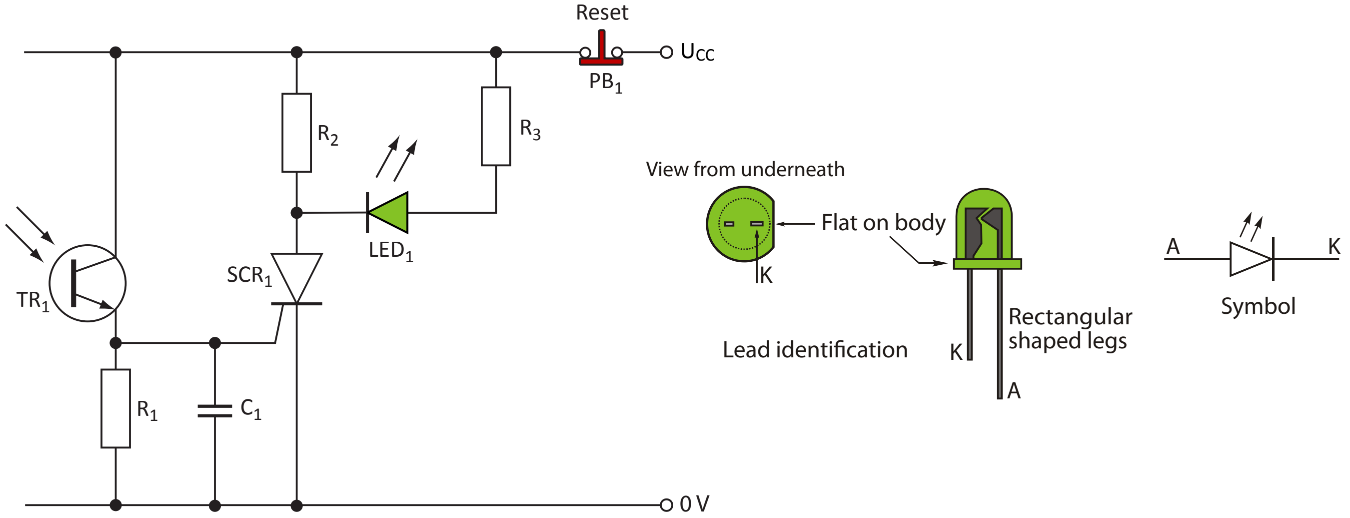
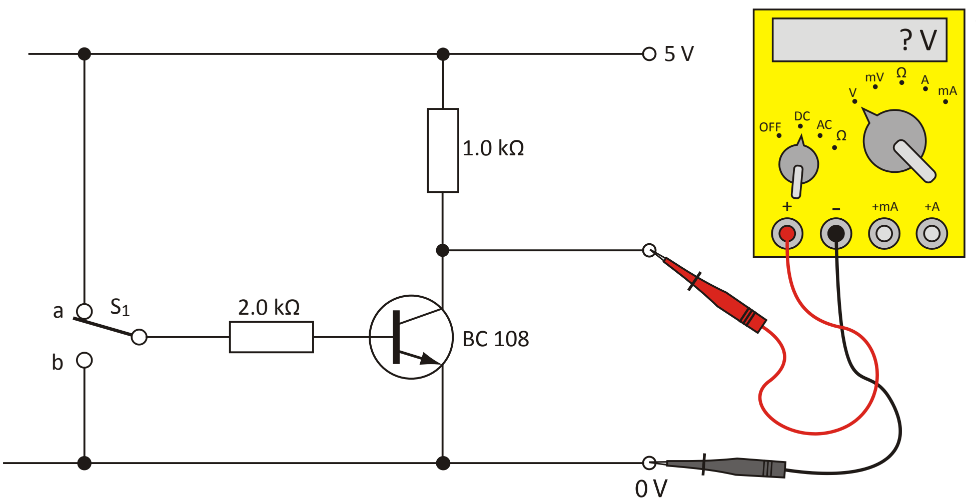
Level 3 Diploma
in
Installing Electrotechnical Systems & Equipment

C&G 2357

Unit 309-12 Understand the types, applications and limitations of electronic components in electrotechnical systems and equipment





B&B Training Associates Ltd

Learning Materials for the Electrical Industry

Produced by

B&B Training Associates Ltd

For further information contact:

Mrs A Bratley

23 St Pauls Drive,

Tickton, Nr Beverley,

East Yorkshire

HU17 9RN

Tel:-01964 – 543137

Fax:-01964 – 544109

Email:- sales@bbta.co.uk

timbenstead@bbta.co.uk

terry@bbta.co.uk

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Aims and objectives

By the end of this study book you will have be able to:

- Describe the function and application of electronic components that are used in electrotechnical systems.

  Security alarms.

  Telephones

  Dimmer switches.

  Heating/boiler controls

  Motor control

- State the basic operating principles and applications of electronic components.

  Capacitors

  Resistors

  Rectifiers

  Diodes

  Thermistors

  Diacs

  Triacs

  Transistors

  Thyristors

  Invertors

1: Resistors – their types and uses

In this session the student will:

- Describe the types of resistor that exist and state why they are used.
- Recognise and use resistor colour codes.

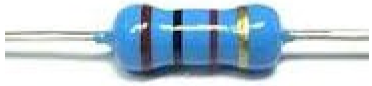
Before we look at circuits and how they operate it is important that you understand what individual components do, the varieties that there are and ways of recognising them.

In this first session we will consider the nature of resistors and where they are used and what they are used for.

A resistor is a device that performs a number of functions. The main ways in which resistors are used are to:

- limit the current flow by increasing the overall value of resistance. This limits the current and causes the added resistor to have a voltage dropped across it
- provide a potential divider arrangement to set the level of voltage available to a portion of a circuit.

Common resistor types

Carbon	Metal film	Wire wound
		
This type of resistor is cheap and not as accurate as others. Their resistance value is likely to change when the temperature varies and it ages. This type of resistor has power ratings of up to 2 W and is found in many radio circuits, as they can be used when high frequencies are present.	This type of resistor is very accurate (±1 %) and quite expensive when compared to the carbon resistors. However, their accuracy and stability are greater. They have power ratings of up to 0.5 W and are used in precision instruments.	This type of resistor has a number of turns of wire wrapped around a piece of ceramic, and although accurate, are less widely used that other resistor types. They are likely to have their value written on them instead of using coloured bands. They only have values of up to 100 kΩ and they don't work well at high frequencies. However, they are exceptionally accurate (±0.01 % to ±0.05 %). They are used in high precision equipment or in power electronics where large currents are flowing.

Power resistors

This resistor will be wire wound and is used in power circuits where a large current could be flowing

Wire wound resistor can have power ratings of up to 200 W but as can be seen, they are quite large in size.

Resistor stack

Another arrangement of resistor is the stack where there is a line of precision resistors contained in one package.

These are used in multi-meters where the range of a scale needs varying.

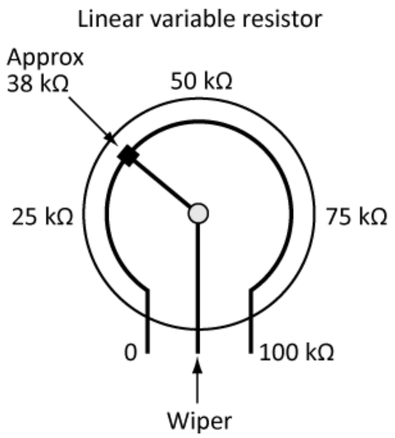
Variable resistor

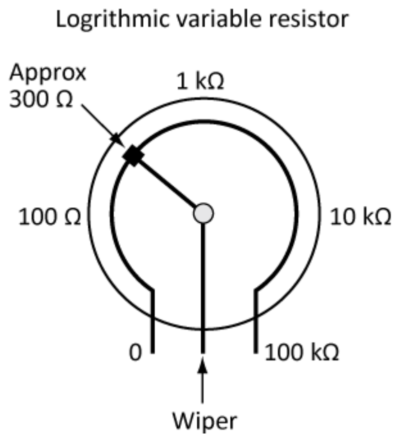
This resistor type enables us to vary the resistance as a method of control.

The pictures above show variable resistors in different forms.
Rotary, preset and slider. There is also the option to cut the spindle to the length required to suit the application.

This type of resistor has three contacts. There is an 'in' and 'out' contact with a third contact that 'taps' the resistor at various points to give us our specific resistance. The arm can be rotated.

The two types of this resistor are linear and log (short for logarithmic). The linear resistor varies constantly up to its maximum, whilst the log resistors resistance rise very rapidly as the arm is rotated.





You can see from the diagram above that the scales vary widely.

This type of resistor is used for setting currents and timing circuits. They are commonly used in sound control circuits.

Power ratings

The power rating of a resistor is a measure of how much power a resistor can dissipate (get rid of) without burning out.

For example, if I have a resistor that has a power rating of 0.5 W, I have to be very aware that depending on the current flowing and the voltage dropped across the resistor, it may not be large enough. In the end, it may be necessary to pick a larger power rated resistor.

The most common available power ratings available for resistors are $\frac{1}{8}W$, $\frac{1}{4}W$, $\frac{1}{2}W$, 1 W and 2W. However, it is always better to select a resistor that is capable of dissipating two or more times the calculated power.

1. I have a 100 kΩ, 0.5 W resistor, what will be the maximum current that can flow through it?

$$P = I^2R \quad \text{transpose}$$
$$I = \sqrt{\frac{P}{R}}$$
$$I = \sqrt{\frac{0.5}{100 \times 10^3}}$$
$$I = \underline{\underline{2.24\text{mA}}}$$

Here then you can see that the current has to be carefully considered when choosing a particular resistor.

2. A circuit draws 10 mA through a 330 Ω resistor, what is the power rating of the resistor?

$$P = I^2R = (10 \times 10^{-3})^2 \times 330 = 0.033W$$

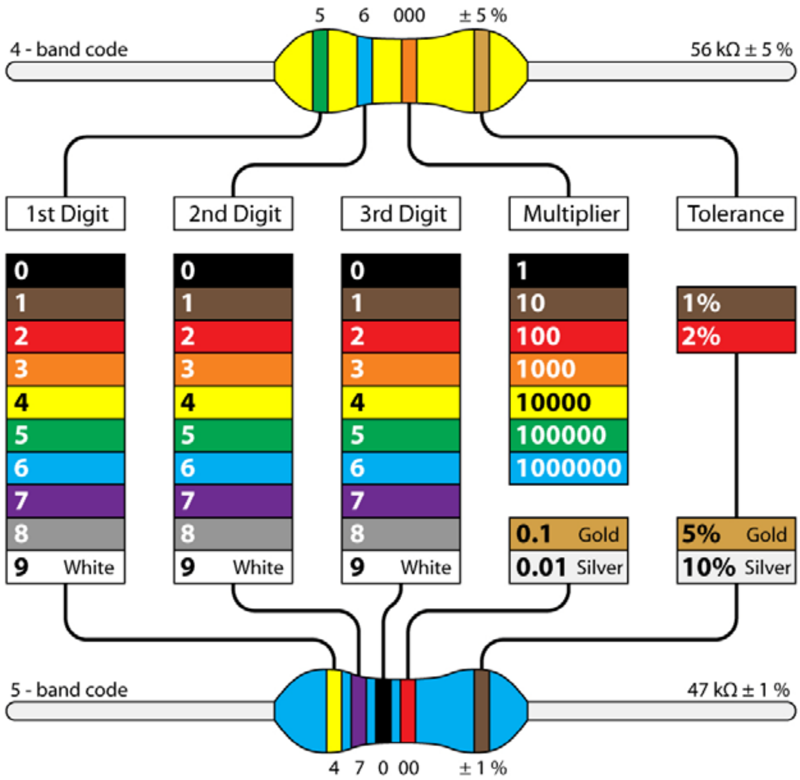
The nearest power rating available is $\frac{1}{8}W$.

3. If a 100 Ω resistor will have 12 V across it what will its power rating need to be?

$P = \frac{U^2}{R} = \frac{12^2}{850} \simeq 170mW$ Select a $\frac{1}{4}W$ resistor or if space is available a $\frac{1}{2}W$.

Resistor colour codes

There are two common ways in which resistors values are determined. One is by deciphering the colour bands on the resistor; the other is to read the value off the resistor body.



It is important that you start reading from the correct end. For resistors the correct end to start from is where the colour bands are closer together reading towards the tolerance band.

There are other tolerance values available but the ones shown are the most common.

How to read the value from the coloured bands.

Significant figures

The significant figures are the first two bands on the four-band resistors. They define the main numbers.

Multiplier

The third band on the resistor is a multiplying figure. In effect it tells you how many zeros need adding to the significant numbers.

Tolerance

The fourth band shows the tolerance, or how close the actual value of the resistor is to that given by the colour code.

Example.

1. A four-band resistor has bands of red, red, black and gold. What is its nominal value?

It might be of value using a table.

Colour	Significant figures		Multiplier	Tolerance	Total value
	Red	Red	Black	Gold	
	2	2	1	±5%	22 Ω±5%

As you can see, the first two colours give us the figures that we use and the third colour tells by how many to multiply that figure by. In this instance it makes no difference as black is a multiplier of 1.

Resistor is 22 Ω with a tolerance of ±5%.

Applying the tolerance; $22\times\frac{5}{100}=\underline{\underline{1.1\Omega}}$. Resistor range; $22\pm1.1=\underline{\underline{20.9\Omega}}$ to $\underline{\underline{23.1\Omega}}$

The tolerance is a figure that states how far the actual resistance value will be around a norm of 22 Ω.

Here we can have a minimum resistance value of 20.9 Ω and a maximum value of 23.1 Ω.

We'll try another example.

2. A four-band resistor has bands of yellow, violet, yellow and silver. What is its resistance value?

Again, a table is of value.

Colour	Significant figures		Multiplier	Tolerance	Total value
	Yellow	Violet	Yellow	Silver	
	4	7	10^4	±10%	$47\times10^4\Omega$ ±10%

47×10^4 is quite clumsy to remember. If you recall the standard notation used throughout this series of study books another way of writing this could be $47\times10^4\Omega=470\times10^3\Omega=470\text{k}\Omega$.

Therefore, in this example we have a resistor that has a value of 470 kΩ ±10 %. This means that the actual value of resistance would fall between 423 kΩ and 517 kΩ.

The only additional thing that you need to be aware of is that if a resistor appears to have only three colour bands on it, then it read for two significant figures and a multiplier without a tolerance figure band. The assumption then is that the tolerance is ±20 %. This makes those resistors very cheap and very inaccurate.

For the five-band resistor, the table is the same as it is for the four-band. The only difference is that instead of having two significant figures we have three. This means that our readings are that bit more accurate.

3. A five-band resistor has colours of orange, yellow, grey, orange, red. What is its value?

Colour	Significant figures			Multiplier	Tolerance	Total value
	Orange	Yellow	Grey	Orange	Red	
	3	4	8	10^3	±2%	$348\times10^3\Omega$ ±2%

In this instance, we have a resistance value of 348 kΩ at ±2 %. This is quite an accurate resistor.

The six-band resistor is worked out in exactly the same way as the five-band resistor. However, the sixth band shows what is called the temperature coefficient of the resistor, and gives an indication of how much it is affected by changes in temperature.

The other way that resistors can be coded is by using BS EN 60062 (previously BS 1852). With this type of coding, the value of the resistor is printed on the component and the multiplier is the same as it would be when we are using standard notation. The only extra thing to remember is the way that the tolerance is recorded.

Uncommon tolerances				Common tolerances				
A	B	C	D	F	G	J	K	M
±0.05 %	±0.1 %	±0.25 %	±0.5 %	±1 %	±2 %	±5 %	±10 %	±20 %

The position of the first letter tells you where you need to place the decimal point.

We'll look at one or two examples.

1. R22J $0.22\Omega \pm 5\%$
2. 2k2G $2200\Omega \pm 2\%$
3. 470kJ $470000\Omega \pm 5\%$
4. 3R9K $3.9\Omega \pm 10\%$
5. 4.7 MΩ at 10% tolerance $4.7M\Omega = 4M7K$
6. 1.2 kΩ at 5% tolerance $1.2k\Omega = 1k2J$
7. 330 Ω at 2% tolerance $330\Omega = 330RG$
8. 1.5 Ω at 1% tolerance $1.5\Omega = 1R5F$

Notice the positioning of the decimal point!

We're now going to take a brief look at how resistors are commonly used. As far as we are concerned in electronics, resistors are used for either limiting the current into a component or as a potential divider.

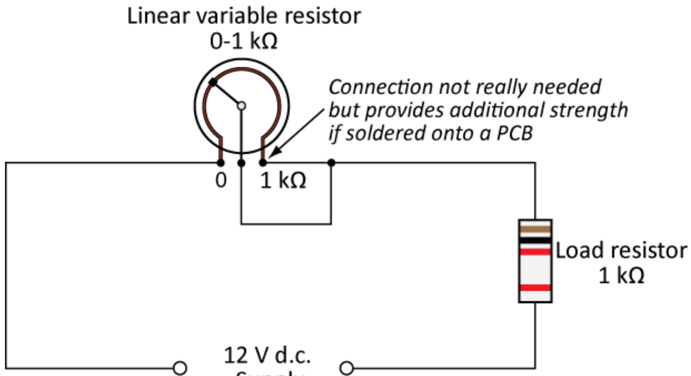
Use of resistors

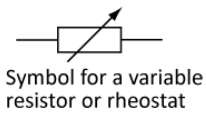
You should remember that when resistors are connected in series then the voltage is divided across the resistors in proportion to the size of resistance. You should also remember that the current remains constant in a series circuit.

In parallel circuits you have learnt that the current divides between the individual resistors depending on their size, and that the voltage remains constant across the resistors.
What happens with variable resistors?

1. Used for current limiting devices

Imagine that I have a load of 1 kΩ and a 12 V supply. We will also add a linear variable resistor in series with the load that has a range from 0 Ω to 1 kΩ.

