DESIGNING AND MAKING A MOTOR SPEED CONTROLLER

WHAT YOU WILL LEARN

After completing this project, you should understand:

- How to design a control system using a block diagram.
- How an open loop control system works.
- How a multivibrator can be used to control the speed of a motor.
- How to change the mark:space ratio of a multivibrator using resistors and capacitors.
- How a Field Effect Transistor (FET) can be used as a buffer.

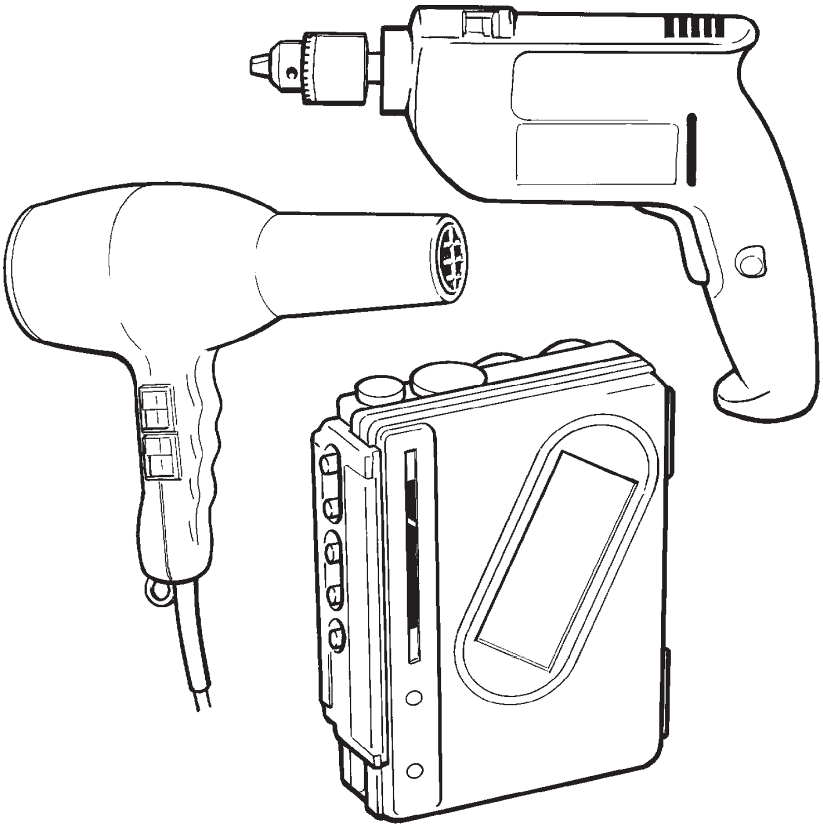
After completing this project, you should be able to:

- Use the following components in control circuits:

  FET
  I.C. 4001
  Capacitor
  Resistor
  Motor
  Switch

- Build a motor speed control system.

Motors are often used as output devices in electronic systems that control movement. When they are used, it is often necessary to be able to vary the speed at which they rotate. A multi-speed hair-drier, food-mixer or electric drill is far more versatile than one with a single speed. A cassette player would be frustrating to use if it could only fast-forward or rewind at the same speed at which it plays. A high-tech electric car could not be driven if you were unable to vary its speed in the same way as in a conventional car.



All the above examples use some kind of motor control system to vary the speed of the motor. This can be done in many different ways. The method used depends on the type of motor, the number or range of speeds required and how accurate and efficient the controller needs to be.

DESIGNING A CONTROL SYSTEM

Control systems can be represented using *block diagrams* . There are three basic building blocks and each block is used to represent a stage in the control system.

The three blocks are:

The Input Block - *Enters information into the control system. It will normally contain a switch or sensor.*

The Process Block - *Receives the information from the input block and uses it to control the output block, switching it on or off depending upon the state of the input.*

The Output Block - *Gives out information or makes things happen. The output block would normally contain components that either light up, make a noise or move.*

Control systems can be designed using these basic blocks in a simple and effective way without necessarily knowing too much about the electronic circuits contained in each block. A simple control system normally contains at least one of each type of block.

