitors.

In the first oscilloscope image, R8 is at minimum resistance.

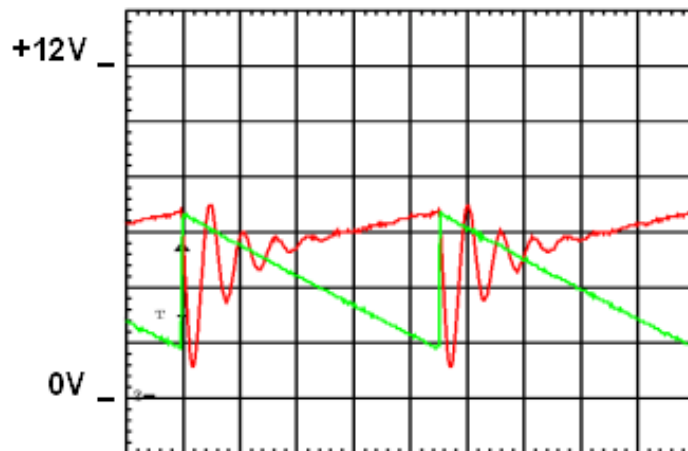
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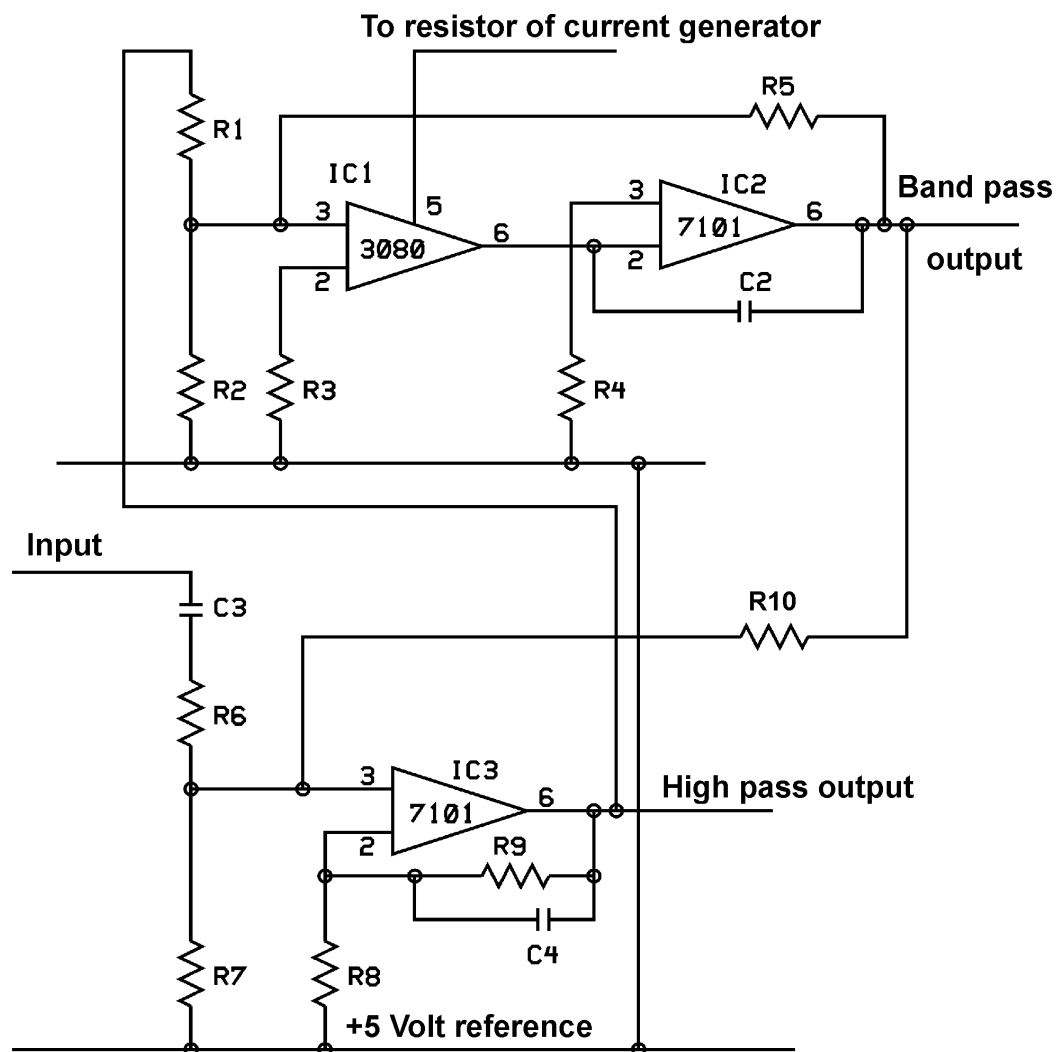
As before, the green trace is the input and the red trace is the output.

In the next image, the value of R8 has been increased to make the decay of the instability clearer.

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High pass and band pass filter.



High pass and band pass filter

R1 330K
R2 22K
R3 10K
R4 10K
R5 470K
R6 330K
R7 22K
R8 10K
R9 1M
R10 82K
C1 REMOVED FROM CIRCUIT
C2 1000pF
C3 0 μ 1F
C4 100pF
IC1 CA3080E connect pin 4 to the 0 Volt rail and pin 7 to the 12 Volt rail. Do not make any connections to the unused pins.
IC2 7101 operational amplifier, any suffix or prefix should be OK. Connect pin 4 to 0V and pin 7 to + 12V. Do not make any connections to the unused pins.
IC3 7101 operational amplifier, any suffix or prefix should be OK. Connect pin 4 to 0V and pin 7 to + 12V. Do not make any connections to the unused pins.

The high pass and band pass filters use the low pass filter as a feedback element. If you subtract the low pass output from the input, what is left is the upper frequencies as the low frequencies have been removed. The upper frequencies however are the input to the low pass filter, so the output of the low pass filter has both upper and lower frequencies removed and is therefore the band pass.

You will note that C1 has become redundant.

R9 and C4 are present to provide stability to the circuit.

The output of IC3 is fed to the input of the low pass filter, which inverts the signal. The output of the low pas filter is added to the input of IC3 by R10. This has the effect of subtraction as the low pass filter inverts the signal.

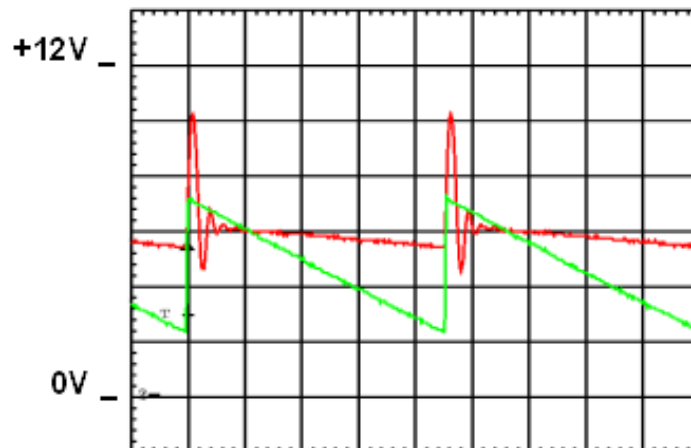
The low pass filter has already been described. Click on link to go to the low pass filter description.

CLICK

In the following scope images, the time base is 500 μ Secs. per large division. The oscillator frequency is 440Hz, the green trace is the input and the red trace is the output.

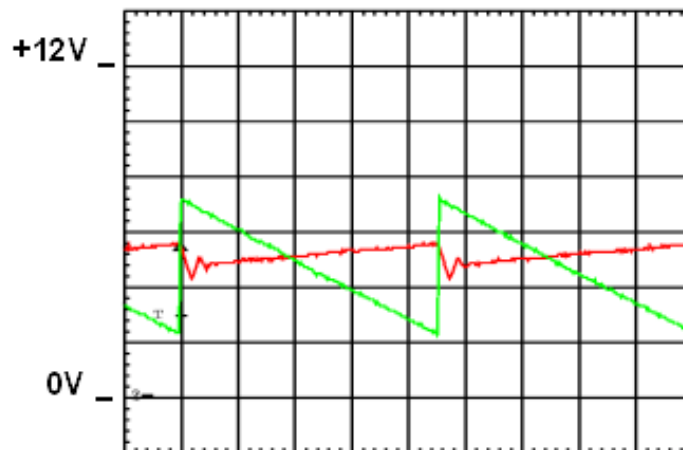
In the first image the red trace is the high pass output.

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In the second image the red trace is the band pass output.

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You will note that the band pass output has a lower amplitude and you may therefore consider amplifying it.

You should build and test the low pass filter part of the circuit first and then build the rest. You should use C1 for this testing procedure and then remove it for the final circuit.

Noise generator.

We have got just the circuit we need already. It only needs to have a few component value changes to make it suitable for sound applications. The circuit in question is the basic random circuit without external input. To see the circuit, [click here](#).

[CLICK](#)

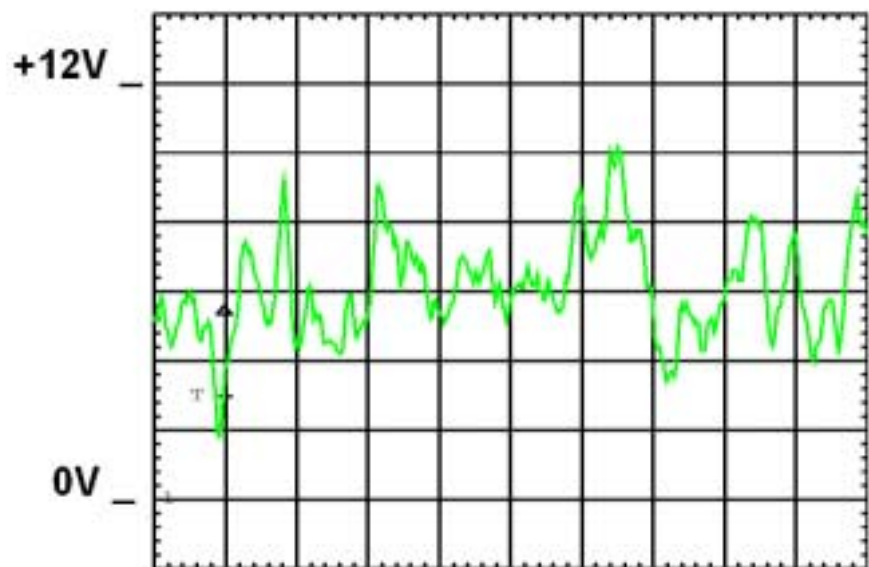
The circuit modifications are firstly change the supply Voltage from 5 Volts to 12 Volts. Secondly you will need to make the noise in the audio range instead of the very low frequencies used for random.

Change the values as follows:

C1 47 μ F
C2 4 μ 7F
C3 do not use
C6 4 μ 7F
C7 do not use

The following 'scope image shows the output of the noise generator. The time base is 2mSecs. per division.

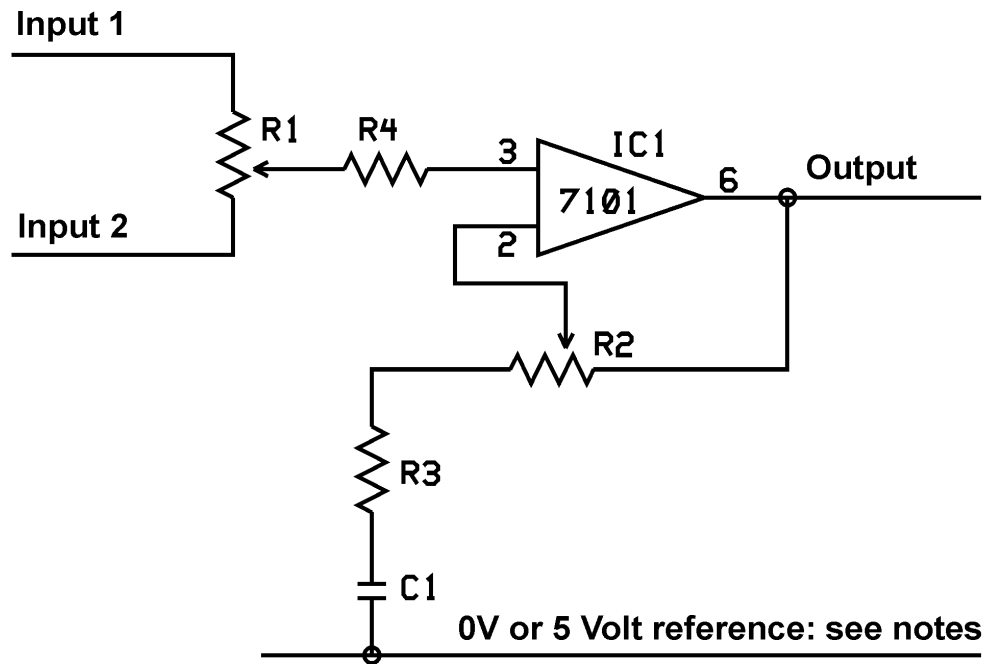
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Summing amplifier.

This circuit is used to add signals together. For example you may wish to add noise to your sound or add a signal to the input of your Voltage controlled oscillator and use the result to control the Voltage controlled filter so that you have a Voltage input that will control the output waveform and that waveform will be the same for different oscillator frequencies.

The following circuit has two controls. One for varying the relative proportions (ratio) of the two inputs. You may want to add different amounts of one of the signals to the other. For example, if you were adding noise to your signal, you would want to be able to adjust the ratio of signal to noise. The other control is used to adjust the amplifier's gain (or volume control).



Summing amplifier

R1 50K potentiometer

R2 50K potentiometer

R3 10K

R4 10K

C1 1 μ F see notes

IC1 7101 operational amplifier, any suffix or prefix should be OK. Connect pin 4 to 0V and pin 7 to + 12V. Do not make any connections to the unused pins.

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Notes

C1 should only be used if the input signals are alternating Voltages, as would be the case if they were from oscillators or noise generators. If C1 is used, it should be connected to the 0 Volt rail. If C1 is not used, C1 should be a short circuit.

If C1 is not used, R3 may either be connected to the 0 Volt rail or to the 5 Volt reference. If the 5 Volt reference is used, the output will be shifted towards 0 Volts and if the 0 Volt rail is used, the output will not be shifted. You may require some output between the two conditions. If this is the case, you should connect a 10K potentiometer between 0 Volts and 5 Volts and connect R3 to the wiper. This will provide an adjustable bias.

Testing

Before applying power to the circuit, inspect the circuit thoroughly using a spy glass ensuring that there are no unwanted short circuits or open circuits and that the circuit follows the diagram exactly. Ensure that the power supply is connected the right way round. Then set your meter to continuity or low Ohms

range. Connect the meter across the 0V and 12V supply and make sure that the reading is not zero or near to zero. You may get a bleep or a low Ohmic value for a short time because of the capacitor in the power supply, but this should not last more than a few seconds. If it is continuous, you have a short circuit somewhere and you should follow the instructions in the fault finding section. If you do not get the expected results, you should switch the circuit off immediately.

Connect your two inputs to the circuit and observe the output. Adjust the controls and see that they do what is expected. Since this circuit may be used for different purposes, it is not possible to be more specific.

Circuit description

When the wiper of R1 is at the input 1 end, the signal on input 2 will have no effect on the circuit. When the wiper of R1 is at the input 2 end, the signal on input 1 will have no effect. When the wiper of R1 is half way between, it will have the average Voltage of the two inputs on it. R4 couples the wiper of R1 to the non-inverting input (pin 3) of the operational amplifier.

When the wiper of R2 is at the output end, the amplifier will have a gain of 1. That is the output will equal the input. When the wiper is at the R3 end, the amplifier will have a gain of 6.

If C1 is present, only the alternating component of the input will be amplified and the average output Voltage will be equal to the average Voltage on the wiper of R1.

Faultfinding

The first thing to do is give the circuit a thorough visual inspection with a spyglass looking for bad solder joints and short circuits. Check that the circuit you have built exactly matches the circuit diagram and that the components are the correct values and connected the right way round.

If the power supply was short-circuited or had a greatly reduced output, remove the and try again. If that does not help, there must be a short circuit or misconnection. If the removal of the IC restores the output of the power supply, check for short circuits on the pins of the IC socket, in particular any outputs of the IC. Make sure that the IC was the correct way round. It is possible that the IC is faulty. The only connections to the 12 Volt rail should be pin 7 of IC1.

Assuming that the power supply is OK, check that pin 4 of IC1 is connected to the 0 Volt rail, that pin 7 is connected to the 12 Volt rail, that none of the unused pins of IC1 are connected anywhere and that the IC has been connected the right way round. Look for short circuits, open circuits and bad solder joints. If none of that helps, try replacing IC1 and if that helps, throw the old IC away.

Low frequency oscillator.

The low frequency oscillator (LFO) uses the same circuitry as the Voltage controlled oscillator (VCO) with a few component value changes. In addition, however you may want to have the facility of starting the LFO when a signal starting a note is present. Sequencers produce just such a signal. The start of a note is signaled by an input rising from 0 Volts to about 14 Volts or so depending on the sequencer.

The LFO is also Voltage controlled so you could, if you wanted, use one LFO as an input to another LFO.

You can use the same waveform converting circuits as the ordinary VCO uses to produce sine, triangle and square waveforms.

The LFO is normally used to modify the frequency and/or volume of the VCO.

To go to the VCO circuit click [here](#).

CLICK

The Modifications to the circuit are as follows.

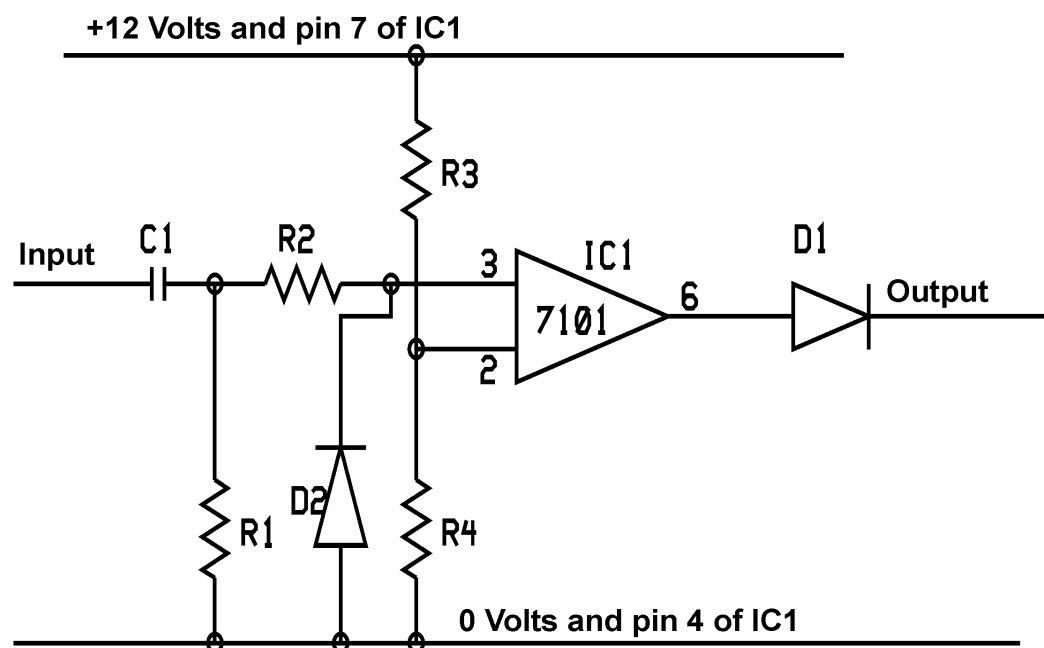
R14 50K

R6 100K

C1 1 μ F

C2 0 μ 01F

The following circuit is used to start the LFO with an external keyboard switch, indicating the start of a note.



External keyboard switch input for starting LFO

R1 1M
 R2 10K
 R3 100K
 R4 10K
 C1 0 μ 01F
 D1 1N4148
 D2 1N4148

IC1 7101 operational amplifier, any suffix or prefix should be OK. Connect pin 4 to 0V and pin 7 to + 12V. Do not make any connections to the unused pins.



Notes

The input can be from a keyboard, a sequencer, a square wave oscillator or pulse generator. The square wave oscillators and pulse generators, described elsewhere in this cd, will function with this circuit. If you have a switch input, you will need to use a digital circuit to produce a clean input signal. A pulse stretcher would be ideal.

The output should be connected to the gate (g) of T1 in the LFO circuit.

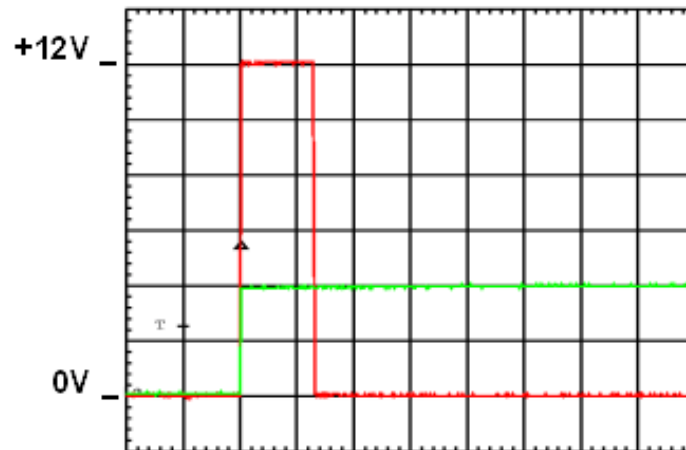
Testing

Before applying power to the circuit, inspect the circuit thoroughly using a spy glass ensuring that there are no unwanted short circuits or open circuits and that the circuit follows the diagram exactly. Ensure that the power supply is connected the right way round. Then set your meter to continuity or low Ohms range. Connect the meter across the 0V and 12V supply and make sure that the reading is not zero or near to zero. You may get a bleep or a low Ohmic value for a short time because of the capacitor in the power supply, but this should not last more than a few seconds. If it is continuous, you have a short circuit somewhere and you should follow the instructions in the fault finding section. If you do not get the expected results, you should switch the circuit off immediately.

Connect the input to a signal producing square waves. This could be a sequencer or an oscillator. The signal source used to create the following image was a bench-top signal generator. Higher Voltage signals cause a longer output pulse.

Connect your oscilloscope to input and pin 6 of IC1. You should then observe a similar image to the one shown here.

In the following 'scope image, the time base is 10mSecs. The green trace shows the input and the red trace shows the output of IC1.



Circuit description

C1 and R1 are the timing components. When the rising edge of the input arrives, C1 conducts, as there is a changing Voltage across it. C1 is a low value so it can only pass high frequencies so only the start of the input pulses get through. The negative pulses are shorted out by D2. R3 and R4 provide a bias for IC1. When the non-inverting input (pin 3) has a higher Voltage than the bias, the output (pin 6) becomes positive.

D1 only allows the positive pulse to pass. When the output of IC1 is at 0 Volts, D1 does not conduct and blocks the signal.

Faultfinding

The first thing to do is give the circuit a thorough visual inspection with a spyglass looking for bad solder joints and short circuits. Check that the circuit you have built exactly matches the circuit diagram and that the components are the correct values and connected the right way round.

If the power supply was short-circuited or had a greatly reduced output, remove the and try again. If that does not help, there must be a short circuit or misconnection. If the removal of the IC restores the output of the power supply, check for short circuits on the pins of the IC socket, in particular any outputs of the IC. Make sure that the IC was the correct way round. It is possible that the IC is faulty. The only connections to the 12 Volt rail should be pin 7 of IC1.

Assuming that the power supply is OK, check the component values. Make sure that pin 4 of IC1 is connected to the 0 Volt rail, that pin 7 is connected to the 12 Volt rail and that the unused pins are not connected anywhere. Check that D1 is the correct way round. Check that the bias Voltage on pin 2 is about 1 Volt. Look for short circuits, open circuits and bad solder joints. If none of this helps, try replacing IC1 and if that helps, throw the old one away.

Logarithmic amplifier.

This circuit is difficult to understand and is probably only needed if you are going to connect the Voltage controlled oscillator to a keyboard or MIDI to analogue interface.

This circuit is definitely not for beginners.

The reason for having a logarithmic amplifier in the first place is that you need to convert a fixed Voltage change of an input signal to a Voltage that will produce a fixed musical pitch change. The usual is 1 Volt per octave. An octave is a doubling of frequency. If you consider a note for 1 Volt input and now you want an octave higher so you have an input of 2 Volts. A three Volt input should then be an octave higher than that, but that would need a 4 Volt input to the oscillator and not a 3 Volt input. The non-linear function that is required to convert the input signal to the correct one for the Voltage controlled amplifier is logarithmic.

Now as it happens, the relationship between the Voltage across the base – emitter junction of a transistor and the collector – emitter current is logarithmic for low values of collector current. We use this relationship to produce a logarithmic amplifier. The problem with this is that the Cutin voltage of a transistor is very temperature dependent. We use two techniques to solve this problem. The first is to use two thermally matched transistors and use one transistor to compensate for the variations in the other. This is fine up to a point, but it is still not good enough. We then work on the basis that if the transistors are kept at a constant temperature, there will not be any drift.

The following circuit uses both of these techniques. Long ago, in the days of prehistory, there used to be some matched transistor pairs in their own little temperature-controlled oven. These devices were commonly used as input stages for operational amplifiers to reduce thermal drift. In the mean time, however operational amplifiers have improved and no longer need such devices. They have now become obsolete, which is unfortunate as they are just what we need. There are however some transistor arrays on a single chip so the transistors on that chip will all be at very nearly the same temperature. We will use these chips to combine an oven circuit with a matched pair of transistors to try and duplicate the old devices. Unfortunately the transistors are not capable of dissipating much power so we can only raise the temperature by about 15 degrees C. This should be enough for most purposes but the circuit may need recalibrating according to external temperatures.

R8 10K
 R9 1K
 R10 100K
 R11 10K
 R12 100K
 R13 1K
 R14 10K
 R15 10K
 R16 10K
 R17 10K
 R18 100K
 R19 10K
 R20 100 Ohms
 R21 200 Ohm potentiometer
 R22 10K
 R23 1M
 R24 2K2
 R25 150 Ohms see notes
 R26 2K2
 C1 0 μ 1F
 C2 0 μ 1F
 C3 0 μ 1F

IC1 7101 operational amplifier, any suffix or prefix should be OK. Connect pin 4 to 0V and pin 7 to + 12V. Do not make any connections to the unused pins.

IC2 7101 operational amplifier, any suffix or prefix should be OK. Connect pin 4 to 0V and pin 7 to + 12V. Do not make any connections to the unused pins.

IC3 7101 operational amplifier, any suffix or prefix should be OK. Connect pin 4 to 0V and pin 7 to + 12V. Do not make any connections to the unused pins.

IC4 CA3040E see notes

IC5 7101 operational amplifier, any suffix or prefix should be OK. Connect pin 4 to 0V and pin 7 to + 12V. Do not make any connections to the unused pins.

IC6 7101 operational amplifier, any suffix or prefix should be OK. Connect pin 4 to 0V and pin 7 to + 12V. Do not make any connections to the unused pins.

IC7 7101 operational amplifier, any suffix or prefix should be OK. Connect pin 4 to 0V and pin 7 to + 12V. Do not make any connections to the unused pins.

Notes

R25 should be glued to the top of IC4 using an epoxy resin as shown in the photograph.

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CA3046E



Testing

Before applying power to the circuit, inspect the circuit thoroughly using a spy glass ensuring that there are no unwanted short circuits or open circuits and that the circuit follows the diagram exactly. Ensure that the power supply is connected the right way round. Then set your meter to continuity or low Ohms range. Connect the meter across the 0V and 12V supply and make sure that the reading is not zero or near to zero. You may get a bleep or a low Ohmic value for a short time because of the capacitor in the power supply, but this should not last more than a few seconds. If it is continuous, you have a short circuit somewhere and you should follow the instructions in the fault finding section. If you do not get the expected results, you should switch the circuit off immediately.

Check the 5 Volt and 10 Volt references.

Apply an input Voltage and check that the output Voltage responds. Adjusting R5 will change the circuit gain but this should be done when the circuit output is connected to the Voltage controlled oscillator.

IC4 will take a few minutes to warm up so you should wait about ten minutes before adjusting R21. R21 alters the temperature of IC4. After each adjustment of R21, you should wait a few minutes to see the result.

The setting of R21 is dependent on the ambient temperature at the time of adjustment. If the ambient temperature is normal, set R21 so that the Voltage at pin 11 of IC4 is about 8 Volts. If it is a cold day the Voltage should be about 7 and if it is a warm day, The Voltage should be about 9.

You should note that a small change in the setting of R21 will cause an immediate large change in the Voltage. You will have to wait for the Voltage level to settle down before you can see the result of your action. You would be advised to make small adjustments once you are close to the ideal setting.

Circuit description

IC1 acts as a buffer so that you can use a potentiometer as a source if you want. IC2 converts the input from 0 to 5 Volts to a 10 to 5 Volt signal.

R7 and R13 reduce the signal level. This circuit works with very small signals. The transistors connected to pins 1, 2, 3, 4, 5 and 6 of IC4 are a matched pair, which are used to produce the logarithmic function. The input signal is connected to the base of one of the transistors. The emitter and collector are in the feedback loop of IC3 causing the correct Voltage at the emitters of the two transistors. The two transistors have their emitters connected together so the emitters have exactly the right Voltage for the collector of the first transistor to conduct sufficient current for it to be at 5 Volts. The base of the second transistor is connected to the 5 Volt reference so the Voltage difference

between base and emitter will be the required Voltage for the appropriate collector current. This is fed to the inverting input of IC5. This must be equal to the current flowing through R12 if we assume an infinite input resistance for IC5. Well its very high anyway.

IC6 converts the signal to the required output of 0 to 5 Volts.

The next part of the circuit controls the temperature of IC4. The transistors connected to pins 6, 7, 8, 9, 10 and 11 are used to provide a heat source together with R25. The transistor connected to pins 12, 13 and 14 is used as a temperature sensor.

The Cutin Voltage decreases with increasing temperature. R18 supplies the current for the temperature sensing transistor and R19 connects the transistor to the non-inverting input of IC7. A reference Voltage is provided by R20, R21 and R22. When the temperature is too low, the output of IC7 is high. When the temperature increases, the output of IC7 starts to reduce until it reaches the Voltage necessary to have the correct current flowing through the transistors to keep the temperature sensing transistor voltage equal to the reference Voltage.

Faultfinding

The first thing to do is give the circuit a thorough visual inspection with a spyglass looking for bad solder joints and short circuits. Check that the circuit you have built exactly matches the circuit diagram and that the components are the correct values and connected the right way round.

If the power supply was short-circuited or had a greatly reduced output, remove the and try again. If that does not help, there must be a short circuit or misconnection. If the removal of the IC restores the output of the power supply, check for short circuits on the pins of the IC socket, in particular any outputs of the IC. Make sure that the IC was the correct way round. It is possible that the IC is faulty. The only connections to the 12 Volt rail should be pin 7 of IC1.

You should use the usual fault finding procedures. The first part to look at is the input circuit comprising IC1 and IC2 and associated components. The next part is more complex as it comprises IC3, IC4 and IC5. The output of IC3 should be approximately 4.5 Volts and vary a bit according to the input . The output of IC5 should be between 5 Volts and 10 Volts according to the input.

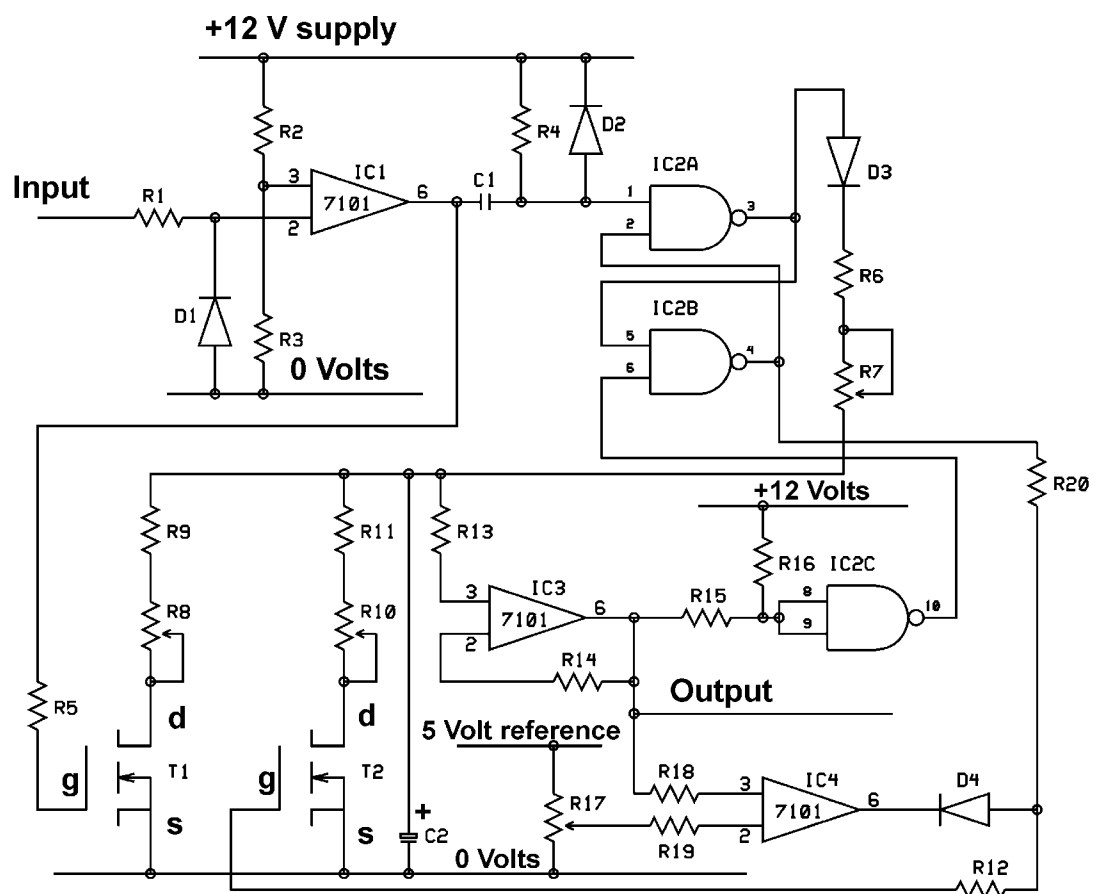
IC6 is again easy to understand.

You can treat IC7 and related circuit as a separate circuit from a fault finding viewpoint. On switch-on, the temperature of IC4 should be too low so the output of IC7 should be at 12 Volts if R21 is correctly set. If it isn't, adjust R21.

It is assumed that anyone attempting to build this circuit has some experience in these matters and the fault finding instructions are therefore limited.

Attack, sustain, decay and release ASDR

This circuit is used to alter the volume accordingly when a note is sounded. Different instruments have different volume envelopes. A plucked instrument, for example has a loud initial sound, which decays quickly to a medium volume before slowly becoming silent. A percussion instrument has an even more marked effect. A bowed instrument on the other hand has a more constant volume.



Attack, sustain, decay and release ASDR

R1	10K
R2	100K
R3	10K
R4	100K
R5	10K
R6	2K2
R7	20K potentiometer
R8	20K potentiometer
R9	2K2
R10	20K potentiometer
R11	2K2

VN10LP



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R12 10K
 R13 10K
 R14 10K
 R15 10K
 R16 22K
 R17 20K potentiometer
 R18 10K
 R19 10K
 R20 10K
 C1 0 μ 1F
 C2 47 μ F tantalum
 D1 1N4148
 D2 1N4148
 D3 1N4148
 D4 1N4148
 T1 VN10LP
 T2 VN10LP

IC1 7101 operational amplifier, any suffix or prefix should be OK. Connect pin 4 to 0V and pin 7 to + 12V. Do not make any connections to the unused pins.

IC2 HEF4011BP

IC3 7101 operational amplifier, any suffix or prefix should be OK. Connect pin 4 to 0V and pin 7 to + 12V. Do not make any connections to the unused pins.

IC4 7101 operational amplifier, any suffix or prefix should be OK. Connect pin 4 to 0V and pin 7 to + 12V. Do not make any connections to the unused pins.



Notes

T1 and T2 are static sensitive devices.

C2 must be connected the right way round. The negative end should be connected to the 0 Volt rail.

IC2 has a spare gate. If this is not used, the inputs should either be connected to the 0 Volt rail or the 12 Volt rail.

Connect the input to a signal producing square waves or pulses. This could be a sequencer or an oscillator. The signal source used to create the following images was a bench-top signal generator.

R7 adjusts the attack.

R17 adjusts the sustain

R10 adjusts the decay.

R5 adjusts the release.

The output Voltage is proportional to the Volume of sound produced . This circuit will be used to provide an input to the Voltage controlled amplifier circuit. When the output is at 0 Volts, there will be silence and when it is at 5 Volts, the sound level will be at maximum.

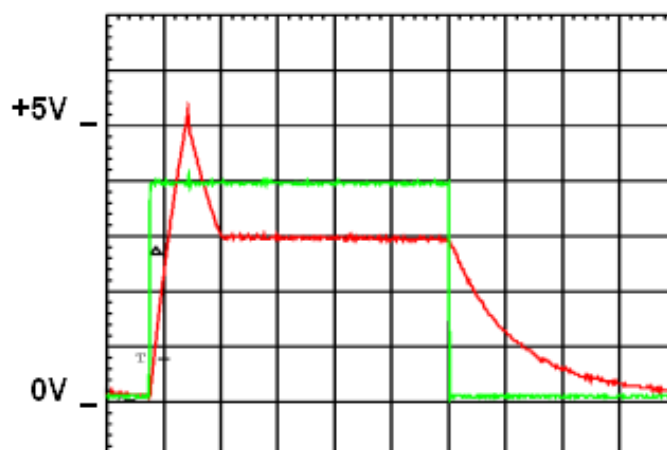
Testing

Before applying power to the circuit, inspect the circuit thoroughly using a spy glass ensuring that there are no unwanted short circuits or open circuits and that the circuit follows the diagram exactly. Ensure that the power supply is connected the right way round. Then set your meter to continuity or low Ohms range. Connect the meter across the 0V and 12V supply and make sure that the reading is not zero or near to zero. You may get a bleep or a low Ohmic value for a short time because of the capacitor in the power supply, but this should not last more than a few seconds. If it is continuous, you have a short circuit somewhere and you should follow the instructions in the fault finding section. If you do not get the expected results, you should switch the circuit off immediately.

Check the 5 Volt reference.

Set all the potentiometers to their mid points.

Connect your oscilloscope probes to the input and output and check that you get similar results to the following oscilloscope image. The time base is set at 500mSecs. per division. The green trace shows the input, which may be of a higher Voltage than shown. Typically, sequencers produce 14 Volt pulses. The red trace shows the output. As you can see, the duration of the input pulse (key press) was about 2.5 Seconds in this example. The images shown in this cd are made using a storage oscilloscope. You will not be able to see such slow traces as continuous lines if you do not have a storage 'scope. You will however see the dots moving up and down and left to right.

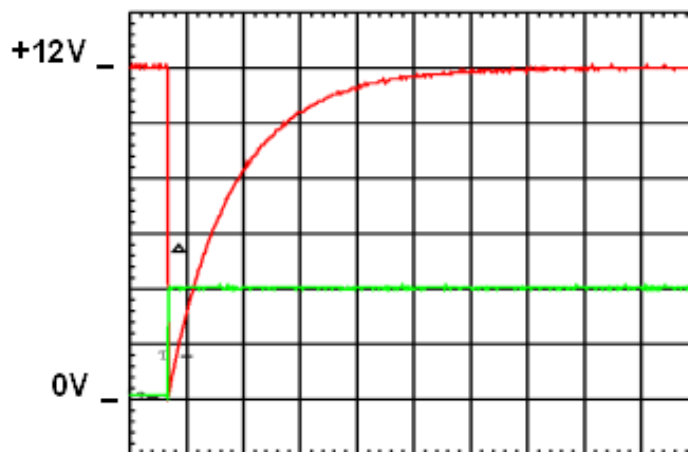


Circuit description

The heart of the circuit is the capacitor C2. This is charged up at the start of the input pulse; this is the attack. When it has reached about 5 Volts, it discharges until it reaches the sustain Voltage; this is called the decay. It remains at the sustain Voltage until the input pulse finishes. When that happens, it discharges; this is the release.

C2 is buffered by IC3, which has a high input resistance so that C2 does not discharge too quickly during the sustain period.

