TVET CERTIFICATE III in COMPUTER SYSTEM TECHNOLOGY

BASICS OF ELECTRONICS

COSBE 301

Apply basics of electronics

Competence

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Sector: ICT

Sub-sector: COMPUTER SYSTEM TECHNOLOGY

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Purpose statement

This module describes the skills and knowledge required to understand and use electronic lab / workshop equipment and different types of electronic devices.

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LEARNING UNIT 1 USE ELECTRONIC LAB / WORKSHOP EQUIPMENT

LO 1.1 IDENTIFY ELECTRONIC LAB / WORKSHOP EQUIPMENT

Content/Topic 1: Identification of electronic lab / workshop equipment

1. **Multimeter**

The multi-meter is the most common electronic instrumentation in use. It is a combination meter that is capable of measuring, resistance, voltage (AC and DC) and usually current. In addition some meters are capable of measuring capacitance, frequency and other variables. An example of one of these meters is the Fluke 189 hand held multi-meter.

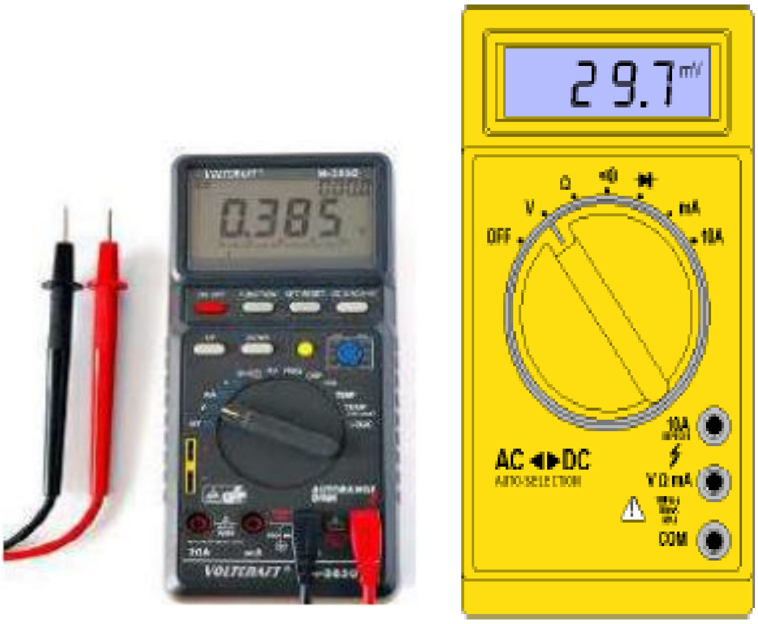


Figure 1: Multmeter

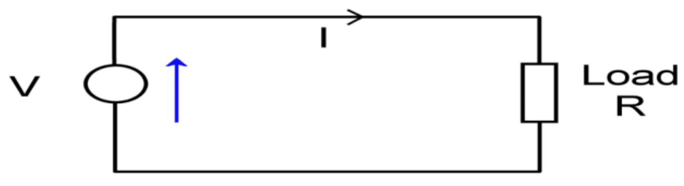
This type meter is very common in most shops and is portable and easily used. This meter is capable of measuring AC and DC Voltage (down to 0.000001 Volts and as high as 1000 Volts), Resistance, Capacitance, Temperature, Current (Down to 0.000001 Amps and as high as 10 Amps).

How to Use a Multimeter to Measure Voltage, Current and Resistance

Volts, Amps, Ohms - What Does it All Mean?

Before we learn how to use a multimeter, we need to become familiar with the quantities we are going to be measuring. The most basic circuit we will encounter is a voltage source, which could be connected to a load. The voltage source could be a battery or a mains power supply. The load might be an appliance such as a bulb or electronic component called a *resistor.* The circuit can be represented by a diagram called a *schematic.* In the circuit below, the voltage source V creates an electrical pressure which forces a current I to flow around the circuit and through the load R. Ohm's Law tells us that if we divide the voltage V by the resistance R, measured in ohms, it gives us a value for the current I in amps:

Current I = V/R



$$\frac{V}{R} = I$$

A basic multimeter allows you to measure the following:

- DC voltage
- DC current
- AC voltage
- AC current (not all basic meters have this function)
- Resistance
- Continuity - indicated by a buzzer or tone

In addition meters may have the following functions:

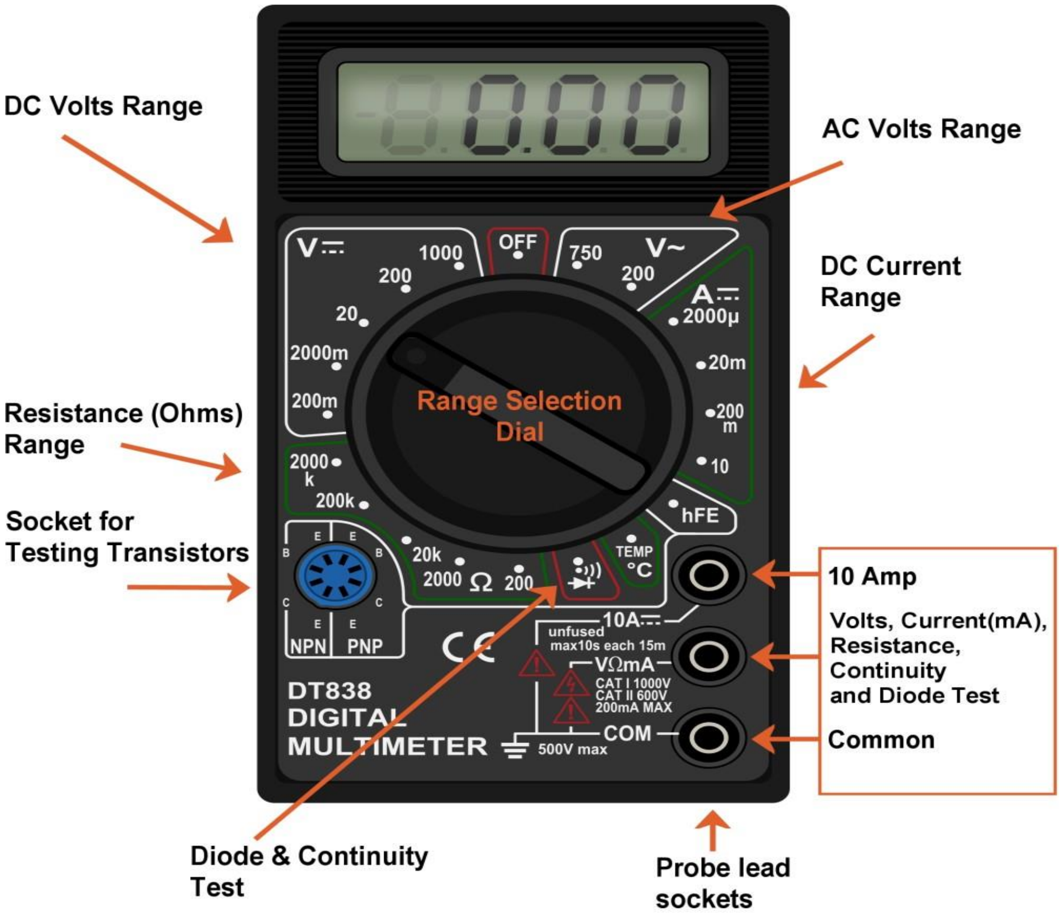
- Capacitance measurement
- Transistor HFE or DC current gain
- Temperature measurement with an additional probe
- Diode test
- Frequency measurement

The value measured by the instrument is indicated on an LCD display or scale.

Parts of a Meter

- **The Display.** This is usually a multidigit, 7 segment LCD display. Some laboratory instruments however have LED displays which are easier to read under certain lighting conditions.
- **Rotary Range Selector Dial.** This allows you to select the function which you will be using on the meter. On a non-auto ranging meter, it also selects the range.
- **Connection Sockets.** These are 4mm diameter female sockets into which 4 mm probe leads are plugged. The arrangement is non-standard and depends on the brand/model of meter, so it's important to understand the function of each socket to avoid damage to the meter:

- Com is the common socket into which the negative or ground lead is plugged.
- If a socket is marked VΩmA, this is the socket into which the positive probe lead is plugged for measuring voltage, resistance or current ("mA" means "milliamps"). If there is no mention of "A" or "mA" on this socket, there will be one or more separate sockets for connecting the probe lead to measure current. These additional sockets may be marked "A" or "mA" with the current rating (e.g. 10A for high current readings and 400 mA for lower current readings).



How Do I Setup a Multimeter to Measure Volts, Amps or Ohms?

Voltage, current and resistance ranges are usually set by turning a rotary range selection dial. This is set to the quantity being measured, e.g. AC volts, DC volts, Amps(current) or Ohms (resistance).

If the meter is non-auto ranging, each function will have several ranges. So for example, the DC volts function range will have 1000V, 200V, 20V, 2V and 200mV ranges. Using the lowest range possible gives more significant figures in the reading.

LCR Meter

Definition: LCR meters can be understood as a multimeter, this is because it can measure resistance, inductance, capacitance as per the requirement. Thus, it is termed as LCR meter. L in its name signifies inductance, C stands for capacitance and R denotes resistance.

An LCR meter is a type of electronic test equipment used to measure the inductance (L), capacitance (C), and resistance (R) of an electronic component. In the simpler versions of this instrument the impedance was measured internally and converted for display to the corresponding capacitance or inductance value.

The significant component of LCR meter is the Wheatstone bridge and RC ratio arm circuits. The component whose value is to be measured is connected in one of the arms of the bridge. There are different provisions for the different type of measurements.

For example, if the value of resistance is to be measured, then Wheatstone bridge comes into picture while the value of inductance and capacitance can be measured by comparing it with standard capacitor present in RC ratio arm circuit.

The above block diagram clearly defines the connection diagram of the LCR meter. The measurement of DC quantities will be done by exciting the bridge with DC voltage. On the contrary, the AC measurements require excitation of the Wheatstone bridge with AC signal.

For providing AC excitation, the oscillator is used in the circuit. It generates the frequency of 1 kHz.

Working of LCR Meter

The bridge is adjusted in null position in order to balance it completely. Besides, the sensitivity of the meter should also be adjusted along with balancing of the bridge. The output from the bridge is fed to emitter follower circuit. The output from emitter follower circuit is given as an input to detector amplifier.

The significance of detector amplifier can be understood by the fact that if the measuring signal is low in magnitude, it will not be able to move the indicator of PMMC meter. Thus, in order to achieve the sustainable indication we need to have a high magnitude measuring signal.

But it is often observed that while dealing with the measurement process, the magnitude of the measuring signal falls down due to attenuation factor. The problem to this solution is to utilize an amplifier.

2. AC /DC variable Power supply

A power supply is a separate unit or part of a circuit that supplies power to the rest of the circuit or to a system. The power supply takes the current from your wall electrical socket and converts it into the various voltages your circuit needs.

Figure 2: power supply

3. Function generator

Function or frequency generators are a class of instrument that are useful for creating a repetitive signal of a various form. In the mechanical world this is most commonly used to generate signals to drive test apparatus. There are two classes of function generator. The first is a standard signal generator that can create a repetitive signal of a sine, triangle or square wave. An example of this type of instrument is the Tenma 5015. This unit is a reasonably simple function generator with a few more advanced features. The most important and basic portions of this unit are the frequency control section, the function select section, the amplitude section and the output section.

• **Frequency Control Section**: The frequency section consists of a series of buttons (Labeled in BLUE) that select a course range setting, and a dial (Labeled **FREQ**) that will is linearly adjustable for a fine adjust. Once the range has been selected with the appropriate button, the dial will allow you to adjust the frequency within the range of 0 to 2x range button. As an example, if I select the 1K button I can adjust the frequency from 0 to 2KHz.

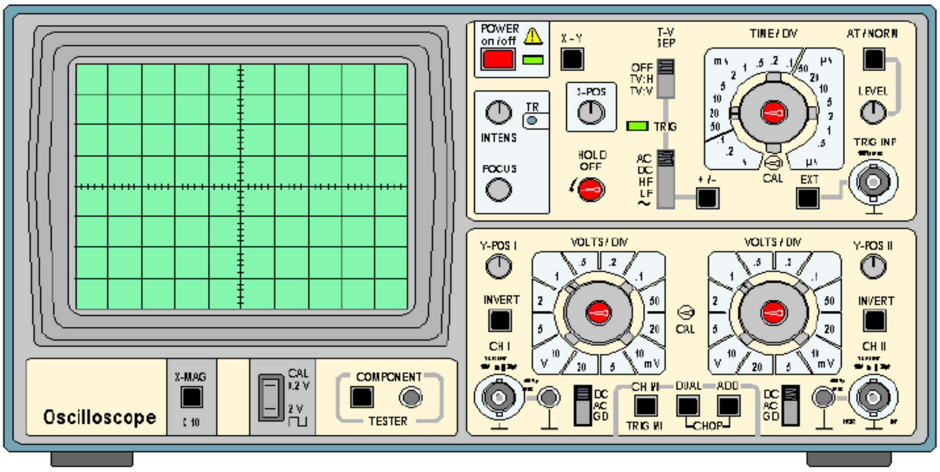
. • **Function Section**: The function selection is a set of buttons (labeled in Red) that select between the a square wave, triangle wave and sine wave output.

• **Amplitude Section**: The amplitude section controls the output amplitude of the wave form. Most frequency generators utilize a simple vernier control knob for the output signal control.

. • **Output Section**: The output section of the instrument actually outputs the signal that has been defined.

Figure 3: function generator

4. Oscilloscope



TURNING ON THE OSCILLOSCOPE

To turn on the oscilloscope, press the power on button on the lower left-hand side of the oscilloscope. Shortly afterwards, you will see a boot screen, and then a start up screen. Press theMENU OFF button to proceed.

OSCILLOSCOPE SETTINGS

As for the arbitrary/function generator, the default settings of the oscilloscope can be manually changed, and are retained when the oscilloscope is turned off.

Fortunately, the oscilloscope settings can be restored to the factory settings. It is a good practice to reset the oscilloscope to factory settings after it is turned on and before any measurements are taken. This way you can always begin working with the scope from the same initial setting.

To restore the oscilloscope to factory settings, press the SAVE/RECALL button at the top of the oscilloscope. Two menus will be displayed: one on the bottom of the screen and one on the right hand side of the screen (see Figure 3). From the bottom menu, press the button bellow “Recall Factory Setup.” Then press the button on the right hand side menu to confirm the change. The oscilloscope is now set to factory settings. Press the MENU OFF button, which is located next to the lower left side of the screen, to remove the menu.

2. LC METER

An **LCR meter** is a type of electronic test equipment used to measure the inductance (L), capacitance (C), and resistance (R) of an electronic component.[1] In the simpler versions of this instrument the impedance was measured internally and converted for display to the corresponding capacitance or inductance value. Readings should be reasonably accurate if the capacitor or inductor device under test does not have a significant resistive component of impedance. More advanced designs measure true inductance or capacitance, as well as the equivalent series resistance of capacitors and the Q factor of inductive components.

Usually the device under test (DUT) is subjected to an AC voltage source. The meter measures the voltage across and the current through the DUT. From the ratio of these the meter can determine the magnitude of the impedance. The phase angle between the voltage and current is also measured in more advanced instruments; in combination with the impedance, the equivalent capacitance or inductance, and resistance, of the DUT can be calculated and displayed. The meter must assume either a parallel or a series model for these two elements. An ideal capacitor has no characteristics other than capacitance, but there are no physical ideal capacitors. All real capacitors have a little inductance, a little resistance, and some defects causing inefficiency. These can be seen as inductance or resistance in series with the ideal capacitor or in parallel with it. And so likewise with inductors. Even resistors can have inductance (especially if they are wire wound types) and capacitance as a consequence of the way they are constructed. The most useful assumption, and the one usually adopted, is that LR measurements have the elements in series (as is necessarily the case in an inductor's coil) and that CR measurements have the elements in parallel (as is necessarily the case between a capacitor's 'plates'). Leakage is a special case in capacitors, as the leakage is necessarily across the capacitor plates, that is, in series.

An LCR meter can also be used to measure the inductance variation with respect to the rotor position in permanent magnet machines. (However, care must be taken, as some LCR meters will be damaged by the generated EMF produced by turning the rotor of a permanent-magnet motor; in particular those intended for electronic component measurements.)

Handheld LCR meters typically have selectable test frequencies of 100 Hz, 120 Hz, 1 kHz, 10 kHz, and 100 kHz for top end meters. The display resolution and measurement range capability will typically change with the applied test frequency since the circuitry is more sensitive or less for a given component (i.e., an inductor or capacitor) as the test frequency changes.

Benchtop LCR meters sometimes have selectable test frequencies of more than 100 kHz. They often include options to superimpose a DC voltage or current on the AC measuring signal. Lower end meters might offer the possibility to externally supply these DC voltages or currents while higher end devices can supply them internally. In addition benchtop meters typically allow the usage of special fixtures (i.e., Kelvin wiring, that is to say, 4-wire connections) to measure SMD components, air-core coils or transformers.

5. Soldering station

It is also called SMD (Surface Mount Device) rework system and SMD repair system. It has control to regulate or manage temperature and flow or hot air. Always buy a good quality ESD-Safe hot air blower.

Figure 4: Soldering station

LO 1.2 APPLY ELECTRONIC LAB / WORKSHOP EQUIPMENT

Content/Topic1:Applications of different types of electronic lab / workshop equipment

Resistance measurement

- **How to Measure Resistance**

1. If the component is on a circuit board or in an appliance, turn off the power
2. Disconnect one end of the component if it's in a circuit. This may involve pulling off spade leads or desoldering. This is important as there may be other resistors or other components having resistance, in parallel with the component being measured.
3. Connect the probes as shown in the photo below.
4. Turn the dial to the lowest Ohm or Ω range. This is likely to be the 200 ohm range or similar.
5. Place a probe tip at each end of the component being measured.
6. If the display indicates "1", this means that resistance is greater than can be displayed on the range setting you have selected, so you must turn the dial to the next highest range. Repeat this until a value is displayed on the LCD.

Connecting Probe Leads to Measure Resistance

How to Check Continuity and Fuses

A multimeter is useful for checking breaks in flexes of appliances, blown filaments in bulbs and blown fuses, and tracing paths/tracks on PCBs

1. Turn the selecting dial on the meter to the continuity range. This is often indicated by a symbol which looks like a series of arcs of a circle (*See the photo showing symbols used on meters above).*
2. Connect the probe leads to the meter as shown in the photo below.
3. If a conductor on a circuit board/ a wire in an appliance needs to be checked, make sure the device is powered down.
4. Place the tip of a probe at each end of the conductor or fuse which needs to be checked.
5. If resistance is less than about 30 ohms, the meter will indicate this by by a beep tone or buzzing sound. The resistance is usually indicated on the display also. If there is break in continuity in the device being tested, an overload indication, usually the digit "1", will be displayed on the meter.

Connecting Probe Leads to Check Diodes or Continuity

- **Power Measurement**

1. Turn the dial of the meter to the diode test setting, which is indicated by a triangle with a bar at the end (*see the photo showing symbols used on meters above).*

2. Connect the probes as shown above.
3. Touch the tip of the negative probe to one end of the diode, and the tip of the positive probe to the other end.
4. When the black probe is in contact with the cathode of the diode (usually indicated by a bar marked on the component) and the red probe makes contact with the anode, the diode conducts, and the meter indicates the voltage. This should be about 0.6 volts for a silicon diode and about 0.2 volts for a Schottky diode. When the probes are reversed, the meter should indicate a "1" because the diode is open circuit and non-conducting.
5. If the meter reads "1" when the probes are placed either way, the diode is likely to be faulty and open circuit. If the meter indicates a value close to zero, the diode is shorted circuited.
6. If a component is in circuit, resistances in parallel will affect the reading and the meter may not indicate "1" but a value somewhat less.

How to Measure Wattage and the Power Consumption of an Appliance With a Multimeter

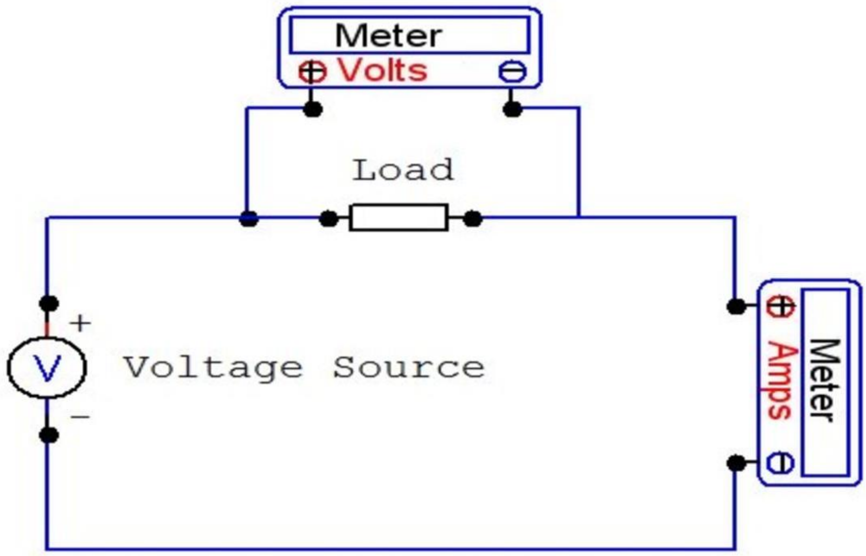
Watts = Volts x Current

So to measure the power in watts of a load/appliance, both the voltage across the load and the current passing through it must be measured. If you have two DMMs, you can measure the voltage and current simultaneously. Alternatively measure the voltage first, and then disconnect the load so that the DMM can be inserted in series to measure current. When any quantity is measured, the measuring device has an influence on the measurement. So the resistance of the meter will reduce current slightly, and give a lower reading than the actual value with the meter not connected.

Three ways to measure current drawn by an electrical appliance:

1. The safest way to measure the power consumption of an appliance powered from the mains is to use a power adapter. These devices plug into a socket and the appliance is then plugged into the adapter which displays information on an LCD. Typical parameters displayed are voltage, current, power, kwh, cost and how long the appliance was turned on (useful for fridges, freezers and air conditioners which cut in and out).
2. An alternative way of safely measuring current drawn by an electrical appliance is to make up a test lead using a short piece of power cord with a trailing socket on one end and a mains plug on the other. The inner neutral core of the power cord could be freed and separated from the outer sheath, and current measured with a clamp meter or probe (Don't remove the insulation!)
3. Another way is to cut the neutral core, add 4mm banana plugs to each of the cut ends and plug these into the meter.

Only make connections and adjust range on the meter with the power off!



Measuring watts = volts x amps

How to Check Peak Voltages - Using a DVA Adapter

Some meters have a button which sets the meter to read max and min RMS voltages and/or peak voltages (of the waveform). An alternative is to use a DVA or Direct Voltage Adapter. Some components such as CDI (Capacitor Discharge Ignition) modules on vehicles, boats and small engines produce pulses which vary in frequency and can be short duration. A DVA adapter will sample and hold the peak value of the waveform and output it as a DC voltage so the component can be checked to see whether it's producing the correct voltage level. A DVA adapter typically has two probe leads as input for measuring voltage and either two output leads with banana plugs or a connector with fixed plugs attached for plugging into a meter with standard spaced sockets. The meter is set to a high DC voltage range (e.g. 1000 volts DC) and the adapter typically outputs 1 volt DC per 1 volt AC input.

Important information for anyone using a DVA to check ignition circuits!

In this application, the adapter is used for measuring the primary voltage of a stator/ignition coil, not the secondary voltage, which could be about 10,000 volts or more.

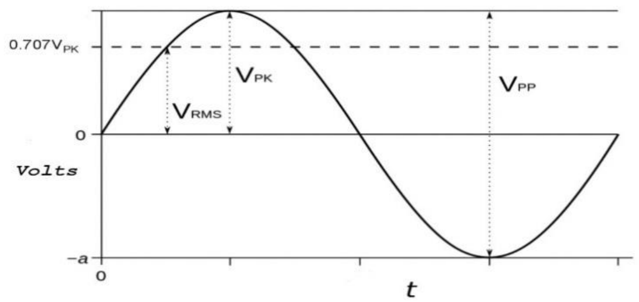
Fluke also manufacture meters that can capture the peak level of short transients e.g. - The Fluke-87-5, Fluke-287 and Fluke-289 models.

True RMS Multimeters.

The voltage supply to your home is AC, and voltage and current vary in polarity over time. The waveform is sinusoidal as in the diagram below and the change of direction of current is known as the frequency and measured in Hertz (Hz). This frequency can be 50 or 60 Hz, depending on which country you live in. The RMS voltage of an AC waveform is the effective voltage and similar to the average voltage. If the peak voltage is V_{peak}, then the RMS voltage for a sinusoidal voltage is $V_{peak} / \sqrt{2}$ (approx 0.707 times the peak voltage). The power in a circuit is the RMS voltage multiplied by the RMS current flowing in a load. The voltage normally printed on appliances is the RMS voltage even though this is not usually stated.

A basic multimeter will indicate RMS voltages for sinusoidal voltage waveforms. The supply to our homes is sinusoidal so this isn't a problem. However if a voltage is non sinusoidal, e.g. a square or triangular wave, then the meter will not indicate the true RMS voltage. True RMS meters however are designed to correctly indicate RMS values for all shaped waveforms.

The AC Supply Feeding Our Homes is a Sine Wave



RMS and peak voltages of an AC sine waveform. Vpp is the peak to peak voltage

- **Voltage measurement**

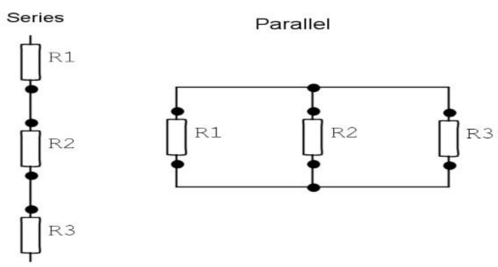
How to Measure Voltage

1. Power off the circuity/wiring under test if there is a danger of shorting out closely spaced adjacent wires, terminals or other points which have differing voltages.
2. Plug the black ground probe lead into the COM socket on the meter (see photo below).
3. Plug the red positive probe lead into the socket marked V (usually also marked with the Greek letter "omega" Ω and possibly a diode symbol).
4. If the meter has has a manual range selection dial, turn this to select AC or DC volts and pick a range to give the required accuracy. So for instance measuring 12 volts on the 20 volt range will give more decimal places than on the 200 volt range.

   If the meter is autoranging, turn the dial to the 'V' setting with the symbol for AC or DC (see "What Do the Symbols on the Range Dial Mean?" below).
5. A multimeter must be connected in parallel in a circuit (see diagram below) in order to measure voltage. So this means the two test probes should be connected in parallel with the voltage source, load or any other two points across which voltage needs to be measured.
6. Touch the black probe against the first point of the circuitry/wiring.
7. Power up the equipment.

8. Touch the other red probe against the second point of test. Ensure you don't bridge the gap between the point being tested and adjacent wiring, terminals or tracks on a PCB.
9. Take the reading on the LCD display.

Series and Parallel Connections



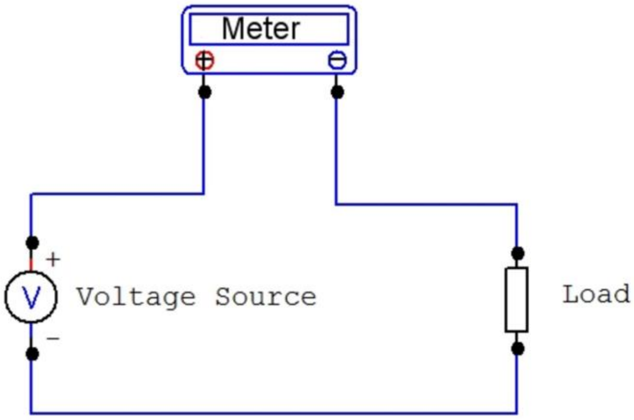
- **Current measurement**

How to Measure Current

1. Turn off the power in the circuit being measured.
2. Connect the probe leads as shown in the photo below. Plug the black ground probe lead into the COM socket.
3. Plug the red positive probe lead either into the mA socket or the high current socket which is usually marked 10A (some meters have a 20 A socket instead of 10A). The mA socket is often marked with the maximum current and if you estimate that the current will be greater than this value, you must use the 10 A socket, otherwise you will end up blowing a fuse in the meter. On some meters, there is no additional socket for measuring current and the same socket is used as for measuring voltage (usually marked VΩmA).
4. A multimeter must be inserted in series in a circuit in order to measure current. See the diagram below.
5. Turn the dial on the meter to the highest current range (or the 10A range if the probe is in the 10A socket). If the meter is autoranging, set it to the "A" or mA setting. (See the photo above for an explanation of symbols used).
6. Turn on the power.
7. If the range is too high, you can switch to a lower range to get a more accurate reading.
8. Remember to return the positive probe to the V socket when finished measuring current. The meter is practically a short circuit when the lead is in the mA or 10 A socket. If you forget and connect the meter to a voltage source when the lead is in this position, you may end up blowing a fuse at best or blowing up the meter at worst! (On some meters the 10A range is un-fused).

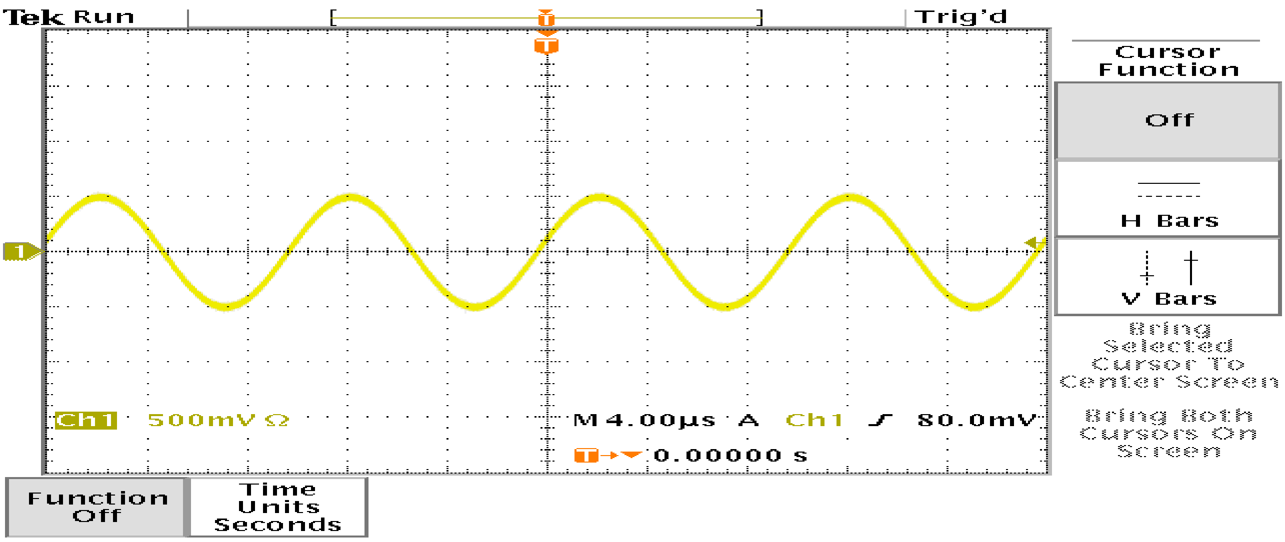
Connecting Probe Leads to Measure Current

Measuring Current - Meter in Series



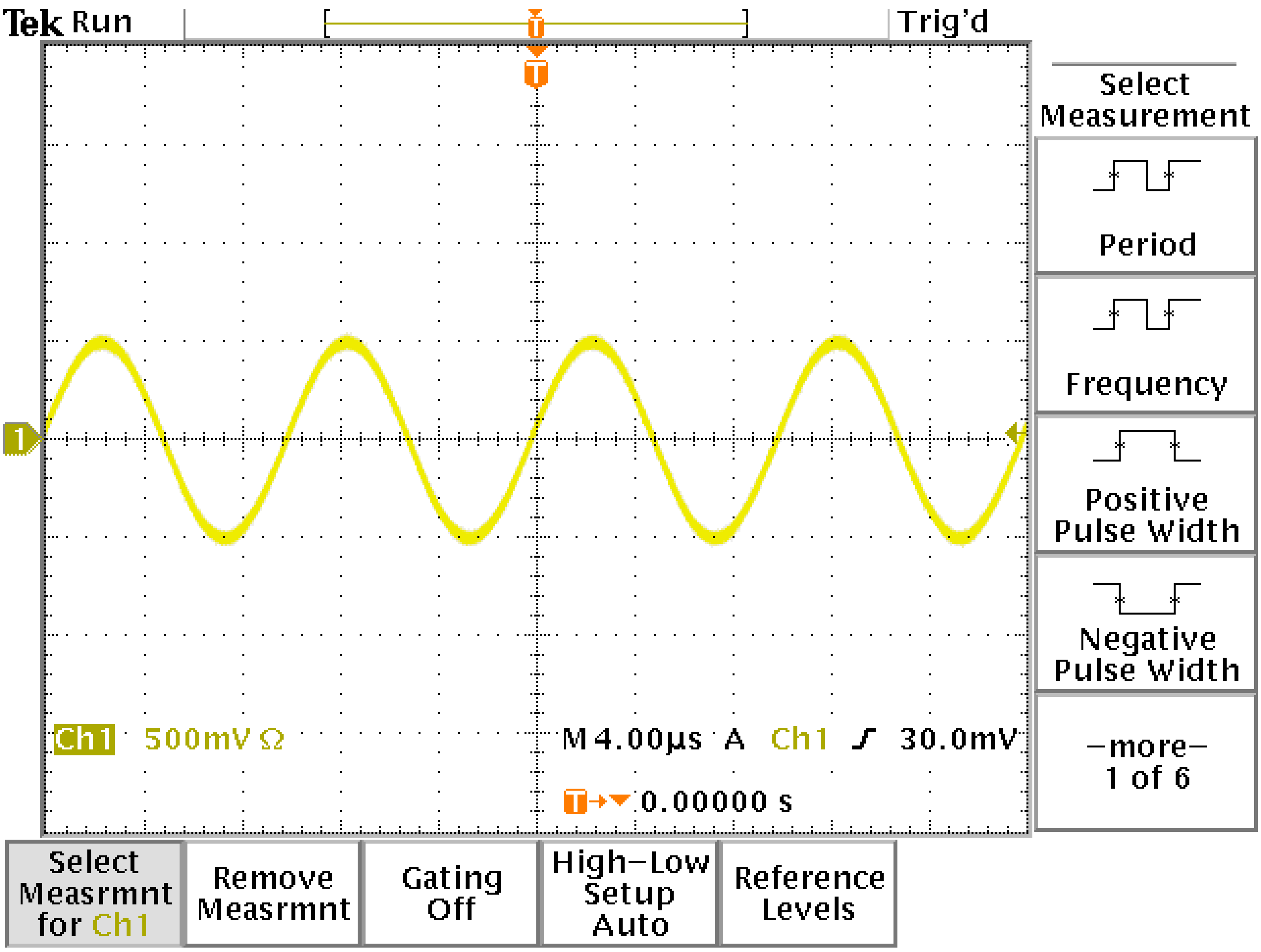
➢ **MEASURING FREQUENCY AND PERIOD**

To measure the frequency and period of the signal, select “V Bars” from the menu. Now in the upper right of the screen you will see two sets of measurements. The measurements on the right are the values of where the selected cursor intersects the waveform. The measurements on the left give the difference between the cursors and the time position of the selected cursor.



AUTOMATIC MEASUREMENTS

The oscilloscope also has built in functions to measure most display signals. To access the automatic measurements press the MEASURE button located towards the top of the oscilloscope. Pressing the MEASURE button brings up the menu shown in Figure 6. The “-more-“ menu option cycles through the available measurements. The first item on the bottom menu cycles through the available channels to make measurements for.



TRIGGER

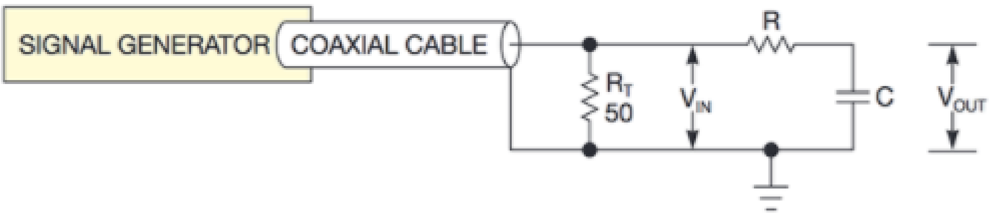
The oscilloscope trigger stabilizes repeated waveforms and captures single-shot waveforms. The trigger makes repeated waveforms appear static by repeatedly displaying the same portion of the signal. There are four types of triggers: edge, logic, pulse and video.

For this lab, and the labs to follow, you will mostly be concerned with edge triggering. The trigger level and slope controls provide the basic trigger point definition.

The slop control determines whether the trigger point is on the rising (positive) or falling (negative) edge of the signal. The level control determines where on the edge the trigger point occurs.

➢ **Measurement of capacitance and inductance**

Engineers usually have access to signal and function generators, as well as frequency counters and oscilloscopes, but they may not have access to capacitance or inductance meters. Using the test setup in the following figure, you can measure capacitance or inductance using a function generator, a multimeter, a frequency counter, and an oscilloscope.



You can measure capacitance or inductance with this test setup.

Use the setup to measure the magnitude of two signals. You can then calculate the capacitance or inductance without measuring phase angles. You can express the ratio of input voltage to output voltage as:

$$\left|\frac{V_{IN}}{V_{OUT}}\right| = \frac{\sqrt{R^2 + X_C^2}}{X_C}, \qquad (1)$$

which you can put into the standard form: which you can put into the standard form:

$$X_C^2 + \frac{R^2}{1 - \left|\frac{V_{IN}}{V_{OUT}}\right|^2} = 0. \qquad (2)$$

After solving the **equation** for X_C, the result is:

$$X_C = \frac{R}{\sqrt{\left|\frac{V_{IN}}{V_{OUT}}\right|^2 - 1}}. \qquad (3)$$

Using the relationship

$$C = \frac{1}{2\pi f X_C}, \qquad (4)$$

the basic **equation** for capacitance is:

$$C = \frac{\sqrt{\left|\frac{V_{IN}}{V_{OUT}}\right|^2 - 1}}{2\pi f R}. \qquad (5)$$

Using the convenient ratio $|V_{IN} / V_{OUT}| = 2$, then

Using the convenient ratio $|V_{IN} / V_{OUT}| = 2$, then

$$C = \frac{\sqrt{3}}{2\pi f R}. \qquad (6)$$

To measure the value of a capacitor, measure the input voltage and then adjust the frequency of the signal generator to make the output voltage one-half of the input voltage. You need not use a 2-to-1 ratio for V_{IN}/V_{OUT}. You can just measure the input voltage and the output voltage and use one of the basic equations to calculate the value of the capacitance or inductance, but a ratio close to 2-to-1 is a good choice.

LO 1.3 TEST ELECTRONIC LAB / WORKSHOP EQUIPMENT

Content/Topic1 : Testing different types of electronic lab / workshop equipment

- **Multimeter Testing**

How Do You Check Voltage With a Multimeter?

Plug the black probe into COM and the red probe into the socket marked VΩ. Set the range to DC or AC volts and touch the probe tips to the two points between which voltage needs to be measured.

How Do You Check if a Wire is Live With a Multimeter?

For this it's best to stay safe and use a non-contact volt tester or phase tester screwdriver. These will indicate if voltage is e.g> 100 volts. A multimeter can only measure the voltage between live and neutral or live and earth if these conductors/terminals are accessible, which may not always be the case.

How Do You Check Voltage Drop With a Multimeter?

Voltage drop occurs across a resistance or along a power cable. So follow the same procedure as for measuring voltage and measure voltage at the two points of interest and subtract one from the other to measure voltage drop.

Why is Voltage Drop Important?

If voltage drop is excessive, appliances may not work properly. Cable should be sized adequately to minimise voltage drop for the current it needs to carry and the distance over which current travels.

This article is accurate and true to the best of the author's knowledge. Content is for informational or entertainment purposes only and does not substitute for personal counsel or professional advice in business, financial, legal, or technical matters.

Question: To be clear, am I correct in my interpretation that if I want to check that there is 230v in my electrical connections in a light fitting that is glowing dimly, I need the lamp in first to complete the circuit, then I check either end of the fitting placing the meter in parallel? Conversely, if I were to use the meter in lieu of the lamp, then this would be in series and the reading would be false or the meter would simply not work?

Answer: If the fitting is wired correctly, it doesn't matter much if the lamp is in place or not as regards measuring the voltage. Yes, you do connect a meter in parallel with a load (i.e. the lamp in your case) to measure voltage. But because a lamp doesn't take much current, it doesn't drop voltage significantly. Now if the load was high powered e.g. a heater, the voltage would drop a few volts. The open circuit voltage of a voltage source is always higher than the output voltage on load because a real voltage source always has internal resistance, plus the connecting wires have resistance also. So if the connecting wires are long or cross-sectional area is small, the voltage drop can be considerable if the wiring is sized inappropriately. If you connect the meter to the fitting without the lamp, it's in parallel with the output terminals on the fitting and because it's set to "volts", no current flows through it (well actually just a little, but microamps because it has such a high resistance). If the meter was set to "amps" it would be like a short circuit and effectively in series with the supply and a fuse would blow. Maybe the concept of parallel and series is a bit confusing. Just remember that when the meter is set to volts, it measures the voltage between two points and when set to amps, it measures the current flowing between the two points.

- **AC /DC variable Power supply Testing**

1. Plug the **power supply** into the wall.
2. Find the big 24-ish pin connector that connects to the motherboard.

3. Connect the GREEN wire with the adjacent BLACK wire.

4. The **power supply's** fan should start up. If it doesn't then it's dead.

5. If the fan starts up, then it could be the motherboard that's dead.

- Oscilloscope testing

Setting Up and Using an Oscilloscope

Once you have an oscilloscope, there are basic things you need to do to set it up and begin using it. This chapter briefly describes these things. In particular, proper grounding is very important for safety reasons; not just for yourself but also for the integrated circuits (ICs) you are testing. Setting oscilloscope controls, calibrating the oscilloscope, connecting probes, and compensating the probes are also described, along with basic oscilloscope measurement techniques.

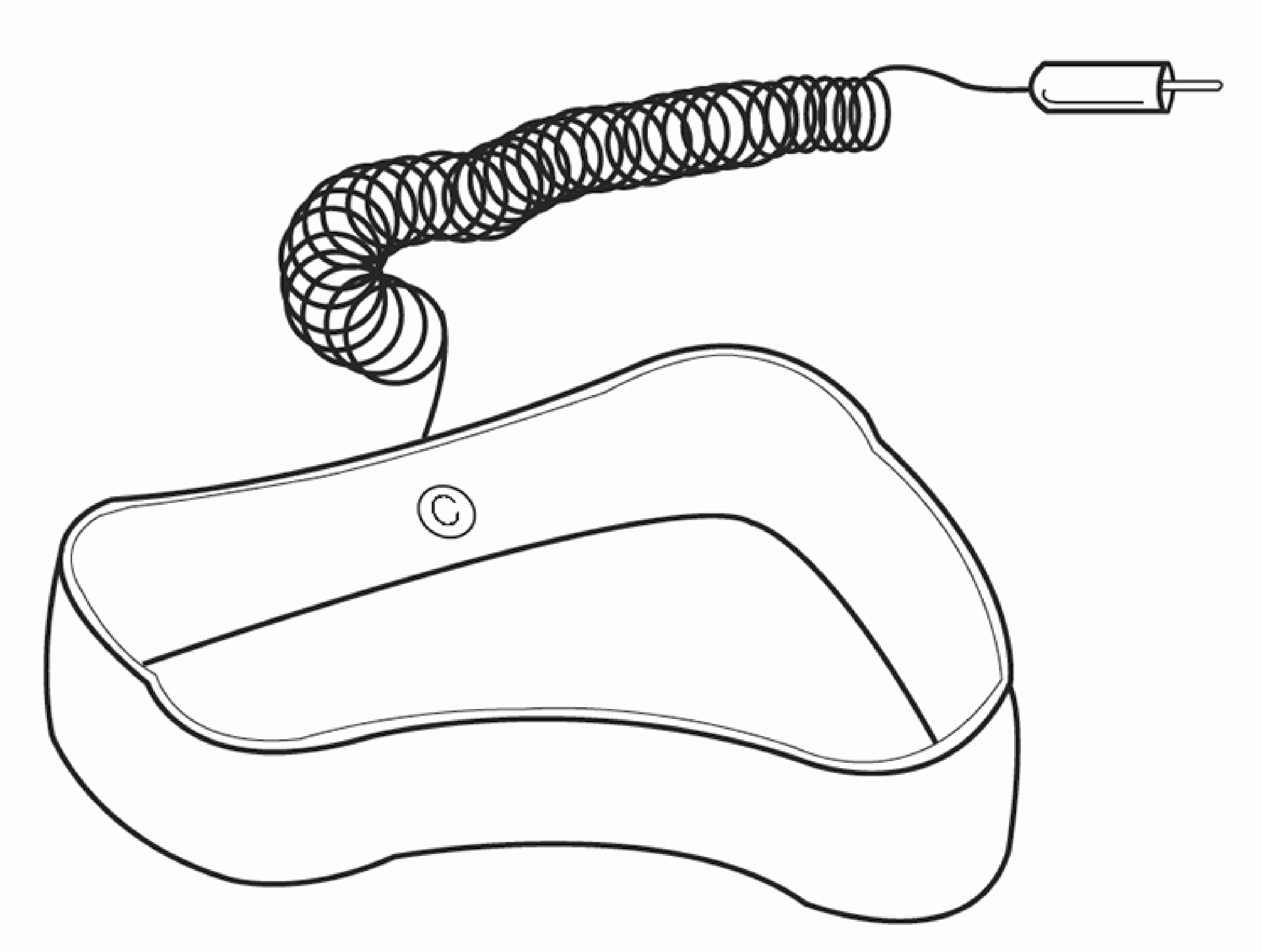
Proper grounding is an important step when you set up to take measurements or work on a circuit:

- Properly grounding the oscilloscope protects you from a hazardous shock.
- Properly grounding yourself protects your ICs from damage.

To ground the oscilloscope means to connect it to an electrically neutral reference point, such as earth ground. Ground your oscilloscope by plugging its three-pronged power cord into an outlet grounded to earth ground. Grounding the oscilloscope is necessary for safety. If a high voltage contacts the case of an ungrounded oscilloscope, any part of the case, including knobs that appear insulated. It can give you a shock. However, with a properly grounded oscilloscope, the current travels through the grounding path to earth ground rather than through you to earth ground.

Grounding is also necessary for taking accurate measurements with your oscilloscope. The oscilloscope needs to share the same ground as any circuits you are testing. Some oscilloscopes do not require separate connection to earth ground. These oscilloscopes have insulated cases and controls, which keeps any possible shock hazard away from the user.