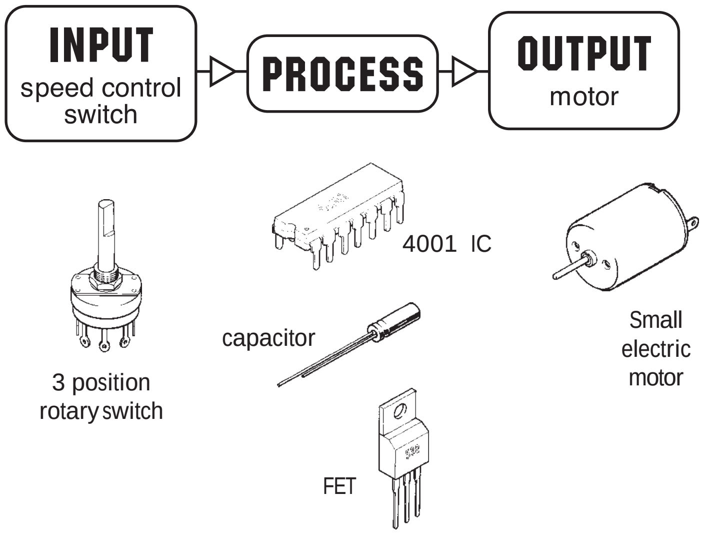
YOUR TASK

DESIGN BRIEF

A manufacturer of small electrical goods intends to launch a new product. It will be a small, hand-held, portable fan with three speed settings. Design and make a motor speed controller that could be used in this product.

DESIGNING THE CONTROL SYSTEM

The output block will obviously contain a motor. This needs to be small and powered by batteries if it is to be used in a portable, hand-held fan. The input block needs some kind of switch to set the speed of the motor. There also needs to be a process block to convert the input switch position into the correct electrical signal to drive the motor at the desired speed. The block diagram for the control system looks like this:



This block diagram represents an example of *open-loop control*. This is because it is connected in a single line and the information only passes in one direction from input to output.

When you have drawn a block diagram for an electronic control system and decided what function each block will perform you could use a kit to model a prototype system.

NOTE

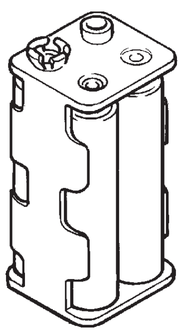
For more information on open and closed loop systems see Technology Study File 5 (Investigating Control).

MATERIALS AND COMPONENTS AVAILABLE

Before you make the motor control system, you need some more information. You need to know what power supply to use, what components are available to make up each system block and how they are used.

DESIGNING AND MANUFACTURING CONSTRAINTS

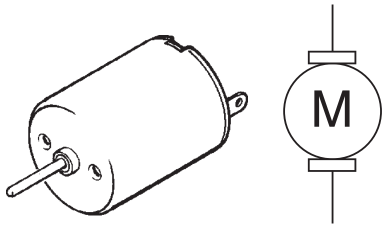
Power Supply - You will be using a 6 Volt power supply which will be provided by four 1.5 Volt cells in a cell holder.



OUTPUT BLOCK

SYSTEM OUTPUT POSSIBILITIES

The output block will contain the motor. This needs to be a 6 Volt DC motor. There are many types available but it will probably look something like this.



Small electric motor

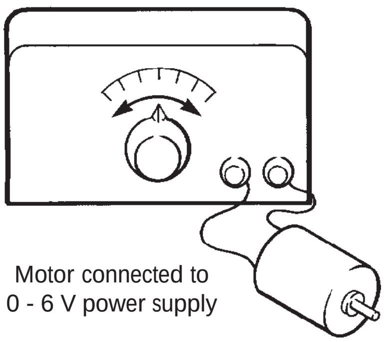
Circuit symbol for motor

INVESTIGATING THE MOTOR

If you connect the motor to a 6 Volt power supply, it will turn at its maximum speed. The design brief asks for a speed controller. There are a few ways that you can control the speed of a motor - some are more obvious than others.

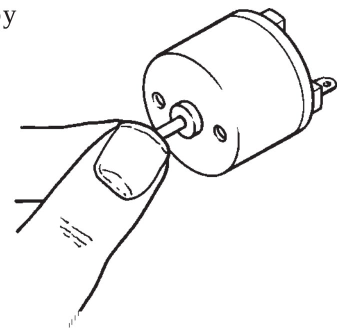
SCIENCE OPPORTUNITY

One way of changing the motor speed is to change the supply voltage. A smaller supply voltage makes the motor rotate more slowly. You could try this by using a variable power supply and changing the output voltage to different values between 0 and 6 Volts. As the voltage is reduced, the motor speed becomes slower.

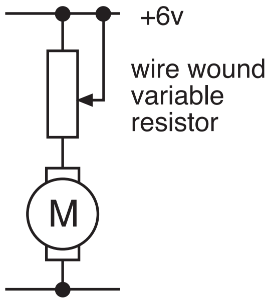


Motor connected to 0 - 6 V power supply

This seems like a good solution but some closer investigation reveals a problem. As you reduce the speed of the motor in this way, the motor *torque* is also reduced. Torque is the turning force of the motor. You can investigate this by trying to stop the motor shaft from rotating with your fingers. It will be much easier to do this when the motor is rotating more slowly. Because of the reduction in motor torque, this is not a very good solution.



Another way of changing the motor speed is to change the amount of current flowing through it. This can be done by connecting a resistor in series with the motor like this.