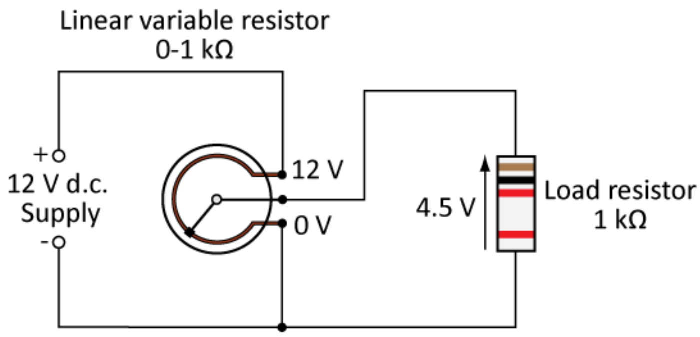


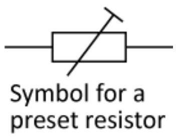


This configuration controls current flow

If you consider Ohm's Law ($I = \frac{U}{R}$) you will realise that if you increase the value of the resistance whilst keeping the voltage constant then the current must fall.
This is not saying that we are using less power in total, but we are limiting the current in the load and so we are reducing the power dissipated in the load.

2. Used as potential dividers.





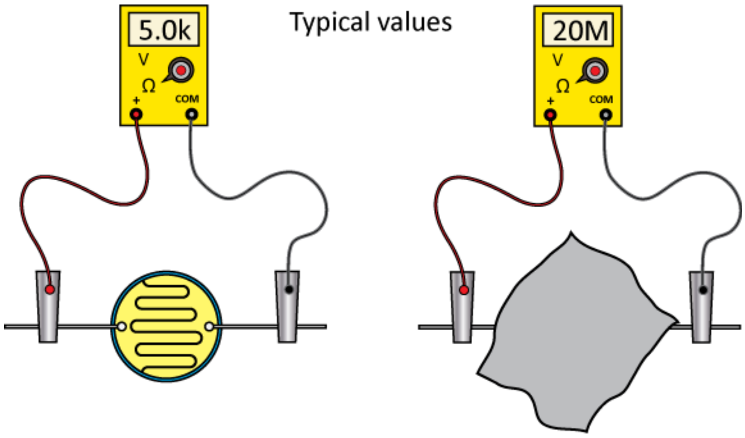
This configuration controls the voltage across the load

With this arrangement the potential difference across the load can vary between 0V and 12V. At the current position of the wiper, the load voltage is about 4.5 V.

Light dependent Resistor (LDR)

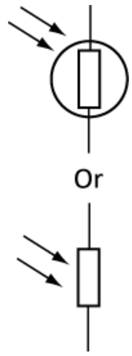
Before we leave the section on resistors we ought to mention about LDR.

An LDR is a light-sensing part which is used when it is necessary to detect basic changes in light levels within an electronic device. LDR's are also known as photo resistors, photoconductors, photoconductive cells or CdS cells (the chemical symbol for Cadmium-Sulphide), of which LDR's are made.



Light Dark

LDRs bing tested in light and dark conditions

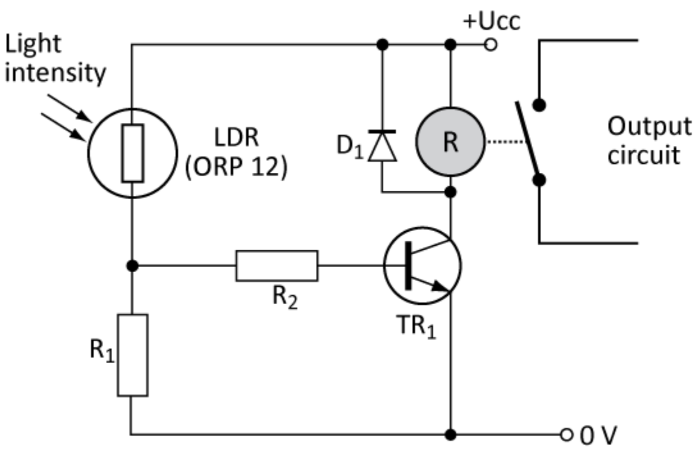


Symbol

Typical LDR

LDR applications

This component is used in many electronic circuit designs because of its low cost, simple structure and rugged features. The photo-resistor is widely used in circuits such as photographic meters, flame or smoke detectors, burglar alarms, card readers, controls for street lighting and many others.



This is a typical circuit which could be used to detect the presence of a flame in a boiler.

The resistance of the LDR will decrease under the influence of the light from a flame. This will cause TR_1 to conduct energising the relay thereby switching on the output circuit.

Exercise 1.

1. Explain how a resistor works as a current limiting device in a circuit.

2. With the aid of a diagram show how resistors can be used as potential dividers.

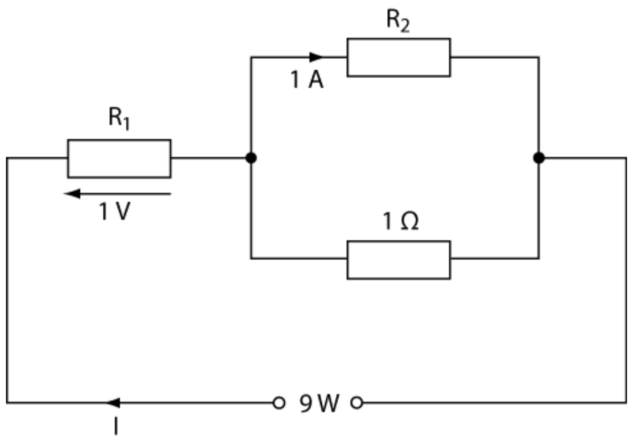
3. For the following values of resistance convert them into both four-band and five-band colour codes and their associated letter codes:-
   i) 100 Ω
   ii) 470 Ω
   iii) 74 000 Ω.

4. Work out the following resistor values from the colour codes.
   i) Yellow, violet, red,
   ii) Brown, black, brown, gold.
   iii) Brown, black, black, red.

5. State the resistor values:
   i) 270 kJ.
   ii) 10 RG.
   iii) 1 kK.

Challenging questions

6. Consider the circuit and determine;
   a) The circuit current I
   b) The value of R_1
   c) The value of R_2



7. A 2.2 kΩ variable resistor is connected to a 24 V a.c. source, what should its power rating be?

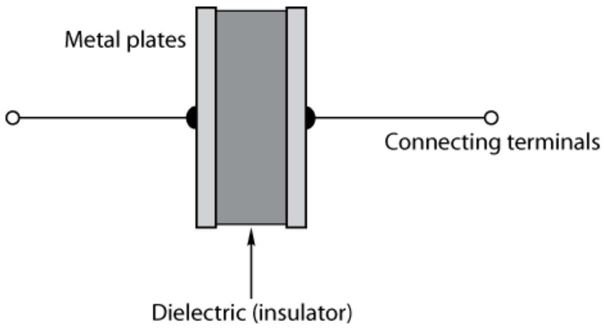
8. A particular load which draws 250 mA requires 10 V d.c . to operate but the supply source is 12 V. Draw a circuit diagram of how this can be achieved and determine the power rating of any resistor used.

2: Capacitors – their types and uses

In this session the student will:

- Describe the types of capacitor that exist and state why they are used.
- Recognise and use capacitor colour codes.
- Gain an understanding of how capacitors are sized.

As with resistors, there are a large number of different types of capacitors and it is important that you learn to recognise them. Getting it wrong with a capacitor can lead to damage of the circuit and the component.



A capacitor is a device that is capable of storing an electrical charge. It is made up of two conductors separated by an insulator called a dielectric. The name that we give to a particular capacitor is based on the type of dielectric used.

The measure of a capacitor's value is given the term ***farad***. The farad is a very large value and it is rare to find capacitors having values of more than 1 farad, although there are some. However, the most common ways of describing capacitors is either using the ***micro-farad (µF)*** or the ***pico-farad (pF)***. Either way these values are very small.

The important thing that has to be remembered with capacitors is that they have a working voltage. If you exceed this figure then you will destroy the component. If the capacitor is being connected into an a.c. circuit then you should take into account, not only its rms value but also its peak value.

We'll take each type of capacitor in turn.

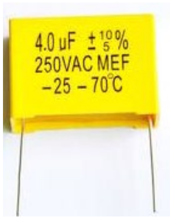
Types of capacitor

Ceramic disc

This type has a working voltage of up to 750 V d.c. and capacitance values of between 2.2 pF and 0.1 μF. It has excellent stability and a tolerance of ±2 %, and it is used in high frequency circuits.

Notice the shapes?

Polyester



This type of capacitor is used in general circuits although not high frequency circuits. It has a working voltage of 250 V d.c. and capacitance values of between 10 000 pF and 20 μF.

Paper

This type of capacitor has a working voltage of up to 600 V d.c. and has capacitance values of between 1 μF and 10 μF.

They are used in fluorescent lighting circuits, motors etc. particularly for power factor correction.

Air

Air capacitors have capacitance values ranging from 50 pF to 1 000 pF. They are used where a variety of capacitances are required such as in radios etc. The variation in capacitance values allows specific frequencies to be picked up.

Polystyrene

This type has a working voltage of 150 V d.c. and capacitance values of 10 pF to 22 000 pF. It is used in radio frequency circuits and has a tolerance of ±1 % to ±5 %.

Mica

This type of capacitor is expensive but very accurate, within 1% and has excellent stability. It comes in a range of capacitance values from 2 pF to 10 000 pF, and has a working voltage of up to 350 V d.c. It is used in tuned circuits and filters.

All the capacitors up until now have been the types that are called ***non-polarised***. Effectively this means that it doesn't matter which way around the capacitor is connected. The non-polarised type has small capacitance values.

The other types of capacitors are called ***polarised*** or ***electrolytic*** capacitors.

Electrolytic

Electrolytic capacitors are used where large values of capacitance are required in a small space. They usually have values ranging from 0.1 µF to 10 F! The largest types are used in computer memory retention.

Axial type Radial type

These capacitors come in a variety of shapes and sizes, but it is critical that they are connected the right way round. All electrolytic capacitors have some means of stating which end is positive and which is negative. With some it can be arrows pointing to the negative terminal, with others it can be a ridge set at the positive end. Whatever way is used it is essential that these capacitors are only used on d.c. circuits and are always connected the right way round, even when testing them!

Although electrolytic capacitors have their values printed onto them, many of the non-polarised types use colour coding similar to that used by resistors.

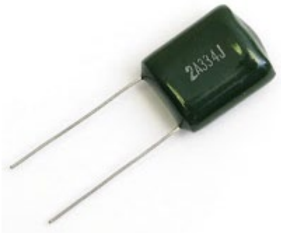
Tantalum bead

This is a type of electrolytic capacitor and look like a small raindrop.
These are very sensitive to reverse voltages and will be damaged by voltages as low as 0.3 V, however they do have similar advantages to electrolytic capacitors.
The + sign denotes the positive lead.

These are very sensitive to reverse voltages and will be damaged by voltages as low as 0.3 V, however they do have similar advantages to electrolytic capacitors.

Decoding capacitors.

Throughout your career you will come across many types of capacitor, such as those that have already been shown, but what is needed now is how to decode them, i.e. get their value.



For example the code on this polyester film capacitor is 334J.

What value is that?

See the end of this section for the answer!

Except for electrolytic and other big capacitors, all the other capacitors values are printed in coded form only. There are two types of coding method used by the capacitors manufacturers.

1. Colour Coding
2. Number Coding

The unit of Capacitance is the Farad. Capacitors are usually measured in microfarads (µF).

However, before going onto the capacitor codes let us consider unit conversion between equivalent values for pico, nano and micro farads.

Pico Farads (pF)	Nano Farads (nF)	Micro Farads (µF)
1	0.001	0.000001
10	0.01	0.00001
100	0.1	0.0001
1000	1	0.001
10000	10	0.01
100000	100	0.1
1000000	1000	1
10000000	10000	10
100000000	100000	100

From the table above, a 1 000 pF capacitor could be stated as being 10 nF or 0.01 µF.

Colour Coding

Mostly the un-polarized mica or polyester molded capacitors are colour coded. These coding are similar to the colour code used for the resister.

The colour is noted from top to bottom. The first two colours are the significant digits, the third colour is the multiplier the 4^{th} one is the tolerance and the fifth one is voltage rating.

Consider the table below.

Colour	1^{st} Digit	2^{nd} Digit	Multiplier	Tolerance (pF)	Tolerance *	Voltage
Black	0	0	1	±20%	±2.0 pF	100
Brown	1	1	10	±1%	±0.1 pF	200
Red	2	2	100	±2%	±0.25 pF	300
Orange	3	3	1 000	±3%	-	400
Yellow	4	4	10 000	±4%	-	500
Green	5	5	100 000	±5%	±0.5 pF	600
Blue	6	6	Not used	-	-	700
Violet	7	7	Not used	-	-	800
Grey	8	8	10^8	+80%, -20%	-	900
White	9	9	10^9	±10%	±1 pF	1 000

You can see the chart has two tolerance values in it. While calculating the capacitance if the resulting value is greater than 10 pF means the first tolerance column is considered. If the resulting value is less than 10 pF means the second tolerance column is taken. There is a significant difference between the two methods, so don't miss them while decoding the capacitor.

Capacitor Value = [Digit1 Digit 2 x multiplier] ± Tolerance

Let see a small example for this

Here we have one colour coded un-polarized polyester capacitor. It has four colours and their values are tabulated below.

<table>
<tr><td>Orange</td><td>1st & 2nd Digit</td><td>33</td><td rowspan="4">Capacitor value is;
$33\times10^4=0.33\mu$
$0.33\mu F \pm 10\%, 300V$</td></tr>
<tr><td>Yellow</td><td>Multiplier</td><td>10^4</td></tr>
<tr><td>White</td><td>Tolerance</td><td>±10%</td></tr>
<tr><td>Red</td><td>Voltage</td><td>300 V</td></tr>
</table>

Number Coding

The ceramic capacitors have number coding on it. Number codes are similar to the colour code but they are trickier and can confuse easily. Most of the capacitors have three numbers and some of them have two numbers. The ceramic capacitor is always numbered in **PICO FARADS** unless it is mentioned with special letters (these cases are explained in the worked examples). It may have alphabets for referring the tolerance, voltage range, thermal coefficient and dielectric material. The first two digits are the significant digits and the third digit is the multiplier.

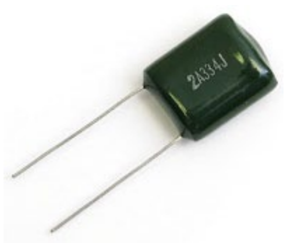
The tolerance code chart and multiplier chart are given below.

Code	Tolerance	Code	Tolerance
A	±0.05 pF	K	±10%
B	±0.1 pF	L	±15%
C	±0.25%pF	M	±20%
D	±0.5 pF	N	±30%
E	±0.5%	P	-0 to 100%
F	±1%	S	-20 to 50%
G	±2%	W	-0 to 200%
H	±3%	X	-0 to 40%
J	±5%	Z	-20 to 80%

3rd Digit	Multiplier
0	1
1	10
2	100
3	1 000
4	10 000
5	100 000
6	Not used
7	Not used
8	0.01
9	0.1

The only difference between the colour coding and number coding is, the numbers are directly printed to represent the significant digits and the other parameters.

Example



Back to our original question, what is the value of this capacitor if its markings are 334J?

33 are first two significant digits, 4 is the multiplier and J is the tolerance value. Using the charts above.

Capacitance value is = 33 with 4 zeros ± 5% pF = **330 000 ± 5% pF**

Further examples

Case 1: A capacitor is marked as 5p6. It means 5.6 pF (similar to the resistor marking)

Case 2: A capacitor is marked as 2n2. It means 2.2nf which is equal to 2200 pF

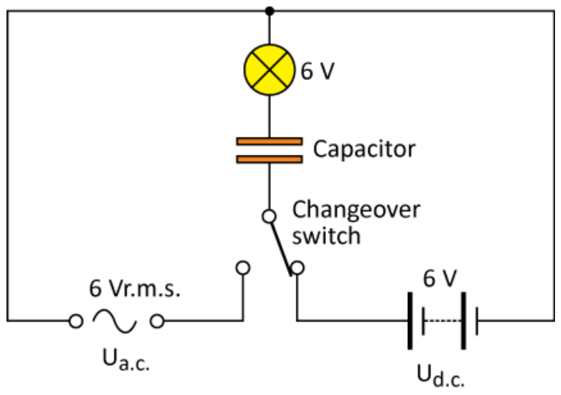
Case 3: A capacitor is marked as .1. It means 0.1 µF *(Remember, marking starting with a decimal always represents microfarads)*.

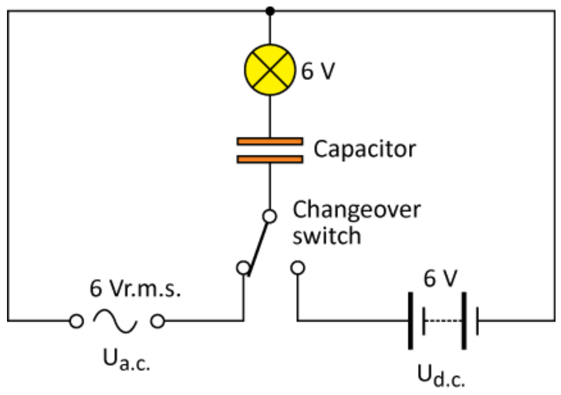
Case 4: A capacitor is marked as .33. It means 0.33 µF

Case 5: A capacitor is marked as 2p2B. It means 2.2 pF ± 0.1 pF.

Capacitors connected to a d.c. source.

Let's consider how capacitors work when dealing with a.c. and d.c. supplies. Look at the switch positions below.



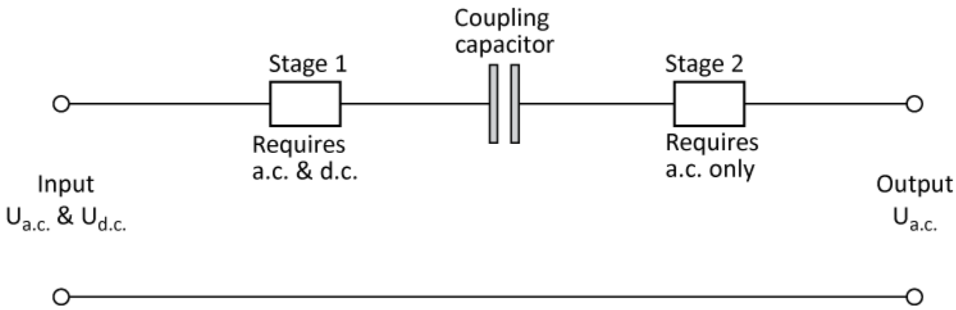


When a d.c. supply is connected to the lamp, a small flicker will be created as the capacitor charges up. As the capacitor charges then the lamp will dim until it goes out. The capacitor is charged thereby blocking d.c.