D1 protects IC1 from negative inputs from external devices like sequencers. R2 and R3 provide a low level bias. When the input signal is at 0 Volts, the output of IC1 is nearly at 12 Volts. This turns T1 on and C2 discharges through R8 and R9. As soon as the input becomes positive, the output of IC1 becomes nearly 0 Volts, which turns T1 off and causes a negative spike to appear at the input (pin 1) of IC2A. This can be seen in the following 'scope image. The time base is 10mSecs. per division. The green trace shows the start of the input pulse and the red trace shows pin 1 of IC1A. The time period of the spike is determined by the values of C1 and R4. D2 prevents positive spikes.

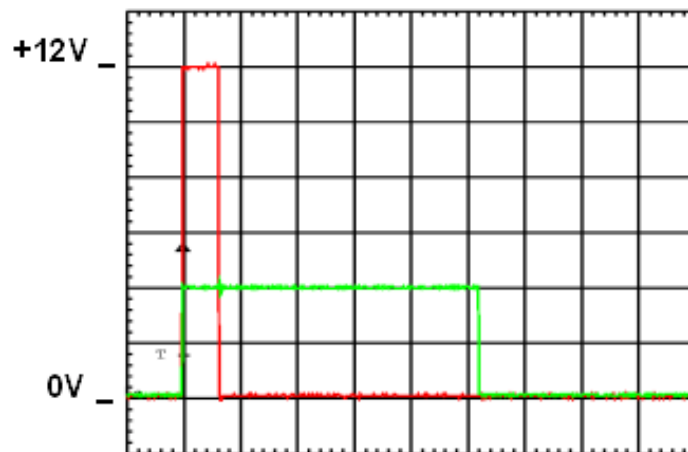


IC2A and IC2B are configured as an RS Flip Flop or latch. When a '0' appears at pin 1, the output (pin 3) of IC2A becomes a '1'. This is connected to pin 5 of IC2B. Pin 6 of IC2B is also a '1', so the output (pin 4) of IC2B becomes a '0'. This is connected to the input (pin 2) of IC2A. So when the input (pin 1) of IC2A becomes a '1' again, there is still a '0' on one of the inputs of IC2A so its output remains a '1'. The signal is latched until the input (pin 6) of IC2B becomes a '0'. So after the input becomes a '1', the output of IC2A will be a '1' and the output of IC2B becomes a '0' until the input (pin 6) of IC2B becomes a '0'.

When the output of IC2A is a '1', D3 conducts and C2 charges up via R7 and R7 and T2 is turned off. This gives us the start condition when the attack is active. When the Voltage across C2 reaches about 5 Volts, The input (pins 8 and 9) of IC2C becomes a '1' and its output therefore becomes a '0'. This is

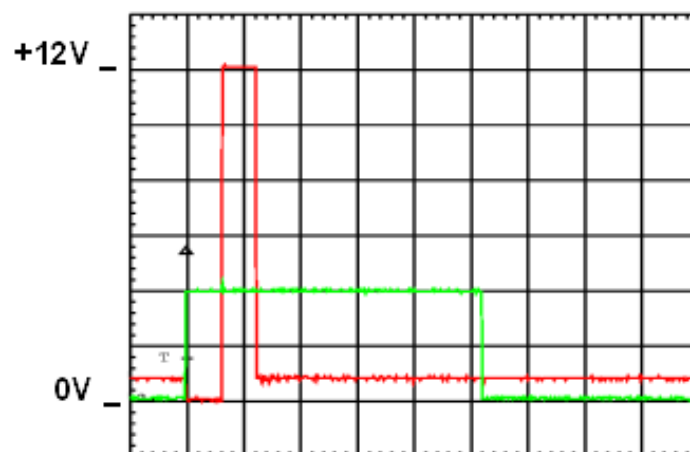
connected to pin 6 of IC2B and resets the latch. The output of IC1A becomes a '0' so C2 stops being charged up and the output of IC2B becomes a '1', so T2 turns on. This causes C2 to discharge via R10 and R11. This is the decay part of the Volume envelope.

In the following 'scope image, the time base is 500mSecs. per division. The green trace shows the input and the red trace shows the output (pin 3) of IC1A.



When C2 discharges enough so that the Voltage across it becomes less than the Voltage set by the sustain potentiometer R17, the output of IC4 becomes nearly 0 Volts and the diode D4 conducts causing T2 to turn off. At this point, C2 is neither charging nor discharging so the Voltage across it remains constant. There will be some very small discharge so the Voltage across C2 will eventually decay to zero, but that will take some time.

In the following 'scope image, the time base is 500mSecs. per division, the green trace is the input and the red trace is gate (g) of T2.



When the input returns to 0 Volts again, T2 remains off as the Voltage across C2 is less than the sustain Voltage. T1 is turned on and C2 discharges via R8 the release control and R9.

Faultfinding

The first thing to do is give the circuit a thorough visual inspection with a spyglass looking for bad solder joints and short circuits. Check that the circuit you have built exactly matches the circuit diagram and that the components are the correct values and connected the right way round.

If the power supply was short-circuited or had a greatly reduced output, remove the and try again. If that does not help, there must be a short circuit or misconnection. If the removal of an IC restores the output of the power supply, check for short circuits on the pins of the IC socket, in particular any outputs of the IC. Make sure that the IC's were the correct way round. It is possible that an IC is faulty. The only connections to the 12 Volt rail should be pin 7 of IC1, IC3 and IC4, pin 14 of IC2 R2, R4, D2, and R16.

Assuming that the 12 Volt supply is OK, check the 5 Volt reference. If this is not OK, check the value of R17. Check that R17 has been connected correctly. Look for short circuits, open circuits and bad solder joints.

Assuming that the 5 Volt reference is OK, check that you have an input signal.

Assuming that you have an input signal, check that D1 is the correct way round. Check the value of R1. Check that pin 4 of IC1 has been connected to the 0 Volt rail and that pin 7 has been connected to the 12Volt rail. Check that the output of IC1 is 0 Volts when the input signal is high and 12 Volts when the input signal is low. If it isn't, check the values of R2 and R3. Look for short circuits, open circuits and bad solder joints. If none of that helps, try replacing IC1 and if that helps, throw the old IC away.

Assuming that the output of IC1 is OK, check the waveform at the input (pin 1) of IC2A. It should look like the one in the circuit description. If it doesn't, check that D2 is the correct way round, check the values of C1 and R4. . Look for short circuits, open circuits and bad solder joints. If none of that helps, try replacing IC2 and if that helps, throw the old IC away.

Assuming that the waveform at the input of IC1A is OK, thoroughly check the connections to IC2 against the circuit diagram. Check that pin 7 is connected to the 0 Volt rail and that pin 14 is connected to the 12 volt rail. Check that D3 and D4 are the correct way round. Check the outputs of IC1A and IC1B when the input signal is present. Check that C2 charges up and that when it does, the output of IC3 follows the Voltage on C3. Check that T1 and T2 are connected the correct way round. Check that C2 is the correct way round, if it isn't, replace it and throw the old one away. Check that the potentiometers R7, R8, and R10 are correctly connected. Check that when the output of IC3 rises to a bit over 5 Volts, the output of IC2C becomes a '0'. If it doesn't, check the values of R15 and R16. . Look for short circuits, open circuits and bad solder

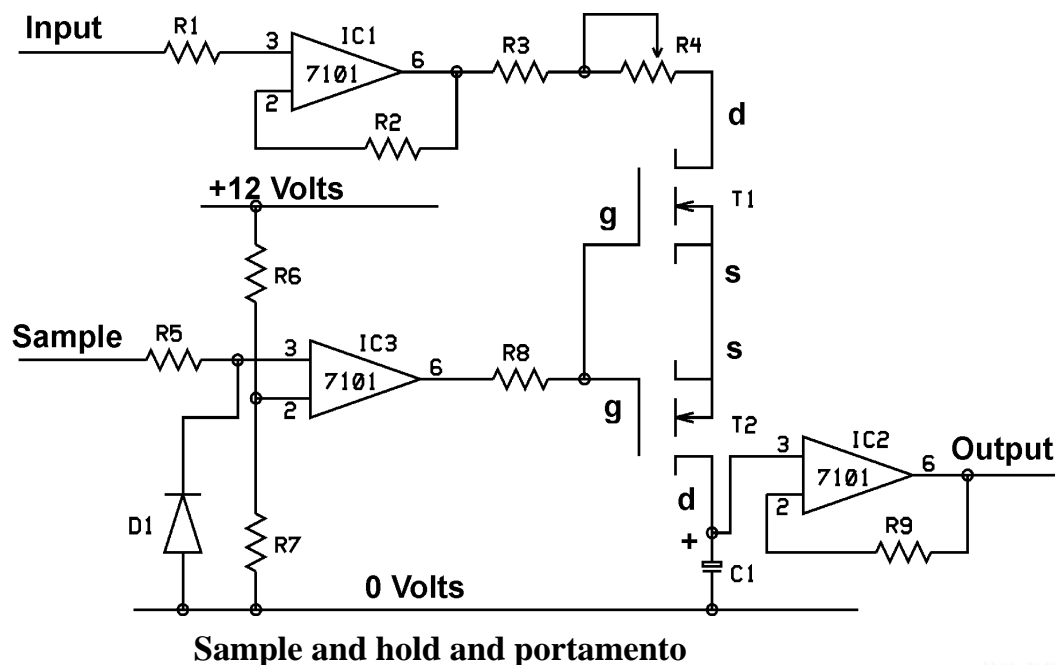
joints. If none of that helps, try replacing IC2 and if that helps, throw the old IC away.

Sample and hold and portamento.

This circuit is used to remember the Voltage of the last keyboard input and provide for portamento, which is note sliding between keyboard input values.

The circuit should be inserted between the keyboard, or other note generating Voltage input and either the logarithmic amplifier or the Voltage controlled oscillator directly.

The Voltage, which controls the pitch (frequency) of the note produced is remembered during a keyboard input and remembered on a capacitor until a new keyboard input. If the capacitor is prevented from charging up or discharging quickly, the note slides and you have portamento.



R1	10K
R2	10K
R3	1K
R4	100K potentiometer
R5	10K
R6	100K
R7	10K
R8	47K
R9	10K
C1	4 μ 7F tantalum
D1	1N4148
T1	VN10LP
T2	VN10LP

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VN10LP



IC1 7101 operational amplifier, any suffix or prefix should be OK. Connect pin 4 to 0V and pin 7 to + 12V. Do not make any connections to the unused pins.

IC2 7101 operational amplifier, any suffix or prefix should be OK. Connect pin 4 to 0V and pin 7 to + 12V. Do not make any connections to the unused pins.

IC3 7101 operational amplifier, any suffix or prefix should be OK. Connect pin 4 to 0V and pin 7 to + 12V. Do not make any connections to the unused pins.

Notes

T1 and T2 are static sensitive.

The input is the Voltage input, which will be used to define the oscillator frequency.

Connect the sample input to a signal producing square waves or pulses. This could be a sequencer or an oscillator. When this signal is a '1', the output Voltage becomes equal to the input. When the signal is a '0', the output Voltage is the Voltage that it was immediately before the signal became a '0' and is not affected by the input Voltage.

R4 adjusts the amount of portamento.

Testing

Before applying power to the circuit, inspect the circuit thoroughly using a spy glass ensuring that there are no unwanted short circuits or open circuits and that the circuit follows the diagram exactly. Ensure that the power supply is connected the right way round. Then set your meter to continuity or low Ohms range. Connect the meter across the 0V and 12V supply and make sure that the reading is not zero or near to zero. You may get a bleep or a low Ohmic value for a short time because of the capacitor in the power supply, but this should not last more than a few seconds. If it is continuous, you have a short circuit somewhere and you should follow the instructions in the fault finding section. If you do not get the expected results, you should switch the circuit off immediately.

Connect the input to a variable Voltage source (a potentiometer will do) between 0 Volts and 5 Volts. Connect the sample input to the 12 Volt rail. Check that the output Voltage equals the input Voltage.

Now connect the sample input to 0 Volts. Check that the output Voltage remains constant. Change the input Voltage and check that the output Voltage does not change. It will change a little but over a time period of a few seconds you should not observe a significant output Voltage change.

Circuit description

IC1 acts as a buffer. The output follows the input (the output Voltage equals the input Voltage).

C1 is the storage device, which remembers the input Voltage. When T1 and T2 are on, C1 charges up and discharges to follow the Voltage at the output of IC1. When R4 is set to have a high resistance, The Voltage across C1 cannot follow the output of IC1 very quickly. This is the portamento effect. When T1 and T2 are off, C1 is open circuit and neither charges nor discharges. It therefore remembers the last Voltage across it. In fact the components are not perfect so there will be a very slow discharge. IC2 acts as a voltage follower to follow the Voltage across C1.

R6 and R7 provide a bias for IC3. R5 and D1 prevent negative sample input Voltages from causing damage to IC3. When the sample input is 0 Volts, the output of IC3 is 0 Volts and T1 and T2 are off. When the sample input Voltage is higher than the bias Voltage, the output of IC3 is 12 Volts and T1 and T2 are turned on.

You will note that the circuit uses two transistors instead of one. This is because MOSFET's act like diodes and conduct if the drain (d) becomes more negative than the source (s). By connecting them back to back, only one of them can conduct when the gate (g) Voltage is zero.

Faultfinding

The first thing to do is give the circuit a thorough visual inspection with a spyglass looking for bad solder joints and short circuits. Check that the circuit you have built exactly matches the circuit diagram and that the components are the correct values and connected the right way round.

If the power supply was short-circuited or had a greatly reduced output, remove the and try again. If that does not help, there must be a short circuit or misconnection. If the removal of an IC restores the output of the power supply, check for short circuits on the pins of the IC socket, in particular any outputs of the IC. Make sure that the IC was the correct way round. It is possible that an IC is faulty. The only connections to the 12 Volt rail should be pin 7 of IC1, IC2 and IC3, and R6.

Assuming that the power supply is OK, check that D1 is the correct way round. Check that C1 is the correct way round. The negative end should be connected to the 0 Volt rail. If it is the wrong way round, replace it and throw the old one away. Check that R4 is connected correctly. Check that T1 and T2 are connected correctly.

Check that the output Voltage of IC1 equals the input Voltage. Do the same for IC2. This may be more difficult if you are using a cheap meter and the transistors are off, because C1 will discharge through the meter.

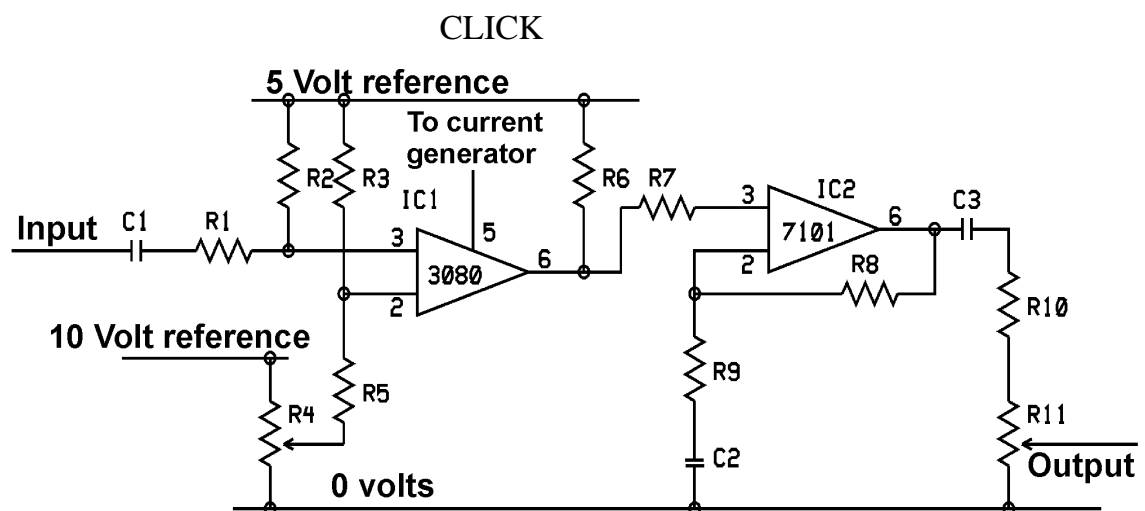
Check that the output of IC3 is 0 Volts when the sample input is 0 Volts and that it is 12 Volts when the sample input has a Voltage higher than 2 Volts.

Look for short circuits, open circuits and bad solder joints. Check the component values. Make sure that pin 7 of the IC's are connected to the 12 Volt rail and that pin 4 of the IC's are connected to the 0 Volt rail.

Audio output circuit.

This circuit is a Voltage controlled amplifier with a master Volume control.

The circuit uses a current converter circuit as an input to pin 5 of IC1. The input to the current converter circuit determines the output volume. Change the value of R1 in the current converter circuit to 100K. Click here to go to the current converter circuit.



Audio output circuit

R1	470K
R2	4K7
R3	10K
R4	20K potentiometer
R5	1M
R6	47K
R7	10K
R8	100K
R9	68K
R10	82K see notes
R11	10K potentiometer
C1	1 μ F ceramic
C2	1 μ F ceramic



C3 1 μ F ceramic

IC1 CA3080E connect pin 4 to the 0 Volt rail and pin 7 to the 12 Volt rail. Do not make any connections to the unused pins.

IC2 7101 operational amplifier, any suffix or prefix should be OK. Connect pin 4 to 0V and pin 7 to + 12V. Do not make any connections to the unused pins.

OPERATIONAL AMPLIFIER



Notes

The value of R10 is for AUX inputs on amplifiers. If you are using an amplifier with a high sensitivity input (a guitar amplifier for example), you will need to change the value of R10 to 1M.

R11 is used as a master volume control.

R4 is used to adjust the bias of IC1 to prevent clipping of the output waveform.

Testing

Before applying power to the circuit, inspect the circuit thoroughly using a spy glass ensuring that there are no unwanted short circuits or open circuits and that the circuit follows the diagram exactly. Ensure that the power supply is connected the right way round. Then set your meter to continuity or low Ohms range. Connect the meter across the 0V and 12V supply and make sure that the reading is not zero or near to zero. You may get a bleep or a low Ohmic value for a short time because of the capacitor in the power supply, but this should not last more than a few seconds. If it is continuous, you have a short circuit somewhere and you should follow the instructions in the fault finding section. If you do not get the expected results, you should switch the circuit off immediately.

Connect the input to a signal source. This could be the output of your oscillator, filter, summing amplifier or a signal generator. Connect a variable Voltage input to the current converter circuit. This could be a 10K potentiometer connected between 0 Volts and the 5 Volt reference. Set R11 to its mid point.

Connect one oscilloscope probe to the circuit input and the other to the output (pin 6) of IC2. You should see identical waveforms on input and output except that the output amplitude will be greater when the current converter input is on maximum.

Observe that the output amplitude varies with the input Voltage to the current converter circuit. It should be zero when the current converter input is zero and maximum when the input is 5 Volts.

Set the amplifier to maximum gain by applying 5 Volts to the input of the current converter circuit. Adjust R4 to give an average output Voltage of 6 Volts at the output of IC2.

Now connect a scope probe to the circuit output and observe that its amplitude is dependent on the setting of R11.

Circuit description

IC1 has a current output, which is dependent on both the input and the current flowing into pin 5. If the current into pin 5 is reduced, the output current flowing into R6 will have a reduced amplitude.

IC1 can only operate effectively in this multiplying mode if the input signals are small. C1 couples the input to the circuit allowing a Voltage shift. The signal is reduced by R1 and R2 and is biased at 5 Volts because R2 is connected to the 5 Volt reference instead of the 0 Volt rail.

R3 connects the inverting input (pin 2) of IC1 to the 5 Volt reference so both inputs are at the same average Voltage. We need to make a small adjustment to this as the amplifiers are not perfect and we want the average output voltage to be 6 Volts and not 5 Volts when the output is at maximum gain.

IC2 is configured as an amplifier having a gain of about 2.5. C2 decouples the feedback circuit so that the direct Voltage levels are not altered. It has a gain of 1 for direct Voltages and a gain of 2.5 for alternating Voltages.

R10 and R11 act as potential dividers to reduce the output signal.

Faultfinding

The first thing to do is give the circuit a thorough visual inspection with a spyglass looking for bad solder joints and short circuits. Check that the circuit you have built exactly matches the circuit diagram and that the components are the correct values and connected the right way round.

If the power supply was short-circuited or had a greatly reduced output, remove the IC's one at a time and try again. If that does not help, there must be a short circuit or misconnection. If the removal of an IC restores the output of the power supply, check for short circuits on the pins of the IC socket, in particular any outputs of the IC. Make sure that the IC was the correct way round. It is possible that an IC is faulty. The only connections to the 12 Volt rail should be pin 7 of IC1, and IC2.

Assuming that the 12 Volt supply is OK, check the 5 Volt reference. If it is not OK, check that the only connections to it are R2, R3 and R6. Check the values of those resistors. Look for short circuits, open circuits and bad solder joints.

Assuming that the 5 Volt reference is OK, check the output (pin 6) of IC1 with an oscilloscope. You should get a signal of a slightly lower amplitude than the input signal when the input to the current converter is at 5 Volts. If you don't, check the component values. Check that R4 is connected correctly. Check that pin 4 is connected to the 0 Volt rail and that pin 7 is connected to the 12 Volt rail. Check that pin 5 is connected to one of the output resistors of the current converter circuit and that pins 1 and 8 are not connected anywhere. Look for short circuits, open circuits and bad solder joints. If none of this helps, try replacing IC1 and if that helps, throw the old IC away.

Assuming that the output of IC1 is OK, check that pin 4 of IC2 is connected to the 0 Volt rail and that pin 7 is connected to the 12 Volt rail. Check that none of the unused pins are connected anywhere. Check the component values. Check that C2 is not shorted out. Look for short circuits, open circuits and bad solder joints. If none of this helps, try replacing IC2 and if that helps, throw the old IC away.

Assuming that the output of IC2 is OK, check that R11 has been connected correctly and that the component values are OK. Look for short circuits, open circuits and bad solder joints.

Complete synthesizer system

The circuits described in this chapter are sufficient for you to build a simple 1970's style music synthesizer. There are many commercial sound effect additions, which are readily available, should you wish to produce other sound effects.

In most cases however, you are unlikely to need an entire synthesizer so you will only need some of the circuits.

You will need the 5 Volt and 10 Volt reference circuit for most of the circuits.

In all of the Voltage controlled circuits you can use a potentiometer connected between 0 Volts and the 5 Volt reference with the wiper as an input to the circuit.

The basic circuit is the Voltage controlled oscillator. This may be all you need. If it is, you will need some sort of amplifier to drive a loudspeaker. There is a simple circuit for this in this chapter. If you want to output the signal to external devices like amplifiers or echo units for example, you should use the audio output circuit.

There is no reason why you should not use more than one Voltage controlled oscillator driven from the same control Voltage and adding the signals together. Doubling the value of C1 will give a signal an octave lower and halving the value of C1 will give an octave higher.

If you want to change the timbre of the sound, you will need to use the Voltage controlled filter circuits. You may of course use a commercial circuit for this. You can also add some noise to the signal

The low frequency oscillator is used to vary the pitch, volume or filter. This is generally what gives the instrument its typical synthesizer sound. If you want a more organ sound, you will not need a LFO. Again there is no reason why you should not use one LFO as an input to another LFO.

If you have an input for keyboard pressing, (this can be from a sensor with digital output, a sequencer, a random time generator or from a simple oscillator) you can use it as an input to the attack, sustain, decay and release circuit. The output of the ASDR circuit can be used to control any of the Voltage variable functions, in particular the output volume.

If you are using a midi to Voltage interface, you will need the logarithmic amplifier. The circuit is a bit difficult to understand and you are unlikely to need it. It is included here for completeness. If you have a midi input, you can use a modern synthesizer and do not need to build one.

If you have a varying voltage input for your frequency and you want to provide definite notes even if they are not in the musical scale, you can use the sample and hold circuit. This may be the case if your frequency input was coming directly from the basic random voltage circuit described in the chapter on random. You would also need to use the sample and hold circuit if you wanted portamento or you have a keyboard type input as you need to remember the voltage whilst the note is decaying if you are using the ASDR circuit.

You will need to use a summing amplifier whenever you add signals together. If, for example, you wanted to add the output of a LFO to the output of the ASDR circuit to use as the controlling input of the audio output circuit, you would need a summing amplifier. You could find that you need several of them depending on the complexity of your synthesizer.

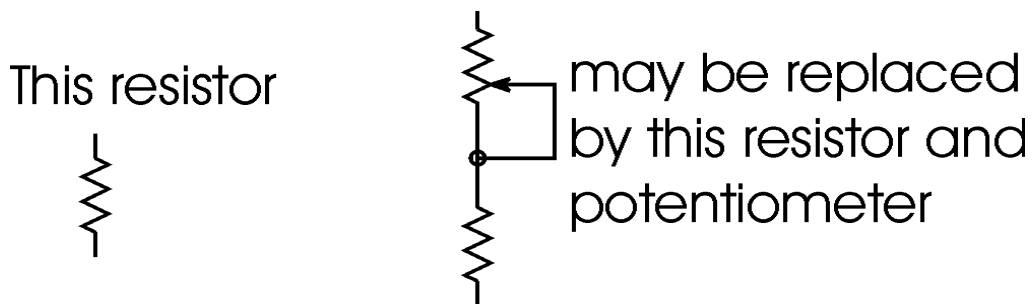
A working knowledge of the use of synthesizers is a definite advantage.

Chapter 13

Timers

Timers are readily available commercially. This chapter contains some simple circuits, which are cheap to build and may be more convenient to use, particularly if they need to be within other circuits.

In the following circuits, the timing resistors may be replaced by a resistor and potentiometer connected in series. This allows you to vary the times without changing the components. The little arrow on the circuit is called the wiper. The wiper moves from one end of the resistor to the other as you turn the control on the potentiometer. This is like the volume control on your sound system. To find out which of the three terminals is which on the potentiometer, set your meter to measure resistance, set the potentiometer to about half way, then measure the resistance between the three terminals. The top and bottom terminals will have the resistance of the value of the potentiometer and the wiper, which is usually the center terminal, will have about half the resistance to either end.



Pulse stretchers

Pulse stretchers are used when the input signals are not on long enough. This may be the case with PIR movement detectors or vibration switches for example.

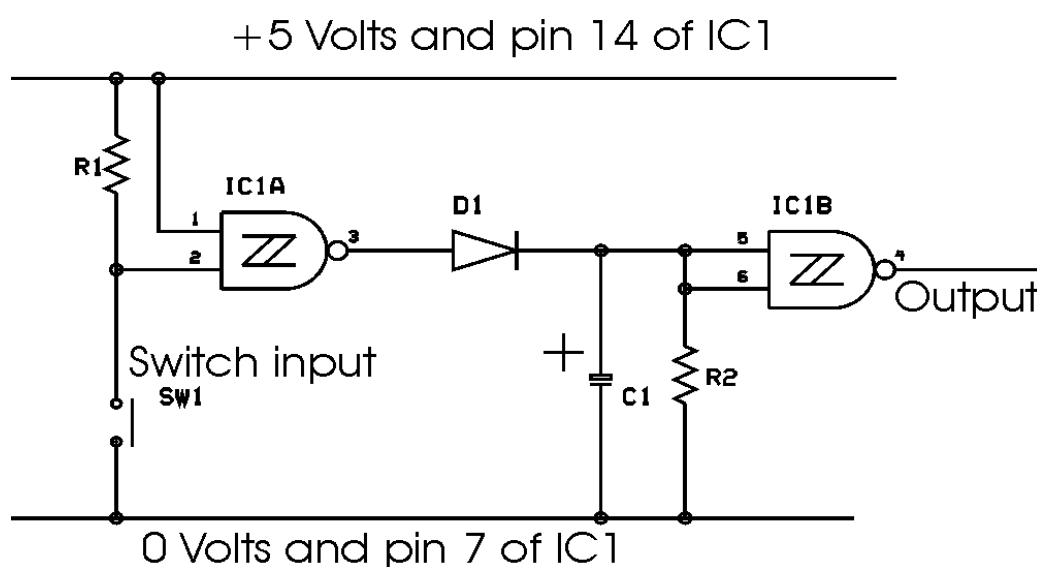
The first two circuits are for stretching pulses for times up to 20 minutes and are not suitable for very long times. The reason is that capacitors leak and the leakage current is dependent on the capacitance, the quality of the component and the temperature. The leakage increases with value and temperature, so as you try to get longer time periods, the leakage increases so the effective value of the timing resistor decreases. This has a limiting effect on the maximum time. If you need to have long time periods of minutes rather than seconds, you will need to look at the leakage specifications of the timing capacitor. It needs to be of a high quality and low leakage. For short times of a few seconds, you should use tantalum capacitors.

The first circuit shows a normally open switch as an input. Normally open switches close (make a connection) when something is detected but are otherwise open (there is no connection). This circuit may be used without R1

and SW1 for input which are normally +5Volts and become 0 Volts for a short period of time. In this case the input should be connected to pin 2 of IC1. The output is normally at +5Volts and becomes 0Volts when an input signal is present and for a period of time afterwards.

This circuit is ideal for preventing problems associated with turning motors off. If we want to ensure that a motor is turned off for a minimum time, we can substitute the motor ON/OFF input signal for the switch SW1 by connecting the input to pin 2 of IC1 and the output signal then becomes the new ON/OFF signal. The motor will then turn off instantly but cannot be turned on again until the time period of the circuit is over. The time delay for such circuits would normally be quite short as it prevents the motor being turned on instantly.

If you want to have a second input, which is not a switch input, you can use pin 1 of IC1. If pin 1 is connected to 0Volts, there will be a stretched output. SW1 can of course be connected in parallel with (directly across) any number of switches. In which case any switch operating will cause an output. Alternatively SW1 may be any digital input.



Pulse stretcher for normally open switch input

R1 10K

D1 1N4148

IC1 4093 any prefix or suffix is OK. Note: these devices are static sensitive

and should be mounted on a socket. There are 4 gates per device (IC1A, IC1B, IC1C and IC1D). They are identical and so may be interchanged. The spare gates may be used in other parts of the circuit. If they are not used,



the inputs should either be connected to 0Volts or +5Volts whichever is the more convenient.

R2 should have a value between 4K7 and 1M.

The time that the output persists longer than the input is a bit less than $C1$ times $R2$ seconds. For example if $C1$ was $100\mu\text{F}$ and $R2$ was 100K then the pulse input would be stretched by a bit less than 10 seconds and if $R2$ was 1M instead, the input would be stretched by a bit less than 100 seconds.

Note that $C1$ is likely to be electrolytic and must therefore be connected the right way round with the negative end connected to 0 Volts.

Testing

Before applying power to the circuit, inspect the circuit thoroughly using a spy glass ensuring that there are no unwanted short circuits or open circuits and that the circuit follows the diagram exactly. Ensure that the power supply is connected the right way round. Then set your meter to continuity or low Ohms range. Connect the meter across the 0V and 5V supply and make sure that the reading is not zero or near to zero. You may get a bleep or a low Ohmic value for a short time because of the capacitor in the power supply, but this should not last more than a few seconds. If it is continuous, you have a short circuit somewhere and you should follow the instructions in the fault finding section. If you do not get the expected results, you should switch the circuit off immediately.

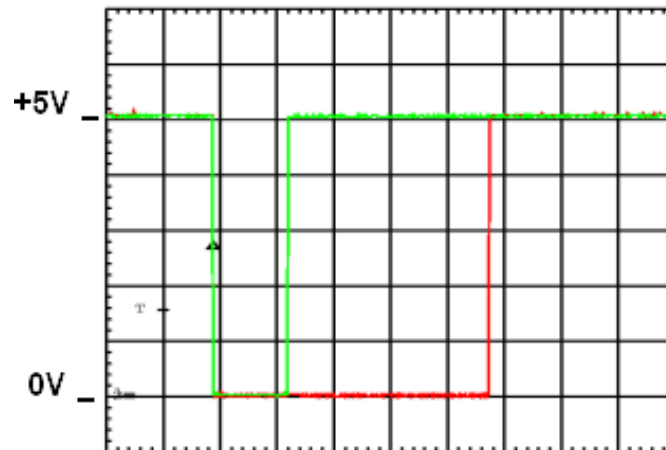
Set your meter to the 20 Volt DC range. Connect your meter across the 5 Volt supply and switch on the supply. If the reading is much below 5 Volts, switch off immediately and go to the fault finding section.

Connect your meter between 0 Volts and the output (pin 4) of IC1B. You should get 5 Volts. Now operate the switch SW1. The reading should now be 0 Volts. Switch off SW1 and see that the output remains 0 Volts for the required time and then reverts back to 5 Volts.

Circuit description

For this example, $C1$ was $4\mu\text{7F}$ and $R2$ was 1M. In the oscilloscope images, the time base (horizontal direction) was 1 second per large division. By the calculation the pulse should be stretched by 4.7 Sec. but was in fact only stretched by about 3.5 Sec. you can see that multiplying $C1$ by $R2$ to give a time is a reasonably close approximation.

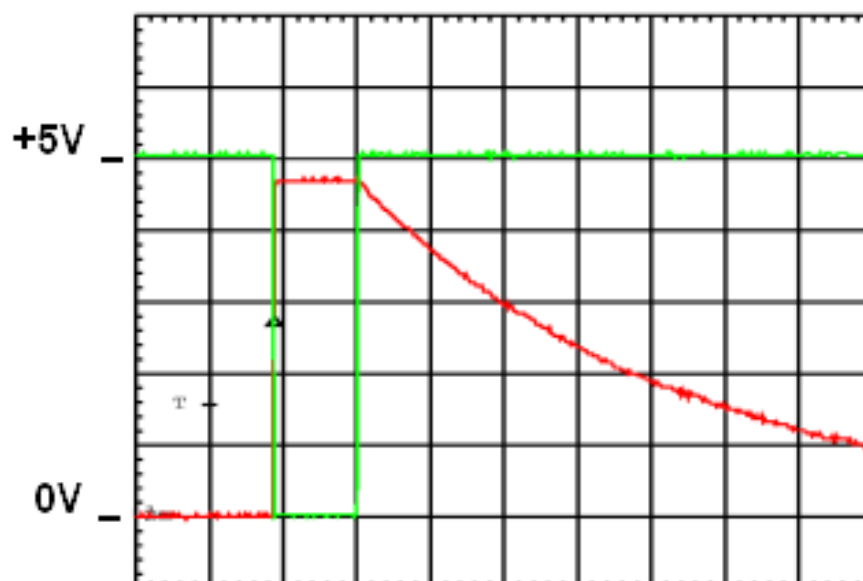
In the following image, the green trace shows the input (pin 2) of IC1A and the red trace shows the output (pin 4) of IC1B. You will note that the red trace goes to 0 Volts when the green trace does but waits about 3.5 seconds after the green trace goes to 5 Volts before it does.



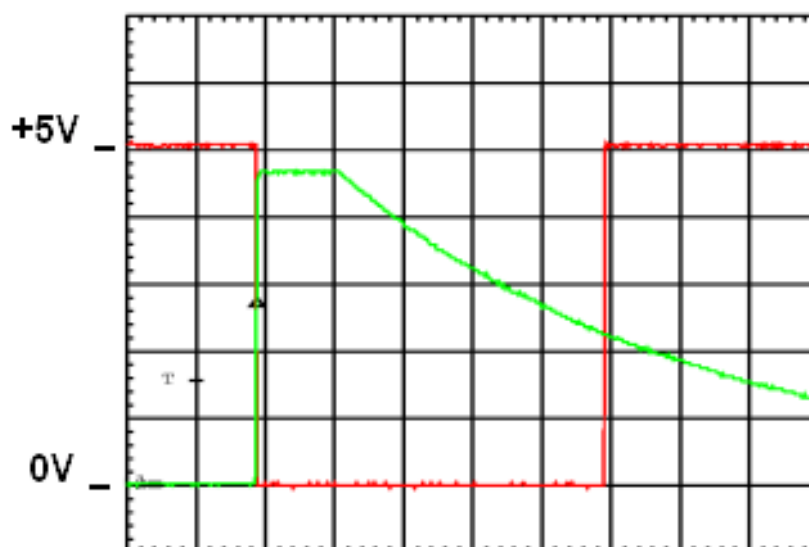
R1 holds the input (pin 2) of IC1A at 5 Volts and the other input (pin 1) is connected to 5 Volts. This means that when the switch is not operated, both inputs of IC1A are at 5 Volts and therefore the output of IC1A will be 0 Volts. The diode D1 will therefore not conduct and C1 is free to discharge through R2 to 0 Volts. This puts 0 Volts on the inputs (pins 5 and 6) of IC1B and causes the output (pin 4) of IC1B to be at 5 Volts.

When the switch SW1 is operated, the input (pin 2) of IC1A becomes 0 Volts and causes the output of IC1A to go to 5 Volts. D1 now conducts and charges C1 up to 4.5 Volts. The 0.5 Volts less than the supply Voltage is the Cutin Voltage of the diode. The input of IC1B is now positive so the output becomes 0 Volts. When the switch is opened again, the output of IC1A goes to 0 Volts and C1 discharges through R2. The input to IC1B remains a '1' until C1 has discharged enough for the input to become a '0' after which, the output of IC1B becomes a '1' again.

In the following 'scope image, the green trace shows the switch input and the red trace shows the Voltage across C1.



In the following 'scope image, the green trace shows the Voltage across C1 and the red trace shows the output of IC1B.



Faultfinding

The first thing to do is give the circuit a thorough visual inspection with a spy glass looking for bad solder joints and short circuits. Check that the circuit you have built exactly matches the circuit diagram and that the components are the correct values and connected the right way round.

If the power supply was short circuited or had a greatly reduced output, remove IC1 and try again. If that does not help, there must be a short circuit or misconnection. If the removal of IC1 restores the output of the power supply, check for short circuits on the pins of the IC socket, in particular any outputs of the IC (pins 3, 4, 10 and 11). Make sure that the IC was the correct way round. It is possible that the IC is faulty. Check that the only connections to the 5 Volt rail are R1 and pin 14 of IC1. Check that none of the outputs (pins 3, 4, 10 and 11) of IC1 are connected anywhere that they shouldn't. Make sure that any unused inputs to the IC are either connected to 0 Volts or to 5 Volts.

Assuming that the power supply is now OK, set your meter to the 20 Volt DC range and connect the common terminal to the 0 Volt rail. Measure the Voltage across the switch SW1. It should be 5 Volts. If it is not, check that R1 is the correct Value and is connected between the 5 Volt rail and the switch terminal. Look for short circuits, open circuits and bad solder joints. Check that you are using the correct terminals of the switch. If none of this helps, try removing the IC. If that helps and replacing it also helps, throw the old IC away. Now operate the switch and check that the Voltage is now 0 Volts. If it isn't, there must either be something wrong with the switch or you have not connected it correctly.

Assuming that the switch is now OK, check the Voltage on the output (pin 3) of IC1A. When SW1 is not operated, the output should be 0 Volts and when it

is operated, the output should be 5 Volts. If it isn't, check that pin 1 is connected to the 5 Volt rail. Check that pin 3 is not connected anywhere other than to D1. Check that pin 7 of IC1 is connected to the 5 Volt rail and that pin 7 is connected to the 0 Volt rail. Check that C1 and R2 are not shorted, are the correct values and are connected to the correct places. Look for short circuits, open circuits and bad solder joints. If none of this helps, try replacing IC1. If that helps, throw the old IC away.

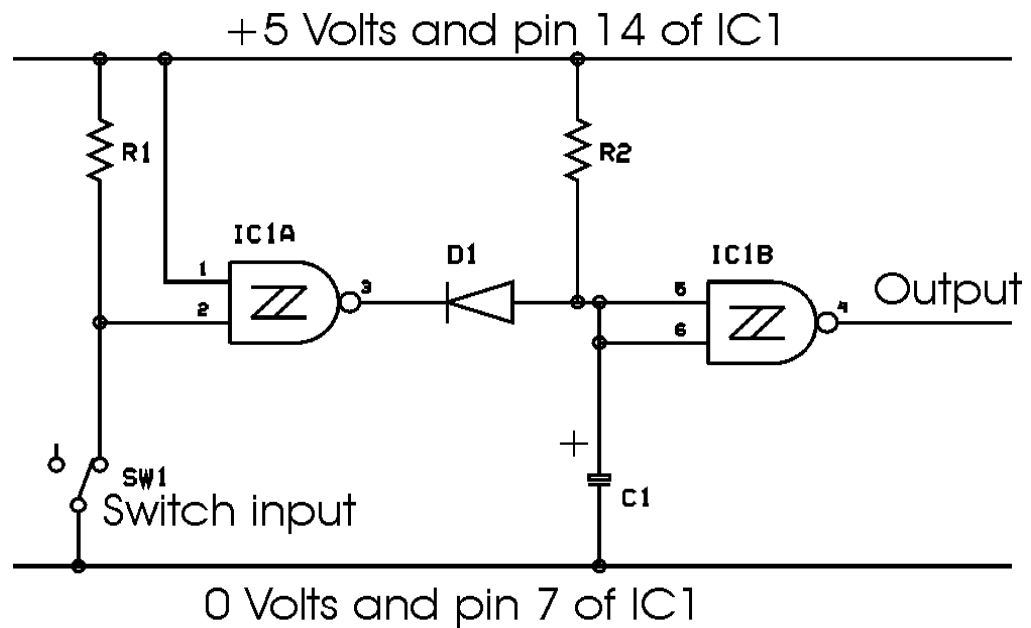
Assuming that the output of IC1A is OK, measure the Voltage at the inputs (pins 5 and 6) of IC1B. When SW1 is not operated, you should have 0 Volts or a Voltage which is slowly getting less. When the switch is operated, the Voltage should quickly rise to about 4.5 Volts. If the Voltage does not rise, check that D1 is the correct way round and that it is soldered properly and to the right places. Check that C1 is not short circuited. Check that R2 is at least 4K7. If C1 is electrolytic/tantalum, check that it is connected the correct way round. The negative end should be connected to the 0 Volt rail. Check that pins 5 and 6 of IC1 are connected properly and not connected anywhere that they shouldn't be. If none of this helps, try replacing the IC and if that helps, throw the old one away.