Quite a lot of current is needed to drive a motor so you need to use a resistor that can pass a similar amount. A wire-wound resistor could do this. Larger values of resistance allow less current to flow through the motor so it rotates more slowly. Again, this seems like a good solution but closer investigation reveals the same faults as before. As you reduce the speed of the motor, the motor *torque* also becomes less. This is because the two solutions are in fact the same. Investigating Ohm's Law can explain this.

Ohm's Law tells us that voltage, current and resistance are linked together and changing one of them will always affect the others. This is shown by using this simple mathematical formula.

Voltage = Current x Resistance

In the first solution, the voltage across the motor was reduced while the resistance of the motor was kept constant. This meant that, if the equation was still to balance, the current flowing through the motor also had to decrease. This happened because a smaller voltage pushed less current through the motor.

In the second solution, the amount of current flowing through the motor was decreased by connecting a resistor in series. For the equation to balance, the voltage across the motor also had to decrease. This happened because the resistor and the motor formed a potential divider. The resistor 'used up' some of the supply voltage leaving a smaller voltage across the motor.

Both solutions therefore are actually the same and are not satisfactory because of the loss in motor torque when the supply voltage is reduced.

Looking at these first two solutions shows you that a more satisfactory solution would be to control the speed of the motor without changing the supply voltage. One way to do this is to continuously switch the motor on and off very quickly. This provides *pulses* of energy to the motor. Long pulses will make the motor turn faster than short pulses. Each pulse has the full supply voltage so the motor torque remains high. For this solution to be effective, you need to switch the motor on and off very quickly. You obviously couldn't do this manually with a switch so you need a control circuit to do it automatically. This is provided by the process block.

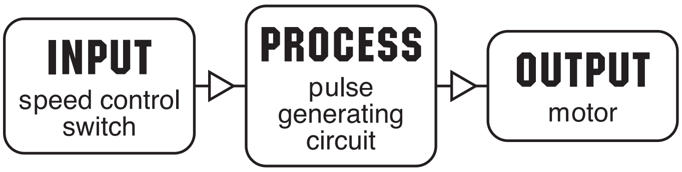
NOTE

This is a fundamental concept in modern motor control.

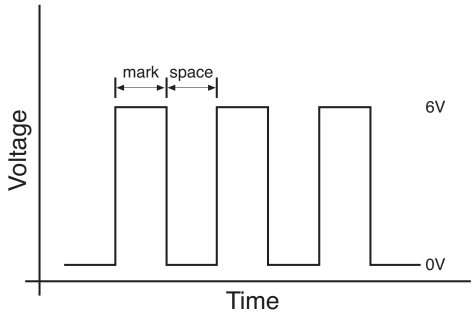
THE PROCESS BLOCK

SYSTEM PROCESSING POSSIBILITIES

The block diagram now looks like this.



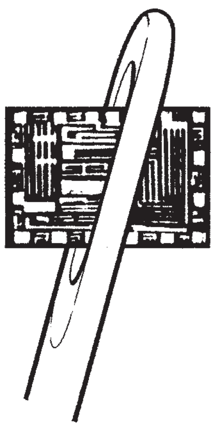
For the motor to be switched on and off by a series of pulses, the process block must provide an output signal that looks like this.



The output switches on and off between 0 Volts and 6 Volts. A 6 Volt pulse or *mark* switches the motor on and a 0 Volt *space* will switch the motor off. A circuit that can provide a regular series of pulses like this is known as a **multivibrator**.

There are many different ways of making a multivibrator circuit that produces a regular series of pulses. In this project you will be using an *integrated circuit* (IC).

An integrated circuit is a tiny chip of semi-conducting material, usually silicon, that has a whole circuit produced on it. This is why they are also known as a silicon chips or micro-chips. The chip is normally no bigger than $0.2mm^2$, small enough to pass through the eye of a needle!

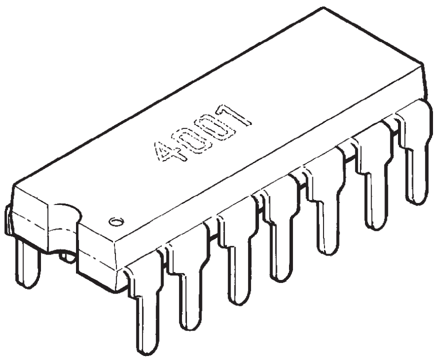


To make them easier to handle and use, they are fitted into larger plastic cases with connecting leads. ICs have revolutionised the electronics industry by enabling engineers to design and make electronic products that are much smaller and that consume far less power. The first computers used to take up a whole floor of a office block. The same machines now could be made to fit in your pocket. ICs are an example of a very high technology product, yet they are also very cheap to buy. The majority of ICs cost less than £1. This is because they are made in very large quantities in countries where the workers are paid low wages. The price of a product does not always reflect its true worth!