When connected to the a.c. supply, the lamp will be at full brightness as the capacitor permits a current to flow as it charges and discharges every half-cycle of the a.c. supply.

When we recognise that a capacitor blocks direct current and allows alternating current to pass we can use them for coupling and decoupling in amplifier circuits.

When we connect a capacitor in series with two loads then the capacitor will allow the a.c. part of a complex signal to pass but will block any stray d.c. that we don't want transmitted to the next part of the circuit.



I have already stated that a capacitor is a device used for storing a charge of electricity however there are a couple of other uses that will be considered, especially when we look at power supplies and timing circuits later on in this study book.

Exercise 2.

1. What does a capacitor do?

2. What are the two categories of capacitor?

3. What are the issues associated with using electrolytic capacitors?

4. Work out the following capacitor values from the colour codes.
   i) Red, red, yellow, black, red.
   ii) Blue, grey, orange, white, yellow.

5. A capacitor is marked as 5p6J, what is its value range?

6. A ceramic capacitor is marked as 106.G, what is its value range?

7. If we wanted to block the d.c. component of a signal what could we do?

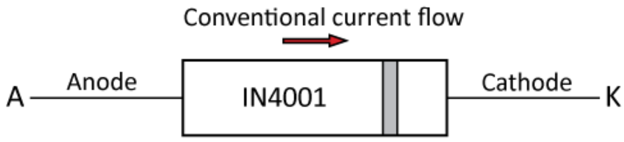
8. A circuit has two ceramic disc capacitors connected in series. They have markings 345 and 105 stamped on them. It is intended to replace them with one ceramic disc capacitor, what marking should be stamped on it. (Ignore the tolerance letter).

3: Semi-conductors 1: Diodes

In this session the student will:

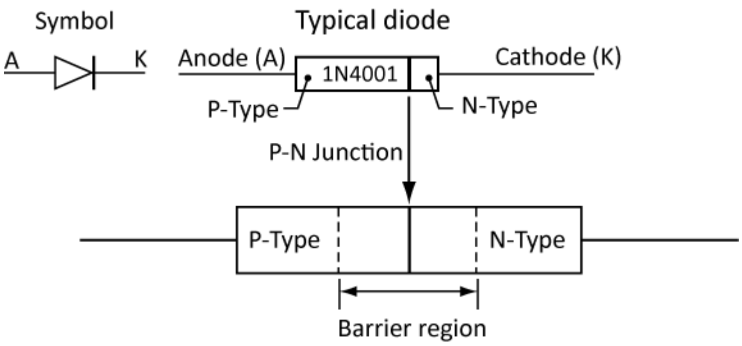
- Gain an understanding of how diodes work and why they are used.

A diode is a specialized electronic component with two electrodes called the *anode* and the *cathode*. The silver band is next to the cathode and therefore shows the user which way to connect it into the circuit for the function it is to perform.



IN4001; Has a P.I.V. of 50 V with a maximum forward current of 1 A

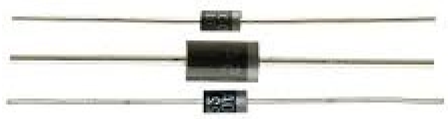
Most diodes are made with semiconductor materials such as silicon or germanium. The silicon and germanium is doped with impurities to give two distinct properties which give different conducting characteristics. These are called p-type and n-type materials. Such an arrangement is shown below.



All we are concerned with at the moment is that the positive lead is connected to the anode and the negative lead is connected to the cathode. The forming of the P & N type material creates a barrier potential which the current has to cross.

Diodes can be used as rectifiers, signal limiters, voltage regulators, switches, signal modulators, signal mixers, signal demodulators, and oscillators.

Some typical shapes of a diode are shown below.



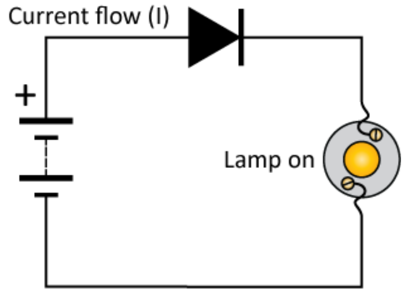
Small rectifier or signal diodes

The tab or the stud can be the anode or cathode.

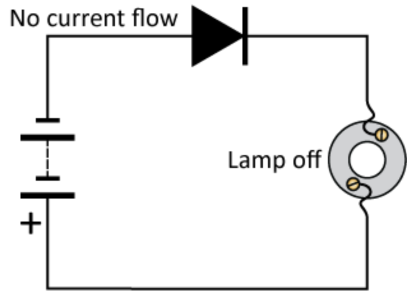
Heavy duty diode

Why is it important that we connect the diode in the manner mentioned above?

The fundamental property of a diode is its ability to conduct electric current in only one direction.



a) Diode forward biased, lamp lit

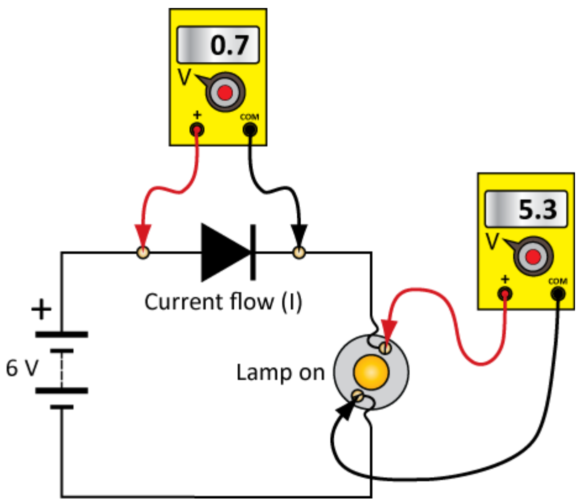


b) Diode reversed biased, lamp dark

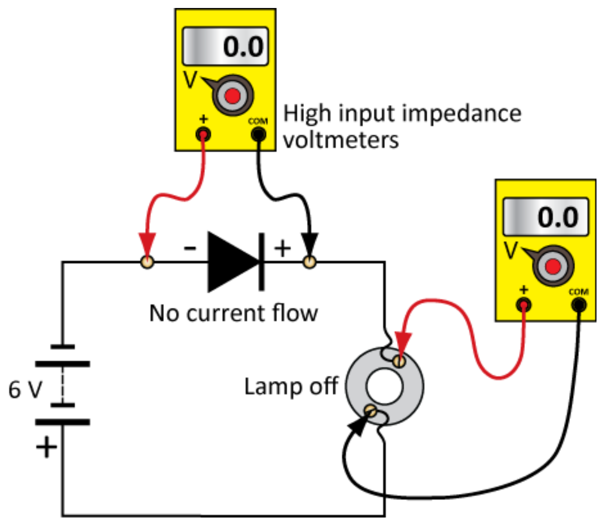
When the anode is connected to the positive of a supply source with respect to the cathode the diode is said to be forward biased. The diode will allow current to flow. See a) above.

When the anode is connected to the negative of a supply source with respect to the cathode the diode is said to be reversed biased. The diode will now not allow current to flow. See b) above.

However, for current to flow the anode voltage must be larger than the cathode by approximately 0.7 V. This is the amount that is dropped across a diode when it is operating. This voltage is called the forward breakover voltage.



Diode forward biased showing 0.7 V dropped across the diode and 5.3 V across the lamp.



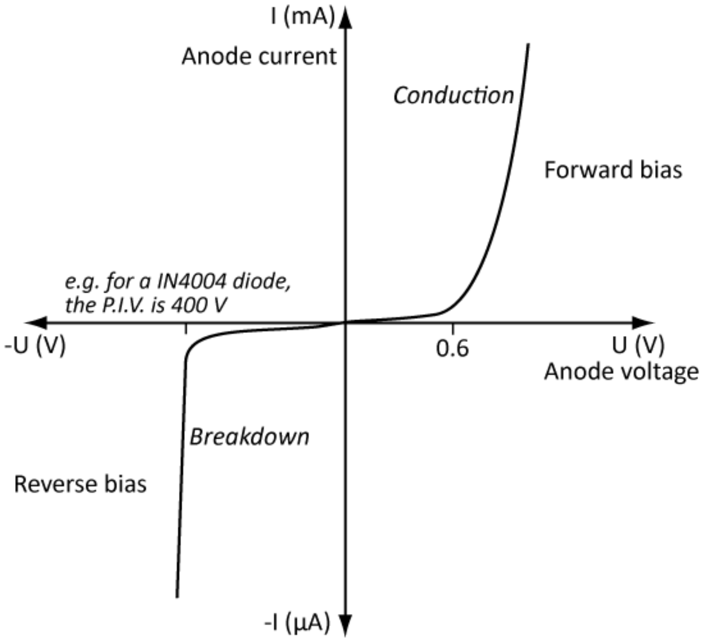
Diode reverse bias showing no current flow and hence no potential difference across the lamp.

Semiconductor diodes can be designed to produce direct current (d.c.) when visible light, infrared transmission (IR), or ultraviolet (UV) energy strikes them. These diodes are known as photovoltaic cells and are the basis for solar electric energy systems and photosensors.

Yet another form of diode, commonly used in electronic and computer equipment, emits visible light or IR energy when current passes through it. Such a device is the familiar light-emitting diode (LED). These will be discussed later.

An important consideration when choosing a diode is the amount of voltage it can withstand when reverse biased. If too much voltage is applied in this situation, we can end up destroying the component. When a diode reaches this point, we say that it has reached its ***breakdown voltage***.

The graph below shows a generalised shape of what will happen when a diode is connected with forward and reverse bias.



To the right (forward bias) you can see that as the voltage increases up to approximately 0.6 -0.7 V (silicon) or 0.2 V (germanium) there is only a small amount of current flow. This is due to the odd electron moving when it shouldn't.

When we get more than 0.6 V across the diode, then the diode allows current to flow and is effectively '***turned on***'.

If we were to connect the diode in reverse mode and increased the voltage beyond say 400 V, then we would destroy the diode. However, if we could do this without destroying the diode we would get the shape that we see at the left of the graph.

We can see that again small amounts of current flow (leakage current). However, when a particular voltage is reached called the ***peak inverse voltage***[1] (**PIV**), large amounts of current flow. At this point, the diode has been destroyed, unless it happens to be a zener diode, which will be discussed next.

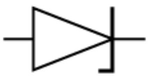
1 Also called the breakdown voltage or the maximum repetitive reverse voltage.

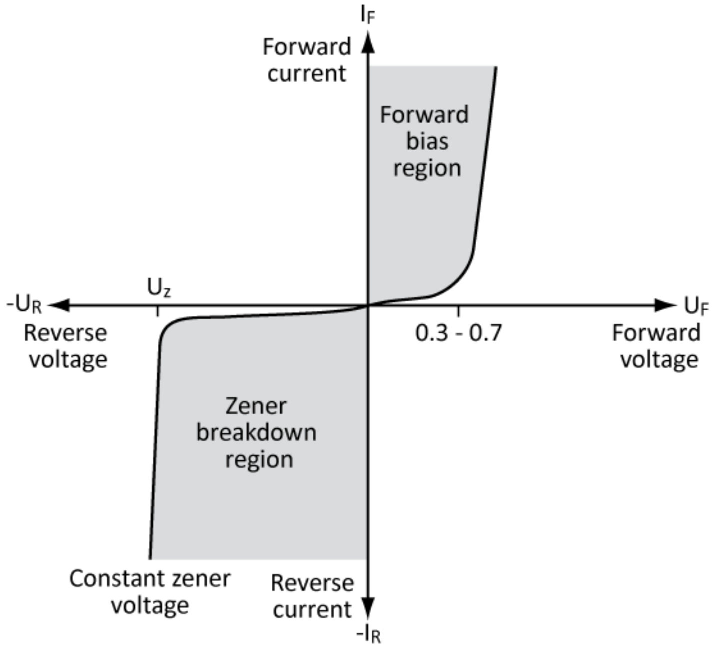
Zener diode

A zener diode is a special diode that is designed to be connected in reverse mode. Although it behaves like a standard diode when it is connected forward biased, it is not used for this. Its particular quality is that it can be connected in reverse bias, and for a wide range of voltages, it remains set at a constant value.

The symbol for a zener diode is shown below along with its operating characteristic.

Zener diode symbol





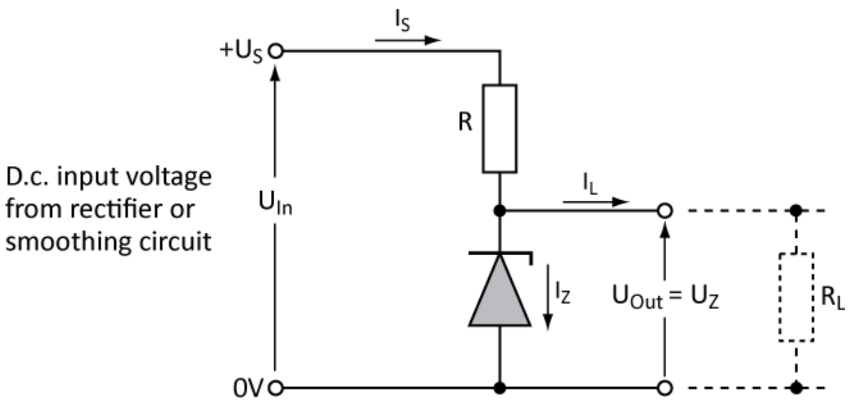
In this graph, we are only really interested in the reverse bias region.

Notice that the breakdown voltage is at a very precise point and that even when the reverse voltage is increased, the voltage across the zener stays the same.

This type of diode is used for setting voltage levels at a particular breakdown voltage, making the zener diode is the simplest types of voltage regulator, and the point at which a zener diode breaks down or conducts is called the "Zener Voltage" (U_Z).

This breakdown voltage point can range from less than one volt to hundreds of volts.

A typical circuit for a zener diode is shown below.



In this circuit the zener is placed in the circuit to give a set output voltage.

A zener diode is always operated in its reverse biased condition. A voltage regulator circuit can be designed using a zener diode to maintain a constant d.c. output voltage across the load in spite of variations in the input voltage or changes in the load current. The zener voltage regulator consists of a current limiting resistor R connected in series with the input voltage U_S with the zener diode connected in parallel with the load R_L in this reverse biased condition. The stabilized output voltage is always selected to be the same as the breakdown voltage U_Z of the diode.
With no load connected to the circuit, the load current will be zero, ($I_L = 0$), and all the circuit current passes through the zener diode which in turn dissipates its maximum power.

How to determine the size of the series resistor R.

Example
A 5.0 V stabilised power supply is required to be produced from a 12 V d.c. power supply input source. The maximum power rating P_Z of the zener diode is 2 W. Using the zener regulator circuit above calculate:

a) The maximum current flowing through the zener diode.
b) The minimum value of the series resistor R.
c) The load current I_L if a load resistor of 1 kΩ is connected across the zener diode.
d) The zener current I_Z at full load.

Solution

a) Max zener current; $I_Z = \frac{Zener\,wattage}{Zener\,voltage} = \frac{2}{5} = 400\,mA$

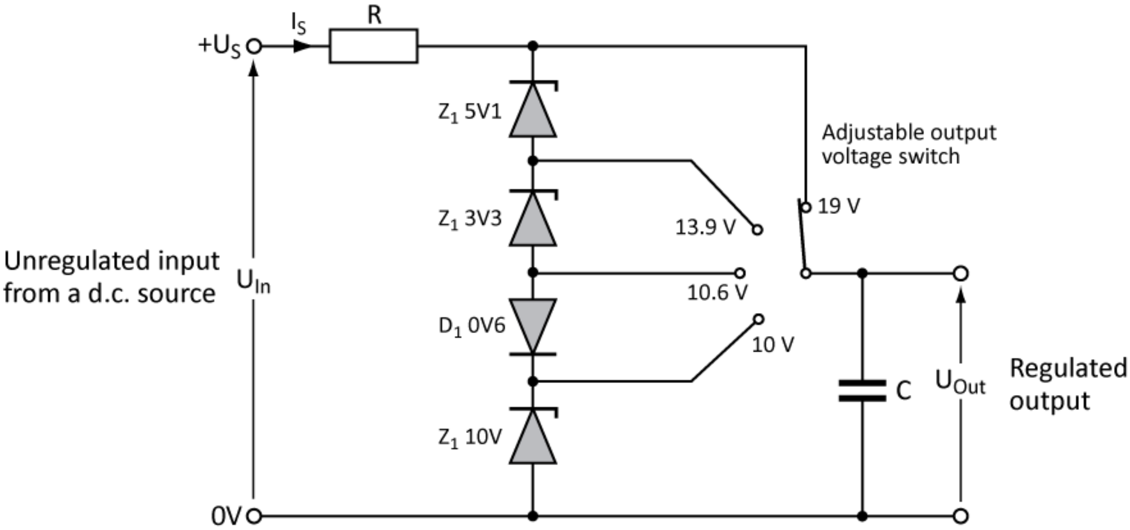
b) Value of resistor R; $R = \frac{Supply\,voltage - zener\,voltage}{Zener\,current} = \frac{12-5}{0.4} = 17.5\Omega$

c) Load current I_L; $I_L = \frac{Zener\,voltage}{Load\,resistance} = \frac{5}{10^3} = 5\,mA$

d) The zener current; $I_Z = I_S - I_L = 400 - 5 = 395\,mA$

Zener Diodes Connected in Series

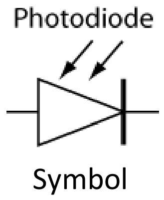
As well as producing a single stabilised voltage output, zener diodes can also be connected together in series along with normal silicon signal diodes to produce a variety of different reference voltage output values as shown below.