If you are working with ICs, you also need to ground yourself. ICs have tiny conduction paths that can be damaged by static electricity that builds up on your body. You can ruin an expensive IC simply by walking across a carpet or taking off a sweater and then touching the leads of the IC. To solve this problem, wear a grounding strap, as shown in Figure 64. This strap safely sends static charges on your body to earth ground.



Oscilloscope Instructions

1. Set the oscilloscope to display channel 1.
2. Set the vertical volts/division scale and position controls to mid–range positions.
3. Turn off the variable volts/division.
4. Turn off all magnification settings.
5. Set the channel 1 input coupling to DC.
6. Set the trigger mode to auto.
7. Set the trigger source to channel 1.
8. Turn trigger holdoff to minimum or off.
9. Set the horizontal time/division and position controls to mid-range positions.
10. Adjust channel 1 volts/division such that the signal occupies as much of the 10 vertical divisions as possible without clipping or signal distortion.

Calibrating the Instrument

In addition to proper oscilloscope setup, periodic instrument self-calibration is recommended for accurate measurements. Oscilloscope calibration is needed if the ambient temperature has changed more than 5° C (9° F) since the last self-calibration or once per week. In the oscilloscope menu, this can sometimes be initiated as Signal Path Compensation. Refer to the manual that accompanied your oscilloscope for more detailed instructions.

Connecting the Probes

Once you have properly grounded the oscilloscope and yourself, and you've set up the oscilloscope in standard positions, you are ready to connect a probe to your oscilloscope. A probe, if well-matched to the oscilloscope, enables you to access all of the power and performance in the oscilloscope and will ensure the integrity of the signal you are measuring. Measuring a signal requires two connections:

- The probe tip connection
- The ground connection

Probes often come with a clip attachment for grounding the probe to the circuit under test. In practice, you attach the grounding clip to a known ground in the circuit, such as the metal chassis of a product you are repairing, and touch the probe tip to a test point in the circuit.

Compensating the Probes

Passive attenuation voltage probes must be compensated to the oscilloscope. Before using a passive probe, you need to compensate it to balance its electrical properties to a particular oscilloscope. You should get into the habit of compensating the probe every time you set up your oscilloscope. A poorly adjusted probe can make your measurements less accurate. Figure 65 illustrates the effects on a 1 MHz test signal when using a probe that is not properly compensated.

Most oscilloscopes have a square wave reference signal available at a terminal on the front panel used to compensate the probe. General instructions to compensate the probe are as follows:

1. Attach the probe to a vertical channel.
2. Connect the probe tip to the probe compensation, i.e. square wave reference signal.
3. Attach the ground clip of the probe to ground.
4. View the square wave reference signal.
5. Make the proper adjustments on the probe so that the corners of the square wave are square.

Oscilloscope Measurement Techniques

The two most basic measurements you can make are:

- Voltage measurements
- Time measurements

Just about every other measurement is based on one of these two fundamental techniques.

This section discusses methods for taking measurements visually with the oscilloscope screen. This is a common technique with analog instruments, and also may be useful for “at-a-glance” interpretation of digital oscilloscope displays.

Note that most digital oscilloscopes include automated measurement tools that simplify and accelerate common analysis tasks, thus improving the reliability and confidence of your measurements. However, knowing how to make measurements manually as described here will help you understand and check the automatic measurements.

Voltage Measurements

Voltage is the amount of electric potential, expressed in volts, between two points in a circuit. Usually one of these points is ground (zero volts), but not always. Voltages can also be measured from peak-to-peak. That is, from the maximum point of a signal to its minimum point. You must be careful to specify which voltage you mean. The oscilloscope is primarily a voltage-measuring device. Once you have measured the voltage, other quantities are just a calculation away. For example, Ohm’s law states that voltage between two points in a circuit equals the current times the resistance. From any two of these quantities you can calculate the third using the formula shown below.

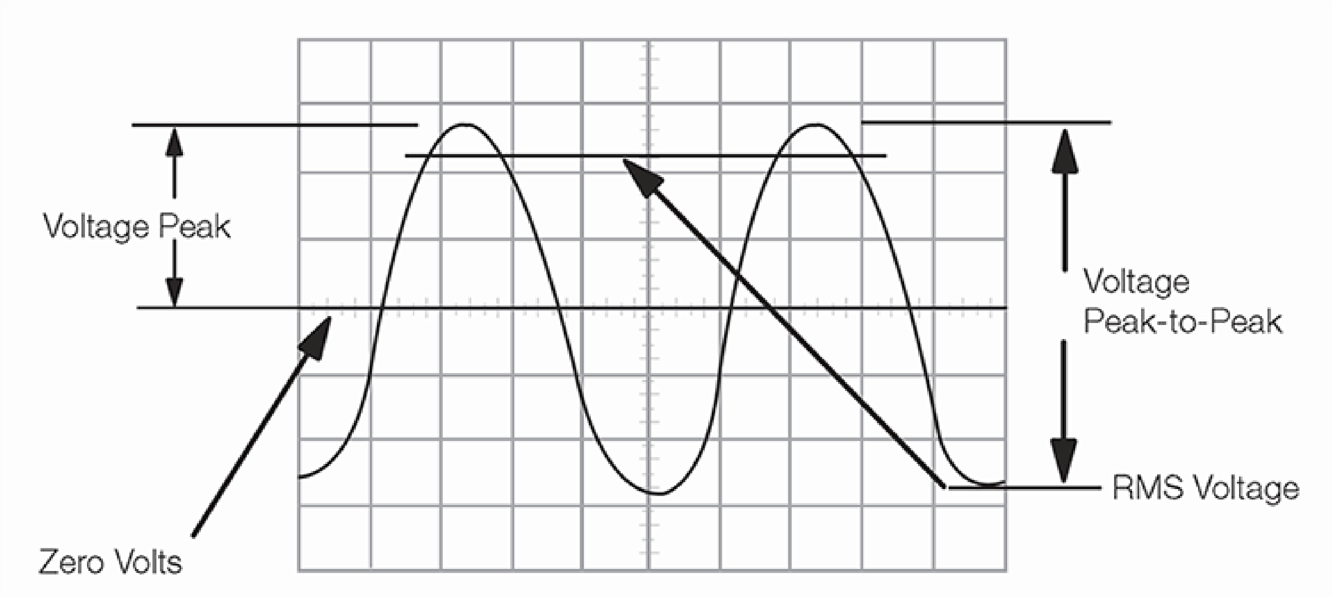
$$\text{Voltage} = \text{Current } x \text{ Resistance}$$

$$\text{Current} = \frac{\text{Voltage}}{\text{Resistance}}$$

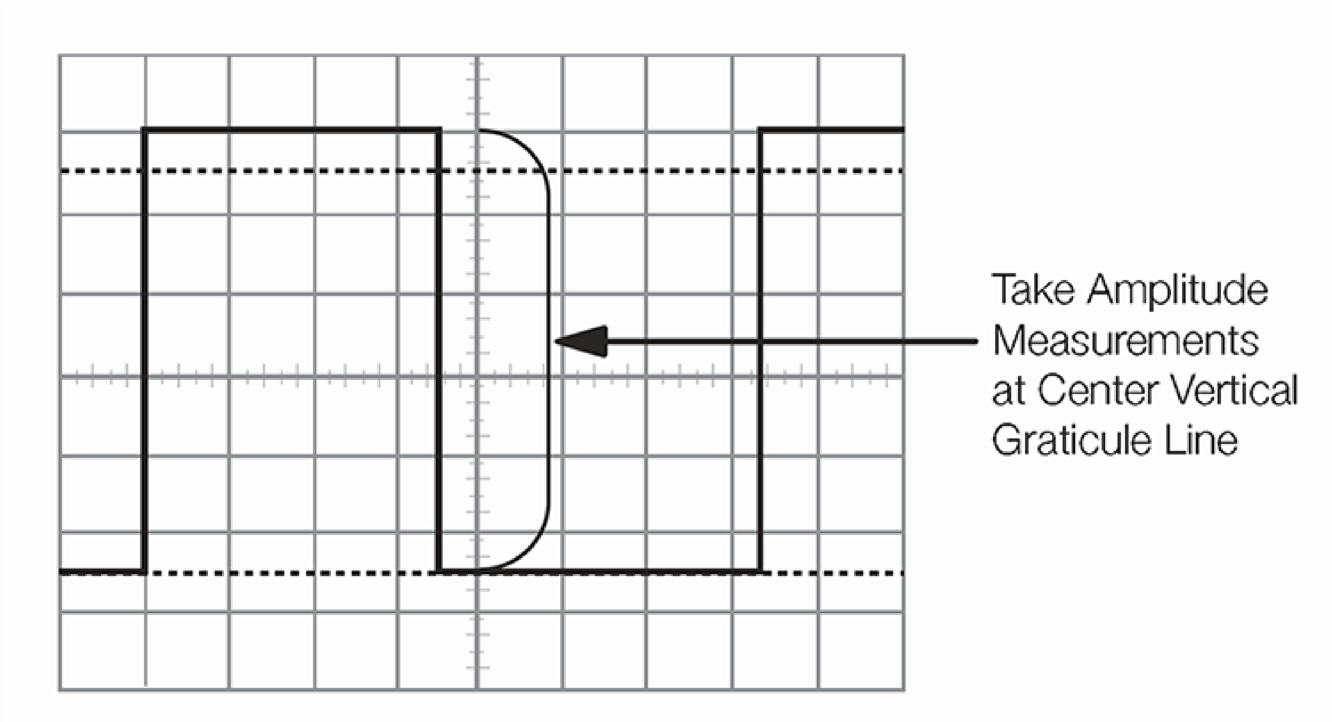
$$\text{Resistance} = \frac{\text{Voltage}}{\text{Current}}$$

Voltage = Current x Resistance

Another handy formula is the power law, which states that the power of a DC signal equals the voltage times the current. Calculations are more complicated for AC signals, but the point here is that measuring the voltage is the first step toward calculating other quantities. Figure 66 shows the voltage of one peak (Vp) and the peak-to-peak voltage (Vp–p).



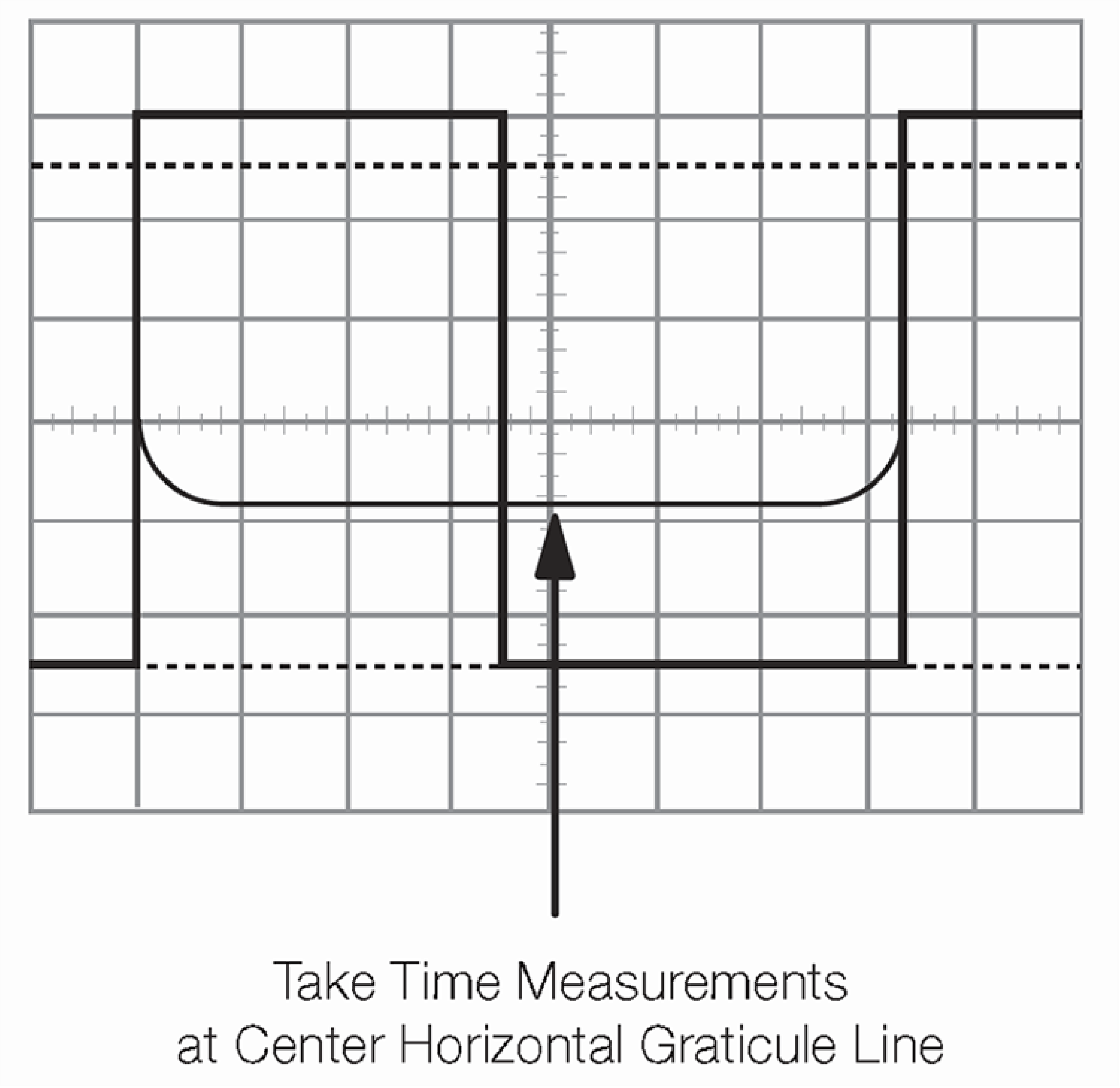
The most basic method of taking voltage measurements is to count the number of divisions a waveform spans on the oscilloscope's vertical scale. Adjusting the signal to cover most of the display vertically makes for the best voltage measurements, as shown in the following figure. The more display area you use, the more accurately you can read the measurement.



Many oscilloscopes have cursors that let you make waveform measurements automatically, without having to count graticule marks. A cursor is simply a line that you can move across the display. Two horizontal cursor lines can be moved up and down to bracket a waveform's amplitude for voltage measurements, and two vertical lines move right and left for time measurements. A readout shows the voltage or time at their positions.

Time and Frequency Measurements

You can make time measurements using the horizontal scale of the oscilloscope. Time measurements include measuring the period and pulse width of pulses. Frequency is the reciprocal of the period, so once you know the period, the frequency is one divided by the period. Like voltage measurements, time measurements are more accurate when you adjust the portion of the signal to be measured to cover a large area of the display, as illustrated in Figure the figure bellow.



Pulse Width and Rise Time Measurements

In many applications, the details of a pulse’s shape are important. Pulses can become distorted and cause a digital circuit to malfunction, and the timing of pulses in a pulse train is often significant.

Standard pulse measurements are pulse rise time and pulse width. Rise time is the amount of time a pulse takes to go from a low to high voltage. By convention, the rise time is measured from 10% to 90% of the full voltage of the pulse. This eliminates any irregularities at the pulse's transition corners.

Pulse width is the amount of time the pulse takes to go from low to high and back to low again. By convention, the pulse width is measured at 50% of full voltage. Figure 69 illustrates these measurement points.

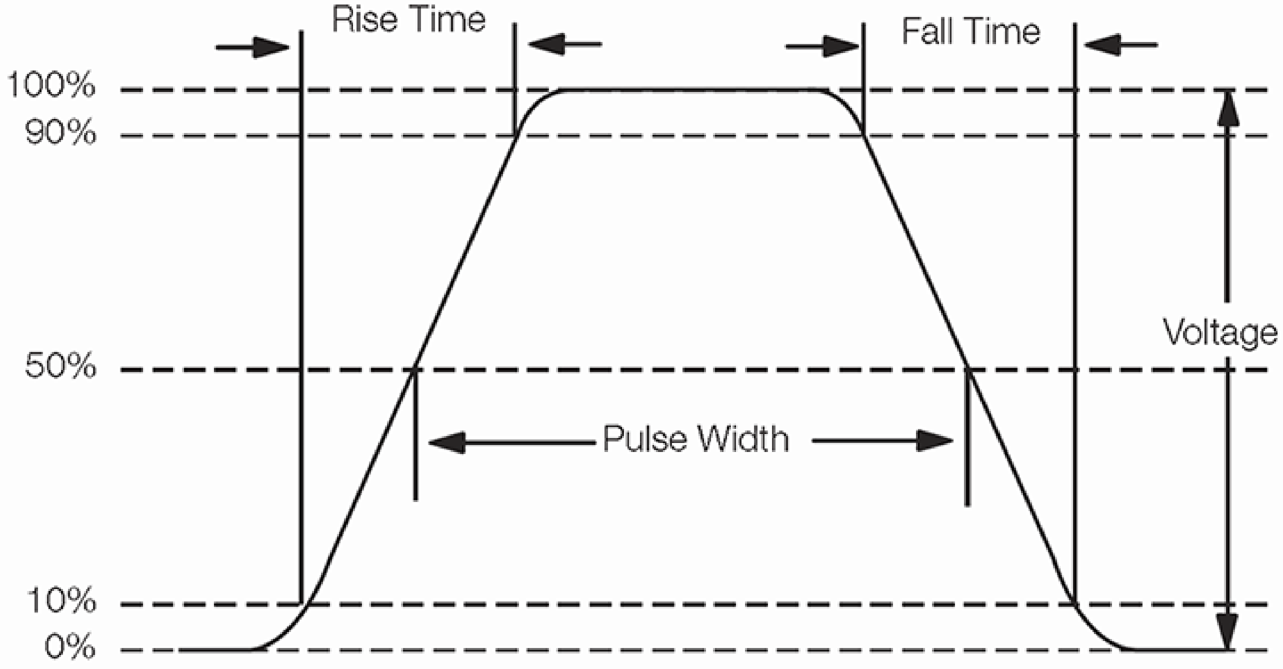


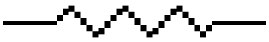
Figure 69. Rise time and pulse width measurement points.

LO 2.1: IDENTIFY PASSIVE DEVICES

Content/Topic1: Identification of different types of resistors:

1. RESISTOR

The resistance, in this way, can be defined as the property of all materials to oppose the flow of electric current. The unit of resistance is **Ohm** (Ω).The symbol of resistance manufactured version of resistance. The symbol of resistance is (Fig. 1) and denoted by letter R.

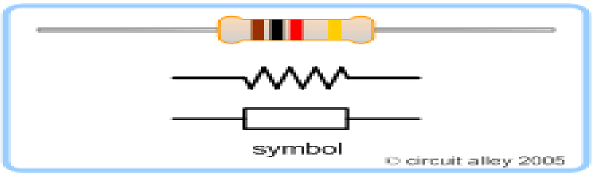


TYPES OF RESISTORS

Resistors are made in many forms, but they all belong to either of two groups (fixed or variable).

A. FIXED RESISTORS

Fixed resistors are resistors whose resistance characteristic value does not change and cannot be changed. All fixed resistor have the same schematic symbol, shown below:



Schematic symbol for a fixed resistor

Classification of fixed resistors: The major classes of resistors used in electronics are: Carbon resistor, wire-wound resistor, and film resistors.

1. Carbon resistor

Carbon resistors are made of finely ground particles of carbon mixed with ceramic materials and enclosed in an insulating material. Carbon resistors are compact, robust, easy to manufacture and cheap.

1. **Wire-wound resistor**

Wire-wound resistor consists of uniform wire wound around insulating material. The resistance of this kind of resistor is very accurate.

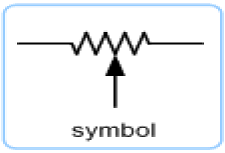
2. **Film resistor:**

Thin or thick layer of resistive material (carbon composition) is deposited in an insulating base to make a film resistor. Film resistors are very compact and accurate. Film resistors are widely used in integrated circuits.

B. VARIABLE RESISTOR

A variable resistor is a type of resistor in which its resistance can be set during operation or preset at a certain resistance for accuracy and control. Variable resistor usually has their maximum resistance value marked on them. A typical type of variable resistor used as a volume control adjustment in an amplifier is a **potentiometer** (POT).

For circuits that requires only to set a resistance once or during maintenance to a certain value, a trimmer potentiometer (TRIM POT) is used. The schematic symbol for a variable resistor is the figure shown below.



1.1.2 Resistor characteristics

If a resistor's material is homogeneous and has a constant cross-sectional area A and length L, then the resistance is given by:

$$R = \frac{\rho L}{A}$$

where ρ is the resistivity of the material.

LDR (Light Depending Resistor)

Light depending resistor (LDR) or photo resistor is device whose resistivity is a function of the incident electromagnetic radiation hence they are light sensitive devices as photo conductors' photo conductivity cells or simply photo cells they are made up of semi conductor materials having high resistance there are many different symbols used to indicate a LDR ane of the figure below the arrow indicates light following on it.

APPLICATION OF LDR

LDR have low case and simple structure they are often used as light sensors, they are used when there is need to detect absences or presences of light like in camera light meter in street lamps alarm clock burglar alarm circuit light intensity meters for counting the packages moving on a convey or belt, etc.

THE TWO METHOD OF APPLICATION LDR

Analog applications:

- Camera exposure control
- Auto slide focus-dual cell
- Photocopy machines- density of toner
- Colorimetric test equipment
- Densitometer

Digital applications:

- Automatic headlight dimmer
- Night light control
- Oil burner flame out
- Street light control
- Absence/ presence (beam breaker)
- Position sensor

WORKING PRINCIPLE OF LDR

Light depending resistor works on the principle or photo conductivity. Photo conductivity is on optical phenomenon in which the materials conductivity hence resistivity reduces when light is absorbed by the material when light falls when the photons fall on the valance band of the semiconductor material are excited to the conductor band these photons in the incident greater than the band which results in large number of charge carries the result of this flowing and hence is said that the resistance of the device has decreased this is the most common working principle of LDR.

The Thermistor

The **Thermistor** is another type of temperature sensor, whose name is a combination of the words THERM-ally sensitive res-ISTOR. A thermistor is a type of resistor which changes its physical resistance with changes in temperature.

Thermistor

Thermistors are generally made from ceramic materials such as oxides of nickel, manganese or cobalt coated in glass which makes them easily damaged. Their main advantage over snap-action types is their speed of response to any changes in temperature, accuracy and repeatability.

Most types of thermistor's have a Negative Temperature Coefficient of resistance or (NTC), that is their resistance value goes DOWN with an increase in the temperature but some with a Positive Temperature Coefficient, (PTC), their resistance value goes UP with an increase in temperature are also available.

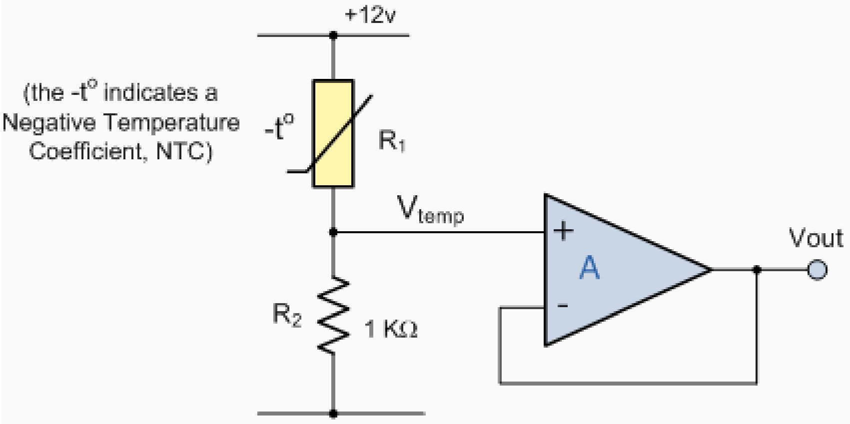
Thermistors are constructed from a ceramic type semiconductor material using metal oxide technology such as manganese, cobalt and nickel, etc. The semiconductor material is generally formed into small pressed discs or balls which are hermetically sealed to give a relatively fast response to any changes in temperature.

Thermistors are rated by their resistive value at room temperature (usually at 25^{o}C), their time constant (the time to react to the temperature change) and their power rating with respect to the current flowing through them. Like resistors, thermistors are available with resistance values at room temperature from 10's of MΩ down to just a few Ohms, but for sensing purposes those types with values in the kilo-ohms are generally used.

Thermistors are passive resistive devices which means we need to pass a current through it to produce a measurable voltage output. Then thermistors are generally connected in series with a suitable biasing resistor to form a potential divider network and the choice of resistor gives a voltage output at some pre-determined temperature point or value for example:

Example No1

The following thermistor has a resistance value of 10KΩ at 25°C and a resistance value of 100Ω at 100°C. Calculate the voltage drop across the thermistor and hence its output voltage (Vout) for both temperatures when connected in series with a 1kΩ resistor across a 12v power supply.



At **25°C**

$$Vout = \frac{R_2}{R_1+R_2} xV = \frac{1000}{10000+1000} x12v = 1.09v$$

At **100°C**

$$Vout = \frac{R_2}{R_1+R_2} xV = \frac{1000}{100+1000} x12v = 10.9v$$

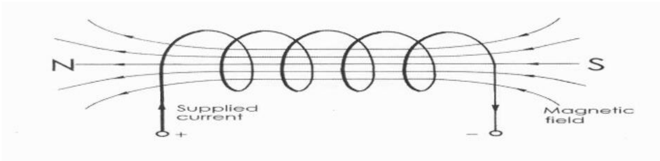
2. INDUCTORS

When current flows through a wire that has been coiled, it generates a magnetic field. This magnetic field reacts so as to oppose any change in the current. This reaction of the magnetic field, trying to keep the current flowing at a steady rate, is known as **Inductance** and the force it develops is called an inductor.

The wire coil in the relay is the simplest form of inductor, which is a passive energy storage element that stores energy in the form of a magnetic field.

Itcan be shown that, when a current flows in a wire, a magnetic field is produced around the wire. If the wire is formed into a coil, the magnetic field resembles that of a bar magnet.

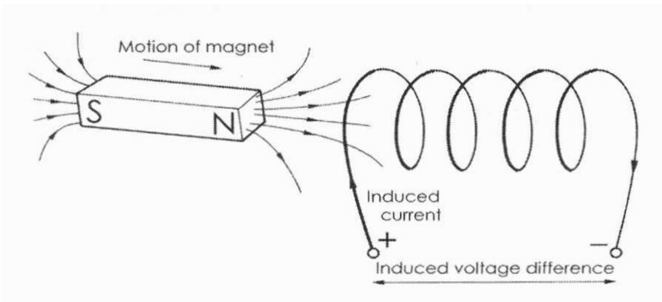
The magnetic field is represented by **lines of force** that show the direction of the field in and around the coil.



Inductor symbol

Induction

A current through a coil produces a magnetic field, as described above. The reverse action also occurs. In the drawing below, a bar magnet moving toward a coil **induces** a current in the coil:



The current flows and the voltage difference is produced only when the magnet is moving. If we hold the magnet still, the current stops. If we move the magnet away from the coil, the current flows in the opposite direction.

The induced magnetic field opposes the motion of the magnet. When we move the magnet away, the current reverses and the field reverses too. Now there is a south pole near the north pole of the magnet. Unlike poles attract. There is a force trying to prevent us from moving the magnet away.

Self induction

When the current through a coil changes, the magnetic field through the coil changes. This changing field acts just like a magnet being moved around near the coil, it induces another current in the coil. The direction of the current opposes the change in current through the coil. This effect, in which a coil induces current in itself, is called **self induction.**

Types of inductor

There are **two main types of inductor**:

Chokes: the voltage induced in a coil is proportional to the rate of change of the magnetic field.

A high-frequency signal changes from positive to negative and back again very quickly much faster than a low-frequency signal. So, when an alternating signal is passing through a coil, the rate of change of the magnetic field is greater for high-frequency signals than for low-frequency signals.
Tuning coils: Used in radio transmitters and receivers to tune a circuit to a particular radio frequency. The coil is wound on a plastic former. It may have a core of ferrite or iron dustceramic that can be screwed in or out of the coil to tune it.

Two or more coils can be wound on one former to make a transformer.

Inductance

The unit of inductance and self-inductance is the henry, symbol L. It is defined by this equation:voltage = -L x rate of change of current
The current through an inductor cannot change instantaneously because it is the integral of the voltage. It takes time to increase or decrease the current flowing through an inductor, such as a relay or motor. Sparks induced by the high induced voltage may occur when suddenly switching off the relay.

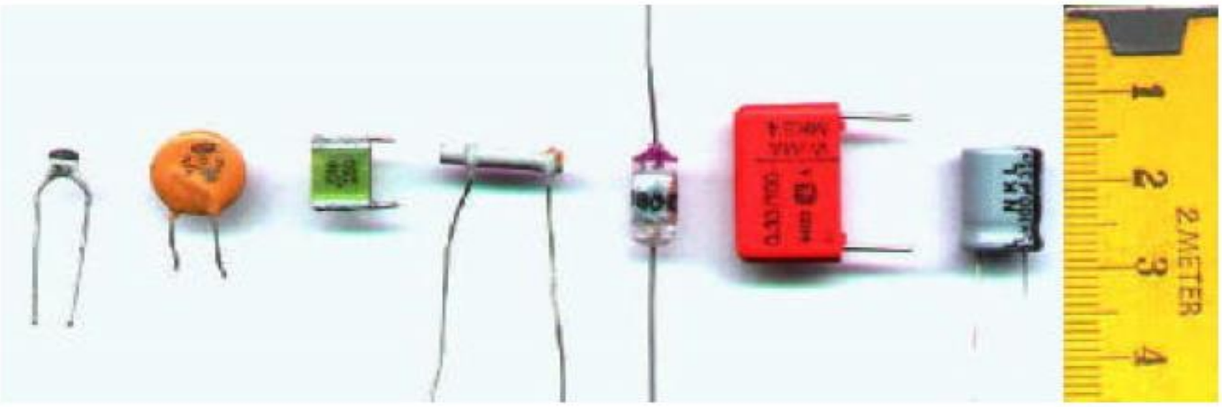
3. **CAPACITOR**

Topic2: Identification of different types of capacitors

4. CAPACITOR

Capacitance is the property of a system of conductor and insulator which allow them to store electric charge when a potential difference exists between the conductors. In other words capacitance is the property of a circuit in which energy can be stored in the form of electric charges

Capacitors picture and symbols



A **capacitor** is made with two plates of a highly conductive semiconductor material separated by a pure semiconductor material or another insulator like glass silicon dioxide (SiO_2).

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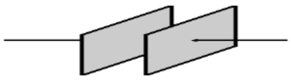
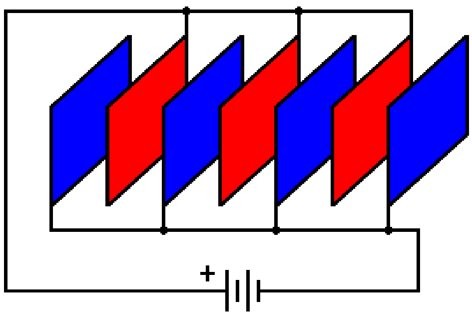


A practical capacitor is not limited to two plates. As shown below, it is quite possible to place a number of plates in parallel and then connect alternate plates together. In addition, it is not necessary for the insulating material between plates to be air. Any insulating material will work, and some insulators have the effect of massively increasing the capacity of the resulting device to hold an electric charge. This ability is known generally as capacitance, and capacitors are rated according to their capacitance.



The capacitance C of **n** plate capacitor is equal to $C = (n-1)k\frac{A}{d}$.

A capacitor has equal amount of positive and negative charges in each metal plate when the capacitor is not charged (i.e. not included in the circuit where potential difference exist). In this case the capacitor is called **neutral** or uncharged. When the capacitor is included in a circuit where potential difference exist, the capacitor becomes **charged** (i.e. one plate has excessive positive and another plate has excessive negative charge).

Once the capacitor is charged, the potential difference between the plates remains for a long time if the capacitor is not included in any discharging circuit.

The unit of capacitance is Farad (F). The capacitance in-terms of unit is defined as:

$C = \frac{Q}{V}$ Where Q – quantity of charges (Columb)

V – applied voltage that causes the flow of charges in the plates of capacitor (Volt).

One Farad (1F) is the capacitance of a capacitor that can store one Columb of charges when the applied potential difference between the plates of the capacitor is one volt:

1F = 1 Columb/ 1 Volt

Practically, one Farad is a big value and the capacitor with such capacitance must be very large in size. In electronics we use micro, nano and pico Farads.

1μF (micro) = 10^{-6} F, 1 nF(nano) = 10^{-9} F; 1 pF (Pico) = 10^{-12} F

The capacitance is inversely proportional to the distance between the plates. That is, for fixed area of the plates, the capacitance increases if distance between the plates is decreased. $C = k\frac{A}{d}$

Where C – capacitance (F);

A – area of the plates (m.sq.);

d – distance between the plates (m)

k – dielectric constant of the material used between the plates (F/m)

According to the type of the dielectric material used between the plates, the capacitors are classified into air, mica, paper, ceramic and electrolytic.

In air capacitor the dielectric between the plates is air. The capacitance of the air capacitor usually lies between 10 to 400 pF.**In mica capacitor** thin mica sheets are staked between tinfoil sections (plates) to provide required capacitance. The entire unit is generally molded in a Bakelite case. Mica capacitors are often used for small capacitance values of 50 to 500 pF.

In paper capacitor two rolls of tinfoil conductors separated by a tissue paper are rolled into a compact cylinder. The entire cylinder is generally encased in plastic module. Paper capacitors are used for medium capacitance values of 0.001 to 1 μF.

The ceramic dielectric materials are used in ceramic capacitors. When ceramics are used as dielectric very high value of dielectric constant can be obtained. The capacitance up to 0.01 μF can be obtained in much less space than a paper capacitor if ceramic material is used.

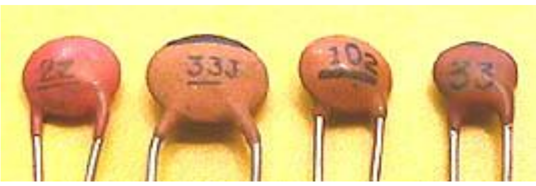


Figure 5:Ceramic capacitors

In air, paper, mica and ceramic capacitors there is no required polarity, since either side (plate) can be made more positive. It means that any plate of these capacitors can be connected to the positive terminal of the voltage source.

Very high value of capacitance can be obtained if electrolytes of borax, phosphate or carbonate are used as dielectric material. These types of capacitors are called **electrolytic capacitors** and they can provide capacitance values up to 5000 µF. electrode and the soaked gauze. The negative aluminum electrode simply provides a connection to the electrolyte.

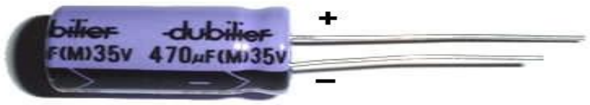


Figure 6 :Electrolytic capacitors

Capacitor Colour Codes

Generally, the actual values of Capacitance, Voltage or Tolerance are marked onto the body of the capacitors in the form of alphanumeric characters. However, when the value of the capacitance is of a decimal value problems arise with the marking of a "Decimal Point" as it could easily not be noticed resulting in a misreading of the actual value. Instead letters such as p (pico) or n (nano) are used in place of the decimal point to identify its position and the weight of the number.

For example, a capacitor can be labelled as, n47 = 0.47nF, 4n7 = 4.7nF or 47n = 47nF and so on. Also, sometimes capacitors are marked with the capital letter K to signify a value of one thousand pico-Farads, so for example, a capacitor with the markings of 100K would be 100 x 1000pF or 100nF.

To reduce the confusion regarding letters, numbers and decimal points, an International colour coding scheme was developed many years ago as a simple way of identifying capacitor values and tolerances. It consists of coloured bands (in spectral order) known commonly as the **Capacitor Colour Code** system and whose meanings are illustrated below:

Capacitor Colour Code Table

Colour	Digit A	Digit B	Multiplier D	Tolerance (T) > 10pf	Tolerance (T) < 10pf	Temperature Coefficient (TC)
Black	0	0	x1	± 20%	± 2.0pF	
Brown	1	1	x10	± 1%	± 0.1pF	$-33x10^{-6}$
Red	2	2	x100	± 2%	± 0.25pF	$-75x10^{-6}$
Orange	3	3	x1,000	± 3%		$-150x10^{-6}$
Yellow	4	4	x10,000	± 4%		$-220x10^{-6}$
Green	5	5	x100,000	± 5%	± 0.5pF	$-330x10^{-6}$
Blue	6	6	x1,000,000			$-470x10^{-6}$
Violet	7	7				$-750x10^{-6}$
Grey	8	8	x0.01	+80%,-20%		
White	9	9	x0.1	± 10%	± 1.0pF	
Gold			x0.1	± 5%		
Silver			x0.01	± 10%		

LO 2.2 SELECT PASSIVE DEVICE

Content/Topic1: Proper selection of passive devices relatively to work to be done

A. Resistors

The resistance, in this way, can be defined as the property of all materials to oppose the flow of electric current. The unit of resistance is **Ohm** (Ω). Resistor is considered as all materials whose ability of opposing the flow of electric current.

Resistor rating

Resistors, have two ratings, or values, associated with them.

First, of course is the resistance value itself. This is measured in units called ohms and symbolized by the Greek letter Omega (Ω). The second rating is the amount of power the resistor can dissipate as heat without itself overheating and burning up.

Resistance Value

Resistors have a resistance value, indicating how strongly the component resists the electrical flow. Resistance is measured in "ohms", often indicated in technical literature by the uppercase Greek letter Omega (Ω).

Wattage

Resistors have wattage specification that indicates how much power the resistor can dissipate (as heat) before it burns up.

Power rating of resistor

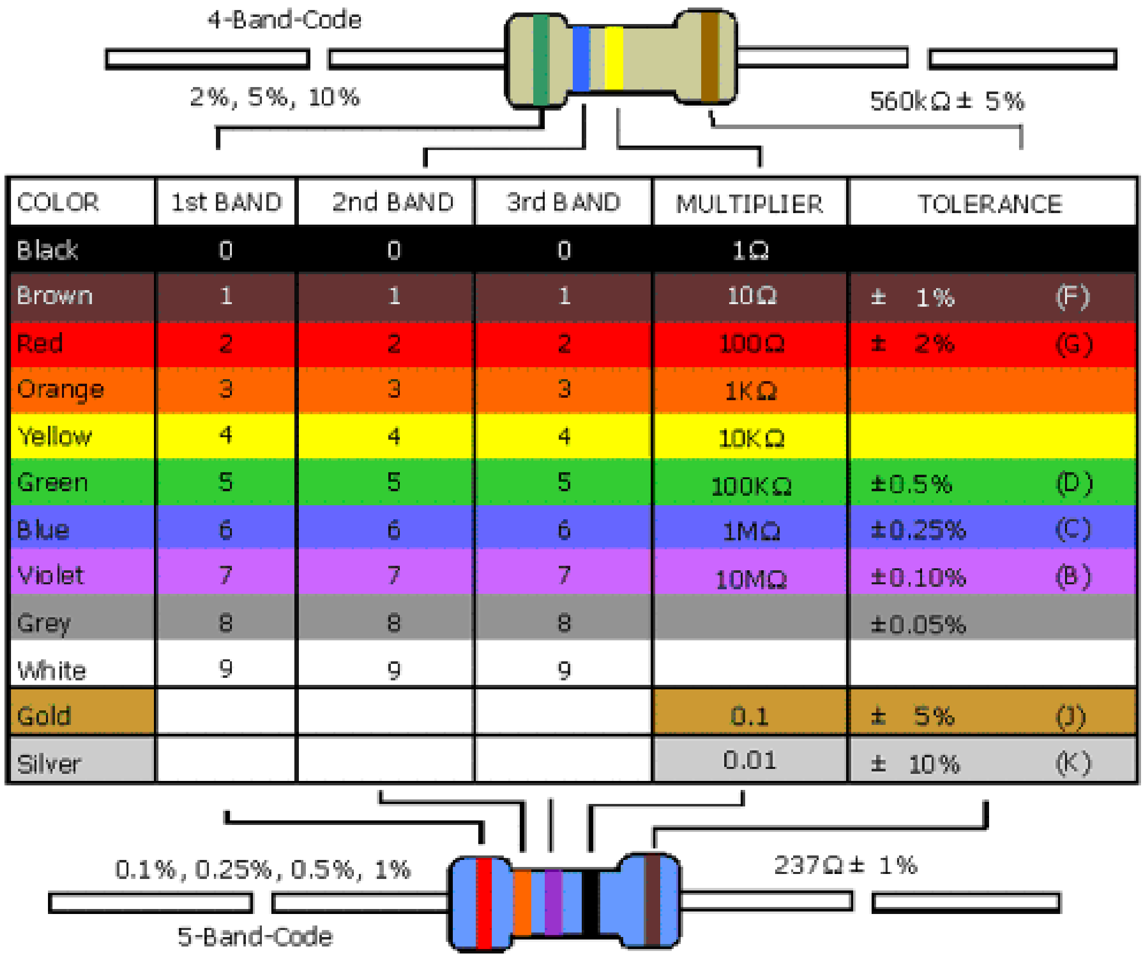
The resistance, while opposing the flow of current through it, converts some portion of electrical energy into thermal energy (heat). The dissipated power is related to the current and resistance according to: $\mathbf{P = I^2 R}$

STANDARD RESISTOR VALUES AND COLOR CODES

Some resistors are large enough in size to have their resistance in printed on the body. However, there are some resistors that are too small in size. Therefore, a system of **color coding** is used to indicate their values.

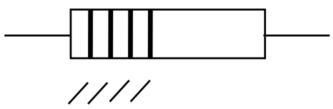
The tolerance of a resistor is the permitted variation in percent from its indicated (not measured) value.

A total of 12 bars of different colors are used to express the ohmic value and tolerance of a resistor. The numerical value associated with each colour is indicated in the table below:



COLOR	1st BAND	2nd BAND	3rd BAND	MULTIPLIER	TOLERANCE
Black	0	0	0	1Ω	
Brown	1	1	1	10Ω	± 1% (F)
Red	2	2	2	100Ω	± 2% (G)
Orange	3	3	3	1KΩ	
Yellow	4	4	4	10KΩ	
Green	5	5	5	100KΩ	±0.5% (D)
Blue	6	6	6	1MΩ	±0.25% (C)
Violet	7	7	7	10MΩ	±0.10% (B)
Grey	8	8	8		±0.05%
White	9	9	9		
Gold				0.1	± 5% (J)
Silver				0.01	± 10% (K)

Method of calculating the ohmic value and tolerance:



The color bands are always read **left to right** from the end that has the bands closest to it. The 1st and the 2nd color bands represent the first significant digit (A) and the second significant digit (B) respectively of the resistance value. The 3rd band is the multiplier factor (C) and the 4th band indicates the tolerance (D) in percent.

In the case of a resistor with three color bands only, it means that the fourth band has no color. Thus, this band is given the tolerance of 20%.

$R = AB \times 10^{C} \pm D$

B. Inductors

INDUCTOR RATINGS

- Wire gauge and physical size of the coil determine the current handling capacity.
- Core material will have a temperature dependence. Air is best, followed by iron powder, then ferrites.

Self-Inductance

Inductance: is the name given to the property of a component that opposes the change of current flowing through it and even a straight piece of wire will have some inductance. Inductors do this by generating a self-induced emf within itself as a result of their changing magnetic field. When the emf is induced in the same circuit in which the current is changing this effect is called **Self-induction**, **(L)** but it is sometimes commonly called back-emf as its polarity is in the opposite direction to the applied voltage. When the emf is induced into an adjacent component situated within the same magnetic field, the emf is said to be induced by **Mutual-induction**, (M) and mutual induction is the basic operating principal of transformers, motors, relays etc. Self-inductance is a special case of mutual inductance, and because it is produced within a single isolated circuit we generally call self-inductance simply, **Inductance**. The basic unit of inductance is called the **Henry**, (H) after Joseph Henry, but it also has the units of **Webers per Ampere** (1 H = 1 Wb/A).

The relationship between self-inductance, **(L)** and the number of turns, **(N)** and for a simple single layered coil can be given as:

Self-inductance of a Coil

$$L = N\frac{\Phi}{I}$$

Where:

- **L** is in Henries
- **N** is the Number of turns
- **Φ** is the Magnetic Field linkage
- **I** is in Amperes

When the magnetic flux linking a conductor or a coil changes, an e.m.f (electromotive force) is induced in it. The magnitude of induced e.m.f in a coil is equal to the rate of change of magnetic flux linkages.

$$e.m.f = e = N\frac{d\phi}{dt}$$

The self-inductance of a coil or to be more precise, the coefficient of self-inductance also depends upon the characteristics of its construction. For example, size, length, number of turns etc. It is therefore possible to have inductors with very high coefficients of self induction by using cores of a high permeability and a large number of coil turns. Then for a coil, the magnetic flux that is produced in its inner core is equal to:

$$\Phi = B \times A$$

If the inner core of a coil is hollow "air cored", the magnetic induction in its air core will be given as.

$$B = \mu_o H = \mu_o \frac{N.I}{\ell}$$

Then by substituting these expressions in the first equation above for Inductance will give us:

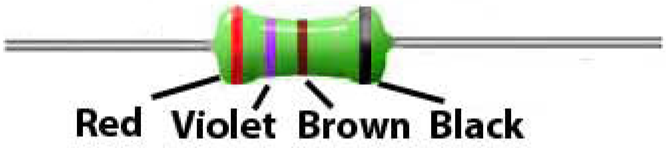
$$L = N\frac{\Phi}{I} = N\frac{B.A}{I} = N\frac{\mu_o.N.I}{\ell.I}$$

Finally giving us an equation for the coefficient of self-inductance for an air cored coil of:

$$\boxed{L = \mu_o \frac{N^2.A}{\ell}}$$

- Where:
- L is in Henries
- μ_o is the Permeability of Free Space ($4.\pi.10^{-7}$)
- N is the Number of turns
- A is the Inner Core Area in m^2
- l is the length of the Coil in metres

Inductor Colour Codes



Therefore value = 27 x10 = 270µH +/-20%

Band	1	2	3	4
Meaning	1st Digit	2nd Digit	Multiplier (No. of zeros)	Tolerance %
Gold			x 0.1 (divide by 10)	+/-5%
Silver			x 0.01 (divide by 100)	+/-10%
Black	0	0	x1 (No Zeros)	+/-20%
Brown	1	1	x10 (0)	
Red	2	2	x100 (00)	
Orange	3	3	x1000 (000)	
Yellow	4	4	x10000 (0,000)	
Green	5	5		
Blue	6	6		
Violet	7	7		
Grey	8	8		
White	9	9		

Note: If no Band 4 is used, tolerance is also +/-20%

LO 2.3 TEST PASSIVE DEVICES

Content/Topic 1: Proper testing of passive devices using various related techniques

How to Test Resistors

Resistors regulate the amount of current flowing in an electronic circuit. Resistors present a resistance, or impedance, to the electrical circuit and reduce the amount of current that is allowed to flow. Resistors are utilized for simple signal conditioning and to protect active electronic devices that could be damaged by receiving excess current. Resistors must be properly sized and intact to perform these functions. Use these tips to learn how to test resistors.