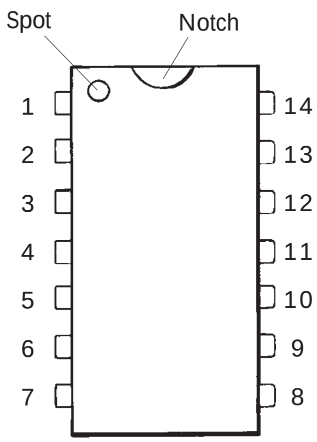
NOTE

TEP's teaching chips are encapsulated in clear plastic. The chips structure can be viewed under a low power microscope.

There are many different types of IC designed to do different jobs. You will be using an IC 4001.

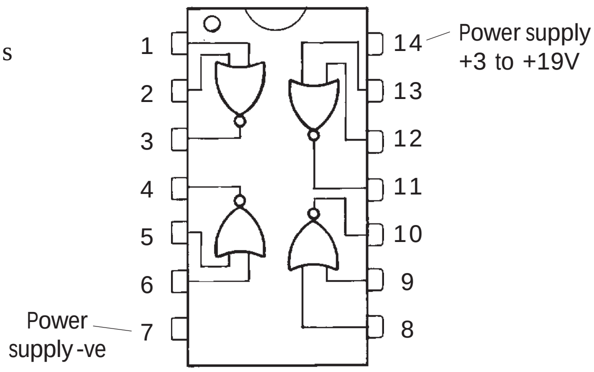


You can see that the IC has got 14 connecting pins. These pins are numbered from 1 to 14. To find out which pin is which, you need to look carefully at the case. On one end there is a notch. To the left of the notch there is a spot. The pin next to the spot is pin 1. The pins then count around in an anti-clockwise direction from pin 1.



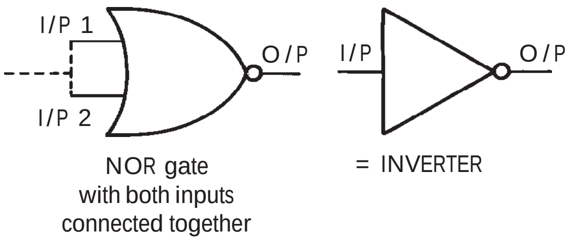
When engineers design electronic control systems that use ICs, they do not need to know much about what happens inside the chip itself. They mainly need to know what each pin on the IC does. (For example, is it a power supply connection, an input, an output etc.)

The IC 4001 actually contains four separate circuits. Each circuit is a NOR gate.



Using Logic Gates For Control

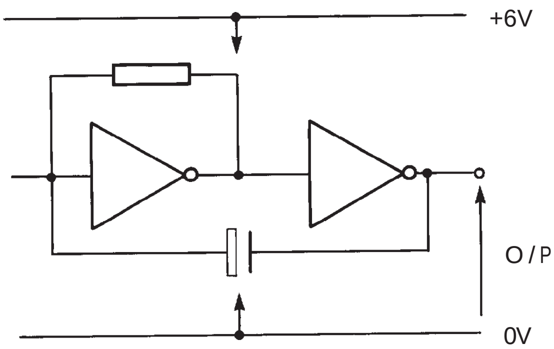
To make a multivibrator circuit, you will only need to use two of the gates connected as inverters. To convert a NOR gate into an inverter, you need to connect the two inputs together.



The truth table will remind you how an inverter functions.

INPUT	OUTPUT
LOW	HIGH
HIGH	LOW

The two inverters are connected together like this using two external components - a capacitor and a resistor.



The capacitor and resistor control the length of the mark and space pulses at the output.

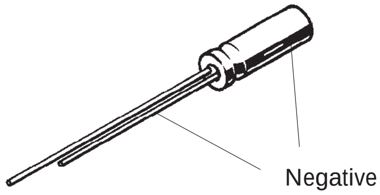
CAPACITORS

A capacitor is a device that stores electrical charge. If it is connected to a power supply, it charges (or fills) up. The amount of time it takes to charge up depends upon two things.

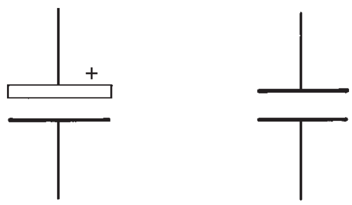
Firstly, it depends on the size of the capacitor. A big capacitor will take a long time to charge. Capacitors are measured in Farads. Most capacitors are only a fraction of one Farad in size and so they are measured in micro-Farads (μF).

1 μF = 0.000001 Farads

The capacitor you will be using has a value of 1μF. It looks like this.



Notice that the negative leg is clearly indicated. This means that this capacitor must be connected correctly into the circuit. This is because it is an *electrolytic* capacitor. Not all capacitors are like this. Most don't have positive and negative connections so they can be connected in any direction. Notice the difference in the two circuit symbols.



When using capacitors it is always important to check whether they are polarised.