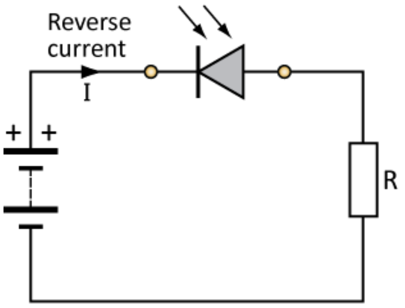


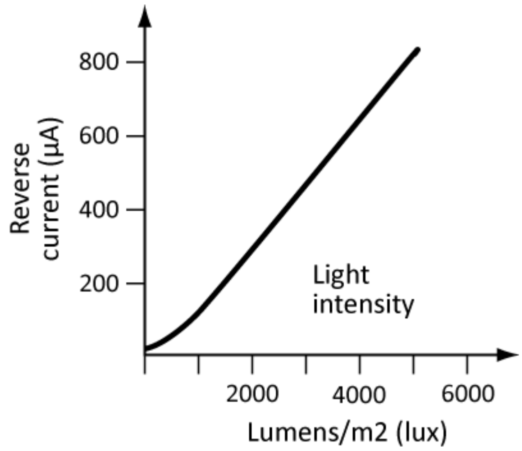
The values of the individual Zener diodes can be chosen to suit the application while the silicon diode will always drop about 0.6 - 0.7V in the forward bias condition. The supply voltage, U_{in} must be higher than the largest output reference voltage and in our example above this is 19 V.

Photodiodes

A photodiode consists of an active p-n junction which is operated in the reverse bias mode. When light falls on the junction, reverse current flows which is proportional to the illuminance.







The mechanism of the photodiode is like that of a (miniaturized) solar cell. Their response time is fast, in the order of nanoseconds. As light detectors, they are reverse-biased - the reverse current is linearly proportional to the illuminance striking the diode. They are not as sensitive as a photo-transistor, but their linearity can make them useful in simple light meters

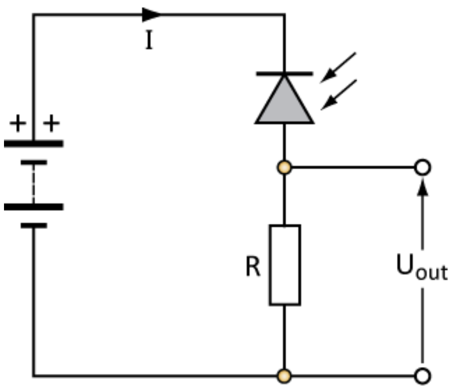


Figure 1

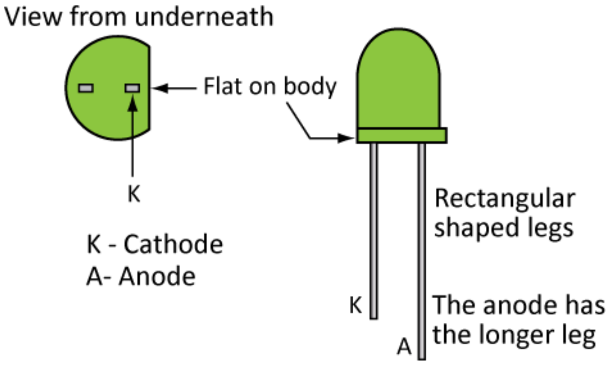
The simplest electronic circuit (figure 1) for detecting optical powers with a photodiode consists of a voltage source and a resistor *R*. The voltage source provides some bias voltage to the photodiode, and the resistor converts the generated photocurrent into a voltage, which can then be processed further.

In dark conditions the reverse current is very small giving a low out voltage. In daylight conditions the reverse current is high causing a rise in output voltage. On its own, the photodiode only has limited applications, but when used with amplifiers and other electronic conditioning elements its use is greatly increased. The phototransistor is a more sensitive light to current transducer and this will be discussed later on.

Light emitting diode

This is the last diode we need to consider in this section, and although it has been dealt with before we shall give it another look.

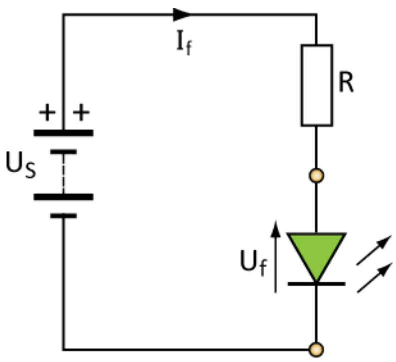
LEDs come in a variety of colours (red, green, yellow, orange) and are used as low current indicators. The LED doesn't emit light when it is reverse biased.



The LED shown has two legs, one shorter than the other. They are designed like this on purpose for you to know which way round to connect them. The diode also has a flattened side, which is always next to the cathode, just in case you cut them to the same length!

The anode and the cathode are the names that we give to the two legs. The anode is connected to the supply side and the cathode is connected to the load side in any circuit. Have a look at the diagram below.

Here we have a diode protected by a resistor connected to a supply.



- ***U_S*** is the supply voltage, ***U_F*** is the voltage dropped across the diode and ***I_F*** is the current through the diode.
- ***U_F*** is commonly about 2.2 V; I_F is 5.25 mA (red diode), 10-40 mA (green and yellow diodes).
- ***R*** is found using the following equation.

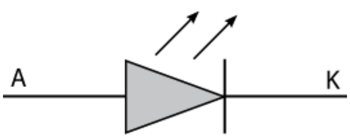
$$R = \frac{U_S - U_F}{I_F}$$

Example

If the supply were 6 V, U_F were 2.2 V and I_F 10 mA, the value of R would be:

$$R = \frac{U_S - U_F}{I_F} = \frac{6 - 2.2}{10 \times 10^{-3}} = \frac{3.8}{10 \times 10^{-3}} = \underline{\underline{380\Omega}}$$

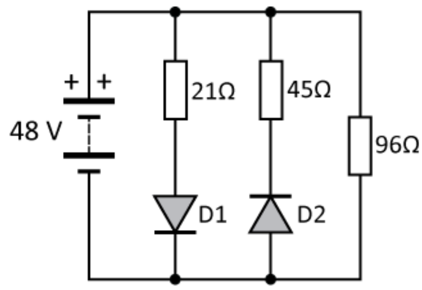
You can see how all this works out hopefully.



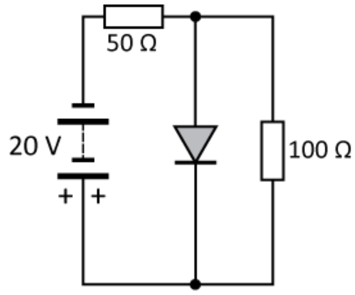
This IEC 60617 (formerly BS EN 60617) symbol shows how an LED is labelled.

Exercise 3.

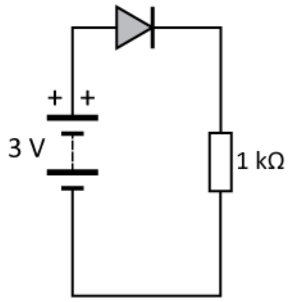
1. The two diodes shown in the circuit below can be assumed to have a forward resistance of 3Ω and an infinite reverse resistance. Calculate the currents flowing in each branch of the circuit,
   a) When the battery is connected as shown
   b) When the battery is reversed



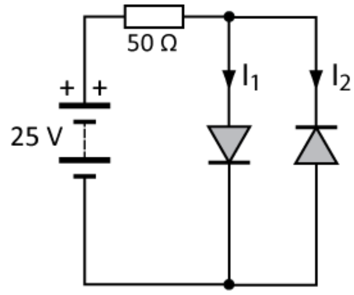
2. The silicon diodes shown in the circuit diagrams below are typical and have the characteristics as shown in the graph of page 24. Calculate;
   a) The current flowing in the 100 Ω resistor of circuit 1
   b) The voltage across the 1 kΩ resistor of circuit 2
   c) The current I_1 and I_2 of circuit 3.



Circuit 1



Circuit 3



Circuit 3

3. State the difference between a general purpose diode and a zener diode.

4. A load requiring a 20 V stabilised supply is fed from a 50 V d.c. source. A zener diode having a voltage rating of 20 V with a 2 W power rating is to be used.
   a) Determine the value of the series resistor required.

   Challenging part

   b) If the zener stabilises down to 5 mA, calculate the greatest and least supply voltage in which the output voltage can remain stabilized. The load has a value of 1 kΩ.

5. Determine the value of a resistor to be connected in series with a blue LED which requires 3.6 V and 30 mA to achieve sufficient brightness if connected to a 12 V d.c. source.

4: Semi-conductors 2: Rectification, Thyristors and Triacs

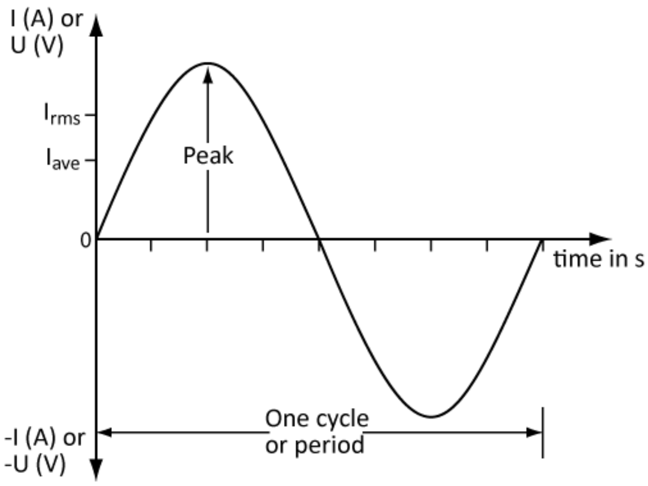
In this session the student will:

- Gain an understanding of how rectification of an a.c. waveform occurs.
- Describe what thyristors are and how they relate to rectification.

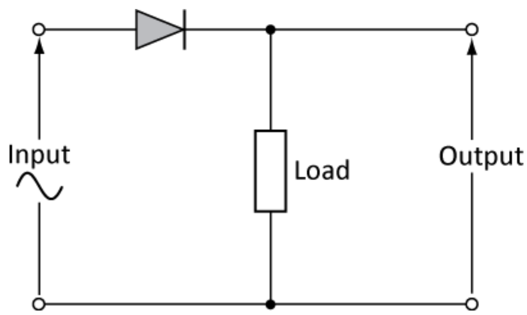
In the last session we considered the nature of diodes in some detail. In this session we are going to consider a further use for them in rectification circuits, and then consider how thyristors – seen as switchable diodes – can be used for that same purpose.

Half-wave rectifier

So far we have only considered what happens with a diode when it is connected to a d.c. supply. With an a.c. supply things change slightly. We accept that a diode will only conduct when it is forward biased, however with an a.c. supply we have the diode alternately connected forward and reverse simply by the changes in the sine wave.



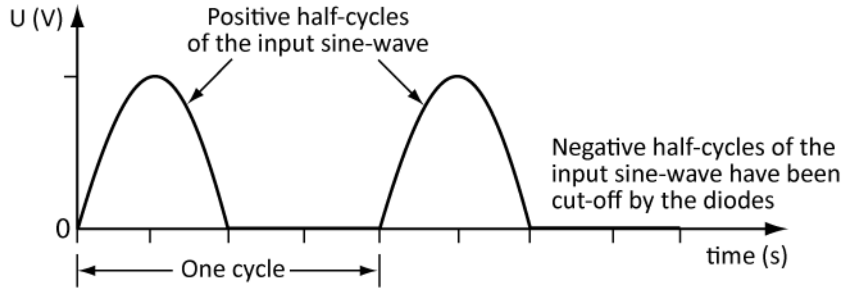
Supply waveform



Basic half-wave rectifier circuit

You can see from the diagram that a single diode is connected in series with the load. An a.c. supply is connected to the circuit. The diode, on the positive half-cycle, will conduct. Current will flow because the diode is correctly biased. However, on the negative half-cycle, the diode will not conduct; this is because the diode is now reverse biased. Have a look below.

Output waveform from single diode rectifier



You can see that half of the waveform has been eliminated. This reduces the effectiveness of the rectification, and the d.c. supply is far too 'lumpy'.

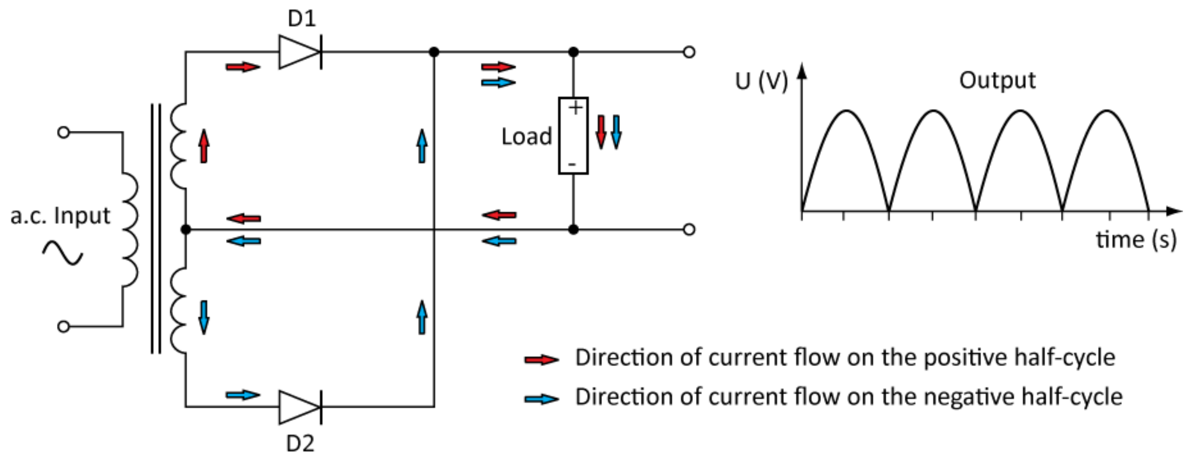
To this end, we need to fill in the gaps and for this to happen we need to look at full-wave rectification.

Full-wave rectifier

There are two ways in which diodes can be used to gain full-wave rectification. The combination of transformer, diodes, resistors and capacitors enable us to get a stable d.c. power supply from an a.c. input.

Split-phase

Take a look at the diagram below.



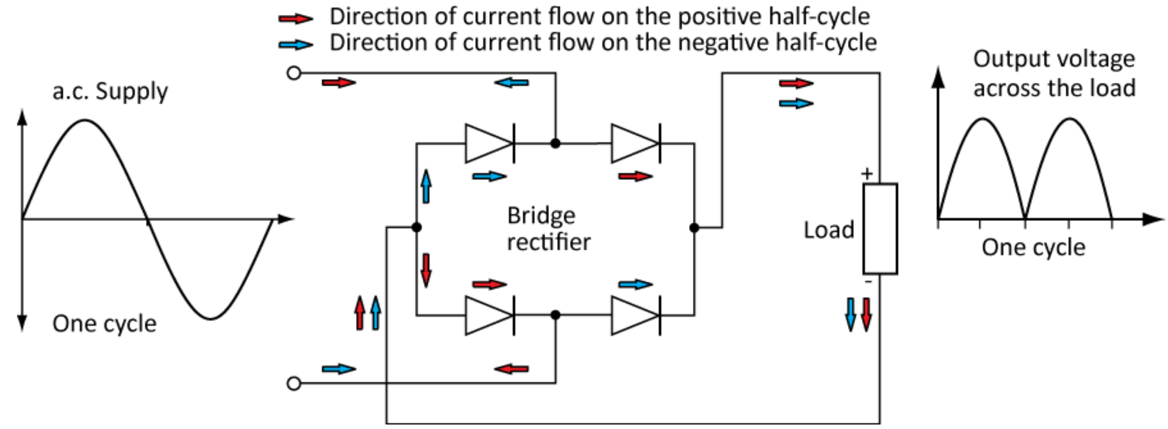
Here we not only see the circuit, but also the current directions on each half cycle of the a.c. supply. You can see that two diodes are used along with a centre-tapped transformer.

Having the transformer centre-tapped allows for a positive and negative voltage to be supplied through the diodes in turn. This allows D1 to permit current to flow, followed by D2 for the negative part of the cycle.

This type of arrangement is seldom used as the peak inverse voltage (PIV) is twice as much as for the normal full-wave circuit. In addition the transformer is expensive with each winding being required to carry the full load.

Bridge rectifier

Below is a diagram of a full-wave bridge rectifier.



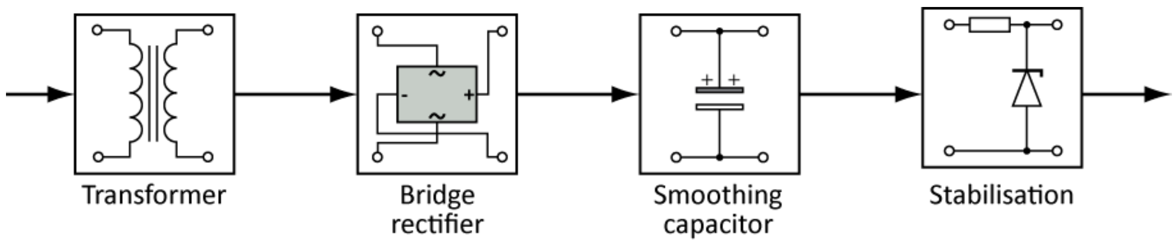
We have our a.c. supply coming in and we have a d.c. supply being provided to the load. The directions of current are shown on the diagram for each half-cycle of the a.c. waveform.

Summary

Rectification, smoothing and stabilising

The block diagram below shows the arrangement of the route in getting a d.c. stabilised supply from an a.c. source.

So, what do all these components do? We'll look at each part of the block diagram in turn.



The transformer reduced the a.c. supply from a probable 230 V to a more useable value for the particular load.

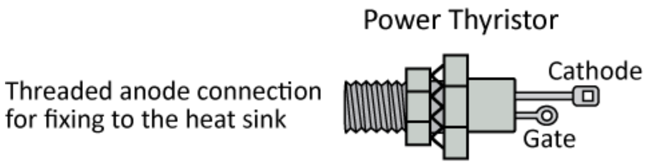
The bridge rectifier converts the a.c. into unsmoothed d.c. The output at this point is still too 'lumpy' i.e. it has a lot of a.c. ripple. So how do we smooth this out?