Assuming that the Voltage across C1 quickly increases when the input switch is operated and slowly decreases after the switch is turned off, check pin 4 for open circuits, short circuits and bad solder joints. If none of this helps, try replacing the IC. If that helps, throw the old one away.

The second circuit is used when the input is a normally closed switch, as is the case with PIR detectors. This circuit may also be used without R1 or SW1 for signals, which are normally on 0Volts and go to +5 Volts. In this case the input should be connected to pin 2 of IC1. The output is normally on 0Volts and becomes +5Volts when a signal is present and for a time afterwards. Please note that there will be an output signal when the power is first applied to this circuit whether or not there is an input signal.

If you want to inhibit the input, (prevent it from working) you can connect pin 1 of IC1 to 0Volts instead of +5Volts. You may want to do this if you have two circuits and you only want one of them to work at a time.

You may connect any number of switches in series with SW1. If any one of the switches are operated, there would be a stretched output.



Pulse stretcher for normally closed switch input

R1 10K

D1 1N4148

IC1 4093 any prefix or suffix is OK.

Note: these devices are static sensitive and should be mounted on a socket. There are 4 gates per device (IC1A, IC1B, IC1C and IC1D). They are identical and so may be interchanged. The spare gates may be used in other parts of the circuit. If they are not used, the inputs should either be connected to 0Volts or +5Volts whichever is the more convenient.

R2 should have a value between 4K7 and 1M.

The time that the output persists longer than the input is a little less than $C1 \times R2$ seconds. For example if C1 was 100 μ F and R2 was 100K then the pulse input would be stretched by a bit less than 10 seconds and if R2 was 1M instead, the input would be stretched by a bit less than 100 seconds. Note that C1 is likely to be electrolytic and must therefore be connected the right way round with the negative end connected to 0 Volts.



Testing

Before applying power to the circuit, inspect the circuit thoroughly using a spy glass ensuring that there are no unwanted short circuits or open circuits and that the circuit follows the diagram exactly. Ensure that the power supply is connected the right way round. Then set your meter to continuity or low Ohms range. Connect the meter across the 0V and 5V supply and make sure that the reading is not zero or near to zero. You may get a bleep or a low Ohmic value for a short time because of the capacitor in the power supply, but this should not last more than a few seconds. If it is continuous, you have a short circuit somewhere and you should follow the instructions in the fault finding section.

If you do not get the expected results, you should switch the circuit off immediately.

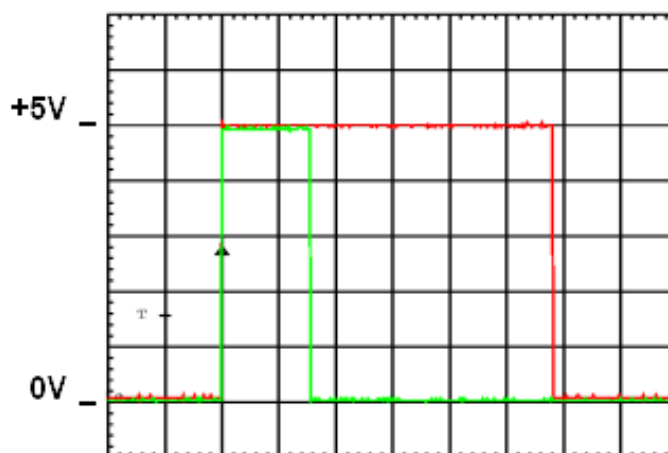
Set your meter to the 20 Volt DC range. Connect your meter across the 5 Volt supply and switch on the supply. If the reading is much below 5 Volts, switch off immediately and go to the fault finding section.

Connect the meter between 0 Volts and the output (pin 4) of IC1B. It should read 0 Volts. Now operate the switch SW1. The output should now be 5 Volts. Now return SW1 to its normal (non-operated) state. The output should remain at 5 Volts for the appropriate time and then revert to 0 Volts.

Circuit description

For this example, C1 was $4\mu 7F$ and R2 was 1M. In the oscilloscope images, the time base (horizontal direction) was 1 second per large division. By the calculation the pulse should be stretched by 4.7 Sec. but was in fact only stretched by about 4 Sec. you can see that multiplying C1 by R2 to give a time is a reasonably close approximation.

In the following image, the green trace shows the input (pin 2) of IC1A and the red trace shows the output (pin 4) of IC1B. You will note that the red trace goes to 5 Volts when the green trace does but waits about 4 seconds after the green trace goes to 0 Volts before it does.

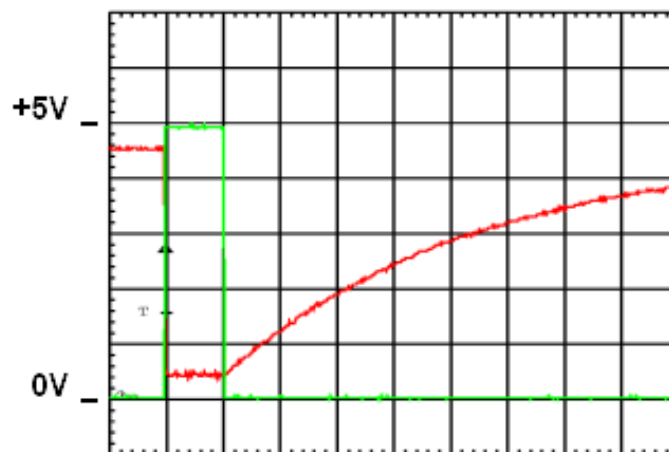


R1 holds the input (pin 2) of IC1A at 5 Volts when SW1 is operated and the other input (pin 1) is connected to 5 Volts. This means that when the switch is not operated, both inputs of IC1A are at 5 Volts and therefore the output of IC1A will be 0 Volts. When the input switch is not operated, the output (pin 3) of IC1A is 5 Volts. The diode D1 will therefore not conduct and C1 is free to charge through R2 to 5 Volts. This puts 5 Volts on the inputs (pins 5 and 6) of IC1B and causes the output (pin 4) of IC1B to be at 0 Volts.

When the switch SW1 is operated, the input (pin 2) of IC1A becomes 5 Volts and causes the output of IC1A to go to 0 Volts. D1 now conducts and

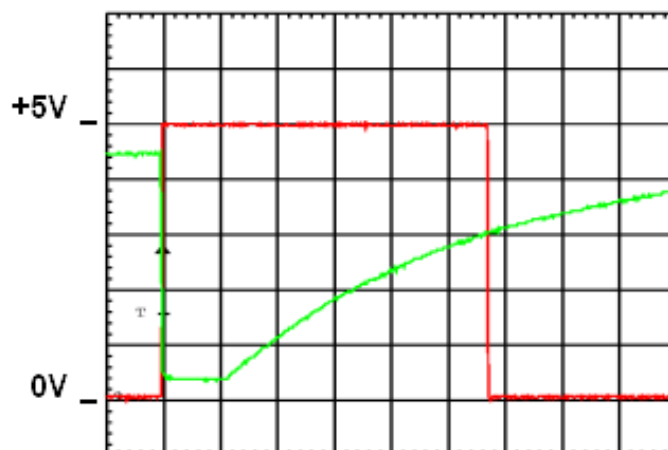
discharges C1 to 0.5 Volts. The 0.5 Volts is the Cutin Voltage of the diode. The input of IC1B is now '0' so the output becomes '1'. When the switch is closed again, the output of IC1A goes to 5 Volts and C1 charges through R2. The input to IC1B remains a '0' until C1 has charged enough for the input to become a '1' after which, the output of IC1B becomes a '0' again.

In the following 'scope image, the green trace shows the switch input and the red trace shows the Voltage across C1.



You will note that the red trace does not rise all the way to the 5 Volt rail. This is because the 'scope probe has a resistance of 10M when in X10 mode and R2 is 1M so the 'scope acts as a load on the circuit having a 10% reducing effect on the circuit's functioning which in turn causes the timing to be increased. This effect would be far less noticeable if R2 were 100K. This is a case of the measuring instrument affecting the what is being measured.

In the following 'scope image, the green trace shows the Voltage across C1 and the red trace shows the output of IC1B.



Faultfinding

The first thing to do is give the circuit a thorough visual inspection with a spy glass looking for bad solder joints and short circuits. Check that the circuit you

have built exactly matches the circuit diagram and that the components are the correct values and connected the right way round.

If the power supply was short circuited or had a greatly reduced output, remove IC1 and try again. If that does not help, there must be a short circuit or misconnection. If the removal of IC1 restores the output of the power supply, check for short circuits on the pins of the IC socket, in particular any outputs of the IC (pins 3, 4, 10 and 11). Make sure that the IC was the correct way round. It is possible that the IC is faulty. Check that the only connections to the 5 Volt rail are R1 and pin 14 of IC1. Check that none of the outputs (pins 3, 4, 10 and 11) of IC1 are connected anywhere that they shouldn't. Make sure that any unused inputs to the IC are either connected to 0 Volts or to 5 Volts.

Assuming that the power supply is now OK, set your meter to the 20 Volt DC range and connect the common terminal to the 0 Volt rail. Measure the Voltage across the switch SW1. It should be 0 Volts. If it isn't, there must either be something wrong with the switch or you have not connected it correctly. Look for short circuits, open circuits and bad solder joints. Check that you are using the correct terminals of the switch. If none of this helps, try removing the IC. If that helps and replacing it also helps, throw the old IC away. Now operate the switch and check that the Voltage is now 5 Volts. If it is not, check that R1 is the correct Value and is connected between the 5 Volt rail and the switch terminal

Assuming that the switch is now OK, check the Voltage on the output (pin 3) of IC1A. When SW1 is not operated, the output should be 5 Volts and when it is operated, the output should be 0 Volts. If it isn't, check that pin 1 is connected to the 5 Volt rail. Check that pin 3 is not connected anywhere other than to D1. Check that pin 7 of IC1 is connected to the 5 Volt rail and that pin 7 is connected to the 0 Volt rail. Check that C1 and R2 are not shorted, are the correct values and are connected to the correct places. Look for short circuits, open circuits and bad solder joints. If none of this helps, try replacing IC1. If that helps, throw the old IC away.

Assuming that the output of IC1A is OK, measure the Voltage at the inputs (pins 5 and 6) of IC1B. When SW1 is not operated, you should have 5 Volts or a Voltage which is slowly getting more. When the switch is operated, the Voltage should quickly fall to about 0.5 Volts. If the Voltage does not fall, check that D1 is the correct way round and that it is soldered properly and to the right places. Check that C1 is not short circuited. Check that R2 is at least 4K7. If C1 is electrolytic/tantalum, check that it is connected the correct way round. The negative end should be connected to the 0 Volt rail. Check that pins 5 and 6 of IC1 are connected properly and not connected anywhere that they shouldn't be. If none of this helps, try replacing the IC and if that helps, throw the old one away.

Assuming that the Voltage across C1 quickly decreases when the input switch is operated and slowly increases after the switch is turned off, check pin 4 for open circuits, short circuits and bad solder joints. If none of this helps, try replacing the IC. If that helps, throw the old one away.

Timers (pulse)

The previous circuits extend the length of time signals are present. The following circuits use the start or end of a signal as an input rather than the whole signal and produce a pulse output.

This type of circuit is called an edge triggered monostable multivibrator. Fortunately, some very nice people have done all the hard work for us and we only have add some timing components and to connect the right pins of an IC for the circuit to be made. Not only that, but we get two of them on one IC.

The circuits described herein will use the HEF4538BP dual monostable multivibrator. The timing components are a resistor in the range of 4K7 to 1M and a capacitor having a minimum value of 2000pF. The pulse time is approximately the resistance times the capacitance. These circuits are suitable for producing pulses up to 20 minutes long. The reason is that capacitors leak and the leakage current is dependent on the capacitance, the quality of the component and the temperature. The leakage increases with value and temperature, so as you try to get longer time periods, the leakage increases so the effective value of the timing resistor decreases. This has a limiting effect on the maximum time. If you need to have long time periods of minutes rather than seconds, you will need to look at the leakage specifications of the timing capacitor. It needs to be of a high quality with low leakage. For short times of a few seconds, you should use tantalum capacitors.

Each half of the HEF4538BP has three inputs, timing inputs and two outputs.

One of the inputs is a reset input, which will normally be connected to the 5 Volt rail. This will have the effect of possibly giving an output pulse when the circuit is first switched on. If this is likely to be a problem there is a circuit, which will cause the circuit to automatically reset on switch-on.

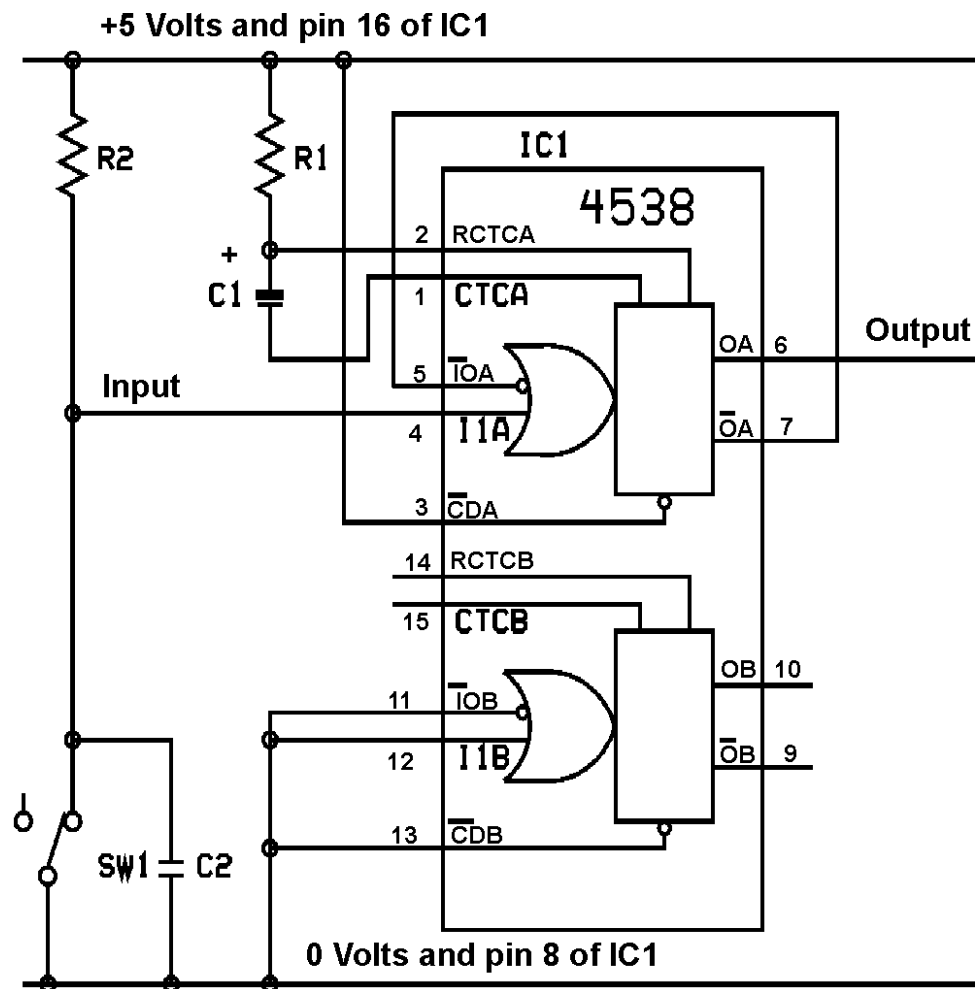
The other two inputs are used according to whether you want a pulse to start when the input goes from a '0' to a '1' or whether from a '1' to a '0'.

The two outputs are the inverse of each other. That is, one output will pulse from '0' to '1' and back to '0' again and the other output will pulse from '1' to '0' and then back to '1' again.

You should always connect unused inputs to either the 0 Volt rail or the 5 Volt rail. The timing inputs are an exception to this.

Pulse generator for positive going inputs.

The following circuit can be used either with normally closed switch inputs or with positively going voltage pulse inputs.



Pulse generator for positive going inputs

R1 should have a value between 4K7 and 1M.

C1 should be at least 2000pF.

R2 10K this is only needed if the circuit is used in conjunction with a switch.

C2 0μ1F this is only needed if the circuit is used in conjunction with a switch.

IC1 HEF4538BP

Dual monostable multivibrator



The output pulse time is a little longer than C1 times R1 seconds. If C1 is 100μF and R1 is 100K then the output pulse will persist for a little longer than 10 seconds and if R1 is increased to 1M, the pulse time will increase to a little longer than 100 seconds. This circuit is for producing pulses of up to 20 minutes and is not suitable for very long times. The reason is that capacitors leak and the leakage current is dependent on the capacitance, the quality of the

component and the temperature. The leakage increases with value and temperature, so as you try to get longer time periods, the leakage increases so the effective value of the timing resistor decreases. This has a limiting effect on the maximum time. If you need to have long time periods of minutes rather than seconds, you will need to look at the leakage specifications of the timing capacitor. It needs to be of a high quality and low leakage. For short times of a few seconds, you should use tantalum capacitors.

Note the polarity of C1. It must have its negative end connected to the CTCA (pin 1 for one half of the IC and CTCB pin 15 for the other half).

The circuit shown uses half of the IC, so the other half is available for another monostable multivibrator. The input pins have been connected to the 0 Volt rail but if the other half of the circuit is to be used, they should not be.

If a switch input is used, there should be a capacitor C2 connected across the contacts because this circuit is edge triggered and switches do not switch cleanly but bounce for a few mSecs. C2 prevents this bounce from affecting the circuit.

Should you want the output to be inverted (go from a '1' to a '0' and back to a '1' again), you can use pin 7 as an output instead of pin 6.

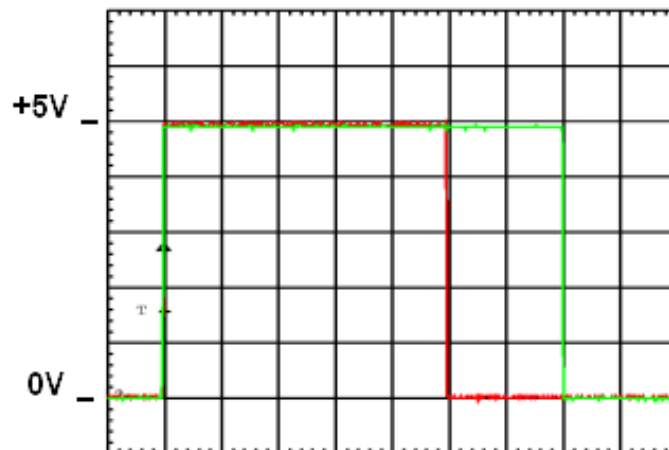
If you need to prevent an output pulse at switch-on, you should not connect pin 3 directly to the 5 Volt rail but should add the timing components as shown in the next circuit. These hold pin 3 to a '0' for a short period of time after switch-on, after which pin 3 goes to a '1' for normal operation.

The circuit function will now be described by way of oscilloscope images.

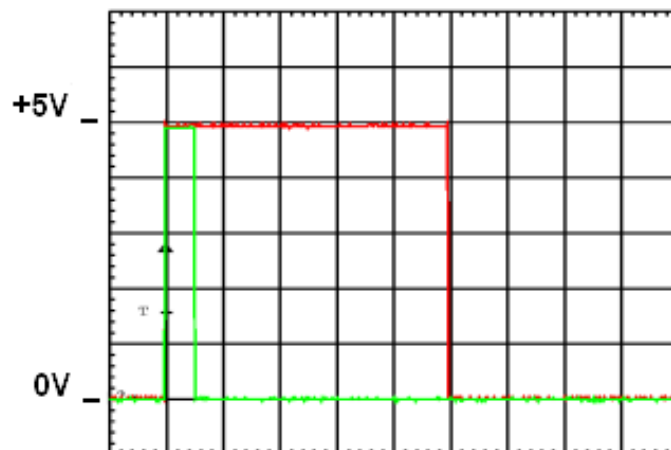
In the following 'scope images, C1 was 4 μ 7F and R1 was 1M. The time base (horizontal direction) is 1 Second per large division. The green trace shows the input (pin 4) and the red trace shows the output (pin 6).

You will note that the output pulse is independent of the length of time that the input pulse is present and that you can have multiple input pulses without affecting the output pulse. This is because the input will only respond to the positive edge of the input pulse if the other input (pin 5) $\bar{I}OA$ is a '1'. This is the case before the input starts to rise as it is connected to the output on pin 7, which is the inverse of the output on pin 6. The moment it does, however, the output on pin 7 becomes a '0' as it is the inverse of the output on pin 6. This inhibits the IOA input on pin 4. If this connection between pin 7 and pin 5 were not made, the circuit would act as a pulse stretcher and the output pulse width (time) would be dependent on the input pulse width on pin 4. Note that the \bar{I} above the I indicates that the input is NOTED, that is, it is inverted, so that the active input is not a '1' but is a '0'. This convention applies equally to outputs.

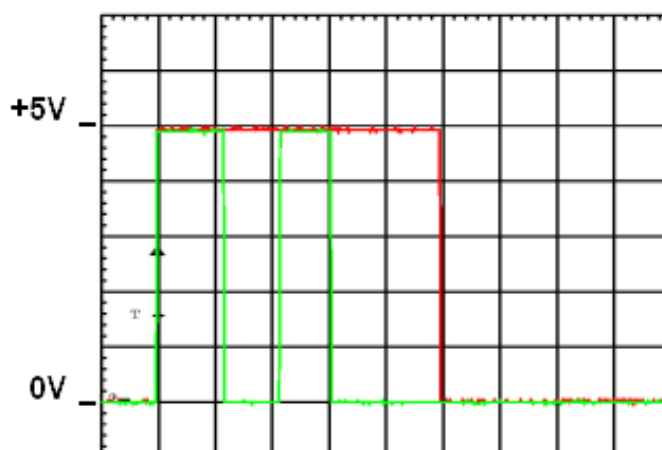
This 'scope image shows that the input can persist for longer than the output.



This 'scope image shows the output with a short pulse input.



This 'scope image shows that multiple input pulses occurring within the output pulse time frame do not affect the output.



Testing

Before applying power to the circuit, inspect the circuit thoroughly using a spy glass ensuring that there are no unwanted short circuits or open circuits and that the circuit follows the diagram exactly. Ensure that the power supply is connected the right way round. Then set your meter to continuity or low Ohms range. Connect the meter across the 0V and 5V supply and make sure that the reading is not zero or near to zero. You may get a bleep or a low Ohmic value for a short time because of the capacitor in the power supply, but this should not last more than a few seconds. If it is continuous, you have a short circuit somewhere and you should follow the instructions in the fault finding section. If you do not get the expected results, you should switch the circuit off immediately.

Set your meter to the 20 Volt DC range. Connect your meter across the 5 Volt supply and switch on the supply. If the reading is much below 5 Volts, switch off immediately and go to the fault finding section.

Connect the meter between 0 Volts and the output (pin 6) of IC1. It should read 0 Volts. Now operate the switch SW1. The output should now be 5 Volts. Now return SW1 to its normal (non-operated) state. The output should remain at 5 Volts for the appropriate time and then revert to 0 Volts.

Faultfinding

The first thing to do is give the circuit a thorough visual inspection with a spy glass looking for bad solder joints and short circuits. Check that the circuit you have built exactly matches the circuit diagram and that the components are the correct values and connected the right way round.

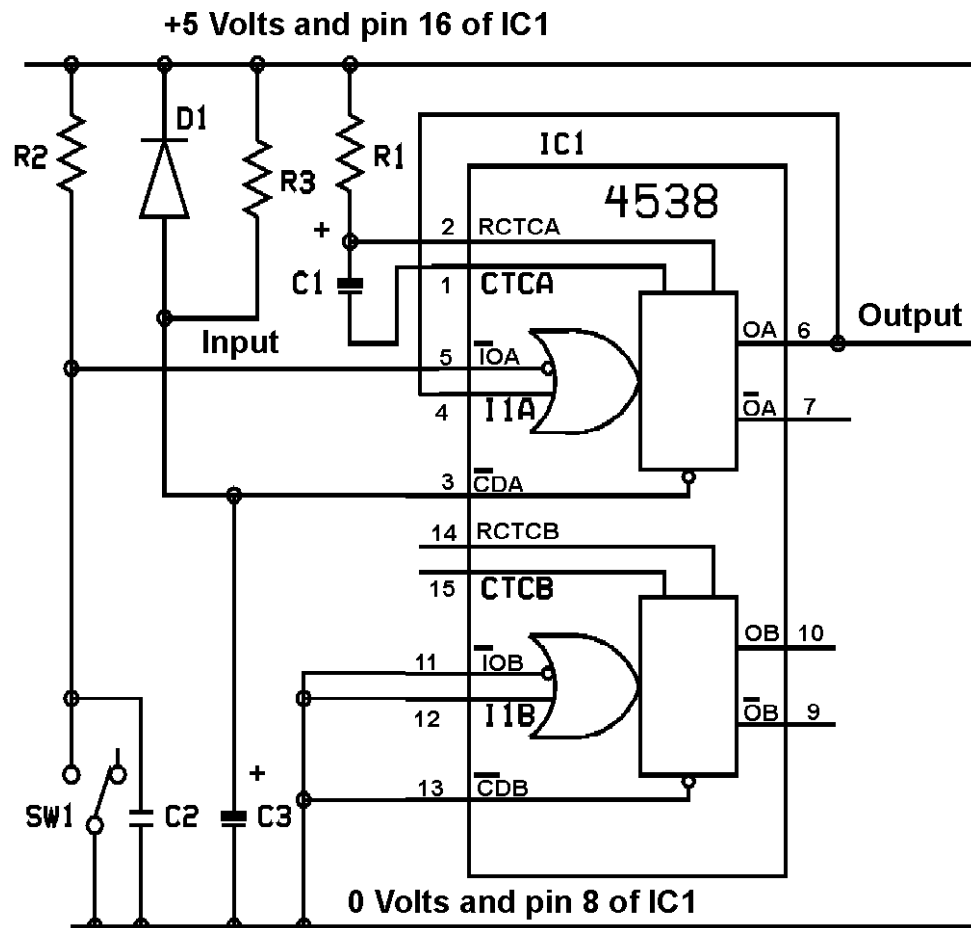
If the power supply was short circuited or had a greatly reduced output, remove IC1 and try again. If that does not help, there must be a short circuit or misconnection. If the removal of IC1 restores the output of the power supply, check for short circuits on the pins of the IC socket, in particular any outputs of the IC (pins 6, 7, 9 and 10). Make sure that the IC was the correct way round. It is possible that the IC is faulty. Check that the only connections to the 5 Volt rail are R1, R2 and pins 3 and 16 of IC1. Check that none of the outputs (pins 6, 7, 9 and 10) of IC1 are connected anywhere that they shouldn't. Make sure that any unused inputs to the IC are either connected to 0 Volts or to 5 Volts. The circuit diagram shows them as connected to 0 Volts.

Assuming that the power supply is OK, check the values of all the components and look for short circuits, open circuits and bad solder joints. Ensure that C1 is connected the correct way round. If it wasn't, it may well be damaged and should be replaced, throwing the old one away. Check that pin 8 is connected to 0 Volts and that pin 16 is connected to the 5 Volt rail. Check that pin 3 is connected to the 5 Volt rail. Check that the circuit you have built exactly

matches the circuit diagram. If all else fails, try replacing the IC. If that helps, throw the old one away.

Pulse generator for negative going inputs.

The only differences between this circuit and the previous circuit are that it gives an output on the falling edge of an input signal rather than the rising edge and that a few components have been added to prevent an output pulse immediately after the power is switched on. This last part of the circuit will not normally be needed.



Pulse generator for negative going inputs

R2	10K
R3	100K
C2	0 μ 1F
C3	4 μ 7F
D1	1N1418
IC1	HEF4538BP

Dual monostable multivibrator



R2 and C2 are only needed if a switch input is used. R3, C3 and D1 are only

needed if you have a problem with having an output pulse when the power is switched on. If this is not a problem, leave these components out and connect pin 3 to the 5 Volt rail instead.

The output pulse time is a little longer than $C1 \times R1$ seconds. If $C1$ is $100\mu\text{F}$ and $R1$ is 100K then the output pulse will persist for a little longer than 10 seconds and if $R1$ is increased to 1M , the pulse time will increase to a little longer than 100 seconds. This circuit is for producing pulses of up to 20 minutes and is not suitable for very long times. The reason is that capacitors leak and the leakage current is dependent on the capacitance, the quality of the component and the temperature. The leakage increases with value and temperature, so as you try to get longer time periods, the leakage increases so the effective value of the timing resistor decreases. This has a limiting effect on the maximum time. If you need to have long time periods of minutes rather than seconds, you will need to look at the leakage specifications of the timing capacitor. It needs to be of a high quality and low leakage. For short times of a few seconds, you should use tantalum capacitors.

Note the polarity of $C1$. It must have its negative end connected to the CTCA (pin 1 for one half of the IC and CTCB pin 15 for the other half).

The circuit shown uses half of the IC, so the other half is available for another monostable multivibrator. The input pins have been connected to the 0 Volt rail but if the other half of the circuit is to be used, they should not be.

If a switch input is used, there should be a capacitor $C2$ connected across the contacts because this circuit is edge triggered and switches do not switch cleanly but bounce for a few mSecs. $C2$ prevents this bounce from affecting the circuit.

Should you want the output to be inverted (go from a '1' to a '0' and back to a '1' again), you can use pin 7 as an output instead of pin 6.

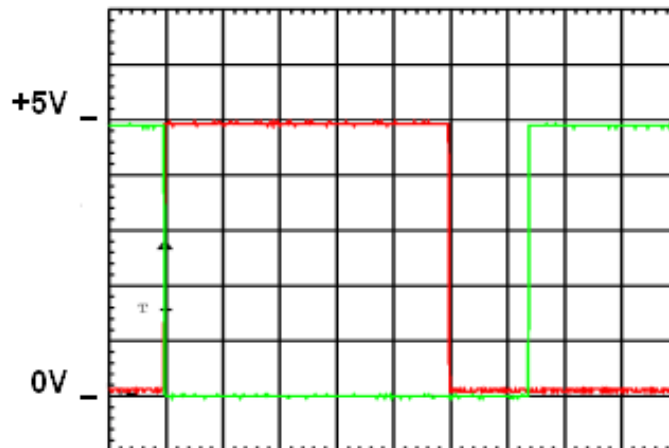
The circuit function will now be described by way of oscilloscope images.

In the following 'scope images, $C1$ was $4\mu\text{F}$ and $R1$ was 1M . The time base (horizontal direction) is 1 Second per large division. The green trace shows the input (pin 5) and the red trace shows the output (pin 6).

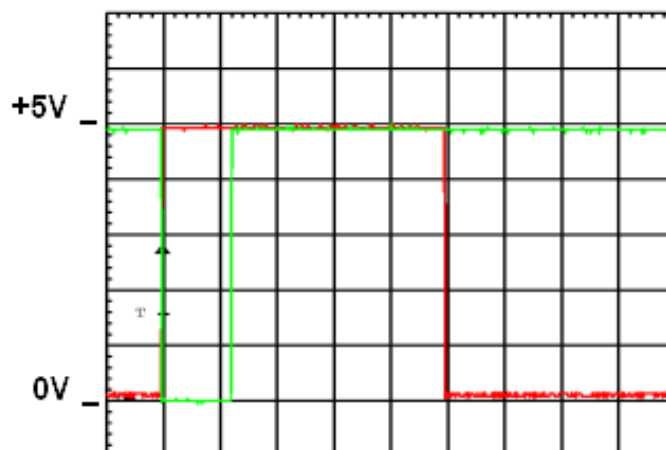
You will note that the output pulse is independent of the length of time that the input pulse is present and that you can have multiple input pulses without affecting the output pulse. This is because the input will only respond to the falling edge of the input pulse if the other input (pin 4) IOA is a '0'. This is the case before the input starts to rise as it is connected to the output on pin 6. The moment it does, however, the output on pin 6 becomes a '1'. This inhibits the IOA input on pin 5. If this connection between pin 6 and pin 4 were not made, the circuit would act as a pulse stretcher and the output pulse width (time)

would be dependent on the input pulse width on pin 5. Note that the \bar{I} above the I indicates that the input is NOTED, that is, it is inverted, so that the active input is not a '1' but is a '0'. This convention applies equally to outputs.

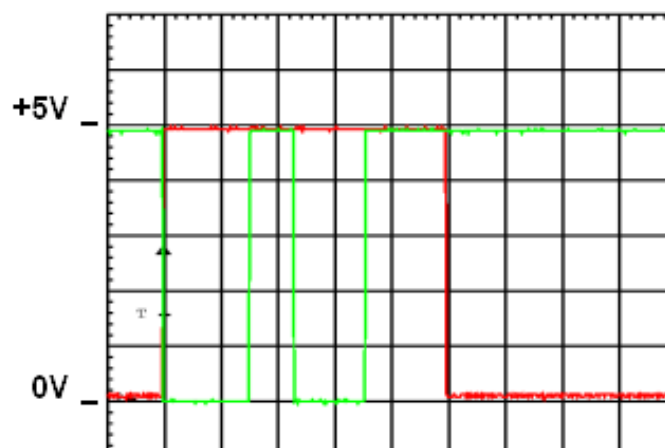
This 'scope image shows that the input can persist for longer than the output.



This 'scope image shows the output with a short pulse input.



This 'scope image shows that multiple input pulses occurring within the output pulse time frame do not affect the output.



Testing

Before applying power to the circuit, inspect the circuit thoroughly using a spy glass ensuring that there are no unwanted short circuits or open circuits and that the circuit follows the diagram exactly. Ensure that the power supply is connected the right way round. Then set your meter to continuity or low Ohms range. Connect the meter across the 0V and 5V supply and make sure that the reading is not zero or near to zero. You may get a bleep or a low Ohmic value for a short time because of the capacitor in the power supply, but this should not last more than a few seconds. If it is continuous, you have a short circuit somewhere and you should follow the instructions in the fault finding section. If you do not get the expected results, you should switch the circuit off immediately.

Set your meter to the 20 Volt DC range. Connect your meter across the 5 Volt supply and switch on the supply. If the reading is much below 5 Volts, switch off immediately and go to the fault finding section.

Connect the meter between 0 Volts and the output (pin 6) of IC1. It should read 0 Volts. Now operate the switch SW1. The output should now be 5 Volts. Now return SW1 to its normal (non-operated) state. The output should remain at 5 Volts for the appropriate time and then revert to 0 Volts.

Faultfinding

The first thing to do is give the circuit a thorough visual inspection with a spy glass looking for bad solder joints and short circuits. Check that the circuit you have built exactly matches the circuit diagram and that the components are the correct values and connected the right way round.

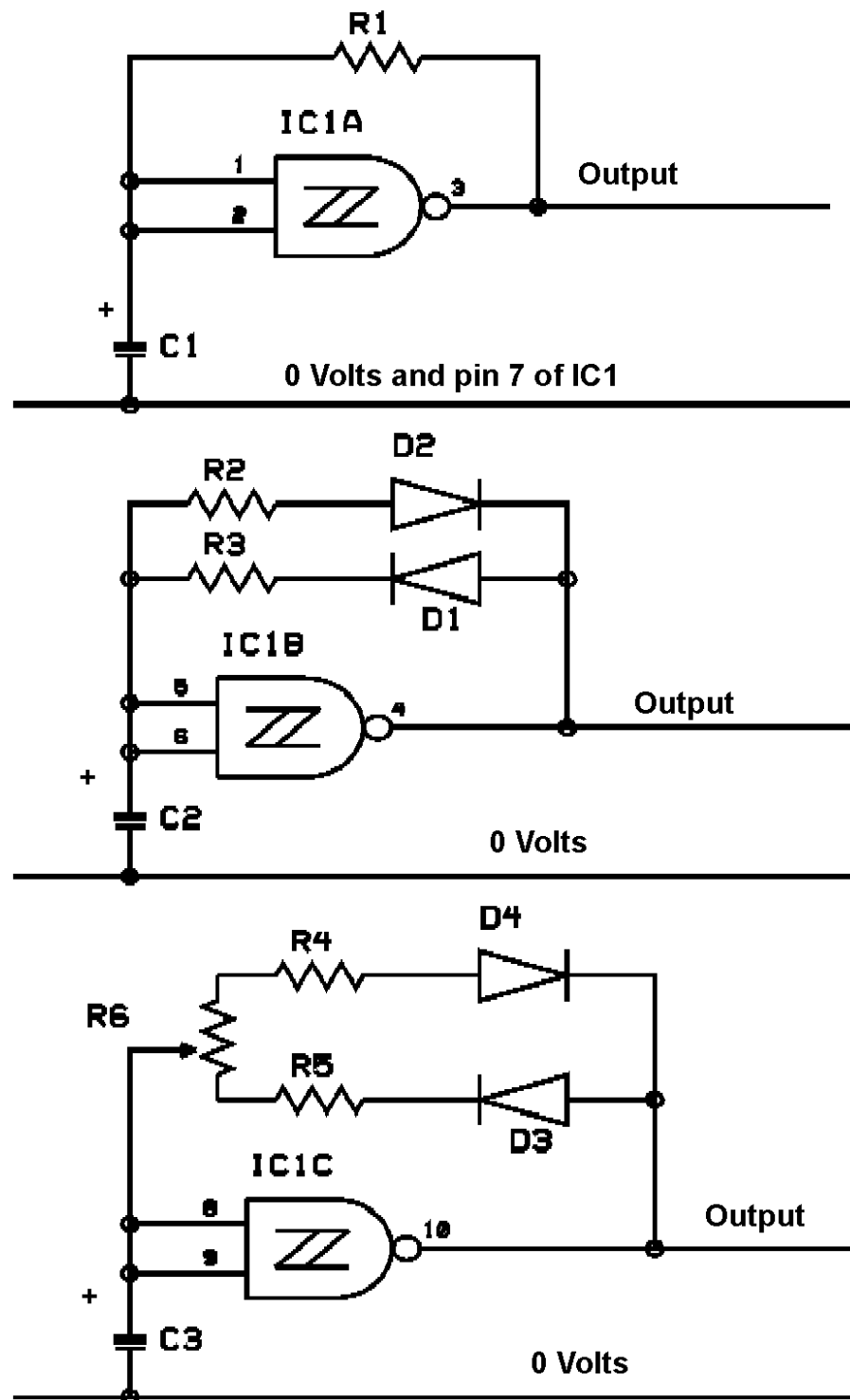
If the power supply was short circuited or had a greatly reduced output, remove IC1 and try again. If that does not help, there must be a short circuit or misconnection. If the removal of IC1 restores the output of the power supply, check for short circuits on the pins of the IC socket, in particular any outputs of the IC (pins 6, 7, 9 and 10). Make sure that the IC was the correct way round. It is possible that the IC is faulty. Check that the only connections to the 5 Volt rail are R1, R2, R3, D1 and pin 16 of IC1. Check that none of the outputs (pins 6, 7, 9 and 10) of IC1 are connected anywhere that they shouldn't. Make sure that any unused inputs to the IC are either connected to 0 Volts or to 5 Volts. The circuit diagram shows them as connected to 0 Volts.