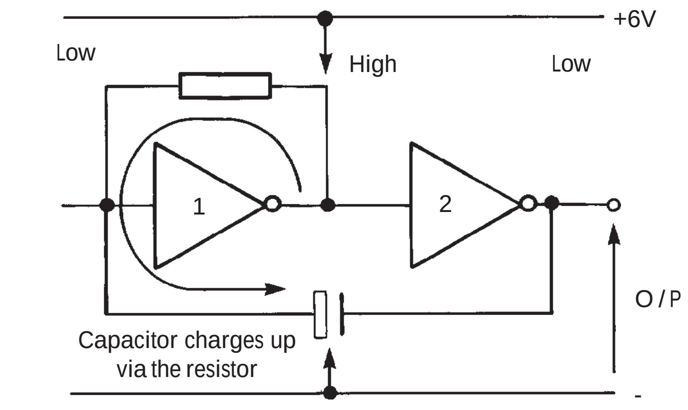
The second thing that affects how long a capacitor takes to charge up is how much resistance it is charging through. The larger the resistance, the longer it will take to charge.

This means that larger values of capacitance or resistance will give longer marks and spaces. Smaller values of capacitance or resistance will give shorter marks and spaces.

MULTIVIBRATOR OPERATION

The description of how the multivibrator operates can be quite difficult to follow. The best way to understand it is to break it down into a series of stages:

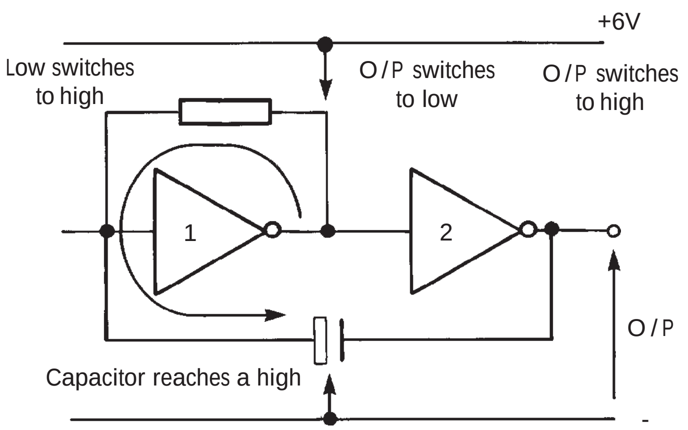
Stage 1 - You must start by assuming that the output is either high or low at the instant the circuit is switched on. (In reality, it could be either. This is because the circuit is designed to switch automatically between high and low at the output, but you have to start the explanation somewhere!) Assume that the input of inverter 1 is LOW, which means its output will be HIGH. This will make the output of inverter 2 LOW.



STAGE 1

In this state, the capacitor begins to charge via the resistor until the voltage at the junction of the resistor and the capacitor has risen to a HIGH.

Stage 2 - When the voltage at the junction of the resistor and the capacitor has risen to a HIGH, the output of inverter 1 will switch to a LOW. This causes the output of inverter 2 to switch to a HIGH.

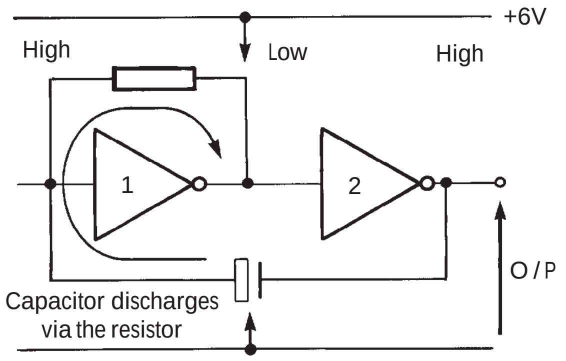


STAGE 2

NOTE

This is a relatively difficult sequence to understand. The process block can be treated as a black box if necessary.

Stage 3 - The capacitor now begins to discharge via the resistor until the voltage at the junction of the capacitor and the resistor has reached a LOW. When this happens, the output of inverter 1 switches to a HIGH and this causes the output of inverter 2 to switch to a LOW. This brings the cycle back to the starting point at stage 1 where it begins again.



STAGE 3

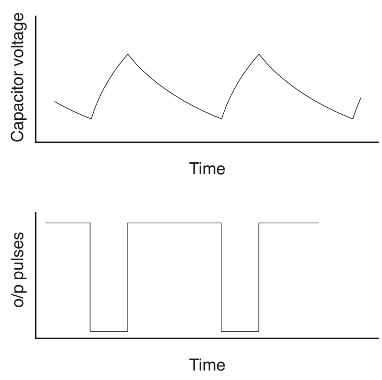
If you find this explanation difficult to follow, just remember the key points.

1. *A multivibrator is a circuit that provides a regular series of pulses.*

2. *The length of the pulses is set by the value of the capacitor and the resistor. Larger values of capacitance or resistance give you longer pulses.*

The process block is now almost complete. You have a circuit that can supply a regular series of pulses that can turn the motor on and off very quickly.