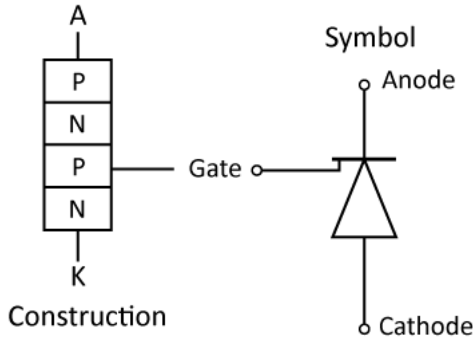
The purpose of the smoothing capacitor is to reduce the a.c. ripple. It does this by discharging its stored energy when the supply falls, then charges again when the supply rises. This point in the block diagram is probably good enough for battery chargers but not where fine control is required.

As discussed previously the zener diode stabilises the output to the familiar flat line associated with pure d.c.

Thyristors or SCR (silicon controlled rectifier)

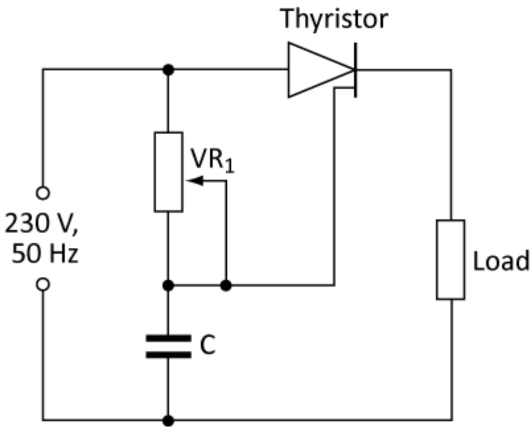
A thyristor very simply acts as a switched diode. It is made up from n and p-type material formed into a sort of sandwich. In fact, it is a ***pnpn*** device.





It has three pins called a ***cathode***, ***anode*** and ***gate***.

When the gate has a supply applied to it, the thyristor turns on. It then remains on until the supply voltage passes through zero or reverses. Have a look below.

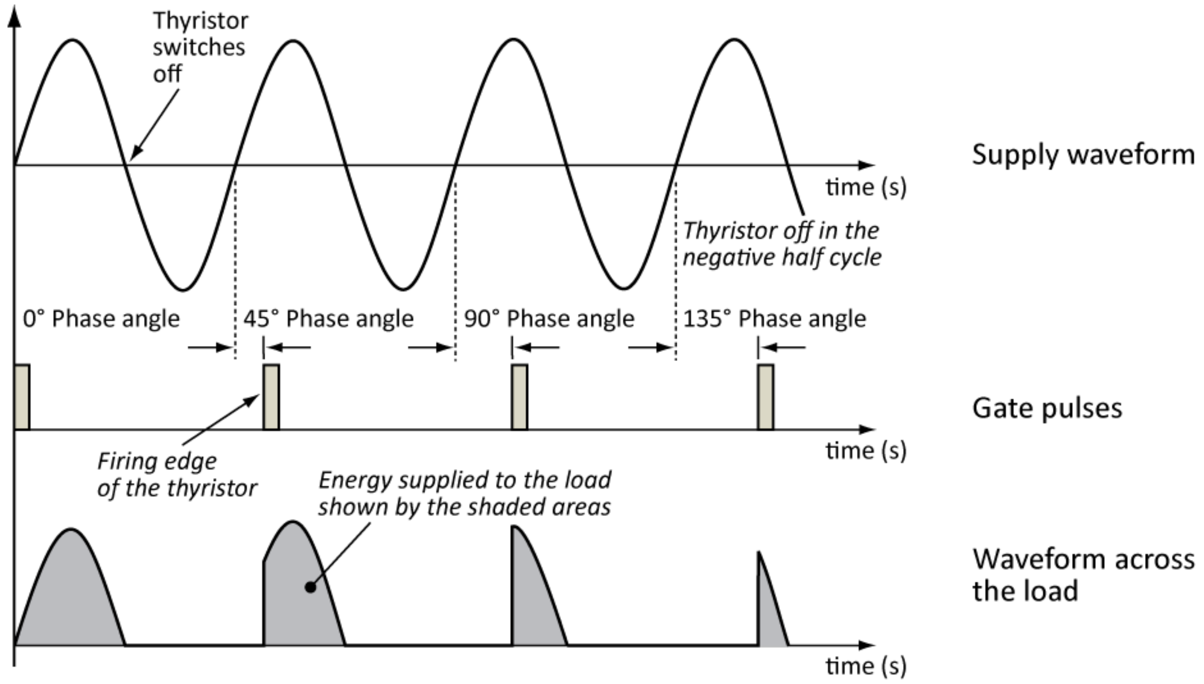


Notice the series connection of the resistor and capacitor. From previous lessons you have learnt that a capacitor charges up and the rate at which it charges is dependent upon the supply voltage. If a resistor is placed in series with a capacitor the charging rate can be controlled, more so if the resistor is a variable one.
This forms a very simple but effective timing circuit.

You must remember that, as with the diode, the thyristor only conducts when it is forward biased and when the gate has a signal to it. When the supply is interrupted to the anode the thyristor is turned off and cannot conduct until another signal voltage is applied to the gate. The thyristor will also turn off if the current flowing through it drops below a set value called it *holding value*.

A separate circuit is generally required to provide a signal to the gate of the thyristor. In the circuit above, we are using a capacitor/resistor network. This arrangement provides a point in time when the right voltage is reached to turn on the thyristor.

A thyristor is naturally turned off as the a.c. positive half-cycle passes through zero (0). This means that there is no additional circuitry needed.



The gate pulses switch the thyristor on at certain times in the positive half of the cycle and permits current to flow. When the supply waveform passes through zero the current stops flowing and the thyristor then acts like a reverse-biased diode.

The amount of energy that a thyristor will permit to flow is limited. Remember that it is a switched diode, and as such will only allow the positive half-cycle of a supply to flow. This means that at least half of the energy is not used.

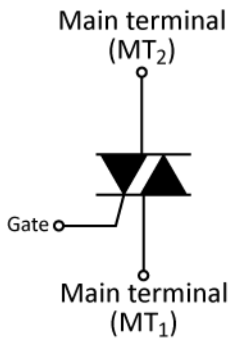
Thyristors are used to control the amount of current being supplied to a component or load. They are used to control the brightness of a lamp (dimmer switch), or the speed of a motor.

To make use of both halves of the cycle, a triac along with a diac is used and this will now be discussed.

Triac and diac

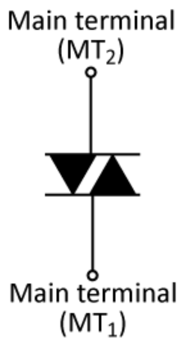
A triac differs from a thyristor in that it can conduct on both halves of an a.c. waveform. It will still shut off if the amount of current flow through the device is less than it requires to maintain conduction, which is called the holding current. It still needs a signal on its gate to put it into the conduction mode for both the positive and negative periods of the a.c. cycle.

The triac is not used alone; it normally has a diac forming part of the gate circuit. A diac can best be described as a bi-direction diode. As a normal diode needs at least 0.6 -0.7 V to make it conduct, the diac requires about 30 V. This is a good thing because triacs are notorious for not firing symmetrically. This means these devices usually won't trigger at the exact same gate voltage level for one polarity as for the other. Using a diac means it gets a definite pulse onto the gate of the triac; it stops the slow rising voltage you normally see with a resistor capacitor network.



Triac symbol

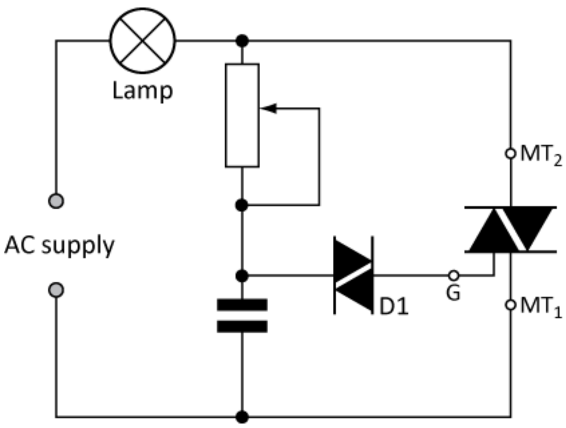

Typical triac



Diac symbol


Typical diac

TRIACs are usually seen in simple, low-power applications like household dimmer switches.



A simple lamp dimmer circuit is shown here, complete with the phase-shifting resistor-capacitor network necessary for after-peak firing.
It does matter which way the triac is connected despite it being able to conduct in both directions, the wrong way round and it will not conduct.

Exercise 4.

1. In the circuit of Fig E4-1, the transformer produces a peak secondary voltage of 20 V. Sketch the waveform appearing across the load R_L indicating all values on each cycle. Assume the diodes are ideal.

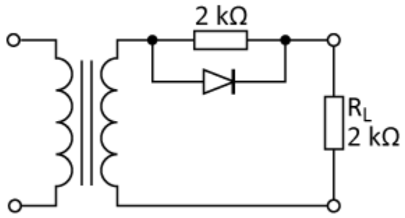


Fig E4-1

2. In the circuit of Fig. E4-2 below, the supply applied to terminals A-B is shown to be 70.7 V_{rms}. Sketch the waveform appearing at the output terminals C-D showing the peak values of voltage on each cycle. Assume the diodes are ideal.

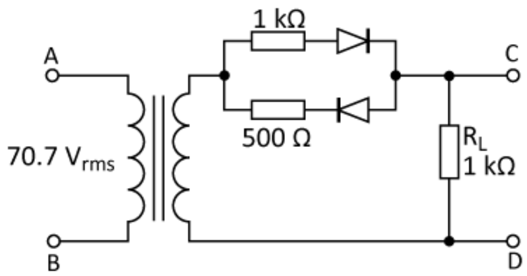
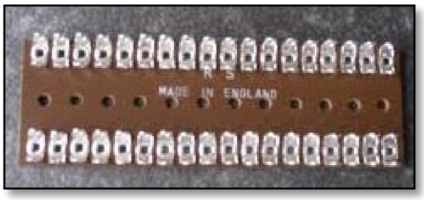


Fig. E4-2

3. Using a piece of tag strip of the type shown in Fig E4-3 below, construct a stabilised d.c. supply from the secondary terminals of a transformer.



Construct the circuit using 4 diodes, a capacitor, a resistor and a zener diode.

Fig. E4-3

4. For the circuit of Fig. E4-4, describe its operation and state how it can be improved.

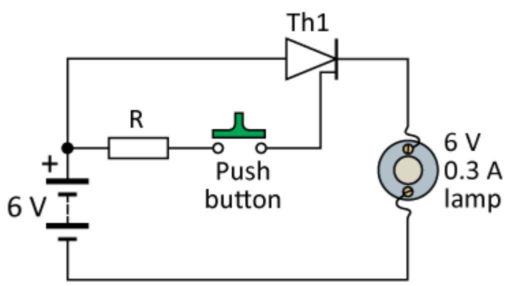


Fig. E4-4

5: Semi-conductors 3: Transistors & Phototransistors

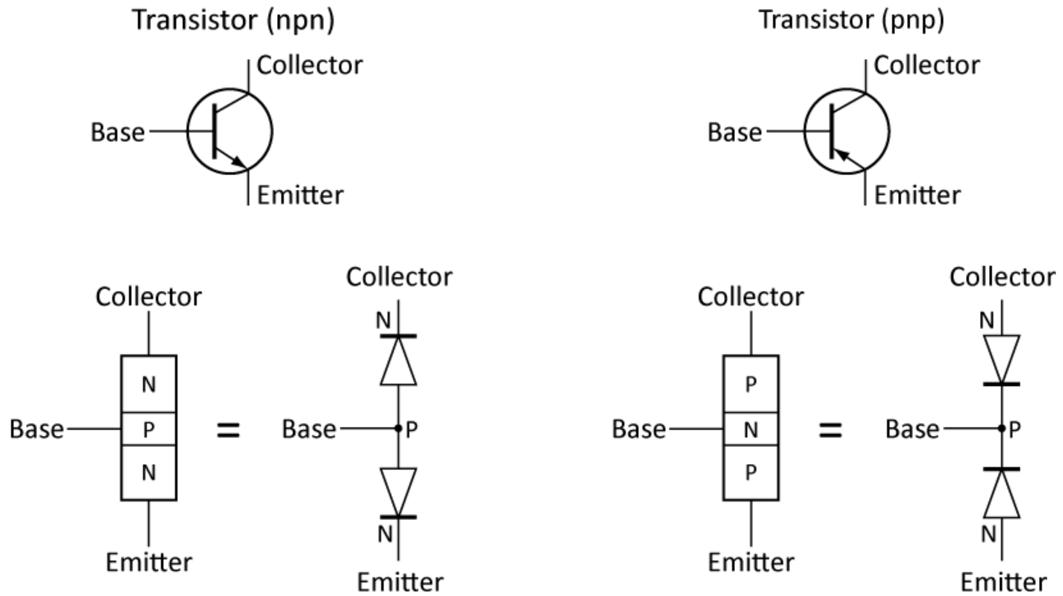
In this session the student will:

- Gain an understanding of what transistors and phototransistors are and how they work.
- Gain an understanding of how a transistor operates as an amplifier.

In this session we are going to discuss the most famous semiconductor device – the transistor. The transistor has literally changed the world. We will then go on to look at the phototransistor which is similar to the photodiode but is more sensitive in its operation.

We have already seen that the diode acts like a one-way street: only allowing current to flow in one direction, and is a simple p-n junction. We have seen that the thyristor is a controlled diode and once fired will conduct until the anode connection is isolated from the supply.

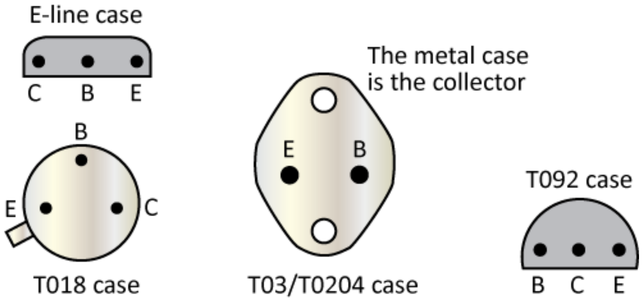
The transistor is a semiconductor, not with a single p-n junction, but with two p-n junctions.
Have a look at the drawings below. Notice how the junctions are formed.



The left-hand diagram shows a p-type material sandwiched between two n-type materials: this is called an ***npn transistor***. The right-hand diagram shows an n-type material sandwiched between two p-type materials: this is a ***pnp transistor***. It is as if we have two diodes facing each other!
Transistors are manufactured in different forms but they all have three legs which are called the ***base***, ***emitter*** and ***collector***.

Pin arrangements

As can be seen below the basic pin layout of transistors is varied. Care must be taken when using the metal case types as the casing is live. If in doubt, don't touch!



The questions now become;

i) How do transistors work and

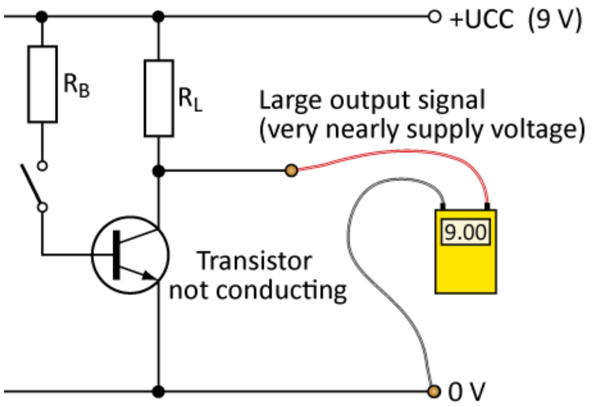
ii) How are they used?

How they are used is simple to answer; transistors can be used as switches or as amplifiers.

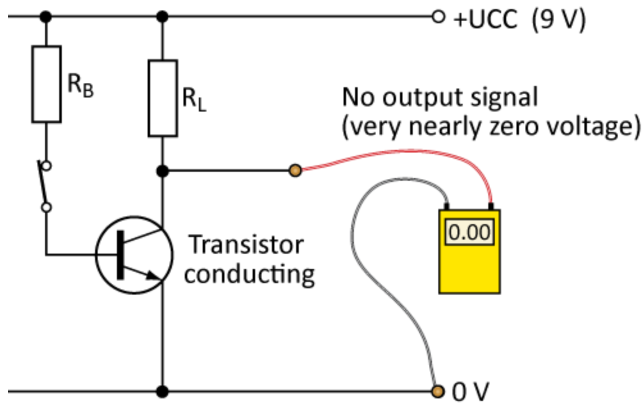
To understand their operation it is easiest to see them in a circuit that is being used as a switch.

The NPN transistor

Consider the simple diagrams below. To get an npn transistor to conduct there must be a positive going signal fed to the base terminal. The output is taken from the collector. The resistor R_L is simply a current to voltage convertor. The resistor R_B is there to protect the base from too much current flow.



a) Switch open therby no signal going into the base of the transistor.



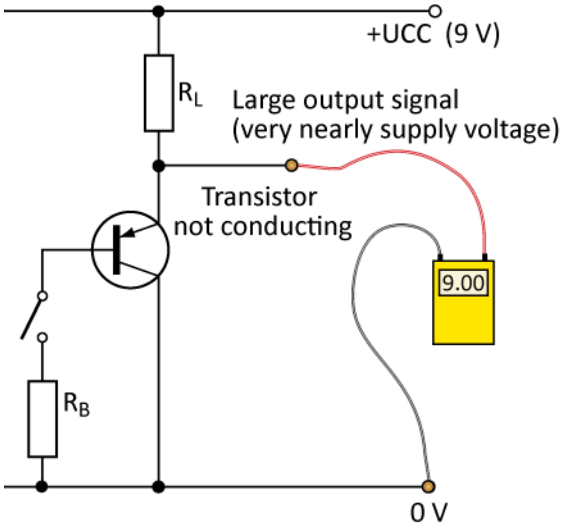
b) Switch closed therby there is a signal going into the base of the transistor.

There are two things to notice about the diagrams shown above.