Assuming that the power supply is OK, check the values of all the components and look for short circuits, open circuits and bad solder joints. Ensure that C1 and C3 are connected the correct way round. If they weren't, they may well be damaged and should be replaced, throwing the old ones away. Check that pin 8 is connected to 0 Volts and that pin 16 is connected to the 5 Volt rail. Check that pin 3 is either connected to the 5 Volt rail or to R3 and that C3 is not short circuited. Check that the circuit you have built exactly matches the circuit

diagram. If all else fails, try replacing the IC. If that helps, throw the old one away.

Oscillators and pulse generators

These circuits produce a continuous stream of pulses and have been utilized in various other sections of this cd.



R4 2K2

R5 2K2

Diodes are 1N4148

IC1 4093 any prefix or suffix will do. Connect pin 14 to +5 Volts and pin 7 to 0 Volts.

The other resistors and capacitors will have values dependent on the time periods required. The time periods are approximately one half of the capacitance times the resistance. The resistor values should be in the range of 2K2 to 1M. If electrolytic/tantalum capacitors are used, the negative ends must be connected to the 0 Volt rail.



These circuits are not suitable for pulse times in excess of 20 minutes because of capacitor leakage. For times of a few seconds, you should use tantalum capacitors. For longer times, you should use high quality low leakage capacitors.

The circuit above shows three separate circuits. A circuit, which produces a square wave, a circuit for producing pulses with independent control of pulse width and time between pulses and finally a circuit for producing a variable ON/OFF ratio.

In the second and third circuits, the diodes are used to provide different timing values or the resistors as one diode allows the capacitor to charge up and the other allows the capacitor to discharge.

Testing

Before applying power to the circuit, inspect the circuit thoroughly using a spy glass ensuring that there are no unwanted short circuits or open circuits and that the circuit follows the diagram exactly. Ensure that the power supply is connected the right way round. Then set your meter to continuity or low Ohms range. Connect the meter across the 0V and 5V supply and make sure that the reading is not zero or near to zero. You may get a bleep or a low Ohmic value for a short time because of the capacitor in the power supply, but this should not last more than a few seconds. If it is continuous, you have a short circuit somewhere and you should follow the instructions in the fault finding section. If you do not get the expected results, you should switch the circuit off immediately.

Set your meter to the 20 Volt DC range. Connect your meter across the 5 Volt supply and switch on the supply. If the reading is much below 5 Volts, switch off immediately and go to the fault finding section.

Set your meter to the 20 Volt DC range and connect between 0 Volts and the output. The output should toggle between nearly 0 Volts and nearly 5 Volts. If

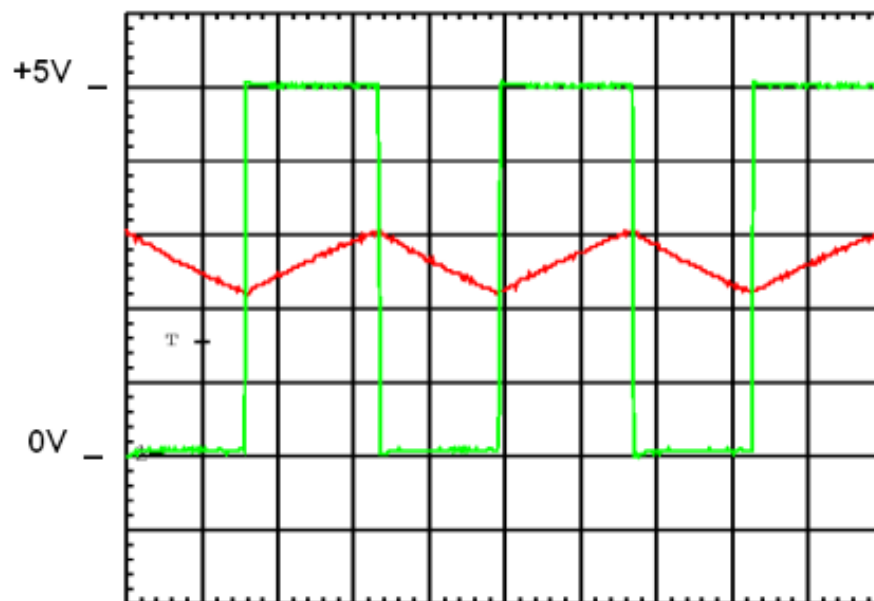
the oscillation is not at a very low frequency, the times will be too short for your meter and it will display the average output Voltage of approximately 2.5 Volts.

Circuit description

IC1A, R1 and C1 form a square wave oscillator. You will note that IC1A is a Schmitt trigger. That is, the input Voltage that is required for a '1' is higher than the input Voltage for a '0'. The difference between these Voltages is called the hysteresis or deadband.

The following oscilloscope image shows the output of IC1A in green and the input in red.

When the output is a '1' (nearly 5Volts), C1 is charged up via R1 until it reaches the Voltage level of a '1' on the input. When that happens, the output becomes a '0' (nearly 0Volts) and C1 discharges via R1 until the Voltage level of a '0' on the input is reached. When this happens the output becomes a '1' again and the process is repeated.



The timing is of course dependent on the values of R1 and C1.

In the other circuits, the capacitor charging and discharging times are not equal if the resistor values are different or, in the last circuit, if the potentiometer is not set to its mid point.

Faultfinding

The first thing to do is give the circuit a thorough visual inspection with a spy glass looking for bad solder joints and short circuits. Check that the circuit you have built exactly matches the circuit diagram and that the components are the correct values and connected the right way round.

Make sure that the power supply is switched off. Set your meter to continuity and connect across the 5 Volt supply. There should be a short time when the meter indicates a short. This is because of the capacitor in the power supply. This should not last for long. If it is continuous, you have a short circuit somewhere. Check that the +5 Volts of the supply is only connected to pin 14 of IC1. If this is not the problem, remove the IC and check the supply for short circuits. If this is not the cause of the problem then the +5 Volt end of the supply must be connected somewhere where it shouldn't. If it was the cause, it is possible that you have a faulty IC.

Assuming that you do not have a short circuit across the supply, set your meter to the 20 Volt DC range, connect across the supply and switch on. You should have a reading of 5 Volts. If you do not, remove the IC and check the Voltage. If after removing the IC the reading is correct, then look to see if any of the pins are connected where they should not be. If all the connections are OK, replace the IC with a new one and try again. If that solves the problem, throw the faulty IC away so that you do not inadvertently use it again.

Check the circuit for short circuits, open circuits and bad solder joints. Check that pin 7 of IC1 is connected to the 0 Volt rail and that pin 14 is connected to the 5 Volt rail. Check that the circuit you have built exactly matches the circuit diagram. Ensure that unused inputs to the IC are either connected to 0 Volts or to 5 Volts. Ensure that none of the outputs are short circuited either to the 0 Volt rail or to the 5 Volt rail. If none of this helps, try replacing the IC. If that helps, throw the old IC away.

Chapter 14

Sequencers

There are two basic types of sequencer. One is time based. The sequence of events is determined by some kind of clock. The other is event based. Sensors determine the sequence of events, so that an event will not happen unless the previous event has finished. It is possible to combine the two.

An automatic washing machine is an example of a system controlled by a sequencer.

Programmable Logic Controllers (PLC's) and microprocessors are often used in sequencer applications but are outside the scope of this cd.

The simplest form of timed sequencer is the electro-mechanical type, which uses a motor to drive a series of cams. The cams operate the microswitches. This type is ideal for timed events, which take longer than a couple of seconds each. If you need to ensure that one event has finished before the next can start, you can switch off the motor until the event has finished. Automatic washing machines do it this way but they do have very sophisticated switches and wiring. The motors for this type of sequencer are generally mains driven synchronous motors.

For faster sequencing, electronics will be required.

There are two basic types of electronic sequencer. The one type is time based in that the events are timed and after a period of time the next operation starts and after another period of time the next starts and so on. The other type of sequencer is event based in that the next operation starts after the first has finished. This type will need to know when operations finish. This would normally be by way of a limit switch but any digital signal will do.

Let us first consider the time-based type. Since it is likely that the time intervals required will not all be the same, we will consider a circuit that will provide a number of output pulses each of which can be of different lengths of time and following each other in sequence.

Time based sequencers.

We have just such a circuit already in the chapter on timers. It only needs to be configured. If you use the circuit for pulse generators for negative going input pulses, all you would need to do is connect the output of one to the input of the next. The switch inputs would then become redundant. You now have two alternatives. You can either start the sequence from some input to the first pulse generator or connect the output of the last pulse generator to the input of the first, in which case, the circuit would keep on going and start again automatically once it had come to the end. With this circuit configuration, the following pulse would start as soon as the previous one finishes. In either case

you should ensure that all the pulse generators are off immediately after the power is switched on so the start-up circuit comprising R3, C3 and D1 should be present and all the pins 13 of all the 4538's in the circuit should be connected to all the pins 3. You only need one resistor one capacitor and one diode. It is not necessary to have separate ones for each part of the circuit.

To go to the circuit, click here [CLICK](#)

The circuit for pulse generators uses one half of an IC. In this application you would want to use both halves so that each IC would give two pulse generators and not one. All you would have to do is duplicate the circuit for the other half of the IC.

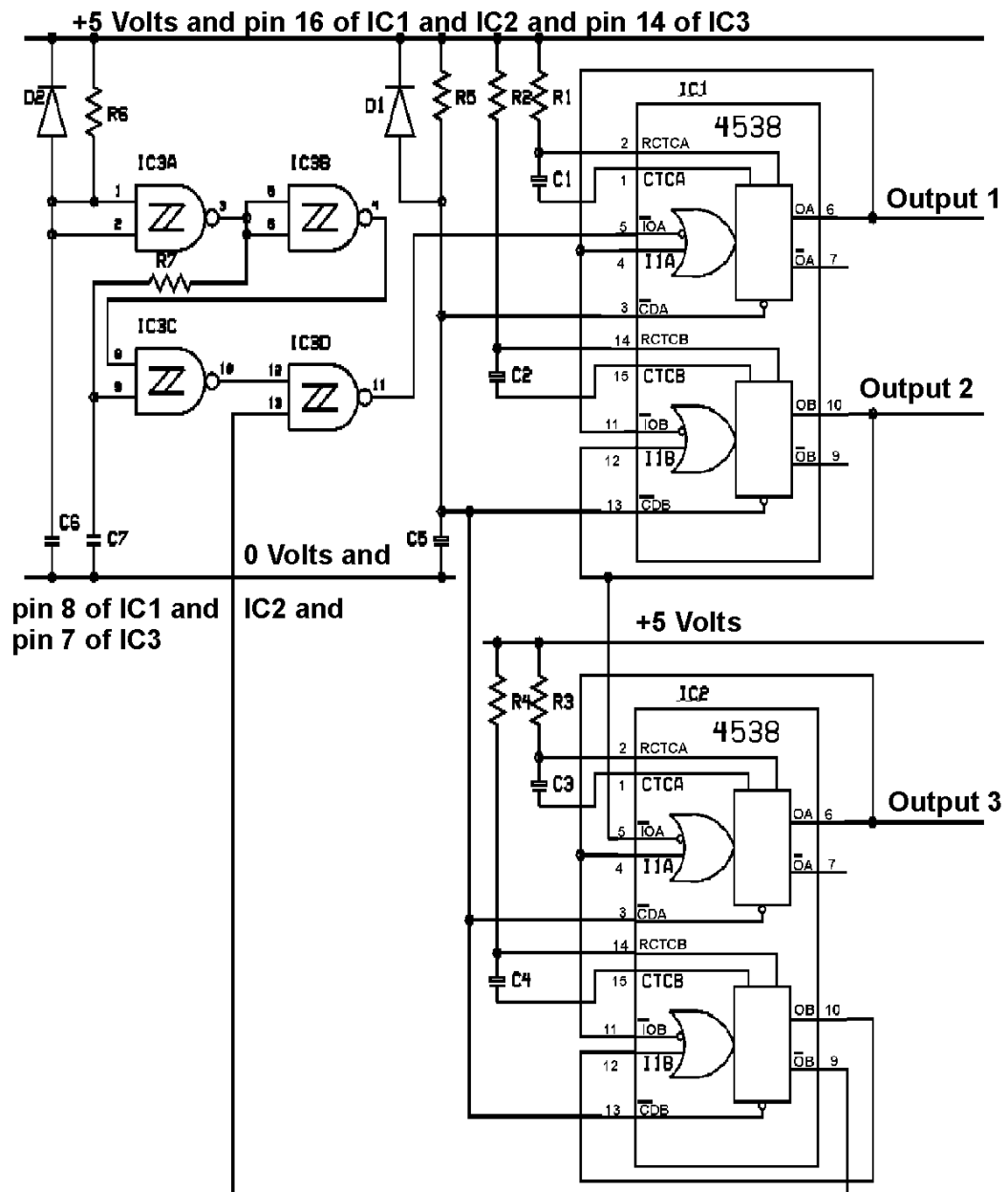
There is a problem with the continuously operating circuit, which needs to be addressed. The problem is that although it will work continuously once it has started, there is no means of getting it started without some additional circuitry. We need to do three things to have an ordered start-up procedure. First we need to ensure that all the monostable multivibrators are reset after the power is switched on. We then need to produce a pulse on the input of the first monostable multivibrator and then we need to ensure that the last monostable multivibrator in the chain produces a pulse for the first.

The following circuit shows how to solve these problems and has a sequence of three outputs. The circuit can be expanded by adding more monostable multivibrators. The last monostable multivibrator is used to provide a short pulse to start the first monostable multivibrator.

The circuit, as stated, is basically the same as in the chapter on timers apart from the additional circuit required to solve the problems previously mentioned. This additional circuit is the only part of the circuit, which will be described in detail.

Click here for a detailed description of the main part of the circuit.

[CLICK](#)



Time based sequencer

R4	100K
R5	100K
R6	220K
R7	100K
C4	0 μ 1F
C5	4 μ 7F
C6	4 μ 7F
C7	0 μ 1F
D1	1N4148
D2	1N4148
IC1	HEF4538BP
IC2	HEF4538BP
IC3	HEF4093BP



Dual monostable multivibrator



The other component values are discussed in the chapter on timers.

Testing

Before applying power to the circuit, inspect the circuit thoroughly using a spy glass ensuring that there are no unwanted short circuits or open circuits and that the circuit follows the diagram exactly. Ensure that the power supply is connected the right way round. Then set your meter to continuity or low Ohms range. Connect the meter across the 0V and 5V supply and make sure that the reading is not zero or near to zero. You may get a bleep or a low Ohmic value for a short time because of the capacitor in the power supply, but this should not last more than a few seconds. If it is continuous, you have a short circuit somewhere and you should follow the instructions in the fault finding section. If you do not get the expected results, you should switch the circuit off immediately.

Set your meter to the 20 Volt DC range. Connect your meter across the 5 Volt supply and switch on the supply. If the reading is much below 5 Volts, switch off immediately and go to the fault finding section.

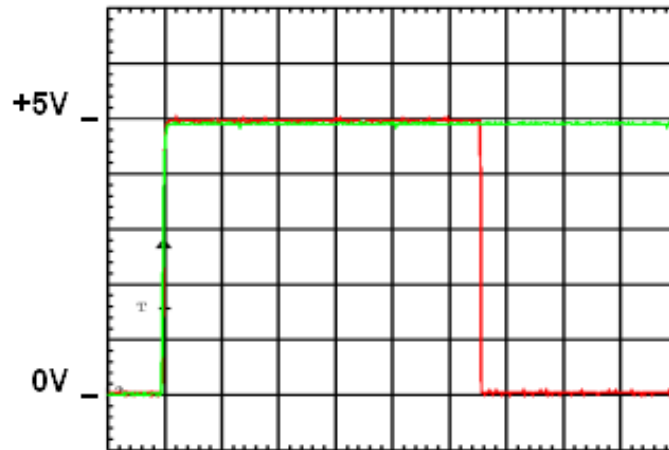
Connect the common (COM) terminal of your meter to the 0 Volt rail. Measure the Voltage on output 1. Now switch on the supply. It should read 0 Volts for about 1 second and then read 5 Volts for the time determined by the values of R1 and C1 after which it should return to 0 Volts. If the output pulse time is short, your meter may not have time to make a measurement but an oscilloscope would. After the time periods of outputs 2 and 3, output 1 should again go to 5 Volts and then back to 0 Volts in a continuous cycle.

Circuit description

IC1 and IC2 are reset on switch-on for about half a second. This time is determined by the values of R5 and C5.

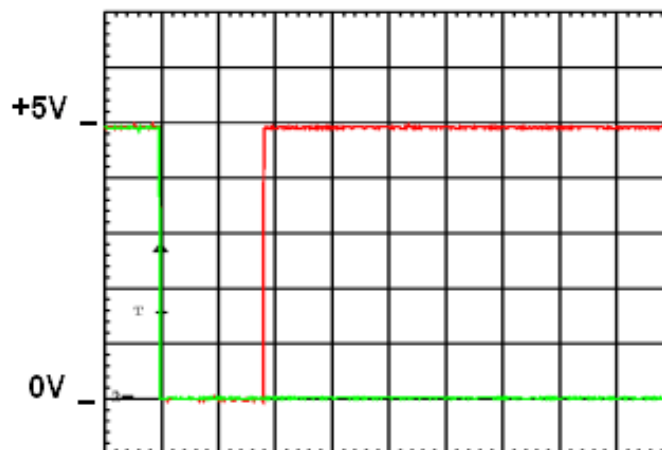
We have a similar circuit at the input of IC3A. The time constant here is about double as the value of C6 is the same as C5 but the value of R6 is about double that of R5. On switch-on, the Voltage across C6 is zero. It charges up to 5 Volts through R6. It takes about a second for the Voltage on the input of IC3A to reach a '1'.

In the following oscilloscope image, the time base (horizontal direction) is 200mSecs per large division. The green trace shows the power supply on switch-on and the red trace shows the output (pin 3) of IC3A. The output is the inverse of the input. So when the input (pins 1 and 2) is a '0', which it is on switch-on, the output is a '1'. As soon as the input reaches the Voltage necessary for the IC to interpret it as a '1', the output goes to a '0'. As you can see this takes about one second.



Whilst the output (pin 3) of IC3A is a '1', the capacitor C7 is charged up to 5 Volts via R7 and the output (pin 4) of IC3B is a '0'. When the output of IC3A goes to a '0', a second or so after switch-on, the output of IC3B becomes a '1' and C7 begins to discharge through R7. Before it discharges, however, it is still a '1'. So both inputs (pins 8 and 9) to IC3C are '1's for a period of time determined by the values of R7 and C7. The result of this is that the output (pin 10) of IC3C gives a short pulse from a '1' to a '0' and back to a '1' again a second after switch-on.

In the following 'scope image, the time base is 5mSecs per large division, the green trace shows the falling edge of the output of IC3A a second after switch-on and the red trace shows the output of IC3C.

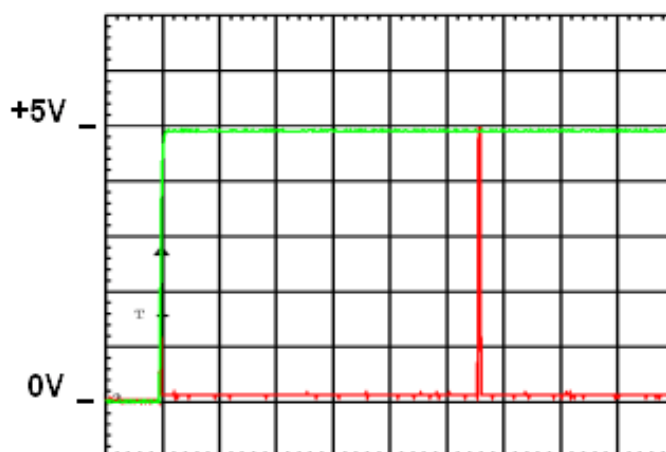


You can see that a second or so after switch-on there is a pulse of about 10mSecs at the output of IC3C. Any '0' on the inputs (pins 12 and 13) of IC3D will produce a '1' at the output (pin 11) of IC3D. The output of IC3C is connected to the input pin 12 of IC3D. The other input (pin 13) is connected to the inverting output (pin 9) of the second (B) monostable multivibrator of IC2. This output will normally be a '1' and only becomes a '0' for about 10 mSecs after the multivibrator has been triggered.

The result of this is that the output (pin 11) of IC3D will normally be a '1' and will give 10mSec pulses of '1's either a second after switch-on or after output 3

of the circuit has finished. The falling edge of this output triggers the first monostable multivibrator causing an output 1.

In the following 'scope image, the time base is 200mSec, the green trace shows the 5 Volt rail on switch-on and the red trace is the output of IC3D.



Faultfinding

The first thing to do is give the circuit a thorough visual inspection with a spy glass looking for bad solder joints and short circuits. Check that the circuit you have built exactly matches the circuit diagram and that the components are the correct values and connected the right way round.

If the power supply was short circuited or had a greatly reduced output, remove the IC's one at a time and try again. If that does not help, there must be a short circuit or misconnection. If the removal of an IC restores the output of the power supply, check for short circuits on the pins of the IC socket, in particular any outputs of the IC's. Make sure that the IC's were the correct way round. It is possible that an IC is faulty. Check the connections to the 5 Volt. Check that none of the outputs (pins 6, 7, 9 and 10) of IC1 and IC2 and (pins 3, 4, 10 and 11) of IC3 are connected anywhere that they shouldn't.

Assuming that the power supply is OK, check the values of all the components and look for short circuits, open circuits and bad solder joints. Ensure that the electrolytic/tantalum capacitors are connected the correct way round. If they weren't, they may well be damaged and should be replaced, throwing the old ones away. Check that pin 8 of IC1 and IC2 and pin 7 of IC3 are connected to 0 Volts and that pin 16 of IC1 and IC2 and pin 14 of IC3 are connected to the 5 Volt rail. Check that pins 3 and 13 of IC1 and IC2 are connected to the junction of R5 and C5 and that R5 is connected to the 5 Volt rail. Check that the circuit you have built exactly matches the circuit diagram. If all else fails, try replacing the IC's one at a time. If that helps, throw the faulty ones away.

Set your meter to the 20 Volt DC range and connect the common (COM) terminal to 0 Volts. A few seconds after switch-on, check the voltage on pins 1

and 2 of IC3. You should read 5 Volts on both inputs. If you don't, check that R6 is connected properly and that C6 is not shorted circuited.

Assuming that the input of IC3A is OK, check that the output (pin 3) of IC3A is at 0 Volts. If it isn't, look for short circuits, open circuits, bad solder joints and check the value of R7. If none of this helps, try replacing IC3. If that helps, throw the old one away.

Assuming that the output of IC3A is OK, check the output (pin 4) of IC3B. It should be 5 Volts. If it isn't, check that pin 7 of IC3 is connected to the 0 Volt rail and that pin 14 is connected to the 5 Volt rail. Check for short circuits on pin 4 and pin 8. Check that pin 3 is connected to both pins 5 and 6 of IC3. If none of this helps, try replacing IC3. If that helps, throw the old one away.

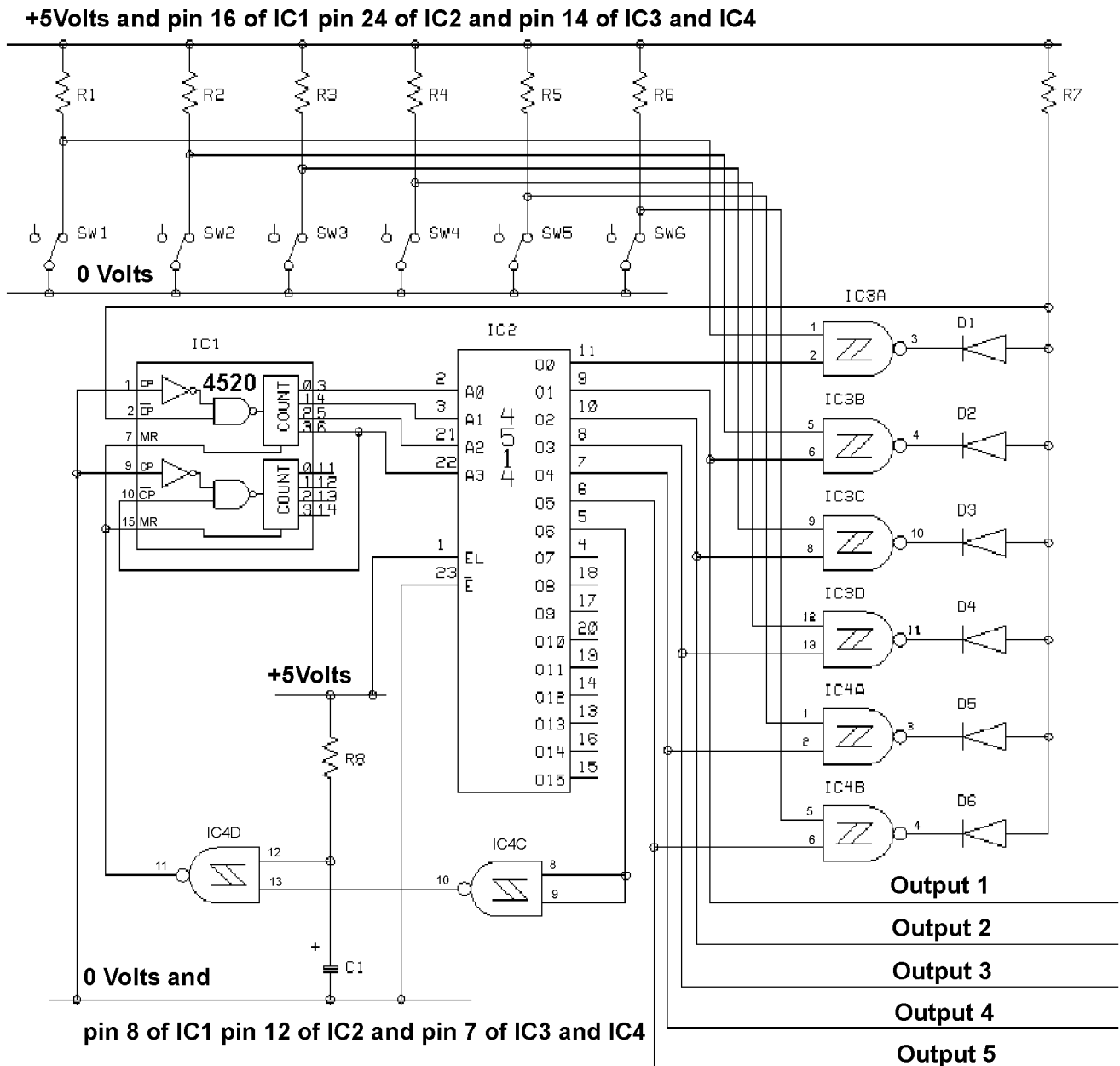
Assuming that the output of IC3B is OK, check the output (pin 10) of IC3C. It should be 5 Volts. If it isn't, check that R7 is properly connected between pin 3 and pin 9. Check that the only connection to pin 8 is pin 4. Check that the only connection to pin 10 is pin 12. Look for short circuits, open circuits and bad solder joints. If none of this helps, try replacing IC3. If that helps, throw the old one away.

Assuming that the output (pin 10) of IC3C is OK, check that the output (pin 11) of IC3D is 0 Volts. If it isn't, check that pin 10 is connected to pin 12 and that pin 13 is connected to pin 9 of IC2. Check the input (pin 13) of IC3D is 5 Volts. If it isn't, go to the fault finding section of the pulse generator circuit. Look for short circuits, open circuits and bad solder joints. If both inputs (pins 12 and 13) of IC3D are 5 Volts and the output (pin 11) of IC3D is not 0 Volts, check that the output is only connected to pin 5 of IC1 and that there is not a short circuit. If none of this helps, try replacing IC3. If that helps, throw the old one away.

Event based sequencer.

This type of sequencer needs signals to indicate the end of each signal. Usually this will be from limit switches but some of the operations may be timed in which case a pair of pulse timers will be required for each operation. The first timer is triggered by the operation's output and the second timer, which is triggered by the end of the first timer produces the signal to advance the sequencer.

If the end of operation signal does not get removed before the sequencer outputs a signal to start that operation again, the sequencer will immediately go to the next operation. If you have a situation in which the operation stops at the end of its operation and does not return to another start position, you will have to produce a pulse output rather than a continuous output from your end of operation detector.



Event based sequencer

R1	10K
R2	10K
R3	10K
R4	10K
R5	10K
R6	10K
R7	10K
R8	100K
C1	4 μ 7F negative end must be connected to 0V
D1	1N4148
D2	1N4148
D3	1N4148
D4	1N4148
D5	1N4148
D6	1N4148



IC1 HEF4520BP
IC2 HEF4514BP
IC3 HEF4093BP
IC4 HEF4093BP



Notes

This circuit, as drawn, provides 5 outputs having no output until a start sequence input is provided by SW1. If you require an initial signal, you can use the first output on pin 11 of IC2. This will then give you six outputs.

The circuit has been drawn to provide 5 outputs. This is to simplify the drawing. IC2 has 16 outputs. You will need a signal to reset the counter IC1. The output on pin 5 of IC2 is used in the drawing. Should you require more or less outputs, you would need to change the output used for the counter (IC1) reset, which is connected to the input (pins 8 and 9) of IC4C. This signal comes from the output following the last used output of IC2. If you wanted less outputs, you would need fewer NAND gates and diodes on the outputs of IC2 and connect the inputs of IC4C to a different output of IC2. If you want more outputs, you will need more NAND gates, diodes and input switches.

The maximum number of outputs is 16 less one for the start condition and one for the end condition, giving 14. If you need more than that, you can expand the system by using more than one 4514 using the same address inputs (pins 2, 3, 21 and 22). You then use another 4514 to provide information about which of the 4514's is active. This decoder needs to have its address inputs connected to the other counter of IC1. The connections are as follows. Let us say that the decoding 4514 IC is numbered IC5. Then pin 2 of IC5 is connected to pin 11 of IC1, pin 3 of IC5 to pin 12 of IC1, pin 21 of IC5 to pin 13 of IC1 and pin 22 of IC5 is connected to pin 14 of IC1. If the EL input (pin 1) of a 4514 is a '0', the outputs will all be '0's. You should therefore connect the EL pins of the output 4514's to the outputs of IC5 in order. The input of IC4C will of course need to be connected to the output directly after the last used output. This will allow the system to be expanded to have up to 254 outputs in sequence.

If you have a system in which there is some movement from one position to another, you may need to ensure that it goes back to its starting position before the next sequence starts. If you are using limit switches and you are using the last operation output to make all the previous operations go back to their starting positions, you will need to stop the individual movements with limit switches but only produce an end of sequence signal when the last movement has finished. The easiest way of doing this is to provide two limit switches for the starting point of each movement. If you use one of the switches to stop the movement and the other can be connected in parallel with the other duplicate switches. In this way the switch signal for the end of movement for the

sequencer will only produce a signal when they are all open. For this method to work, you must ensure that the end of sequence limit switch operates before the limit switch that stops the movement.

The circuit has been drawn using switch inputs but it works equally well using Voltage signals instead of switches.

Testing

Before applying power to the circuit, inspect the circuit thoroughly using a spy glass ensuring that there are no unwanted short circuits or open circuits and that the circuit follows the diagram exactly. Ensure that the power supply is connected the right way round. Then set your meter to continuity or low Ohms range. Connect the meter across the 0V and 5V supply and make sure that the reading is not zero or near to zero. You may get a bleep or a low Ohmic value for a short time because of the capacitor in the power supply, but this should not last more than a few seconds. If it is continuous, you have a short circuit somewhere and you should follow the instructions in the fault finding section. If you do not get the expected results, you should switch the circuit off immediately.

Set your meter to the 20 Volt DC range. Connect your meter across the 5 Volt supply and switch on the supply. If the reading is much below 5 Volts, switch off immediately and go to the fault finding section.

Connect the common (COM) terminal of your meter to the 0 Volt rail. Measure the output 0 (pin 11) of IC2. It should be 5 Volts. Now operate SW1. The meter should now read 0 Volts. Measure output 1, it should be 5 Volts. Now operate SW2. The meter should now read 0 Volts. Do this for all the outputs and switches in turn. Check that the output 0 is at 5 Volts again after the last switch has been operated.

Circuit description

IC1 is a dual 4 bit binary counter. The counter is decoded by IC2. IC2 has 16 outputs corresponding to the outputs of IC1, which counts from 0 to 15. Only one of the outputs of IC2 will be a '1' at any time. Which output is a '1' is dependent on the output of the counter IC1. IC1 is configured to count up on the falling edge of an input on pin 2. The counter will reset to zero when the MR (Master Reset) input (pin 7) is a '1'. The output of the first counter is fed to the input of the second counter in case you want to expand the system beyond 14 outputs.

On switch-on, C1 is at 0 Volts and slowly charges up to 5 Volts via R8. This signal is inverted by IC4D to provide a '1' on the MR input of the counter. This resets the counter to zero temporarily. Output 0 will now be a '1'. All the other outputs will be '0's. Any zero on the input to a NAND gate will produce a '1' on its output. Before SW1 is operated it produces a '0' on the input of IC3A

which in turn produces a '1' at the gate's output. None of the diodes are therefore conducting and the input (pin 2) of the counter is a '1'. When SW1 is operated, pin 1 of IC3 becomes a '1', so both inputs of IC3A are '1's so the output (pin 3) of IC3A becomes a '0' causing D1 to conduct and a '0' to appear at the input to the counter. This causes the counter to count up one. The output 0 now becomes '0' and the output 1 becomes a '1'. By the same process, if SW2 operates, the counter counts one more and output 1 becomes '0' and output 2 becomes '1'. This process is the same for switches 3, 4 and 5.

When output 5 is a '1' and SW6 operates, the counter gets another input and counts one more. This causes output 5 to be a '0' and output 6 (pin 5) of IC2 to become a '1'. IC4C inverts this and causes a '0' to appear at pin 13 of IC4D. Any '0' on the input of a NAND gate causes its output to be a '1'. This '1' is connected to the counter reset so the counter's output is now zero and the process is finished until started again by SW1.

Faultfinding

The first thing to do is give the circuit a thorough visual inspection with a spy glass looking for bad solder joints and short circuits. Check that the circuit you have built exactly matches the circuit diagram and that the components are the correct values and connected the right way round.

If the power supply was short circuited or had a greatly reduced output, remove the IC's one at a time and try again. If that does not help, there must be a short circuit or misconnection. If the removal of an IC restores the output of the power supply, check for short circuits on the pins of the IC socket, in particular any outputs of the IC's. Make sure that the IC's were the correct way round. It is possible that an IC is faulty. Check the connections to the 5 Volt. Check that none of the outputs of any of the IC's are connected anywhere that they shouldn't.

Assuming that the power supply is OK, make sure that none of the switches is in its operating condition. Check the voltages across the switches. They should be 0 Volts. If any of them are not, check that the switches have been connected correctly. When the switches are not operated, they should be short circuited and when they are operated they should be open circuited. If this is not the case, you are either using the wrong terminals on the switch or the switch is faulty. Now operate the switches one at a time and measure the Voltages across them. The meter should read 5 Volts. If they do not, you are either using the wrong terminals on the switch or the switch is faulty. If you have a faulty switch, replace it and throw the old one away.

Assuming that the switches are OK, check the outputs of IC3 and IC4A and IC4B. They should all be 5 Volts. If they are not, check that the switch inputs, which should be connected to the inputs of the faulty ones, are connected properly. Look for short circuits, open circuits and bad solder joints. Now

check to see that the faulty outputs of those IC's are not connected anywhere other than to the appropriate diodes. Look for short circuits, open circuits and bad solder joints. Make sure that pin 7 of IC3 and IC4 are connected to the 0 Volt rail and that pin 14 of those IC's are connected to the 5 Volt rail. If none of this helps, try replacing the problem IC. If that helps, throw the old one away.

Assuming that the outputs of IC3 and IC4A and IC4B are OK, check that the input (pin 2) of IC1 is at 5 Volts. If it isn't, check that it is connected to R7 and the anodes of the diodes and to nowhere else. Look for short circuits, open circuits and bad solder joints. Check that R7 is connected to the 5 Volt rail.

Assuming that the input to IC1 is OK, switch off the power supply for a while until the power supply is less than 1 Volt, make sure that none of the switches are operated and then switch the power supply on again. Check that the outputs of the counter (IC1) are all 0 Volts. The outputs are pins 3, 4, 5 and 6. If they are not, look for short circuits, open circuits and bad solder joints. Make sure that they are only connected to the appropriate pins of IC2 and to nowhere else. Make sure that pin 8 of IC1 is connected to 0 Volts and that pin 16 is connected to the 5 Volt rail. If none of this helps, try replacing the IC. If that helps, throw the old one away. If that does not help, check the circuit for resetting the counter. This comprises IC4C, IC4D, C1 and R8. Look for short circuits, open circuits and bad solder joints. Try replacing IC4. And repeat the procedure at the beginning of this paragraph. If that helps, throw the old IC away.

Assuming that the outputs of IC1 are OK, check that the output 0 (pin 11) of IC2 is at 5 Volts. If it isn't, check that pin 12 of IC2 is connected to the 0 Volt rail and that pin 24 is connected to the 5 Volt rail. Check that pin 1 is connected to the 5 Volt rail. Check that pin 23 is connected to the 0 Volt rail. Check that the address inputs (pins 2, 3, 21, and 22) are connected to the appropriate outputs of IC1 and to nowhere else. Look for short circuits, open circuits and bad solder joints. If none of this helps, try replacing IC2. If that helps, throw the old IC away.

Assuming that output 0 is OK, operate SW1. Check that output 0 is now 0 Volts. If it isn't, check that the output (pin 3) of IC3A is 0 Volts. If it isn't check that pin 2 of IC3 is connected to pin 11 of IC2. Check that the diodes are all the correct way round. Look for short circuits, open circuits and bad solder joints. If none of this helps, try replacing IC3. If that helps, throw the old one away. If the output of IC3A is OK but the problem still exists, check that D1 is the correct way round. Check that the input to the counter (pin 2) of IC1 is 0 Volts. If it isn't, check that it is connected to the junction of R7 and the diodes and that the diodes are connected the right way round. If none of this helps, check the Voltage on pin 7 of IC1. It should be 0 Volts. If it isn't, check that it is connected to the output (pin 11) of IC4D. If that doesn't help, check that the input (pin 12) of IC4D is 5 Volts. If it isn't, check R8 and C1. Look for short

circuits, open circuits and bad solder joints. Now check that the output (pin 10) of IC4D is 5 Volts. If it isn't, check that the input is connected to pin 5 of IC2. Check for short circuits, open circuits and bad solder joints. Check that pin 10 is connected to pin 13 of IC4 and nowhere else. If none of this helps, try replacing IC4. If that helps, throw the old IC away. Make sure that pin 1 of IC1 is connected to 0 Volts. See if pin 3 of IC1 is now 5 Volts. If it isn't, try replacing IC1 and try again. If the output pin 3 of IC1 is 5 Volts but the output 0 Pin 11 of IC2 is 5 Volts, check that pin 23 of IC2 is connected to 0 Volts, that pin 1 of IC2 is connected to 5 Volts, that pin 12 of IC2 is connected to 0 Volts and that pin 24 of IC2 is connected to 5 Volts. If all these connections are OK and pin 11 is not connected to anywhere other than to pin 2 of IC3, try replacing IC2. If that helps, throw the old one away.

Assuming that the output 0 is OK, check the other outputs one at a time using the same procedure but looking at the appropriate IC according to which output is being looked at. After that, check that the last switch resets the counter. If it doesn't, check IC4C and IC4D as before.

Chapter 15

Logic

Logic devices have been used in other chapters. This chapter will refer to some of those circuits and will add more circuits to enable you to have a more comprehensive repertoire.

Logic deals with truth and falsehood. All logical functions can be made using the three basic functions of AND OR and NOT. Some very nice people have made our lives a lot easier by combining these to form more complex functions in single chips. The chapter on 'General Electronic Components' describes the function of some logic devices. [Click here](#) to go to the relevant section.