The design brief asks for a control system that can vary the speed of the motor. To do this, you need to be able to vary the width of the mark and space pulses.

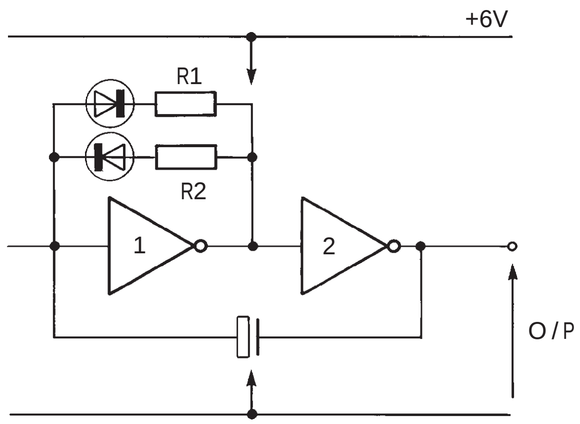


- *A long mark and a short space will make the motor turn quickly.*
- *A short mark and a long space will make the motor turn slowly.*

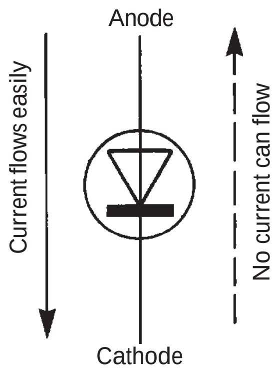
This means you will have to modify the multivibrator circuit to provide mark and space pulses of different lengths. Remember, it is the size of the resistor and the capacitor that set the length of the pulses.

Normally, the circuit provides mark and space pulses of the same length. This is because the length of the mark and the length of the space is controlled by the same capacitor and resistor. Changing either the capacitance or resistance will change the length of both the mark and the space. To produce marks and spaces of different lengths, the circuit needs to use one value of capacitance or resistance for the mark and a **different** value of capacitance or resistance for the space. (In practice, it is most common to change the value of the resistor.)

The circuit will have to contain two resistors - one to set the length of the mark and one to set the length of the space. There also needs to be some way of deciding which resistor controls the mark and which resistor controls the space. This is done by using *diodes* to steer the current that charges and discharges the capacitor through the correct resistor. The modified circuit looks like this:



The diodes allow current to flow in only one direction. They allow current to flow if the voltage on the anode is more positive than the voltage on the cathode. They prevent current from flowing when the voltage on the anode is more negative than the voltage on the cathode.



When the output pulse is a space (**Stage 1**), the capacitor is charging. This means that R1 is operating.

When the output pulse is a mark (**Stage 3**), the capacitor is discharging. This means that R2 is operating.

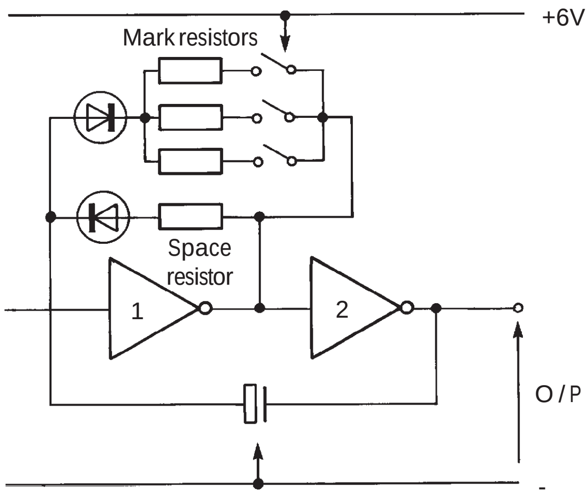
You now have a multivibrator circuit capable of supplying mark and space pulses of different lengths.

INPUT BLOCK

SYSTEM INPUT POSSIBILITIES

Looking back at the design brief shows you that the manufacturer requires a motor speed controller with three speed settings. To do this, you have to be able to change the value of the resistor that controls the length of the mark pulse (R1). The value of R2 can stay the same. The easiest way to do this is to use switches to switch in three different values of R1, one for each speed setting.

A simple way to do this is shown here. The actual way in which you do this depends on the type of switch you choose to use.

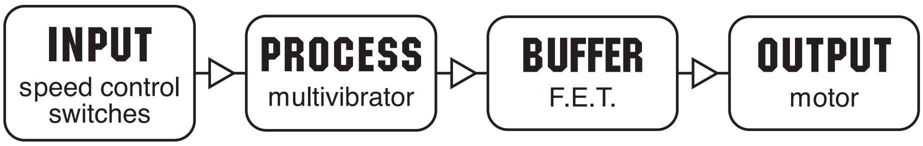


You have to decide on the three different resistor values. The best way to do this is to build the circuit and then experiment with different resistors. It is best to start with the same values for R1 and R2. This will give you an equal length of mark and space. The motor will run at approximately half speed. To increase the speed of the motor, you need a longer mark pulse so you have to use a larger value of R1. To reduce the speed of the motor, you need a shorter mark pulse so you have to use a smaller value of R1.