Remove power from the circuit containing the resistor: This can be done by unplugging it from the mains or by removing the batteries if it is a portable device. Keep in mind that some devices still can be charged with a potentially harmful voltage until minutes after removing its power

Isolate the resistor from the circuit: An attempt to measure a resistor that is still connected to the circuit can yield an incorrect calculation, as part of the circuit might also be measured.

Disconnect one end of the resistor from the circuit. It does not matter which end of the resistor is disconnected. Disconnect the resistor by pulling on the resistor. If the resistor is soldered in place, melt the solder with an electronic grade soldering iron and pull the resistor free using small needle nose pliers. Soldering irons are available at electronic parts and hobby stores.

Inspect the resistor: If the resistor shows signs of blackening or charring, it may be damaged by excess current flow. A resistor showing blackening or charring should be replaced and discarded

Read the resistor value visually: The resistor value will be printed on the resistor. Smaller resistors may have their value indicated by color coded bands.

Note the resistor tolerance. No resistor is precisely the value indicated on it. The tolerance indicates how much the printed value may vary and still be considered a properly sized resistor. For example, a 1,000 ohm resistor with a 10 percent tolerance indication is still considered to be accurate if it measures no less that 900 ohms and no more than 1,100 ohms.

Prepare a digital multimeter (DMM) to measure the resistor: DMMs are available at electronics parts and hobby stores.

Ensure that the DMM comes on and does not indicate a low battery condition.

Set the adjustable scale of the DMM to the next setting higher than the expected resistor value. For example, if the DMM may be set to scales that are multiples of 10 and a resistor marked as 840 ohms is to be measured, set the DMM to the 1,000 ohm scale.

Measure the resistance: Connect the 2 leads of the DMM to the 2 legs of the resistor. Resistors have no polarity, so it does not matter which DMM lead is connected to which resistor leg

Determine the actual resistance of the resistor: Read the result shown on the multimeter. In determining whether or not the resistor is within the allowable range for that resistor, do not forget to take the resistor tolerance into account.

Reattach a resistor that gives an accurate reading: Reconnect it to the circuit by pressing it back into place if you pulled it free with your fingers. If the solder joint had to be melted and the resistor had to be disconnected using pliers, melt the solder with the soldering iron and use the needle nose pliers to push the resistor back in to place.

Replace a resistor that measures outside of the acceptable value range: Discard the old resistor. Resistors are available in electronics parts stores and hobby stores. Note that replacing the malfunctioning resistor will not necessarily fix the problem, if the resistor fails again the source of the problem should be sought elsewhere in the circuit.

Capacitors testing

To **test** the **capacitor** with a multimeter, set the meter to read in the high ohms range, somewhere above 10k and 1m ohms. Touch the meter leads to the corresponding leads on the **capacitor**, red to positive and black to negative. The meter should start at zero and then moving slowly toward infinity.

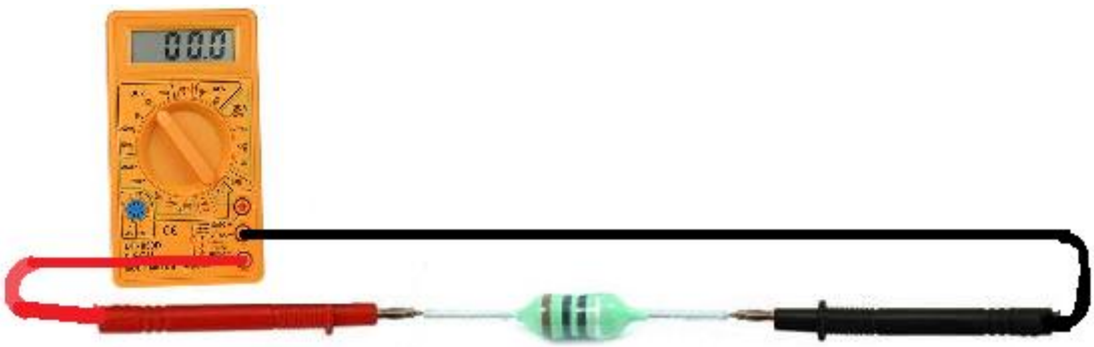
Inductors testing

Test an Inductor with a Multimeter in the Ohmmeter Setting for Resistance

The best test to check whether an inductor is good or not is by testing the inductor's resistance with your multimeter set to the ohmmeter setting.

By taking the inductor's resistance, we can determine whether the inductor is good or bad.

We do this by taking the probes of the multimeter and placing them across the leads of the inductor. The orientation doesn't matter, because resistance isn't polarized.



The inductor should read a very low resistance across its terminals, only a few ohms. If an inductor reads a high resistance, it is defective and should be replaced in the circuit.

If an inductor is reading very, very small resistance, less than an ohm (very close to 0Ω), this may be a sign that it's shorted. Functional inductors normally read a few ohms, greater than 1Ω and normally less than 10Ω. This is a healthy range for an inductance value. Outside this range and this is normally a sign the inductor is bad.

So a resistance check is a simple but effective method for finding out if an inductor is defective or not.

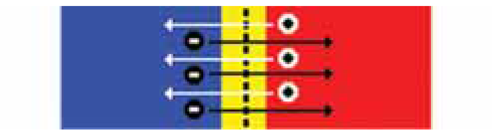
LEARNING UNIT 3 APPLY ACTIVE DEVICES

LO 3.1 IDENTIFY ACTIVE DEVICES

Content/Topic1: Identification of different types of diodes

1. Ordinary diode/ Semiconductor Diode

A pn junction is known as a **semi-conductor** or ***crystal diode**. The outstanding property of a crystal diode to conduct current in one direction only permits it to be used as a rectifier. A crystal diode is usually represented by the schematic symbol shown in the arrow in the symbol indicates the direction of easier conventional current flow.



Crystal diode has two terminals. When it is connected in a circuit, one thing to decide is whether the diode is forward or reverse biased. There is an easy rule to ascertain it. If the external circuit is trying to push the conventional current in the direction of arrow, the diode is forward biased. On the other hand, if theconventional current is trying to flow opposite to arrowhead, the diode is reversing biased. Putting in simple words:

(i) If arrowhead of diode symbol is positive w.r.t. bar of the symbol, the diode is forward biased.

(ii) If the arrowhead of diode symbol is negative w.r.t. bar, the diode is reversing biased.

Identification of crystal diode terminals. While using a crystal diode, it is often necessary to know which end is arrowhead and which end is bar. For this purpose, the following methods are available:

(i) Some manufacturers actually paint the symbol on the body of the diode e.g. BY127, BY114 crystal diodes manufactured by BEL [See Fig8]

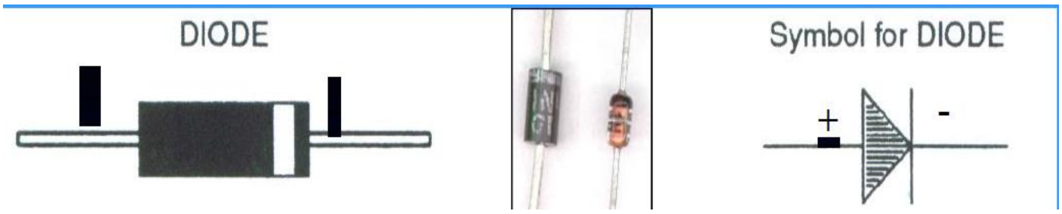


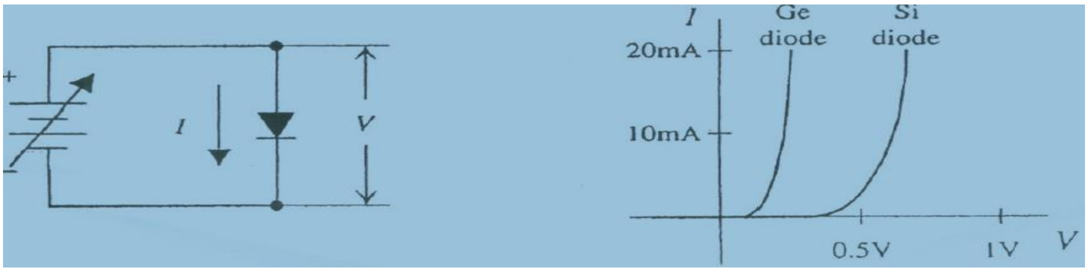
Figure 7: Diodes

(ii) Sometimes, red and blue marks are used on the body of the crystal diode. Red mark denotes arrow whereas blue mark indicates bar e.g. OA80 crystal diode [See Fig. 6.2 (ii)].

How Diode Works?

A diode's one-way gate feature does not work all the time. Typically for silicon diodes, an applied voltage of 0.6V or greater is needed otherwise, the diode will not conduct. This feature is useful in forming a voltage-sensitive switch.

I-V characteristics for silicon and germanium diodes are shown below.



Resistance of Crystal Diode

It has already been discussed that a forward biased diode conducts easily whereas a reverse biased diode practically conducts no current. It means that forward resistance of a diode is quite small as compared with its reverse resistance.

1. Forward resistance. The resistance offered by the diode to forward bias is known as forward resistance. This resistance is not the same for the flow of direct current as for the changing current. Accordingly; this resistance is of two types, namely; d.c. forward resistance and a.c. forward resistance.

(i) d.c. forward resistance. It is the opposition offered by the diode to the direct current. It is measured by the ratio of d.c. voltage across the diode to the resultingd.c. current through it. Thus, referring to the forward characteristic in Fig. 6.5, it is clear that when forward voltage is OA, the forward current is OB.

What is Diode Biasing? Forward & Reverse Bias Diodes

Diodes nominally conduct electricity in one direction, and the voltage they apply follows a so-called "forward bias" orientation. If the voltage moves in the opposite direction, we call that orientation a "reverse bias." In reverse bias, current flow is nominally blocked as a sort of electronic check valve.
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Diode Markings & Electrical Circuit Symbols Overview

Diodes are generally marked with a line that runs perpendicular to the terminal direction. This line indicates the negative direction when connected in a forwardly biased orientation. Symbolically, we represent a diode arrow pointing from the positive forward-biased terminal to a line at the negative terminal.

The arrow indicates conventional current flow notation, though the electrons actually flow in the opposite direction. Ironically, the electron flow through this symbol matches pneumatic check valve more closely, just without the little circle ball symbol that's trapped in the triangular funnel.

How Does Diode Bias Work?

So how does diode bias work with no physical "rubber ball" to stop electrons from spilling out? As you might suspect, the answer is rooted in electromagnetic physics. A diode is generally constructed with a positively charged P-type semiconducting material, along with a negatively charged N-type semiconductor, attached to each other via a nominally charge-free depletion region.

- When forward biased with a charge of between around .3 and .7 volts, the depletion region shrinks, allowing for the flow of electricity.

- When reverse biased, the depletion region expands, not allowing current to flow unless overloaded to the point of failure.

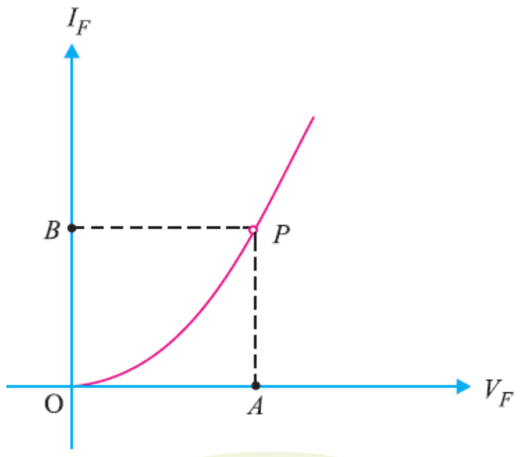
In a forward-biased situation, the P-type semiconductor region connects to a positive power supply voltage, effectively pushing it into the depletion region. A negative voltage is in turn applied to the N-type semiconductor, and as negative charges repel, they push electrons into the depletion region and closer to the P side of the diode. The circuit is complete once the diode is sufficiently forward biased and electrons can flow.

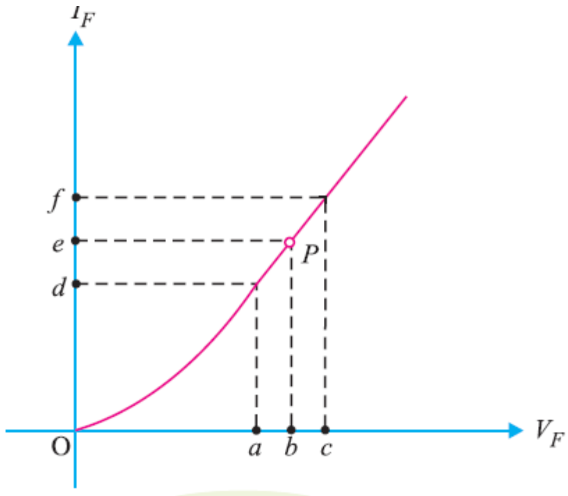
With voltage moving in the opposite manner, the positive and negative semiconductor regions pull further apart, increasing the influence of the depletion region and disallowing current flow.

$$\text{d.c. forward resistance, } R_f = \frac{OA}{OB}$$

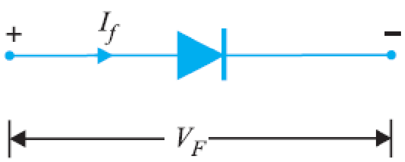
(ii) a.c. forward resistance. It is the opposition offered by the diode to the changing forward current. It is measured by the ratio of change in voltage across diode to the resulting change in current through it i.e.

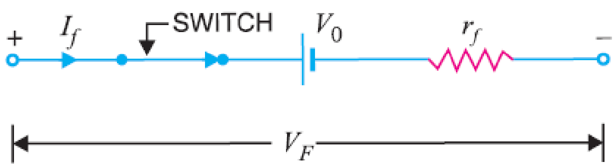
$$\text{a.c. forward resistance, } r_f = \frac{\text{Change in voltage across diode}}{\text{Corresponding change in current through diode}}$$

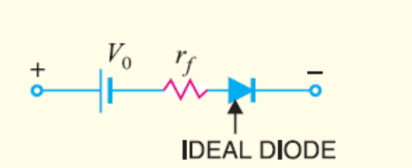
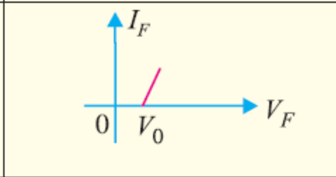
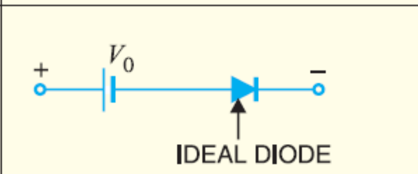
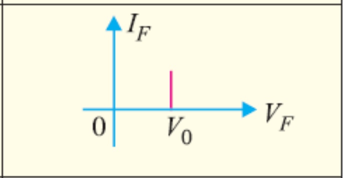
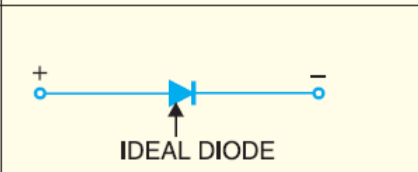
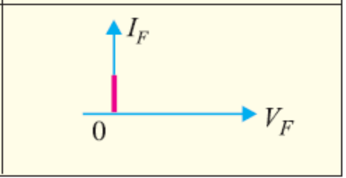




Equivalent Circuit of Crystal Diode





S.No.	Type	Model	Characteristic
1.	Approximate model		
2.	Simplified model		
3.	Ideal Model		

Example1. An a.c. voltage of peak value 20 V is connected in series with a silicon diode and load resistance of 500 Ω. If the forward resistance of diode is 10 Ω, find :

(i) peak current through diode (ii) peak output voltage

What will be these values if the diode is assumed to be ideal ?

<u>Solution:</u> Peak input voltage = 20 V

Forward resistance, rf = 10 Ω

Load resistance, RL = 500 Ω

Potential barrier voltage, V0 = 0.7 V

The diode will conduct during the positive half-cycles of a.c. input voltage only. The equivalent circuit is shown in Fig 9

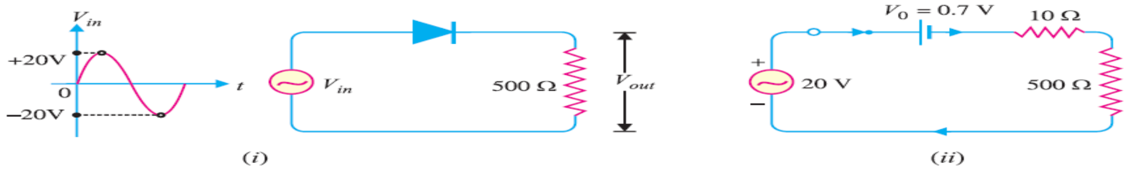


Figure 8:diode circuit

(*i*) The peak current through the diode will occur at the instant when the input voltage reaches positive peak *i.e.* $V_{in} = V_F = 20$ V.

$$\therefore \quad V_F = V_0 + (I_f)_{peak}\,[r_f + R_L] \quad \ldots(i)$$

$$\text{or} \quad (I_f)_{peak} = \frac{V_F - V_0}{r_f + R_L} = \frac{20 - 0.7}{10 + 500} = \frac{19.3}{510}\text{ A} = \mathbf{37.8\ mA}$$

(*ii*) Peak output voltage $= (I_f)_{peak} \times R_L = 37.8\text{ mA} \times 500\ \Omega = \mathbf{18.9\ V}$

Ideal diode. For an ideal diode, put $V_0 = 0$ and $r_f = 0$ in equation (*i*).

$$\therefore \quad V_F = (I_f)_{peak} \times R_L$$

$$\text{or} \quad (I_f)_{peak} = \frac{V_F}{R_L} = \frac{20\text{ V}}{500\ \Omega} = \mathbf{40\ mA}$$

Peak output voltage $= (I_f)_{peak} \times R_L = 40\text{ mA} \times 500\ \Omega = \mathbf{20\ V}$

Example2. Find the current through the diode in the circuit shown in Fig10 Assume the diode to be ideal.

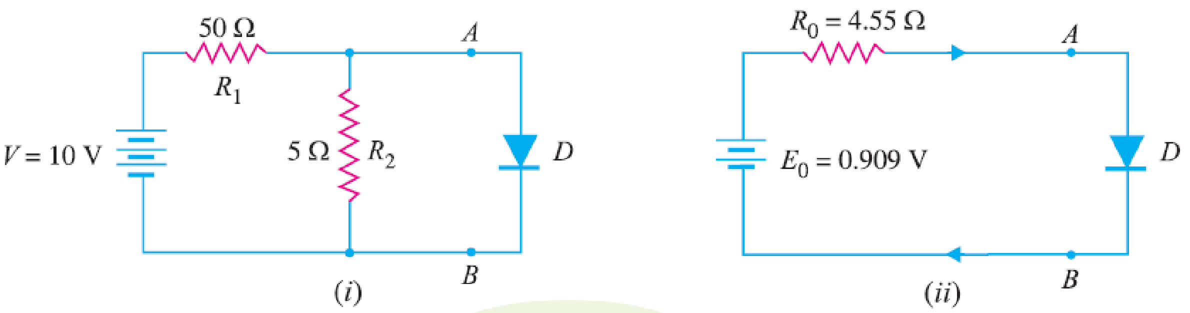


Figure 9

Solution: We shall use Thevenin's theorem to find current in the diode. Referring to Fig 10

E0 = Thevenin’s voltage

= Open circuited voltage across AB with diode removed

$$= \frac{R_2}{R_1 + R_2} \times V = \frac{5}{50 + 5} \times 10 = 0.909\text{ V}$$

R_0 = Thevenin’s resistance

= Resistance at terminals *AB* with diode removed and battery replaced by a short circuit

$$= \frac{R_1 R_2}{R_1 + R_2} = \frac{50 \times 5}{50 + 5} = 4.55\ \Omega$$

Fig10 (ii) shows Thevenin’s equivalent circuit. Since the diode is ideal, it has zero resistance.

$$\text{Current through diode} = \frac{E_0}{R_0} = \frac{0.909}{4.55} = 0.2\text{ A} = \mathbf{200\ mA}$$

Example3: Find the voltage VA in the circuit shown in Fig 11 Use simplified model.

Figure 10

Solution: It appears that when the applied voltage is switched on, both the diodes will turn "on". But that is not so. When voltage is applied, germanium diode (V0 = 0.3 V) will turn on first and a level of 0.3

V is maintained across the parallel circuit. The silicon diode never gets the opportunity to have 0.7 V across it and, therefore, remains in open-circuit state as shown in Fig11 (ii).

$$V_A = 20 - 0.3 = 19.7\ \text{V}$$

Important Terms

While discussing the diode circuits, the reader will generally come across the following terms:

(i) Forward current. It is the current flowing through a forward biased diode. Every diode has a maximum value of forward current which it can safely carry. If this value is exceeded, the diode may be destroyed due to excessive heat. For this reason, the manufacturers' data sheet specifies the maximum forward current that a diode can handle safely.

(ii) Peak inverse voltage. It is the maximum reverse voltage that a diode can withstand without destroying the junction. If the reverse voltage across a diode exceeds this value, the reverse current increases sharply and breaks down the junction due to excessive heat. Peak inverse voltage is extremely important when diode is used as a rectifier. In rectifier service, it has to be ensured that reverse voltage across the diode does not exceed its PIV during the negative half-cycle of input a.c. voltage. As a matter of fact, PIV consideration is generally the deciding factor in diode rectifier circuits. The peak inverse voltage may be between 10V and 10 kV depending upon the type of diode.

(iii) Reverse current or leakage current. It is the current that flows through a reverse biased diode. This current is due to the minority carriers. Under normal operating voltages, the reverse current is quite small. Its value is extremely small (< 1μ A) for silicon diodes but it is appreciable (j100 μA) for germanium diodes.

It may be noted that the reverse current is usually very small as compared with forward current. For example, the forward current for a typical diode might range upto 100 mA while the reverse current might be only a few µA—a ratio of many thousands between forward and reverse currents.

Diode Rectifiers

For reasons associated with economics of generation and transmission, the electric power available is usually an a.c. supply. The supply voltage varies sinusoidally and has a frequency of 50 Hz. It is used for lighting, heating and electric motors. But there are many applications (e.g. electronic circuits) where d.c. supply is needed. When such a d.c. supply is required, the mains a.c. supply is rectified by using crystal diodes. The following two rectifier circuits can be used : (i) Half-wave rectifier (ii) Full-wave rectifier

Half-Wave Rectifier

In half-wave rectification, the rectifier conducts current only during the positive half-cycles of input a.c. supply. The negative half-cycles of a.c. supply are suppressed i.e. during negative half-cycles, no current is conducted and hence no voltage appears across the load. Therefore, current always flows in one direction (i.e. d.c.) through the load though after every half-cycle.

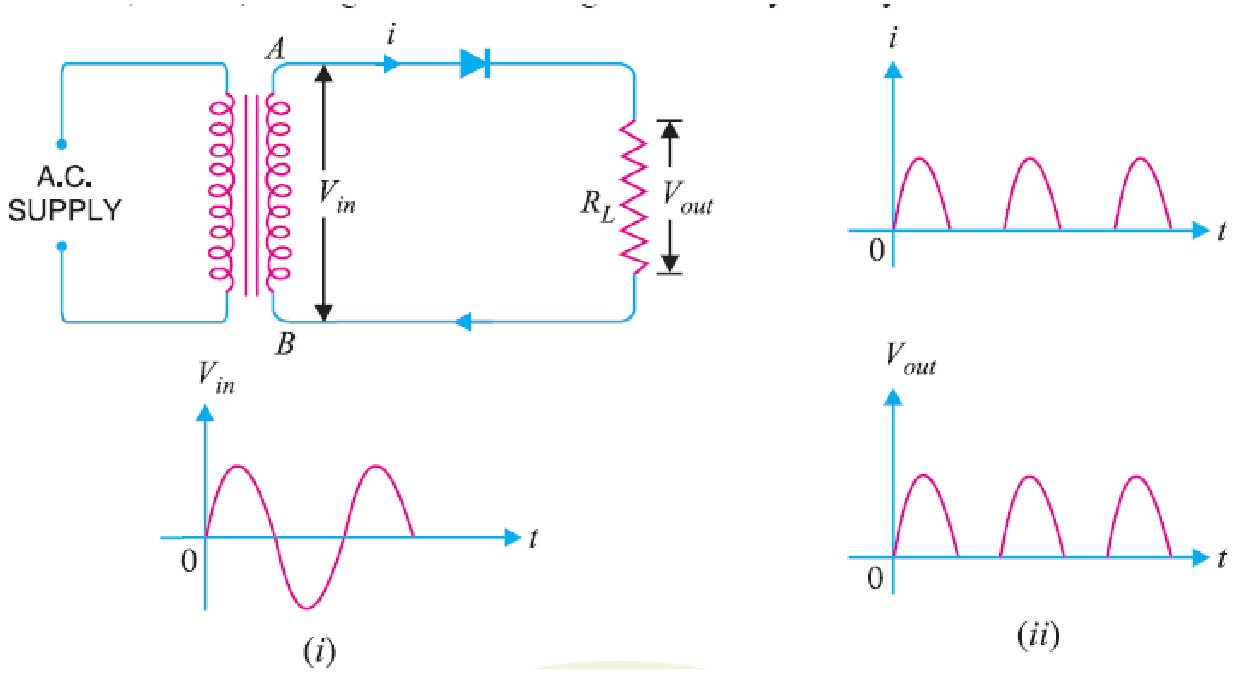


Figure 11

Operation. The a.c. voltage across the secondary winding AB changes polarities after every half-cycle. During the positive half-cycle of input a.c. voltage, end A becomes positive w.r.t. end B. This makes the diode forward biased and hence it conducts current. During the negative half-cycle, end A is negative w.r.t. end B. Under this condition, the diode is reverse biased and it conducts no current. Therefore, current flows through the diode during positive half-cycles of input a.c. voltage only; it is blocked during the negative half-cycles [See Fig. 12 (ii)]. In this way, current flows through load RL always in the same direction. Hence d.c. output is obtained across RL. It may be noted that output across the load is pulsating d.c. These pulsations in the output are further smoothened with the help of filter circuits discussed later.

Disadvantages :

The main disadvantages of a half-wave rectifier are :

(i) The pulsating current in the load contains alternating component whose basic frequency is equal to the supply frequency. Therefore, an elaborate filtering is required to produce steady direct current.

(ii) The a.c. supply delivers power only half the time. Therefore, the output is low.

IMPORTANT FOLMULAE

$$f_{out} = f_{in}$$

$$\text{Rectifier efficiency, } \eta = \frac{\text{d.c. power output}}{\text{Input a.c. power}}$$

$$I_{av} = I_{dc} = \frac{2\,I_m}{2\,\pi} = \frac{I_m}{\pi}$$

$$V_{o(avg.)} = \frac{V_S\sqrt{2}}{\pi}$$

$$= V_m/\pi$$

$$= 0.318\ V_m$$

A crystal diode having internal resistance rf = 20Ω is used for half-wave rectification.

If the applied voltage v = 50 sin ω t and load resistance RL = 800 Ω, find :

(i) Im, Idc, Irms (ii) a.c. power input and d.c. power output

(iii) d.c. output voltage (iv) efficiency of rectification.

Solution.

$$v = 50 \sin \omega t$$

$$\therefore \quad \text{Maximum voltage, } V_m = 50 \text{ V}$$

(*i*) $$I_m = \frac{V_m}{r_f + R_L} = \frac{50}{20 + 800} = 0.061 \text{ A} = \mathbf{61\ mA}$$

$$I_{dc} = I_m/\pi = 61/\pi = \mathbf{19.4\ mA}$$

$$I_{rms} = I_m/2 = 61/2 = \mathbf{30.5\ mA}$$

(*ii*) $$\text{a.c. power input} = (I_{rms})^2 \times (r_f + R_L) = \left(\frac{30.5}{1000}\right)^2 \times (20 + 800) = \mathbf{0.763\ watt}$$

$$\text{d.c. power output} = I_{dc}^2 \times R_L = \left(\frac{19.4}{1000}\right)^2 \times 800 = \mathbf{0.301\ watt}$$

(*iii*) $$\text{d.c. output voltage} = I_{dc} R_L = 19.4 \text{ mA} \times 800\ \Omega = \mathbf{15.52\ volts}$$

(*iv*) $$\text{Efficiency of rectification} = \frac{0.301}{0.763} \times 100 = \mathbf{39.5\%}$$

Example: A half-wave rectifier is used to supply 50V d.c. to a resistive load of 800 Ω. The diode has a resistance of 25 Ω. Calculate a.c. voltage required.

Solution.

$$\text{Output d.c. voltage, } V_{dc} = 50 \text{ V}$$

$$\text{Diode resistance, } r_f = 25\ \Omega$$

$$\text{Load resistance, } R_L = 800\ \Omega$$

Let V_m be the maximum value of a.c. voltage required.

$$\therefore \quad V_{dc} = I_{dc} \times R_L$$

$$= \frac{I_m}{\pi} \times R_L = \frac{V_m}{\pi (r_f + R_L)} \times R_L$$

or $$50 = \frac{V_m}{\pi (25 + 800)} \times 800$$

$$\therefore \quad V_m = \frac{\pi \times 825 \times 50}{800} = \mathbf{162\ V}$$

Full-Wave Rectifier

In full-wave rectification, current flows through the load in the same direction for both half-cycles of input a.c. voltage. This can be achieved with two diodes working alternately. For the positive half cycle of input voltage, one diode supplies current to the load and for the negative half-cycle, the other diode does so ; current being always in the same direction through the load. Therefore, a full-wave rectifier utilises both half-cycles of input a.c. voltage to produce thed.c. output. The following two circuits are commonly used for full-wave rectification :

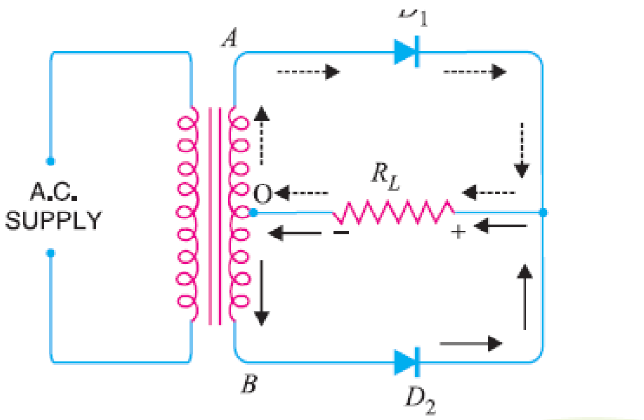
(i) Centre-tap full-wave rectifier (ii) Full-wave bridge rectifier

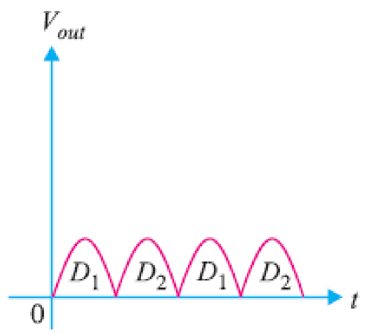
Centre-Tap Full-Wave Rectifier

The circuit employs two diodes D1 and D2 as shown in Fig. 6.24. A centre tapped secondary winding AB is used with two diodes connected so that each uses one half-cycle of input a.c. voltage. In other words, diode D1 utilises the a.c. voltage appearing across the upper half (OA) of secondary winding for rectification while diode D2 uses the lower half winding OB.

Operation

During the positive half-cycle of secondary voltage, the end A of the secondary winding becomes positive and end B negative. This makes the diode D1 forward biased and diode D2 reverse biased. Therefore, diode D1 conducts while diode D2 does not. The conventional current flow is through diode D1, load resistor RL and the upper half of secondary winding as shown by the dotted arrows. During the negative half-cycle, end A of the secondary winding becomes negative and end B positive. Therefore, diode D2 conducts while diode D1 does not. The conventional current flow is through diode D2, load RL and lower half winding as shown by solid arrows. Referring to Fig. 6.24, it may be seen that current in the load RL is in the same direction for both half-cycles of input a.c. voltage. Therefore, d.c. is obtained across the load RL. Also, the polarities of the d.c. output across the load should be noted.





Peak inverse voltage.

Suppose Vm is the maximum voltage across the half secondary winding. Fig. 6.25 shows the circuit at the instant secondary voltage reaches its maximum value in the positive direction. At this instant, diode D1 is conducting while diode D2is non-conducting. Therefore, whole of the secondaryvoltage appears across the non-conducting diode. Consequently, the peak inverse voltage is twice the maximum voltage across the half-secondary winding i.e.

PIV = 2 Vm

Disadvantages

(i) It is difficult to locate the centre tap on the secondary winding.

(ii) The d.c. output is small as each diode utilises only one-half of the transformer secondary voltage.

(iii) The diodes used must have high peak inverse voltage.

Full-Wave Bridge Rectifier

The need for a centre tapped power transformer is eliminated in the bridge rectifier. It contains four diodes D1, D2, D3 and D4 connected to form bridge as shown in Fig 13 the a.c. supply to be rectified is applied to the diagonally opposite ends of the bridge through the transformer. Between other two ends of the bridge, the load resistance RL is connected.

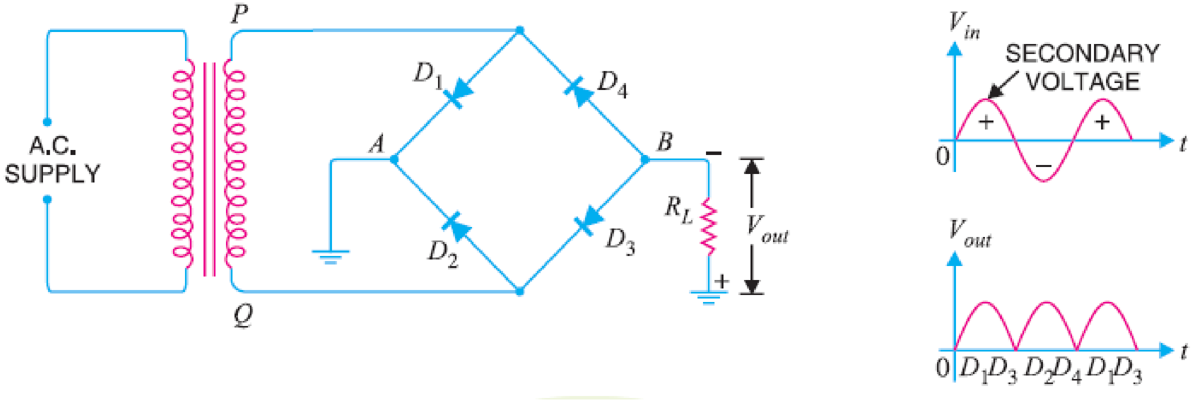
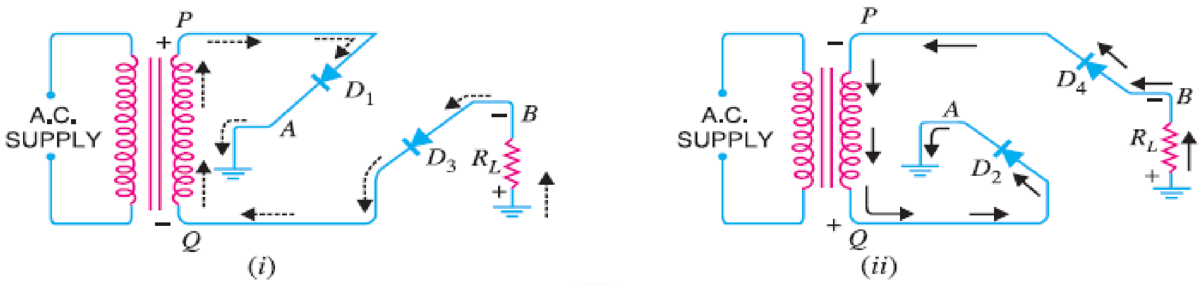


Figure 12

Operation

During the positive half-cycle of secondary voltage, the end P of the secondary winding becomes positive and end Q negative. This makes diodes D1 and D3 forward biased while diodes D2 and D4 are reverse biased. Therefore, only diodes D1 and D3 conduct. These two diodes will be in series through the load RL as shown in Fig. 6.27 (i). The conventional current flow is shown by dotted arrows. It may be seen that current flows from A to B through the load RL.

During the negative half-cycle of secondary voltage, end P becomes negative and end Q positive. This makes diodes D2 and D4 forward biased whereas diodes D1 and D3 are reverse biased. Therefore, only diodes D2 and D4 conduct. These two diodes will be in series through the load RL asshown in Fig. 6.27 (ii). The current flow is shown by the solid arrows. It may be seen that againcurrent flows from A to B through the load i.e. in the same direction as for the positive half-cycle. Therefore, d.c. output is obtained across load RL.



Peak inverse voltage. The peak inverse voltage (PIV) of each diode is equal to the maximum secondary voltage of transformer. Suppose during positive half cycle of input a.c., end P of secondary is positive and end Q negative. Under such conditions, diodes D1 and D3 are forward biased while diodes D2 and D4 are reverse biased. Since the diodes are considered ideal, diodes D1 and D3 can be replaced by wires as shown in Fig. 6.28 (i). This circuit is the same as shown in Fig. 14 (ii).

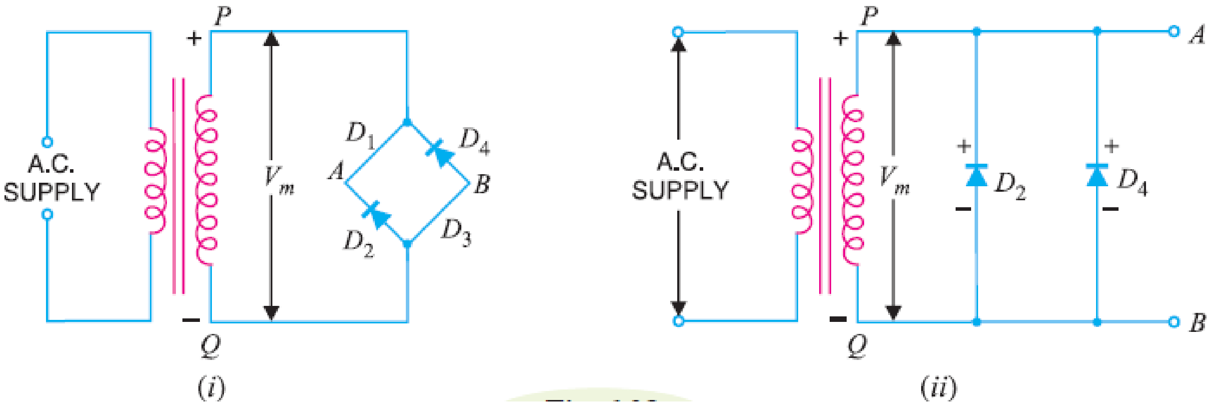


Figure 13

IMPORTANT FOLMULAES

$$V_{o(avg.)} = (2\ V_m)/\pi = 0.636\ V_m$$

$$I_{o(avg.)} = (2\ I_m)/\pi = 0.636\ I_m = \frac{0.636\ V_m}{R}$$

$$P_{o(avg.)} = V_{o(avg.)} * I_{o(avg.)}$$

Example 6.21. The bridge rectifier shown in Fig. 15 uses silicon diodes. Find (i) d.c. output voltage (ii) d.c. output current. Use simplified model for the diodes.

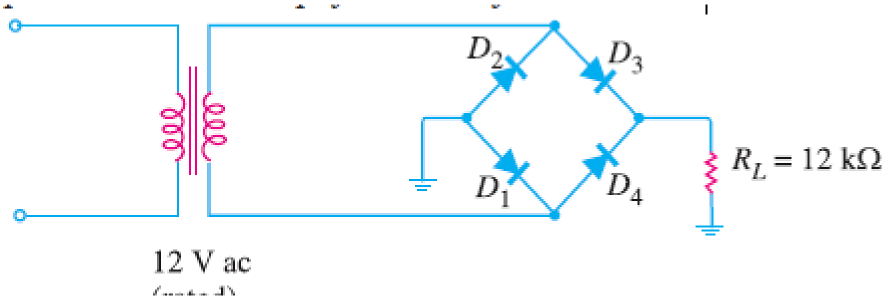


Figure 14

Solution. The conditions of the problem suggest that the a.c voltage across transformer secondary is 12V r.m.s.

∴ Peak secondary voltage is

$$V_{s\,(pk)} = 12 \times \sqrt{2} = 16.97\ V$$

(*i*) At any instant in the bridge rectifier, two diodes in series are conducting.

∴ Peak output voltage is

$$V_{out\ (pk)} = 16.97 - 2\ (0.7) = 15.57\ \text{V}$$

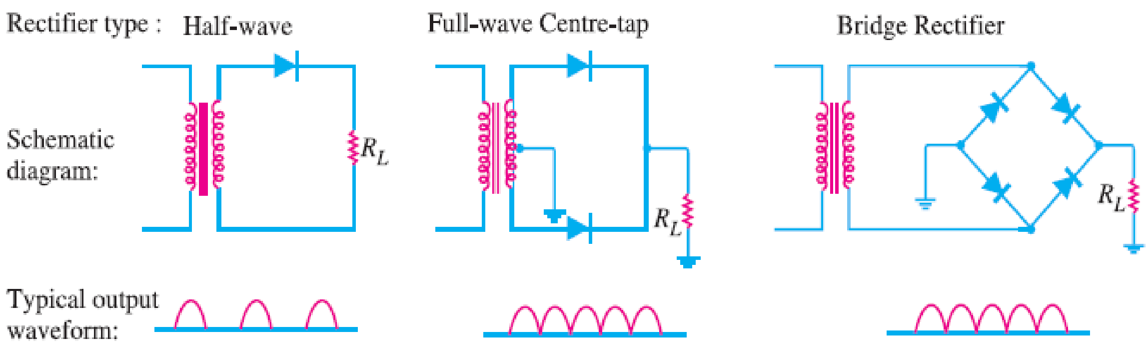
∴ Average (or d.c.) output voltage is

$$V_{av} = V_{dc} = \frac{2\ V_{out\ (pk)}}{\pi} = \frac{2 \times 15.57}{\pi} = \mathbf{9.91V}$$

(*ii*) Average (or d.c.) output current is

$$I_{av} = \frac{V_{av}}{R_L} = \frac{9.91\text{V}}{12\ \text{k}\Omega} = \mathbf{825.8\ \mu A}$$

Comparison of Rectifiers



S. No.	Particulars	Half-wave	Centre-tap	Bridge type
1	No. of diodes	1	2	4
2	Transformer necessary	no	yes	no
3	Max. efficiency	40.6%	81.2%	81.2%
4	Ripple factor	1.21	0.48	0.48
5	Output frequency	f_{in}	$2\ f_{in}$	$2\ f_{in}$
6	Peak inverse voltage	V_m	$2\ V_m$	V_m

2. Zener diode

Voltage, called breakdown voltage is reached where the reverse current increases sharply to a high value. The breakdown region is the knee of the reverse characteristic as shown in Fig. 16. The satisfactory explanation of this breakdown of the junction was first given by the American scientist C. Zener. Therefore, the breakdown voltage is sometimes called zener voltage and the sudden increase in current is known as zenercurrent. The breakdown or zener voltage depends upon the amount of doping. If the diode is heavily doped, depletion layer will be thin and consequently the breakdown of the junction will occur at a lower reverse voltage. On the other hand, a lightly doped diode has a higher breakdown voltage.

When an ordinary crystal diode is properly doped so that it has a sharp breakdown voltage, it is called a zener diode.

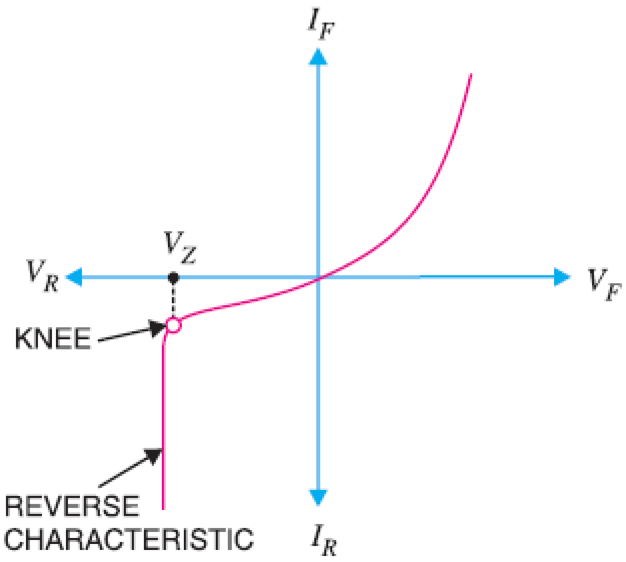


Figure 15

A properly doped crystal diode which has a sharp breakdown voltage is known as a zenerdiode.

Figure 16: symbol of a zener diode.

It may be seen that it is just like an ordinarydiode except that the bar is turned into z-shape.

The following points may be noted about the zener diode:

(i) A zener diode is like an ordinary diode except that it is properly doped so as to have a sharp breakdown voltage.

(ii) A zener diode is always reverse connected i.e. it is always reverse biased.

(iii) A zener diode has sharp breakdown voltage, called zener voltage VZ.

(iv) When forward biased, its characteristics are just those of ordinary diode

(v) The zener diode is not immediately burnt just because it has entered the *breakdown region. As long as the external circuit connected to the diodelimits the diode current to less than burn out value, the diode will not burn out.The analysis of circuits using zener diodes can be made quite easily by replacing the zener diode by its equivalent circuit.

(i) “On” state. When reverse voltage across a zener diode is equal to or more than break down voltage VZ, the current increases very sharply. In this region, the curve is almost vertical. It means that voltage across zener diode is constant at VZ even though the current through it changes. Therefore, in the breakdown region, an **ideal zener diode can be represented by a battery of voltage VZ as shown in Fig. 18 (ii). Under such conditions, the zener diode is said to be in the “ON” state.

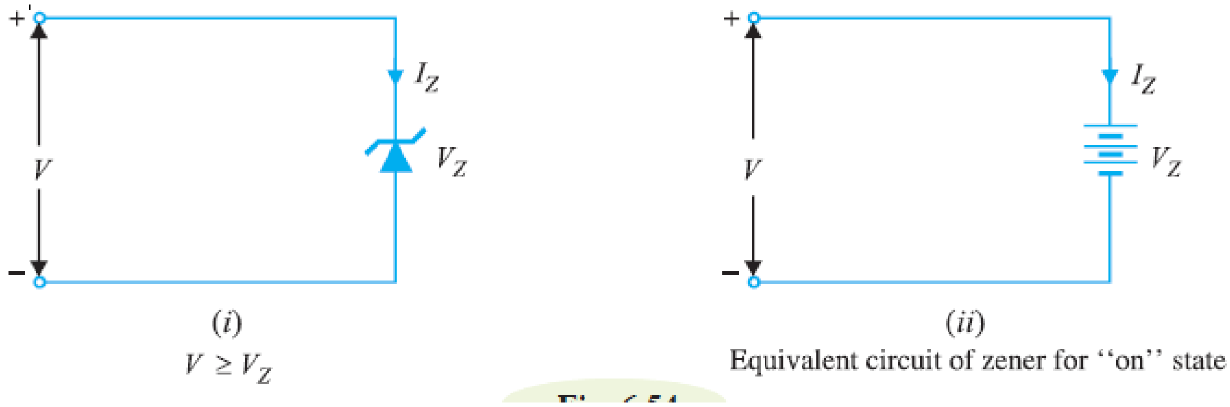


Figure 17

(ii) "OFF" state. When the reverse voltage across the zener diode is less than VZ but greater than 0 V, the zener diode is in the "OFF" state. Under such conditions, the zener diode can be represented by an open-circuit as shown in Fig19 (ii).