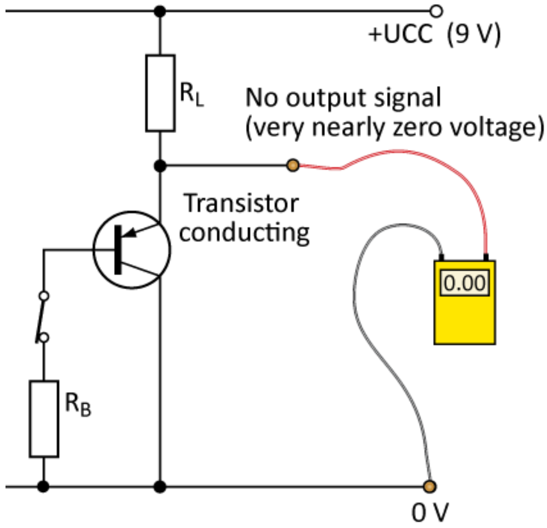
1. When there is no signal on the base, the output is at a maximum. When there is a signal the output is at a minimum.
2. The output inverts the signal going into the base of the transistor.

The PNP transistor

The circuits below will show that for a pnp transistor, the configuration is a mirror image of the circuits for a npn transistor. Most circuits today use npn transistors.



a) Switch open, no signal going into the base of the transistor.



b) Switch closed, there is a signal going into the base of the transistor.

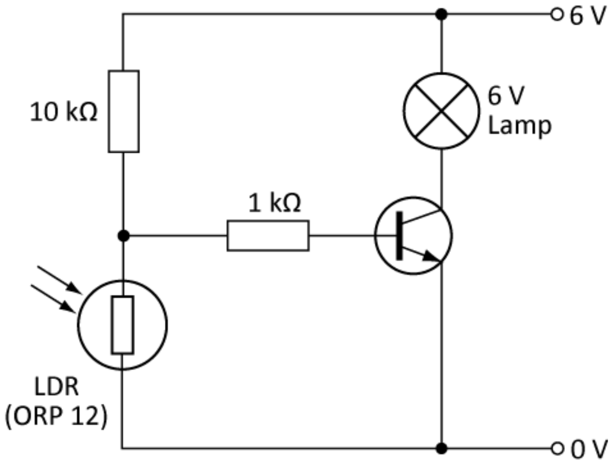
To get a pnp transistor to conduct there needs to be a negative signal on the base or at least to be 0.7 V less than the potential at the emitter. Remember the volt-drop across a diode discussed in a previous session.

Transistors can be thought of as being a simple relay in as much that a small current can control a much larger current.
For the transistor a small current going into the base will allow a much larger current flow in the collector or output circuit. This increase is called the gain or amplification of a transistor.

Why use a transistor and not a relay for controlling circuits?

The action of a relay is that it is either on or off. The beauty of a transistor is that it can be on, off or somewhere in between. It can be used to amplify an a.c. signal which as you know varies in voltage as it goes through its cycle. This will be discussed after we look at a simple switching type circuit.

Automatic light detector



This circuit shows a small 6 V lamp connected to the collector of the transistor.

When it is light the LDR (light dependent resistor) has a low resistance. As the surroundings get darker the resistance of the LDR rises. As the resistance of the LDR rises, the current flowing to the base of the transistor will rise. This is because the current will always flow down the path of least resistance.

Effectively, with the 10kΩ resistor and the LDR, we are creating a simple potential divider circuit. The LDR acts like an automatic variable resistor. As the resistance changes the volt drop also changes and the transistor is able to turn on.

SAQ/homework!

Alter the automatic light detector circuit above so that instead of the detector part controlling a 6 V lamp; a 230 V 500 W sunflood can be used instead. State what you consider might be an operational drawback with this circuit.

Available parts.

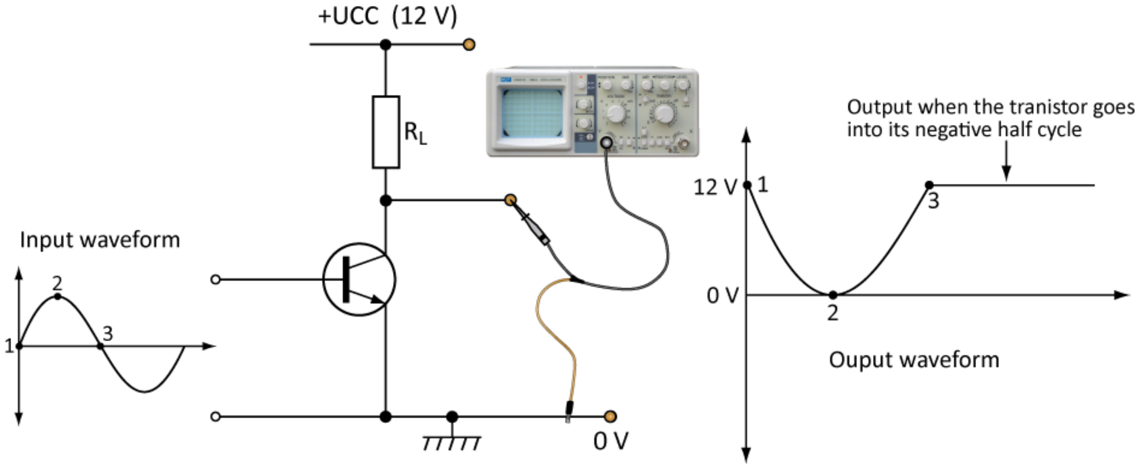
Transformer	230/12 V
Relay	12 V 50 Hz a.c. coil. 5 A switching capacity
Photodiode or LDR	
Transistor	TO18 case e.g. 2N2222A
Resistors	Selection available
Bridge rectifier	
Capacitors	
Diodes	To be used as a flywheel diode to protect the transistor.
Zener diode	12 V
LED	To be used as a circuit live indicator

At this stage do not worry about the values of resistors and capacitors, just construct a circuit that will work!

Transistor as an amplifier

Earlier we saw how a transistor operates as a switch. We saw that when sufficient current is applied to the base of a transistor it turns on and current flows.

Now let us consider how the transistor can be used as an amplifier. Have a look at the diagram below.



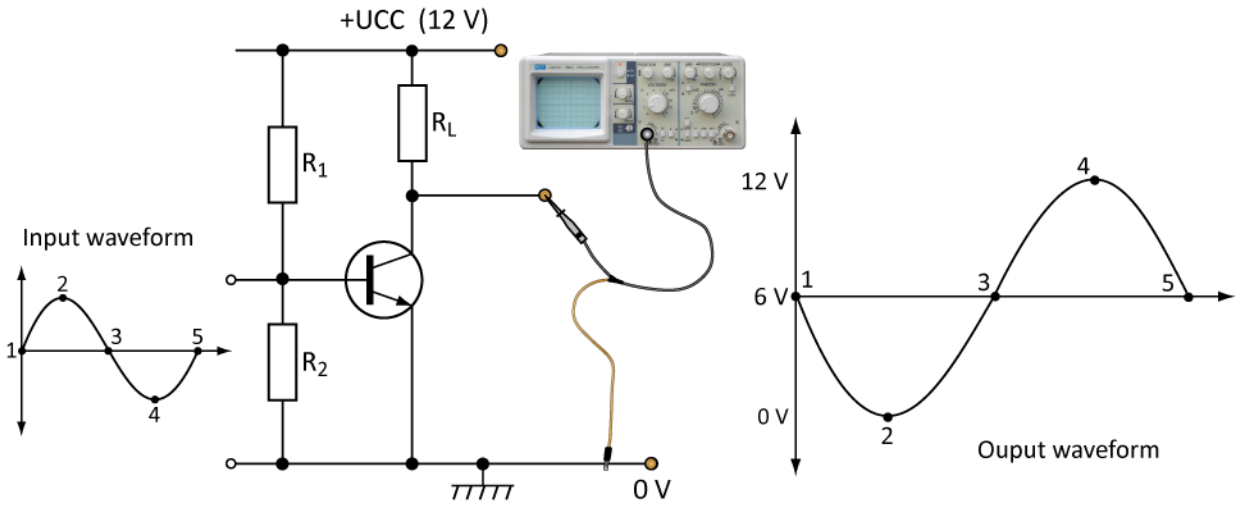
There is a problem with this circuit; can you see what it is?

Thinking about how the transistor works as a switch will help you work out what is happening here.

Remember, when the base is 0V i.e. position 1, the transistor is not conducting therefore the output is high. When the input is at a maximum i.e. position 2, the transistor is fully turned on and the output is at a minimum. And so on until we get to position 3.

But what happens when the input waveform goes into its negative half cycle, the transistor cannot turn off any more so the output is a straight line as shown in the diagram above.

How do we stop this happening? See the circuit below.



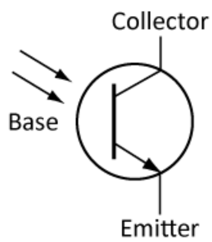
In the diagram above, we have the classic transistor amplifier circuit. The two resistors at the left provide a potential divider that sets the base current at a set value. We call this the ***transistor base bias***. This sets the base at a position halfway between ***OFF*** and ***ON*** and allows the transistor to turn fully on and off as it follows the input signal. Notice again that the output is larger than the input (voltage gain) and that the signal is inverted. We call this arrangement a single-stage amplifier.

It is beyond the scope of this study to determine the values of the various components to enable a simple amplifier function.

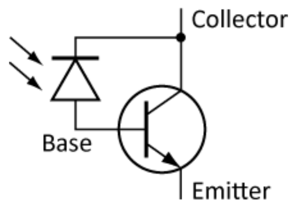
Phototransistor

We have already looked at the photodiode; the phototransistor is very similar in operation but is more sensitive to changes in light.

General symbol



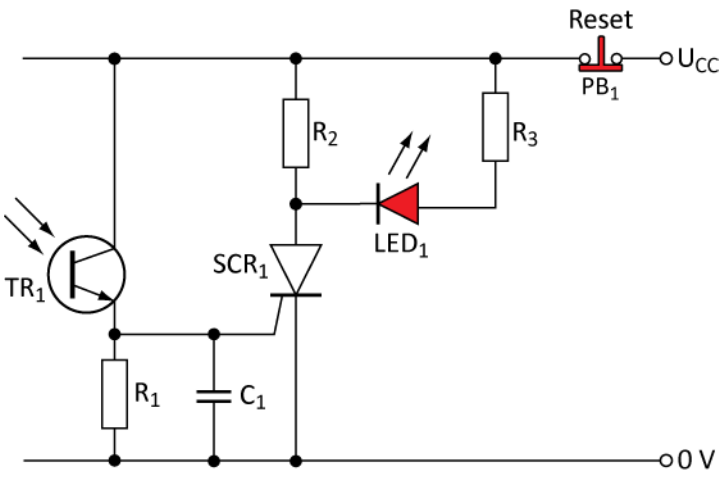
Equivalent circuit



3 Terminal device

2 Terminal device

The diagram below shows a typical phototransistor circuit used to detect the presence of a flame.



When light from the flame is detected by transistor it conducts, producing a voltage across R_1. This fires SCR_1 completing the circuit for LED_1.
To reset, use PB_1, this removes the supply from the anode of the thyristor.

Exercise 5.

1. With the positive probe of the ohmmeter connected to the base of the NPN transistors as shown in Fig. E5-1, what will be the ohmmeter readings shown on the two meters?

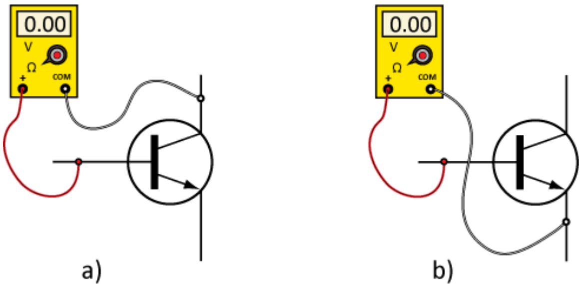


Fig. E5-1

	a)	**b)**
a)	Low resistance	Low resistance
b)	High resistance	Low resistance
c)	Infinite	High resistance
d)	Open circuit	Infinite

2. With the ohmmeters connected to the PNP transistors as shown in Fig. E5-2, what will be the readings indicated on the two meters?

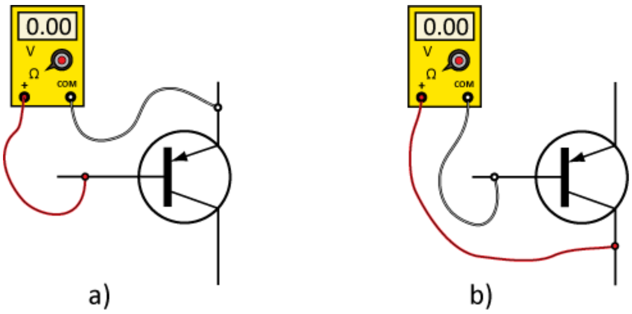


Fig. E5-2

	a)	**b)**
a)	Low resistance	High resistance
b)	High resistance	Low resistance
c)	Open circuit	Low resistance
d)	Infinite	Infinite

3. What is the resistor coloured brown called shown in Fig. E5-3?

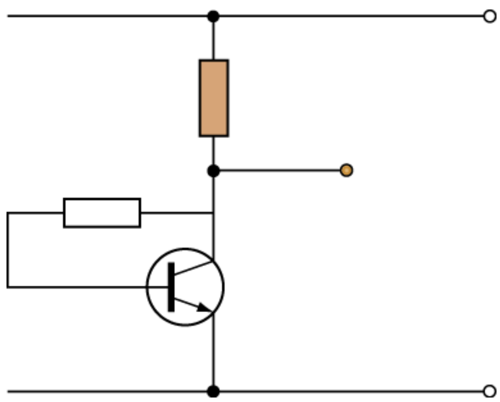


Fig. E5-3

a) Base bias resistor
b) emitter feedback resistor
c) Load resistor
d) Bypass resistor

4. What is the resistor coloured red called shown in Fig. E5-4?

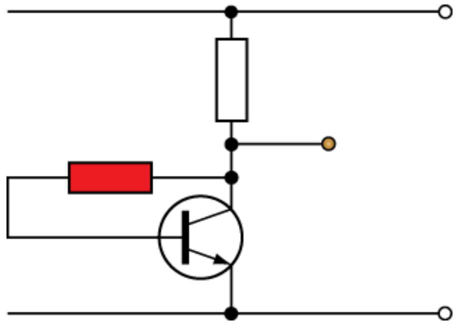


Fig. E5-4

a) Emitter feedback resistor
b) Load resistor
c) Bypass resistor
d) Base bias resistor

5. When the base of Fig. E5-5 is raised, the emitter output voltage will;

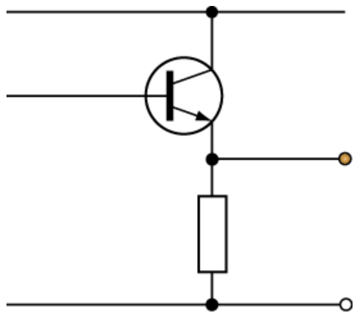


Fig. E5-5

a) Fall
b) Remain fixed
c) Rise
d) Oscillate

6. The output signal at the collector of Fig. E5-6 will be;

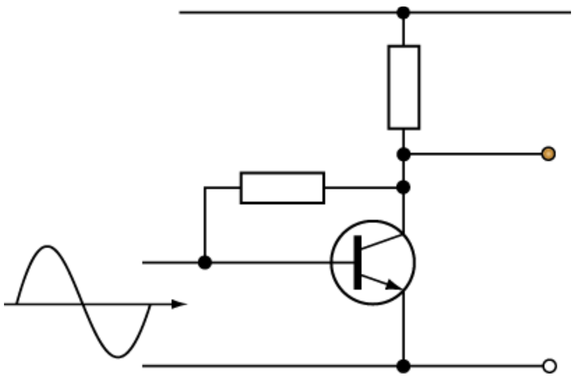


Fig. E5-6

a) In-phase with the input signal
b) Inverted
c) Lag the input signal by 90°
d) Lead the input signal by 90°

7. The purpose of the input capacitor shown in Fig. E5-7 is to:

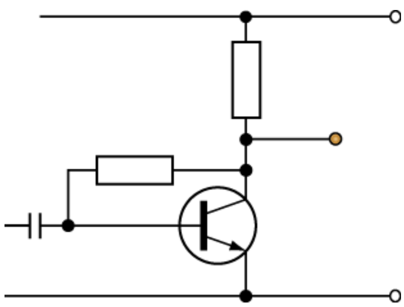


Fig. E5-7

a) Block d.c. from the input signal
b) to pass a.c. on the input into the base
c) To allow the stage to operate
d) To allow the transistor to self bias

6: Temperature devices and inverters

In this session the student will:

- Have an understanding of how temperature devices work.
- Be able to state what an inverter is and where they are used.

In this session we are going to briefly consider two separate areas.

- Discover that temperature devices are used not only to measure temperature but also to control current flow at certain values of temperature.
- Discuss that an inverter changes a signal from one form to another and why this is useful to the electrical industry.

Temperature devices

There are three main types of temperature sensitive devices that you may come across in your career.

I. Thermistor
II. Thermocouple
III. Resistance temperature device or RTD as it is commonly known.

Thermistor

The thermistor changes resistance as the temperature varies.

There are two types of thermal resistor, the ntc (negative temperature coefficient) and the ptc (positive temperature coefficient).

NTC

As the temperature increases then the resistance decreases in value.

PTC

As the temperature increases then so does the resistance value.

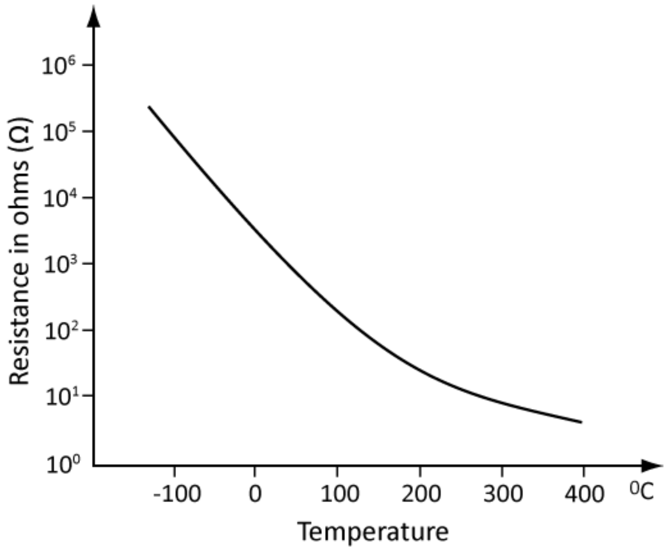
As you can see from above, it is not always easy to tell each thermistor apart.