With all this detail added the block diagram for the motor speed control system looks like this.

The input block sets the speed of the motor in the output block. It does this by controlling the length of the mark and space pulses produced by a multivibrator circuit in the process block. The pulses produced by the process block switch the motor on and off very quickly. Longer mark pulses will make the motor turn faster than shorter mark pulses.

Before you can put this all together and draw the final circuit diagram, there is one last problem to solve. This is how you are going to connect the output of the multivibrator to the motor. You cannot connect them directly as the IC 4001 cannot supply enough current to drive the motor. Attempting to draw too much current from the IC would damage it. This means you need to add another block to the system. This block is known as a *Buffer*. It goes in between the process and the output.

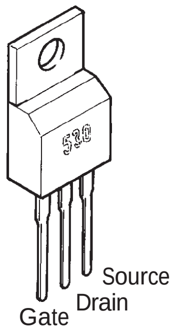


The buffer allows the pulses to control the motor but only draw a very small amount of current from the IC 4001 in the process block.

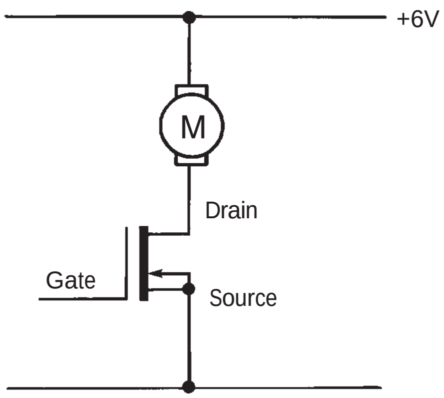
The main component that is used in the buffer block is a field effect transistor or **FET**.

You will be using a type IR530 which looks like this:

The three legs of the FET have names. It is quite easy to see which leg is which from the picture.

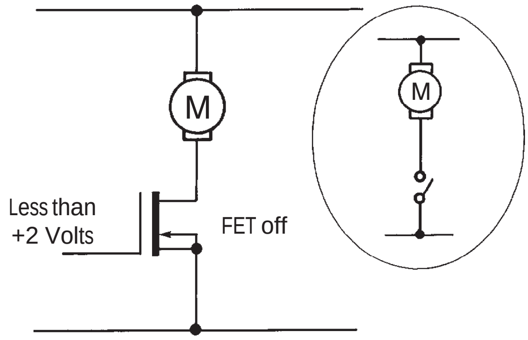


You will need to connect the FET and the motor like this:

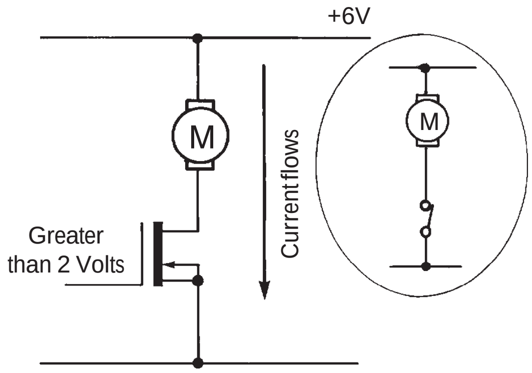


The FET works like an electronic switch. To turn it on, you need to put a positive voltage onto the **gate**. This allows current to flow through the FET from **drain** to **source.**

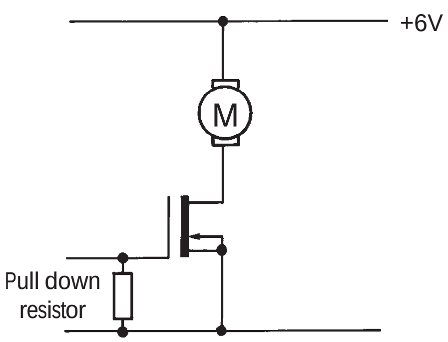
A gate voltage of **less** than 2 Volts turns the FET fully off.



A gate voltage of **greater** than 2 Volts turns the FET fully on.



When you use a FET like this, you need to connect a *pull down* resistor to the gate like this:

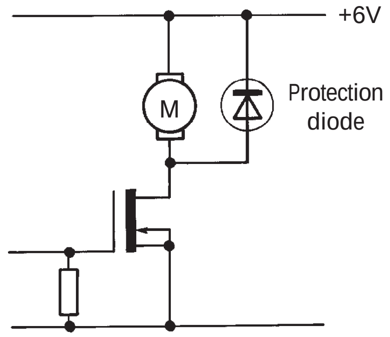


This makes sure that the FET stays switched off when there is no input voltage on the gate.

The FET is a very good component to use as a buffer stage. This is because although it requires only a tiny current to switch it on, it can turn on a load that requires up to 15 A!