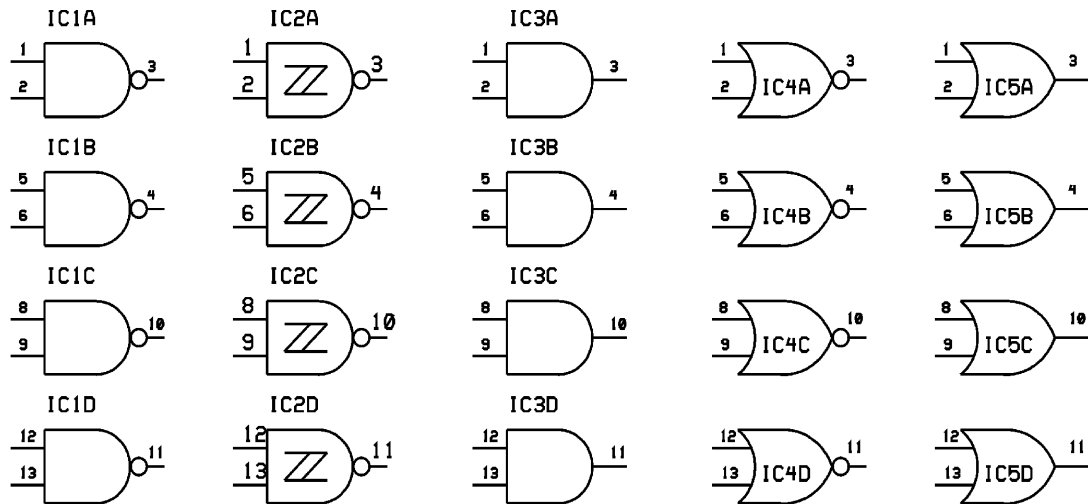
CLICK

If you intend to use a lot of logic devices, it would be a good idea to obtain a data book on the 4000 series devices. These may be obtained from the IC manufacturers, but you should ask your distributor first.

You should note that it is usual to use 'H' for a '1' being short for high and 'L' for a '0' being short for low, when using function/truth tables in data books. Function/truth tables describe the relationships between inputs and outputs of the devices. These can look a bit daunting at first but once you actually look at them closely and try to understand what is going on, they are really quite simple. So the trick is to persevere and look at some simple gates first. You should then be able to read them without much difficulty.

The number of different components has been reduced to a minimum, in this cd, to allow the reader to purchase components in reasonable quantities to get the benefit of reduced prices and use spare gates in other parts of your circuit. You may however find that using different logic devices results in a saving. The circuits in this cd are of a modular nature so that they can be combined to form a complete circuit. If these circuits all use the same devices, there is a benefit as there are usually some spare gates in a circuit module, which can be used in another circuit module.

The gates used in this cd are all two input devices. There are some gates, which have three inputs, some with four inputs and some with eight inputs. The same logic applies and if you look at the truth tables you will be able to see what is going on. If for example you use an eight input AND gate, all of the eight input would have to be '1's to get a '1' at the output. Similarly if you use an eight input OR gate, if any one of the eight inputs is a '1', you will get a '1' at the output.



IC1 4011 NAND gates
 IC2 4093 NAND gates with Schmitt trigger inputs
 IC3 4081 AND gates
 IC4 4001 NOR gates
 IC5 4071 OR gates

Pin 7 should be connected to the 0 Volt rail and pin 14 should be connected to the positive supply, which is usually +5 Volts but is +12 Volts in some circuits.

In the above examples, you can see that each IC has four identical circuits so it makes no difference to your circuit if you use IC1D instead of IC1A. The modular nature of the circuits described in this cd can be confusing from a point of view of the component identification numbers. If for example a circuit module only uses IC1A and IC1B and you have another module in the same overall circuit also uses IC1A and IC1B of the same IC type (for example they may both be 4093 IC's), then you can use a single IC for both modules by using IC1C and IC1D instead of IC1A and IC1B in one of the modules. This will save you an IC.

When using electrical contacts, like switches or relay contacts for example, you should use a capacitor across the contacts and use a logic device with a Schmitt input. Normally a pull-up resistor is required. A pull-up resistor connects the input of your device to the positive supply and the switch is connected between the input and the 0 Volt rail. In this way there will be a '1' on the input when the switch is open and a '0' when it is closed. A 10K resistor is normally used together with a 0μ1F capacitor. The reason for this is that switches bounce when operated. That is they open and close a few times before they settle down to their final state. This happens very quickly so you would not be aware of it but your circuit might well not function correctly if it gets a series of input pulses instead of a nice clean switch. This bouncing usually lasts for a few mSecs. but it is dependent on the type of switch. The use of a Schmitt trigger input is to reduce the possibility of false signals. The following circuit uses switch inputs.

The first thing to do when designing logic circuits is to define the function precisely. This is actually harder than it sounds but here are some hints.

Write down a list of what the circuit needs to do in terms of IF THEN statements. Here are some examples.

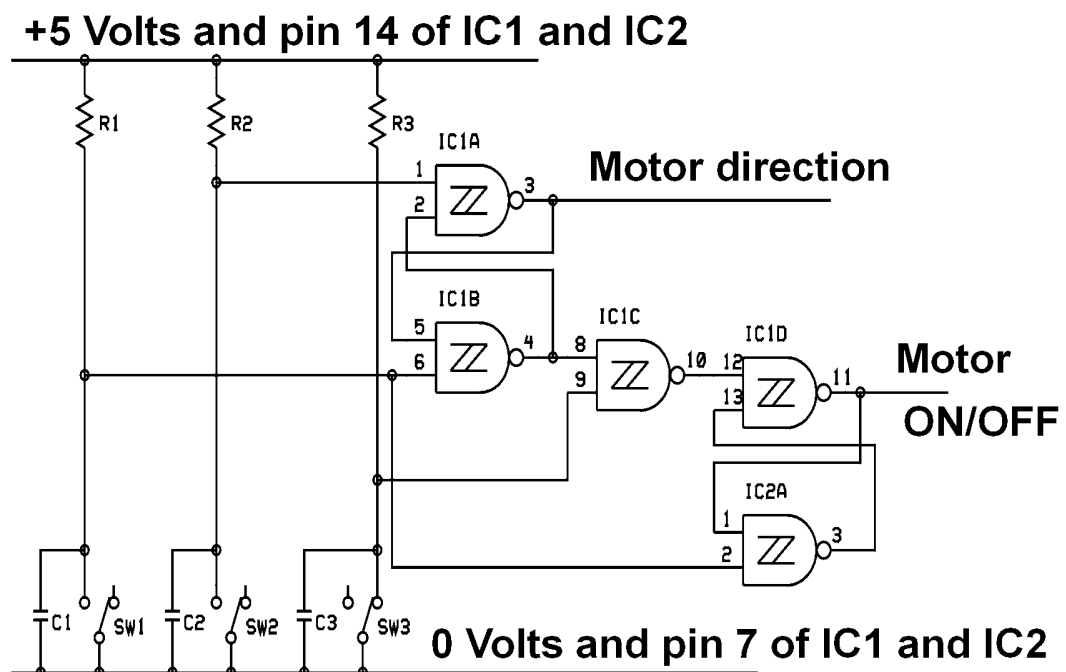
Example 1.

IF movement of person detected AND work ready at start position, THEN start movement of work to end position.

IF work at end position, THEN reverse direction of movement.

IF work at start position, THEN stop movement of work towards start position.

From these simple statements, we can see that we will need an AND gate to fulfill the requirements of the first statement and we will need memories to remember which way the work is going and whether the work should be moving or not. The easy way to cope with memories is to use latches, which can be set at the start of the work's movement and reset at the end of the movement.



In the circuit above, the resistors are 10K, the capacitors are 0.1μF and the IC's are HEF4093BP. SW1 is a limit switch indicating the start position, SW2 is a limit switch indicating the end of movement position and SW3 is a normally closed (N/C) movement detector output (relay contact).

Circuit description.

You will note that there are capacitors across the switch inputs and that the gates have Schmitt trigger inputs. This is because switch contacts bounce and cause a noisy signal when activated.

IC1A and IC1B are configured as a latch to remember the direction of movement. IC1C is performing the AND function. IC1D and IC2A are configured as a latch to remember the movement sensor condition.

In the start condition, SW1 is closed and SW2 is open. There is therefore a '0' on pin 6 of IC1 and a '1' on pin 1 of IC1. A '0' on any input of a NAND gate produces a '1' on its output. Pin 4 of IC1 is therefore a '1'. Pin1 of IC1 is also a '1', so pin 3 of IC1 is a '0' and is connected to pin 5 of IC1. If SW1 now becomes open, causing a '1' on pin 6, the output (pin 4) of IC1B will remain a '1' because pin 5 is a '0'. The direction of movement output is now set at '0', which would cause the movement away from the start position even if the motor were to be switched on causing the start position switch SW1 to open.

When someone moves, SW3 becomes activated causing a '1' at pin 9 of IC1. Pin 8 is also a '1' as it is connected to pin 4. The output (pin 10) of IC1C will therefore become a '0'. This is our AND function.

The second latch comprising IC1D and IC2A is now set and the motor on/off signal becomes a '1'. This starts the motor. The motor will continue to be on even if the motion detector no longer causes SW3 to be open.

When the motor reaches the end position switch SW2, pin 1 of IC1A becomes a '0' causing the output (pin 3) to become a '1'. This changes the motor direction. This signal is also connected to pin 5 of IC1 so both inputs to IC1B are '1's and therefore the output (pin 4) becomes a '0'. This output is connected to pin 2 of IC1 and therefore keeps the motor direction output on a '1' until the motor reaches the start position again.

When the motor reaches the start position again, SW1 is operated and a '0' appears at pin 6 of IC1 causing the motor direction to revert to its forward direction and a '0' appears at pin 2 of IC1A causing the motor to stop.

Well what if you wanted the motor to turn off for a while before going back to the start? You now have a further statement as in example 2.

Example 2.

IF movement of person detected AND work ready at start position, THEN start movement of work to end position.

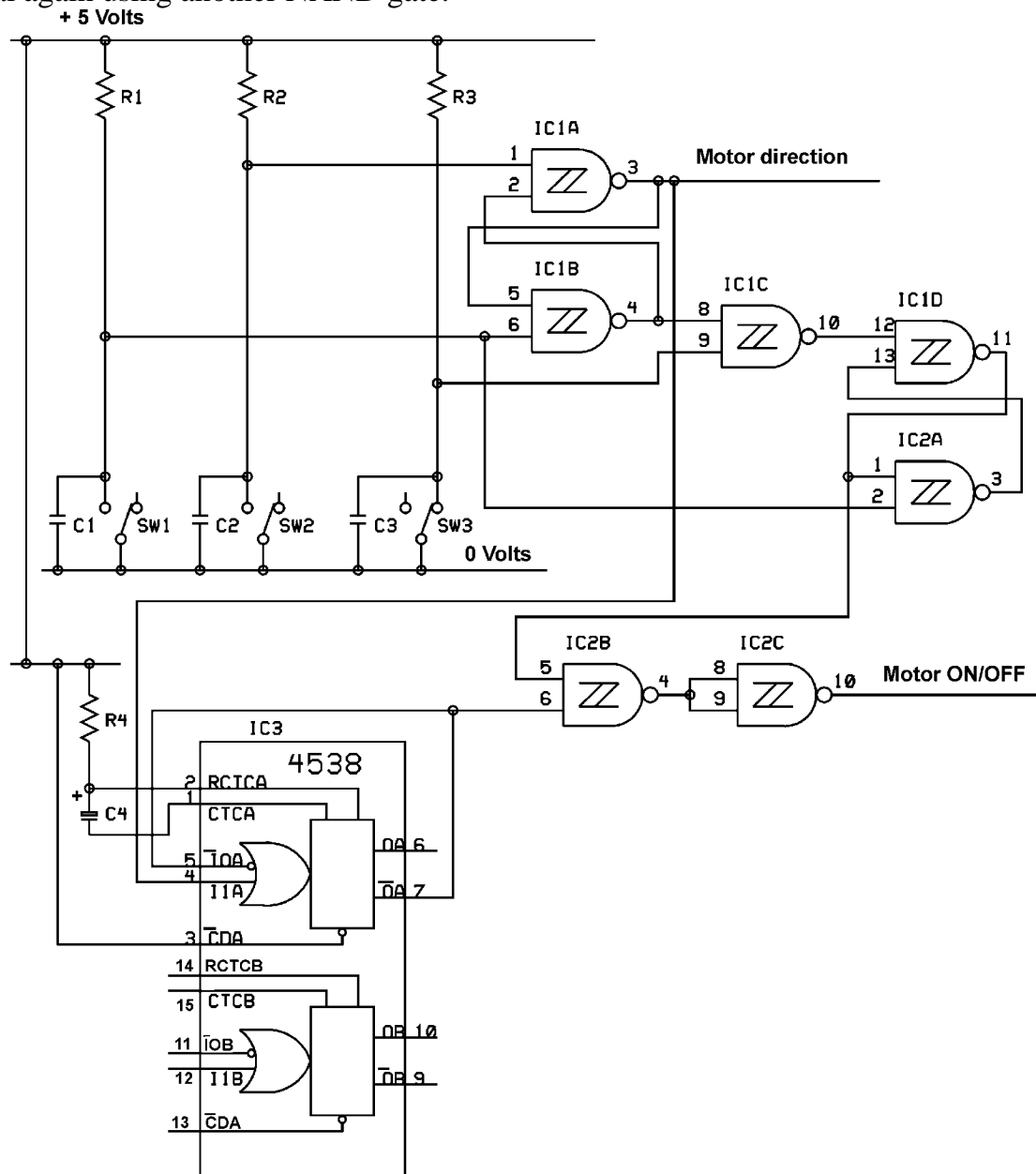
IF work at end position, THEN reverse direction of movement AND start timer.

IF timer is on, THEN motor is off.

IF work at start position, THEN stop movement of work towards start position.

Use the circuit of example 1 as a starting point and add more electronics for the extra conditions. You would need a timer to determine how long you wanted the motor to be turned off. This time could be a fixed time, as produced by one

of the circuits in the chapter on timers or it could be a random time as produced by the random time circuit in the chapter on random or it could be generated by some other sensor. In any event it should be triggered by the rising edge of the motor direction output. All you now need is an AND gate to AND the Motor ON/OFF output with the timer output and use the output of the AND gate as your new motor on/off signal. Well you will probably have a couple of spare NAND gates available. So use a NAND gate for your two inputs, and invert the signal again using another NAND gate.



The timing circuit of IC3 is described in the chapter on timers. [Click here to go to the circuit description.](#)

CLICK

In the previous example, the motor ON/OFF signal appears at the output of IC1D. This is now connected to one of the inputs of IC2B. The other input is connected to the inverted output (pin 7) of the monostable multivibrator IC3. This output is normally a '1' and goes to a '0' for a period of time determined by the values of R4 and C4. This pulse is started when the input on pin 4 of IC3 goes from a '0' to a '1'. So until the motor direction goes to a '1', the output on pin 7 of IC3 is a '1'. This has the effect of allowing the motor ON/OFF signal to pass unhindered from the output of IC1 to the output of IC2.

When the motor direction signal becomes a '1', the monostable output on pin 7 becomes a '0' for a period of time. This causes the output of IC2B to be a '1' whatever the output of IC1D. When the output of IC2B is a '1', the output of IC2C is a '0' and the motor is turned off.

At the end of the pulse from the monostable, the output of IC1D is no longer inhibited by the monostable as there is now a '1' on pin 6 of IC2B and the motor can turn on again.

Example 3.

Let us consider the problem of using logic devices to solve the limit switch problem in the chapter on prime movers.

The problem is that we want to prevent a motor from moving beyond fixed points at each end of its travel, but the switches used will force the moving part away from the limit switches because of the springs in the switches. The simple solution of using switches with diodes across them will therefore not work very well.

Let us define the problem in a more suitable way.

If the forward switch is activated then the motor cannot go forward.

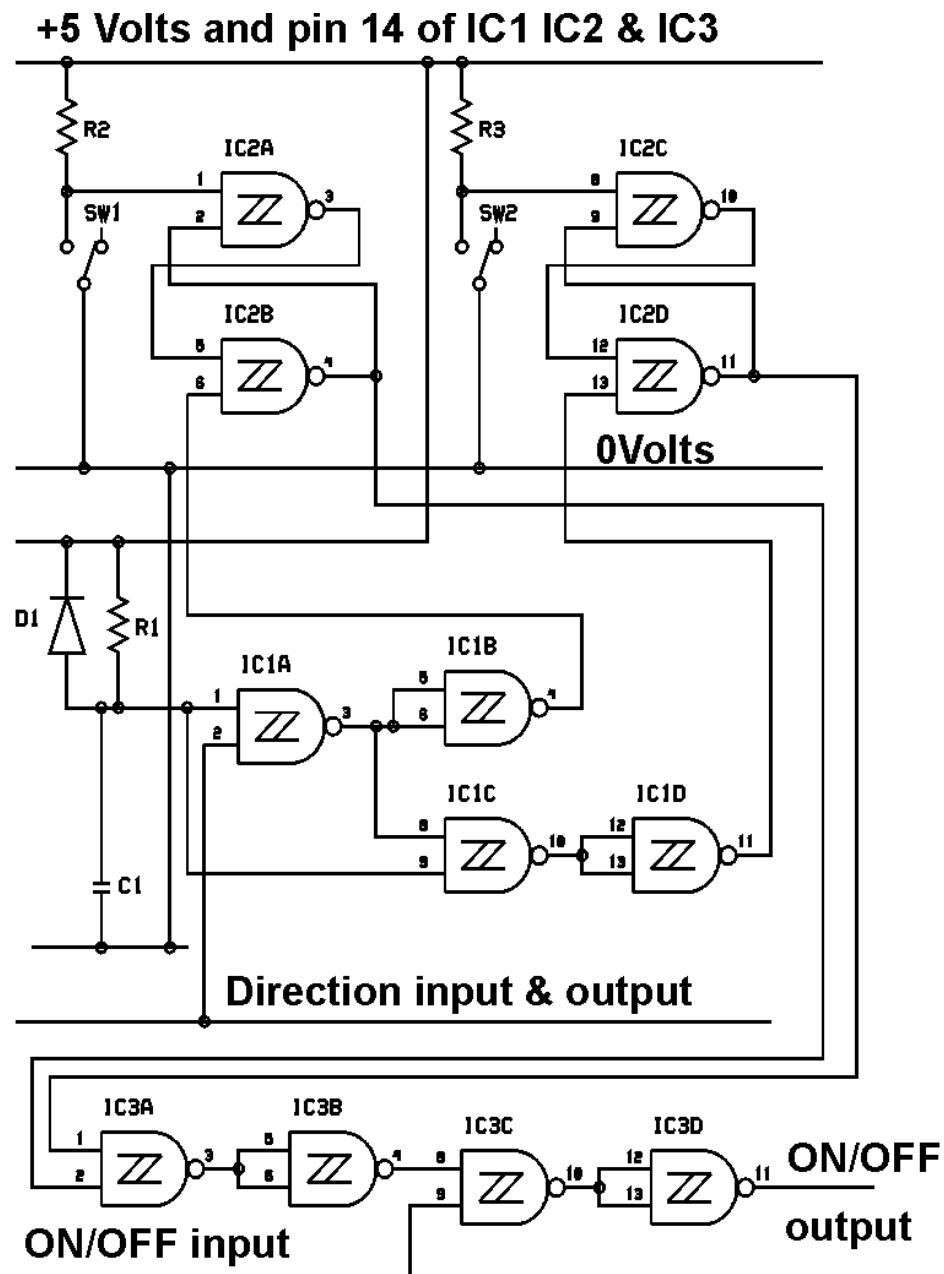
If the forward switch is not activated but has been activated and there has not been a reverse direction, then the motor cannot go forward.

There will be two similar statements for the reverse direction.

It will be clear that we will need two latches, one for each end of travel so that we can remember whether a switch has been activated or not. We will need to activate the latches when the limit switches are operated and release the latches if the direction signal is away from the switch.

There is a slight problem with this, as we don't know what states the latches will be in when power is first applied. It is possible that on switch on, both directions of movement will be inhibited. We therefore need to reset both latches when power is first applied.

Let us first consider an implementation of the circuit using NAND gates only and then duplicate the function using NAND and AND gates. You will note that in terms of the number of different IC's used, there is no difference and that if you only use the NAND gates you will have the advantage of using the same device types throughout. On the other hand, there are more connections and you will not have any spare gates available for other parts of your circuit.



Limit switch circuit for motor control

Circuit description

IC1 is configured as the two latches, one for each end of motor travel.

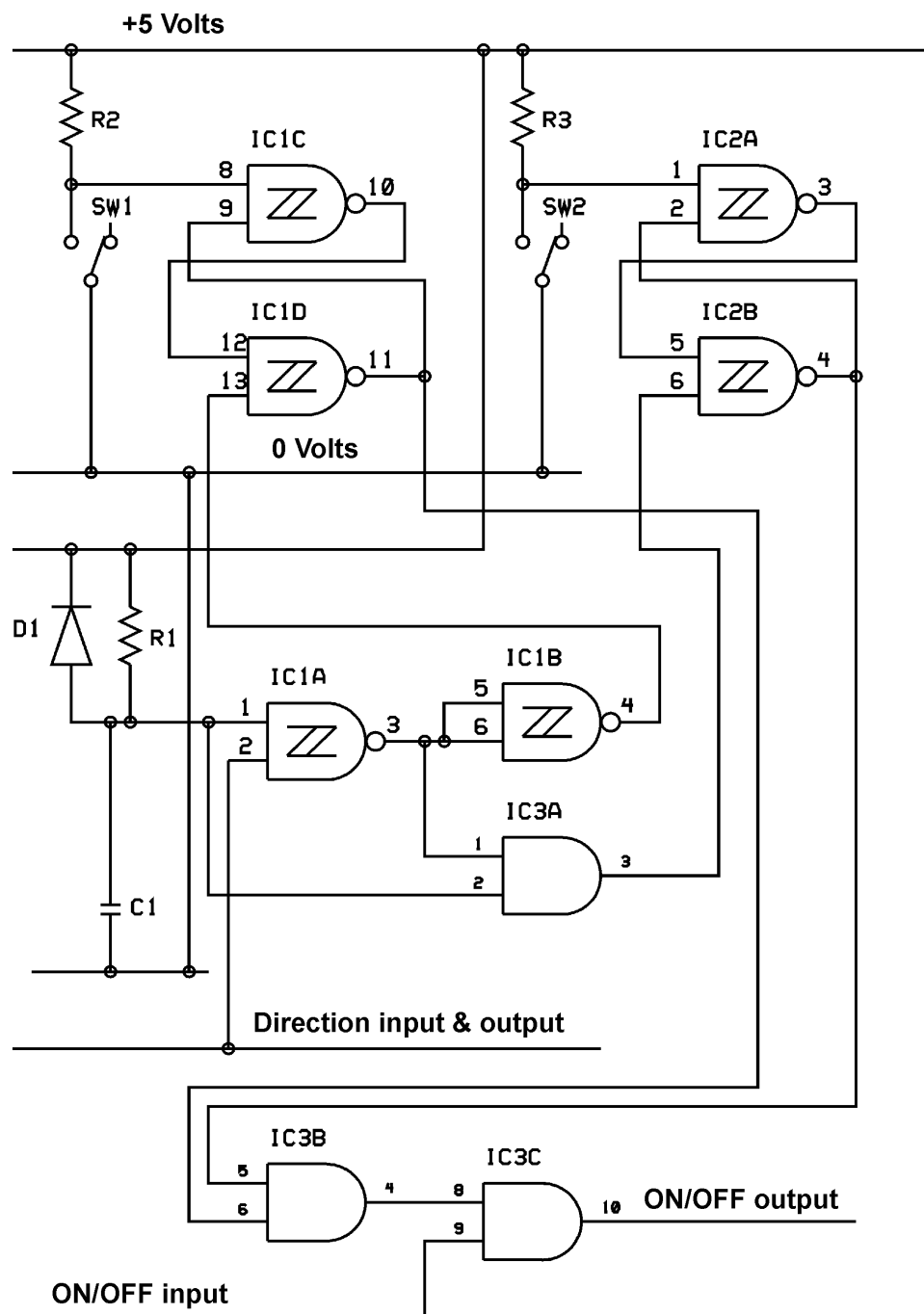
If either of the two latches is set, IC3 inhibits the motor on signal.

IC1 has two purposes, one is to provide a reset signal for the latches on switch-on and the other is to steer the direction signal to reset the appropriate latch.

On switch-on, C1 is discharged and slowly charges up via R1. During the time it takes for C1 to charge up, the two latches are reset.

You will note that there are no capacitors across the limit switches. This is because they are connected to the inputs of latches so multiple signals for a few mSecs, will not affect the circuit function.

Other implementation of example 3.



In the first implementation, you will note that IC1D is only acting as an inverter to convert IC1C from a NAND to an AND gate. Similarly IC3B is used to convert IC3A and IC3D is used to convert IC3C. If you add up the number of gates used in the first implementation, it comes to 12, which requires 3 IC's. If you use the second implementation, you need 6 NAND gates and 3 AND gates. This is still 3 IC's but leaves you with 2 spare NAND gates and 1 spare AND gate.

You should be familiar with latch circuits of IC1C and D and of IC2A and B as the functioning of this kind of latch has been fully described earlier in this chapter.

Let us consider the start up circuit of IC1A, IC1B and IC3A. When the power is off, C1 is discharged via D1. C1 would discharge eventually anyway but D1 is there incase the power is turned on and off in quick succession. When the power is turned on, it takes time for C1 to charge up via R1. During this time, pin 1 of IC1 and pin 2 of IC3 are both '0' Normally you should use a Schmitt trigger input when a slow moving input is used, however it really doesn't matter whether you get multiple pulses whilst the input is close to the transition from a '0' to a '1' in this particular instance. Suitable value for C1 and R1 would be 1 μ F and 1M.

Whilst C1 is charging up, the outputs of IC1B and IC3A are both '0's and therefore the latches will both be reset.

When the direction signal is a '0', the output of IC1B will be a '0' and the latch circuit of IC1C and IC1D will be reset. This allows the motor to move until SW2 is operated.

When the direction signal is a '1', the output of IC1A becomes a '0' and therefore the output of IC3A becomes a '0' and the latch circuit of IC2A and IC2B will be reset. This allows the motor to move until SW1 is operated.

If either of the latch circuits is set, the output of IC3B will be '0' and therefore the output of IC3C will be a '0' and the motor will be turned off.

The motor therefore can move until it reaches a limit switch. When it does, the appropriate latch is set and the motor stops. When the direction signal changes state, the motor can then move away from the limit switch.

Example 4.

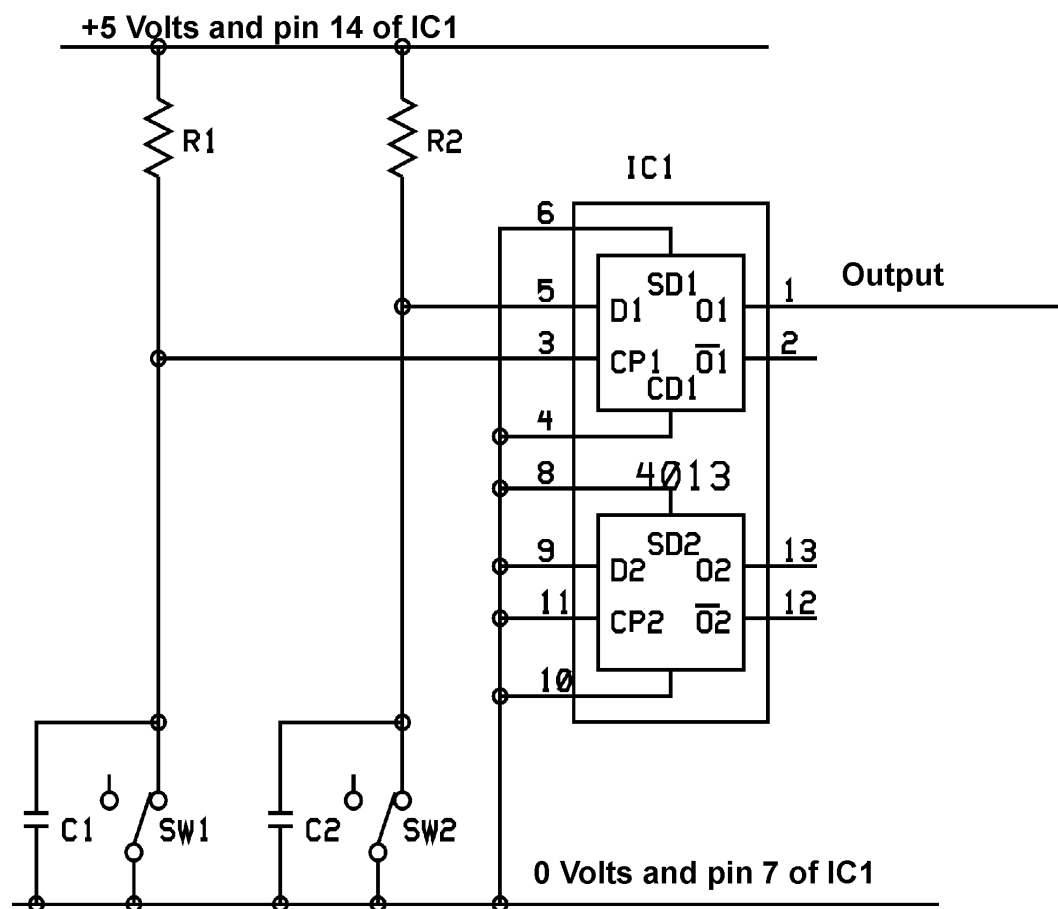
Let us consider the problem of which signal comes first.

Here is a little aside for your consideration and is proof positive that questions are often more interesting than answers. Which came first, the chicken or the egg. Well logic tells you that the chicken cannot have come without an egg so

we are then left with the problem of how you can get a chicken egg without having a chicken. The answer is obvious. It wasn't a chicken that laid the egg. It was something similar to a chicken. Oh well, never mind.

What we really want to know is which of two signals comes first. Say, for example, you have two infrared beams close to each other and someone breaks the beams. If the beams are close enough, there will be a time when both beams are broken at the same time. If we know which one is broken first, we will know which direction the person was traveling.

The solution to this is simple. If we sample the state of one beam at the instant that the other beam is broken, we will know the answer. The result will be a '0' for one direction and a '1' for the other. All we need is an edge-triggered latch.



The HEF4013BP has two identical D type edge triggered Flip Flops. The circuit shows the second one having its inputs connected to the 0 Volt rail. If you want to use both halves of the IC, copy the circuit of the first half.

The signal on the D input (pin 5) is transferred to the output (pin 1) on the rising edge of the Clock Pulse input (pin 3). The output remains the same until another Clock Pulse input occurs. Pin 2 is another output, which is the inverse of the output on pin 1.

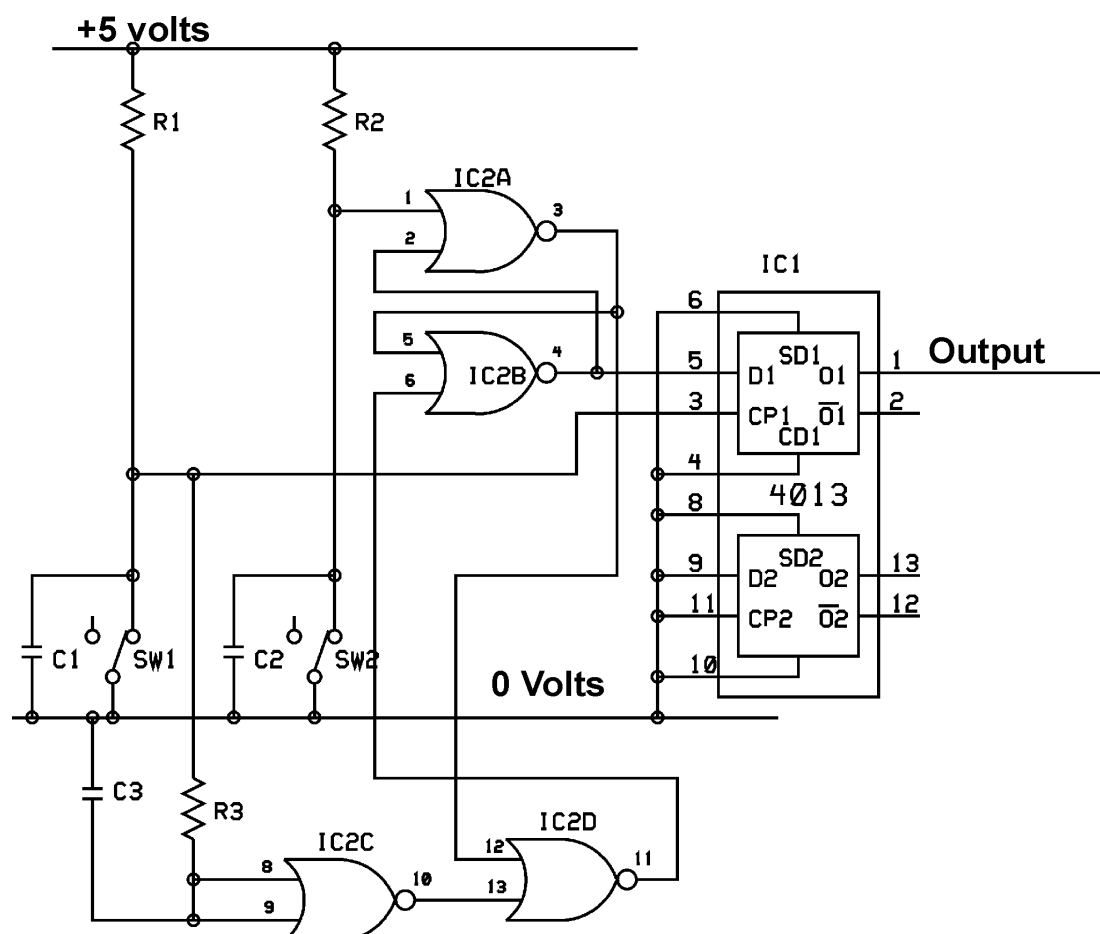
When SW1 is operated, the output is latched and will be a '0' if SW2 is not operated and a '1' if SW2 is operated at the instant when SW1 was operated.

You will note that the circuit cannot give a meaningful output until SW1 has been operated. If there has never been a chicken or an egg, the question of which came first has no meaning.

Example 5.

If you consider the previous problem but add the complication that the signal do not necessarily overlap, you will appreciate that you will need to have a latch on the SW2 signal. There are some further considerations as you will need to have a suitable starting condition as the question of which comes first is dependent on when you start looking. There may also a problem if the two signals overlap.

In this circuit it is more convenient to use NOR gates rather than NAND gates to implement the latch. The effect of this is that a '1' rather than a '0' sets or resets the latch.



As you can see from the drawing, the only difference between this circuit and the last one is some logic associated with SW2.

IC2A and IC2B are configured as a latch. With a NOR gate, a '1' on any input will cause a '0' on the output.

When SW2 is operated, there is a '1' on pin 1 of IC2A. This causes a '0' at the output (pin 3). The output of IC2A is connected to pin 5 of IC2B. Now if pin 6 is also a '0', there will be a '1' at the output of IC2B. This is connected to the input on pin 2 of IC2A. So when SW2 is closed again, the output of IC2A remains on a '0' and the output of IC2B remains on a '1' until a '1' appears at pin 6 of IC2B, when the latch is reset. As you can see, it works in exactly the same way as a NAND gate latch except that the signals are inverted.

All that is now needed is a provision for the latch reset. We don't want the latch to reset at the instant that SW1 is operated, as we need a stable signal on pin 5 of IC1 whilst the signal on pin 3 is rising. We need to wait a bit so that the circuit cannot get confused. Things must be ordered, we need to sense the state of the latch before we reset it and not during the reset. R3 and C3 delay the signal. A 1 μ F and 10K resistor will give a 10mSec delay, which is plenty.

When SW1 is operated, IC1 reads the latch and a short while later, a '1' appears at the inputs of IC2C, which inverts the signal. So there is now a '0' at pin 13 of IC2D. If the latch had been set, there will be a '0' at pin 12 as well. This will cause a '1' at the output of IC2D. This will reset the latch. When the latch has been reset, a '1' will appear on pin 12 of IC2D, which will cause the output of IC2D to become a '1' ready for the next input from SW2.

Example 6.

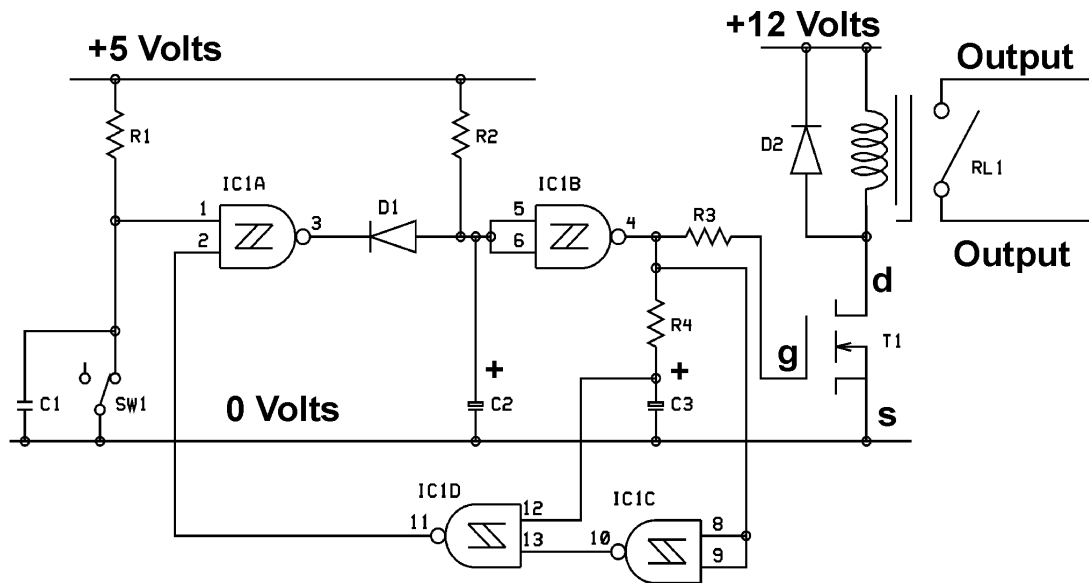
Say, for example, that you want to turn a cine-projector on when someone enters a space using a PIR detector, but it needs to stay on longer than the sensor signal because they may stop moving to watch the film. Now you don't want to turn the projector on again immediately after it has been turned off, as electronic equipment does not like being turned off and on quickly. You need to inhibit the input from the PIR detector for a few seconds after the projector has been turned off.

The problem can be written as follows.

If the projector has been off for more than a few seconds AND there is a PIR signal, then turn projector on for a time longer than the PIR sensor signal.

In the following circuit, T1 and R11 are a MOSFET transistor and a relay. The output is the switch contacts of the relay, which should be wired in series with the projector. You should read the notes on switching motors and lights. Pay particular attention to the notes regarding switching mains powered devices. [Click here to go to the relevant chapter.](#)

CLICK



This circuit assumes that you are using an intruder detector, which has a normally closed switch output.

Assume for the moment that the output has been off for a while. Pin 12 of IC1D will therefore be a '0'. The output of IC1D will therefore be a '1'.

When someone moves, SW1 will open causing a '1' on pin 1 of IC1A. Both inputs of IC1A are now '1's, so the output of IC1A will be a '0'. D1 discharges C2. The output of IC1B becomes a '1' and turns T1 on via R3. T1 turns the relay RL1 on and the projector is turned on. The input to IC1C is now a '1' so the output of IC1C is a '0', which causes a '1' at the output of IC1D.

When the movement detector stops sending a signal, SW1 is closed and the output of IC1A becomes a '1'. D1 block any current from flowing into C2. C2 charges up slowly via R2. Whilst it is charging up, the relay remains on, as there is still a '0' at the input of IC1B. When C1 has charged up sufficiently for its Voltage to rise above the level required for IC1B to see a '1' at its input, the output of IC1B becomes a '0' and the projector is turned off.

Whilst the output of IC1B was a '1', C3 was being charged up via R4. When the output of IC1B goes to a '0', there is a time determined by the values of R4 and C3 during which the input on pin 12 of IC1D is considered to be a '1'. Now the input of IC1C is a '0' so its output is a '1'. So for this time after the relay has been turned off, both inputs to IC1D are '1's, so the output of IC1D becomes a '0'. This inhibits signals from the PIR, as any '0' on the input of IC1A will produce a '1' on its output.

Further examples.

There are many examples of logic within the circuits of this cd. You are recommended to view the following examples.

Have a look at the following circuit to see an example of logic gates being used to produce a sequence of pulses. [Click here to go to circuit.](#)

CLICK

Have a look at the following circuit to see an example of diodes used in an AND function. [Click here to go to circuit.](#)

CLICK

Chapter 16

Random

Random numbers generated by computer are not actually random. They are generated by putting a number into a mathematical formula, which gives very different answers with small changes of input number, which is called the seed. The number generated is then used as the seed for the next number.

The main requirement for random events is that they should not be predictable by the viewer or the artist.

Random implies probability. The probability of an event happening at any time can be made variable.

There are two simple ways of producing truly random events. One is to use a counter, which is stopped when some external event happens. The resultant number will be random as there is no definite correlation between the external event, which could be an input from a movement detector for example, and the counter. The other is to use noise. Noise is random. All electronic devices produce noise, so it is only a matter of amplification. If you set your sound system to full volume you should hear some hiss. The better the equipment, the less the hiss, but it will be there. That hiss is electrical noise.