The current is limited only by both external resistance and the power dissipation of zener diode. This assumption is fairly reasonable as the impedance of zener diode is quite small in the breakdown region.

Figure 18

Zener Diode as Voltage Stabiliser

A zener diode can be used as a voltage regulator to provide a constant voltage from a source whose voltage may vary over sufficient range. The circuit arrangement is shown in Fig. 20 (i). The zenerdiode of zener voltage VZ is reverse connected across the load RL across which constant output is desired. The series resistance R absorbs the output voltage fluctuations so as to maintain constant voltage across the load. It may be noted that the zener will maintain a constant voltage VZ (= E0) across the load so long as the input voltage does not fall below VZ.

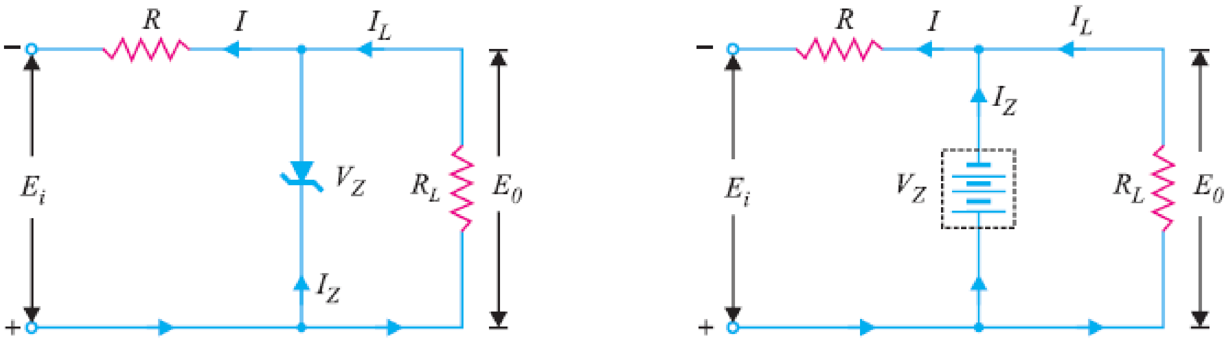


Figure 19

When the circuit is properly designed, the load voltage E0 remains essentially constant (equal toVZ) even though the input voltage Ei and load resistance RL may vary over a wide range.

(i) Suppose the input voltage increases. Since the zener is in the breakdown region, the zenerdiode is equivalent to a battery VZ as shown in Fig. 20 (ii). It is clear that output voltage remains constant at VZ (= E0). The excess voltage is dropped across the series resistance R. This will cause an increase in the value of total current I. The zener will conduct the increase of current in I while the load current remains constant. Hence, output voltage E0 remains constant irrespective of the changes in the input voltage Ei.

(ii) Now suppose that input voltage is constant but the load resistance RL decreases. This will cause an increase in load current. The extra current cannot come from the source because drop in R (and hence source current I) will not change as the zener is within its regulating range. The additional load current will come from a decrease in zener current IZ. Consequently, the output voltage stays at constant value.

Voltage drop across R = Ei − E0

Current through R, I = IZ + IL

Solving Zener Diode Circuits

The analysis of zener diode circuits is quite similar to that applied to the analysis of semiconductor diodes. The first step is to determine the state of zener diode i.e., whether the zener is in the “on” state or “off” state. Next, the zener is replaced by its appropriate model. Finally, the unknown quantities are determined from the resulting circuit.

1. Ei and RL fixed. This is the simplest case and is shown in Fig21 (i). Here the applied voltage Ei as well as load RL is fixed. The first step is to find the state of zener diode. This can be determined by removing the zener from the circuit and calculating the voltage V across the resulting open-circuit as shown in Fig21 (ii).

$$V = E_0 = \frac{R_L E_i}{R + R_L}$$

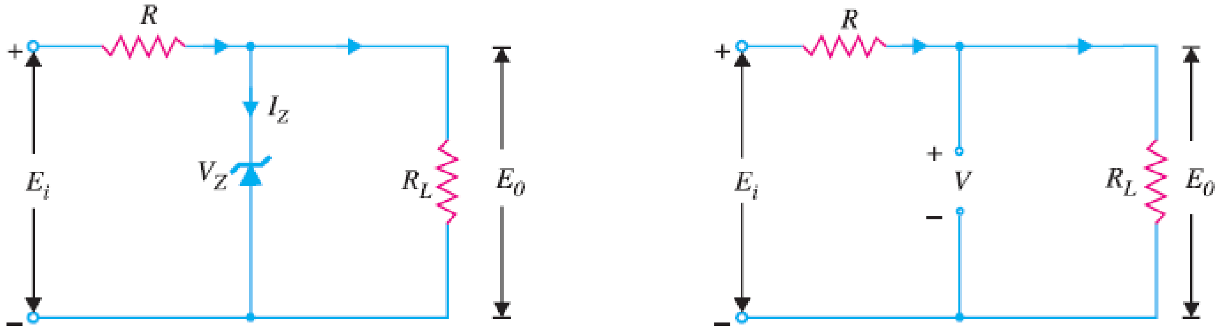


Figure 20

If V ≥ VZ, the zener diode is in the “on” state and its equivalent model can be substituted as shown in Fig. 22 (i). If V < VZ, the diode is in the “off” state as shown in Fig. 22 (ii).

(i) On state. Referring to circuit shown in Fig. 22 (i),

E0 = VZ

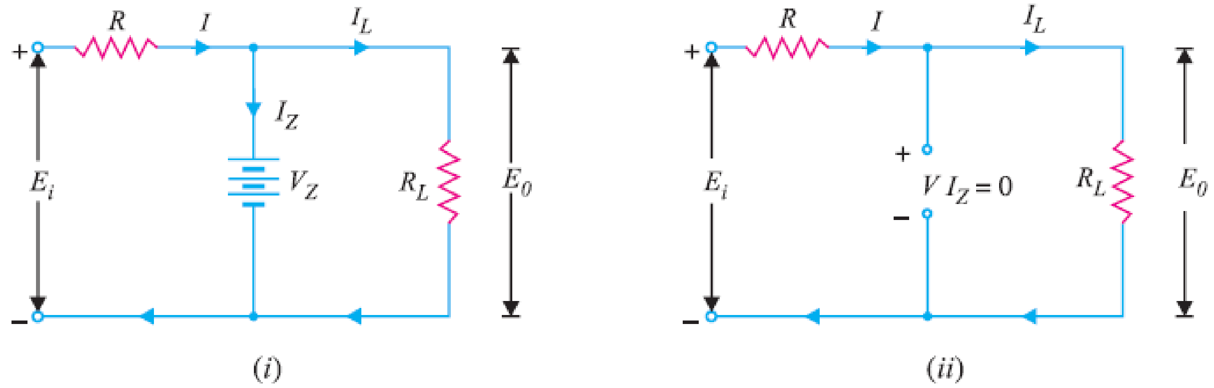


Figure 21

$$I_Z = I - I_L \quad \text{where } I_L = \frac{E_0}{R_L} \text{ and } I = \frac{E_i - E_0}{R}$$

$$\text{Power dissipated in zener, } P_Z = V_Z I_Z$$

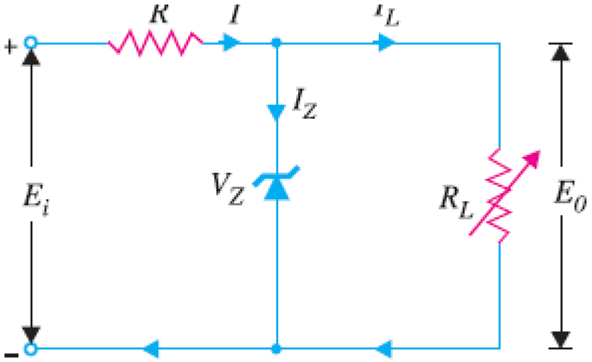
(ii) Off state. Referring to the circuit shown in Fig. 22 (ii),

$$I = I_L \quad \text{and} \quad I_Z = 0$$
$$V_R = E_i - E_0 \quad \text{and} \quad V = E_0 \quad (V < V_Z)$$
$$P_Z = V I_Z = V(0) = 0$$

2. Fixed Ei and Variable RL. This case is shown in

Fig. 6.59. Here the applied voltage (Ei) is fixed while load resistance RL (and hence load current IL) changes. Note that there is a definite range of RL values (and hence IL values) which will ensure the zener diode to be in “on” state. Let us calculate that range of values.

(i) RLmin and ILmax. Once the zener is in the "on" state, load voltage E0 (= VZ) is constant. As a result, when load resistance is minimum (i.e., RLmin), load current will be maximum (IL = E0/RL). In order to find the minimum load resistance that will turn the zener on, we simply calculate the value of RL that will result in E0 = VZ i.e.,



$$E_0 = V_Z = \frac{R_L\ E_i}{R + R_L}$$

$$R_{Lmin} = \frac{R\ V_Z}{E_i - V_Z}$$

This is the minimum value of load resistance that will ensure that zeneris in the "on" state. Any value of load resistance less than this value will result in a voltage E0 across the load less than VZ and the zener will be in the "off" state.

Clearly ;

$$I_{Lmax} = \frac{E_0}{R_{Lmin}} = \frac{V_Z}{R_{Lmin}}$$

(ii) ILmin and RLmax. It is easy to see that when load resistance is maximum, load current is minimum.

Now, Zener current, IZ = I − IL

When the zener is in the "on" state, I remains **fixed. This means that when IL is maximum, IZ will be minimum. On the other hand, when IL is minimum, IZ is maximum. If the maximum current that a zenercan carry safely is †IZM, then, If you remove the zener in the circuit shown in Fig. 23, then voltage V across the open-circuit is

$$V = \frac{R_L\ E_i}{R + R_L}$$

The zener will be turned on when V = VZ.

Voltage across R, VR = Ei − E0 and I = VR/R. As Ei and E0 are fixed, I remains the same.

† Max. power dissipation in zener, $P_{ZM} = V_Z\ I_{ZM}$

$$I_{Lmin} = I - I_{ZM}$$

and $$R_{Lmax} = \frac{E_0}{I_{Lmin}} = \frac{V_Z}{I_{Lmin}}$$

If the load resistance exceeds this limiting value, the current through zener will exceed IZM and the device may burn out.

3. Fixed RL and Variable Ei. This case is shown in Fig. 24. Here the load resistance RL is fixed while the applied voltage (Ei) changes. Note that there is a definite range of Ei values that will ensure

that zener diode is in the "on" state. Let us calculate that range of values.

(i) Ei (min). To determine the minimum applied voltage that will turn the zener on, simply calculate the value of Ei that will result in load voltage

E0 = VZ i.e.,

$$E_0 = V_Z = \frac{R_L\ E_i}{R + R_L}$$

$$E_{i\,(min)} = \frac{(R + R_L)\ V_Z}{R_L}$$

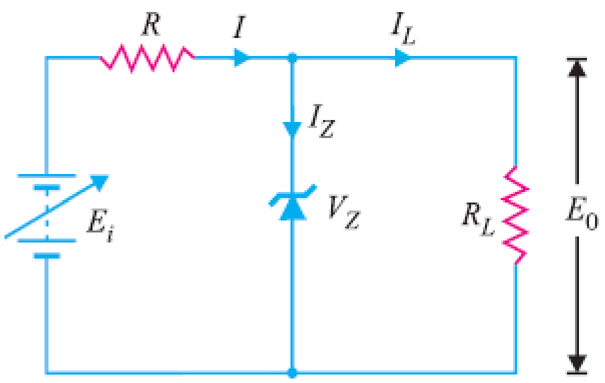


Figure 22

(ii) Ei (max)

Now, current through R, I = IZ + IL

Since IL (= E0/RL = VZ/RL) is fixed, the value of I will be maximum when zener current is maximum i.e.,

$$I_{max} = I_{ZM} + I_L$$

$$E_i = I\,R + E_0$$

Since E0 (= VZ) is constant, the input voltage will be maximum when I is maximum.

∴Ei (max) = Imax R + VZ

Example : For the circuit shown in Fig. 6.61 (i), find :

(i) the output voltage (ii) the voltage drop across series resistance

(iii) the current through zener diode.

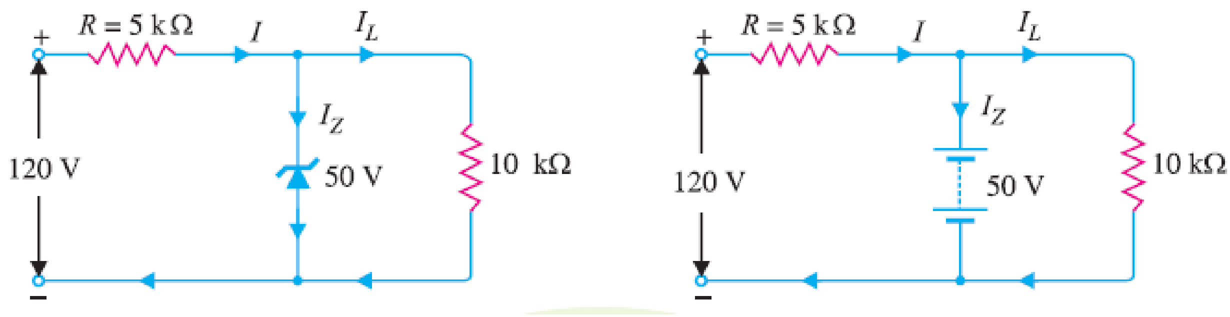


Figure 23

Solution. If you remove the zener diode in Fig. 6.61 (*i*), the voltage *V* across the open-circuit is given by :

$$V = \frac{R_L\ E_i}{R + R_L} = \frac{10 \times 120}{5 + 10} = 80\ \text{V}$$

Since voltage across zener diode is greater than V_Z (= 50 V), the zener is in the "on" state. It can, therefore, be represented by a battery of 50 V as shown in Fig. 6.61 (*ii*).

(*i*) Referring to Fig. 6.61 (*ii*),

Output voltage $= V_Z = 50\ \text{V}$

(*ii*) Voltage drop across *R* $=$ Input voltage $- V_Z = 120 - 50 = 70\ \text{V}$

(*iii*) Load current, $I_L = V_Z/R_L = 50\ \text{V}/10\ \text{k}\Omega = 5\ \text{mA}$

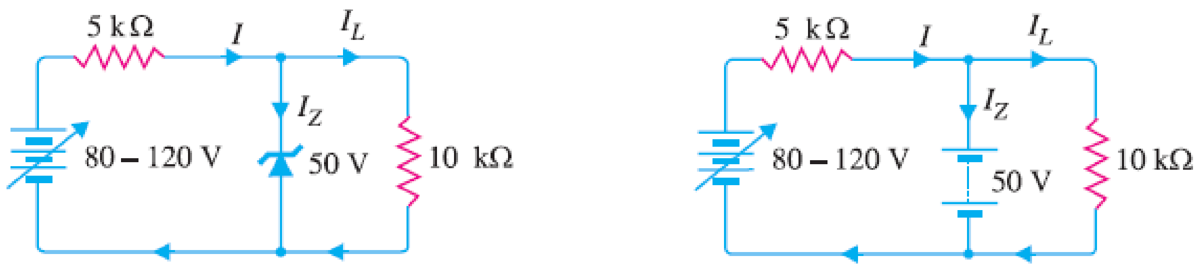
Current through *R*, $I = \dfrac{70\ \text{V}}{5\ \text{k}\Omega} = 14\ \text{mA}$

Applying Kirchhoff's first law, $I = I_L + I_Z$

∴ Zener current, $I_Z = I - I_L = 14 - 5 = 9\ \text{mA}$

Example: For the circuit shown in Fig. 25 (i), find the maximum and minimum values of zener diode current.

Solution: The first step is to determine the state of the zener diode. It is easy to see that for the given range of voltages (80 – 120 V), the voltage across the zener is greater than VZ (= 50 V). Hence the zener diode will be in the "on" state for this range of applied voltages. Consequently, it can be replaced by a battery of 50 V as shown in Fig. 25 (ii).



(i) (ii)

Figure 24

Maximum zener current. The zener will conduct *maximum current when the input voltage is maximum *i.e.* 120 V. Under such conditions :

$$\text{Voltage across } 5\text{ k}\Omega = 120 - 50 = 70\text{ V}$$

$$\text{Current through } 5\text{ k}\Omega,\ I = \frac{70\text{ V}}{5\text{ k}\Omega} = 14\text{ mA}$$

$$\text{Load current, } I_L = \frac{50\text{ V}}{10\text{ k}\Omega} = 5\text{ mA}$$

$$\text{Applying Kirchhoff's first law, } I = I_L + I_Z$$

$$\therefore \quad \text{Zener current, } I_Z = I - I_L = 14 - 5 = \mathbf{9\text{ mA}}$$

* $I_Z = I - I_L$. Since I_L ($= V_Z/R_L$) is fixed, I_Z will be maximum when I is maximum.

Now, $I = \frac{E_i - E_0}{R} = \frac{E_i - V_Z}{R}$. Since V_Z ($= E_0$) and R are fixed, I will be maximum when E_i is maximum and *vice-versa*.

Minimum Zener current. The zener will conduct minimum current when the input voltage is minimum *i.e.* 80 V. Under such conditions, we have,

$$\text{Voltage across } 5\text{ k}\Omega = 80 - 50 = 30\text{ V}$$

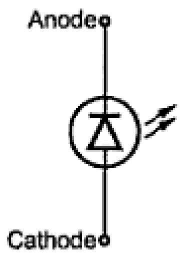
$$\text{Current through } 5\text{ k}\Omega,\ I = \frac{30\text{ V}}{5\text{ k}\Omega} = 6\text{ mA}$$

$$\text{Load current, } I_L = 5\text{ mA}$$

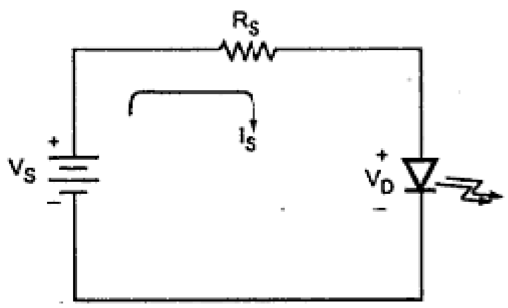
$$\therefore \quad \text{Zener current, } I_Z = I - I_L = 6 - 5 = \mathbf{1\text{ mA}}$$

Light Emitting Diode (LED)

The LED is an optical diode, which emits light when forward biased. The fig bellow shows the symbol of LED which is similar to p-n junction diode apart from the two arrows indicating that the device emits the light energy.



Biasing of LED



Consider a source connected to LED and a resistor as shown in the figure bellow, The outward arrows associated with a diode indicate that it is LED.

The resistor Rs is the current limiting resistor. Due to this resistor, the current through the circuit is limited and prevented from exceeding the maximum current rating of the diode.

Let V_S = Supply voltage

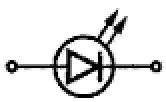
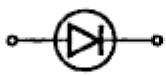
V_D = Drop across LED

Applying KVL to the circuit we can write,

$$V_S = I_S R_S + V_D$$

$$I_S = \frac{V_S - V_D}{R_S}$$

Comparison of LED and P-N Junction Diode

Sr. No.	LED	P-N junction diode
1.	It emits light, when forward biased.	It does not emit light.
2.	It uses materials like gallium, arsenide phosphide and gallium phosphide.	It uses materials like silicon and germanium.
3.	The drop across forward biased LED is about 2 V.	The drop across forward biased diode is about 0.7 V, much less than that of LED.
4.	Reverse breakdown voltage is low, about 3 V to 10 V.	Reverse breakdown voltage is high, about 50 V and more.
5.	Needs large power for the operation.	Needs less power for the operation.
6.	Draws considerable current from battery.	Draws less current.
7.	Symbol is 	Symbol is 
8.	The applications are optocouplers, seven segment displays, alpha numeric displays.	The applications are rectifiers, clippers, clampers, voltage multipliers and many other electronic circuits.

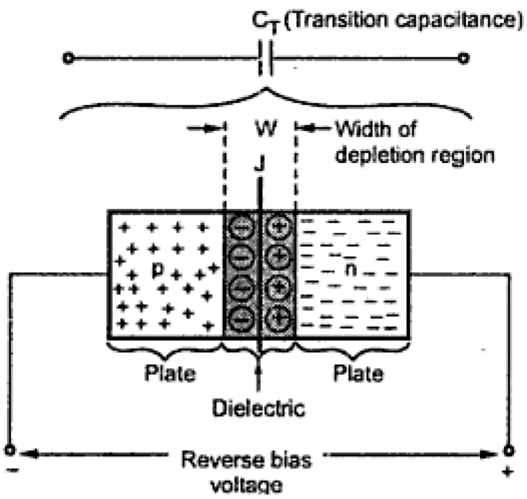
Applications of LED

Due to the advantages like low voltage, long life, cheap, reliable, fast on-off switching etc., the LEDs are used in many applications. The various applications of LED are,

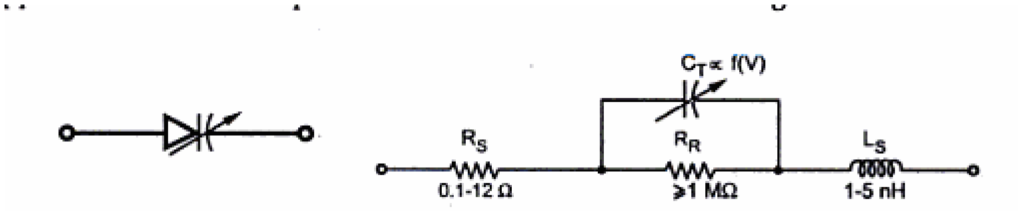
1. All kinds of visual displays i.e. seven segment displays and alpha numeric displays. Such displays are commonly used in the watches and calculators.
2. In the optical devices such as optocouplers.
3. As on-off indicator in various types of electronic circuits.
4. Some LEDs radiate infrared light which is invisible. But such LEDs are useful in remote controls and applications like burglar alarm.

3. Varactor diode

In a normal diode, the depletion region exists between p- region and n- region as shown in fig bellow. The p-region and n-region act like the plates of capacitor while the depletion region acts like dielectric. Thus there exists a capacitance at the p-n junction called transition capacitance, barrier capacitance or depletion region capacitance. It is denoted as C_t.



Symbol and Equivalent Circuit

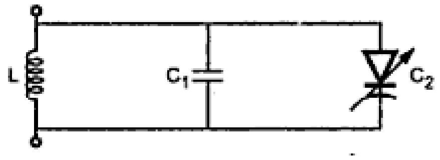


(a) Symbol (b) Equivalent circuit

Applications

The main application of varactor diode is LC tuned circuits. The following figure shows how varactor diode can be connected in a LC tuned circuits. The resonance frequency for a parallel LC tuned circuit is given by,

$$f_r = \frac{1}{2\pi\sqrt{LC}}$$



As varactor diode is connected in parallel, the resultant capacitance becomes $C_1 + C_2$. Hence the resonance frequency becomes,

$$f_r = \frac{1}{2\pi\sqrt{L(C_1 + C_2)}}$$

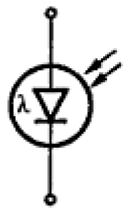
The various other applications of varactor diodes are,

1. Tuned circuits
2. FM modulators
3. Automatic frequency control devices
4. Adjustable bandpass filters
5. Parametric amplifiers
6. Television receivers

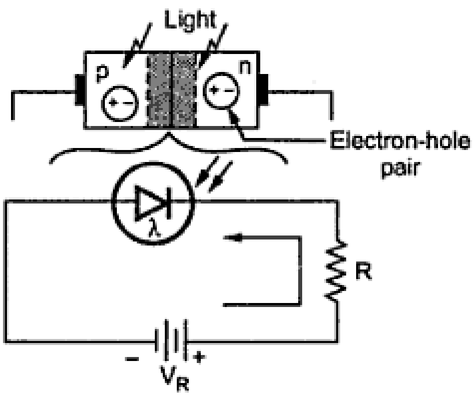
4. Photo-diode

The photodiode is semiconductor p-n junction devices whose region of operation is limited to the reverse biased region the figures bellow show the symbol of photodiode and the working principle of photodiode.

The photodiode is a semiconductor p-n junction device whose region of operation is limited to the reverse biased region. The following figures one shows the symbol of photodiode while other shows the working principle of photodiode.



(a) Symbol



(b) Principle of operation

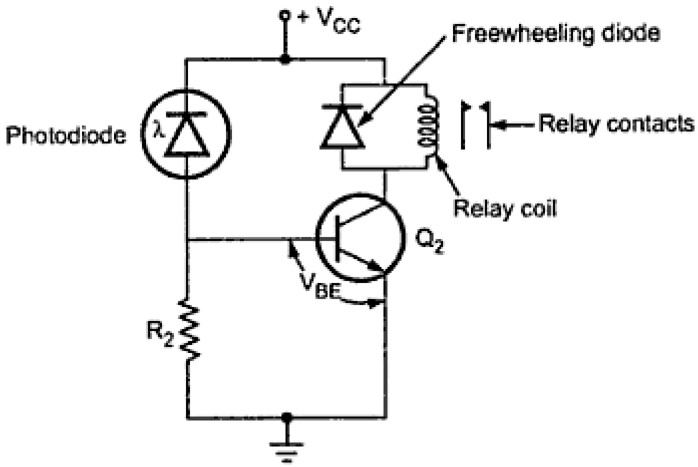
Photodiode Applications

The two commonly used systems using photodiode are alarm system and a counting system.

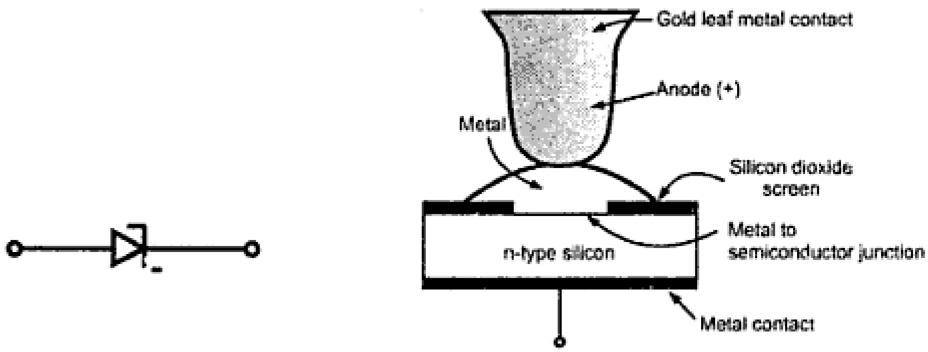
Photodiode Control Circuit

The following circuit shows the typical photodiode control circuit. When there is no light incident on the photodiode, the current through the photodiode is negligible, dark current.

Part of this current is current through R2. Such a small current through R2 keeps the voltage drop across R2 low, making transistor and relay "OFF". When light is incident on the photodiode the current through diode and hence the current through R2 is sufficient to forward bias both the junctions, making transistor and relay "ON".



5. Schottky diode



(a) Symbol

(b) Construction

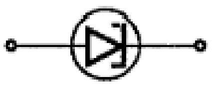
Applications

Due to fast switching characteristics, the Schottky diodes are very useful for high frequency applications such as digital computers, high speed TTL, radar systems, mixers, detectors in communication equipments and analog to digital converters.

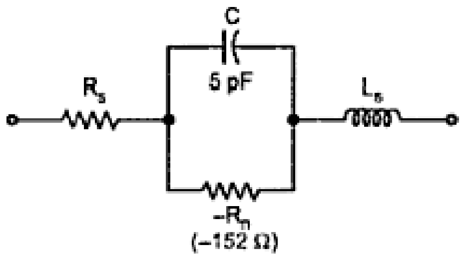
6. Tunnel diode

A normal p-n junction has an impurity concentration of about 1 part in 10^8. This much amount of doping has the depletion layer width of about 5 microns i.e. 5×10^{-4}cm. The diodes in which the concentration of impurity atoms is greatly increased upto 1 part in 10^3, to get completely changed characteristics, are called as Tunnel diodes. These diodes are first introduced by Leo Esaki in 1958.

Due to the heavy doping the depletion region gets reduced considerably, of the order of 10^{-6}cm i.e. about 1/100 the width of depletion region in normal p-n junction diode. Due to the thin depletion region, an electron penetrates through the barrier. This is called as tunneling and hence such high impurity density p-n junction devices are called as tunnel diodes. Many carriers in tunnel diodes penetrate the barrier at velocities far more than the velocities available in the conventional diodes, at low forward bias voltages. Due to such effect, it shows a negative resistance region in its volt-ampere characteristics. This negative resistance region is the most important feature of a tunnel diode.



(a) Symbol



(b) Equivalent circuit in negative resistance region

Aplication of tunel diode

1. As a high speed switch.
2. In pulse and digital circuits.
3. In negative resistance and high frequency (microwave) oscillator.
4. In switching networks.
5. In timing and computer logic circuitry.
6. Design of pulse generators and amplifiers.

Topic2: Identification of different types of transistor;

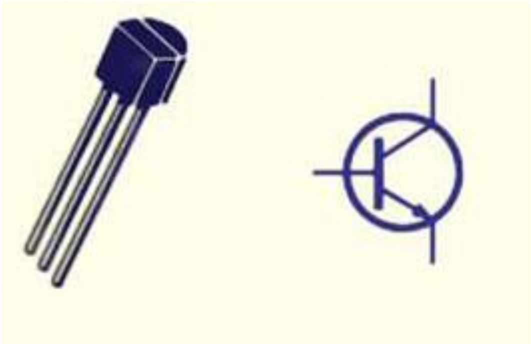
1. BJT (NPN and PNP)

A transistor consists of two pn junctions formed by *sandwiching either p-type or n-type semiconductor between a pair of opposite types. Accordingly; there are two types of transistors, namely;

(i) n-p-n transistor (ii) p-n-p transistor

An n-p-n transistor is composed of two n-type semiconductors separated by a thin section of ptype as shown in Fig. 8.1 (i). However, a p-n-p transistor is formed by two p-sections separated by a thin section of n-type as shown in Fig. 8.1 (ii).

(i) (ii)

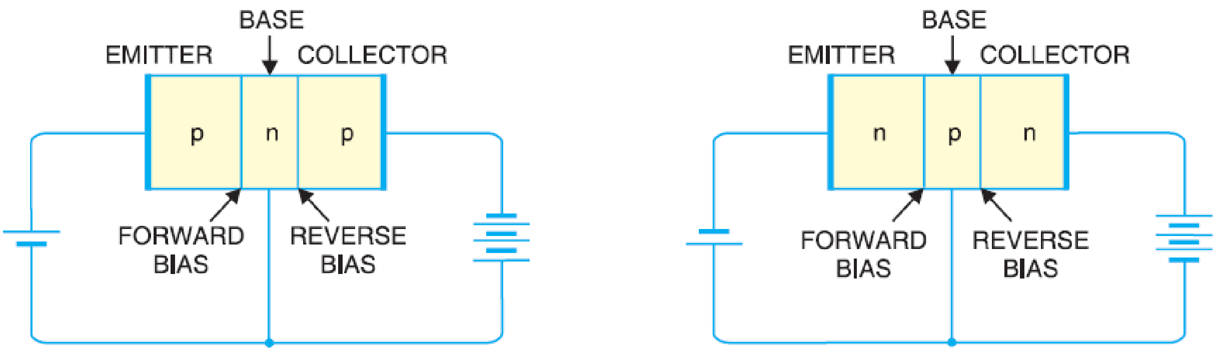


Naming the Transistor Terminals

A transistor (pnp or npn) has three sections of doped semiconductors. The section on one side is the emitter and the section on the opposite side is the collector. The middle section is called the base and forms two junctions between the emitter and collector.

(i) Emitter. The section on one side that supplies charge carriers (electrons or holes) is called the emitter. The emitter is always forward biased w.r.t. base so that it can supply a large number of *majority carriers. In Fig. 8.2 (i), the emitter (p-type) of pnp transistor is forward biased and supplies hole charges to its junction with the base. Similarly, in Fig. 8.2 (ii), the emitter (n-type) of npn transistor has a forward bias and supplies free electrons to its junction with the base.

(ii) Collector. The section on the other side that collects the charges is called the collector. The collector is always reverse biased. Its function is to remove charges from its junction with the base. In Fig. 8.2 (i), the collector (p-type) of pnp transistor has a reverse bias and receives hole charges that flow in the output circuit. Similarly, in Fig. 8.2 (ii), the collector (n-type) of npn transistor has reverse bias and receives electrons.



(i) (ii)

(iii) Base. The middle section which forms two pn-junctions between the emitter and collector is called the base. The base-emitter junction is forward biased, allowing low resistance for the emitter circuit. The base-collector junction is reverse biased and provides high resistance in the collector circuit.

Some Facts about the Transistor

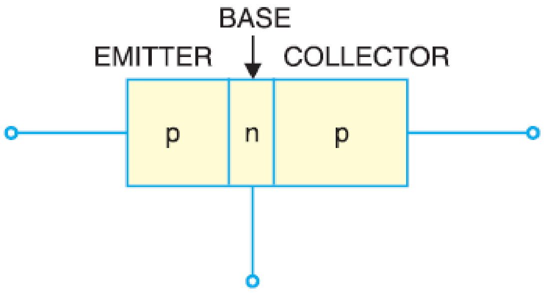
Before discussing transistor action, it is important that the reader may keep in mind the following facts about the transistor :

(i) The transistor has three regions, namely; emitter, base and collector. The base is much thinner than the emitter while **collector is wider than both as shown in Fig. 8.3. However, for the sake of convenience, it is customary to show emitter and collector to be of equal size.

(ii) The emitter is heavily doped so that it can inject a large number of charge carriers (electrons or holes) into the base. The base is lightly doped and very thin ; it passes most of the emitter injected charge carriers to the collector. The collector is moderately doped.

* Holes if emitter is p-type and electrons if the emitter is n-type.

** During transistor operation, much heat is produced at the collector junction. The collector is made larger to dissipate the heat.



(i) (ii)

(iii) The transistor has two pnjunctions i.e. it is like two diodes. The junction between emitter and base may be called emitter-base diode or simply the emitter diode. The junction between the base and collector may be called collector-base diode or simply collector diode.

(iv) The emitter diode is always forward biased whereas collector diode is always reverse biased.

(v) The resistance of emitter diode (forward biased) is very small as compared to collector diode (reverse biased). Therefore, forward bias applied to the emitter diode is generally very small whereas reverse bias on the collector diode is much higher.

Transistor Action

The emitter-base junction of a transistor is forward biased whereas collector-base junction is reverse biased. If for a moment, we ignore the presence of emitter-base junction, then practically* no current would flow in the collector circuit because of the reverse bias. However, if the emitter-base junction is also present, then forward bias on it causes the emitter current to flow. It is seen that this emitter current almost entirely flows in the collector circuit. Therefore, the current in the collector circuit depends upon the emitter current. If the emitter current is zero, then collector current is nearly zero. However, if the emitter current is 1mA, then collector current is also about 1mA. This is precisely what happens in a transistor. We shall now discuss this transistor action for npnand pnptransistors.

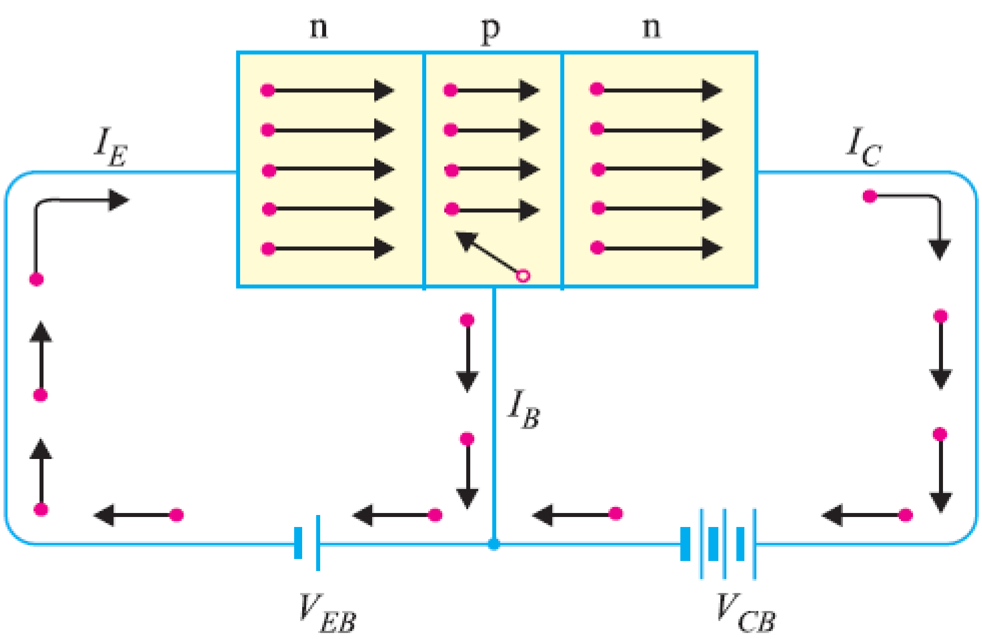
(i) Working of npn transistor. Fig. 8.4 shows the npntransistor with forward bias to emitter base junction and reverse bias to collector-base junction. The forward bias causes the electrons in the n-type emitter to flow towards the base. This constitutes the emitter current IE. As these electrons flow through the p-type base, they tend to combine with holes. As the base is lightly doped and very thin, therefore, only a few electrons (less than 5%) combine with holes to constitute base** current IB. The remainder (***more than 95%) cross over into the collector region to constitute collector current IC. In this way, almost the entire emitter current flows in the collector circuit. It is clear that emitter current is the sum of collector and base currents i.e.

IE = IB + IC

* In actual practice, a very little current (a few µA) would flow in the collector circuit. This is called collector cut off current and is due to minority carriers.

** The electrons which combine with holes become valence electrons. Then as valence electrons, they flow down through holes and into the external base lead. This constitutes base current IB.

*** The reasons that most of the electrons from emitter continue their journey through the base to collector to form collector current are : (i) The base is lightly doped and very thin. Therefore, there are a few holes which find enough time to combine with electrons. (ii) The reverse bias on collector is quite high and exerts attractive forces on these electrons.



Basic connection of *npn* transistor

(ii) Working of pnp transistor. Fig. 8.5 shows the basic connection of a pnptransistor. The forward bias causes the holes in the p-type emitter to flow towards the base. This constitutes the emitter current IE. As these holes cross into n-type base, they tend to combine with the electrons. As the base is lightly doped and very thin, therefore, only a few holes (less than 5%) combine with the electrons. The remainder (more than 95%) cross into the collector region to constitute collector current IC. In this way, almost the entire emitter current flows in the collector circuit. It may be noted that current conduction within pnptransistor is by holes. However, in the external connecting wires, the current is still by electrons.

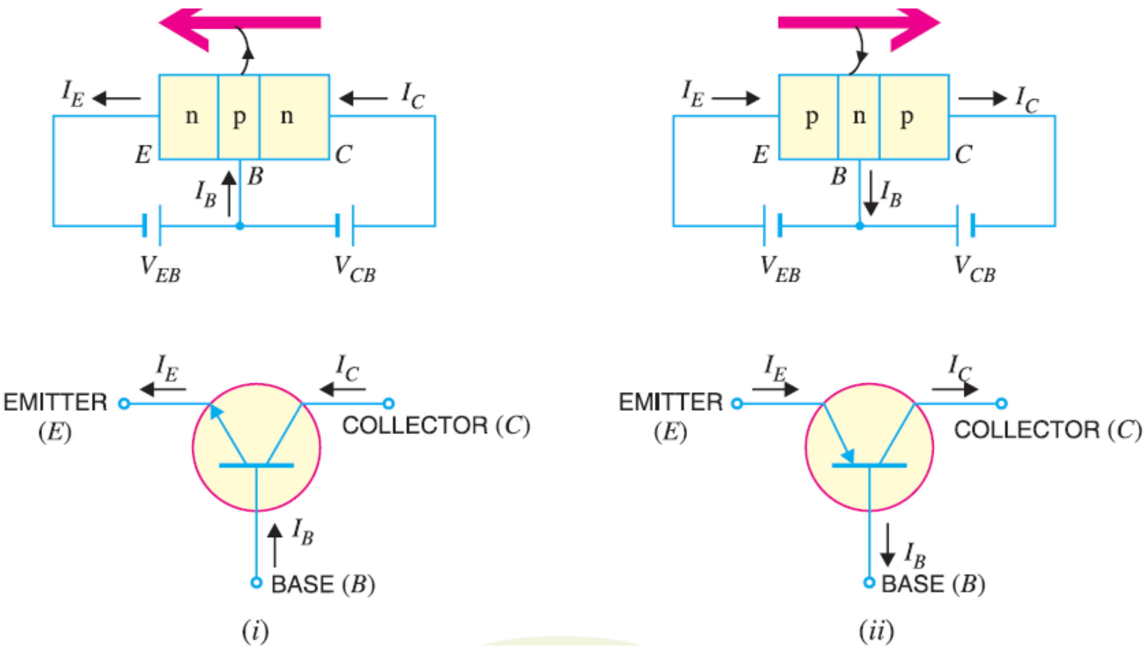
Importance of transistor action.

The input circuit (i.e. emitter-base junction) has low resistance because of forward bias whereas output circuit (i.e. collector-base junction) has high resistance due to reverse bias. As we have seen, the input emitter current almost entirely flows in the collector circuit. Therefore, a transistor transfers the input signal current from a low-resistance circuit to a high-resistance circuit. This is the key factor responsible for the amplifying capability of the transistor.

Note. There are two basic transistor types : the **bipolar junction transistor (**BJT**)** and **fieldeffect transistor** (FET). As we shall see, these two transistor types differ in both their operating characteristics and their internal construction. **Note that when we use the term transistor, it means bipolar junction transistor (**BJT**).** The term comes from the fact that in a bipolar transistor, there are two types of charge carriers (viz. electrons and holes) that play part in conductions. Note that bi means two and polar refers to polarities. The field-effect transistor is simply referred to as FET.

Transistor Symbols

In the earlier diagrams, the transistors have been shown in diagrammatic form. However, for the sake of convenience, the transistors are represented by schematic diagrams. The symbols used for npnand pnptransistors are shown in Fig I &ii respectively.



Transistor Connections

There are three leads in a transistor viz., emitter, base and collector terminals. However, when a transistor is to be connected in a circuit, we require four terminals; two for the input and two for the output. This difficulty is overcome by making one terminal of the transistor common to both input and output terminals. The input is fed between this common terminal and one of the other two terminals. The output is obtained between the common terminal and the remaining terminal. Accordingly; a transistor can be connected in a circuit in the following three ways :

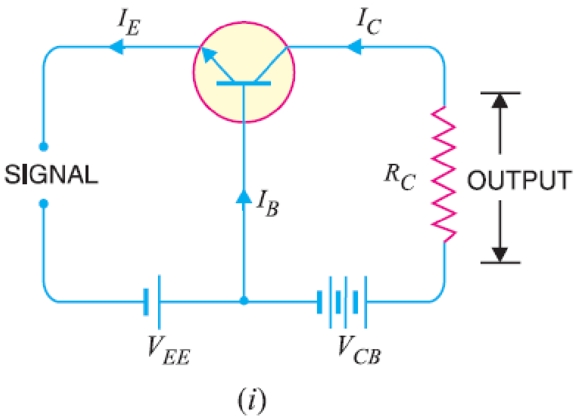
(i) common base connection **(ii)** common emitter connection

(iii) common collector connection

Each circuit connection has specific advantages and disadvantages. It may be noted here that regardless of circuit connection, the emitter is always biased in the forward direction, while the collector always has a reverse bias.

Common Base Connection

In this circuit arrangement, input is applied between emitter and base and output is taken from collector and base. Here, base of the transistor is common to both input and output circuits and hence the name common base connection. In Fig. 8.9 (i), a common base npntransistor circuit is shown whereas Fig. 8.9 (ii) shows the common base pnptransistor circuit.



1. Current amplification factor (). It is the ratio of output current to input current. In a common base connection, the input current is the emitter current IE and output current is the collector current IC. The ratio of change in collector current to the change in emitter current at constant collector base voltage VCB is known as **current amplification factor i.e.

$$*\alpha = \frac{\Delta I_C}{\Delta I_E} \text{ at constant } V_{CB}$$

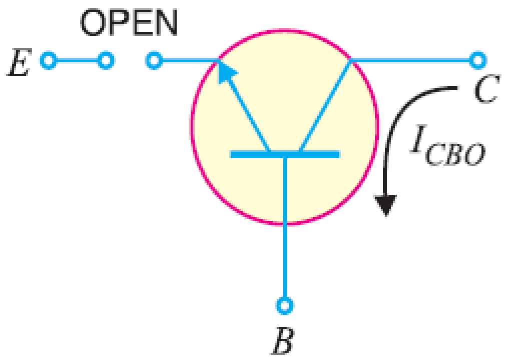


fig10

This value can be increased (but not more than unity) by decreasing the base current. This is achieved by making the base thin and doping it lightly. Practical values of β in commercial transistors

Range from 0.9 to 0.99.

2. Expression for collector current.

The whole of emittercurrent does not reach the collector. It is because a small percentage of it, as a result of electron-hole combinations occurring in base area, gives rise to base current. Moreover, as the collector-base junction is reverse biased, therefore some leakage current flows due to minority carriers. It follows, therefore, that total collector current consists of:

(i) That part of emitter current which reaches the collector terminal i.e. ***αIE.

(ii) The leakage current Ileakage. This current is due to the movement of minority carriers across base-collector junction on account of it being reverse biased. This is generally much smaller than IE.

∴ Total collector current, IC = αIE + Ileakage

It is clear that if IE = 0 (i.e., emitter circuit is open), a small leakage current still flows in the collector circuit. This I leakageis abbreviated as ICBO, meaning collector-base current with emitter open. The ICBO is indicated in Fig. 8.10.

$$\therefore \qquad I_C = \alpha I_E + I_{CBO}$$

$$\text{Now} \qquad I_E = I_C + I_B$$

$$\therefore \qquad I_C = \alpha (I_C + I_B) + I_{CBO}$$

$$\text{or} \qquad I_C (1 - \alpha) = \alpha I_B + I_{CBO}$$

$$\text{or} \qquad I_C = \frac{\alpha}{1-\alpha} I_B + \frac{I_{CBO}}{1-\alpha}$$

Relation (i) or (ii) can be used to find IC. It is further clear from these relations that the collector current of a transistor can be controlled by either the emitter or base current.

Fig. 8.11 shows the concept of ICBO. In CB configuration, a small collector current flows even when the emitter current is zero. This is the leakage collector current (i.e. the collector current when emitter is open) and is denoted by ICBO. When the emitter voltage VEE is also applied, the various currents are as shown in Fig. 8.11 (ii).