The ntc type are commonly used to protect circuits from high initial currents, where the high initial resistance of the thermistor limits the current until the current steadies and the thermistor falls back in value.

The ptc type are often used as overloads within internal motor circuits and other equipment, where the resistance increases with the rise in temperature due to the increased overload current, thus limiting the current.

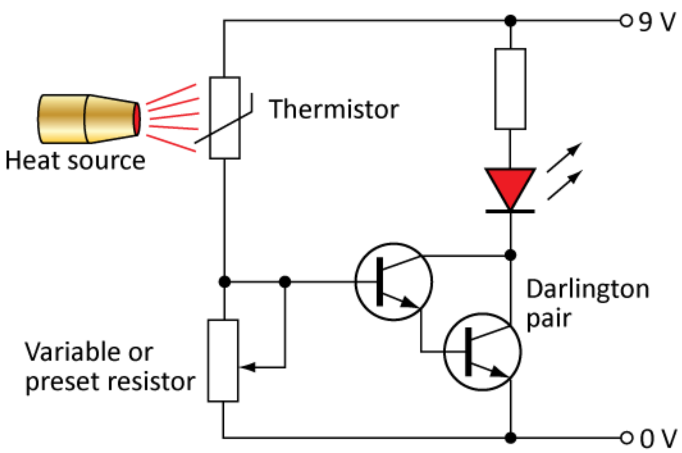
The problem with a thermistor is that it is not a linear response, even though it is very responsive to changes in temperature. However, the accuracy of thermistors is so high that really long cables do not make any substantial impact on the accuracy. Thermistors pick up a change in temperature very quickly, which make it possible to make temperature-related decisions promptly.

A disadvantage of thermistors is that they are not appropriate for industrial use, as they can only be used in temperature of up to 130 degrees Celsius. They are, however, commonly used in home appliances such as freezer, water heaters and air conditioning units.



You can see from this graph of a thermistor temperature response, that this creates inaccuracies if we want to carry out any calculations or transmit any signals.

Typical circuit



As the thermistor gets warm it resistance drops (see graph above). The potential on the base of the first resistor rises and starts to conduct. This puts a positive potential on the base of the second transistor and due to the amplification factors, this fully conducts turning on the LED.

The Darlington pair increases sensitivity of the circuit.

Thermocouple

A thermocouple is based on the principle that an electromagnetic force (emf) is generated when heat is applied to the junction of two dissimilar metals such as iron and copper (sensing junction). At the other end of the wires, usually as part of the input instrument, is another junction, called the cold junction or reference junction.

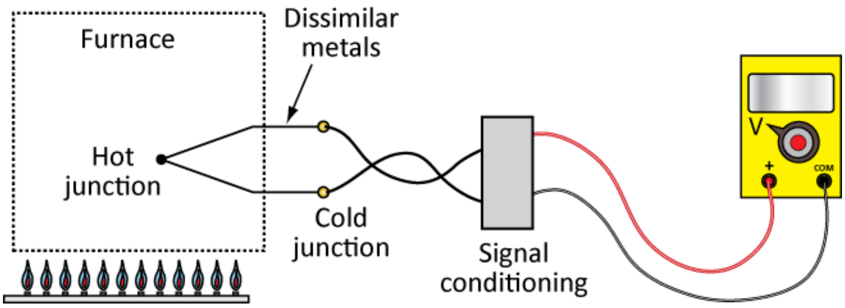
A small voltage signal is generated by heating the junction of the two different metals. They have a wide range of measuring ranges and come in many different physical sizes and with different configurations.

The accuracy of thermocouples is not that high, though they are fairly precise. The strength of the signal is not that high either and requires amplification. However, their response time is very fast and they are quite rugged so can be used in a wide range of environments.

Domestic use where a thermocouple is being used directly as a thermometer for determining if meat is cooked for eg.

Typical themocouple end showing the joint of two metals.

Thermocouple used with a typical digital multi-function meter for measuring the casing temperature of an electric motor.



Here you can see that when two dissimilar metals are heated at the 'hot junction' then a voltage is generated. Without some form of signal conditioning the output voltage from the thermocouple would be in µV, which is very small to read.

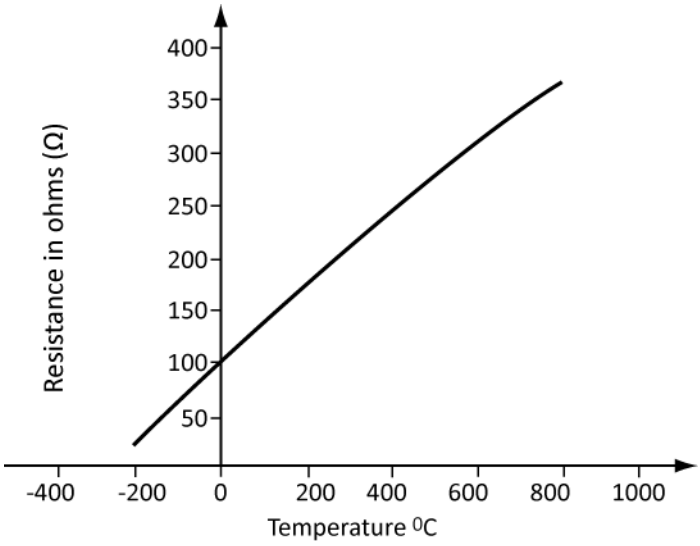
The types of thermocouple that exist are recognised by the type of metals used, and these metals use a letter code, see manufacturer's data for more details.

Resistance temperature device (RTD)

Resistance temperature detectors or RTD's as they are more commonly known, are another common way to measure temperature. RTD's are very similar in appearance to thermocouples but they function completely different.

As previously discussed, thermocouples produce a very small voltage when heated, an RTD does not produce any voltage at all, and so it relies on an instrument for power. RTD's are electrical resistors that change resistance as temperature changes. With all common types of RTD's, the resistance increases as the temperature increases. This is referred to as a positive temperature coefficient.

Graph showing the relationship between temperature and resistance.



Typical RTD sensing element

RTDs are commonly specified at 100 Ohms, which means that the element should show 100 Ohms resistance at zero degrees Celsius.

With a temperature range up to 850°C, RTDs can be used in all but the highest-temperature industrial processes. When made using metals such as platinum, they are very stable and are not affected by corrosion or oxidation.

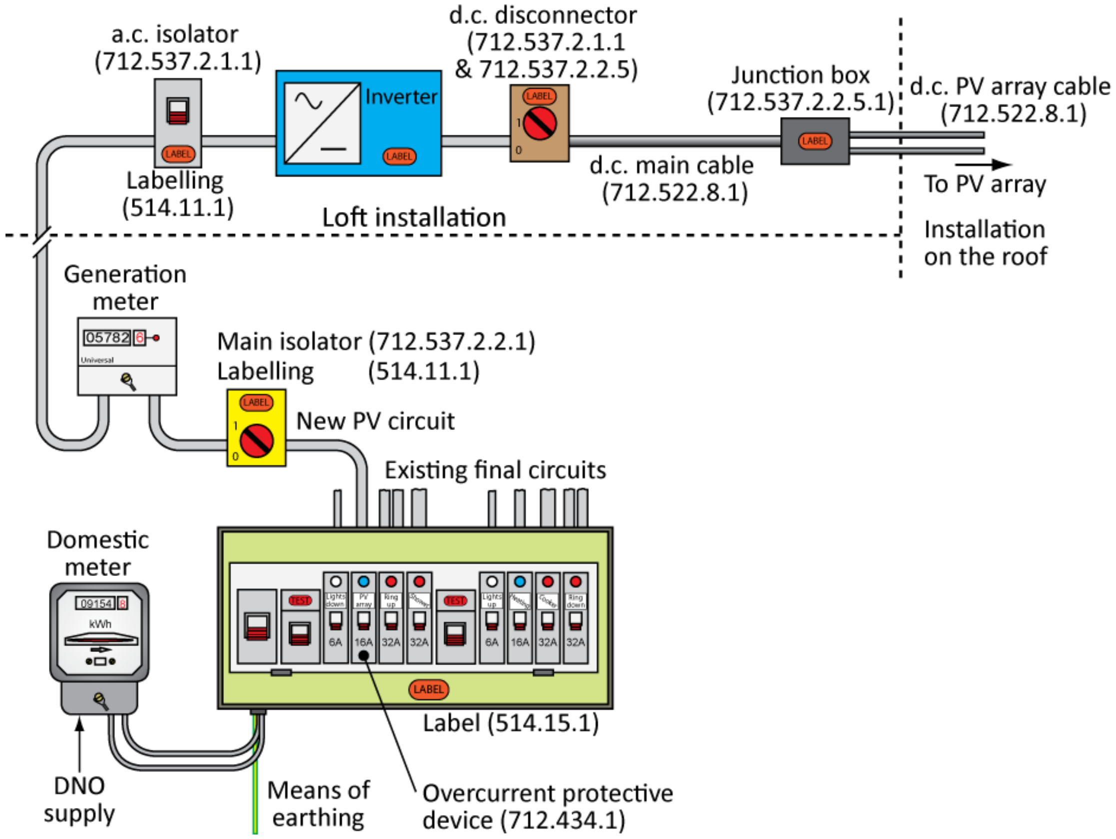
Where the environment is hazardous to temperature sensing elements ii is common to use a Thermowell to house the sensor. A typical example is shown to the right.

Inverters

The syllabus states that inverters be discussed but without detailing precisely what the awarding body mean by this. It is only fitting therefore to mention all types, and within the electrical field there are quite a range of inverters used.

In electronics, inverters are used to change the input signal from one state to another. This could be from a high to a low and vice versa. It could also be from a positive going signal to a negative signal as is commonly performed by the NOT gate in digital electronics.

The emerging electrician today will most likely come across inverters in the area of PV panels where the d.c. generated by the action of the sun on photovoltaic cells needs to be converted to an a.c. supply for domestic and commercial use.
Consider the diagram below which you first met in unit 302.



UPS

Another type of inverter commonly used in domestic and commercial settings is the UPS which stands for Uninterruptible Power Supplies.
These provide safe back-up solutions in the event of power failure. They are particularly useful for rural areas where supply reliability is of paramount importance or for businesses handling sensitive data that cannot be lost due to power failures, think military or the tax offices.

UPS systems are available as single-phase or three-phase units with varying levels of output power to match a variety of loads.

Typical single-phase UPS unit (2 kVA)

Typical three-phase UPS unit (500 kVA)

Both of the units above house batteries which are trickled charged from the supply and come on-line in the event of power failure. This happens extremely fast so that there is no discernible change in operation. This offers time to save and shut down non essential systems

Exercise 6.

1. There are four main types of temperature sensitive devices that you may come across in your career.
   i) Bi-metallic strip
   ii) Thermistor
   iii) Thermocouple
   iv) Resistance temperature device.

   Briefly describe the operation of each and state a typical application.

2. A chicken farmer complains to you about the lack of reliability of his electricity supply, especially during rearing time. Briefly outline the sort of solutions you would suggest to him.

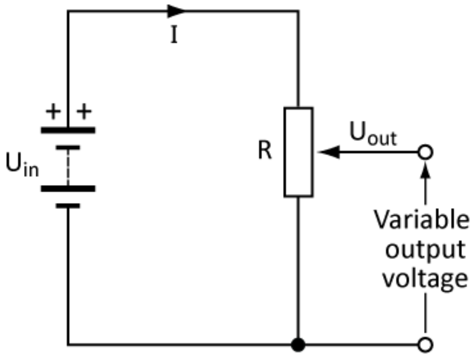
7: Electronic devices used in systems

In this session the student will:

- Have an understanding of how electronic devises discussed in previous session are used in circuits

Resistors

In the past few sessions you have learnt about resistors and how they not only limit current flow but can be thought of a being able to turn a current into a voltage.

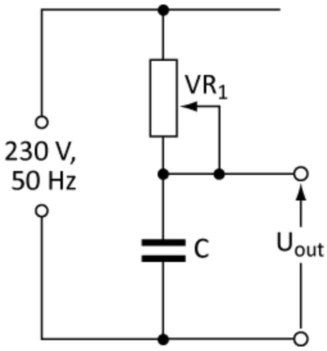


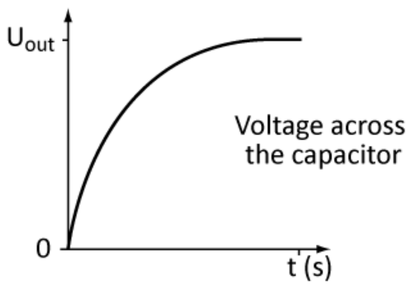
The output can vary from 0 V to nearly the supply voltage.

Care needs to be taken with the power rating of the variable resistor

Capacitors

We have looked at capacitors and you have learnt that they can pass a.c. signals but block d.c. We also considered how they are used with resistors to form timing circuits which are used in speed control and lamp dimmer circuit which will be looked at again further on into this session.





The rate of growth of the voltage across the capacitor is determined by the values of the resistor and capacitor. There is an interesting formula which allows the voltage to be calculated at whatever time you wish but we shall leave that for now!

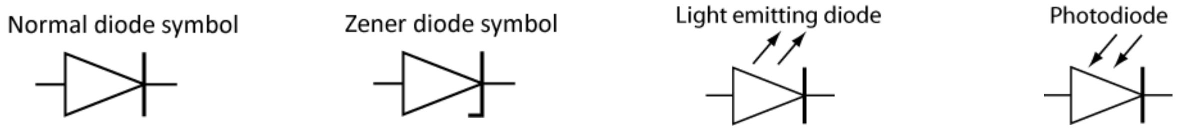
Capacitors are also useful for absorbing energy or voltage spike and for that reason they are used as filters again with a resistor to form what is called a snubber circuit.

Diodes

In the diodes session you learnt that a normal diode is a PN junction and is described as being an electrical one-way street and drops 0.6 – 0.7 V volts across itself in normal use. Or put another way, the anode must be 0.7 V larger than the cathode for the diode to conduct.

We also discussed the Zener diode which is designed to operate it he reverse mode and is used as a voltage stabiliser. The LED gives a light output when it is forward biased but requires a series resistor to limit the current flow to about 20 mA.

We considered the photo-diode which is used in the reverse biased mode similar to the zener but this device conducts current when the light falling upon it increases.



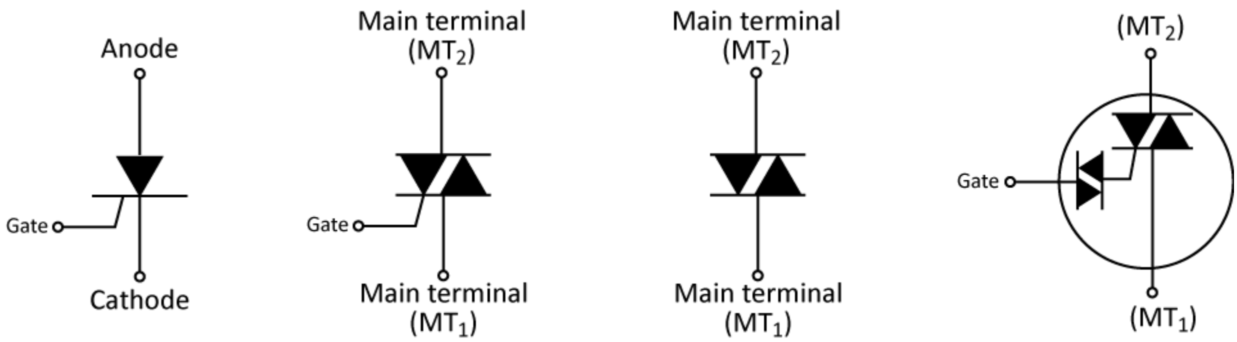
Rectification

We then went on to consider rectification. This is the process of converting an a.c. source into an d.c. supply needed for electronic circuits.

This required one diode for half-wave and four diodes for full-wave. The circuit also required smoothing to reduce the a.c. ripple which is dealt with by using a large electrolytic capacitor, and then some form of stabilising using say a zener diode.

Thyristors were introduced which are also called SCRs (silicon controlled rectifiers). These devices can only conduct for the positive half cycle but then switch themselves off for the duration of the negative half-cycle. They require a signal pulse onto their gate to put them into the conduction mode.

The triac is also a three terminal device and is similar to the thyristor in that it requires a signal onto its gate to make it conduct, but the difference between the two is that the triac will conduct in the negative half-cycle. However, the triac is not as stable as the thyristor in that its firing is not precise at each point in the a.c. supply. For this reason a diac is used in the gate circuit to give it a definite voltage pulse as the diac requires about 30 V before it will conduct. Both the thyristor and triac are used in speed control and lamp dimming type of circuits.



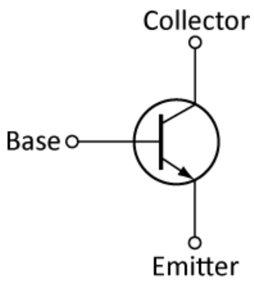
Thyrsitor Triac Diac Quadrac

Transistors

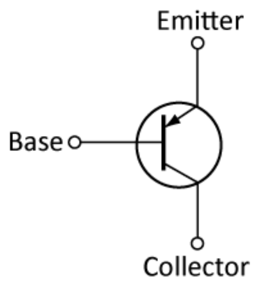
Here you learnt that there are two types of transistor; an *npn* which requires a positive signal onto its base to make it conduct and a pnp; this requires the base to more negative than the emitter by 0.7 V to make it conduct.

Both types of transistor have three legs called the base, collector and emitter and both can be used as a switching action or as an amplifier. The amount by which the transistor increases the input signal is called the gain or amplification factor. The output of one transistor can be fed into the base of a second transistor to improve the gain and this arrangement is called a Darlington pair.