There are two different cases to be considered. In the first we have some kind of sensor causing a signal and you want to make something happen at random as a result. This may take the form of randomly choosing from a set different actions or choosing whether or not the action will take place or choosing at random some function of that action, for example the length of time that action will persist for.

In the second case you are not using a sensor but the change in action of the work happens randomly whether anyone is there to see it or not.

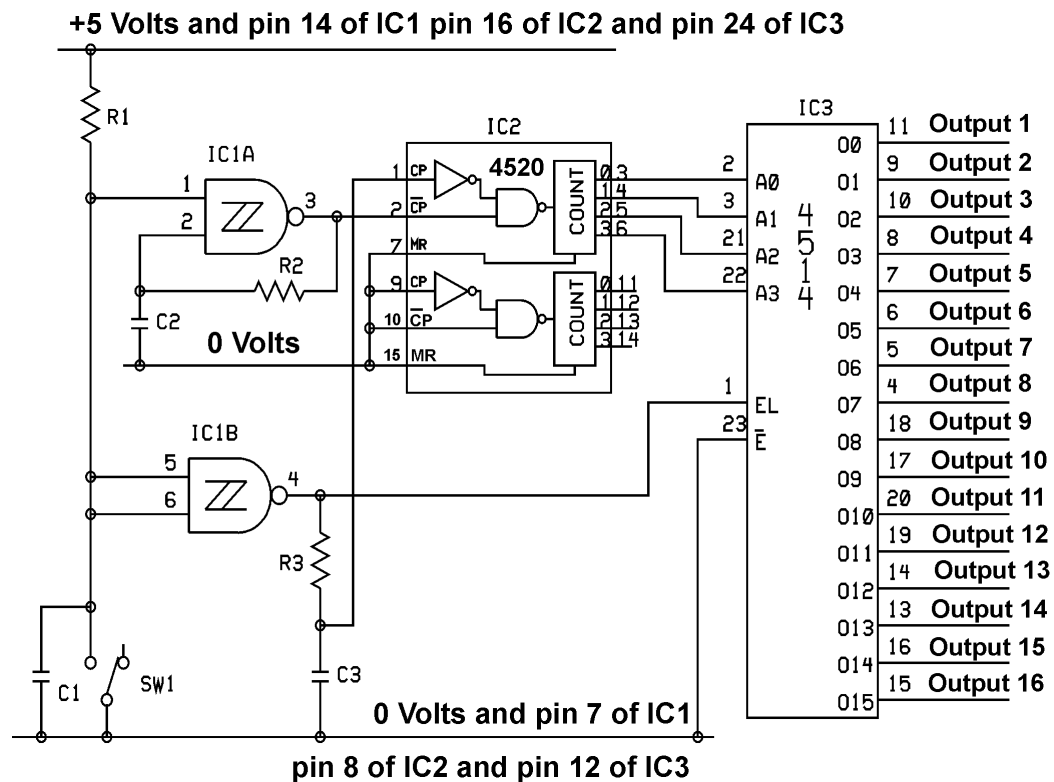
Random event with external input.

In the following circuit, some form of sensor, with a digital output, causes one of 16 outputs to be on whilst the rest are off. Each of the 16 has an equal chance of being on.

The circuit shows a normally open switch SW1 as the input. Should you require a normally closed input, you should invert the signal with one of the spare gates. The switch may be replaced with a digital output from another circuit in which case a '0' will cause a change in output. There is of course a one in sixteen chance that the outputs will remain unchanged.

The circuit works by having an oscillator connected to a counter, which counts from zero to fifteen repeatedly. The counter is decoded to give sixteen outputs,

only one of which can be on at any time. When an input is applied, the oscillator is stopped and the counter's output is transferred to the decoder's output. When the input signal is removed, the counter starts counting again.



Random event with external input

- R1 10K
- R2 22K
- R3 100K
- C1 0 μ 1F
- C2 2200pF
- C3 0 μ 1F
- IC1 HEF4093BP
- IC2 HEF4520BP
- IC3 HEF4514BP



Note

Pin 23 of IC3 needs to be connected to 0 Volts to enable the outputs. If you want to disable the outputs, you can do so by having a digital signal on this pin

instead of connecting the pin to 0 Volts. In this case the outputs would be enabled when the signal is a '0', and disabled when it is a '1'.

If you only want 8 possible outputs, you can connect pin 22 of IC3 to the 0 Volt rail instead of to pin 6 of IC2. If you only want 4 outputs, you can connect pin 21 of IC3 to the 0 Volt rail instead of to pin 5 of IC2 as well as connecting pin 22 to 0 Volts. You can also use OR gates on the outputs to reduce the number of outputs. This would allow for different probabilities as you could, for example, have three outputs OR'ed, which would then have three times the chance of giving an output than a single output.

Ensure that the spare gates have their inputs (pins 8, 9, 12 and 13) are connected somewhere. If the gates are not used, the inputs should be connected either to the 0 Volt or 5 Volt rails.

Testing

Before applying power to the circuit, inspect the circuit thoroughly using a spy glass ensuring that there are no unwanted short circuits or open circuits and that the circuit follows the diagram exactly. Ensure that the power supply is connected the right way round. Then set your meter to continuity or low Ohms range. Connect the meter across the 0V and 5V supply and make sure that the reading is not zero or near to zero. You may get a bleep or a low Ohmic value for a short time because of the capacitor in the power supply, but this should not last more than a few seconds. If it is continuous, you have a short circuit somewhere and you should follow the instructions in the fault finding section. If you do not get the expected results, you should switch the circuit off immediately.

Set your meter to the 20 Volt DC range. Connect your meter across the 5 Volt supply and switch on the supply. If the reading is much below 5 Volts, switch off immediately and go to the fault finding section.

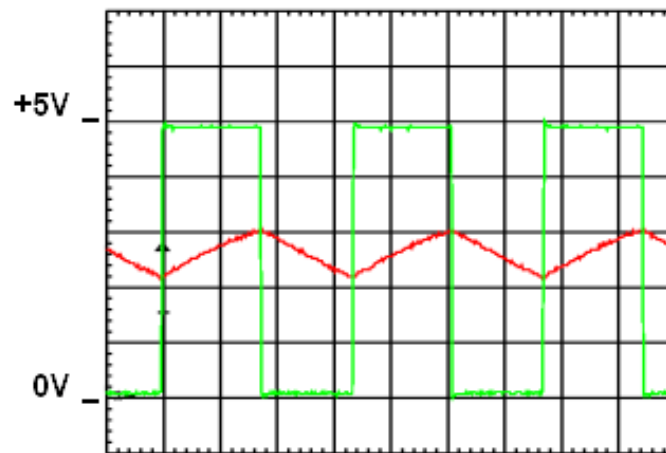
Connect the common (COM) terminal of your meter to the 0 Volt rail. Operate the switch SW1 for a short time. Measure the Voltages on the outputs. One of the outputs should be 5 Volts and the rest should be 0 Volts. Now operate the switch again for a short time. You will probable now have a different output having 5 Volts with the rest having 0 Volts. Try this a few times to make sure that you are getting random outputs and that it is not always the same output. If you wanted to see if all the outputs are functioning correctly, you would have to operate the switch many times.

Circuit description

IC1A, R2 and C2 form a square wave oscillator. You will note that IC1A is a Schmitt trigger. That is, the input Voltage that is required for a '1' is higher than the input Voltage for a '0'. The difference between these Voltages is called the hysteresis or deadband.

When the output is a '1' (nearly 5Volts), C2 is charged up via R2 until it reaches the Voltage level of a '1' on the input. When that happens, the output becomes a '0' (nearly 0Volts) and C2 discharges via R2 until the Voltage level of a '0' on the input is reached. When this happens the output becomes a '1' again and the process is repeated.

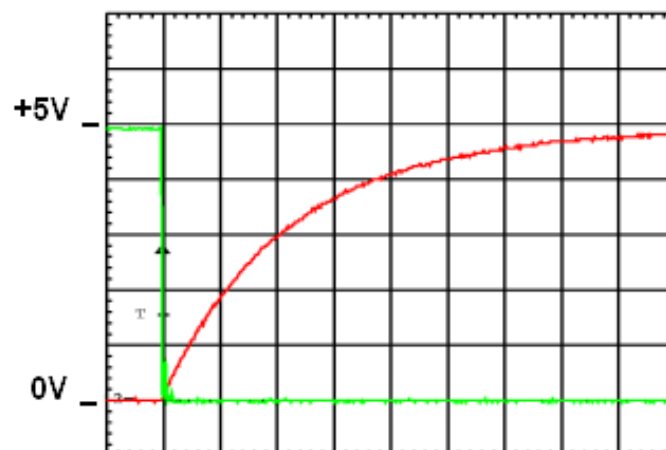
In the following oscilloscope image, the time base (horizontal direction) is 10 μ Sec. per large division, the green trace is the output (pin 3) of IC1A and the red trace is the input (pin 2) of IC1A.



The oscillator can only function if the input (pin 1) of IC1A is a '1'. If it is a '0', the output will be a '1'. When the input switch SW1 is operated, the input (pin 1) of IC1A becomes a '0'.

The counter, IC2, counts the pulses from the oscillator IC1A provided that the CP (Clock Pulse) input (pin 1) is a '0'. The CP input is a '0' until a short while after the input switch is operated.

In the following oscilloscope image, the time base (horizontal direction) is 5mSec. per large division, the green trace is the input (pins 5 and 6) of IC1B and the red trace is the input (pin 1) of IC2.

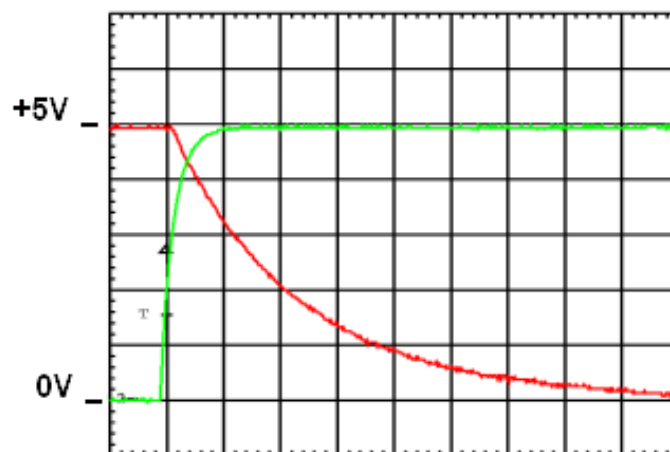


This time delay of about 10mSecs is not important as the oscillator input is stopped immediately by the input to IC1A (pin 1) becoming a '0'. The time delay when the switch is released is important however.

When the switch is operated, the counter stops and the Enable Latch (EL) input (pin 1) of IC3 becomes a '1' and the output of the counter is transferred to the internal latch of the decoder IC3. IC3 decodes the number appearing on the Address (A) inputs A0, A1, A2 and A3. One of the sixteen outputs of the decoder becomes a '1' according to the number appearing at the address inputs.

When the switch is released, the input (pins 5 and 6) of IC1B becomes '1' about 1mSec later. After this time, the EL input of IC3 becomes '0' and the decoder remembers the last number on the address inputs. About 10mSecs. later, the CP input (pin 1) of the counter (IC2) becomes a '0' and the counter starts to count again.

In the following 'scope image, the time base is 5mSecs. per large division, the green trace is the input (pins 5 and 6) of IC1B and the red trace is the CP input (pin 1) of IC2.



Faultfinding

The first thing to do is give the circuit a thorough visual inspection with a spy glass looking for bad solder joints and short circuits. Check that the circuit you have built exactly matches the circuit diagram and that the components are the correct values and connected the right way round.

If the power supply was short circuited or had a greatly reduced output, remove the IC's one at a time and try again. If that does not help, there must be a short circuit or misconnection. If the removal of an IC restores the output of the power supply, check for short circuits on the pins of the IC sockets, in particular any outputs of the IC's. Make sure that the IC's were the correct way round. It is possible that an IC is faulty. Check the connections to the 5 Volt rail. Check that none of the outputs of the IC's are connected anywhere that they shouldn't. The only connections to the 5 Volt rail should be R1, pin 14 of IC1, pin 16 of IC2 and pin 24 of IC3.

Assuming that the power supply is OK, set your meter to the 20 Volt DC range. Connect the common (COM) terminal to the 0 Volt rail. Measure the Voltage on pin 1 of IC1. It should be 5 Volts when the switch is not operated and 0 Volts when it is. If you do not get this result, check that the switch has been correctly connected. Look for short circuits, open circuits and bad solder joints. Check that R1 is the correct value. If none of this helps, try removing IC1. If that helps, try replacing it. If that helps, throw the old one away and if not, look for short circuits and wrong connections on pins 1, 3, 4, 5 and 6.

Assuming that the switch input is OK, measure the output (pin 4) of IC1B. This should be 0 Volts when the switch is not operated and 5 Volts when it is. If you do not get these results, check that pin 7 of IC1 is connected to 0 Volts and pin 14 is connected to the 5 Volt rail. Look for short circuits, open circuits and bad solder joints. If this does not help, try replacing the IC. If that helps, throw the old one away.

Assuming that the output of IC1B is OK, measure the output (pin 3) of IC1A. When the switch is not operated, this should be about 2.5 Volts because there is a square wave output so half of the time it is 5 Volts and half the time it is 0 Volts. When the switch is operated, the output should be 5 Volts. Check the values of C2 and R2. Look for short circuits, open circuits and bad solder joints. If none of this helps, try replacing the IC. If that helps, throw the old one away.

Assuming that the output of IC1A is OK, measure the outputs (pins 3, 4, 5 and 6) of IC2 one at a time when the switch is not operated. They should all be about 2.5 Volts, because they will have square wave outputs. If you do not get these results, check that pin 8 is connected to 0 Volts and that pin 16 is connected to the 5 Volt rail. Check that pin 7 is connected to 0 Volts. Check the values of R3 and C3. Check that pin 1 is connected to the junction of R3 and C3. Look for short circuits, open circuits and bad solder joints. If none of this helps, try replacing the IC. If that helps, throw the old one away.

Assuming that the outputs of IC2 are OK, check that pin 12 of IC3 is connected to 0 Volts and that pin 24 is connected to 5 Volts. Check that the four address inputs (pins 2, 3, 21 and 22) are connected to the counter outputs (pins 3, 4, 5 and 6 of IC2). Check that pin 23 is connected to 0 Volts and that pin 1 of IC3 is connected to pin 4 of IC1. Look for short circuits, open circuits and bad solder joints. If none of this helps, try replacing the IC. If that helps, throw the old one away.

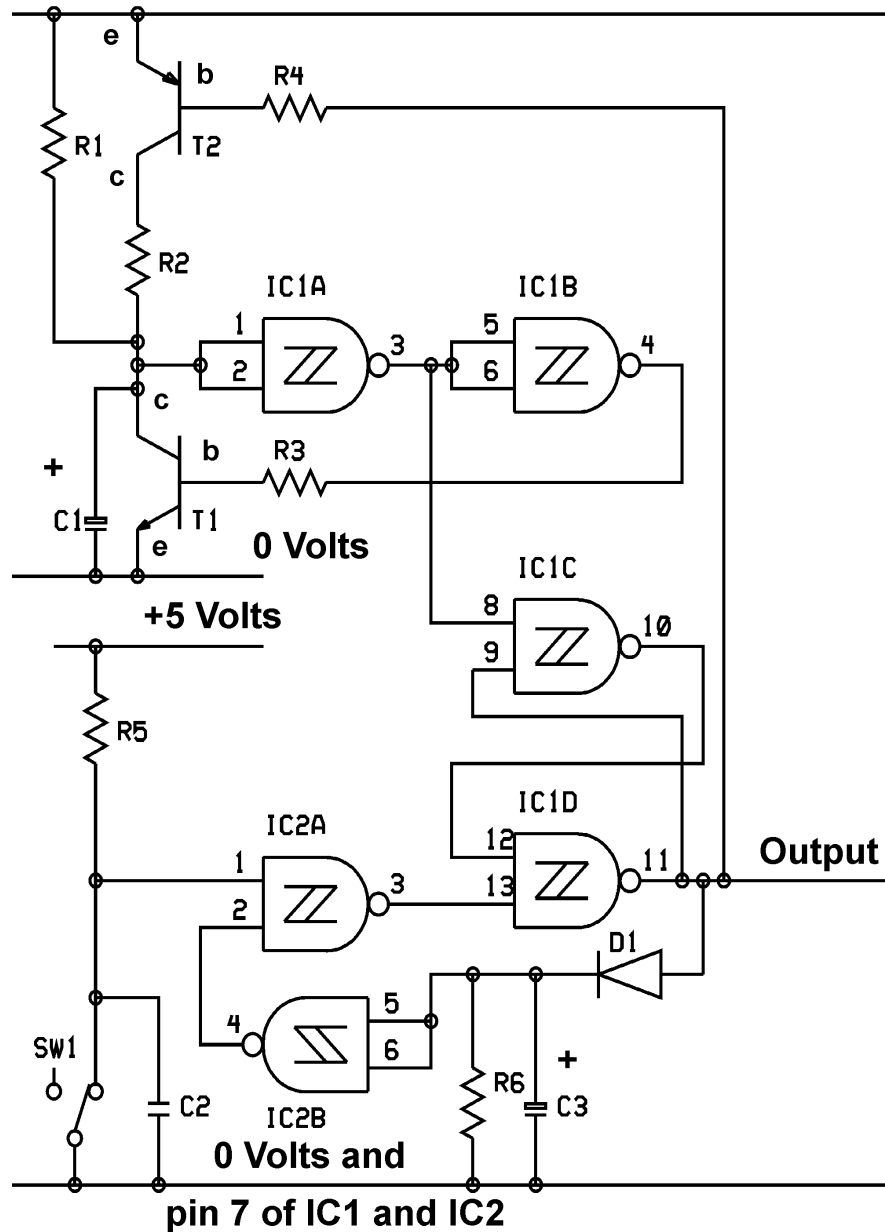
Random time with external input

In the following circuit, an input switch or positive going Voltage signal causes a randomly timed output pulse. In a private view situation, it is possible to have

continuous signals from a sensor, so a fixed time is used, after the output pulse, to inhibit input signals.

You will need an oscilloscope to fault find this circuit.

+5 Volts and pin 14 of IC1 and IC2



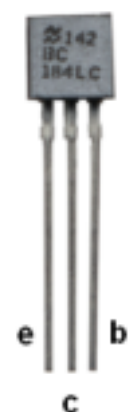
Random time with external input

- R1 1M
- R2 1K
- R3 10K
- R4 10K
- R5 10K
- R6 1M
- C1 see notes
- C2 0 μ 1F

BC214L



BC184L



C3 see notes
T1 BC184LC
T2 BC214L
D1 1N4148
IC1 HEF4093BP
IC2 HEF4093BP

Notes

C1 defines the maximum time the output pulse will persist. The maximum time in seconds will be approximately half of the capacitance value in micro Farads.

This circuit is suitable for producing pulses up to 10 minutes long. The reason is that capacitors leak and the leakage current is dependent on the capacitance, the quality of the component and the temperature. The leakage increases with value and temperature, so as you try to get longer time periods, the leakage increases so the effective value of the timing resistor decreases. This has a limiting effect on the maximum time. If you need to have long time periods of minutes rather than seconds, you will need to look at the leakage specifications of the timing capacitor. It needs to be of a high quality with low leakage. For short times of a few seconds, you should use tantalum capacitors.

C3 defines the time after the output pulse during which input signals are ignored/inhibited. This time in seconds is approximately equal to the value of C3 in micro Farads. C3 has the same restrictions in value and type as C1.

Electrolytic capacitors are polarized and must be connected the right way round. The negative ends should be connected to the 0 Volt rail.

If you need to ensure a minimum time for the output pulse, you can connect the output to the input of a pulse stretcher. Pulse stretchers are described in the chapter on timers.

Make sure that the inputs to the unused gates of IC2 are either connected to 0 Volts or to 5 Volts.

Testing

Before applying power to the circuit, inspect the circuit thoroughly using a spy glass ensuring that there are no unwanted short circuits or open circuits and that the circuit follows the diagram exactly. Ensure that the power supply is connected the right way round. Then set your meter to continuity or low Ohms range. Connect the meter across the 0V and 5V supply and make sure that the reading is not zero or near to zero. You may get a bleep or a low Ohmic value for a short time because of the capacitor in the power supply, but this should not last more than a few seconds. If it is continuous, you have a short circuit somewhere and you should follow the instructions in the fault finding section.

If you do not get the expected results, you should switch the circuit off immediately.

Set your meter to the 20 Volt DC range. Connect your meter across the 5 Volt supply and switch on the supply. If the reading is much below 5 Volts, switch off immediately and go to the fault finding section.

If the maximum output pulse time is more than a second or so, you can use a meter to test the circuit. If it is not, you will need an oscilloscope. Assuming that the times are long enough to be seen on a meter, set your meter to the 20 Volt DC range and connect between the 0 Volt rail and the output. You may need to wait for the circuit to complete an output pulse before you can test the circuit. If this is the case, it will take twice as long as the maximum time period to be ready for the first input pulse. If this is the case, the output will initially be 5 Volts. When the circuit has settled down, the reading should be zero. Now operate the input switch SW1 for a short period. The reading should now be 5 Volts for a random period, which should not be much greater than the required maximum time. The output should then return to Zero.

Operate the input switch a few times to see that the output pulse time changes at random.

Operate the input switch and keep it operated. See that the output pulse finishes and then waits for the required time before the output produces another pulse.

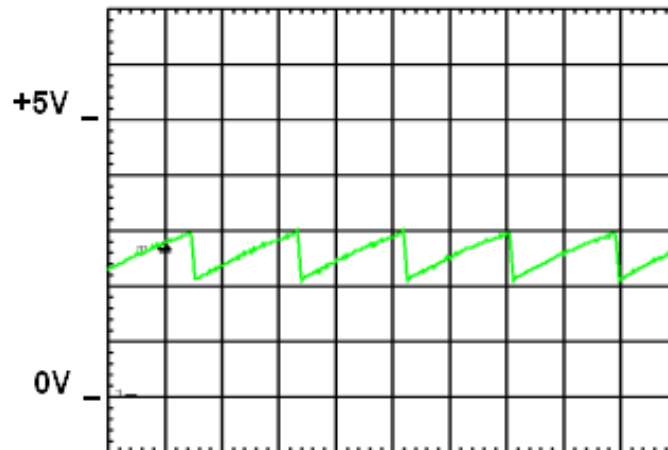
Circuit description

In the following description, C1 was $47\mu\text{F}$ and C3 was $4\mu\text{7F}$.

It should be noted that you should use a X10 probe on your oscilloscope if you want to see the images described here as the circuit will not function correctly if a times 1 probe is connected across C1.

A saw-tooth (a kind of triangular) oscillator comprising IC1A, IC1B, T1, T2, R1, R2 and C1, has two separate frequencies. When T2 is on, the frequency is high and when it is off, the frequency is a thousand times slower. Normally T2 is on. When there is an input, a latch circuit remembers the input and the output pulse starts. This turns T2 off and the oscillator continues its cycle at slow speed. When it reaches the end of its cycle, the input latch is reset, the output pulse ends, T2 is turned on again and the input is inhibited for a time dependent on R6 and C3. The time it takes to finish the cycle depends on how much C1 was charged when the input switch was operated. This is how the output pulse has a random time.

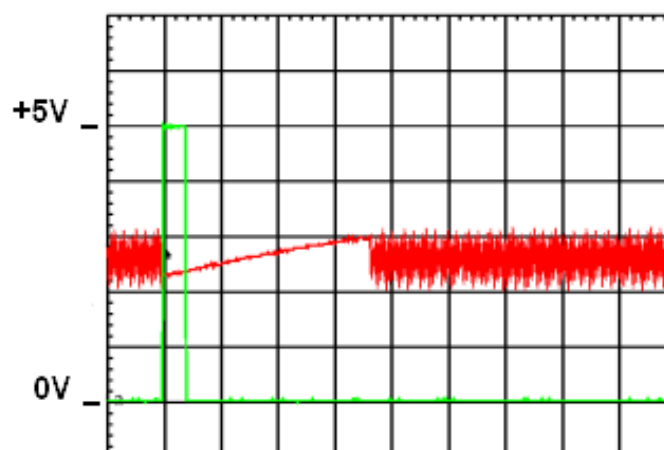
The following oscilloscope image shows the voltage across C1 when T2 is on. The time base (horizontal direction) is 10mSecs. per large division.



IC1 is a quadruple 2 input NAND gate with Schmitt trigger inputs. The input Voltage for a '0' input is lower than the input Voltage for a '1' input in Schmitt trigger circuits. C1 charges up via R2 and to a lesser extent via R1. When it reaches the Voltage for IC1A to read a '1' as an input (pins 1 and 2), its output (pin 3) becomes a '0'. This is connected to the input (pins 5 and 6) of IC1B and is inverted by IC1B to give a '1' at the output (pin 4) of IC1B. The output of IC1B is connected to the base (b) of T1 and turns the transistor on. This discharges C1 quickly until it reaches the Voltage, which IC1A considers to be a '0'. The cycle is then repeated as T1 is turned off again.

When T2 is turned off, C1 does not charge up Via R2 anymore but only via R1. Since R1 is 1000 times greater than R2, C1 charges up 1000 times more slowly.

In the following 'scope image, the time base is 5 Secs. per large division, the green trace is the signal across the input switch SW1 and the red trace is the signal across C1.



As you can see, instead of taking about 20 mSecs. per cycle it now takes about 20 seconds.

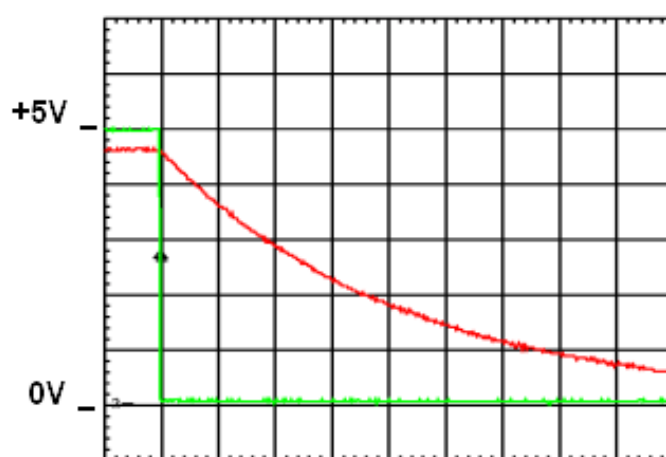
When SW1 is not operated, the input (pin 1) of IC2A is a '0', this makes the output (pin 3) of IC2A a '1'.

When SW1 is operated, the input (pin 1) of IC2A becomes a '1' as R5 connects it to the 5 Volt rail. If the output of the circuit (pin 11 of IC1D) has been a '0' for some time, the input (pins 5 and 6) of IC2B will also be a '0' so its output (pin 4) of IC2B will be a '1'. This means that both inputs of IC2A are '1's and therefore the output (pin 3) of IC2A will be a '0'.

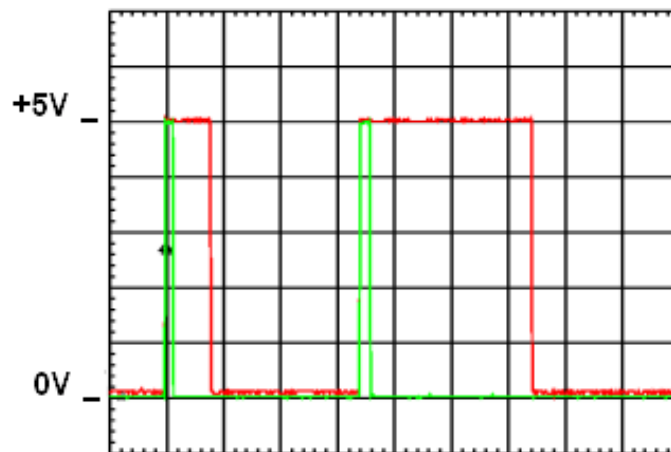
When the output of IC2A is a '0', the output of IC1D (the output of the circuit) becomes a '1'. When the output of IC1A is a '1', which it is for most of the time, both inputs of IC1C become '1's and therefore the output (pin 10) of IC1C becomes a '0'. This causes the output of IC1D to remain a '1' even if the input switch is no longer operated. It is latched. Now that the output is a '1', T2 is turned off and C1 charges up very slowly as previously described. When the output is a '1', C3 is charged up via D1 causing a '1' at the inputs (pins 5 and 6) of IC2B. This causes a '0' at the output (pin 4) of IC2B, which in turn causes a '1' at the input (pin 13) of IC1D.

When C1 charges up enough to cause a '1' at the input of IC1A, The output of IC1A becomes a '0'. This causes a '1' at the output (pin 10) of IC1C. Both inputs of IC1D are now '1's, so the output becomes a '0'. This is the end of the output pulse. C3 holds the input to IC2B at a '1' until it discharges through R6. The effect of this is to inhibit further inputs from SW1 as pin 2 of IC2A will be a '0' until C3 has discharged enough for IC2B to consider its input to be a '0'.

In the following 'scope image, the time base is 1 Sec per large division, the green trace shows the end of the output pulse and the red trace shows the Voltage across C3.

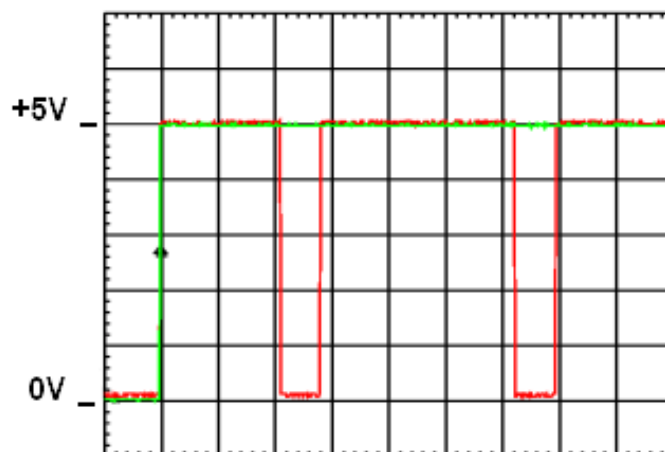


The following 'scope image shows the output when the input switch is operated a couple of times. The time base is 5 Secs. per division, the green trace is the input and the red trace the output. The time that the red trace persists is of course random.



If the input switch is continuously operated, there will be a continuous stream of output pulses. The time between pulses is fixed and determined by the values of C3 and R6. The output pulse widths will probably change, but will not change in a purely random way.

In the following 'scope image, the time base is 5 Secs. per large division, the green trace is the input signal and the red trace is the output signal.



Fault finding

The first thing to do is give the circuit a thorough visual inspection with a spy glass looking for bad solder joints and short circuits. Check that the circuit you have built exactly matches the circuit diagram and that the components are the correct values and connected the right way round.

If the power supply was short circuited or had a greatly reduced output, remove the IC's one at a time and try again. If that does not help, there must be a short circuit or misconnection. If the removal of an IC restores the output of the power supply, check for short circuits on the pins of the IC sockets, in particular any outputs of the IC's. Make sure that the IC's were the correct way round. It is possible that an IC is faulty. Check the connections to the 5 Volt rail. Check that none of the outputs of the IC's are connected anywhere that they shouldn't. The only connections to the 5 Volt rail should be R1, R5, pin 14 of IC1, pin 14 of IC2 and the emitter (e) of T2

Assuming that the power supply is OK, set your meter to the 20 Volt DC range and connect the common (COM) terminal to the 0 Volt rail. Measure the Voltage at pin 1 of IC2. When the switch is not operated, the reading should be 0 Volts and when it is, it should be 5 Volts. If you do not get these results, check that R5 is the correct value and connected properly. Check that you are using the correct terminals on your switch. Look for short circuits, open circuits and bad solder joints. If none of this helps, try replacing IC2. If that helps, throw the old one away.

Assuming that the input switch is OK, measure the output (pin 11) of IC1D. If it is 5 Volts, check that the voltage on pins 5 and 6 of IC2 is about 4.5 Volts. If the output is 5 Volts and the input to IC2B is not 4.5 Volts, check that D1 is the correct way round. Check that pin 7 of IC1 and IC2 are connected to the 0 Volt rail. Check that pin 14 of IC1 and IC2 are connected to the 5 Volt rail. Check the value of R6. Make sure that C3 is the correct way round; if it isn't, replace C3. Look for short circuits, open circuits and bad solder joints. If none of this helps, try replacing IC2. If that helps, throw the old one away. If the output (pin 11) of IC1D is 0 Volts, check that the input (pins 5 and 6) of IC2B are also 0 Volts. If the output has recently been 5 Volts, the voltage reading should be reducing to 0 Volts at a rate dependent on the value of C3. Look for short circuits, open circuits and bad solder joints. If none of this helps, try replacing IC2. If that helps, throw the old one away.

Assuming that the input to IC2B is OK, check that the output (pin 4) of IC2B is the inverse of the input. That is, if the input is 0 Volts, the output should be 5 Volts and if the input is 4.5 Volts, the output should be 0 Volts. If you do not get these results, look for short circuits, open circuits and bad solder joints. If none of this helps, try replacing IC2. If that helps, throw the old one away.

Assuming that the output of IC2B is OK, check the output (pin 3) of IC2A. If either input (pin 1 or 2) of IC2A is at 0 Volts, the output (pin 3) should be 5 Volts. If both inputs are 5 Volts (you will have to operate the switch to get this condition), the output (pin 3) should be 0 Volts. This can only happen for a very short time of about 3mSecs if C3 is $4\mu 7F$, as a '0' at the output of IC2A will cause a '0' on pin 2 of IC2A. The time taken for this is dependent on the value of C3, which will charge up through D1, which has a low resistance when it conducts. You will therefore need an oscilloscope to see the brief pulse. If you do not get these results, look for short circuits, open circuits and bad solder joints. If none of this helps, try replacing IC2. If that helps, throw the old one away. It could be that there is a problem with IC1 in particular IC1C and IC1D. Check that the circuit associated with these two gates is correct. If you do not get these results, look for short circuits, open circuits and bad solder joints. If none of this helps, try replacing IC1. If that helps, throw the old one away.

Assuming that IC2A is OK, check that the waveform at the input (pins 1 and 2) of IC1A is OK. You will need an oscilloscope with a X10 probe for this. You should get the saw-tooth waveform shown in the circuit description. Note that if the output is 5 Volts, the wave will take a long time dependent on the value of C1 and if the output is 0 Volts, the wave should be quick. If you do not get the proper waveform, the fault is somewhere in the circuit around IC1A, IC1B, R1, R2, R3, R4, C1, T1 and T2. The most likely is that the transistors have not been correctly connected. Check all the component values. Check that the circuit exactly matches the diagram. Check that C1 is the right way round. If you do not get these results, look for short circuits, open circuits and bad solder joints. If none of this helps, try replacing IC1. If that helps, throw the old one away. If that does not help, try replacing the transistors and if that helps, throw the old ones away.

Assuming that the saw-tooth oscillator is OK, check the connections to IC1C and IC1D. Look for short circuits, open circuits and bad solder joints. If none of this helps, try replacing IC2. If that helps, throw the old one away.

Random events lasting for a random time with external input.

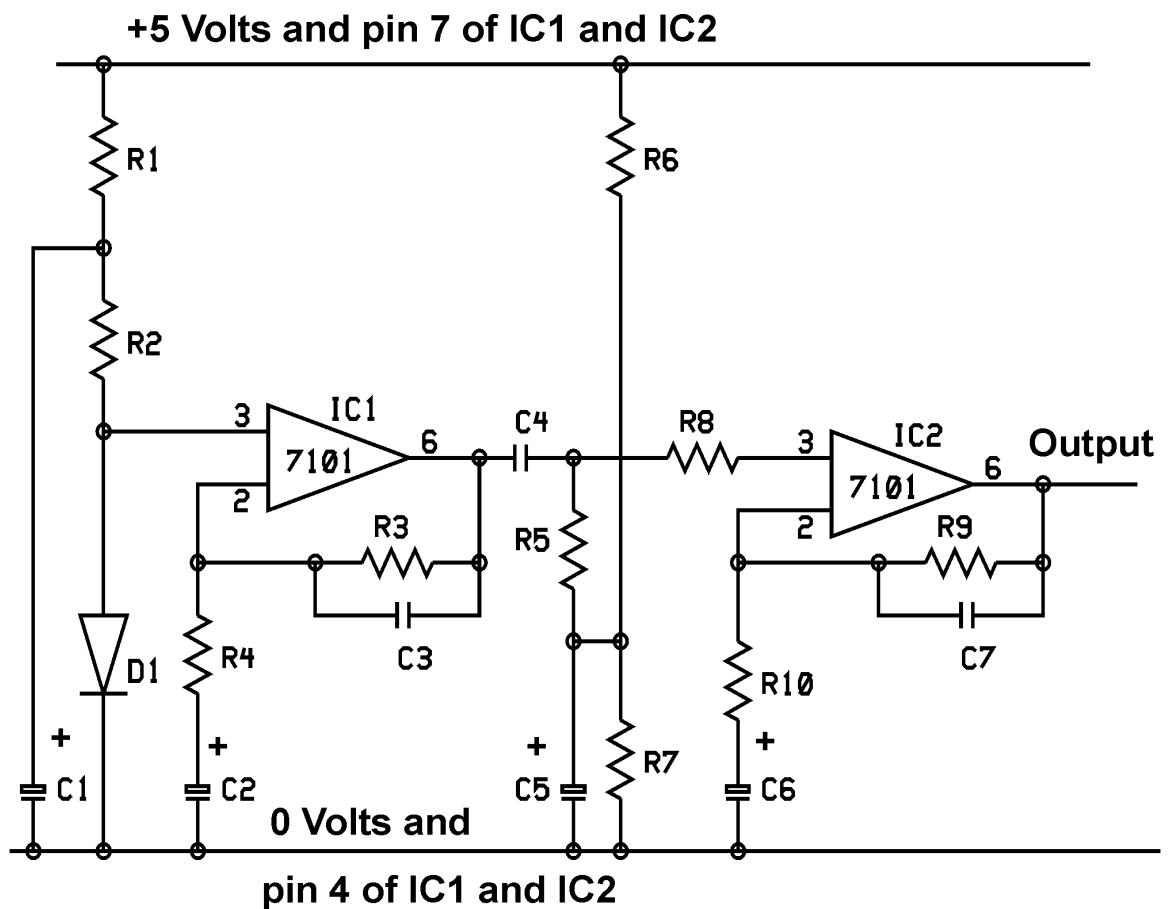
If you use the random time output signal as an input to the random event, the result will be a random event lasting for a random time.

The first thing that will be apparent is that the output of the random time circuit is a pulse which is normally 0 Volts and rises to 5 Volts for a random time and then returns to 0 Volts again. The input required by the random event circuit is the opposite of that in that it needs a signal which is normally 5 Volts and becomes 0 Volts for a period of time. The solution to this problem is to use a spare gate to invert the output signal of the time circuit and use that inverted signal as an input. The switch input SW1 and capacitor C1 of the random event circuit should be removed.

We now have two signals, one for time and one for event. We need to inhibit the event when the time signal is not present. This is easily done by using the output enable pin 23 of the 4514 decoder. When this signal is a '0' the output is enabled and when it is a '1', it is disabled. It is therefore only necessary to connect this pin to the input of the random event circuit instead of the 0 Volt rail.

Basic random circuit without external input.

The following circuit is used in conjunction with the remaining circuits in this chapter. You will need an oscilloscope to test this circuit.



Basic random circuit without external input

R1	10K
R2	10K
R3	1M
R4	1K
R5	1M
R6	10K
R7	10K
R8	10K
R9	1M
R10	1K
C1	470µF electrolytic
C2	47µF tantalum
C3	10000pF (10nF or 0.01µF)
C4	1µF ceramic
C5	4µ7F tantalum
C6	47µF tantalum
C7	10000pF (10nF or 0.01µF)
D1	1N4148
IC1	7101 any prefix or suffix
IC2	7101 any prefix or suffix

OPERATIONAL AMPLIFIER



Notes

The construction of this circuit is critical. It is very sensitive to interference having a very high gain. **It must have a separate power supply** having no other electronics sharing it. The 5 Volt supply must have its own 12 Volt supply as a power source, which must not drive any other devices or circuits.