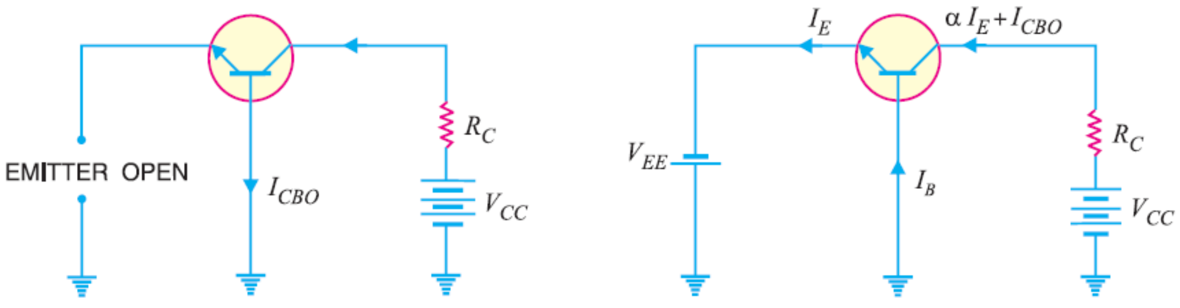
Note. Owing to improved construction techniques, the magnitude of ICBO for general-purpose and low-powered transistors (especially silicon transistors) is usually very small and may be neglected in calculations. However, for high power applications, it will appear in microampere range. Further, ICBO is very much temperature dependent; it increases rapidly with the increase in temperature. Therefore, at higher temperatures, ICBO plays an important role and must be taken care of in calculations.

* If only d.c. values are considered, then $\alpha = I_C/I_E$.

** At first sight, it might seem that since there is no current gain, no voltage or power amplification could be possible with this arrangement. However, it may be recalled that output circuit resistance is much higher than the input circuit resistance. Therefore, it does give rise to voltage and power gain.

*** $\alpha = \frac{I_C}{I_E} \quad \therefore \quad I_C = \alpha I_E$

In other words, αI_E part of emitter current reaches the collector terminal.



(i) (ii)

Example 8.2. *In a common base connection, $I_E = 1mA$, $I_C = 0.95mA$. Calculate the value of I_B.*

Solution. Using the relation, $I_E = I_B + I_C$

or $1 = I_B + 0.95$

$\therefore$ $I_B = 1 - 0.95 = $ **0.05 mA**

Example 8.3. *In a common base connection, current amplification factor is 0.9. If the emitter urrent is 1mA, determine the value of base current.*

Solution. Here, $\alpha = 0.9$, $I_E = 1$ mA

Now $$\alpha = \frac{I_C}{I_E}$$

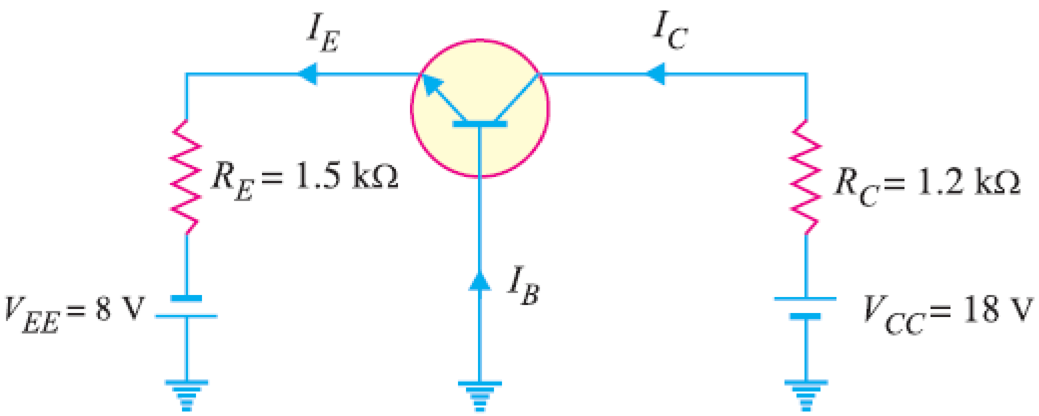
or $I_C = \alpha I_E = 0.9 \times 1 = 0.9$ mA

Also $I_E = I_B + I_C$

$\therefore$ Base current, $I_B = I_E - I_C = 1 - 0.9 = $ **0.1 mA**

Example 8.7. For the common base circuit shown in

Fig. 8.13, determine IC and VCB. Assume the transistor to be of silicon.



Solution. Since the transistor is of silicon, VBE = 0.7V.

Applying Kirchhoff's voltage law to the emitter-side loop,

we get,

$$V_{EE} = I_E R_E + V_{BE}$$

or $$I_E = \frac{V_{EE} - V_{BE}}{R_E}$$

$$= \frac{8V - 0.7V}{1.5\ k\Omega} = 4.87\ mA$$

$$\therefore \quad I_C \simeq I_E = \mathbf{4.87\ mA}$$

Applying Kirchhoff's voltage la
to the collector-side loop, we have,

$$V_{CC} = I_C R_C + V_{CB}$$

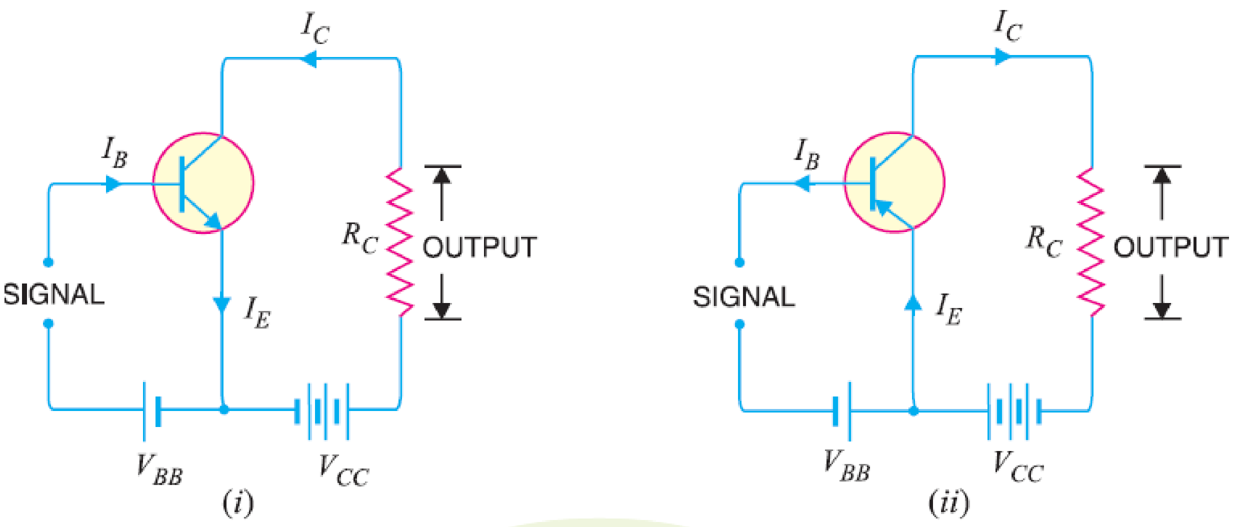
$$\therefore \quad V_{CB} = V_{CC} - I_C R_C$$

$$= 18\ V - 4.87\ mA \times 1.2\ k\Omega = \mathbf{12.16\ V}$$

Common Emitter Connection

In this circuit arrangement, input is applied between base and emitter and output is taken from the collector and emitter. Here, emitter of the transistor is common to both input and output circuits and hence the name common emitter connection. Fig. 8.16 (i) shows common emitter npntransistor circuit whereas Fig. 8.16 (ii) shows common emitter pnptransistor circuit.

* IE has to be kept constant because any change in IE will produce corresponding change in IC. Here, we are interested to see how VCB influences IC.



1. Base current amplification factor (β). In common emitter connection, input current is IB and output current is IC.

The ratio of change in collector current (dIC) to the change in base current (dIB) is known as **base current amplification factor** i.e.

$$\beta^* = \frac{\Delta I_C}{\Delta I_B}$$

Relation between β and α.

$$\beta = \frac{\Delta I_C}{\Delta I_B} \quad ...(i)$$

$$\alpha = \frac{\Delta I_C}{\Delta I_E} \quad ...(ii)$$

Now $I_E = I_B + I_C$

or $\Delta I_E = \Delta I_B + \Delta I_C$

or $\Delta I_B = \Delta I_E - \Delta I_C$

Substituting the value of ΔI_B in exp. (*i*), we get,

$$\beta = \frac{\Delta I_C}{\Delta I_E - \Delta I_C} \quad ...(iii)$$

Dividing the numerator and denominator of R.H.S. of exp. (*iii*) by ΔI_E, we get,

$$\beta = \frac{\Delta I_C / \Delta I_E}{\frac{\Delta I_E}{\Delta I_E} - \frac{\Delta I_C}{\Delta I_E}} = \frac{\alpha}{1-\alpha} \qquad \left[\because \ \alpha = \frac{\Delta I_C}{\Delta I_E}\right]$$

$$\therefore \quad \beta = \frac{\alpha}{1-\alpha}$$

Expression for collector current.

In common emitter circuit, IB is the input current and IC is the output current.

We know $I_E = I_B + I_C \quad ...(i)$

and $I_C = \alpha I_E + I_{CBO} \quad ...(ii)$

From exp. (*ii*), we get, $I_C = \alpha I_E + I_{CBO} = \alpha (I_B + I_C) + I_{CBO}$

or $I_C (1 - \alpha) = \alpha I_B + I_{CBO}$

or $$I_C = \frac{\alpha}{1-\alpha} I_B + \frac{1}{1-\alpha} I_{CBO} \quad ...(iii)$$

From exp. (*iii*), it is apparent that if $I_B = 0$ (*i.e.* base circuit is open), the collector current will be the current to the emitter. This is abbreviated as I_{CEO}, meaning collector-emitter current with base open.

$$\therefore \quad I_{CEO} = \frac{1}{1-\alpha} I_{CBO}$$

Substituting the value of $\frac{1}{1-\alpha} I_{CBO} = I_{CEO}$ in exp. (*iii*), we get,

$$I_C = \frac{\alpha}{1-\alpha} I_B + I_{CEO}$$

or $$I_C = \beta I_B + I_{CEO} \qquad \left(\because \beta = \frac{\alpha}{1-\alpha}\right)$$

Concept of ICEO. In CE configuration, a small collector current flows even when the base current is zero [See Fig. 8.17 (i)]. This is the collector cut off current (i.e. the collector current that flows when base is open) and is denoted by ICEO. The value of ICEO is much larger than ICBO.

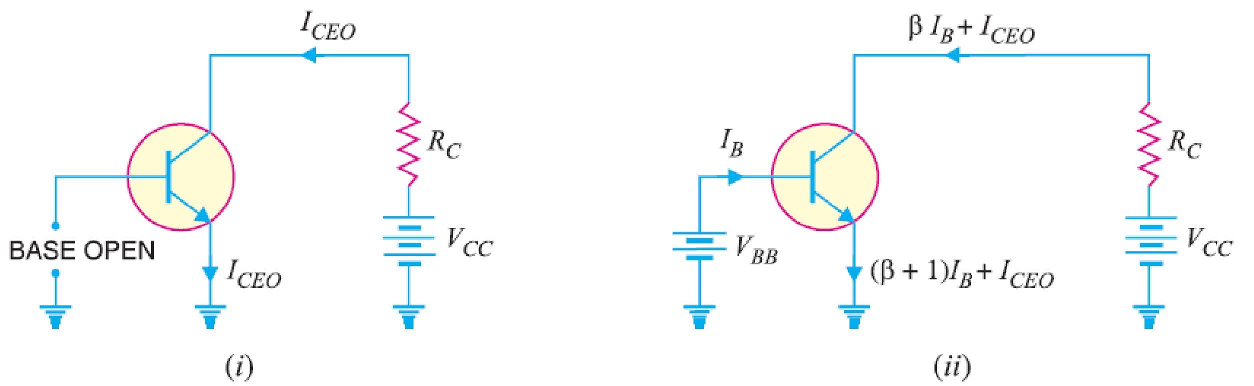


Fig. 8.17

When the base voltage is applied as shown in Fig. 8.17 (*ii*), then the various currents are :

$$\text{Base current} = I_B$$

$$\text{Collector current} = \beta I_B + I_{CEO}$$

$$\text{Emitter current} = \text{Collector current} + \text{Base current}$$

$$= (\beta I_B + I_{CEO}) + I_B = (\beta + 1) I_B + I_{CEO}$$

It may be noted here that :

$$I_{CEO} = \frac{1}{1-\alpha} I_{CBO} = (\beta + 1) I_{CBO} \qquad \left[\because \frac{1}{1-\alpha} = \beta + 1\right]$$

Example 8.8. *Find the value of β if (i) α = 0.9 (ii) α = 0.98 (iii) α = 0.99.*

Solution. (*i*)
$$\beta = \frac{\alpha}{1-\alpha} = \frac{0.9}{1-0.9} = \mathbf{9}$$

(*ii*)
$$\beta = \frac{\alpha}{1-\alpha} = \frac{0.98}{1-0.98} = \mathbf{49}$$

(*iii*)
$$\beta = \frac{\alpha}{1-\alpha} = \frac{0.99}{1-0.99} = \mathbf{99}$$

Example 8.9. *Calculate I_E in a transistor for which β = 50 and I_B = 20 μA.*

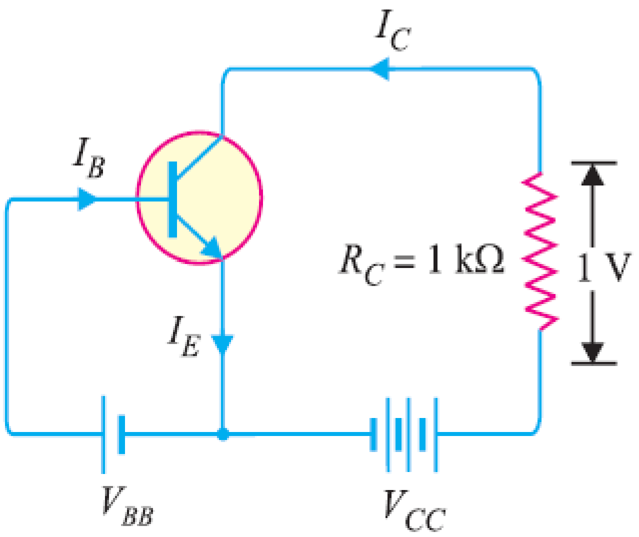
Solution. Here $\beta = 50, \; I_B = 20\mu A = 0.02 \text{ mA}$

Now
$$\beta = \frac{I_C}{I_B}$$

∴
$$I_C = \beta I_B = 50 \times 0.02 = 1 \text{ mA}$$

Using the relation, $I_E = I_B + I_C = 0.02 + 1 = \mathbf{1.02 \text{ mA}}$

Example 8.11. For a transistor, β= 45 and voltage drop across 1kΩ which is connected in the collector circuit is 1 volt. Find the base current for common emitter connection



Solution. Fig. 8.21 shows the required common emitter connection. The voltage drop across R_C (= 1 kΩ) is 1volt.

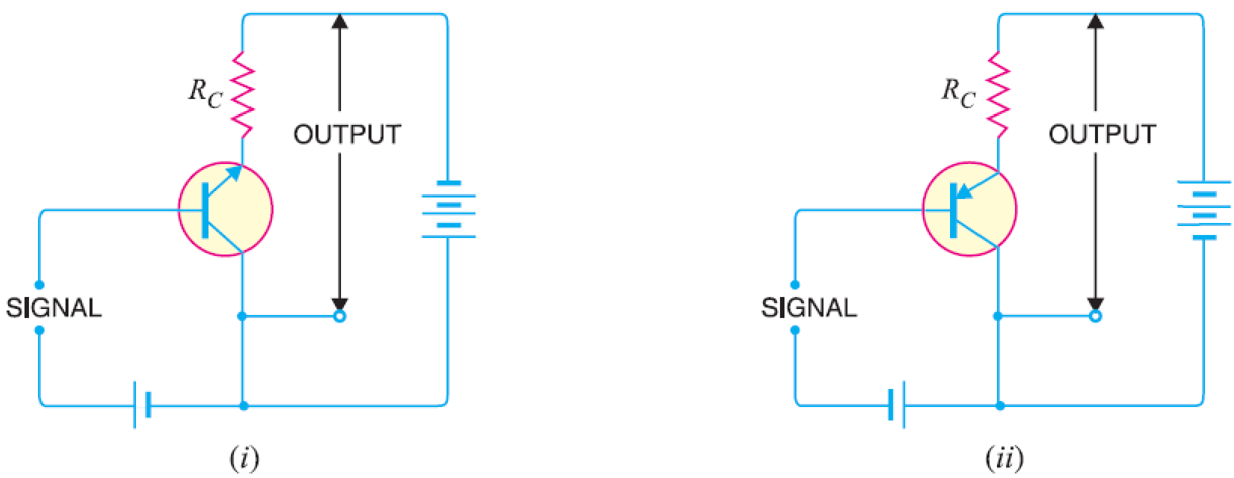
$$\therefore \qquad I_C = \frac{1\ V}{1\ k\Omega} = 1\ \text{mA}$$

$$\text{Now} \qquad \beta = \frac{I_C}{I_B}$$

$$\therefore \qquad I_B = \frac{I_C}{\beta} = \frac{1}{45} = \mathbf{0.022\ mA}$$

Common Collector Connection

In this circuit arrangement, input is applied between base and collector while output is taken between the emitter and collector. Here, collector of the transistor is common to both input and output circuits and hence the name common collector connection. Fig. 8.32 (i) shows common collector npn transistor circuit whereas Fig. 8.32 (ii) shows common collector pnpcircuit.



(i) **Current amplification factor γ.** In common collector circuit, input current is the base current I_B and output current is the emitter current I_E. Therefore, current amplification in this circuit arrangement can be defined as under :

The ratio of change in emitter current (ΔI_E) to the change in base current (ΔI_B) is known as **current amplification factor** *in common collector (CC) arrangement i.e.*

$$\gamma = \frac{\Delta I_E}{\Delta I_B}$$

This circuit provides about the same current gain as the common emitter circuit as $\Delta I_E \simeq \Delta I_C$. However, its voltage gain is always less than 1.

Relation between γ and α

$$\gamma = \frac{\Delta I_E}{\Delta I_B} \qquad ...(i)$$

$$\alpha = \frac{\Delta I_C}{\Delta I_E} \qquad ...(ii)$$

Now $\quad I_E = I_B + I_C$

or $\quad \Delta I_E = \Delta I_B + \Delta I_C$

or $\quad \Delta I_B = \Delta I_E - \Delta I_C$

Substituting the value of ΔI_B in exp. (*i*), we get,

$$\gamma = \frac{\Delta I_E}{\Delta I_E - \Delta I_C}$$

Dividing the numerator and denominator of R.H.S. by ΔI_E, we get,

$$\gamma = \frac{\frac{\Delta I_E}{\Delta I_E}}{\frac{\Delta I_E}{\Delta I_E} - \frac{\Delta I_C}{\Delta I_E}} = \frac{1}{1-\alpha} \qquad \left(\because \alpha = \frac{\Delta I_C}{\Delta I_E}\right)$$

$$\therefore \quad \gamma = \frac{1}{1-\alpha}$$

(ii) **Expression for collector current**

We know $\quad I_C = \alpha I_E + I_{CBO} \qquad$ (See Art. 8.8)

Also $\quad I_E = I_B + I_C = I_B + (\alpha I_E + I_{CBO})$

$$\therefore \quad I_E(1-\alpha) = I_B + I_{CBO}$$

or $$I_E = \frac{I_B}{1-\alpha} + \frac{I_{CBO}}{1-\alpha}$$

or $$I_C \simeq I_E = {}^*(\beta+1) I_B + (\beta+1) I_{CBO}$$

Comparison of Transistor Connections

The comparison of various characteristics of the three connections is given below in the tabular form.

S. No.	Characteristic	Common base	Common emitter	Common collector
1.	Input resistance	Low (about 100 Ω)	Low (about 750 Ω)	Very high (about 750 kΩ)
2.	Output resistance	Very high (about 450 kΩ)	High (about 45 kΩ)	Low (about 50 Ω)
3.	Voltage gain	about 150	about 500	less than 1
4.	Applications	For high frequency applications	For audio frequency applications	For impedance matching
5.	Current gain	No (less than 1)	High (β)	Appreciable

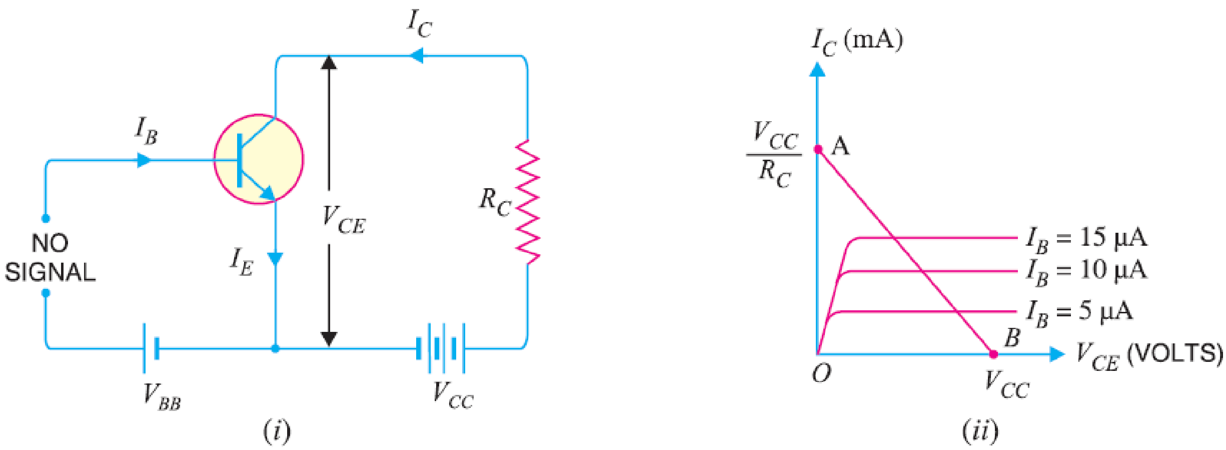
Transistor Load Line Analysis

In the transistor circuit analysis, it is generally required to determine the collector current for various collector-emitter voltages. One of the methods can be used to plot the output characteristics and determine the collector current at any desired collector-emitter voltage. However, a more convenient method, known as load line method can be used to solve such problems. As explained later in this section, this method is quite easy and is frequently used in the analysis of transistor applications.

d.c. load line. Consider a common emitter npntransistor circuit shown in Fig. 8.35 (i) where no signal is applied. Therefore, d.c. conditions prevail in the circuit. The output characteristics of this circuit are shown in Fig. 8.35 (ii).

The value of collector-emitter voltage VCE at any time is given by ;

VCE = VCC – IC RC



As V_{CC} and R_C are fixed values, therefore, it is a first degree equation and can be represented by a straight line on the output characteristics. This is known as *d.c. load line* and determines the locus of $V_{CE} - I_C$ points for any given value of R_C. To add load line, we need two end points of the straight line. These two points can be located as under :

(*i*) When the collector current $I_C = 0$, then collector-emitter voltage is maximum and is equal to V_{CC} *i.e.*

$$\text{Max. } V_{CE} = V_{CC} - I_C R_C$$
$$= V_{CC} \qquad (\because I_C = 0)$$

This gives the first point B ($OB = V_{CC}$) on the collector-emitter voltage axis as shown in Fig. 8.35 (*ii*).

(*ii*) When collector-emitter voltage $V_{CE} = 0$, the collector current is maximum and is equal to V_{CC}/R_C *i.e.*

$$V_{CE} = V_{CC} - I_C R_C$$

or $$0 = V_{CC} - I_C R_C$$

$$\therefore \quad \text{Max. } I_C = V_{CC}/R_C$$

This gives the second point A ($OA = V_{CC}/R_C$) on the collector current axis as shown in Fig. 8.35 (*ii*). By joining these two points, d.c. *load line AB is constructed.

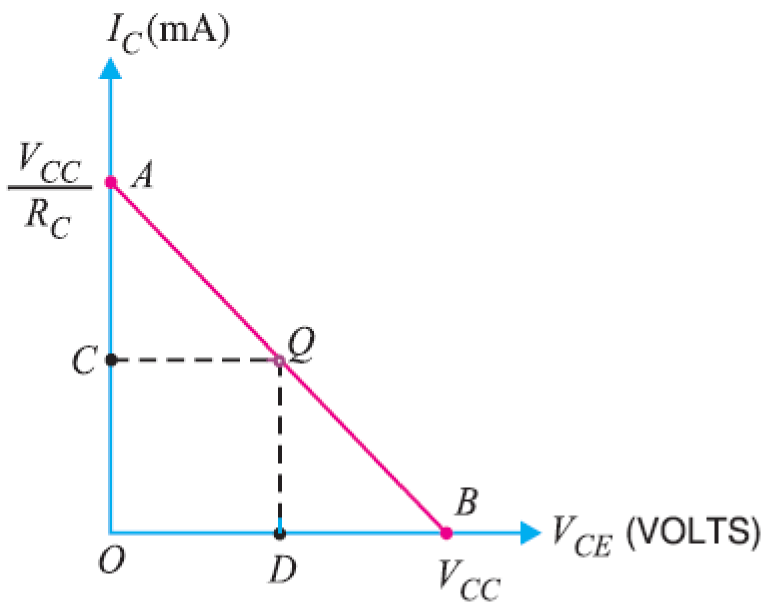


Fig. 8.36

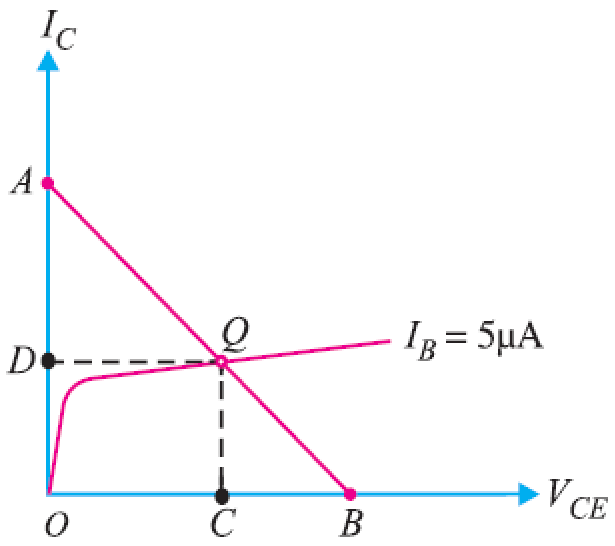
Operating Point

The zero signal values of IC and VCE are known as the **operating point**. It is called operating point because the variations of IC and VCE take place about this point when signal is applied. It is also called quiescent (silent) point or Q-point because it is the point on IC −VCE characteristic when the transistor is silent i.e. in the absence of the signal.

Suppose in the absence of signal, the base current is 5 μA. Then IC and VCE conditions in the circuit must be represented by some point on IB = 5 μA characteristic. But IC and VCE conditions in the circuit should also be represented by some point on the d.c. load line AB. The point Q where the load line and the characteristic intersect is the only point which satisfies both these conditions. Therefore, the point Q describes the actual state of affairs in the circuit in the zero signal conditions and is called the operating point. Referring to Fig. 8.37, for IB = 5 μA, the zero signal values are :

VCE = OC volts

IC = OD mA



It follows, therefore, that the zero signal values of IC and VCE (i.e. operating point) are determined by the point where d.c. load line intersects the proper base current curve.

Example: For the circuit shown in Fig. 26 (i), draw the d.c. load line

Solution. The collector-emitter voltage V_{CE} is given by ;

$$V_{CE} = V_{CC} - I_C R_C$$

When $I_C = 0$, then,

$$V_{CE} = V_{CC} = 12.5 \text{ V}$$

This locates the point B of the load line on the collector-emitter voltage axis.

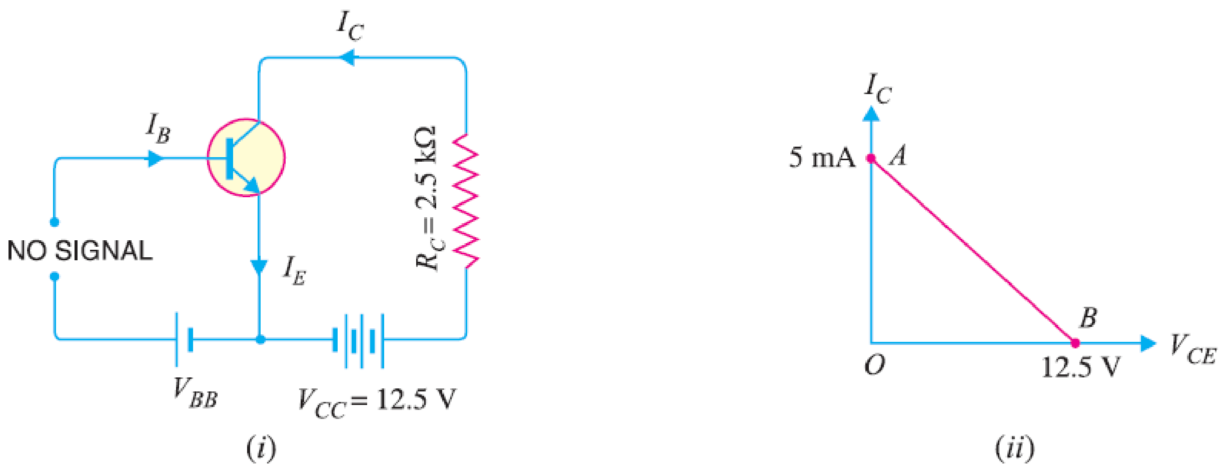


Figure 25

Example: In the circuit diagram shown in Fig. 27 (i), if VCC = 12V and RC = 6 k, draw the d.c. load line. What will be the Q point if zero signal base current is 20μA and β= 50 ?

Solution. The collector-emitter voltage V_{CE} is given by :

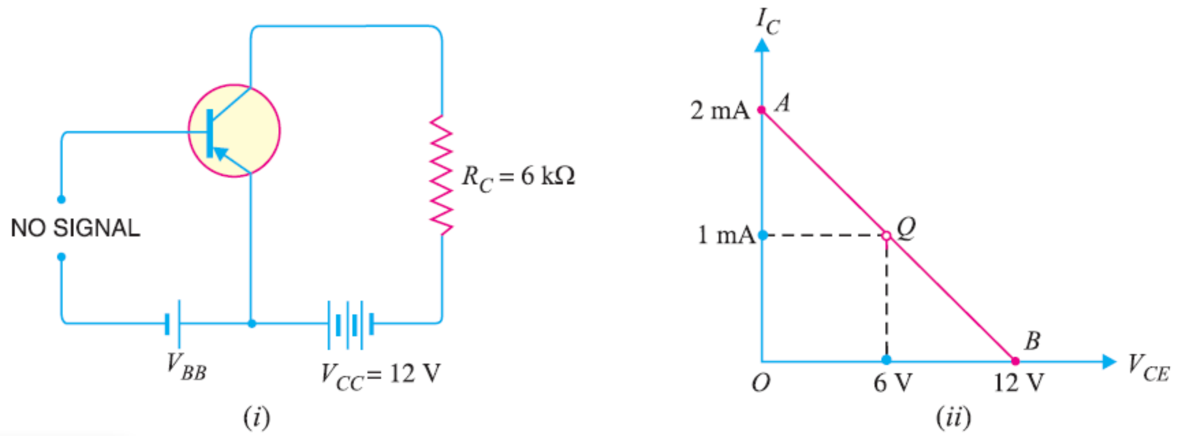
$$V_{CE} = V_{CC} - I_C R_C$$

When $I_C = 0$, $V_{CE} = V_{CC} = 12$ V. This locates the point B of the load line. When $V_{CE} = 0$, $I_C = V_{CC}/R_C = 12 \text{ V}/6 \text{ k}\Omega = 2$ mA. This locates the point A of the load line. By joining these two points, load line AB is constructed as shown in Fig. 8.39 (*ii*).

Zero signal base current, $I_B = 20\ \mu\text{A} = 0.02$ mA

Current amplification factor, $\beta = 50$

$\therefore$ Zero signal collector current, $I_C = \beta I_B = 50 \times 0.02 = 1$ mA



Figure

Zero signal collector-emitter voltage is

$$V_{CE} = V_{CC} - I_C R_C = 12 - 1 \text{ mA} \times 6 \text{ k}\Omega = 6 \text{ V}$$

26 $\therefore$ Operating point is **6 V, 1 mA**.

Example 8.24. *In a transistor circuit, collector load is 4 kΩ whereas quiescent current (zero signal collector current) is 1mA.*

(i) What is the operating point if $V_{CC} = 10$ V ?

(ii) What will be the operating point if $R_C = 5$ kΩ ?

Solution. $V_{CC} = 10$ V, $I_C = 1$ mA

(i) When collector load $R_C = 4\text{ k}\Omega$, then,

$$V_{CE} = V_{CC} - I_C R_C = 10 - 1 \text{ mA} \times 4 \text{ k}\Omega = 10 - 4 = 6\ V$$

$\therefore$ Operating point is **6 V, 1 mA**.

(ii) When collector load $R_C = 5\text{ k}\Omega$, then,

$$V_{CE} = V_{CC} - I_C R_C = 10 - 1 \text{ mA} \times 5 \text{ k}\Omega = 10 - 5 = 5\ V$$

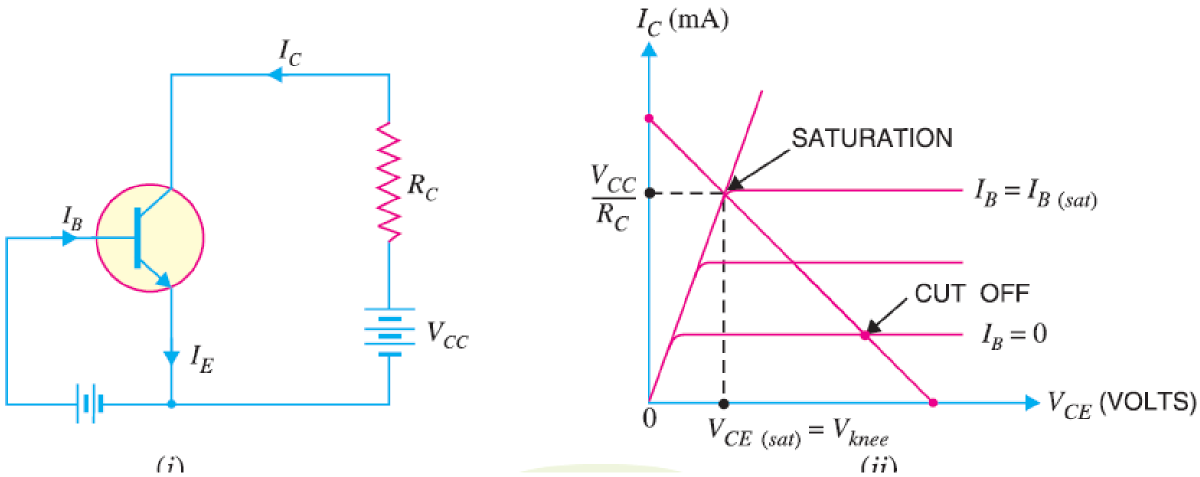
$\therefore$ Operating point is **5 V, 1 mA**.

Cut off and Saturation Points

Fig. 8.49 (i) shows CE transistor circuit while Fig. 8.49 (ii) shows the output characteristcs along with the d.c. load line.

(i) Cut off. The point where the load line intersects the IB = 0 curve is known as cut off. At this point, IB = 0 and only small collector current (i.e. collector leakage current ICEO) exists. At cut off, the base-emitter junction no longer remains forward biased and normal transistor action is lost. The collector-emitter voltage is nearly equal to VCC i.e.

VCE (cut off) = VCC



(ii) Saturation. The point where the load line intersects the IB = IB(sat) curve is called saturation. At this point, the base current is maximum and so is the collector current. At saturation, collectorbase junction no longer remains reverse biased and normal transistor action is lost.

$$I_{C\,(sat)} \simeq \frac{V_{CC}}{R_C}\,; \quad V_{CE} = V_{CE(sat)} = V_{knee}$$

If base current is greater than IB(sat), then collector current cannot increase because collector-base junction is no longer reverse-biased.

(iii) Active region. The region between cut off and saturation is known as active region. In the active region, collector-base junction remains reverse biased while base-emitter junction remains forward biased. Consequently, the transistor will function normally in this region.

Note. We provide biasing to the transistor to ensure that it operates in the active region. The reader may find the detailed discussion on transistor biasing in the next chapter.

Summary. A transistor has two pnjunctions i.e., it is like two diodes. The junction between base and emitter may be called emitter diode. The junction between base and collector may be called collector diode. We have seen above that transistor can act in one of the three states : **cut-off,saturated** and **active**. The state of a transistor is entirely determined by the states of the emitter diode and collector diode [See Fig. 8.50]. The relations between the diode states and the transistor states are :

CUT-OFF: Emitter diode and collector diode are **OFF.**

ACTIVE: Emitter diode is **ON** and collector diode is **OFF.**

SATURATED: Emitter diode and collector diode are **ON.**

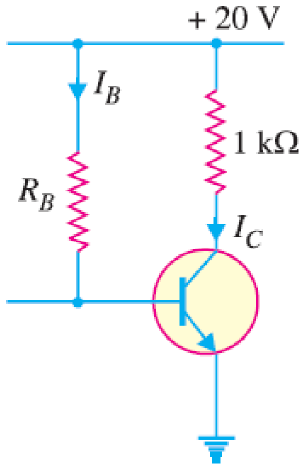
Example: Find IC(sat) and VCE(cut off) for the circuit shown in Fig. 8.52 (i).

Solution: As we decrease RB, base current and hence collector current increases. The increased collector current causes a greater voltage drop across RC ; this decreases the collector-emitter voltage. Eventually at some value of RB, VCE decreases to Vknee. At this point, collector-base junction is no longer reverse biased and transistor action is lost. Consequently, further increase in collector current is

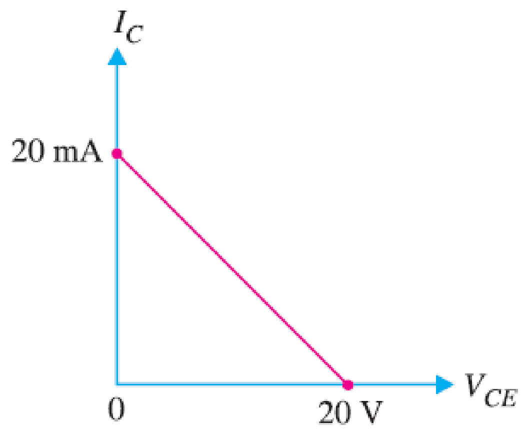
not possible. The transistor conducts maximum collector current ; we say the transistor is saturated.

$$I_{C(sat)} = \frac{V_{CC} - {}^*V_{knee}}{R_C} = \frac{V_{CC}}{R_C} = \frac{20\ V}{1\ k\Omega} = \mathbf{20mA}$$

$$V_{CE(cut\text{-}off)} = V_{CC} = \mathbf{20\ V}$$



(i)



(ii)

Power Rating of Transistor

The maximum power that a transistor can handle without destruction is known as **power rating** *of the transistor.*

When a transistor is in operation, almost all the power is dissipated at the reverse biased *collector-base junction. The power rating (or maximum power dissipation) is given by :

$$P_{D\ (max)} = \text{Collector current} \times \text{Collector-base voltage}$$
$$= I_C \times V_{CB}$$
$$\therefore \quad P_{D\ (max)} = I_C \times V_{CE}$$

$[\because V_{CE} = V_{CB} + V_{BE}$ Since V_{BE} is very small, $V_{CB} \simeq V_{CE}]$

Field Effect Transistors (FET (JFET, MOSFET)

The **field-effect transistor** (**FET**) is a **type** of transistor which uses an electric field to control the flow of current. **FETs** are devices with three terminals: source, gate, and drain. **FETs** are also known as unipolar transistors since they involve single-carrier-**type** operation.

Types of Field Effect Transistors

A bipolar junction transistor (BJT) is a current controlled device i.e., output characteristics of the device are controlled by base current and not by base voltage. However, in a field effect transistor (FET), the output characteristics are controlled by input voltage (i.e., electric field) and not by input current. This is probably the biggest difference between BJT and FET. There are two basic types of field effect transistors:

(i) Junction field effect transistor (JFET)

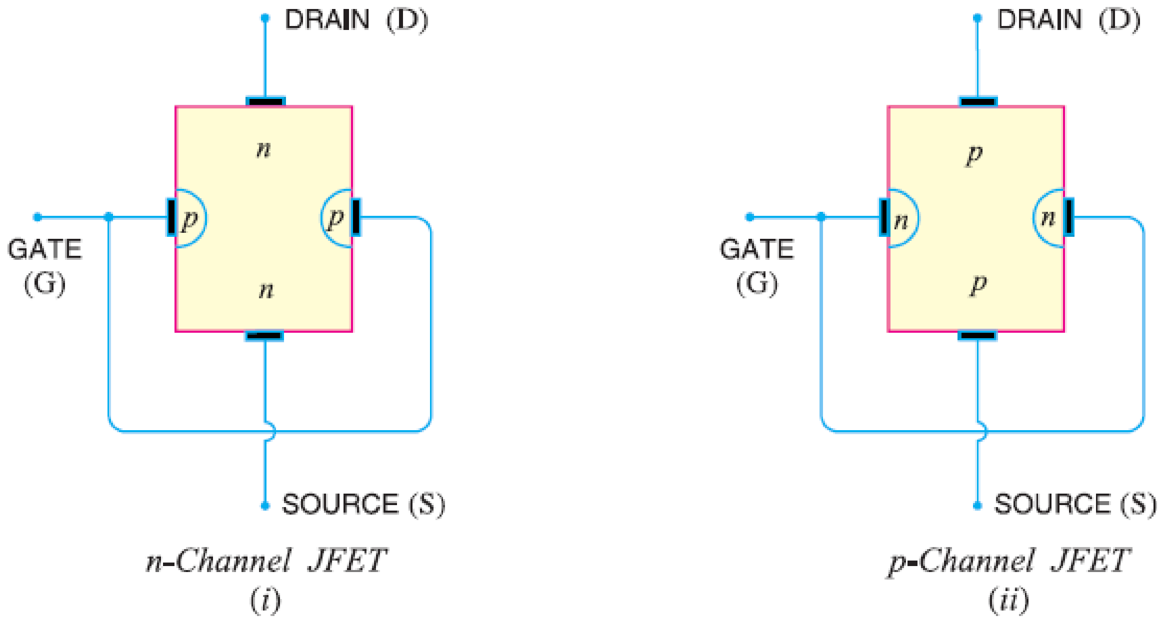
(ii) Metal oxide semiconductor field effect transistor (MOSFET)

To begin with, we shall study about JFET and then improved form of JFET, namely; MOSFET.

Junction Field Effect Transistor (JFET)

A **junction field effect transistor** is a three terminal semiconductor device in which current conduction is by one type of carrier i.e., electrons or holes.TheJFET was developed about the same time as the transistor but it came into general use onlyin the late 1960s. In a JFET, the current conduction is either by electrons or holes and is controlled bymeans of an electric field between the gate electrode and the conducting channel of the device. TheJFET has high input impedance and low noise level.

Constructional details: A JFET consists of a p-type or n-type silicon bar containing two pnjunctions at the sides as shown in Fig.28. The bar forms the conducting channel for the chargecarriers. If the bar is of n-type, it is called n-channel JFET as shown in Fig. 28 (i) and if the bar isof p-type, it is called a p-channel JFET as shown in Fig. 28 (ii). The two pnjunctions formingdiodes are connected *internally and a common terminal called gate is taken out. Other terminals aresource and drain taken out from the bar as shown. Thus a JFET has essentially three terminals viz.,
gate (G), source (S) and drain (D).



n-Channel JFET
(*i*)

p-Channel JFET
(*ii*)

Figure 27

Principle and Working of JFET

Fig. 19.3 shows the circuit of n-channel JFET with normal polarities. Note that the gate is reversing biased.

Principle. The two pnjunctions at the sides form two depletion layers. The current conduction by charge carriers (i.e. free electrons in this case) is through the channel between the two depletion layers and out of the drain. The width and hence *resistance of this channel can be controlled by changing the input voltage VGS. The greater the reverse voltage VGS, the wider will be the depletion layers and narrower will be the conducting channel. The narrower channel means greater resistance and hence source to drain current decreases. Reverse will happen should VGS decrease. Thus JFET operates on the principlethat width and hence resistance of the conducting channel can be varied by changing the reversevoltage VGS. In other words, the magnitude of drain current (ID) can be changed by altering VGS.

Working. The working of JFET is as under:

(i) When a voltage VDS is applied between drain and source terminals and voltage on the gate is zero [See Fig. 29 (i)], the two pnjunctions at the sides of the bar establish depletion layers. The electrons will flow from source to drain through a channel between the depletion layers. The size of these layers determines the width of the channel and hence the current conduction through the bar.

(ii) When a reverse voltage VGS is applied between the gate and source [See Fig. 29 (ii)], the width of the depletion layers is increased. This reduces the width of conducting channel, thereby increasing the resistance of n-type bar. Consequently, the current from source to drain is decreased. On the other hand, if the reverse voltage on the gate is decreased, the width of the depletion layers also decreases. This increases the width of the conducting channel and hence source to drain current.

* The resistance of the channel depends upon its area of X-section. The greater the X-sectional area of this channel, the lower will be its resistance and the greater will be the current flow through it.

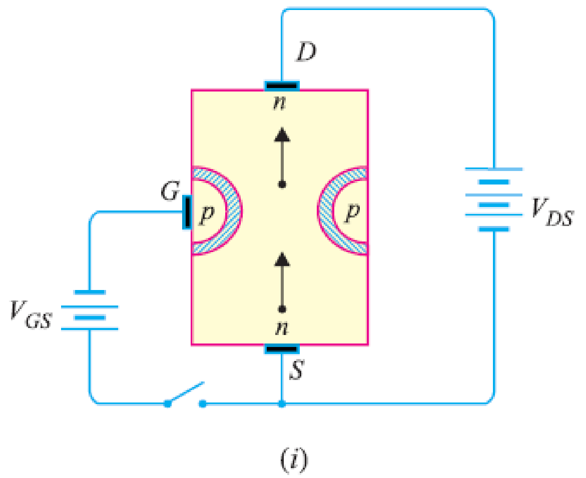


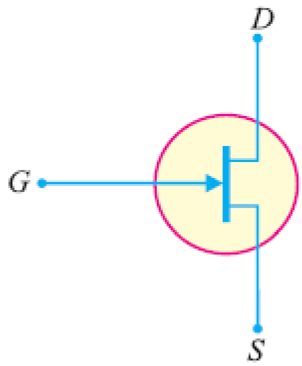
Figure 28

It is clear from the above discussion that current from source to drain can be controlled by the application of potential (i.e. electric field) on the gate. For this reason, the device is called field effecttransistor. It may be noted that a p-channel JFET operates in the same manner as an n -channel JFET except that channel current carriers will be the holes instead of electrons and the polarities of VGS and VDS are reversed.