Finally, a diode needs to be connected across the motor like this:

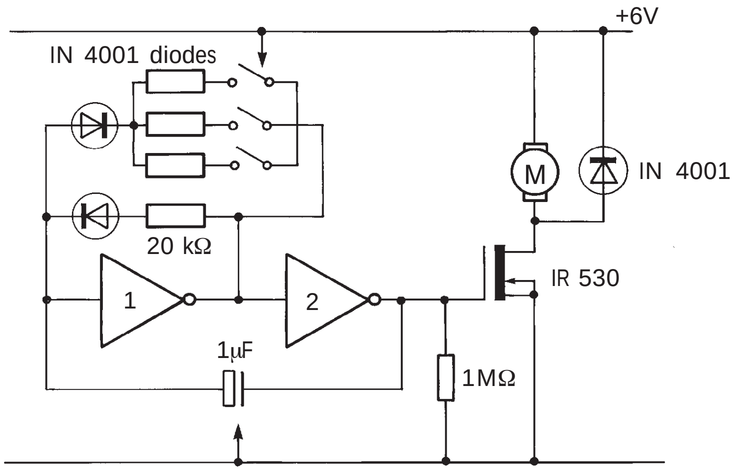
This protects the FET from any *interference* that the motor might create.



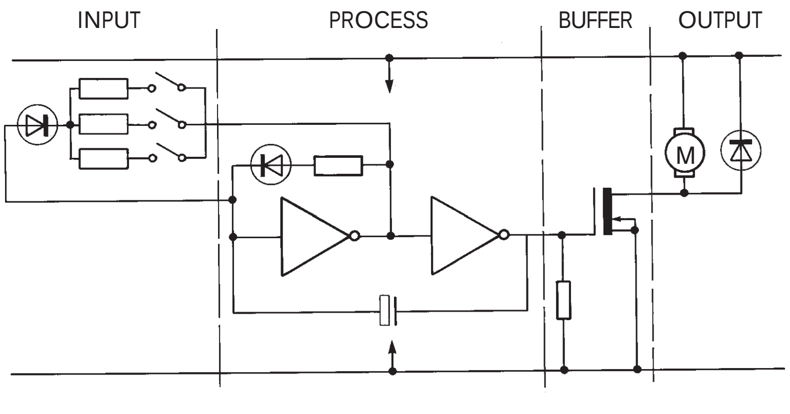
PUTTING IT ALL TOGETHER

◀ SYSTEM SYNTHESIS

The circuit diagram for the motor speed controller is shown below:



Below is the circuit diagram divided into inputs, process, buffer and output. It may help you to understand what each component is doing:



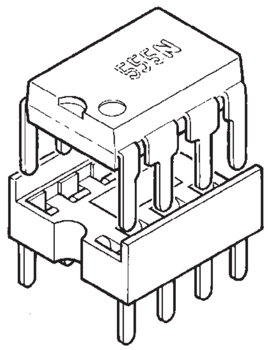
Remember, you are going to have to find the best values for themark pulse resistors by building the circuit and then experimenting with different values. The controller needs to have three **useful** speeds - slow, medium and fast. These will depend on what kind of fan you are going to use. The way in which you connect the resistors will also be affected by the kind of switches that you choose to use.

You will need to make a printed circuit board (PCB) on which to mount the components.

NOTE

To find out about this see Technology Study File 2 (Making a PCB)

Integrated circuits are delicate devices so they need to be handled with care. Don't remove them from their packaging until you are ready to use them and don't handle them unnecessarily. When using them to build circuits you mount the chip in a holder. The holder is soldered onto the PCB and the chip simply plugs into it. This means that the chip does not have to be soldered which could damage it and it can be replaced easily if it is defective.



An IC and holder

TESTING

When you have built the circuit, you will need to test it to see if it works correctly. Start by switching in a mark pulse resistor of the same value as the space pulse resistor. The motor should turn at approximately half full speed. Experiment with different values of mark pulse resistors to find the three most useful speeds.

If the circuit does not work at all, try following this simple fault finding procedure:

NOTE

To find out about this see Technology Study File 2 (Making a PCB)

1. Check the PCB layout is correct and that no tracks are bridged or broken. (Repair if necessary.)

2. Check all soldered joints are good.

3. Check all components are connected correctly. Pay particular attention to the chip. It is quite easy to plug it in the wrong way round.

4. If all this fails, try a new IC 4001.

EVALUATING THE MOTOR SPEED CONTROL SYSTEM

There are a number of things to consider when evaluating your motor speed control system:

- How well does it work?

  Can you control the speed of the motor so there are three useful fan speeds?

- Will it work in the situation for which it was designed ?

  How easy is it to change the speed settings?

  Will it be possible to manufacture the product in a suitable size to make it portable?

- Was trial and error the best way to select the mark pulse resistors?

  Can you think of, or find out about, another way of doing it?