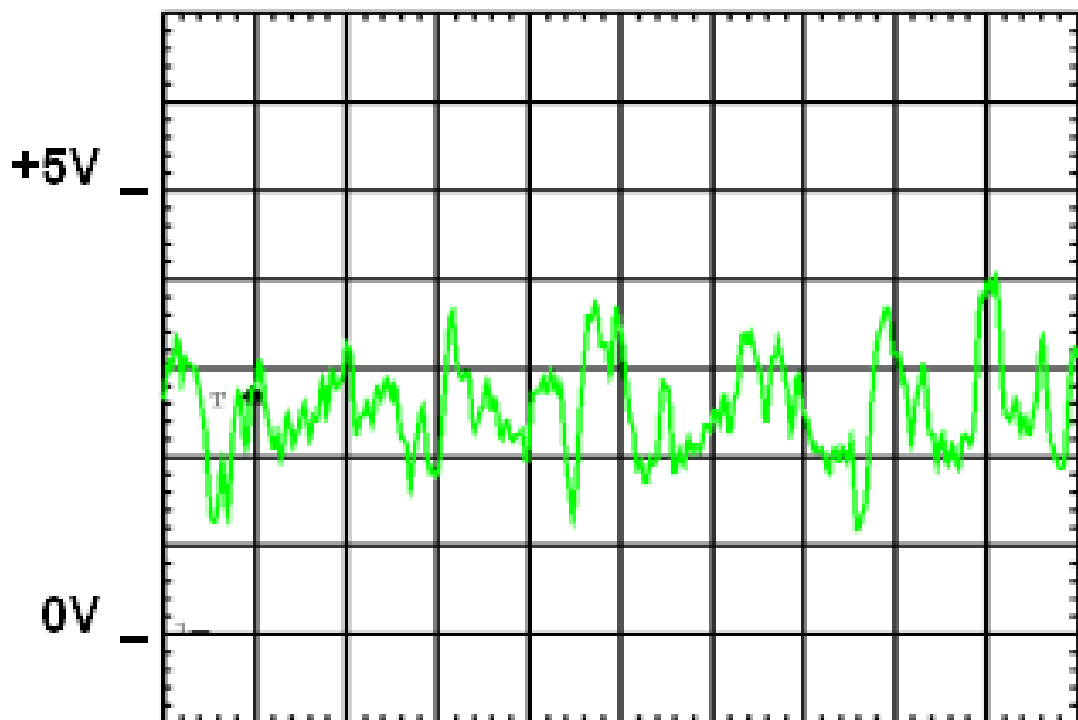
The circuitry must not be on the same board as any other circuit, It must be mounted in a metal box, which must be electrically connected to the 0 Volt rail.

The 0 Volt rail should be connected to the 0 Volt rail of the associated circuits.

The IC's should not have any of the unused pins (1, 5 and 8) connected anywhere. The copper tracks on the board used for the circuit must be kept short by breaking the track as close to the sensitive components as possible. The sensitive components are D1, R2, R3, C3, R4 and C2.

Note the polarity of the electrolytic/tantalum capacitors. The negative ends must be connected to the 0 Volt rail.

The following oscilloscope image shows a typical output for this circuit. The time base (horizontal direction) is 200mSecs. per large division.



Testing

Before applying power to the circuit, inspect the circuit thoroughly using a spy glass ensuring that there are no unwanted short circuits or open circuits and that the circuit follows the diagram exactly. Ensure that the power supply is connected the right way round. Then set your meter to continuity or low Ohms range. Connect the meter across the 0V and 5V supply and make sure that the reading is not zero or near to zero. You may get a bleep or a low Ohmic value for a short time because of the capacitor in the power supply, but this should not last more than a few seconds. If it is continuous, you have a short circuit somewhere and you should follow the instructions in the fault finding section. If you do not get the expected results, you should switch the circuit off immediately.

Connect your oscilloscope between 0 Volts and the output. Switch on the power supply. The output should be at 5 Volts for about 6 seconds. Then it should briefly be 0 Volts after which it should again be 5 Volts for a further 30 seconds or so before giving a random output with an average Voltage of 2.5 Volts as shown in the 'scope image above. The time taken by the circuit before it gives a useful output is the time taken by C2 and C6 to charge up to the correct Voltages via R3 and R9 respectively.

If you get the random output but it has too great an amplitude and occasionally becomes either 0 Volts or 5 Volts, increase the value of R10 to give an amplitude similar to the 'scope image above.

Circuit description

Basically this is an amplifier having a gain of one million. The signal being amplified is the Voltage variation of a forward biased diode. This Voltage variation is matter of quantum physics and in particular the effects of probability on energy levels. All forward biased diodes produce noise. If you turn up the gain on your sound system, you can hear it as hiss. In this circuit, we are amplifying the low frequencies of this hiss. In particular, those frequencies, which are lower than the mains supply frequency. This is to avoid amplifying mains hum rather than noise.

R1 and R2 supply the current for the diode D1. C1 acts as a short circuit for alternating Voltages and removes mains hum and other unwanted signals from the supply to the diode. The Voltage across the diode is approximately 0.5 Volts.

The diode Voltage is connected to the non-inverting input (pin 3) of the operational amplifier IC1. R3 connects the output (pin 6) of IC1 to the inverting input (pin 2) of IC1. This is shorted out at high frequencies by C3. R4 and C2 connect the inverting input to 0 Volts and acts as a resistance for alternating currents, including low frequency ones, but an open circuit for

direct currents. Any small difference in Voltage between the inputs is greatly amplified so if the non-inverting input has a slightly higher Voltage than the inverting input, the output goes more positive. This is fed back to the inverting input via R3 so as the output Voltage increases, the inverting input will increase until the two inputs are equal. Not all of the output Voltage appears at the inverting input as the R4 C2 combination reduces the amount of the output voltage that appears at the inverting input for alternating Voltages. For direct voltages all the output change appears at the inverting input so the gain for direct voltages is one and for alternating Voltages is about 1000 for frequencies which are high enough for C2 to have a low reactance (effective resistance of a capacitor for AC) and low enough for C3 to have a high reactance. This gives the amplifier a filtering function as neither very low frequencies nor very high frequencies are amplified much but in between frequencies are greatly amplified. The average output Voltage of IC1 will therefore be about 0.5. At this point the output alternating Voltage is too small to be easily seen on an oscilloscope and we will need to amplify it much more.

A second, nearly identical amplifier circuit is used to provide a useable signal. This amplifier is biased at 2.5 Volts by R5, R6 and R7. C4 and R8 couple the output of the first amplifier to the input of the second. C5 is there to reduce the effect of mains hum in the power supply. The second amplifier also has a gain of 1000 so the overall gain is one million.

Fault finding

The first thing to do is give the circuit a thorough visual inspection with a spy glass looking for bad solder joints and short circuits. Check that the circuit you have built exactly matches the circuit diagram and that the components are the correct values and connected the right way round.

If the power supply was short circuited or had a greatly reduced output, remove the IC's one at a time and try again. If that does not help, there must be a short circuit or misconnection. If the removal of an IC restores the output of the power supply, check for short circuits on the pins of the IC sockets, in particular any outputs of the IC's. Make sure that the IC's were the correct way round. It is possible that an IC is faulty. Check the connections to the 5 Volt rail. Check that none of the outputs of the IC's are connected anywhere that they shouldn't. The only connections to the 5 Volt rail should be R1, R6 and pin 7 of IC1 and IC2.

Assuming that the power supply is OK, set your meter to the 20 Volt DC range and connect the common (COM) terminal to the 0 Volt rail. Measure the voltage across D1. It should be about 0.5 Volts. If it is 5 Volts, you have either not connected the resistors R2 and R2 correctly or the diode is the wrong way round. If the Voltage is much lower, check that C1 is connected the right way round and look for short circuits, open circuits and bad solder joints. If C1 was the wrong way round, replace it and throw the old one away.

Assuming that the Voltage across D1 is OK, check the output Voltage (pin 6) of IC1. It should be about 0.5 Volts. It will take about 6 seconds after the power supply is turned on for this Voltage to be correct. If you do not get this result, check that pin 4 of IC1 is connected to 0 Volts and that pin 7 is connected to the 5 Volt rail. Check that pins 1, 5 and 8 of IC2 are not connected anywhere. Check that C2 is connected the correct way round having the negative end connected to the 0 Volt rail. If C2 was the wrong way round, replace it and throw the old one away. Check the component values. Look for short circuits, open circuits and bad solder joints. If none of this helps, try replacing IC1. If that helps, throw the old one away.

Assuming that the output of IC1 is OK, measure the Voltage across R7. It should be about 2.5 Volts. If it isn't, check the values of R6 and R7. Check that C5 is connected the correct way round. If C5 was the wrong way round, replace it and throw the old one away. Look for short circuits, open circuits and bad solder joints.

Assuming that the Voltage across R7 is OK, check the Voltage at the junction of R5, R8 and C4. It should be about 2.5 Volts. If it isn't, check that C4 is not short circuited. Check the component values. Check that pin 4 of IC2 is connected to the 0 Volt rail and that pin 7 of IC2 is connected to the 5 Volt rail. Check that pins 1, 5 and 8 of IC2 are not connected anywhere. Look for short circuits, open circuits and bad solder joints. If none of this helps, try replacing IC2. If that helps, throw the old one away.

Assuming that the Voltage at the junction of R5, R8 and C4 is OK, measure the output (pin 6) of IC2. It should be approximately 2.5 Volts but the reading will fluctuate. This reading should be 5 Volts for the first 40 seconds or so after the power is switched on and then go to 2.5 Volts. You should connect your oscilloscope to the output to see what is really happening as your meter is unlikely to give a true indication. Check that C6 is connected the right way round. If it wasn't, replace it and throw the old one away. Check the component values. Look for short circuits, open circuits and bad solder joints. If none of this helps, try replacing IC2. If that helps, throw the old one away.

Random event without external input

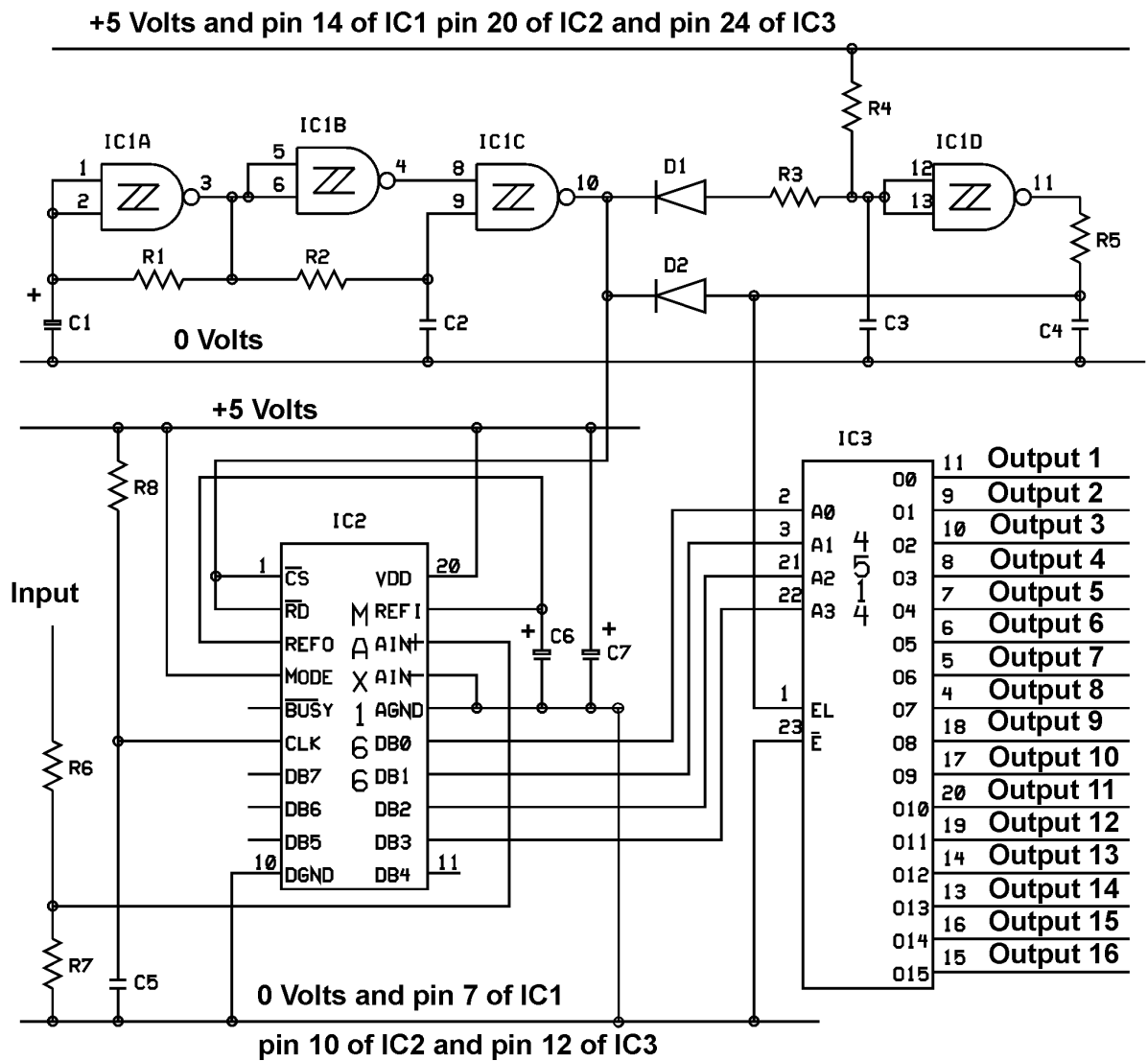
You should use the basic random circuit without external input as an input for this circuit. It is fully described in this chapter. To go to the circuit, [click here](#).

LINK

The principle of operation is to sample the random Voltage signals at a time interval, appropriate to the work, digitize them with an analogue to digital converter and then decode the 4 least significant bits of the output. The A/D converter has an 8 bit output. We will only look at the 4 bits of it that represent

the lower 4 bits of the conversion. This has the advantage that we do not need to have an input, which extends from rail to rail to enable us to have the possibility of a zero output or a full scale output.

You will need the use of an oscilloscope in the fault finding section.



Random event without external input

- R1 see notes
- R2 10K
- R3 1K
- R4 100K
- R5 10K
- R6 10K
- R7 10K
- R8 100K
- C1 see notes
- C2 0μ1F
- C3 10000pF (10nF or 0μ01F)
- C4 10000pF (10nF or 0μ01F)



A/D converter



C5 100pF
 C6 4 μ 7F tantalum
 C7 4 μ 7F tantalum
 D1 1N4148
 D2 1N4148
 IC1 HEF4093BP
 IC2 MAX166CCPP
 IC3 HEF4514BP



Notes

C1 and R1 determine the time that the outputs are on before they switch to another. You should note that it is possible to have the same output more than once in sequence. On average you will get a double output once in sixteen time intervals. On average you will get a treble output once in two hundred and fifty six time intervals. The time interval will be a bit longer than half C1 times R1 seconds. R1 should be in the range of 10K to 1M. If for example R1 was 1M and C1 was 4 μ 7F, the time interval would be approximately 3 seconds.

This circuit is suitable for producing pulses up to 10 minutes long. The reason is that capacitors leak and the leakage current is dependent on the capacitance, the quality of the component and the temperature. The leakage increases with value and temperature, so as you try to get longer time periods, the leakage increases. If the leakage current increases too much, the capacitor will not be able to charge up enough to reach the Voltage necessary to cause a '1' at the input of IC1A. This has a limiting effect on the maximum time. If you need to have long time periods of minutes rather than seconds, you will need to look at the leakage specifications of the timing capacitor. It needs to be of a high quality with low leakage. For short times of a few seconds, you should use tantalum capacitors.

Electrolytic/tantalum capacitors are polarized and must be connected the correct way round. The negative ends should be connected to the 0 Volt rail.

The 0 Volt rail of this circuit should be connected to the 0 Volt rail of the basic random circuit without external input.

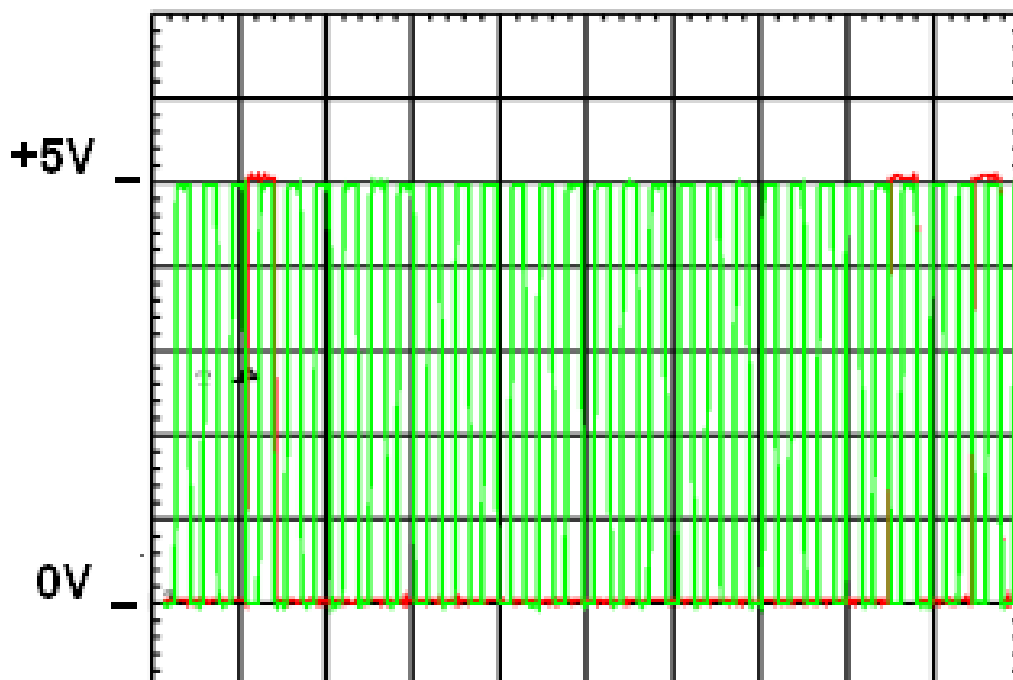
If you only want 8 possible outputs, you can connect pin 22 of IC3 to the 0 Volt rail instead of to pin 12 of IC2. If you only want 4 outputs, you can connect pin 21 of IC3 to the 0 Volt rail instead of to pin 13 of IC2 as well as connecting pin 22 to 0 Volts. You can also use OR gates on the outputs to reduce the number of outputs. This would allow for different probabilities as you could, for example, have three outputs OR'ed, which would then have three times the chance of giving an output than a single output.

Testing

Before applying power to the circuit, inspect the circuit thoroughly using a spy glass ensuring that there are no unwanted short circuits or open circuits and that the circuit follows the diagram exactly. Ensure that the power supply is connected the right way round. Then set your meter to continuity or low Ohms range. Connect the meter across the 0V and 5V supply and make sure that the reading is not zero or near to zero. You may get a bleep or a low Ohmic value for a short time because of the capacitor in the power supply, but this should not last more than a few seconds. If it is continuous, you have a short circuit somewhere and you should follow the instructions in the fault finding section. If you do not get the expected results, you should switch the circuit off immediately.

If the timing is either very slow or very fast, change the value of C1 for testing purposes. A good time for testing would be between 1 and 3 seconds. The reason for this is that multi-meters are quite slow and may not give a reading if the signal being measured does not last for long enough. If the time period is too long, you may have to wait for a very long time for a particular output to be present. The average time being 16 times the clock time period, so if you chose a value of C1 to give 1 second, a particular output will occur one every 16 seconds on average but may take much longer. If you have the use of an oscilloscope, you should chose a much shorter time period, so that you do not have to wait too long.

Switch on the power supplies and wait about 40 seconds or so for the circuit to settle down. Now chose an output and measure it, either using a 'scope or a meter. It should produce a 5 Volt output occasionally and at random for a period of time according to the values of R1 and C1. Note that multiple times will happen occasionally. Now check the other outputs and see that they behave in a similar way. If you are using a meter, this will take some time.



In the oscilloscope image, the time base (horizontal direction) is 200mSecs. per large division. The green trace is the output (pin 3) of IC1A and the red trace is one of the sixteen outputs. You are unlikely to get exactly the same result, as the outputs are random. You can see that there were a large number of pulses after the first output and then two outputs came along in quick succession. If you have an ordinary 'scope, you will not see the trace as lines but will see the dots moving. To get this kind of image, you would need a storage 'scope which is much more expensive.

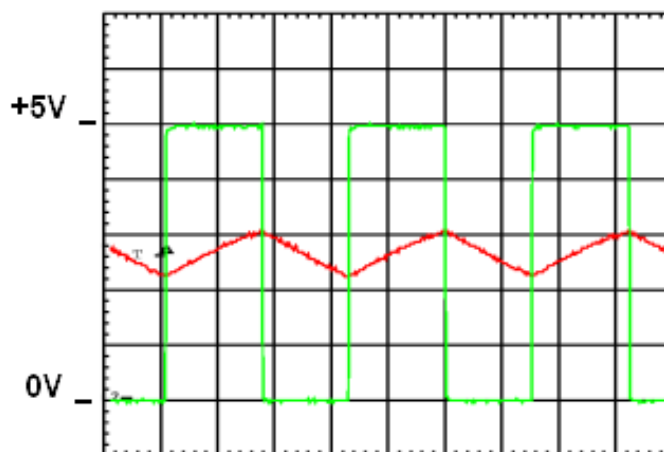
Circuit description

IC1A, R1 and C1 form a square wave oscillator. You will note that IC1A is a Schmitt trigger. That is, the input Voltage that is required for a '1' is higher than the input Voltage for a '0'. The difference between these Voltages is called the hysteresis or deadband.

When the output is a '1' (nearly 5Volts), C1 is charged up via R1 until it reaches the Voltage level of a '1' on the input. When that happens, the output becomes a '0' (nearly 0Volts) and C1 discharges via R1 until the Voltage level of a '0' on the input is reached. When this happens the output becomes a '1' again and the process is repeated.

This oscillator defines the time period of the outputs. The actual time needed will depend on the nature of the work and only you can decide what that should be.

In the following oscilloscope image, the green trace is the output (pin 3) of IC1A and the red trace is the input (pins 1 and 2).



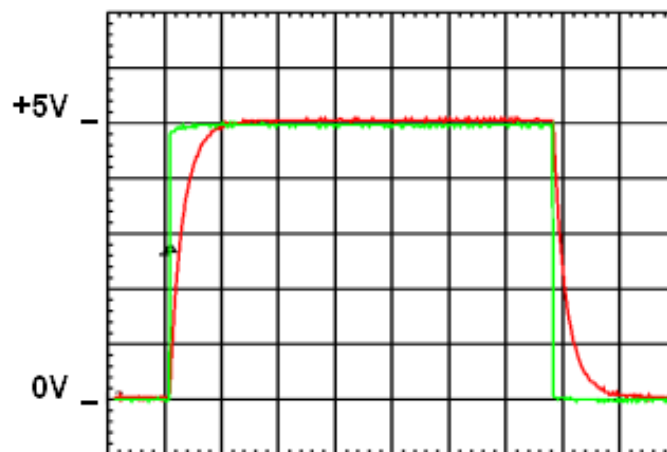
The Analogue to Digital (A/D) converter IC2 needs a pulse going from a '1' to a '0' and back again to a '1' to make it convert the analogue signal from the random Voltage generator into an 8 bit digital number. The decoder IC3 needs a pulse going from a '0' to a '1' and back to a '0' again to latch (remember/store) the lower 4 bits of the number from the A/D converter. This

pulse for the decoder must start after the pulse for the A/D converter has finished. The decoder will then decode the 4 bits that are latched providing the appropriate output. Only one of the sixteen outputs can be on at any one time.

The remaining three gates of IC1 are used to generate the required pulses.

In this example, C1 and R1 were $1\mu\text{F}$ and 100K respectively. This produces a time, which is too short to be of much practical use but which is convenient for demonstrating the principle of operation and testing the circuit.

In the following 'scope image, the time base is 20mSecs. per large division. The green trace is the output (pin 3) of IC1A and the red trace shows the input (pin 9) of IC1C.

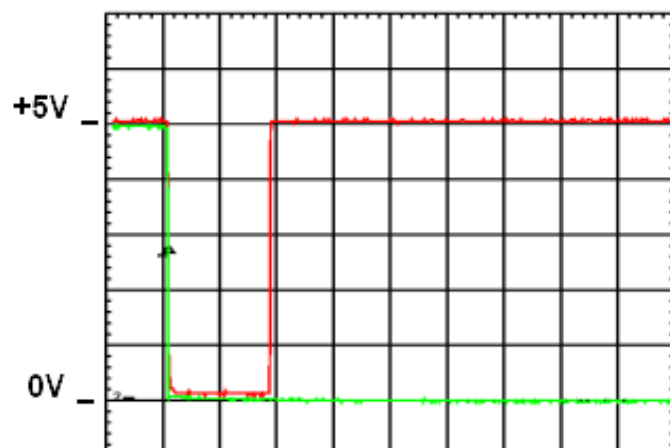


R2 and C2 cause the signal to take longer to rise and fall, as the capacitor needs to be charged up and discharged. IC1B inverts the output of IC1A. That is, a '1' at the output of IC1A causes a '0' at the output (pin 4) of IC1B and a '0' at the output of IC1A causes a '1' at the output of IC1B. When the output of IC1A goes from a '1' to a '0', the output of IC1B becomes a '1'. The input (pin 8) is therefore a '1'. The other input (pin 9) is also a '1' for a short period of time whilst C2 is discharging. Both inputs are therefore '1's for a short period of time after the output of IC1A goes from a '1' to a '0' (the falling edge).

Time base $500\mu\text{Sec}$ per large division.

Green trace is output of IC1A.

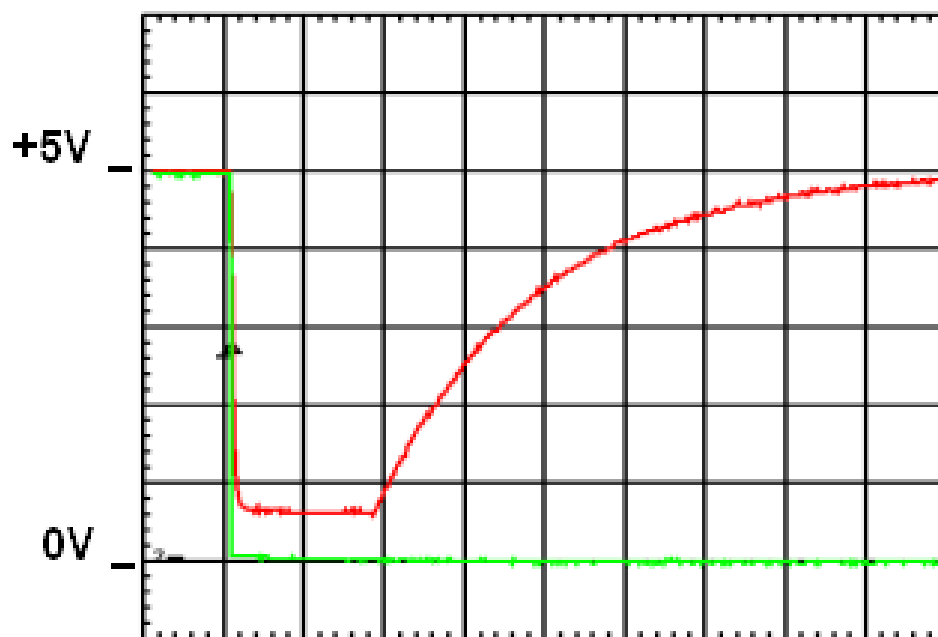
Red trace is output of IC1C.



This pulse at the output of IC1C is used by the A/D converter to start the conversion. As can be seen, it lasts for about 1mSec.

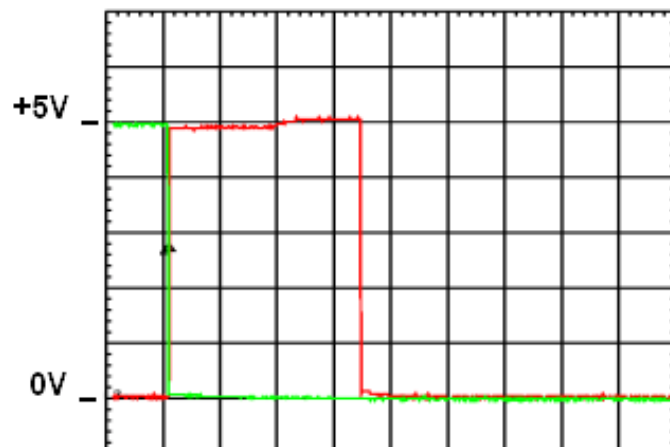
This 1mSec. pulse is stretched by the combination of D1, R3, R4 and C3. When the output of IC1C is 0 Volts, C3 is discharged via R3 and D1. When the output of IC1C is 5 Volts, C3 charges up via R4. R3 is there to delay the start of the pulse a little.

In the following 'scope image, the time base is 500 μ Secs. per large division. The green trace shows the end of the output pulse of IC1A and the red trace shows the input (pins 12 and 13) of IC1D.



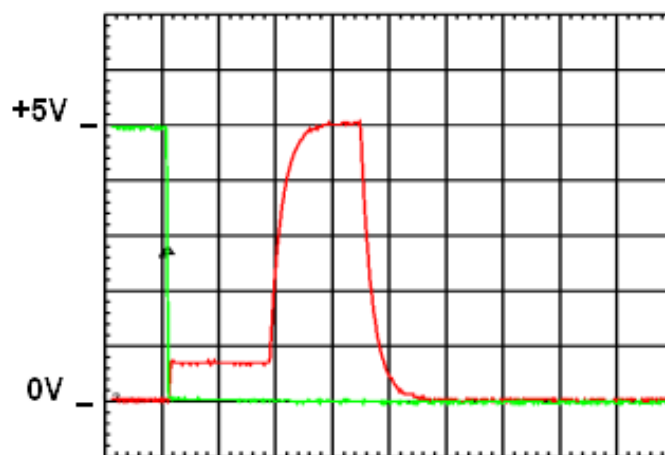
You will note that the input of IC1D drops from 5 Volts to about 0.5 Volts shortly after the Output of IC1A and starts to rise to 5 Volts after the output of IC1C does.

In the following 'scope image, the green trace is the output of IC1A and the red trace is the output (pin 11) of IC1D. The time base is 500 μ Secs. per large division



We need a pulse, which starts shortly after the output of IC1C has returned to 5 Volts. This pulse is to set the input latch of the decoder.

D2, R5 and C4 perform this function. The signal on the EL input (pin 1) of IC3 is normally a '0'. When the output of IC1C is a '0', C4 is discharged by D2 so the EL signal is held at '0' until a short time after the output of IC1C has returned to a '1'. The output pulse of IC1D has effectively had the first part of it removed until a short time after the output pulse of IC1C has finished. The following 'scope image shows the signal at the EL input of IC3 in red. The green trace is the output of IC1A. The time base is 500 μ Secs. per large division.



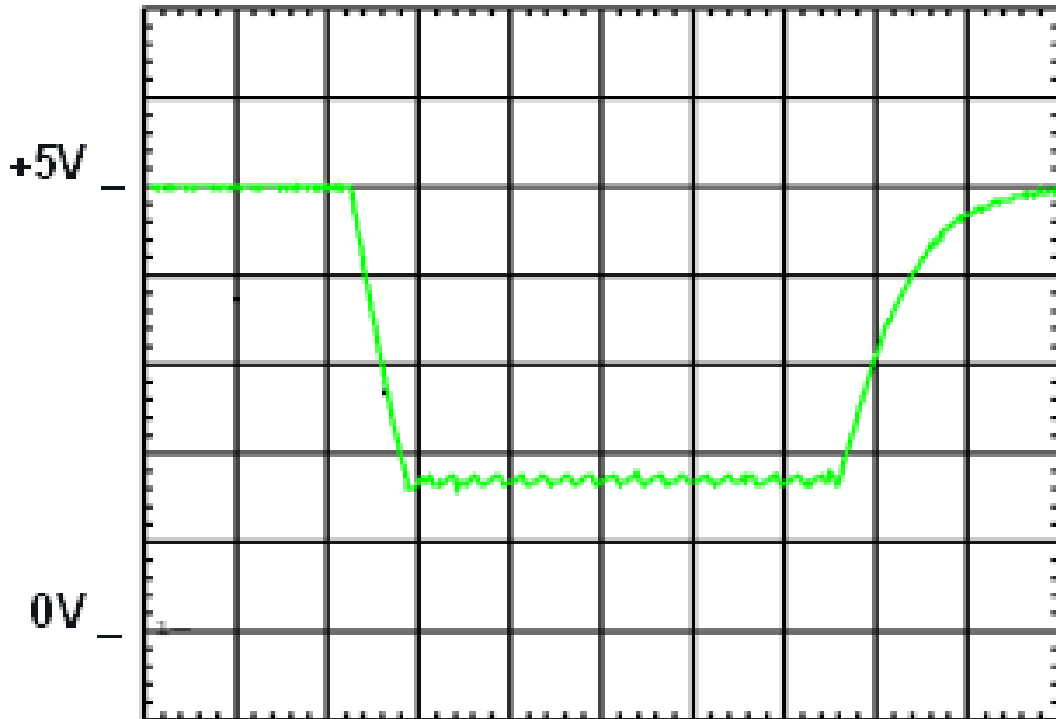
You will note that the red trace shows a Voltage of about 0.5 whilst the output of IC1C is '0'. This is of course the Cutin Voltage of D2.

C6 and C7 are required by IC2 to keep the supply and the reference Voltage, produced by the IC, stable and free of Voltage spikes. And must therefore be connected as close to the IC as possible.

IC2 has an input Voltage range of zero to 2.36 Volts. We want an input from zero to 5 Volts. R6 and R7 potentially divide the input Voltage to provide the correct input range to the IC when we have an input range of zero to 5 Volts.

IC2 has an internal clock (oscillator), which is used by the converter to perform its task. R8 and C5 are the timing components for this internal clock.

The internal clock starts when the IC receives an instruction via the NOT RD and NOT CS inputs. The following 'scope trace shows the waveform at pin 6 during a conversion.



The time base is 2 μ S/Div

Note that the clock input signal reduces from 5 Volts to a bit less than 2 Volts and then has a triangular wave for a while before returning to the 5 Volt rail. This triangular wave is similar to the input of IC3A except that it has a much-reduced amplitude.

These A/D converters work by comparing the input Voltage with a proportion of the internal reference Voltage. They start by seeing whether it is greater or less than half of the full range. If it is, they set bit 7 and if not, bit 7 is cleared. They then see if it is greater or less than the first result plus bit 6. If it is, bit 6 is set and if not it is cleared. This process is continued until all the 8 bits have been processed. This process takes two clock cycles per bit.

The output pulse length of IC1C is long enough for the IC2 to complete its conversion and produce a stable digital result at the outputs DB0 to DB7. We are only using the outputs DB0 to DB3. These are connected to the inputs of IC3. When the EL input (pin 1) of IC3 is a '1', the data at the inputs is transferred to an internal memory and decoded to give one of sixteen possible outputs according to the input data. When the EL input goes to a '0', the memory is latched and the output is no longer dependent on the input data.

Fault finding

The first thing to do is give the circuit a thorough visual inspection with a spyglass looking for bad solder joints and short circuits. Check that the circuit you have built exactly matches the circuit diagram and that the components are the correct values and connected the right way round.

If the power supply was short circuited or had a greatly reduced output, remove the IC's one at a time and try again. If that does not help, there must be a short circuit or misconnection. If the removal of an IC restores the output of the power supply, check for short circuits on the pins of the IC sockets, in particular any outputs of the IC's. Make sure that the IC's were the correct way round. It is possible that an IC is faulty. Check the connections to the 5 Volt rail. Check that none of the outputs of the IC's are connected anywhere that they shouldn't. The only connections to the 5 Volt rail should be R4, R8. C7, pin 14 of IC1, pins 4 and 20 of IC2 and pin 24 of IC3.

Assuming that the power supply is OK, connect the screen of your oscilloscope probe to the 0 Volt rail. Check that pin 7 of IC1, pins 10, 16 and 17 of IC2 and pins 12 and 23 of IC3 are connected to the 0 Volt rail. Check that pin 14 of IC1, pins 4 and 20 of IC2 and pin 24 of IC3 are connected to the 5 Volt rail.

Now follow the circuit description paying attention to the 'scope images. First look at the output (pin 3) of IC1A. See that you have a square wave. Check the values of R1 and C1. Check that C1 is connected the correct way round. The negative end should be connected to 0 Volts. If the capacitor was connected the wrong way round, replace it and throw the old one away. Look for short circuits, open circuits and bad solder joints. If none of this helps, try replacing IC1. If that helps, throw the old one away.

Assuming that the output of IC1A is OK, look at the output of IC1A with one probe and the output (pin 4) of IC1B with the other probe. They should be in anti-phase. That is when one output is at 0 Volts the other should be at 5 Volts. Look for short circuits, open circuits and bad solder joints. If none of this helps, try replacing IC1. If that helps, throw the old one away.

Assuming that the output of IC1B is OK, check the waveform at pin 9 of IC1C. Check the values of R2 and C2. Look for short circuits, open circuits and bad solder joints. If none of this helps, try replacing IC1. If that helps, throw the old one away.

Assuming that the waveform on pin 9 is OK, check the waveform at the output (pin 10) of IC1C. Look for short circuits, open circuits and bad solder joints. If none of this helps, try replacing IC1. If that helps, throw the old one away.

Assuming that the output of IC1C is OK, check the waveform at the input (pins 12 and 13) of IC1D. Check that the diode d1 is the correct way round. Check the values of R3, R4 and C3. Look for short circuits, open circuits and bad solder joints. If none of this helps, try replacing IC1. If that helps, throw the old one away.

Assuming that the input to IC1D is OK, check the output (pin 11) of IC1D. Look for short circuits, open circuits and bad solder joints. If none of this helps, try replacing IC1. If that helps, throw the old one away.

Assuming that the output of IC1D is OK, check the waveform at the EL input (pin 10) of IC3. Check the values of R5 and C4 and check that D2 is connected the correct way round. Look for short circuits, open circuits and bad solder joints. If none of this helps, try replacing IC3. If that helps, throw the old one away.

Assuming that the EL input to IC3 is OK, check the values of R6, R7, R8, C5, C6 and C7. Check that C6 and C7 were connected the correct way round. If they were not, replace them and throw the old ones away. Check that you get the correct waveform on pin 6 of IC2. You will need a X10 probe for this. Check that all the connections to IC2 have been made according to the circuit diagram. Try removing IC3. If that helps, look for short circuits on the address inputs to IC3. Look for short circuits, open circuits and bad solder joints. If none of this helps, try replacing IC2. If that helps, throw the old one away.

Assuming that the CLK input (pin 6) of IC2 is OK, Look for short circuits, open circuits and bad solder joints. If none of this helps, try replacing IC3. If that helps, throw the old one away.