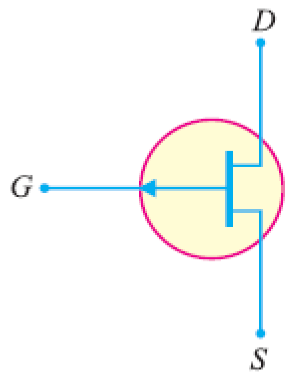
Note. If the reverse voltage VGS on the gate is continuously increased, a state is reached when the two depletion layers touch each other and the channel is cut off. Under such conditions, the channel becomes a nonconductor.

Schematic Symbol of JFET

Fig. 30 shows the schematic symbol of JFET. The vertical line in the symbol may be thought



n-Channel JFET
(i)



p-Channel JFET
(ii)

Figure 29

Types of MOSFETs

There are two basic types of MOSFETs viz.

1. Depletion-type MOSFET or **D-MOSFET.** The D-MOSFET can be operated in both the depletion-mode and the enhancement-mode. For this reason, a D-MOSFET is sometimes called depletion/enhancement MOSFET.

2. Enhancement-type MOSFET or **E-MOSFET.** The E-MOSFET can be operated only in enhancement-mode.

The manner in which a MOSFET is constructed determines whether it is D-MOSFET or EMOSFET.

1. D-MOSFET. Fig. 31 shows the constructional details of n-channel D-MOSFET. It is similar to n-channel JFET except with the following modifications/remarks :

(i) The n-channel D-MOSFET is a piece of n-type material with a p-type region (called substrate) on the right and an insulated gate on the left as shown in Fig. 31. The free electrons (Q it is n-channel) flowing from source to drain must pass through the narrow channel between the gate and the p-type region (i.e. substrate).

(ii) Note carefully the gate construction of D-MOSFET. A thin layer of metal oxide (usually silicon dioxide, SiO_2) is deposited over a small portion of the channel. A metallic gate is deposited over the oxide layer. As SiO_2 is an insulator, therefore, gate is insulated from the channel. Note that the arrangement forms a capacitor. One plate of this capacitor is the gate and the other plate is the channel with SiO_2 as the dielectric. Recall that we have a gate diode in a JFET.

(iii) It is a usual practice to connect the substrate to the source (S) internally so that a MOSFET has three terminals vizsource (S), gate (G) and drain (D).

(iv) Since the gate is insulated from the channel, we can apply either negative or positive voltage to the gate. Therefore, D-MOSFET can be operated in both depletion-mode and enhancement-mode. However, JFET can be operated only in depletion-mode.

* With the decrease in channel width, the X-sectional area of the channel decreases and hence its resistance
increases. This means that conductivity of the channel will decrease. Reverse happens if channel width increases.

** With gate reverse biased, the channel is depleted (i.e. emptied) of charge carriers (free electrons for n-channel and holes for p-channel) and hence the name depletion-mode. Note that depletion means decrease. In this mode of operation, conductivity decreases from the zero-bias level.

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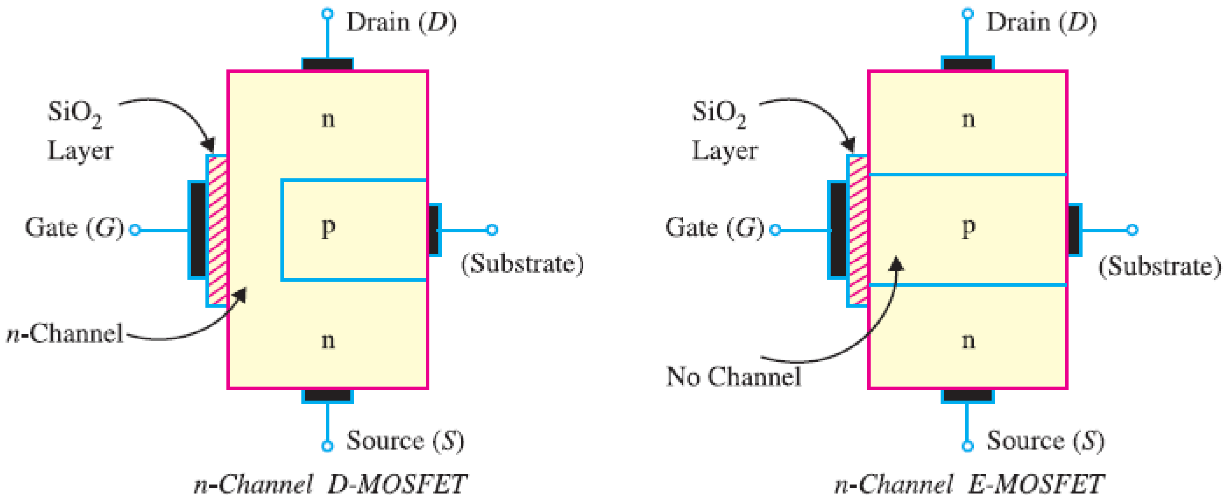


Figure 30

2. E-MOSFET. Fig. 32 shows the constructional details of n-channel E-MOSFET. Its gate construction is similar to that of D-MOSFET. The E-MOSFET has no channel between source and drain unlike the D-MOSFET. Note that the substrate extends completely to the SiO2 layer so that no channel exists. The E-MOSFET requires a proper gate voltage to form a channel (called induced channel). It is reminded that E-MOSFET can be operated only in enhancement mode. In short, the construction of E-MOSFET is quite similar to that of the D-MOSFET except for the absence of a channel between the drain and source terminals.

Symbols for D-MOSFET

There are two types of D-MOSFETs viz(i) n-channel D-MOSFET and (ii) p-channel D-MOSFET.

(i) n-channel D-MOSFET. Fig. 33 (i) shows the various parts of n-channel D-MOSFET.

The p-type substrate constricts the channel between the source and drain so that only a small passage

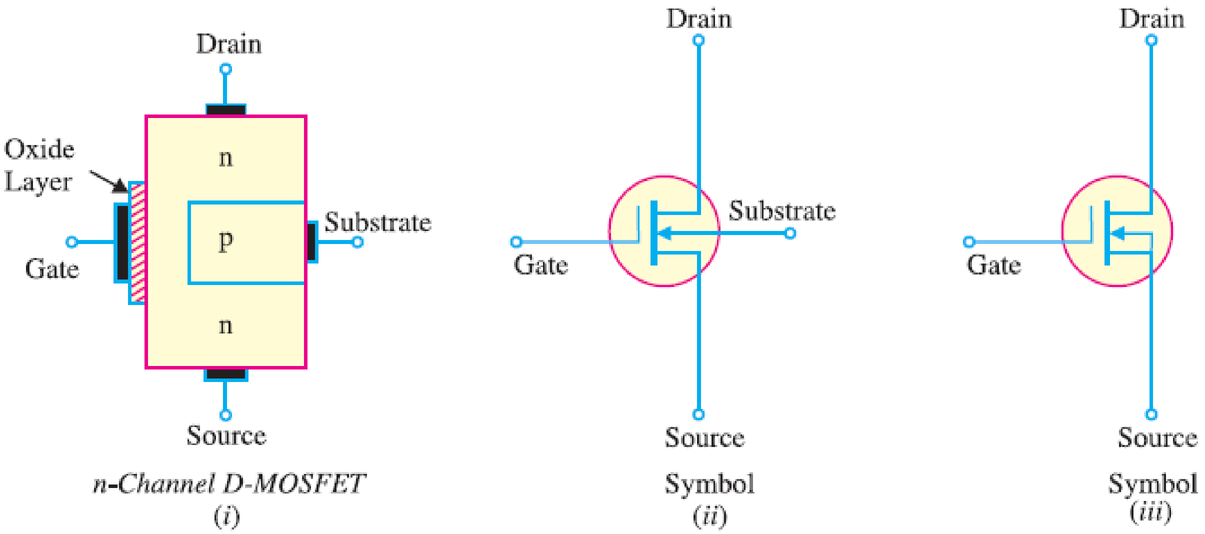
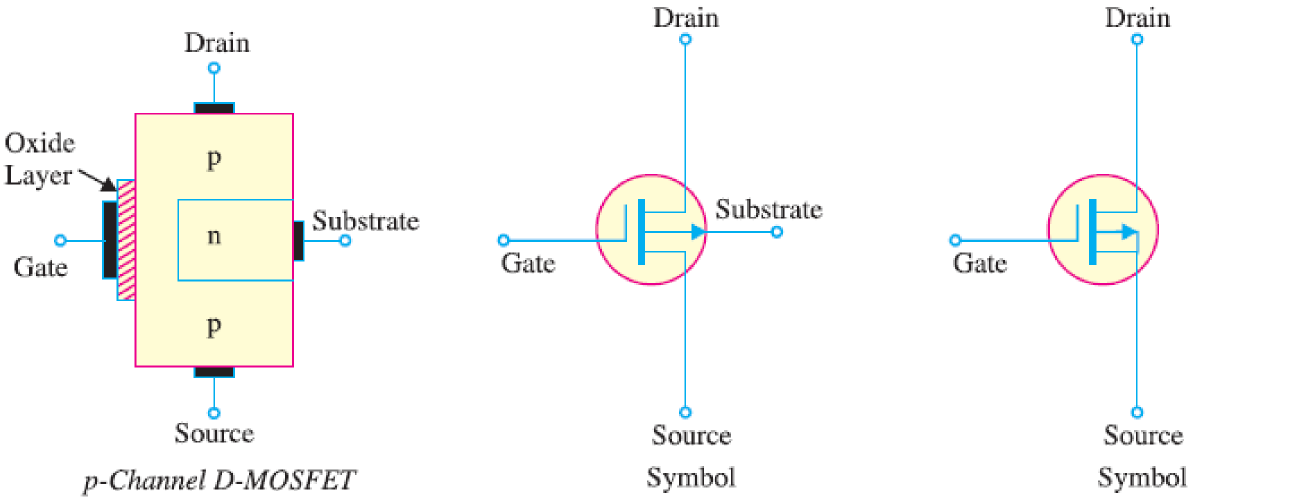


Figure 31

through this narrow channel. The symbol for n-channel D-MOSFET is shown in Fig. 33 (ii). The gate appears like a capacitor plate. Just to the right of the gate is a thick vertical line representing the channel. The drain lead comes out of the top of the channel and the source lead connects to the bottom. The arrow is on the substrate and points to the n-material, therefore we have n-channel DMOSFET.

It is a usual practice to connect the substrate to source internally as shown in Fig. 19.45 (iii). This gives rise to a three-terminal device.

(ii) p-channel D-MOSFET. Fig. 33 (i) shows the various parts of p-channel D-MOSFET. The n-type substrate constricts the channel between the source and drain so that only a small passage remains at the left side. The conduction takes place by the flow of holes from source to drain through this narrow channel. The symbol for p-channel D-MOSFET is shown in Fig. 19.46 (ii). It is a usual practice to connect the substrate to source internally. This results in a three-terminal device whose schematic symbol is shown in Fig. 33 (iii).



p-Channel D-MOSFET
(*i*)
Symbol
(*ii*)
Symbol
(*iii*)

Figure 32

E-MOSFET

Two things are worth noting about E-MOSFET. First, E-MOSFET operates only in the enhancement mode and has no depletion mode. Secondly, the E-MOSFET has no physical channel from source to drain because the substrate extends completely to the SiO2 layer [See Fig. 34 (i)]. It is only by the application of VGS (gate-to-source voltage) of proper magnitude and polarity that the device starts conducting. The minimum value of VGS of proper polarity that turns on the E-MOSFET is called Threshold voltage [VGS (th)]. The n-channel device requires positive VGS (ú VGS (th)) and the p-channel device requires negative VGS (ú VGS (th)).

Operation. Fig. 34 (i) shows the circuit of n-channel E-MOSFET. The circuit action is as under:

(i) When VGS = 0V [See Fig. 34(i)], there is no channel connecting the source and drain. The p substrate has only a few thermally produced free electrons (minority carriers) so that drain current is essentially zero. For this reason, E-MOSFET is normally OFF when VGS = 0 V. Note that this behaviour of E-MOSFET is quite different from JFET or D-MOSFET.

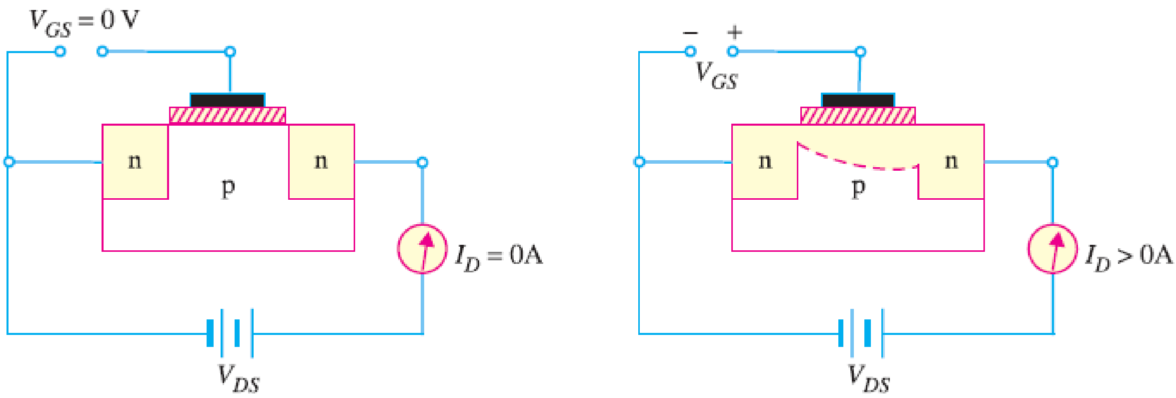


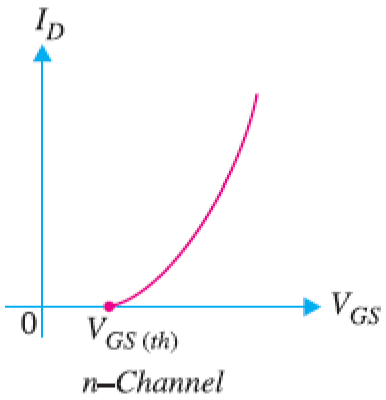
Figure 33

(ii) When gate is made positive (i.e. VGS is positive) as shown in Fig34 (ii), it attracts free electrons into thp region. The free electrons combine with the holes next to the SiO2 layer. If VGS is positive enough, all the holes touching the SiO2 layer are filled and free electrons begin to flow from the source to drain. The effect is the same as creating a thin layer of n-type material (i.e. inducing a thin n-channel) adjacent to the SiO2 layer. Thus the E-MOSFET is turned ON and drain current IDstarts flowing form the source to the drain.

The minimum value of VGS that turns the E-MOSFET ON is called **threshold voltage** [VGS (th)].

(iii) When VGS is less than VGS (th), there is no induced channel and the drain current ID is zero. When VGS is equal to VGS (th), the E-MOSFET is turned ON and the induced channel conducts drain current from the source to the drain. Beyond VGS (th), if the value of VGS is increased, the newly formed channel becomes wider, causing ID to increase. If the value of VGS decreases [not less than VGS (th)], the channel becomes narrower and ID will decrease. This fact is revealed by the transconductancecurve of n-channel E-MOSFET shown in Fig. 35. As you can see, ID = 0 when VGS = 0. Therefore, the value of IDSS for the E-MOSFET is zero. Note also that there is no drain current until VGS reaches

VGS (th).



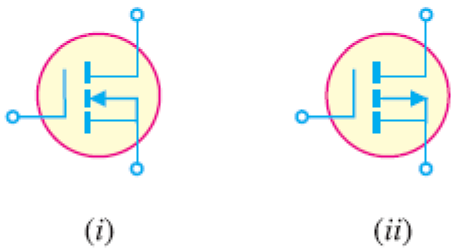


Figure 34

Schematic Symbols. Fig. 35 (i) shows the schematic symbols for n-channel E-MOSFET whereas Fig. 35 (ii) shows the schematic symbol for p-channel E-MOSFET. When VGS = 0, the EMOSFET is OFF because there is no conducting channel between source and drain. The brokenchannel line in the symbols indicates the normally OFF condition.

Equation for Transconductance Curve. Fig. 36 shows the transconductance curve for nchannel E-MOSFET. Note that this curve is different from the transconductance curve for n-channel JFET or n-channel D-MOSFET. It is because it starts at VGS (th) rather than VGS (off) on the horizontal axis and never intersects the vertical axis. The equation for the E-MOSFET transconductance curve (for VGS >VGS (th)) is

$ID = K (VGS - VGS\ (th))^2$

The constant K depends on the particular E-MOSFET and its value is determined from the following equation :

$$K = \frac{I_{D\,(on)}}{(V_{GS\,(on)} - V_{GS\,(th)})^2}$$

Figure 35

3 UJT

Unijunction Transistor (UJT)

A unijunction transistor (abbreviated as UJT) is a three-terminal semiconductor switching device. This device has a unique characteristic that when it is triggered, the emitter current increases regeneratively until it is limited by emitter power supply. Due to this characteristic, the unijunction transistor can be employed in a variety of applications e.g., switching, pulse generator, saw-tooth generator etc.

Construction

Fig. 37 (i) shows the basic *structure of a unijunction transistor. It consists of an n-type silicon bar with an electrical connection on each end. The leads to these connections are called base leads base-one B1 and base two B2. Part way along the bar between the two bases, nearer to B2 than B1, a pnjunction is formed between a p-type emitter and the bar.

* Note that structure of UJT is very much similar to that of the n-channel JFET. The only difference in the two components is that p-type (gate) material of the JFET surrounds the n-type (channel) material.

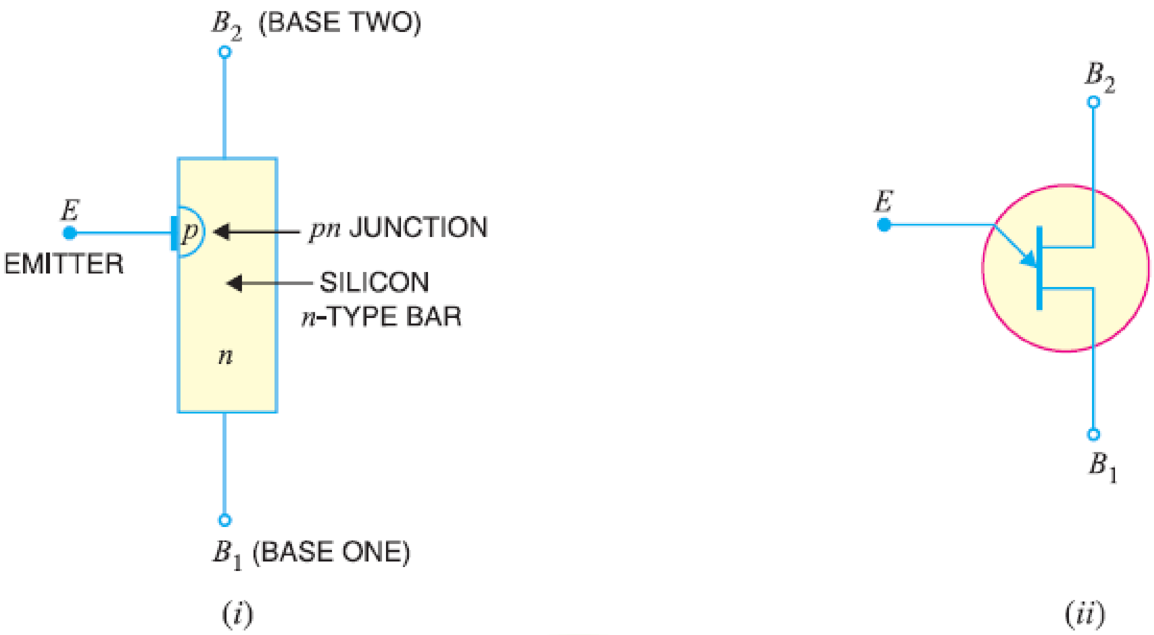


Figure 36

The lead to this junction is called the emitter lead E. Fig. 37 (ii) shows the symbol of unijunction transistor. Note that emitter is shown closer to B2 than B1. The following points are worth noting :

(i) Since the device has one pnjunction and three leads, it is *commonly called a unijunction transistor (unimeans single).

(ii) With only one pn-junction, the device is really a form of diode. Because the two base terminals are taken from one section of the diode, this device is also called double-based diode.

(iii) The emitter is heavily doped having many holes. The n region, however, is lightly doped. For this reason, the resistance between the base terminals is very high (5 to 10 k) when emitter lead is open.

Operation Fig38 shows the basic circuit operation of a unijunction transistor. The device has normally B2 positive w.r.t. B1.

(i) If voltage VBB is applied between B2 and B1 with emitter open [See Fig. 38 (i)], a voltage gradient is established along the n-type bar. Since the emitter is located nearer to B2, more than **half of VBB appears between the emitter and B1. The voltage V1 between emitter and B1 establishes a reverse bias on the pnjunction and the emitter current is cut off. Of course, a small leakage current flows from B2 to emitter due to minority carriers.

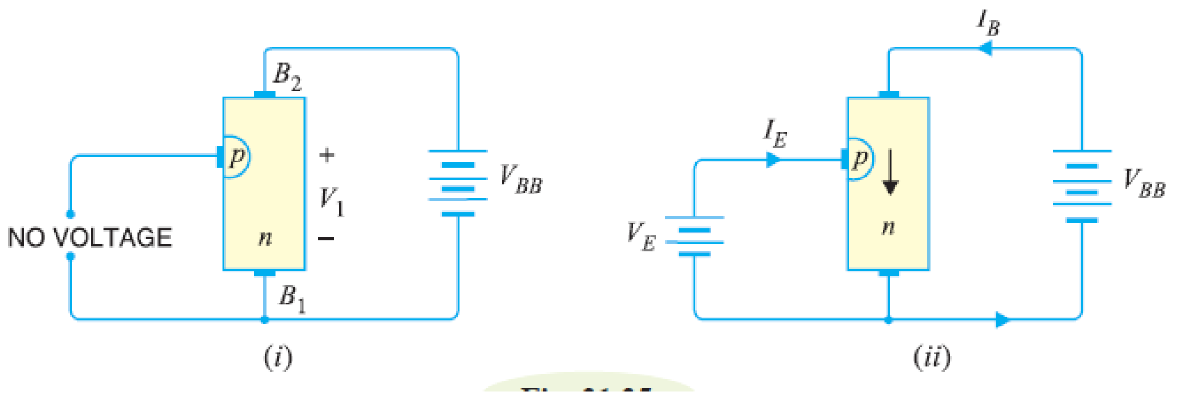


Figure 37

(ii) If a positive voltage is applied at the emitter [See Fig. 38 (ii)], the pnjunction will remain reverse biased so long as the input voltage is less than V1. If the input voltage to the emitter exceeds V1, the pnjunction becomes *forward biased. Under these conditions, holes are injected from p-type material into the n-type bar. These holes are repelled by positive B2 terminal and they are attracted towards B1 terminal of the bar. This accumulation of holes in the emitter to B1 region results in the decrease of resistance in this section of the bar. The result is that internal voltage drop from emitter to B1 is decreased and hence the emitter current IE increases. As more holes are injected, a condition of saturation will eventually be reached. At this point, the emitter current is limited by emitter power supply only. The device is now in the ON state.

(iii) If a negative pulse is applied to the emitter, the pnjunction is reverse biased and the emitter current is cut off. The device is then said to be in the OFF state.

* In packaged form, a UJT looks very much like a small signal transistor. As a UJT has only one pnjunction, therefore, naming it a 'transistor' is really a misnomer.

** The n-type silicon bar has a high resistance. The resistance between emitter and B1 is greater than between B2 and emitter. It is because emitter is nearer to B2 than B1.

Equivalent Circuit of a UJT

Fig. 39 shows the equivalent circuit of a UJT. The resistance of the silicon bar is called the interbaseresistance RBB. The inter-base resistance is represented by two resistors in series viz.

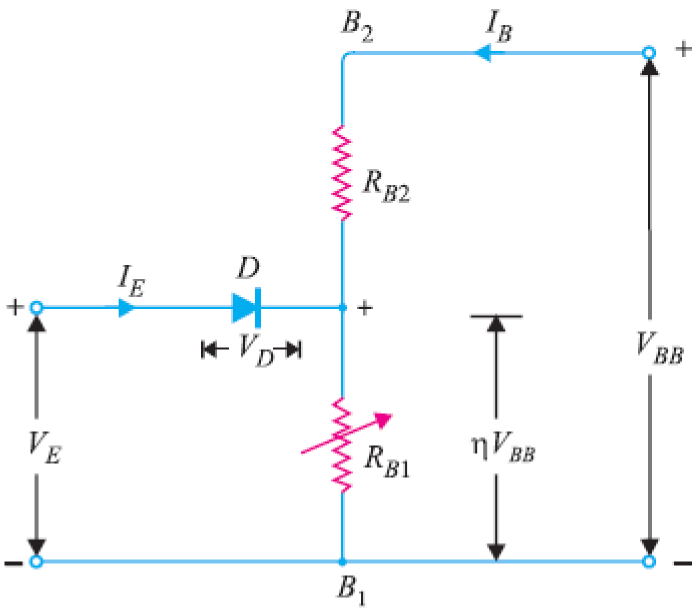


Figure 38

(a) RB2 is the resistance of silicon bar between B2 and the point at which the emitter junction lies.

(b) RB1 is the resistance of the bar between B1 and emitter junction. This resistance is shown variable because its value depends upon the bias voltage across the pnjunction. The pnjunction is represented in the emitter by a diode D. The circuit action of a UJT can be explained more clearly from its equivalent circuit.

(i) With no voltage applied to the UJT, the inter-base resistance is given by ;

$$R_{BB} = R_{B1} + R_{B2}$$

The value of RBB generally lies between 4 kand 10 k.

(ii) If a voltage VBB is applied between the bases with emitter open, the voltage will divide up across RB1 and RB2.

Voltage across R_{B1}, $V_1 = \frac{R_{B1}}{R_{B1} + R_{B2}} V_{BB}$

or $$V_1/V_{BB} = \frac{R_{B1}}{R_{B1} + R_{B2}}$$

The ratio V1/VBB is called intrinsic stand-off ratio and is represented by Greek letter .

Obviously, $\eta = \frac{R_{B1}}{R_{B1} + R_{B2}}$

The value of η usually lies between 0.51 and 0.82.

∴ Voltage across $R_{B1} = \eta V_{BB}$

The voltage ηV_{BB} appearing across R_{B1} reverse biases the diode. Therefore, the emitter current is zero.

(iii) If now a progressively rising positive voltage is applied to the emitter, the diode will become forward biased when input voltage exceeds ηV_{BB} by V_D, the forward voltage drop across the silicon diode *i.e.*

$$V_P = \eta V_{BB} + V_D$$

where V_P = 'peak point voltage'

V_D = forward voltage drop across silicon diode ($\simeq 0.7$ V)

When the diode D starts conducting, holes are injected from p-type material to the n-type bar. These holes are swept down towards the terminal B1. This decreases the resistance between emitter and B1 (indicated by variable resistance symbol for RB1) and hence the internal drop from emitter to B1. The emitter current now increases regenerative until it is limited by the emitter power supply.

Conclusion

The above discussion leads to the conclusion that when input positive voltage to the emitter is less than peak-point voltage VP, the pn-junction remains reverse biased and the emitter current is practically zero. However, when the input voltage exceeds VP, RB1 falls from several thousand ohms to a small value. The diode is now forward biased and the emitter current quickly reaches to a saturation value limited by RB1 (about 20 ohm) and forward resistance of pn-junction (about 200ohm).

Characteristics of UJT

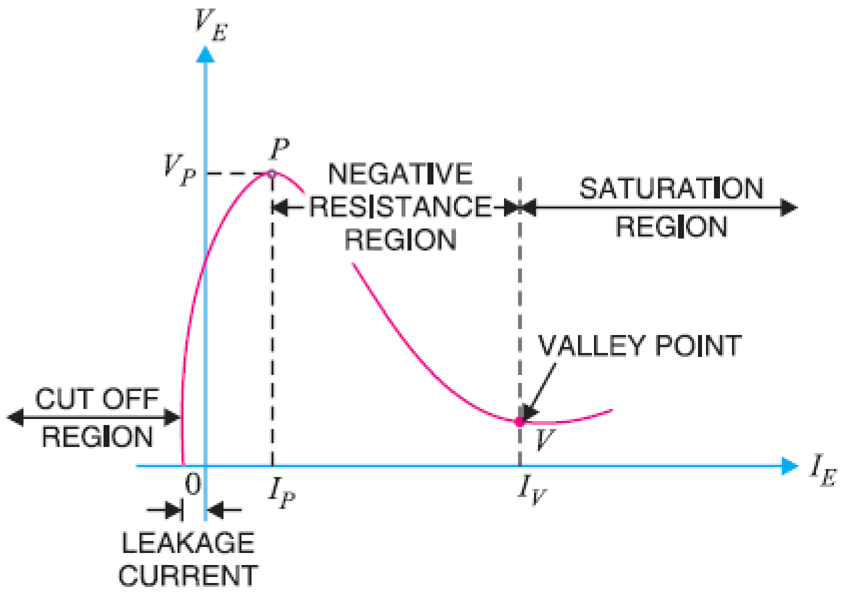


Figure 39

Fig. 40 shows the curve between emitter voltage (VE) and emitter current (IE) of a UJT at agiven voltage VBB between the bases. This is known as the emitter characteristic of UJT. The following points may be noted from the characteristics:

(i) Initially, in the cut-off region, as VE increases from zero, slight leakage current flows from terminal B2 to the emitter. This current is due to the minority carriers in the reverse biased diode.

(ii) Above a certain value of VE, forward IE begins to flow, increasing until the peak voltage VP and current

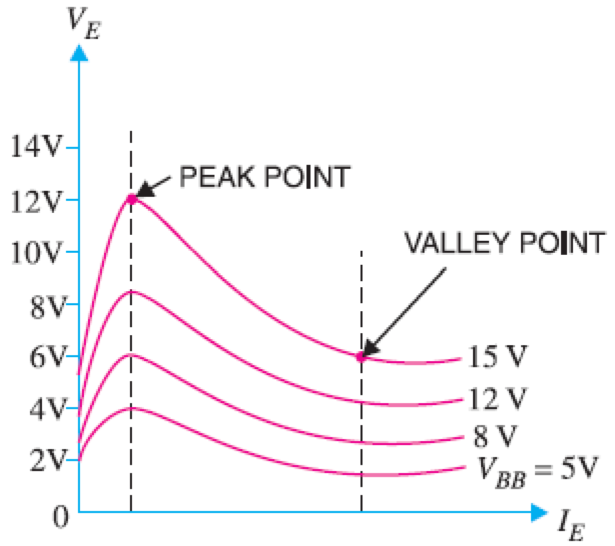
IP are reached at point P.

(iii) After the peak point P, an attempt to increase VE is followed by a sudden increase in emitter current IE with a corresponding decrease in VE.This is a negative resistance portion of the curve because with increase in IE, VE decreases. The device, therefore, has a negative resistance region which is stable enough to be used with a great deal of reliability in many areas e.g., trigger circuits, sawtoothgenerators, timing circuits .

(iv) The negative portion of the curve lasts until the valley point V is reached with valley-point voltage VV and valley-point current IV. After the valley point, the device is driven to saturation.

Fig. 21.28 shows the typical family of VE / IE characteristics of a UJT at different voltages betweenthe bases. It is clear that peak-point voltage (= ηVBB+ VD) falls steadily with reducing VBB and sodoes the valley point voltage VV. The difference VP

−VV is a measure of the switching efficiency of UJT and can be seen to fall off as VBB decreases. For ageneral purpose UJT, the peak - point current is ofthe order of 1 μA at VBB = 20 V with a valley-pointvoltage of about 2.5 V at 6 mA.



Example1: The intrinsic stand-off ratio for a UJT is determined to be 0.6. If the inter-base resistance is 10 k, what are the values of RB1 and RB2 ?

Solution. $R_{BB} = 10\ k\Omega,\quad \eta = 0.6$

Now $R_{BB} = R_{B1} + R_{B2}$

or $10 = R_{B1} + R_{B2}$

Also $\eta = \dfrac{R_{B1}}{R_{B1} + R_{B2}}$

or $0.6 = \dfrac{R_{B1}}{10} \qquad (\because R_{B1} + R_{B2} = 10\ k\Omega)$

$\therefore \quad R_{B1} = 10 \times 0.6 = \mathbf{6\ k\Omega}$

and $R_{B2} = 10 - 6 = \mathbf{4\ k\Omega}$

Example2: A unijunction transistor has 10 V between the bases. If the intrinsic stand off ratio is 0.65, find the value of stand off voltage. What will be the peak-point voltage if the forward voltage drop in the pnjunction is 0.7 V ?

Solution. $V_{BB} = 10\ V;\quad \eta = 0.65;\quad V_D = 0.7\ V$

Stand off voltage $= \eta V_{BB} = 0.65 \times 10 = \mathbf{6.5\ V}$

Peak-point voltage, $V_P = \eta V_{BB} + V_D = 6.5 + 0.7 = \mathbf{7.2\ V}$

Applications of UJT

Unijunction transistors are used extensively in oscillator, pulse and voltage sensing circuits. Some of the important applications of UJT are discussed below :

(i) UJT relaxation oscillator. Fig. 41 shows UJT relaxation oscillator where the discharging of a capacitor through UJT can develop a saw-tooth output as shown. When battery VBB is turned on, the capacitor C charges through resistor R1. During the charging period, the voltage across the capacitor rises in an exponential manner until it reaches the peak – point voltage. At this instant of time, the UJT switches to its low resistance conducting mode and the capacitor is discharged between E and B1. As the capacitor voltageflys back to zero, the emitter ceases to conduct and the UJT is switched off. The next cycle then begins, allowing the capacitor Cto charge again. The frequency of the output saw-tooth wave can be varied by changing the value of R1 since this controls the time constant R1C of the capacitor charging circuit.

The time period and hence the frequency of the saw-tooth wave can be calculated as follows. Assuming that the capacitor is initially uncharged, the voltage VC across the capacitor prior to breakdown is given by :

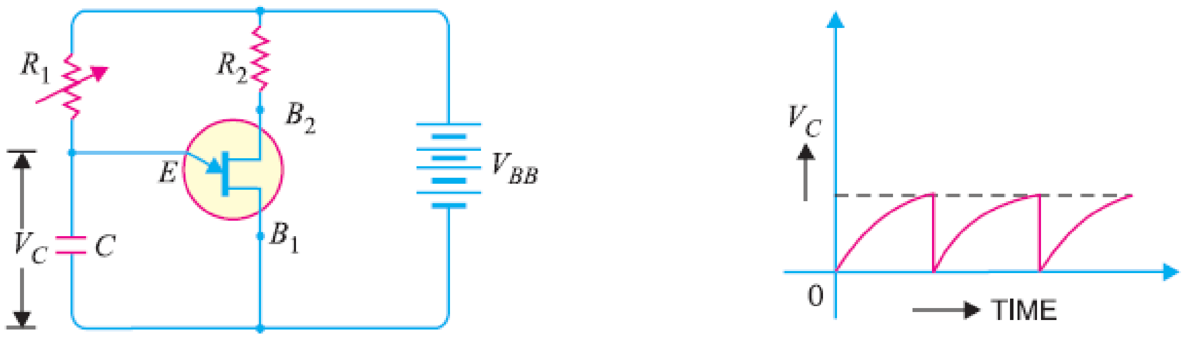


Figure 40

(ii) Overvoltage detector. Fig. 42 shows a simple d.c. over-voltage indicator. A warning pilot - lamp L is connected between the emitter and B1 circuit. So long as the input voltage is less than the peak-point voltage (VP) of the UJT, the device remains switched off. However, when the input voltage exceeds VP, the UJT is switched on and the capacitor discharges through the low resistance path between terminals E and B1. The current flowing in the pilot lamp L lights it, thereby indicating the overvoltage in the circuit.

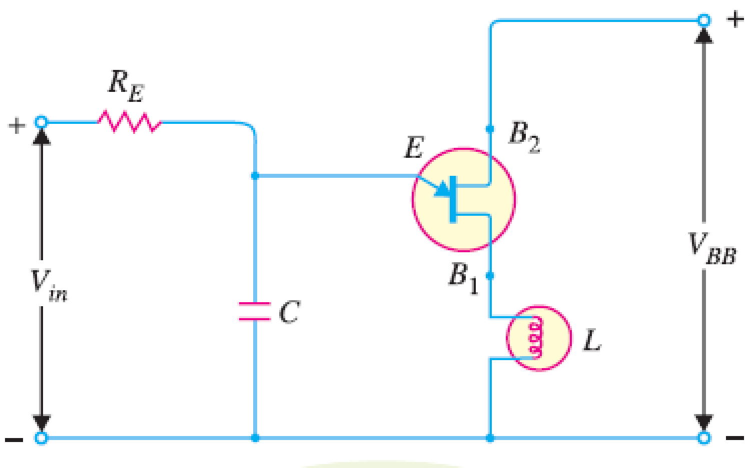
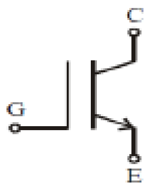


Figure 41

INSULATED GATE BIPOLAR TRANSISTOR (IGBT)

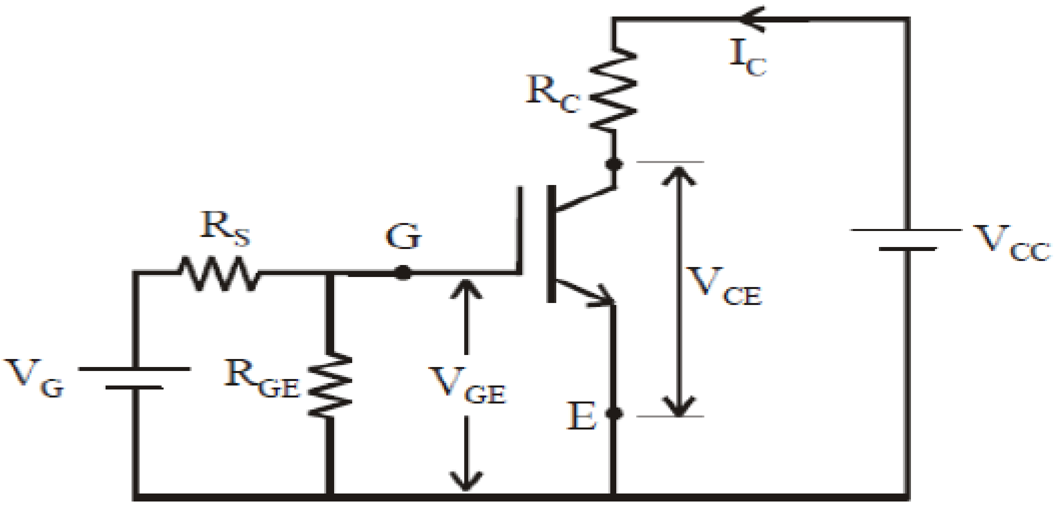
IGBT is a voltage controlled device. It has high input impedance like a MOSFET and low on-state conduction losses like a BJT.



Symbol

IGBT has three terminals gate (G), collector (C) and emitter (E). With collector and gate voltage positive with respect to emitter the device is in forward blocking mode.When gate to emitter voltage becomes greater than the threshold voltage of IGBT.

a. CHARACTERISTIC OF IGBT



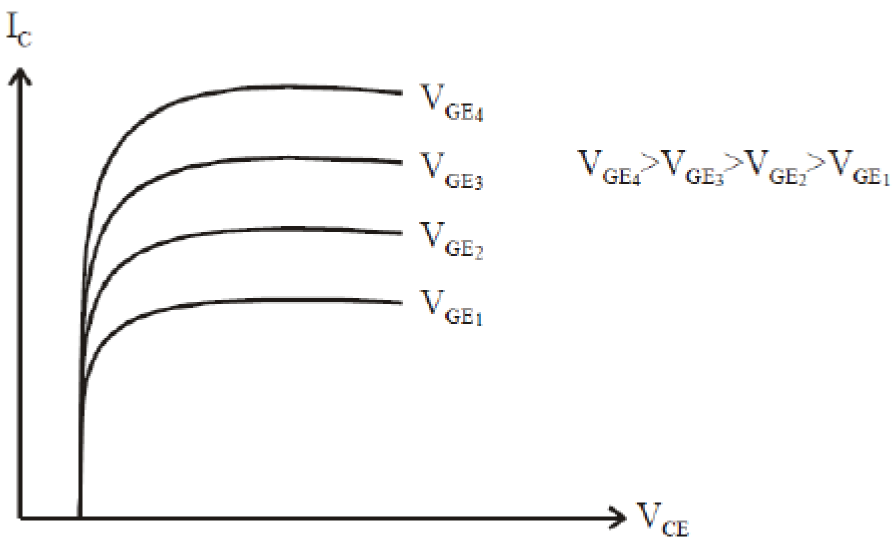


Fig.: Output Characteristics

A plot of collector current I_C versus gate-emitter voltage V_{GE} for a given value of V_{CE} gives the transfer characteristic. Figure below shows the transfer characteristic.

Controlling parameter is the gate-emitter voltage V_{GE} in IGBT. If V_{GE} is less than the threshold voltage V_T then IGBT is in OFF state. If V_{GE} is greater than the threshold voltage V_T then the IGBT is in ON state.

IGBTs are used in medium power applications such as ac and dc motor drives, power supplies and solid state relays.

b. **Comparison between Power BJT AND Power IGBT**

IGBTs are voltage controlled power transistor. They are faster than BJTs, but still not quite as fast as MOSFETs. The IGBTs offer for superior drive and output characteristics when compared to BJT's. IGBTs are suitable for high voltage, high current and frequencies upto 20KHz. IGBTs are available upto 1400V, 600A and 1200V, 1000A.

d. IGBT (INSULATED GATE BIPOLAR TRANSISTORS) FEATURES

IGBT combines the advantages of BJT's and MOSFET's. Features of IGBT are

• IGBT has high input impedance like MOSFET's.

• Low ON state conduction power losses like BJT's.

• There is no secondary breakdown problem like BJT's.

• By chip design and structure design, the equivalent drain to source resistance *DSR* is controlled to behave like that of BJT.

e. IGBT APPLICATIONS

Medium power applications like DC and AC motor drives, medium power supplies, solid state relays and contactors, general purpose inverters, UPS, welder equipment, servo controls, robotics, cutting tools, induction heating

Topic3: Identification of different types of thyristors;

- Diac

The Diacis a two-terminal, three layer bidirectional device which can be switched from its OFFstate to ON state for either polarity of applied voltage.

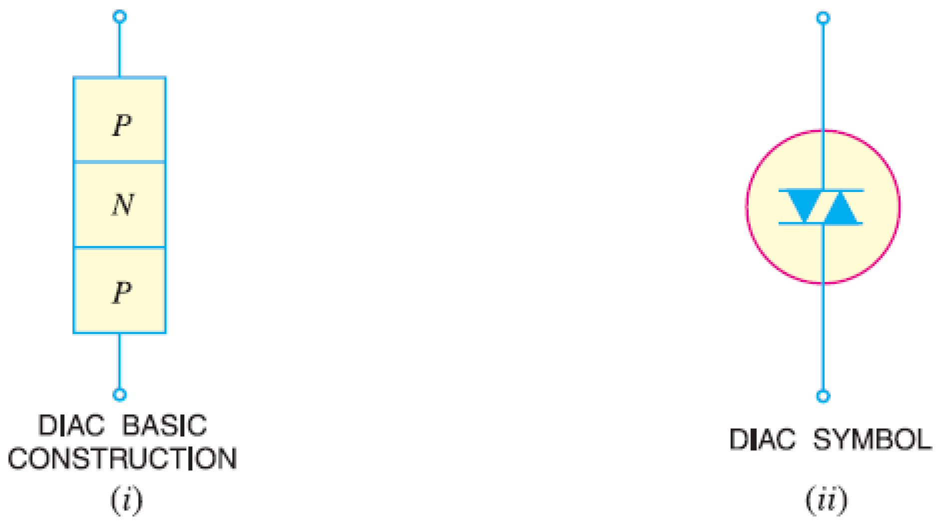


Figure 42

The diac can be constructed in either npnor pnpform. Fig. 43 (i) shows the basic structure of a diac in pnpform. The two leads are connected to p-regions of silicon separated by an n-region. The structure of diac is very much similar to that of a transistor. However, there are several important differences:

(i) There is no terminal attached to the base layer.

(ii) The three regions are nearly identical in size.

(iii) The doping concentrations are identical (unlike a bipolar transistor) to give the device symmetrical properties.

Fig. 43 (ii) shows the symbol of a diac. small leakage current IBO will flow through the device. As the applied voltage is increased, the leakage current will continue to flow until the voltage reaches the breakover voltage VBO. At this point, avalanche breakdown of the reverse-biased junction occurs and the device exhibits negative resistance i.e. current through the device increases with the decreasing values of applied voltage. The voltage across the device then drops to 'breakback' voltage VW.

Fig. 44 shows the V-I characteristics of a diac. For applied positive voltage less than + VBO and negative voltage less than −VBO, a small leakage current (± IBO) flows through the device. Undersuch conditions, the diac blocks the flow of current and effectively behaves as an open circuit. Thevoltages + VBO and −VBO are the breakdown voltages and usually have a range of 30 to 50 volts.

When the positive or negative applied voltage is equal to or greater than the breakdown voltage, diac begins to conduct and the voltage drop across it becomes a few volts. Conduction then continues until the device current drops below its holding current. Note that the breakover voltage and holding current values are identical for the forward and reverse regions of operation.

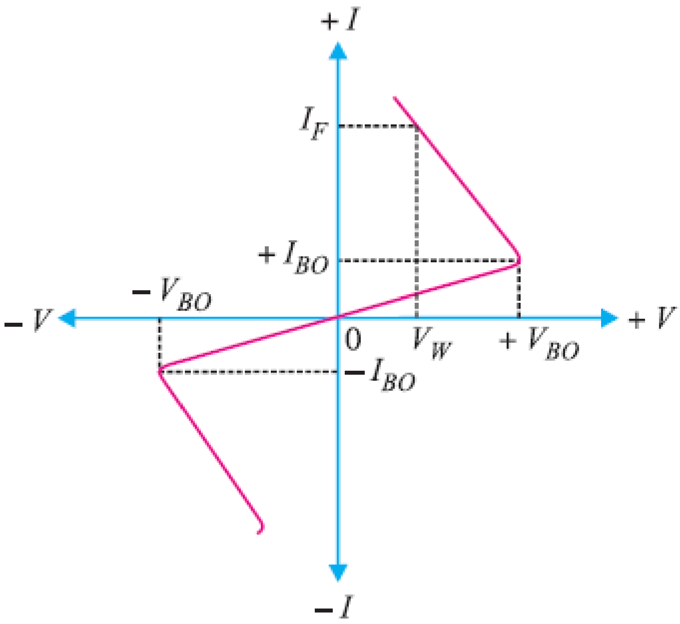


Figure 43

Diacs are used primarily for triggering of triacs in adjustable phase control of a.c. mains power. Some of the circuit applications of diac are (i) light dimming (ii) heat control and (iii) universal motor speed control.