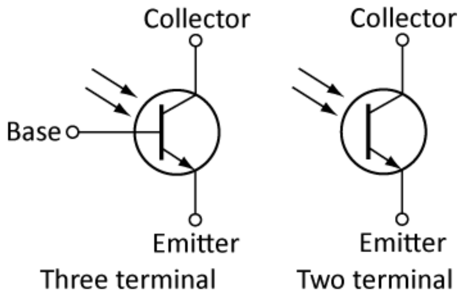
The phototransistor is similar to the photodiode but is more sensitive with regard to current flow when light falls upon it. The phototransistor can be either a three terminal device which has a base connection or a two terminal device without a base connection, i.e. it just uses the incident light to control the base current.



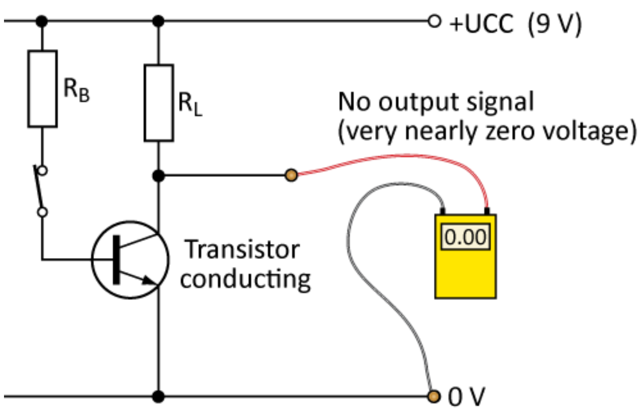
npn transistor



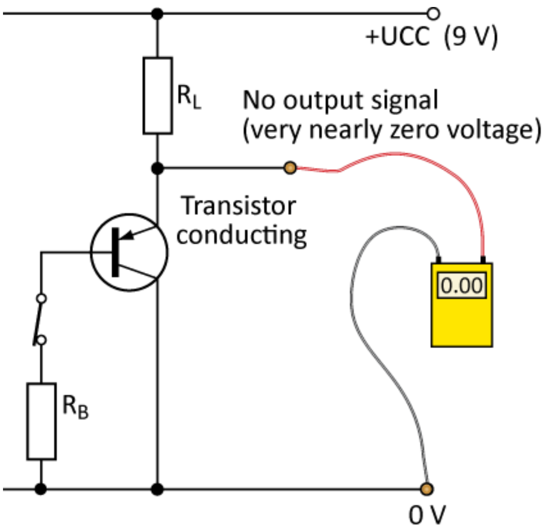
pnp transistor



Phototransistor



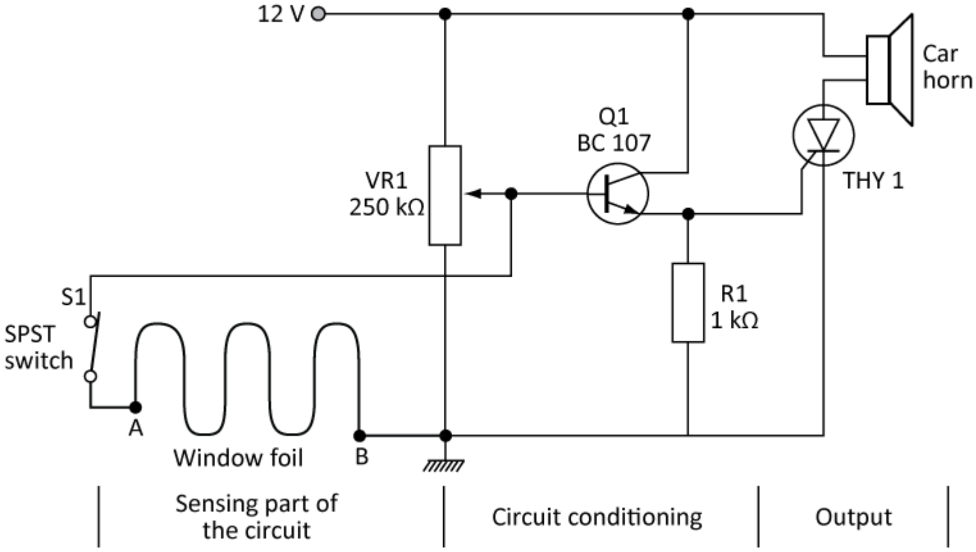
npn transistor used as a switch in its conducting mode.



pnp transistor used as a switch in its conducting mode.

Electronic circuits

Simple burglar alarm



Here is a simple but effective burglar alarm circuit that can be fixed on windows to detect break through.

The circuit uses a fine wire element fixed as a network through the window glass for sensing the break through. Normally the base of Q1 is held to ground potential by the wire element. So Q1 will be off and THY 1 will not be conducting, and the horn will not be sounding.

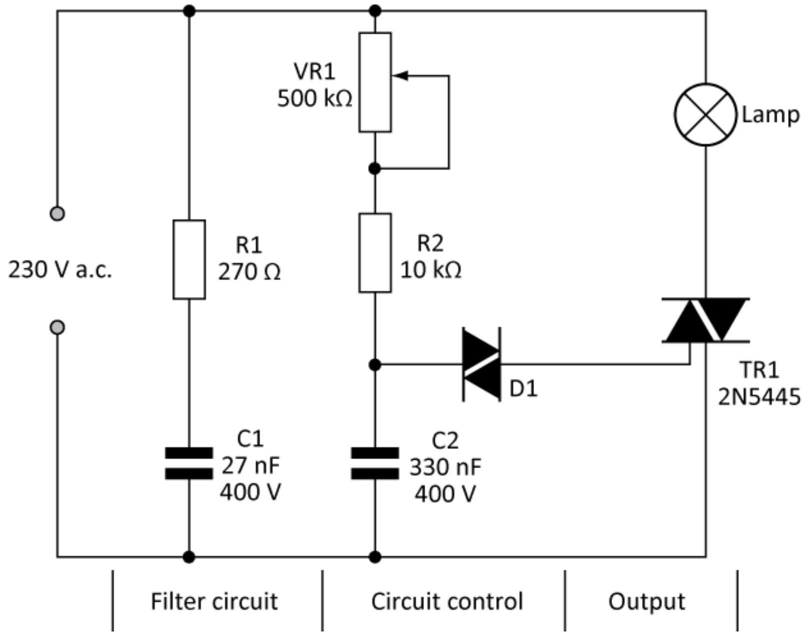
When the wire element is broken the base of Q1 will be raised to a positive potential, Q1 will be now conducting putting a positive voltage onto the gate of THY 1 switching that ON. This will now make the horn sound and this condition will be latched by the THY 1.

The circuit remains ON until the normal condition is restored or the power supply is switched OFF.

SAQ1

At what voltage does a transistor conduct? Therefore what setting does the potentiometer need to be set for?

Lamp dimmer or heater controller



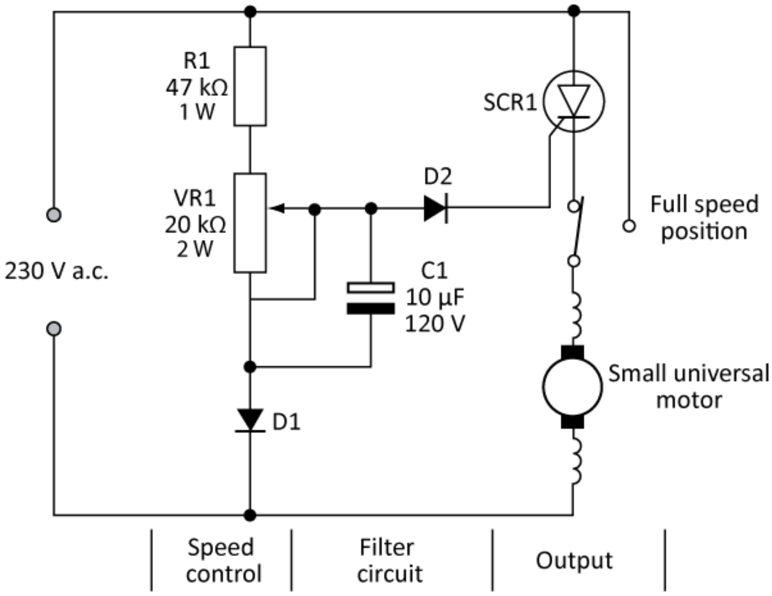
This is the circuit diagram of the simplest lamp dimmer or fan regulator.

The circuit is based on the principle of power control using a triac. The circuit works by varying the firing angle of the triac.

Resistors VR1, R2 and capacitor C2 are associated with this. The firing angle can be varied by adjusting the value of any of these components. In this circuit VR1 is selected as the variable element. By varying the resistance value of VR1 the firing angle of triac changes (in simple words, how much time should triac conduct) changes. This directly varies the load power, since the load is driven by triac. The firing pulses are given to the gate of Triac T1 using diac D1.

The resistor/capacitor network formed by R1 and C1 act as a snubber circuit, this is because triacs can be triggered into conduction by spurious voltage spikes.

Motor speed control



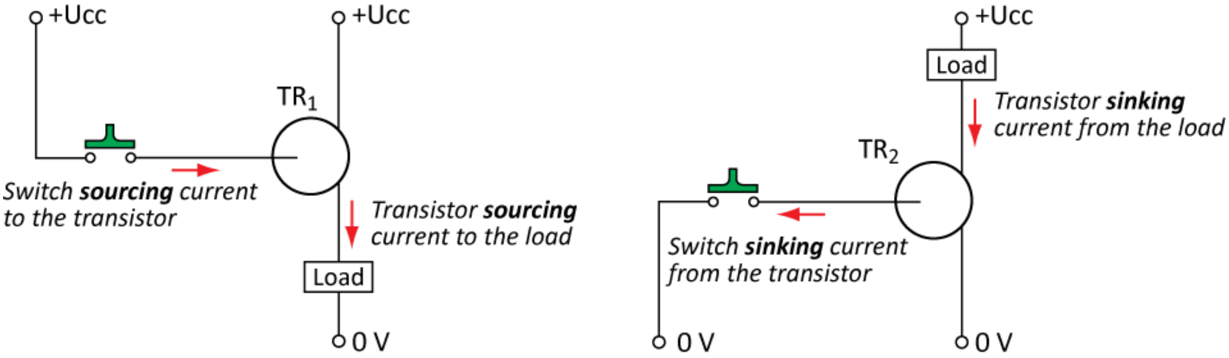
This circuit is a relatively simple low voltage d.c. motor or small universal motor speed controller that can be built fairly cheaply. It uses the fact that the rotational speed of a universal or d.c. motor is directly proportional to the mean value of its supply voltage.

Looking at the circuit, the armature/field windings are in series through the thyristor.
The thyristor's control angle is altered by adjusting the VR1 potentiometer. The purpose of diode D1 is to make sure that only half-wave is used. The rotational speed is easily adjusted from zero to near the maximum value. Full rotational speed can be obtained by using the full-speed option available from the speed selector switch.

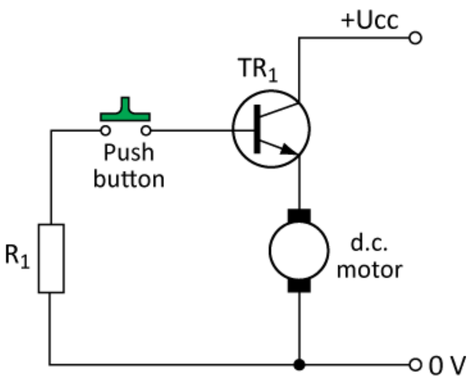
This circuit is widely used in small household appliances such as blenders, sewing machines, hand drills and woodworking machinery.

Exercise 7

1. Choose the right type of bipolar junction transistor for each of these switching applications, drawing the correct transistor symbol inside each circle:

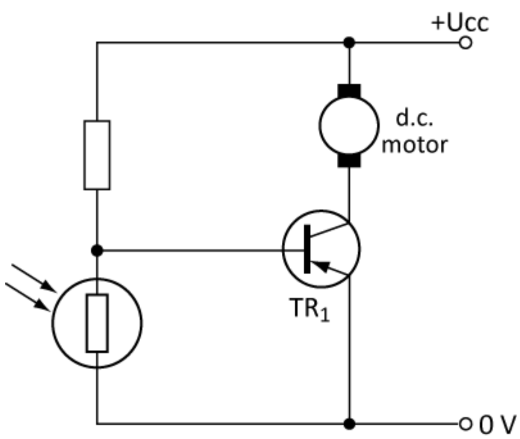


2. A student attempts to build a circuit that will turn a d.c. motor on and off with a very delicate (low current rating) push button switch. Unfortunately, there is something wrong with the circuit, because the motor does not turn on no matter what is done with the switch:



Correct the error(s) in this circuit, showing how it must be set up so that the transistor functions as intended.

3. In the circuit below, the electric motor is supposed to turn on whenever the cadmium sulfide photocell is darkened:

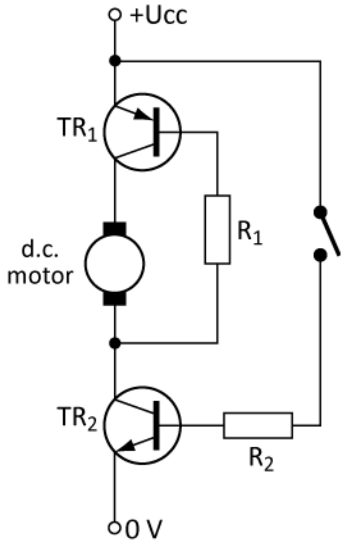


Unfortunately, though, the motor refuses to turn on no matter how little light strikes the photocell.

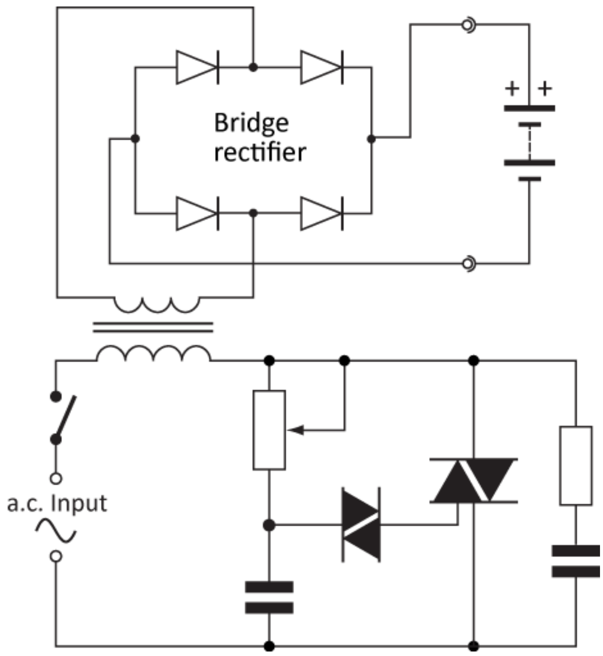
State what you think the problem could be.

Challenging questions

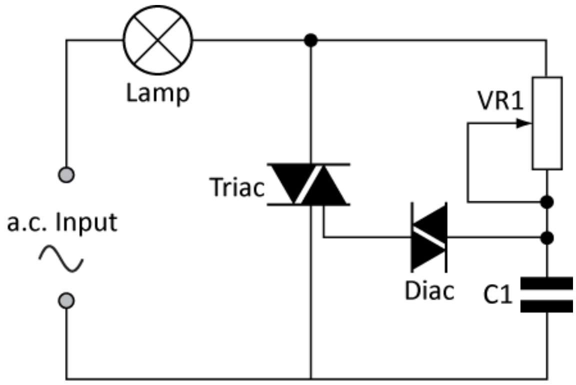
4. Explain how the one toggle switch is able to switch *both* transistors on and off simultaneously in this motor control circuit:



5. Explain how this battery charger circuit uses a Triac to control *d.c.* power to the battery:



6. Predict how the operation of this lamp dimmer circuit will be affected as a result of the following faults. Consider each fault independently (i.e. one at a time, no multiple faults):



Faults

- Potentiometer VR_1 fails open:
- Capacitor C_1 fails shorted:
- Capacitor C_1 fails open:
- Diac fails open:
- Triac fails shorted:

For each of these conditions, explain *why* the resulting effects will occur.

B&B Training Associates

Engineering Learning Materials

Attempt all questions.

All marks are shown in the right-hand margin.

You should aim to pass with an 85 % minimum mark.

Anything less than this mark should lead you to re-read the text.

1. State three types of resistor and give reasons why they might be used. 3
2. A 0.5 W, 470 kΩ resistor is connected across a supply. What is the maximum voltage permitted to drop across the resistor? 3
3. Determine the resistance of the following resistors:
   a) Red; Red; Red; Gold
   b) Red; Brown; Black; Orange; Gold
   c) Yellow; Violet; Red; Yellow; Red 3
4. Using BS EN 60062 coding determine the following values of resistor:
   a) 470kJ
   b) 10RG
   c) 1MK
   d) 2M2M 4
5. Two resistors of 50 Ω and 75 Ω are connected in series across a 18 V supply. If a load of 1 kΩ is connected across the 75 Ω resistor, what voltage will be dropped across the load and how much current will flow in the load resistor? 6
6. Name three types of capacitor and why they might be used. 3
7. What precautions need to be taken when using electrolytic capacitors? 2
8. What colours would the following capacitors have:-
   i) 200 nF with 10 % tolerance and 250 V working voltage
   ii) 650 µF with 20 % tolerance and 400 V working voltage 4
9. Why are capacitors used in electronic circuits? 2
10. Why might you use an oscilloscope? 2
11. If there are four complete cycles in 0.2 s, what is the frequency? 3
12. Draw a stabilised power supply using a zener diode 4
13. What is a diode and how does it function? 4
14. What type of circuits is a diode used in? 3
15. Why do we need to rectify a supply? 1

16. Draw the symbols for the following:
    a) npn transistor
    b) pnp transistor
    c) Zener diode
    d) Thyristor
    e) Photodiode
    f) LED 6
17. What are the two ways in which a transistor functions? 2
18. What is the problem with a single-stage amplifier, and how can this be overcome? 2
19. A LED requires a current of 15 mA to cause it to light. The supply is rated at 12 V. What size of resistor will be required to limit the current to this value? 3
20. Name two types of heat sensing device and describe what their particular properties are and where they might be used. 6
21. You have been asked by your local primary school to build an electronic circuit that is to be used at Halloween time to provide internal light for the school children's pumpkins. They are going to cut two holes out for the eyes and want you to fit two yellow LEDs which are to automatically illuminate when it gets dark. 14

Total marks 80