Random time without external input

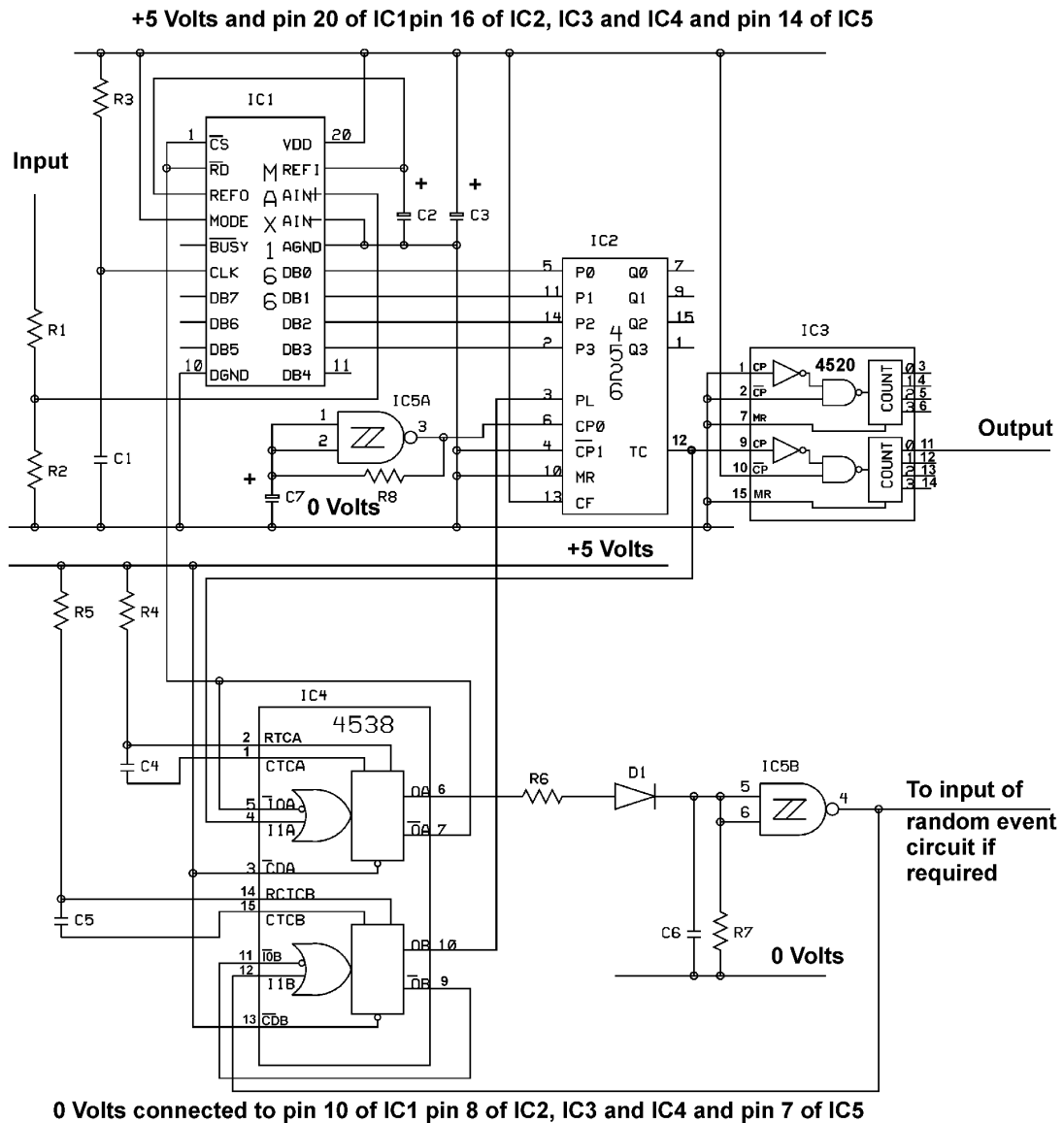
You should use the basic random circuit without external input as an input for this circuit. It is fully described in this chapter. To go to the circuit, [click here](#).

LINK

This circuit should not be attempted by anyone who has not previously made a working circuit. The fault finding section will assume that you have the use of an oscilloscope.

This circuit produces output pulses of random duration and having random time intervals between pulses. It may be used in conjunction with the circuit for random events with external input, to produce random events lasting random times. A description of how this can be achieved is at the end of this chapter.

The circuit uses the random voltage generator, previously described, as an input to an Analogue to Digital (A/D) converter the least significant bits of which are loaded into a counter. A clock is used to cause the counted to count down to zero from the number previously loaded into it. An output pulse persists for the time it takes for the counter to count down to zero. The same procedure is used for the time interval between pulses.



Random time without external input

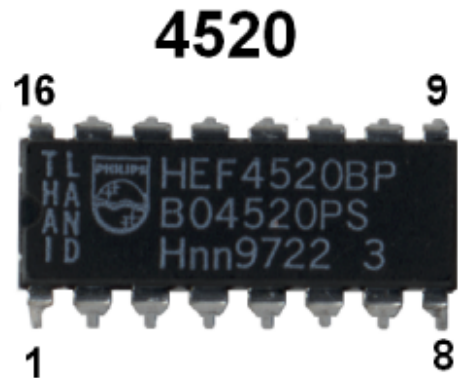
R1	10K
R2	10K
R3	100K
R4	100K
R5	100K
R6	1K
R7	100K
R8	see notes
C1	100pF
C2	4 μ 7F tantalum
C3	4 μ 7F tantalum
C4	10000pF (0 μ 01 or 10nF)
C5	10000pF (0 μ 01 or 10nF)
C6	0 μ 22F
C7	see notes
D1	1N4148

A/D converter



IC1 MAX166CCPP
 IC2 HEF4526BP
 IC3 HEF4520BP
 IC4 HEF4538BP
 IC5 HEF4093BP

Dual monostable multivibrator



Notes

R8 and C7 determine the maximum time interval for the output pulses and spaces between pulses. R8 should have a value between 10K and 1M. The maximum time is about 8 times the value of R8 times C7 so if R8 is 100K and C7 is 4 μ 7F, the maximum time will be about 3 or 4 seconds and the minimum time will be one sixteenth of that. There is a minimum time restriction with this circuit. The maximum time must be at least 0.5 seconds. If you need to have shorter times than that, you will not be able to use this circuit as an input to the random event circuit and you will have to reduce the value of C6. There would still be a restriction of the minimum time but it could be reduced to give a maximum time of as little as 0.1 seconds if the value of C6 is reduced by a factor of ten.

This circuit is suitable for producing pulses up to 2 hours long. The reason is that capacitors leak and the leakage current is dependent on the capacitance, the quality of the component and the temperature. The leakage increases with value and temperature, so as you try to get longer time periods, the leakage increases. If the leakage current increases too much, the capacitor will not be able to charge up enough to reach the Voltage necessary to cause a '1' at the input of IC5A. This has a limiting effect on the maximum time. If you need to have long time periods of minutes rather than seconds, you will need to look at the leakage specifications of the timing capacitor. It needs to be of a high quality with low leakage. For short times of a few seconds, you should use tantalum capacitors.

Electrolytic/tantalum capacitors are polarized and must be connected the correct way round. The negative ends should be connected to the 0 Volt rail.

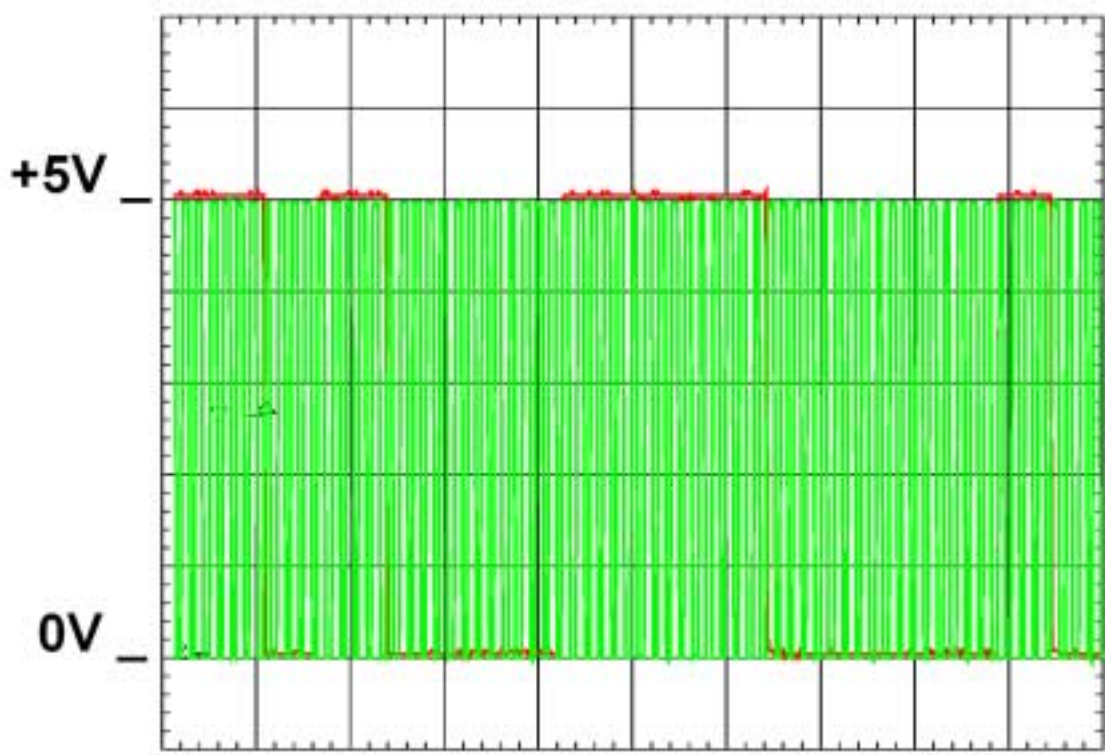
The 0 Volt rail of this circuit should be connected to the 0 Volt rail of the basic random circuit without external input.

Testing

Before applying power to the circuit, inspect the circuit thoroughly using a spy glass ensuring that there are no unwanted short circuits or open circuits and that the circuit follows the diagram exactly. Ensure that the power supply is connected the right way round. Then set your meter to continuity or low Ohms range. Connect the meter across the 0V and 5V supply and make sure that the reading is not zero or near to zero. You may get a bleep or a low Ohmic value for a short time because of the capacitor in the power supply, but this should not last more than a few seconds. If it is continuous, you have a short circuit somewhere and you should follow the instructions in the fault finding section. If you do not get the expected results, you should switch the circuit off immediately.

If the timing very slow, change the value of C7 for testing purposes. A good maximum time for testing would be between 1 and 3 seconds. If the time period is too long, you may have to wait for a very long time for an output to be present and it may persist for a very long time.

Connect the earth lead of your oscilloscope probe to the 0 Volt rail and connect one probe to the output (pin 3) of IC5A and the other probe to the circuit output (pin 11 of IC3). Switch on the power supplies and wait about 40 seconds or so for the circuit to settle down. You should then observe something similar to the following 'scope image. The green trace shows the output of IC5A and the red trace shows the circuit output. The timing will be dependent on the values of R8 and C7. If you are not using a storage 'scope it may be difficult to see as you will see a dot moving up and down instead of a line being produced as the time base (horizontal direction) will be slow.



It is unlikely that you will get exactly the same image as shown as the output is random. The minimum width of the red pulse is the width of a green pulse and the maximum width is sixteen green pulses. It will not be easy to count the pulses unless you are using a storage scope but it is possible.

Circuit description

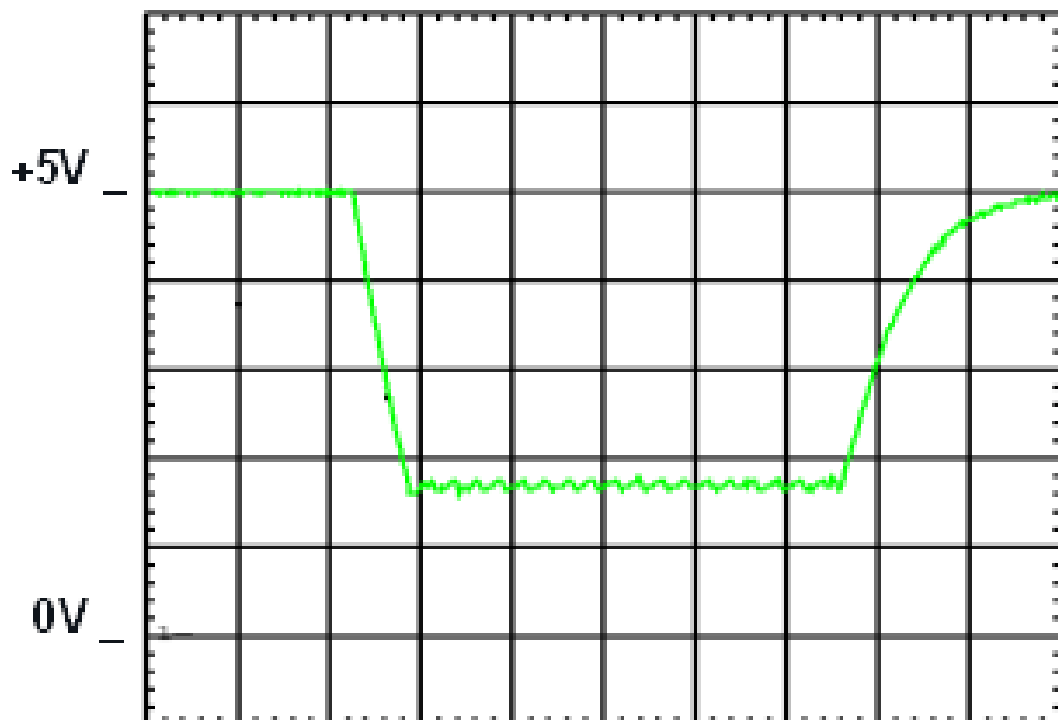
The Analogue to Digital (A/D) converter IC1 needs a pulse going from a '1' to a '0' and back again to a '1' to make it convert the analogue signal from the random Voltage generator into an 8 bit digital number. This pulse is produced by the monostable multivibrator IC4 and is connected to pins 1 and 2 of IC1.

C2 and C3 are required by IC1 to keep the supply and the reference Voltage, produced by the IC, stable and free of Voltage spikes. And must therefore be connected as close to the IC as possible.

IC1 has an input Voltage range of zero to 2.36 Volts. We want an input from zero to 5 Volts. R1 and R2 potentially divide the input Voltage to provide the correct input range to the IC when we have an input range of zero to 5 Volts.

IC1 has an internal clock (oscillator), which is used by the converter to perform its task. R3 and C1 are the timing components for this internal clock.

The internal clock starts when the IC receives an instruction via the NOT RD and NOT CS inputs (pins 1 and 2). The following 'scope trace shows the waveform at pin 6 during a conversion.



The time base is 2μS/Div

Note that the clock input signal reduces from 5 Volts to a bit less than 2 Volts and then has a triangular wave for a while before returning to the 5 Volt rail. This triangular wave is similar to the input of IC5A except that it has a much-reduced amplitude.

These A/D converters work by comparing the input Voltage with a proportion of the internal reference Voltage. They start by seeing whether it is greater or less than half of the full range. If it is, they set bit 7 and if not, bit 7 is cleared. They then see if it is greater or less than the first result plus bit 6. If it is, bit 6 is set and if not it is cleared. This process is continued until all the 8 bits have been processed. This process takes two clock cycles per bit.

The output pulse length of IC5B is long enough for the IC1 to complete its conversion and produce a stable digital result at the outputs DB0 to DB7. We are only using the outputs DB0 to DB3. These are connected to the parallel load inputs of the counter IC2. When the PL input (pin 3) of IC2 is a '1', the data at the inputs is transferred to an internal memory of the counter. When the PL input goes to a '0', the memory is latched and the counter begins to count down to zero. The counter IC2 counts the pulses produced by IC5A. When the counter reaches zero, the Terminal Count (TC) output (pin 12) of IC2 goes from a '0' to a '1'.

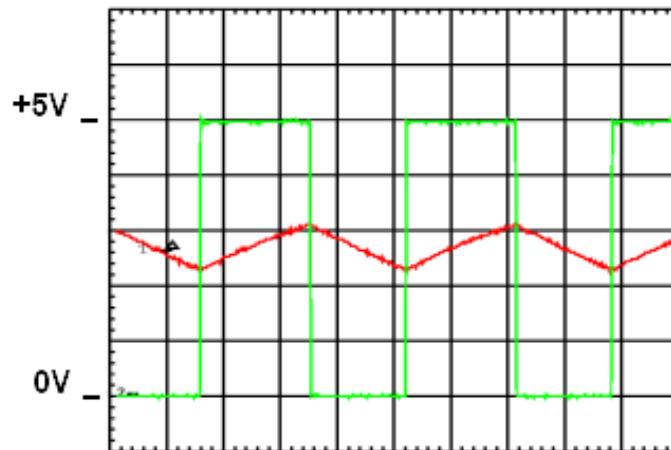
The counter IC3 is used to **toggle** (switch between '0' and '1' and '1' and '0') the circuit output so that it changes state each time there is a pulse output from pin 12 of IC2.

IC5A, R8 and C7 form a square wave oscillator. You will note that IC5A is a Schmitt trigger. That is, the input Voltage that is required for a '1' is higher than the input Voltage for a '0'. The difference between these Voltages is called the hysteresis or deadband.

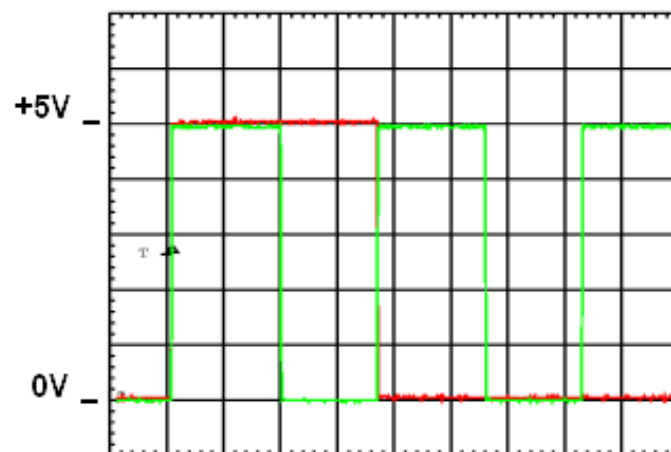
When the output is a '1' (nearly 5Volts), C1 is charged up via R1 until it reaches the Voltage level of a '1' on the input. When that happens, the output becomes a '0' (nearly 0Volts) and C7 discharges via R8 until the Voltage level of a '0' on the input is reached. When this happens the output becomes a '1' again and the process is repeated.

This oscillator defines the time period of the outputs. The actual time needed will depend on the nature of the work and only you can decide what that should be.

In the following oscilloscope image, the green trace is the output (pin 3) of IC5A and the red trace is the input (pins 1 and 2).

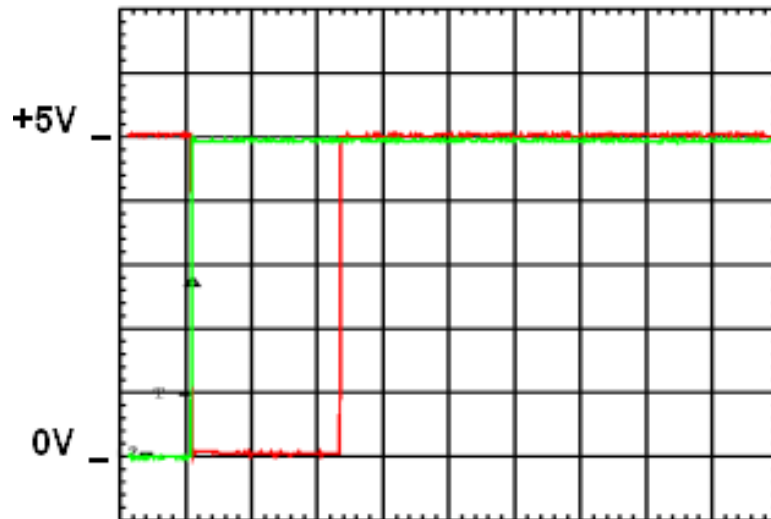


The following 'scope image shows the output of IC5A in green and the TC output of IC2 in red.



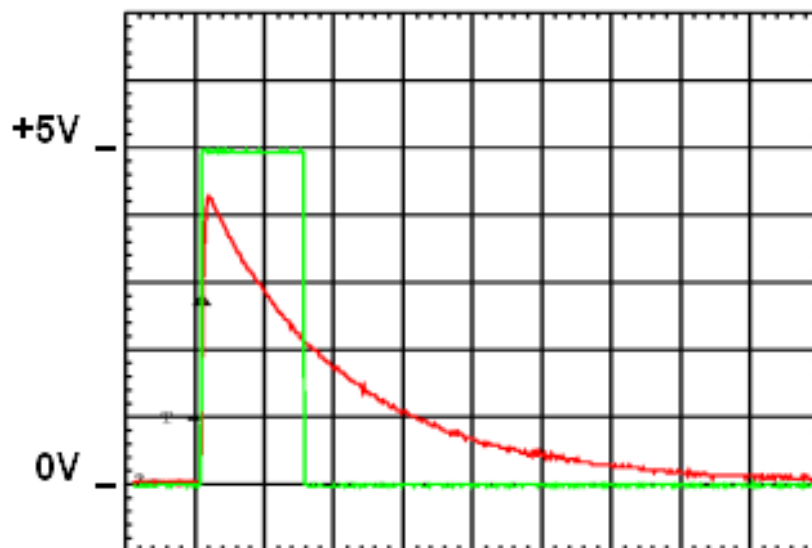
The TC output (pin 12) of IC2 is connected to the input of the monostable multivibrator IC4. When the TC output rises from a '0' to a '1', the output of IC4A produces pulses on pins 6 and 7. The duration of these pulses is determined by the values of the timing components R4 and C4, which give pulses approximately 1 mSec. long. The pulse on pin 6 goes from a '0' to a '1' and back to a '0' again and the output on pin 7 goes from a '1' to a '0' and back to a '1' again. Pin 7 is connected to pin 5 to make the circuit act as a monostable rather than a pulse stretcher by inhibiting the input on pin 4. The output on pin 7 is connected to the convert input (pins 1 and 2) of the A/D converter IC1. This starts the next A/D conversion.

In the following 'scope image, the time base (horizontal direction) is 500μsecs per large division. The green trace shows the start of the TC output pulse (pin 12) of IC2 and the red trace shows the output on pin 7 of IC4.

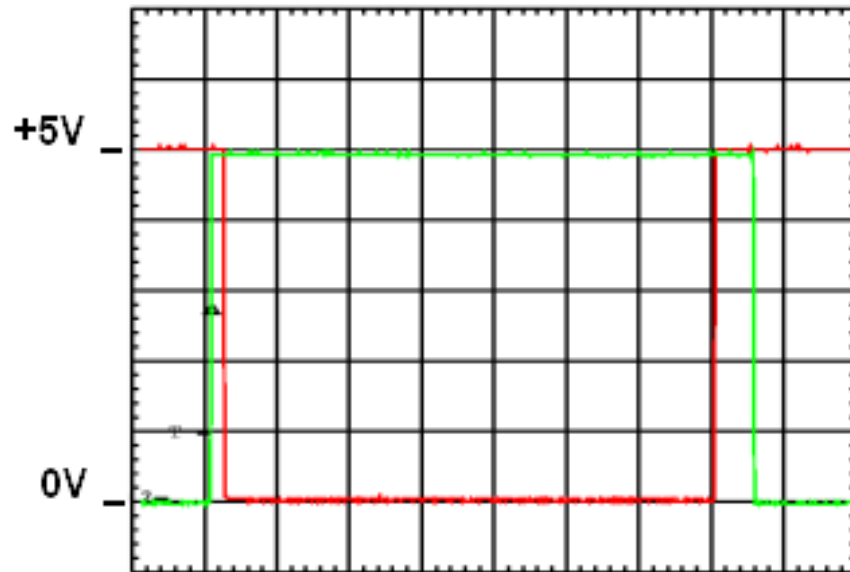


The output on pin 6 is stretched to about 15mSecs. by IC5B, D1, C6 and R7 and is delayed slightly by R6. When the output on pin 6 of IC4 goes to a '1' for about 1mSec., D1 conducts and C6 is charged up to about 4.5 Volts via D1 and R6. After it has been charged up, C6 discharges via R7.

In the following 'scope image, the time base is 10mSec per large division, the green trace is the TC output of IC2 and the red trace is the input (pins 5 and 6) of IC5B.



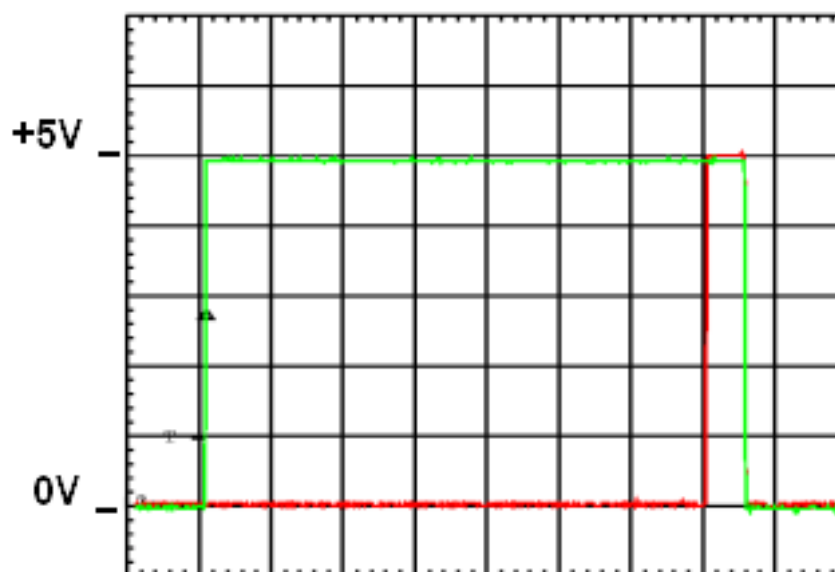
This causes a pulse output on pin 4 of IC5B. In the following 'scope image, the time base is 2msec per large division, the green trace shows the TC output (pin 12) of IC2 and the red trace shows the output (pin 4) of IC5B.



You will note that the red trace starts to fall a little after the green trace starts to rise and that the red trace rises again about 1msec before the green trace falls again. This 1mSec. delay is caused by the monostable IC4B.

The output of IC5B is fed to the input (pin 12) of IC4B. IC4B produces a 1mSecs pulse output when it is triggered by the rising edge of the input. The timing components are R5 and C5. Pin 9 is connected to pin 11 to inhibit the input so that it acts as a monostable multivibrator rather than a pulse stretcher. The output (pin 10) of IC4B is connected to the P1 input (pin 3) of IC2 and causes a new number to be loaded into the counter IC2 so the cycle is complete and the whole process starts again.

In the following 'scope image, the time base is 2mSecs. per large division, the green trace is the TC output of IC2 and the red trace shows the output (pin 10) of IC4B.



Fault finding

The first thing to do is give the circuit a thorough visual inspection with a spy glass looking for bad solder joints and short circuits. Check that the circuit you have built exactly matches the circuit diagram and that the components are the correct values and connected the right way round.

If the power supply was short circuited or had a greatly reduced output, remove the IC's one at a time and try again. If that does not help, there must be a short circuit or misconnection. If the removal of an IC restores the output of the power supply, check for short circuits on the pins of the IC sockets, in particular any outputs of the IC's. Make sure that the IC's were the correct way round. It is possible that an IC is faulty. Check the connections to the 5 Volt rail. Check that none of the outputs of the IC's are connected anywhere that they shouldn't. The only connections to the 5 Volt rail should be R3, R4, R5, C3, pin 20 of IC1, pin 16 of IC2, IC3 and IC4, pin 14 of IC5, pin 4 of IC1, pin 13 of IC2, pin 10 of IC3, and pins 3 and 13 of IC4.

Assuming that the power supply is OK, connect the screen of your oscilloscope probe to the 0 Volt rail. Check that pins 10, 16 and 17 of IC1, pins 4, 8 and 10 of IC2, pins 8 and 15 of IC3, Pin 8 of IC4 and pin 7 of IC5 are connected to the 0 Volt rail. Check that pin 20 of IC1, pin 16 of IC2, IC3 and IC4, pin 14 of IC5, pin 4 of IC1, pin 13 of IC2, pin 10 of IC3, and pins 3 and 13 of IC4 are connected to the 5 Volt rail.

Now follow the circuit description paying attention to the 'scope images. First look at the output (pin 3) of IC5A. See that you have a square wave. Check the values of R8 and C7. Look for short circuits, open circuits and bad solder joints. If that does not help, try replacing IC5. If that helps, throw the old IC away.

Assuming that the output of IC5A is OK, check the TC output (pin 12) of IC2. You should get an occasional pulse from 0 Volts to 5 Volts and then back to 0 Volts again. This output is dependent on the output (pin 10) of IC4 being OK. Check that pin 3 of IC2 is normally at 0 Volts. It should occasionally give a 1mSec pulse of 5 Volts. If you do not get this input on pin 3 of IC2, check that it is connected to pin 10 of IC4. If that does not help, look at the circuit of IC4. Check for short circuits, open circuits and bad solder joints. If that does not help, try replacing IC4. If that helps, throw the old IC away. Now if you still don't get the correct output on pin 12 of IC2, check that pin 13 is connected to the 5 Volt rail and that pins 4 and 10 are connected to the 0 Volt rail. Check for short circuits, open circuits and bad solder joints. If that does not help, try replacing IC2. If that helps, throw the old IC away.

Assuming that the output of IC2 is OK, check the output (pin 11) of IC3. The output should toggle between 0 Volts and 5 volts each time an input pulse from IC2 occurs. Check that pin 12 of IC2 is connected to pin 9 of IC3. Check that

pin 10 is connected to the 5 Volt rail and that pin 15 is connected to the 0 Volt rail. Check for short circuits, open circuits and bad solder joints. If that does not help, try replacing IC3. If that helps, throw the old IC away.

Assuming that the output of IC3 is OK, check the output (pin 6) of IC4. Check the values of R4 and C4. Check that pin 3 is connected to the 5 Volt rail. Check that pin 7 is connected to pin 5 and that it is also connected to pins 1 and 2 of IC1. Check the output (pin 7) of IC4. Check for short circuits, open circuits and bad solder joints. If that does not help, try replacing IC4. If that helps, throw the old IC away.

Assuming that the outputs on pins 6 and 7 of IC4 are OK, check the input (pins 5 and 6) of IC5B. Check the values of R6, R7 and C6. Check that D1 is connected the correct way round. Check for short circuits, open circuits and bad solder joints. If that does not help, try replacing IC5. If that helps, throw the old IC away.

Assuming that the input of IC5B is OK, check the output (pin 4) of IC5B. Check for short circuits, open circuits and bad solder joints. If that does not help, try replacing IC5. If that helps, throw the old IC away. If it does not help, try replacing IC4 and if that helps, throw the old IC away.

Assuming that the output of IC5B is OK, check the output (pin 10) of IC4. Check the values of R5 and C5. Check that pin 13 is connected to the 5 Volt rail. Check that pin 9 is connected to pin 11. Check for short circuits, open circuits and bad solder joints. If that does not help, try replacing IC4. If that helps, throw the old IC away.

Assuming that the output (pin 10) of IC4 is OK, check that you get the correct waveform on pin 6 of IC1. You will need a X10 probe for this. Check that all the connections to IC1 have been made according to the circuit diagram. Try removing IC2. If that helps, look for short circuits on the parallel load inputs to IC2. Look for short circuits, open circuits and bad solder joints. If none of this helps, try replacing IC1. If that helps, throw the old one away.

Assuming that the CLK input (pin 6) of IC1 is OK, Look for short circuits, open circuits and bad solder joints. If none of this helps, try replacing IC2. If that helps, throw the old one away.

Random events lasting random times without external inputs.

Use the previous circuit to generate random times and connect the output of IC5B to the input of the random event with external input circuit, removing the SW1 switch and the capacitor C1 connected across the switch from the random event circuit. Disconnect pin 23 of IC3 from the 0 Volt rail of the random event circuit. Connect the output of the random time circuit to pin 23 of IC3 of the random event circuit.

The result of this will be to give random event outputs, which last a random time and with random time intervals between these events.

When pin 23 of IC3 of the random event circuit is at 5 volts, the outputs of IC3 are disabled.

To go to the random event circuit, [click here](#).

CLICK

You will note that the two circuits both use one half of an HEF4520BP. You can therefore use one HEF4520BP IC instead of two of them. Similarly, only two gates of the HEF4093BP are used by each circuit and the HEF4093BP has four gates per IC, so you would only need one HEF4093BP instead of two of them.

Chapter 17

Microprocessors

Microprocessors (micro's) and Programmable Logic Controllers (PLC's) will not be dealt with in this cd. This chapter only deals with them in general terms.

This chapter is not about computers with keyboards and monitors but about the use of micro's to control motors and lights etc.

Micro's can be used as sequencers, as complex logic devices, as timers or as a combination of all three. The great advantage of using a micro is that, not only can it do all these things but what it does with them can be changed easily without changing the circuit. You only need to change the program.

Micro's, which are used for controlling rather than for general purpose computing, are called microcontrollers. There are a large number to choose from but the author favours the range made by Microchip which are called PIC's.. These need a UV (ultra-violet) eraser to remove the program from them and a programmer to put the program into them and of course a computer.

A favourite type of micro is called a 'STAMP', which uses a PIC but does not need a UV eraser or a programmer. The advantages are that they are quicker and easier to program and do not need any other equipment except, of course, a computer. The disadvantages are that they are more expensive, they are slow and they do not have the versatility of the PIC. If you only want to use a small number of them, then they may be cheaper.

PLC's are micro's with built in input and output interfaces which can be connected directly to your sensors and output devices like motors and lights. They have their own particular programming language, which is dedicated to control. These devices are quite expensive and usually need their own device to program them.

There are many books on the subjects of PIC's and STAMPS, which include working examples of both hardware (how to connect them) and software (programs). PLC's have comprehensive instruction manuals.

Chapter 18

Systems (complete circuits)

Here is a list of the circuits described in this cd. You should read the beginnings of the relevant chapters before the circuit descriptions. If you click on the text of the list, you will be linked directly to the appropriate page in the cd.

Power supplies:

- 5 Volt power supply
- Unregulated mains power supply

Sensors

- Door switch
- Pressure Mat
- PIR detectors
- Temperature sensors
- Light sensors
- Infrared Light Beam
- Optical Computer Interface
- Sound sensors
- Microphone pre-amplifier for long cables
- Sound level detector
- Vibration sensors
- Proximity/touch sensors
- Position sensors
- Distance sensors
- Speed of movement sensors
- Direction of movement sensors
- Limit and position switches/sensors

Signal conditioning

- Variable resistance sensors
- Signal level switches
- Signal level switch with dead-band
- Differential amplifiers
- Differential amplifier used to provide an offset
- Summing amplifiers
- Inverting amplifiers
- Differentiators
- Analogue to digital converters

Prime Movers (motors etc.)

- Turning motors on and off
- Changing direction of movement
- Changing direction of movement using electronic switching
- Speed control
- Limit switches
- Servos
- Stepper motors
- AC motors
- Solenoids
- Pneumatics

Lights

- LED's
- LED switching circuit
- Incandescent (light bulbs)
- Fluorescent
- Neon
- Lasers

Sound

- Sound mute with pause output
- Low power audio amplifier
- Speech recorder and playback

Music synthesizer

- +5 Volt and +10 Volt reference
- Voltage controlled oscillator
- Saw-tooth to square wave converter
- Saw-tooth to triangle wave converter
- Triangle to sine wave converter
- Voltage controlled filter
- Low pass filter
- Low pass filter with resonance
- High pass and band pass filter
- Noise generator
- Summing amplifier
- Low frequency oscillator
- Logarithmic amplifier
- Attack, sustain, decay and release ASDR
- Sample and hold and portamento
- Audio output circuit
- Complete synthesizer system

Timers

- Pulse stretchers
- Timers (pulse)
- Pulse generator for positive going inputs
- Pulse generator for negative going inputs
- Oscillators and pulse generators

Sequencers

- Time based sequencers
- Event based sequencer

Random

- Random event with external input
- Random time with external input
- Random events lasting for a random time with external input
- Basic random circuit without external input
- Random event without external input
- Random time without external input
- Random events lasting random times without external inputs

How to design circuits

You will need to consider what possibilities are available to you. A few of the circuits described in this cd are only usable for people who have successfully made circuits before and some require the use of an oscilloscope.

You should look at various possibilities, as your conception of what is required for your work may well get modified.

As mentioned before, the circuits are like building blocks and are intended to be used together, so that the output of one circuit can be used as the input to another. You may well decide that you need to use some logic devices as well as the circuits described, so it would be a good idea to read the chapter on logic before finalizing your design.

- The first thing to do is make yourself familiar with the types of circuits that are available to you. You should read the appropriate sections but ignore specific circuit descriptions, until you decide to use them in your work.
- You then need to think about your work in terms of function.
- What do you want it to do?
- What causes it to do it?

General considerations.

Make sure that the first circuits you build are simple ones so that you get more used to making working circuits before you embark on more difficult ones. Initially, building circuits directly from circuit diagrams will probably be a daunting task but it will become much easier after you have successfully built a few. You should not try to build a complete system in one go unless you have had a lot of experience. Your chances of success are not good if you plunge straight into a difficult circuit.

Build each module of the circuit one at a time. Ensure that each circuit functions correctly before making the next module. In most cases, you will need to build a 5 Volt power supply so that should be built and tested first. The 5 Volt power supply requires a 12 Volt power supply to power it. This supply will normally also supply your motor or lights or whatever. The 12 Volt supply can be a battery, which could be a number of cells in a battery holder or a car battery. It could also be a mains powered supply, which could be a small battery-eliminator if the work you are powering does not take much current. You should note that motors and incandescent light bulbs take considerably more current at the instant they are switched on than when they are working normally.

The circuits in this cd have been designed to minimize power consumption so that they are suitable for battery operation as well as from mains powered 12 Volt supplies.

Always take your safety and that of others into consideration. Ensure that your work is suitable for the environment in which it is placed. If your work is to be shown in places open to the elements, you will need to protect the electronics from the ingress of moisture.

There are a number of suppliers dedicated to hobbyists. These often have circuits ready built, which are suitable for the artist. It may be easier, in some cases, to buy a ready made circuit than to build your own. You should, however consider how to interface the bought circuit with your home made circuit and the circuits described in this cd have been designed for minimum power consumption to make them suitable for battery operation. This may not be the case with the ready built circuits.

Design examples**Example1.**

Let's consider a simple system in which an LED is turned on for a short time when someone moves in a space.

Apart from a power supply, there are three elements to consider. Firstly you would need a movement sensor, secondly you would need a circuit to produce

a short pulse when the movement detector produces a signal and thirdly you would need a circuit to turn the LED on and off.

A PIR detector would be ideal as a sensor. They require a 12 Volt supply, but that can be the same supply that the 5 Volt power supply uses. The PIR will usually have a normally closed switch as an output. If this were used to switch the LED directly, the LED would be on unless someone moved. We want it to be the other way round and we want a shorter pulse than the output of the PIR detector anyway.

The next module we require is a timer that will produce a pulse output when the switch contacts of the PIR open. You will find such a circuit in the chapter on timers.

The last circuit that you would need is a means of switching the Led using the output pulse of the timer. You will find this in the chapter on lights.

Each circuit should be built and tested in turn.

First make the power supply. Then try out the PIR detector. Then build the pulse generator circuit and connect the PIR output to the input of the pulse generator. When that is all working, build the LED driver circuit and connect its input to the output of the pulse generator circuit.

As you can see, there are several steps in even a simple example, but each step is easy. This is the trick. You need to break down complex circuits into lots of simple ones and test them one at a time. This is unlikely to produce an elegant solution to the problem, but it produces a solution, which can be built simply and will work.

Example 2.

Say you want to make something that has eight motors moving eight different objects and you only want one to move at a time and that which one moves should be a random choice. The movement should start when someone is sensed.

Well here you will need to ensure that the power supply is capable of running a motor. Next you should look at the chapter on sensors so that you can decide which of the many types of sensor would be appropriate, bearing in mind your level of expertise and whether you have the use of an oscilloscope or not. You will need a digital output from your sensor, so if it produces an analogue output, you will need to find a suitable circuit in the section on signal conditioning.

Next you should look at the chapter on random and decide what length of time you are going to have for your motors to be on. If the motors need to go to a particular place and then stop, you will need to use limit switches to prevent the

motors from going too far. In this case you will need to arrange for the motors to return to their starting points. This could be done automatically when they arrive at their end positions or they could be one of the random movements. Again another decision for you to make. If the motors are to be on for a fixed period of time, you can use a pulse generator or eight pulse generators if you need a different time for each motor. You could decide to have a random time and a random motor. The choice is yours; all the circuits are there for you to choose.

The motors will need to be turned on and off and may need to be reversed according to your design. Go to the chapter on prime movers and find a suitable circuit.

Again you will now need to make a complete circuit according to your decisions. You use the same process as before. Make a 5 Volt power supply. Make or buy a sensor. Connect the sensor output to the random circuit input and connect the random circuit outputs to eight motor controllers.

Example3.

Let's be a bit more adventurous. What if you wanted to change the volume of your sound system according to the distance someone is from the work.

There is an audio output circuit described in the section on music synthesizers and that circuit is a Voltage controlled amplifier. You need to connect the output of the sound-producing unit (cd player for example) to the input of your circuit and connect the output to your audio amplifier. The Voltage control input of the circuit need to be connected to the output of the distance-measuring circuit.

The distance measuring circuit is described in the chapter on sensors. Well you might change your mind at this point and decide instead that you might prefer to use a proximity sensor instead. This leaves you with the problem that the distance sensor has a digital output and not an analogue one. In that case you will be restricted to two Volumes, loud and quiet. You just need to convert the digital output of the sensor to an analogue one. Well you can do that with two resistors, connect one end of each resistor to the Voltage control input of the Voltage controlled amplifier. Connect the other end of one of the resistors to the 5 Volt rail and the other end of the other resistor to the digital output. You can change the relative volumes by changing the values of the resistors but you must ensure that the resistor values are always at least 1K.

You can see now that you have a number of possibilities arising from each simple starting point. It is a matter of deciding which is best for the work.