Applications of Diac

Although a triac may be fired into the conducting state by a simple resistive triggering circuit, more reliable and faster turn-on may be had if a switching device is used in series with the gate. One of the switching devices that can trigger a triac is the diac. This is illustrated in the following applications.

(i) Lamp dimmer. Fig. 45 shows a typical circuit that may be used for smooth control of a.c. power fed to a lamp. This permits to control the light output from the lamp. The basic control is by an RC variable gate voltage arrangement. The series R4 – C1 circuit across the triac is designed to limit the rate of voltage rise across the device during switch off.

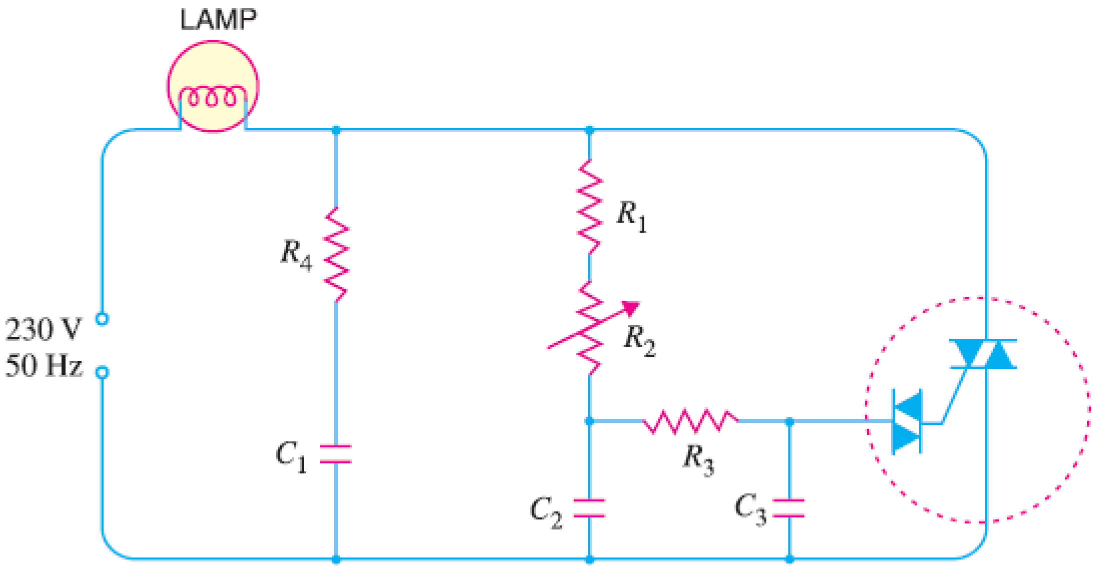
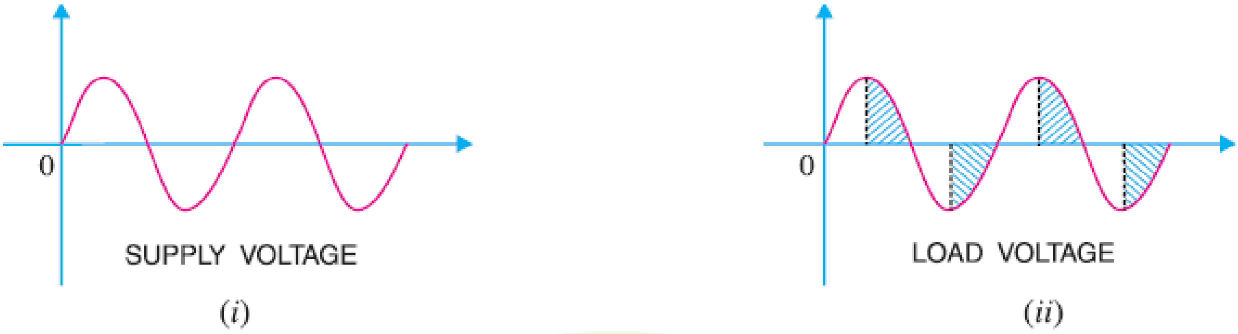


Figure 44

The circuit action is as follows: As the input voltage increases positively or negatively, C1 andC2 charge at a rate determined primarily by R2. When the voltage across C3 exceeds the breakovervoltage of the diac, the diac is fired into the conducting state. The capacitor C3 discharges through the conducting diac into the gate of the triac. Hence, the triac is turned on to pass the a.c. power to the will trigger on the positive or negative half-cycle of input voltage can be controlled. Fig. 21.20 shows the waveforms of supply voltage and load voltage in the diac-triac control circuit



The firing of triac can be controlled upto a maximum of 180°. In this way, we can provide a continuous control of load voltage from practically zero to full r.m.s. value.

(ii) Heat control. Fig. 46 shows a typical diac-triac circuit that may be used for the smooth control of a.c. power in a heater. This is similar to the circuit shown in Fig. 45. The capacitor C1 in series with choke L across the triac helps to slow-up the voltage rise across the device during switch-off. The resistor R4 in parallel with the diac ensures smooth control at all positions of variable resistance R2. The circuit action is as follows : As the input voltage increases positively or negatively, C1 and C2 charge at a rate determined primarily by R2. When the voltage across C3 exceeds the breakovervoltage of the diac, the diac conducts. The capacitor C3 discharges through the conducting diac into the gate of the triac. This turns on the triac and hence a.c. power to the heater. By adjusting the value of R2, any portion of positive and negative half-cycles of the supply voltage can be passed through the heater. This permits a smooth control of the heat output from the heater.

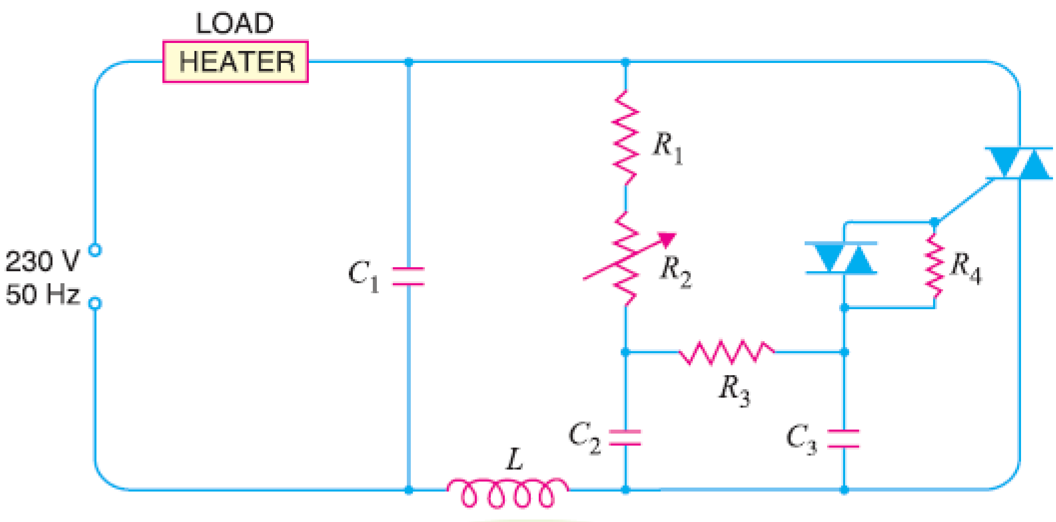


Figure 45

Example: In Fig. 47, the switch is closed. A diac with breakover voltage VBO = 30V isconnected in the circuit. If the triac has a trigger voltage of 1V and a trigger current of 10 mA, what is the capacitor voltage that triggers the triac ?

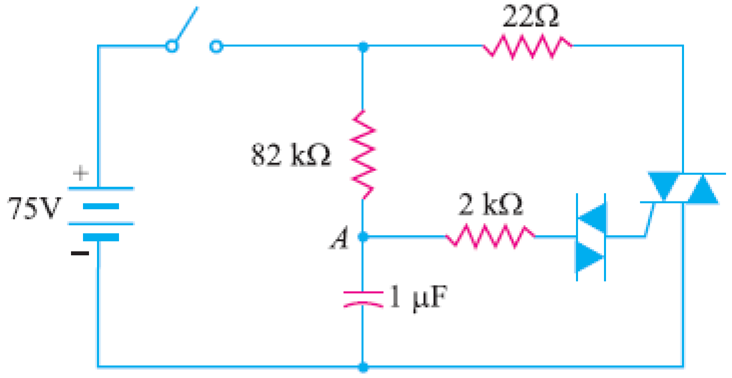


Figure 46

Solution. When switch is closed, the capacitor starts charging and voltage at point *A* increases. When voltage V_A at point *A* becomes equal to V_{BO} of diac plus gate triggering voltage V_{GT} of the triac, the triac is fired into conduction.

$$\therefore \quad V_A = V_{BO} + V_{GT} = 30\text{V} + 1\text{V} = \mathbf{31V}$$

This is the minimum capacitor voltage that will trigger the triac.

Triac

The major drawback of an SCR is that it can conduct current in one direction only. Therefore, an SCRcan only control d.c. power or forward biased half-cycles of a.c. in a load. However, in an a.c.system, it is often desirable and necessary to exercise control over both positive and negative halfcycles.For this purpose, a semiconductor device called triacis used.

A **triac**is a three-terminal semiconductor switching device which can control alternating current in a load. Triac is an abbreviation for triode a.c. switch. 'Tri'– indicates that the device has three terminalsand 'ac' means that the device controls alternating current or can conduct current in either direction.

The key function of a triac may be understood by referring to the simplified Fig. 21.1. The **control circuit of triac can be adjusted to pass the desired portions of positive and negative halfcycleof a.c. supply through the load RL. Thus referring to Fig. 48 (ii), the triac passes the positive half-cycle of the supply from 1 to 180° i.e. the shaded portion of positive half-cycle. Similarly, the shaded portion of negative half-cycle will pass through the load. In this way, the alternating current and hence a.c. power flowing through the load can be controlled.

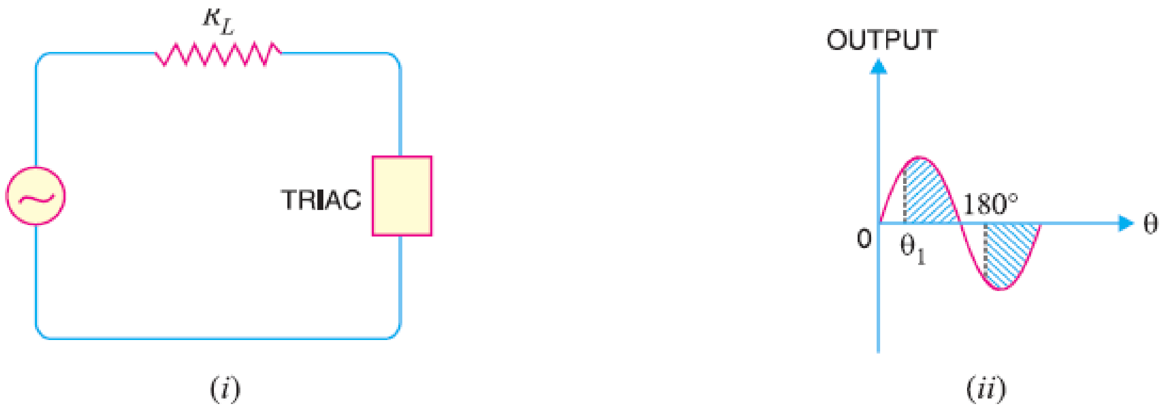


Figure 47

half-cycle of the supply from θ_1 to 180° i.e. the shaded portion of positive half-cycle. Similarly, the shaded portion of negative half-cycle will pass through the load. In this way, the alternating current and hence a.c. power flowing through the load can be controlled.

Since a triac can control conduction of both positive and negative half-cycles of a.c. supply, it is sometimes called a bidirectional semi-conductor triode switch. The above action of a triac is certainly not a rectifying action (as in an *SCR) so that the triac makes no mention of rectification in its name.

Triac Construction

A **triac**is a three-terminal, five-layer semiconductor device whose forward and reverse characteristics are indentical to the forward characteristics of the SCR. The three terminals are designated as main terminal MT1, main terminal MT2 and gate G.

Fig. 49 (i) shows the basic structure of a triac. As we shall see, a triac is equivalent to two separate SCRs connected in inverse parallel (i.e. anode of each connected to the cathode of the other) with gates commoned as shown in Fig. 49 (ii). Therefore, a triac acts like a bidirectional switch i.e. it can conduct current in either direction. This is unlike an SCR which can conduct current only in one direction. Fig. 49(iii) shows the schematic symbol of a triac. The symbol consists of two parallel diodes connected in opposite directions with a single gate lead. It can be seen that even the symbol of triac indicates that it can conduct current for either polarity of the main terminals (MT1 and MT2) i.e.it can act as a bidirectional switch. The gate provides control over conduction in either direction.

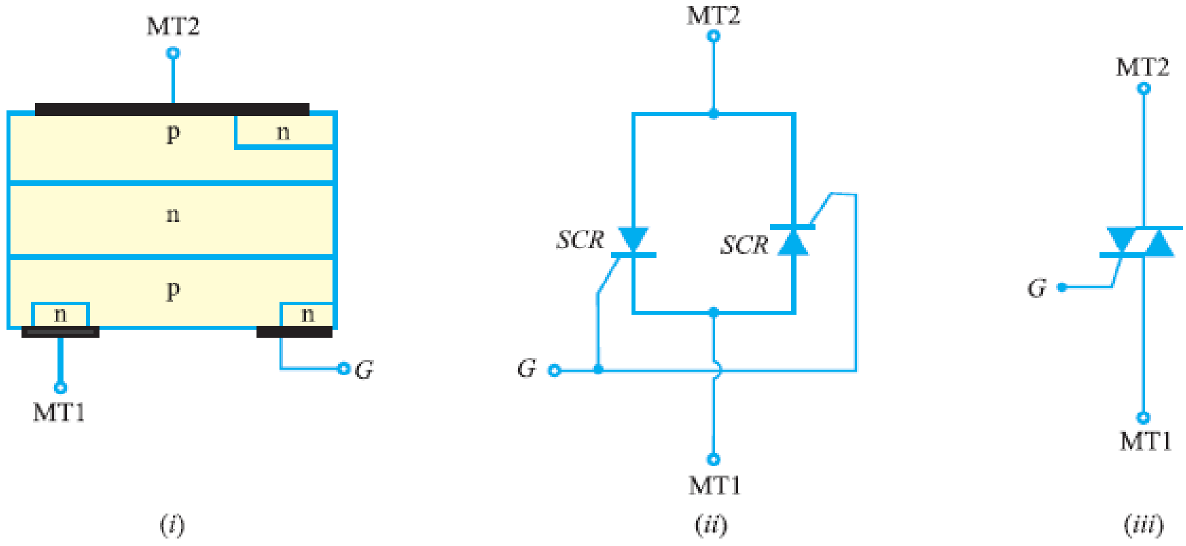


Figure 48

The following points many be noted about the triac:

(i) The triac can conduct current (of course with proper gate current) regardless of the polarities of the main terminals MT1 and MT2. Since there is no longer a specific anode or cathode, the main leads are referred to as MT1 and MT2.

(ii) A triac can be turned on either with a positive or negative voltage at the gate of the device.

(iii) Like the SCR, once the triac is fired into conduction, the gate loses all control. The triac can be turned off by reducing the circuit current to the value of holding current.

(iv) The main disadvantage of triacs over SCRs is that triacs have considerably lower current handling capabilities. Most triacs are available in ratings of less than 40A at voltages up to 600V.

SCR Equivalent Circuit of Triac

We shall now see that a triac is equivalent to two separate SCRs connected in inverse parallel (i.e. anode of each connected to the cathode of the other) with gates commoned. Fig. 50 (i) shows thebasic structure of a triac. If we split the basic structure of a triac into two halves as shown in Fig. 50 (ii), it is easy to see that we have two SCRs connected in inverse parallel. The left half in Fig. 50 (ii) consists of a pnpndevice (p1n2 p2n4) having three pnjunctions and constitutes SCR1. Similarly, the right half in Fig. 50 (ii) consists of pnpndevice (p2n3p1n1) having three pnjunctions and constitutes SCR2. The SCR equivalent circuit of the triac is shown in Fig. 21.4.

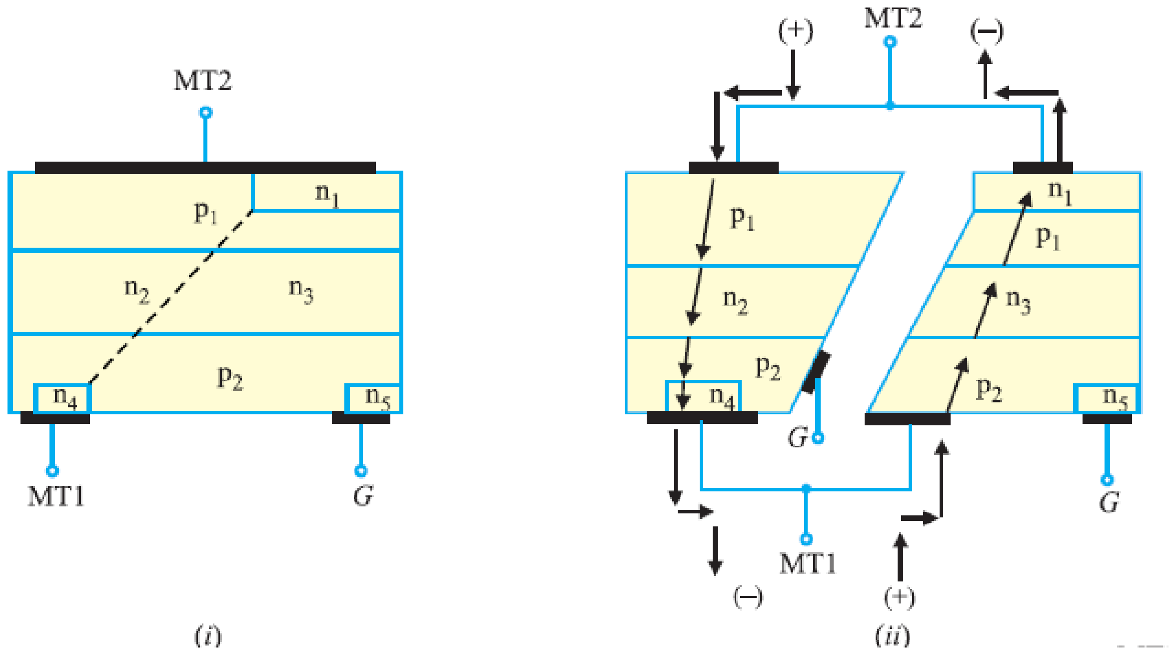


Figure 49

Suppose the main terminal MT2 is positive and main terminal MT1 is negative. If the triac is now fired into conduction by proper gate current, the triac will conduct current following the path (left half) shown in Fig. 51(ii). In relation to Fig. 51, the SCR1 is ON and the SCR2 is OFF. Now suppose that MT2 is negative and MT1 is positive. With proper gate current, the triac will be fired into conduction. The current through the devices follows the path (right half) as shown in Fig. 51 (ii). In relation to Fig. 51, the SCR2 is ON and the SCR1 is OFF. Note that the triac will conduct current in the appropriate direction as long as the current through the device is greater than its holding current.

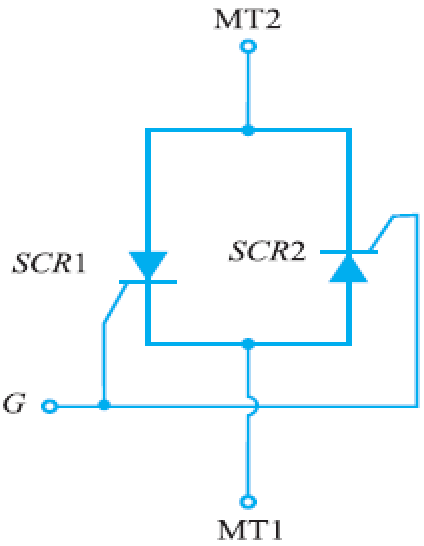


Figure 50

Triac Operation

Fig. 52 shows the simple triac circuit. The a.c. supply to be controlled is connected across the main terminals of triac through a load resistance RL. The gate circuit consists of battery, a current limiting resistor R and a switch S. The circuit action is as follows:

(i) With switch S open, there will be no gate current and the
triac is cut off. Even with no gate current, the triac can be turned on provided the supply voltage becomes equal to the breakover voltage of triac. However, the normal way to turn on a triac is by introducing a proper gate current.

(ii) When switch S is closed, the gate current starts flowing in the gate circuit. In a similar manner to SCR, the breakover voltage of the triac can be varied by making proper gate current to flow. With a few milliamperes introduced at the gate, the triac will start conducting whether terminal MT2 is positive or negative w.r.t. MT1.

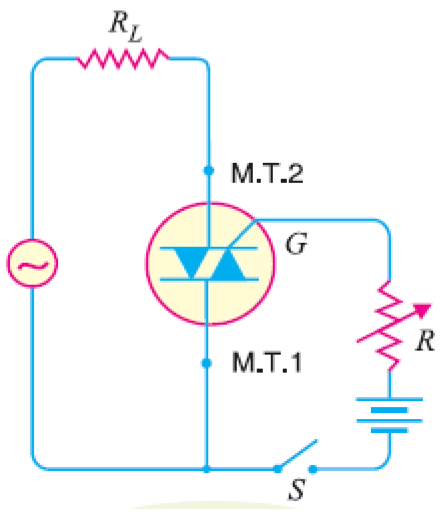


Figure 51

from MT2 to MT1. If the terminal MT2 is negative w.r.t. MT1, the triac is again turned on but this time the conventional current flows from MT1 to MT2. The above action of triac reveals that it can act as an a.c. contactor to switch on or off alternating current to a load. The additional advantage of triac is that by adjusting the gate current to a proper value, any portion of both positive and negative half-cycles of a.c. supply can be made to flow through the load. This permits to adjust the transfer of a.c. power from the source to the load.

Triac Characteristics

Fig. 53 shows the V-I characteristics of a triac. Because the triac essentially consists of two SCRs of opposite orientation fabricated in the same crystal, its operating characteristics in the first and third quadrants are the same except for the direction of applied voltage and current flow. The following points may be noted from the triac characteristics:

(i) The V-I characteristics for triac in the Ist and IIIrd quadrants are essentially identical tothose of an SCR in the Ist quadrant.

(ii) The triac can be operated with either positive or negative gate control voltage but in *normal operation usually the gate voltage is positive in quadrant I and negative in quadrant III.

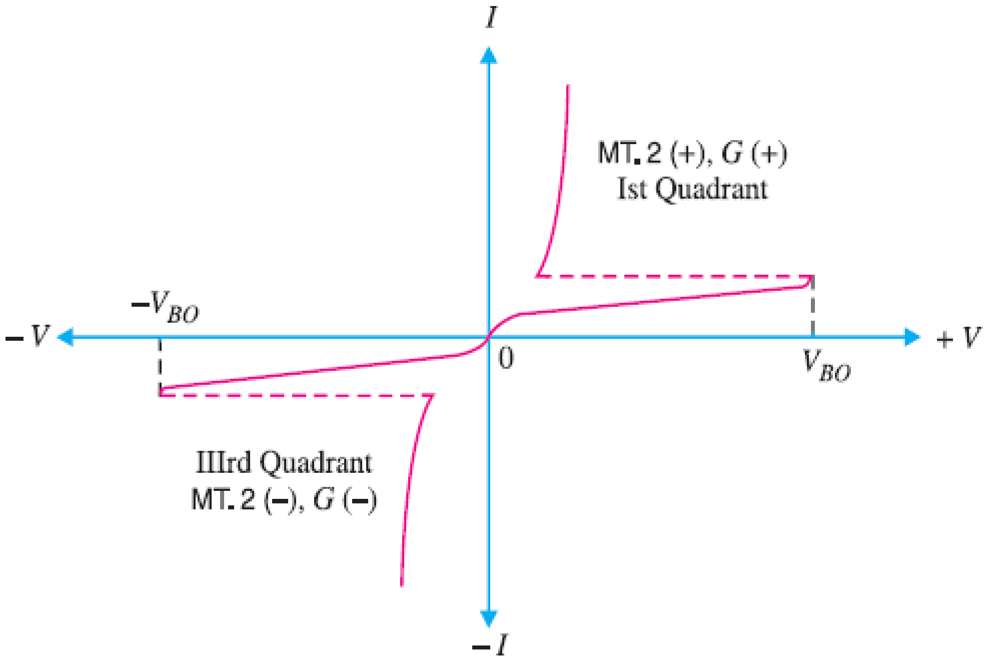


Figure 52

(iii) The supply voltage at which the triac is turned ON depends upon the gate current. The greater the gate current, the smaller the supply voltage at which the triac is turned on. This permits to use a triac to control a.c. power in a load from zero to full power in a smooth and continuous manner with no loss in the controlling device.

Applications of Triac

(i) As a high-power lamp switch. Fig. 54 shows the use of a triac as an a.c. on/off switch.

When switch S is thrown to position 1, the triac is cut off and the output power of lamp is zero. But as the switch is thrown to position 2, a small gate current (a few mA) flowing through the gate turns the triac on. Consequently, the lamp is switched on to give full output of 1000 watts.

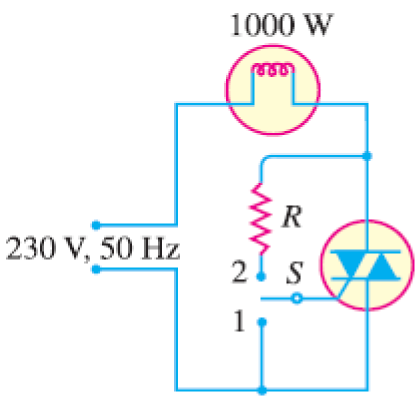
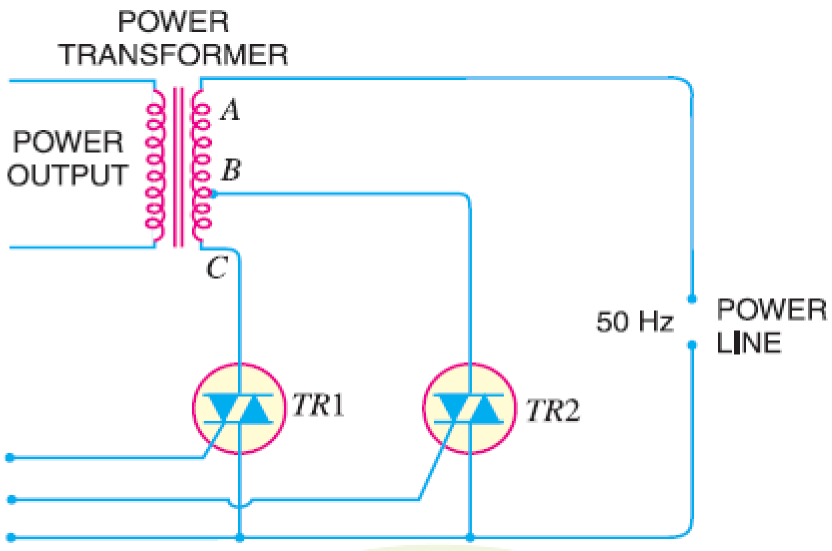


Figure 53

(ii) Electronic change over of transformer taps.

Fig. 21.12 shows the circuit of electronic change over of power transformer input taps. Two triacsTR1 and TR2are used for the purpose. When triacTR1 is turned onand TR2 is turned off, the line input is connected across the full transformer primary AC. However, if it is desired to change the tapping so that input appears across part AB of the primary, then TR2 is turned on and TR1 is turned off. The gate control signals are so controlled that both triacs are never switched on together. This avoids a dangerous short circuit on the section BC of the primary.



Example In Fig. 55, the switch is closed. If the triac has fired, what is the current through 50Ω resistor when (i) triac is ideal (ii) triac has a drop of 1V ?

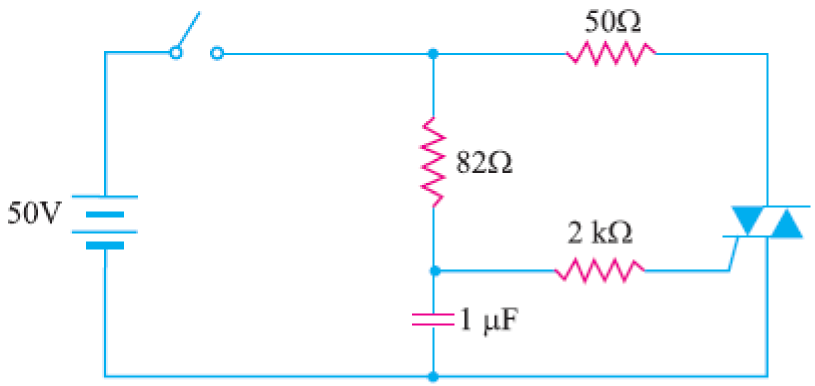


Figure 54

Solution.

(*i*) Since the triac is ideal and it is fired into conduction, the voltage across triac is 0V. Therefore, the entire supply voltage of 50V appears across 50Ω resistor.

$$\therefore \qquad \text{Current in } 50\Omega = \frac{50\text{V}}{50\Omega} = \mathbf{1\ A}$$

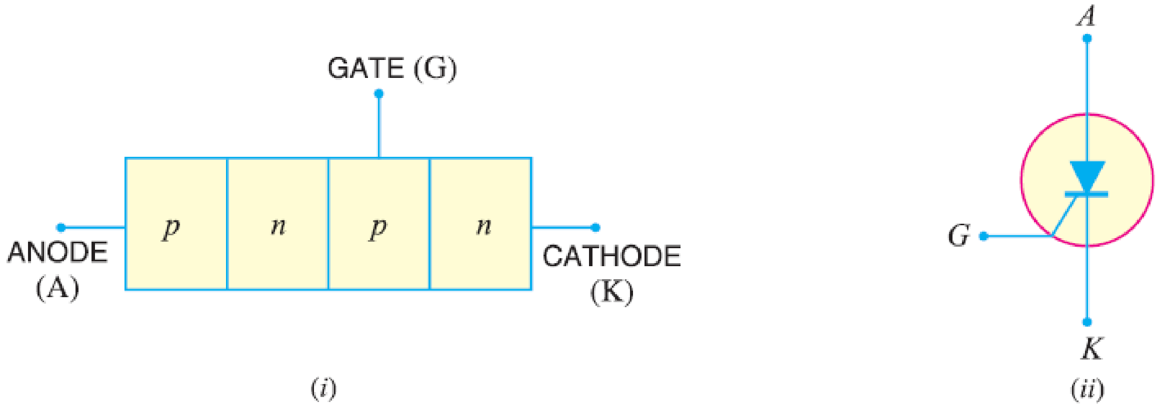
(*ii*) When triac is fired into conduction, voltage across 50Ω resistor = 50V – 1V = 49V.

$$\therefore \qquad \text{Current in } 50\Omega = \frac{49\text{V}}{50\Omega} = \mathbf{0.98\ A}$$

SCR

Silicon Controlled Rectifier (SCR)

A silicon *controlled rectifier is a semiconductor **device that acts as a true electronic switch. It can change alternating current into direct current and at the same time can control the amount of power fed to the load. Thus SCR combines the features of a rectifier and a transistor.



Working of SCR

In a silicon controlled rectifier, load is connected in series with anode. The anode is always kept at positive potential w.r.t. cathode. The working of SCR can be studied under the following two heads:

(i) When gate is open. Fig. 56 shows the SCR circuit with gate open i.e. no voltage applied to the gate. Under this condition, junction J2 is reverse biased while junctions J1 and J3 are forward biased. Hence, the situation in the junctions J1 and J3 is just as in a npntransistor with base open.

Consequently, no current flows through the load RL and the SCR is cut off. However, if the applied voltage is gradually increased, a stage is reached when * reverse biased junction J2 breaks down. The SCR now conducts ** heavily and is said to be in the ON state. The applied voltage at which SCRconducts heavily without gate voltage is called Breakover voltage.

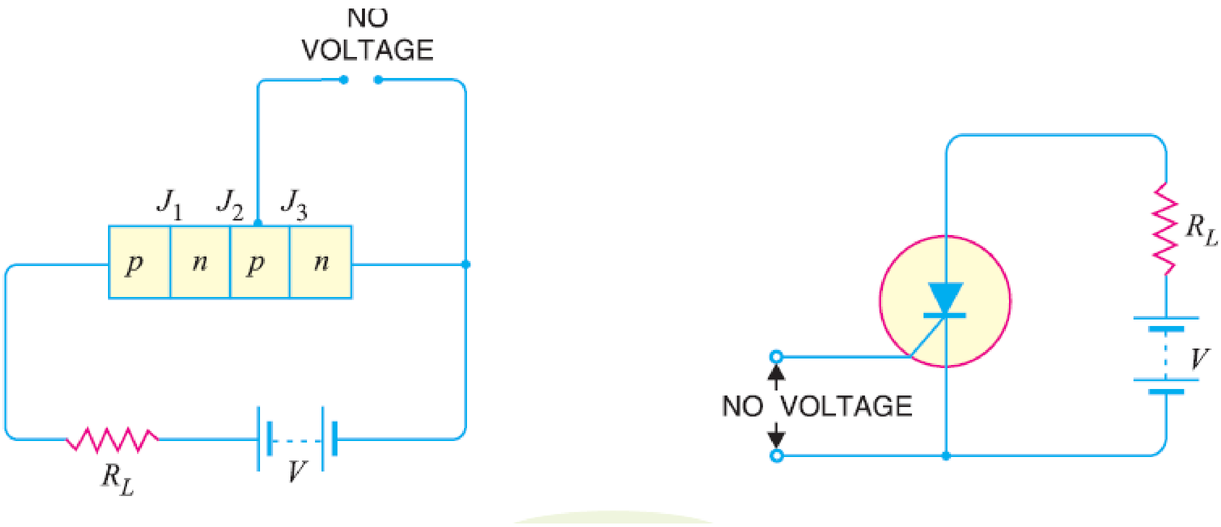


Figure 55

(ii) When gate is positive w.r.t. cathode. The SCR can be made to conduct heavily at smaller applied voltage by applying a small positive potential to the gate as shown in Fig. 57. Now junction J3 is forward biased and junction J2 is reverse biased. The electrons from n-type material start moving across junction J3 towards left whereas holes from p-type towards the right. Consequently, theelectrons from junction J3 are attracted across junction J2 and gate current starts flowing. As soon as the gate current flows, anode current increases. The increased anode current in turn makes more electrons available at junction J2. This process continues and in an extremely small time, junction J2 breaks down and the SCR starts conducting heavily. Once SCR starts conducting, the gate (the reason for this name is obvious) loses all control. Even if gate voltage is removed, the anode current does not decrease at all. The only way to stop conduction (i.e. bring SCR in off condition) is to reduce the applied voltage to zero.

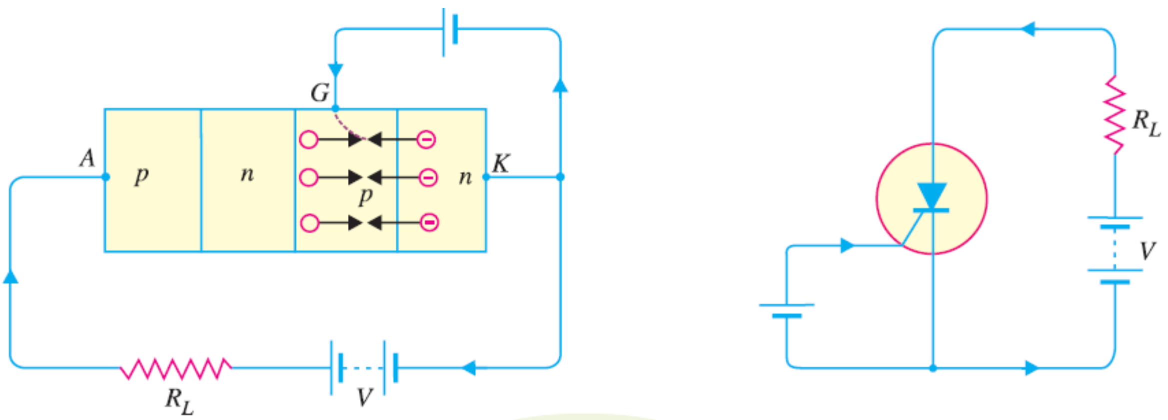


Figure 56

Conclusion The following conclusions are drawn from the working of SCR :

(i) An SCR has two states i.e. either it does not conduct or it conducts heavily. There is no state inbetween. Therefore, SCR behaves like a switch.

(ii) There are two ways to turn on the SCR. The first method is to keep the gate open and make the supply voltage equal to the breakover voltage. The second method is to operate SCR with supply voltage less than breakover voltage and then turn it on by means of a small voltage (typically 1.5 V, 30 mA) applied to the gate.

(iii) Applying small positive voltage to the gate is the normal way to close an SCR because the breakovervoltage is usually much greater than supply voltage.

(iv) To open the SCR (i.e. to make it non-conducting), reduce the supply voltage to zero.

Equivalent Circuit of SCR

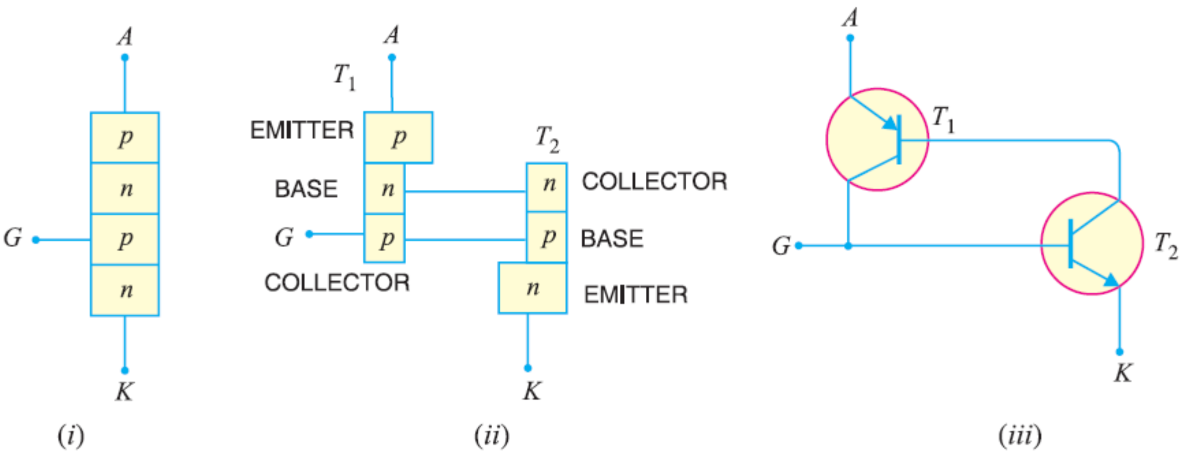


Figure 57

Fig. 58(ii). Thus, the equivalent circuit of SCR is composed of pnptransistor and npntransistor connected as shown in Fig. 58. (iii). It is clear that collector of each transistor is coupled to the base of the other, thereby making a positive feedback loop. The working of SCR can be easily explained from its equivalent circuit. Fig. 59.shows the equivalent circuit of SCR with supply voltage V and load resistance RL. Assume the supply voltage V is less than break over voltage as is usually the case. With gate open (i.e. switch S open), there is no base current in transistor T2. Therefore, no current flows in the collector of T2 and hence that of T1. Under such conditions, the SCR is open. However, if switch S is closed, a small gate current will flow through the base of T2 which means its collector current will increase. The collector current of T2 is the base current of T1. Therefore, collector current of T1 increases. But collector current of T1 is the base current of T2. This action is accumulative since an increase of current in one transistor causes an increase of current in the other transistor. As a result of this action, both transistors are driven to saturation, and heavy current flows through the load RL. Under such conditions, the SCR closes.

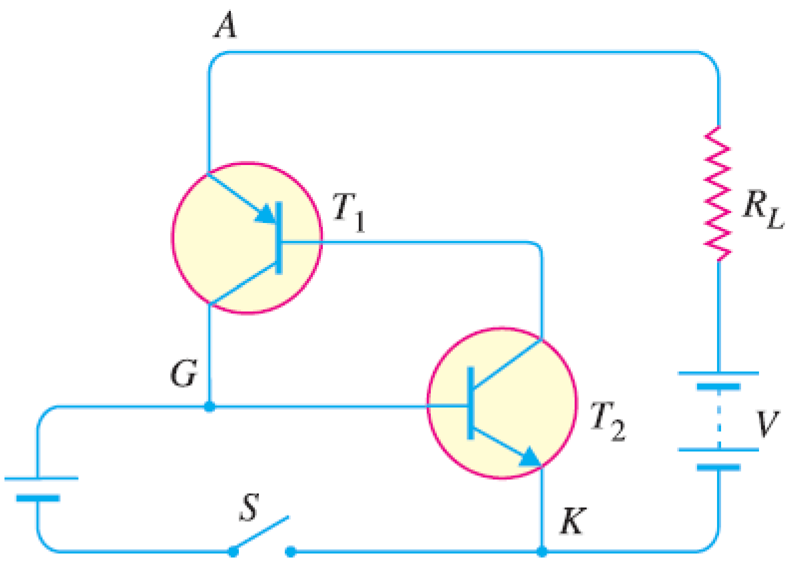


Figure 58

Important Terms

The following terms are much used in the study of SCR :

(i) Breakover voltage **(ii)** Peak reverse voltage

(iii) Holding current **(iv)** Forward current rating

(v) Circuit fusing rating

(i) Breakover voltage. It is the minimum forward voltage, gate being open, at which SCR starts conducting heavily i.e. turned on. Thus, if the break over voltage of an SCR is 200 V, it means that it can block a forward voltage(i.e. SCR remains open) as long as the supply voltage is less than 200 V. If the supply voltage is morethan this value, then SCR will be turned on. In practice, the SCR is operated with supply voltage lessthan break over voltage and it is then turned on by means of a small voltage applied to the gate.

Commercially available SCRs have break over voltages from about 50 V to 500 V.

(ii) Peak reverse voltage (PRV). It is the maximum reverse voltage (cathode positive w.r.t. anode) that can be applied to an SCR without conducting in the reverse direction.

Peak reverse voltage (PRV) is an important consideration while connecting an SCR in an a.c. circuit. During the negative half of a.c. supply, reverse voltage is applied across SCR. If PRV is exceeded, there may be avalanche breakdown and the SCR will be damaged if the external circuit does not limit the current. Commercially available SCRs have PRV ratings upto 2.5 kV.

(iii) Holding current. It is the maximum anode current, gate being open, at which SCR is turned off from ON conditions.

As discussed earlier, when SCR is in the conducting state, it cannot be turned OFF even if gate voltage is removed. The only way to turn off or open the SCR is to reduce the supply voltage to almost zero at which point the internal transistor comes out of saturation and opens the SCR. The anode current under this condition is very small (a few mA) and is called holding current. Thus, if an SCR has a holding current of 5mA, it means that if anode current is made less than 5mA, then SCRwill be turned off.

(iv) Forward current rating.

It is the maximum anode current that an SCR is capable of passing without destruction.

Every SCR has a safe value of forward current which it can conduct. If the value of current exceeds this value, the SCR may be destroyed due to intensive heating at the junctions. For example, if an SCR has a forward current rating of 40A, it means that the SCR can safely carry only 40 A. Any attempt to exceed this value will result in the destruction of the SCR. Commercially available SCRshave forward current ratings from about 30A to 100A.

(v) Circuit fusing (I2t) rating. It is the product of square of forward surge current and the time of duration of the surge i.e.,Circuit fusing rating = I^2t

The circuit fusing rating indicates the maximum forward surge current capability of SCR. For example, consider an SCR having circuit fusing rating of 90 A2s. If this rating is exceeded in the SCRcircuit, the device will be destroyed by excessive power dissipation.

Example: An SCR has a breakover voltage of 400 V, a trigger current of 10 mA and holding current of 10 mA. What do you infer from it ? What will happen if gate current is made 15 mA ?

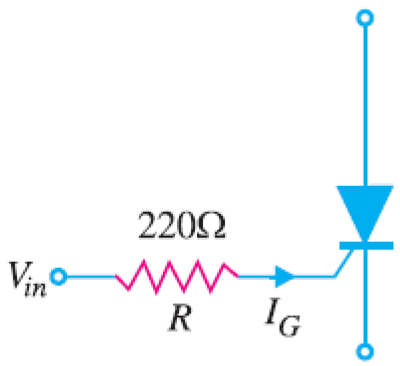
Solution: (i) Breakover voltage of 400 V. It means that if gate is open and the supply voltage is 400 V, then SCR will start conducting heavily. However, as long as the supply voltage is less than 400 V, the SCR stays open i.e. it does not conduct.

(ii) Trigger current of 10 mA. It means that if the supply voltage is less than breakover voltage (i.e. 400 V) and a minimum gate current of 10 mA is passed, the SCR will close i.e. starts conducting heavily. The SCR will not conduct if the gate current is less than 10 mA. It may be emphasised that triggering is the normal way to close an SCR as the supply voltage is normally much less than the breakover voltage.

(iii) Holding current of 10 mA. When the SCR is conducting, it will not open (i.e. stop conducting) even if triggering current is removed. However, if supply voltage is reduced, the anode current also decreases. When the anode current drops to 10 mA, the holding current, the SCR is turned off.

(iv) If gate current is increased to 15 mA, the SCR will be turned on lower supply voltage.

Example: A 220Ωresistor is connected in series with the gate of an SCR as shown in Fig. 20.6. The gate current required to fire the SCR is 7mA. What is the input voltage (Vin) required to fire the SCR ?



Solution: The input voltage must overcome the junction voltagebetween the gate and cathode (0.7V) and also cause 7mA to flow through the 220Ω resistor. According to Kirchhoff's voltage law, Vin is given by;

$$
\begin{aligned}
V_{in} &= V_{GK} + I_G R \\
&= 0.7\text{V} + (7\text{mA})\,(220\Omega) = \mathbf{2.24V}
\end{aligned}
$$

V-I Characteristics of SCR

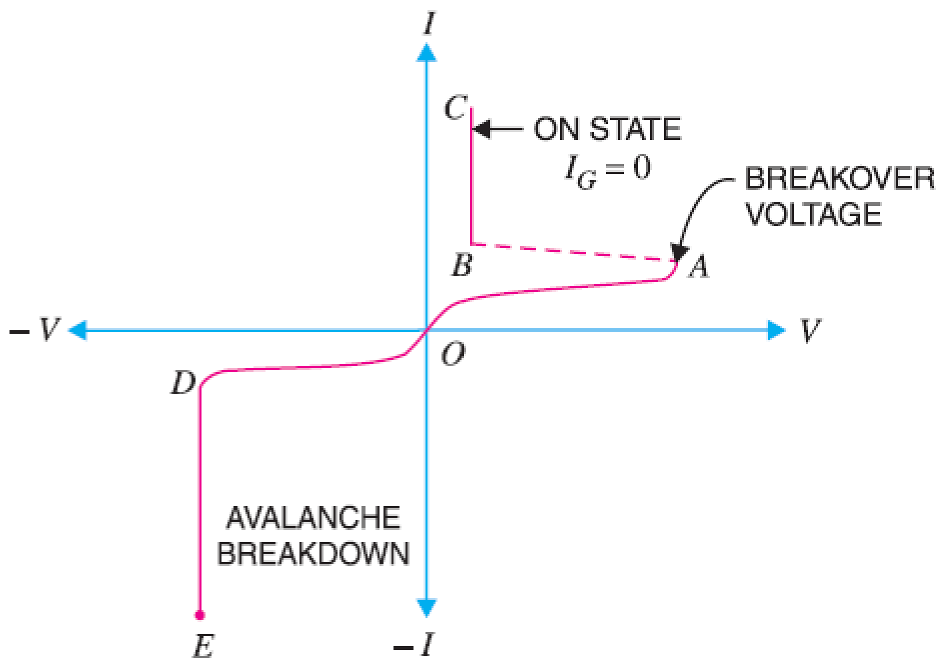
It is the curve between anode-cathode voltage (V) and anode current (I) of an SCR at constant gate current. Fig. 20.7 shows the V-I characteristics of a typical SCR.

(i) Forward characteristics. When anode is positive w.r.t. cathode, the curve between V and I is called the forward characteristic. In Fig. 20.7, OABC is the forward characteristic of SCR at IG = 0.

If the supply voltage is increased from zero, a point is reached (point A) when the SCR starts conducting.

Under this condition, the voltage across SCR suddenly drops as shown by dotted curve AB and most of supply voltage appears across the load resistance RL. If proper gate current is made to flow, SCR can close at much smaller supply voltage.

(ii) Reverse characteristics. When anode is negative w.r.t. cathode, the curve between V and I is known as reverse characteristic. The reverse voltage does come across SCR when it is operated with a.c. supply. If the reverse voltage is gradually increased, at first the anode current remains small (i.e.leakage current) and at some reverse voltage, avalanche breakdown occurs and the SCR starts conductingheavily in the reverse direction as shown by the curve DE. This maximum reverse voltage at which SCR starts conducting heavily is known as reverse breakdown voltage.



SCR in Normal Operation

In order to operate the SCR in normal operation, the following points are kept in view:

(i) The supply voltage is generally much less than breakover voltage.

(ii) The SCR is turned on by passing an appropriate amount of gate current (a few mA) and not by breakover voltage.

(iii) When SCR is operated from a.c. supply, the peak reverse voltage which comes during negative half-cycle should not exceed the reverse breakdown voltage.

(iv) When SCR is to be turned OFF from the ON state, anode current should be reduced to holding current.

(v) If gate current is increased above the required value, the SCR will close at much reduced supply voltage.

SCR as a Switch

The SCR has only two states, namely; ON state and OFF state and no state inbetween. When appropriate gate current is passed, the SCR starts conducting heavily and remains in this position indefinitely even if gate voltage is removed. This corresponds to the ON condition. However, when the anode current is reduced to the holding current, the SCR is turned OFF. It is clear that behaviour of SCR is similar to a mechanical switch. As SCR is an electronic device, therefore, it is more appropriate to call it an electronic switch.

Advantages of SCR as a switch

An SCR has the following advantages over a mechanical or electromechanical switch (relay):

(i) It has no moving parts. Consequently, it gives noiseless operation at high efficiency.

(ii) The switching speed is very high upto 109 operations per second.

(iii) It permits control over large current (30–100 A) in the load by means of a small gate current (a few mA).

(iv) It has small size and gives trouble free service.

SCR Switching

We have seen that SCR behaves as a switch i.e. it has only two states viz. ON state and OFF state. It is profitable to discuss the methods employed to turn-on or turn-off an SCR.

1. SCR turn-on methods. In order to turn on the SCR, the gate voltage VG is increased uptoa minimum value to initiate triggering. This minimum value of gate voltage at which SCR is turned

ON is called gate triggering voltage VGT. The resulting gate current is called gate triggering current IGT. Thus to turn on an SCR all that we have to do is to apply positive gate voltage equal to VGT or pass a gate current equal to IGT. For most of the SCRs,

$$V_{GT} = 2 \text{ to } 10 \text{ V and } I_{GT} = 100\ \mu\text{A to } 1500\ \text{mA}.$$

We shall discuss two methods to turn on an SCR.

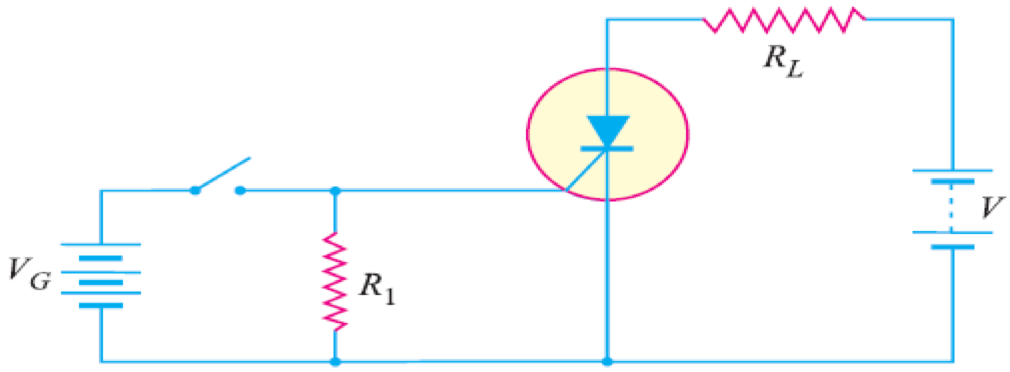
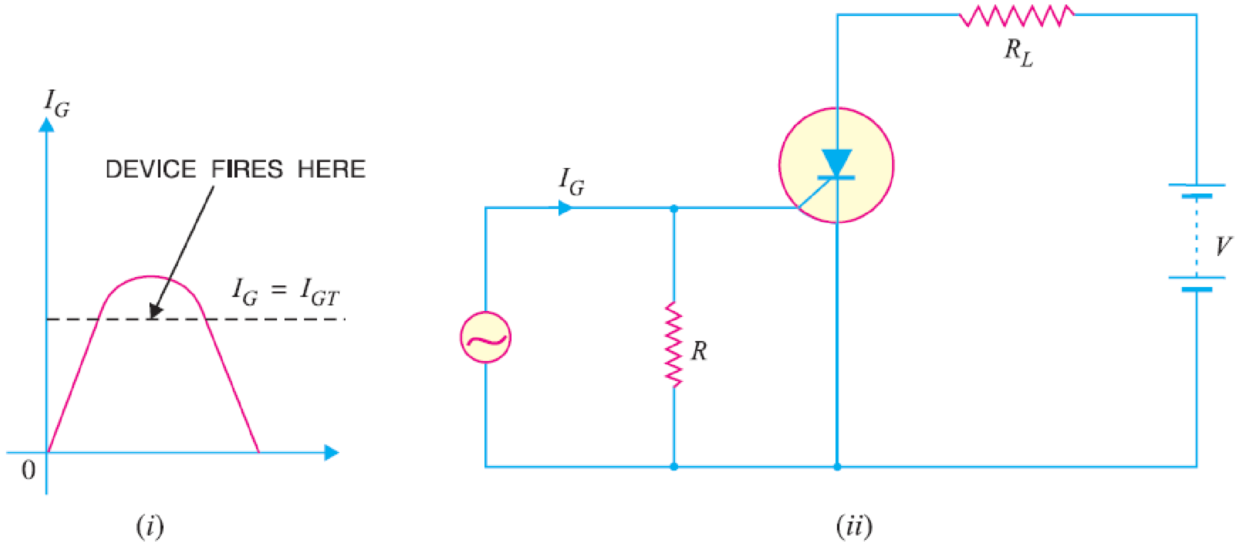


Figure 59

(i) D.C. gate trigger circuit. 60 shows a typical circuit used for triggering an SCR with a d.c. gate bias. When the switch is closed, the gate receives sufficient positive voltage (= VGT) to turn the SCR on. The resistance R1 connected in the circuit provides noise suppression and improves the turn-on time. The turn-on time primarily depends upon the magnitude of the gate current.The higher the gate-triggered current, the shorter the turn-on time.



.Figure 60

(ii) A.C. trigger circuit. An SCR can also be turned on with positive cycle of a.c. gate current. Fig. 61 (ii) shows such a circuit. During the positive half-cycle of the gate current, at some point IG = IGT, the device is turned on as shown in Fig. 61 (i).

SCR turn-off methods. The SCR turn-off poses more problems than SCR turn-on. It is because once the device is ON, the gate loses all control. There are many methods of SCR turn-off but only two will be discussed.

(i) Anode current interruption. When the anode current is reduced below a minimum value called holding current, the SCR turns off. The simple way to turn off the SCR is to open the line switch S as shown in Fig. 20.10.

(ii) Forced commutation. The method of discharging a capacitor in parallel with an SCR to turn off the SCR is called forced commutation. Fig. 20.11 shows the forced commutation of SCRwhere capacitor C performs the commutation. Assuming the SCRs are switches with SCR1 ON and SCR2 OFF, current flows through the load and C as shown in Fig. 20.11. When SCR2 is triggered on, C is effectively paralleled across SCR1. The charge on C is then opposite to SCR1's forward voltage, SCR1 is thus turned off and the current is transferred to R–SCR2 path.

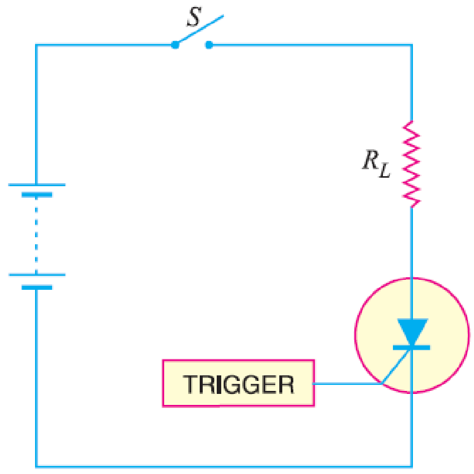


Fig. 20.10

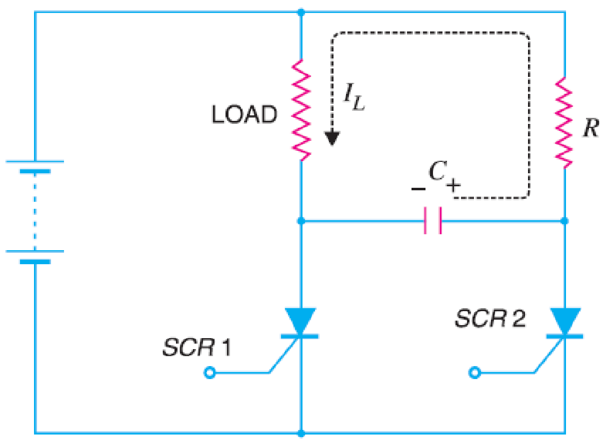


Fig. 20.11

SCR Half-Wave Rectifier

One important application of an SCR is the controlled half-wave rectification. Fig. 62 (i) shows the circuit of an SCR half-wave rectifier. The a.c. supply to be rectified is supplied through the transformer. The load resistance RL is connected in series with the anode. A variable resistance r is inserted in the gate circuit to control the gate current.

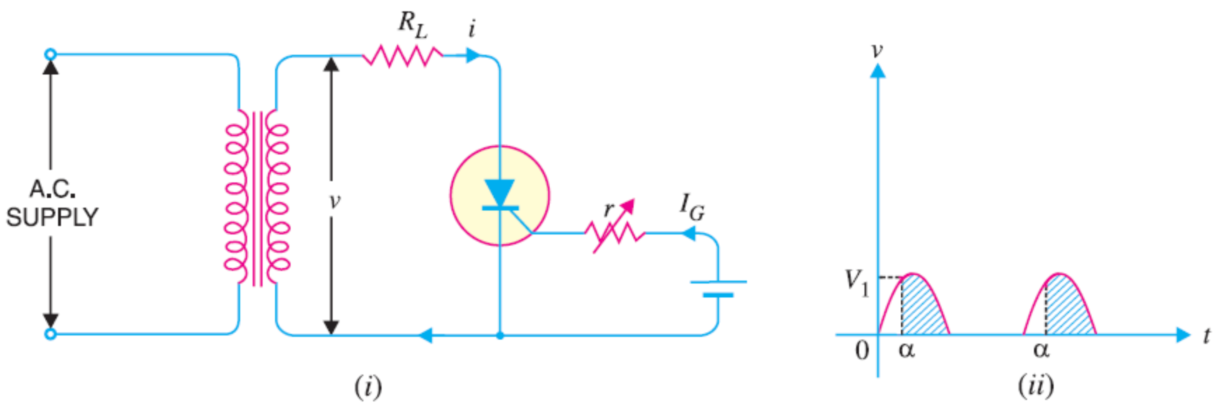


Figure 61

Operation. The a.c. supply to be converted into d.c. supply is applied to the primary of the transformer. Suppose the peak reverse voltage appearing across secondary is less than the reverse breakdown voltage of the SCR. This condition ensures that SCR will not break down during negative half-cycles of a.c. supply. The circuit action is as follows:

(i) During the negative half-cycles of a.c. voltage appearing across secondary, the SCR does notconduct regardless of the gate voltage. It is because in this condition, anode is negative w.r.t. cathode and also PRV is less than the reverse breakdown voltage.

(ii) The SCR will conduct during the positive half-cycles provided proper gate current is made to flow. The greater the gate current, the lesser the supply voltage at which SCR is turned ON. The gate current can be changed by the variable resistance r as shown in Fig. 20.12 (i).

(iii) Suppose that gate current is adjusted to such a value that SCR closes at a positive voltage V1which is less than the peak voltage Vm. Referring to Fig. 62 (ii), it is clear that SCR will start conducting when secondary a.c. voltage becomes V1 in the positive half-cycle. Beyond this, the SCRwill continue to conduct till voltage becomes zero at which point it is turned OFF. Again at the start of the next positive half-cycle, SCR will start conducting when secondary voltage becomes V1.

(iv) Referring to Fig. 62 (ii), it is clear that firing angle is α i.e. at this angle in the positive half-cycle, SCR starts conduction. The conduction angle is ϕ(= 180° −α).

It is worthwhile to distinguish between an ordinary half-wave rectifier and SCR half-wave rectifier. Whereas an ordinary half-wave rectifier will conduct full positive half-cycle, an SCR half-wave rectifier can be made to conduct full or part of a positive half-cycle by proper adjustment of gate current. Therefore, an SCR can control power fed to the load and hence the name controlled rectifier.

$$V_{av} = \frac{V_m}{2\pi}(1 + \cos\alpha)$$

Average current, $$I_{av} = \frac{V_{av}}{R_L} = \frac{V_m}{2\pi R_L}(1 + \cos\alpha)$$

Applications of SCR

The ability of an SCR to control large currents in a load by means of small gate current makes this device useful in switching and control applications. Some of the important applications of SCR are discussed below:

(i) SCR as static contactor. An important application of SCR is for switching operations. As SCR has no moving parts, therefore, when it is used as a switch, it is often called a static contactor.

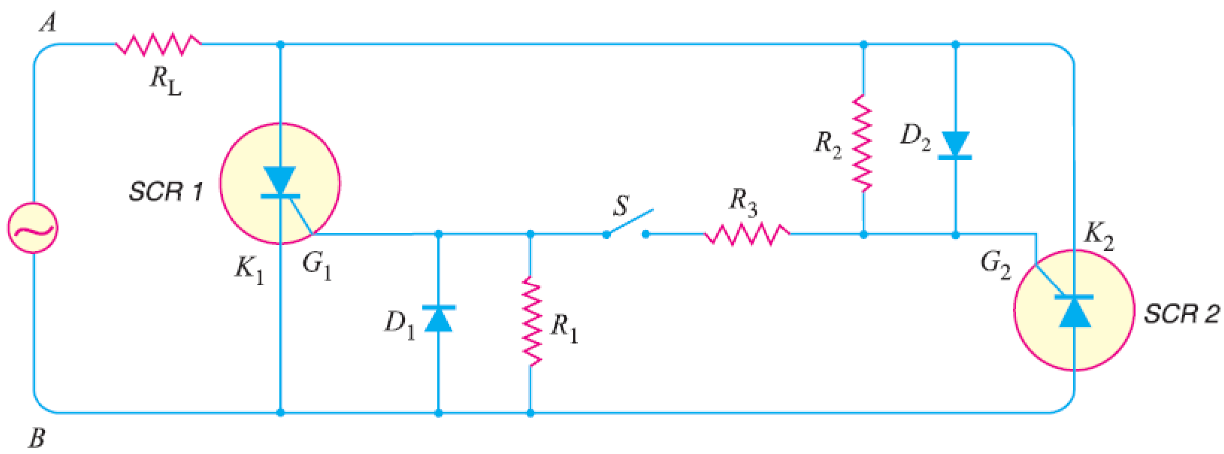


Figure 62

Fig. 63 shows the use of SCR to switch ON or OFF a.c. power to a load RL. Resistances R1 and R2 are for the protection of diodes D1 and D2 respectively. Resistance R3 is the gate current limiting resistor. To start the circuit, switch is closed. During the positive half-cycle of a.c. supply, end A ispositive and end B is negative. Then diode D2 sends gate current through SCR1. Therefore SCR1 is turned ON while SCR2 remains OFF as its anode is negative w.r.t. cathode. The current conduction by SCR1 follows the path ARLK1BA. Similarly, in the next half-cycle, SCR2 is turned ON and conducts current through the load. It may be seen that switch S handles only a few mA of gate current to switch ON several hundred amperes in the load RL. This is a distinct advantage over a mechanical switch.

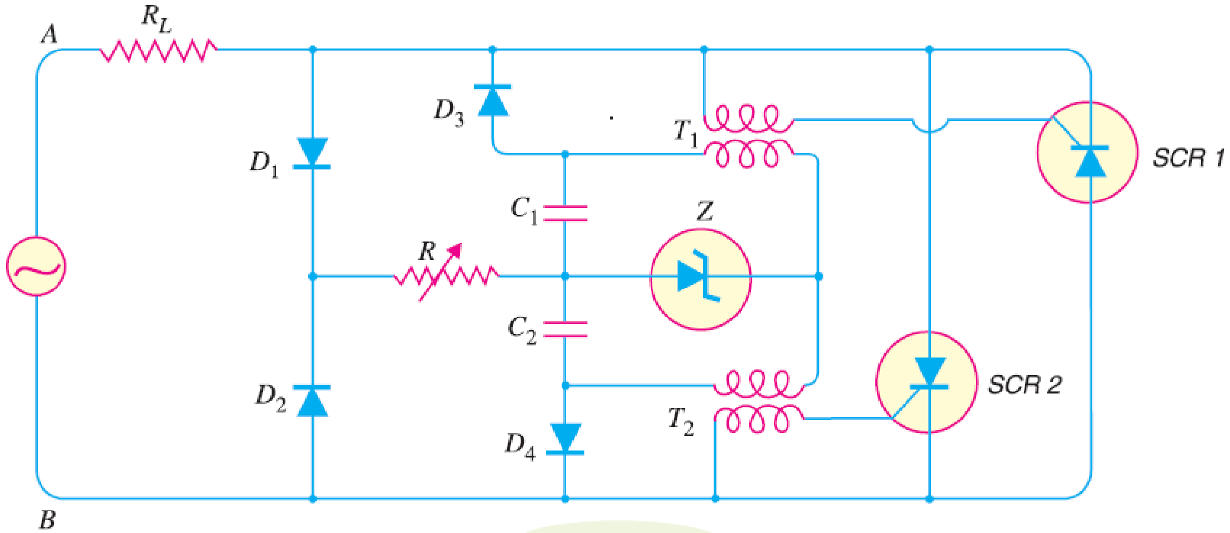


Figure 63

(ii) SCR for power control. It is often necessary to control power delivered to some load such as the heating element of a furnace. Series resistances or potentiometers cannot be used because they waste power in high power circuits. Under such conditions, silicon controlled rectifiers are used which are capable of adjusting the transmitted power with little waste. Fig. 64 shows a common circuit for controlling power in the load RL. During the positive half-cycle of a.c. supply, end A is positive and end B is negative. Therefore, capacitor C2 is charged through AD1 RC2 D4B. The charge on the capacitor C2 depends upon the value of potentiometer R. When the capacitor C2 is charged through a sufficient voltage, it discharges through the zenerZ. This gives a pulse to the primary and hence secondary of transformer T2. This turns on SCR2 which conducts currents through the load RL.

During negative half-cycle of supply, the capacitor C1 is charged. It discharges through the zener and fires SCR1 which conducts current through the load. The angle of conduction can be controlled by the potentiometer R. The greater the resistance of R, lesser is the voltage across C1 or C2 and hence smaller will be the time during which SCR1 and SCR2 will conduct in a full cycle. In this way, we can control a large power of several kW in the load RL with the help of a small potentiometer R.

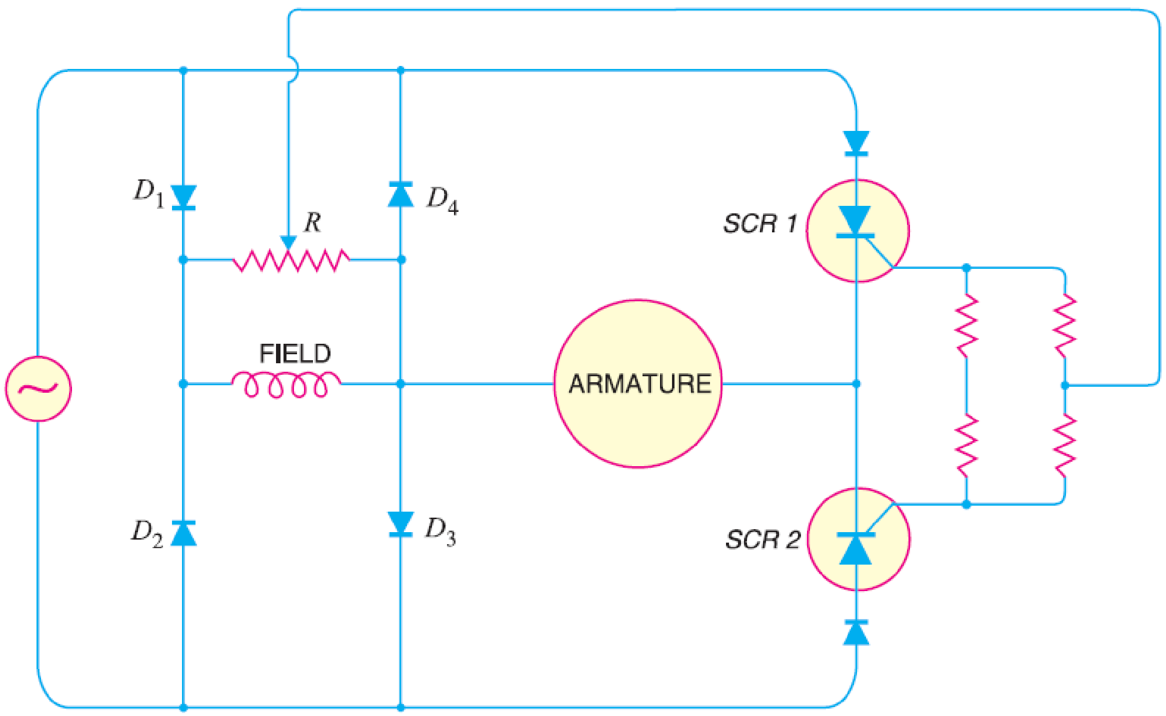


Figure 64

(iii) SCRs for speed control of d.c. shunt motor. The conventional method of speed control of d.c. shunt motor is to change the field excitation. But change in field excitation changes the motor torque also. This drawback is overcome in SCR control as shown in Fig. 65. Diodes D1, D2, D3 and D4 form the bridge. This bridge circuit converts a.c. into d.c. and supplies it to the field winding of the motor. During the positive half-cycle of a.c. supply, SCR1 conducts because it gets gate current from bridge circuit as well as its anode is positive w.r.t. cathode. The armature winding of the motor gets current. The angle of conduction can be changed by varying the gate current. During the negative half-cycle of a.c. supply, SCR2 provides current to the armature winding. In this way, the voltage fed to the motor armature and hence the speed can be controlled.

(iv) Overlight detector. Fig. 66 shows the use of SCR for overlightdetection.The resistor R isa photo-resistor, a device whose resistance decreases with the increase in light intensity. When the light falling on R has normal intensity, the value of R is high enough and the voltage across R1 is insufficient to trigger the SCR. However, when R is in strong light, its resistance decreases and the voltage drop across R1 becomes high enough to trigger the SCR. Consequently, the buzzer sounds the alarm. It may be noted that even if the strong light disappears, the buzzer continues to sound the alarm. It is because once the SCR is fired, the gate loses all control.

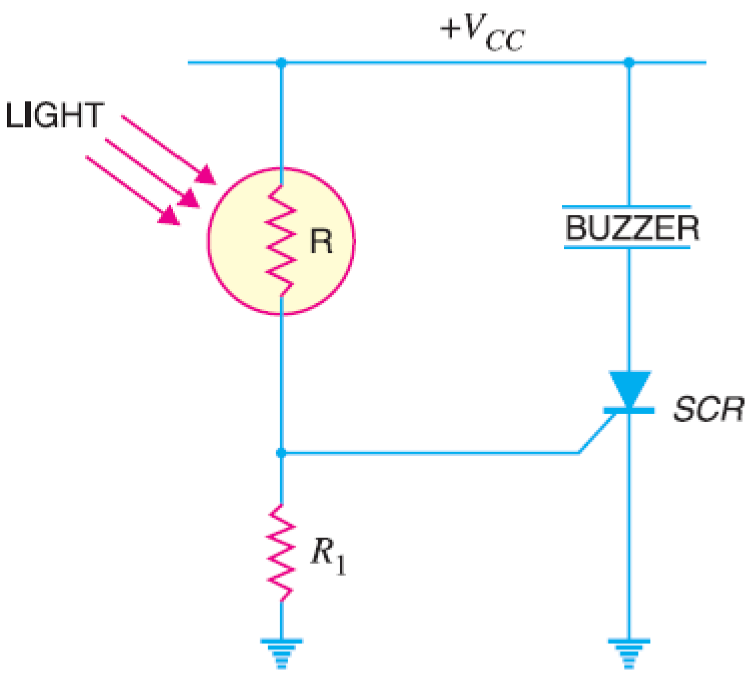
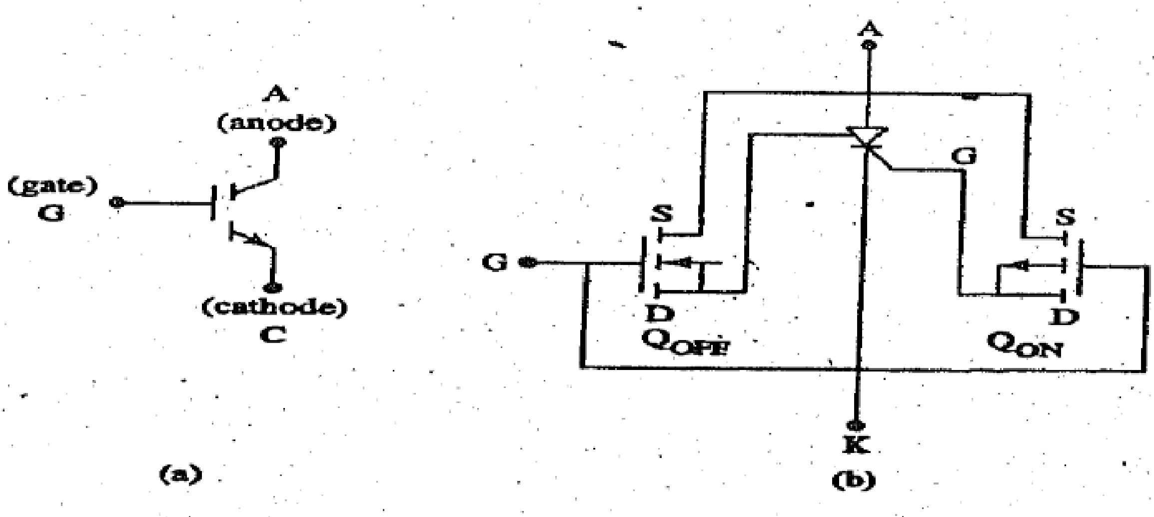


Figure 65

 MCT

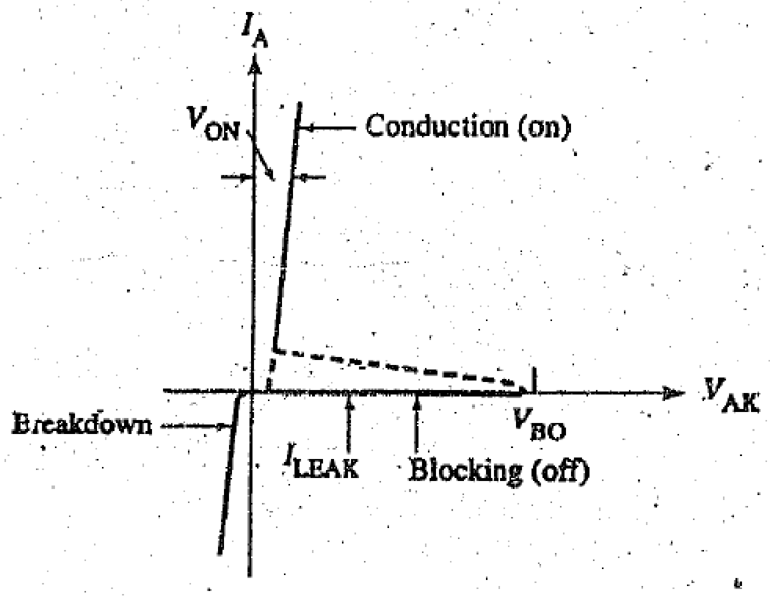
The MOS-controlled thyristor (MCT) is a new device that combines the characteristics of a MOSFET and an SCR. It has a low forward voltage drop in the on state and a low turnoff time. It has high *di/dt* and *dv/dt* capabilities. It is similar in functionality to the GTO but has a lower turnoff gate current requirement. Its main disadvantage is that its reverse voltage blocking ability is very low.



MCT, an SCR and two MOSFETs are combined into a single device. The two MOSFETs have the same gate terminal, which is the gate of the MCT. They also have the same source terminal, which is the anode of the MCT. The N-channel MOSFET Q_{OFF}, which is connected between the anode and one of its internal layers, turns the SCR off while the P-channel MOSFET Q_{ON}, connected between the gate and anode, turns it on.

THE MCT V-I Characteristics

Figure 4.43
MCT *V-I* characteristic



If the cathode (K) is made positive with respect to the anode (A) with either positive or negative voltage applied to the gate, the MCT breaks down at a low voltage. This situation is to be avoided.

The normal way to turn the device on is to forward-bias the MCT by making the anode positive with respect to the cathode and applying a negative voltage to the gate and anode. When on, the voltage drop across the MCT (V_{ON}) is very small (about 1 V) and the anode current is limited only by the load resistance. Once the MCT turns on, removal of the gate voltage will not turn it off. If the MCT is on, the application of a positive voltage to the gate turns the device off until a negative voltage is applied to the gate again.

Figure 4.43 shows the *V-I* characteristic of an MCT. If the anoc positive with respect to the cathode (K), when no voltage is appl the MCT remains in the blocking state, allowing only a small l (I_{LEAK}). The MCT remains in the off state until a breakover reached, at which point the MCT breaks down. However, the MC on this way.

Topic 3: Identification of special devices

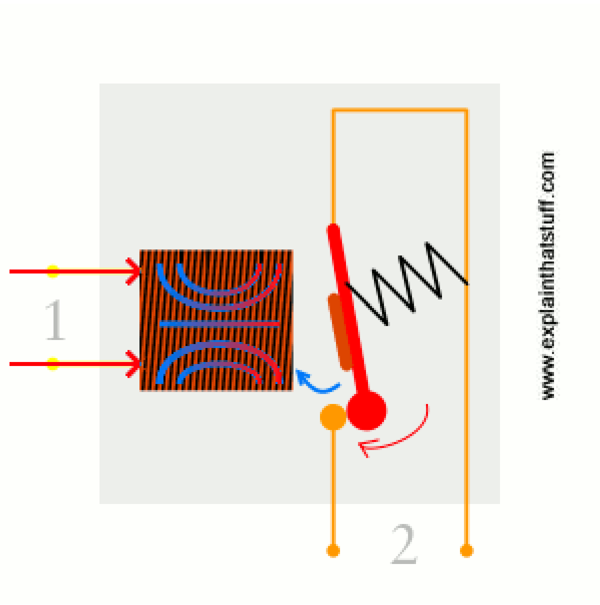
There are different special devices used in electronic circuit include:

Relay , Opto-coupler , Electronic switches , Buzzer.

- **Relay**

A relay is an electromagnetic switch operated by a relatively small electric current that can turn on or off a much larger electric current. The heart of a relay is an electromagnet (a coil of wire that becomes a temporary magnet when electricity flows through it). You can think of a relay as a kind of electric lever: switch it on with a tiny current and it switches on ("leverages") another appliance using a much bigger current. Why is that useful? As the name suggests, many sensors are incredibly sensitive pieces of electronic equipment and produce only small electric currents. But often we need them to drive bigger pieces of apparatus that use bigger currents. Relays bridge the gap, making it possible for small currents to activate larger ones. That means relays can work either as switches (turning things on and off) or as amplifiers (converting small currents into larger ones).

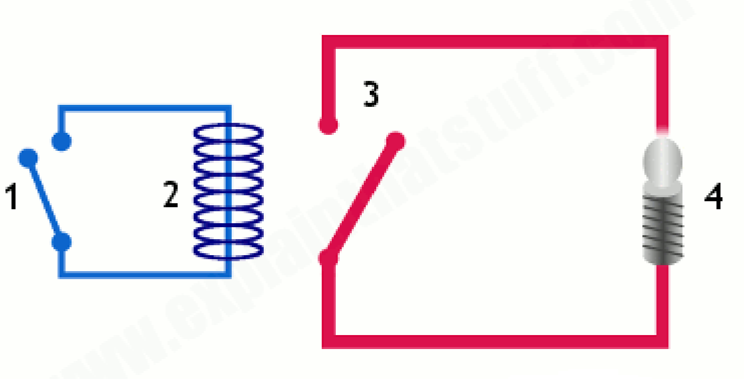
Here are two simple animations illustrating how relays use one circuit to switch on a second circuit.



When power flows through the first circuit (1), it activates the electromagnet (brown), generating a magnetic field (blue) that attracts a contact (red) and activates the second circuit (2). When the power is switched off, a spring pulls the contact back up to its original position, switching the second circuit off again.

This is an example of a "normally open" (NO) relay: the contacts in the second circuit are not connected by default, and switch on only when a current flows through the magnet. Other relays are "normally closed" (NC; the contacts are connected so a current flows through them by default) and switch off only when the magnet is activated, pulling or pushing the contacts apart. Normally open relays are the most common.

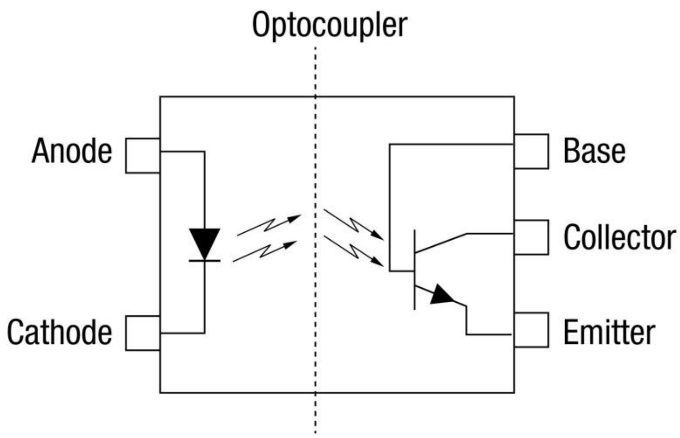
Here's another animation showing how a relay links two circuits together. It's essentially the same thing drawn in a slightly different way. On the left side, there's an input circuit powered by a switch or a sensor of some kind. When this circuit is activated, it feeds current to an electromagnet that pulls a metal switch closed and activates the second, output circuit (on the right side). The relatively small current in the input circuit thus activates the larger current in the output circuit:



1. The input circuit (blue loop) is switched off and no current flows through it until something (either a sensor or a switch closing) turns it on. The output circuit (red loop) is also switched off.
2. When a small current flows in the input circuit, it activates the electromagnet (shown here as a dark blue coil), which produces a magnetic field all around it.
3. The energized electromagnet pulls the metal bar in the output circuit toward it, closing the switch and allowing a much bigger current to flow through the output circuit.
4. The output circuit operates a high-current appliance such as a lamp or an electric motor.

- **Optocoupler**

An optocoupler, as shown in Figure bellow, consists of an input LED, a receiving photodetector and an output driver. The driver circuit and LED circuits are typically built using complementary metal-oxide semiconductor (CMOS) technology, with the insulation or isolation barrier usually consisting of molding compound. Both the input and output of an optocoupler isolator require separate voltage supplies connected through the anode and collector pins, and separate grounds typically connected at the cathode and emitter pins, in order to maintain signal isolation between the input and output.



Communication within an optocoupler occurs when an applied CMOS logic input generates an input-side current, which then creates a proportional LED output for transmission through the molding compound barrier to the receiving photodetector and output.

The isolation performance of an optocoupler is determined by a combination of the LED, the molding compound used between the input and output, and the distance through the molding compound. Because the molding compound is a key contributor to isolation barrier strength, its quality plays a significant role in optocoupler lifetime, reliability and performance.

Standards bodies including Underwriters Laboratories (UL) and Verband der Elektrotechnik (VDE) determine optocoupler ratings, and those ratings specifically define the "distance through insulation" to accommodate molding compound variations during manufacture, along with partial discharge tests to identify molding compound defects that could compromise isolation performance under stress. Optocoupler standards have not historically included lifetime reliability performance data or high-voltage stress testing for sustained applied high voltages, and thus their sustained long-term performance and reliability can vary significantly.

- **Electronic switch**

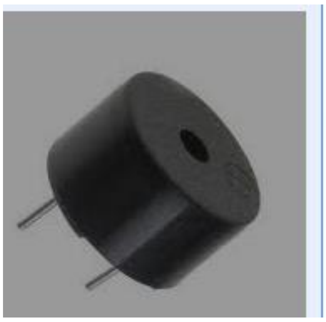
In electronics, an **electronic switch** is an electronic component or device that can switch an electrical circuit, interrupting the current or diverting it from one conductor to another. Electronic switches are considered binary devices because they can be on or completely off. When an electronic switch is on, it is considered closed in a circuit. When the switch is classified as off the switch is open in the circuit.[1]

Typically, electronic switches use solid state devices such as transistors, though vacuum tubes can be used as well in high voltage applications. Electronic switches also consist of complex configurations that are assisted by physical contact. Physical contact typically comes from pressing or flipping a switch with your hand, but other forms of contact like light sensors and magnetic field sensors are used to operate switches.

Different kinds of switches are used for different applications in today's devices. Switches operated by a person are called hand switches, hand switches consist of many types like toggle switches, pushbutton switches, selector switches, and joystick switches. Another popular form of switch is a motion switch, these are typically called limit switches. Limit switches are used to limit the motion of a machine. Limit switches are usually used for preventive safety measures so that a machine will cut off past a specified point. Two of the most common limit switches are lever actuator switches and proximity switches.

In industrial processes, process switches are used to monitor physical quantities. Switches such as speed, pressure, temperature, liquid level, liquid flow, and nuclear level switches are used to monitor vital information so that a process stays in control and never exceeds safety regulations.

❖ **Buzzer**

The **buzzer** consists of an outside case with two pins to attach it to power and ground. ... When current is applied to the **buzzer** it causes the ceramic disk to contract or expand. Changing the This then causes the surrounding disc to vibrate. That's the sound that you hear.

A **buzzer** or **beeper** is an audio signalling device, which may be mechanical, electromechanical, or piezoelectric (piezo for short). Typical uses of **buzzers** and beepers include alarm devices, timers, and confirmation of user input such as a mouse click or keystroke.

Learning Outcome 3.2: Select active device

Topic 1: Proper selection of active devices relatively to work to be done

- Specifications & ratings

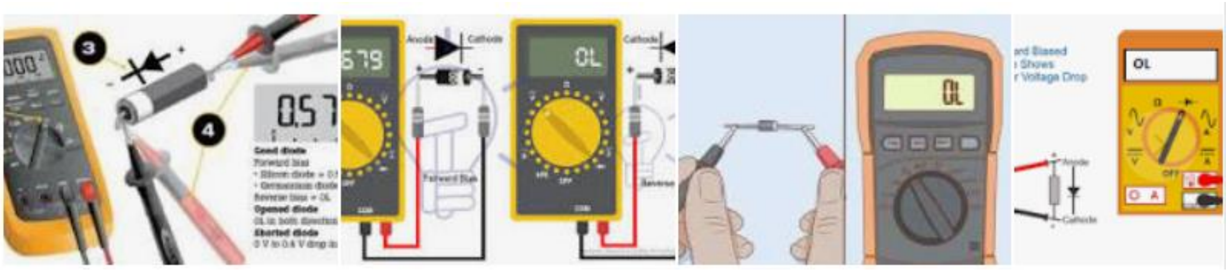
- Applications

Learning Outcome 3.3:Test active devices

Topic1: Proper testing of passive devices using various related techniques

- ✓ Diodes testing

A multimeter can be used to check whether a diode is short circuited or open circuited. A diode is an electronic one way valve or *check valve*, which only conducts in one direction. A multimeter when connected to a working diode indicates the voltage across the componen



A multimeter's Diode Test mode produces a small voltage between test leads. The multimeter then displays the voltage drop when the test leads are connected across a diode when forward-biased. The Diode Test procedure is conducted as follows:

Make certain a) all power to the circuit is OFF and b) no voltage exists at the diode. Voltage may be present in the circuit due to charged capacitors. If so, the capacitors need to be discharged. Set the multimeter to measure ac or dc voltage as required.
Turn the dial (rotary switch) to Diode Test mode. It may share a space on the dial with another function.
Connect the test leads to the diode. Record the measurement displayed.
Reverse the test leads. Record the measurement displayed.

- ✓ Testing the transistor

Remove the transistor from the circuit for accurate test results.

Step 1: (Base to Emitter)

Hook the positive lead from the multimeter to the BASE (B) of the transistor. Hook the negative meter lead to the EMITTER (E) of the transistor. For an good NPN transistor, the meter should show a voltage drop between 0.45V and 0.9V. If you are testing PNP transistor, you should see “OL” (Over Limit).

Step 2: (Base to Collector)

Keep the postitive lead on the BASE (B) and place the negative lead to the COLLECTOR (C).

For an good NPN transistor, the meter should show a voltage drop between 0.45V and 0.9V. If you are testing PNP transistor, you should see "OL" (Over Limit).

Step 3: (Emitter to Base)

Hook the positive lead from the multimeter to the to the EMITTER (E) of the transistor. Hook the negative meter lead to the BASE (B) of the transistor.

For an good NPN transistor, you should see “OL” (Over Limit).If you are testing PNP transistor, the meter should show a voltage drop between 0.45V and 0.9V.

Step 4: (Collector to Base)

Hook the positive lead from the multimeter to the to the COLLECTOR (C) of the transistor. Hook the negative meter lead to the BASE (B) of the transistor.

For an good NPN transistor, you should see “OL” (Over Limit).If you are testing PNP transistor, the meter should show a voltage drop between 0.45V and 0.9V.

Step 5: (Collector to Emitter)

Hook the postitive meter lead to the COLLECTOR (C) and the negative meter lead to the EMITTER (E) – A good NPN or PNP transistor will read "OL"/Over Limit on the meter. Swap the leads (Positive to Emitter and Negative to Collector) – Once again, a good NPN or PNP transistor should read “OL”.

If your bipolar transistor measures contrary to these steps, consider it to be bad.

You may also be able to use the voltage drop to determine which lead is the emitter on an unmarked transistor, as the emitter-base junction typically has a slightly higher voltage drop than the collector-base junction.

Remember: This test only verifies that the transistor is not shorted or open, it does not guarantee that the transistor is operating within its designed parameters. It should only be used to help decide if you need "replace" or "move on to the next component". This test works on bipolar transistors only – you need to use a different method for testing FETs.

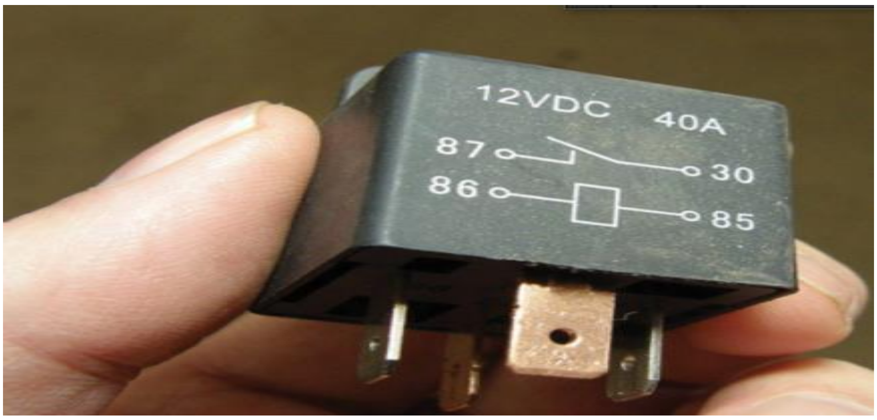
Thyristors testing

A multimeter can be used to test SCRs quite effectively. The first procedure is to check the diode action between the gate and cathode terminals of the SCR. This test is just like what you have done in the case of testing a silicon diode (see testing a silicon diode).

Now put the multimeter selector switch in a high resistance position. Connect the positive lead of multimeter to the anode of SCR and negative lead to the cathode. The multimeter will show an open circuit. Now reverse the connections and the multimeter will again show an open circuit.
Then connect the anode and gate terminals of the SCR to the positive lead of multimeter and cathode to the negative lead. The multimeter will show a low resistance indicating the switch ON of SCR. Now carefully remove the gate terminal from the anode and again the multimeter will show a low resistance reading indicating the latching condition. Here the multimeter battery supplies the holding current for the triac. If all of the above tests are positive we can assume the SCR to be working fine.

Testing special devices (relay, opto-coupler, electronic switches, buzzer)

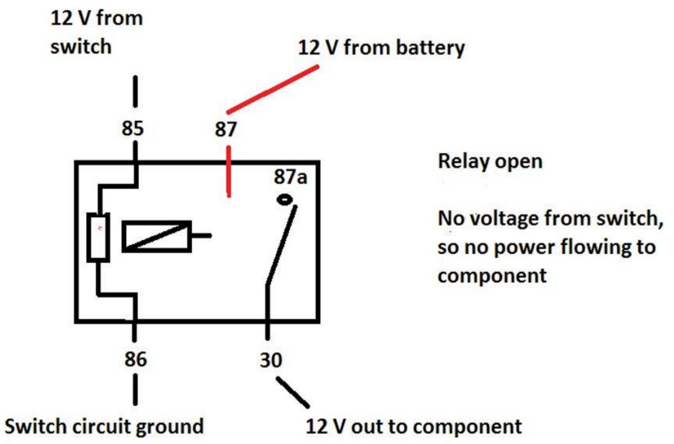
i) **Relay**

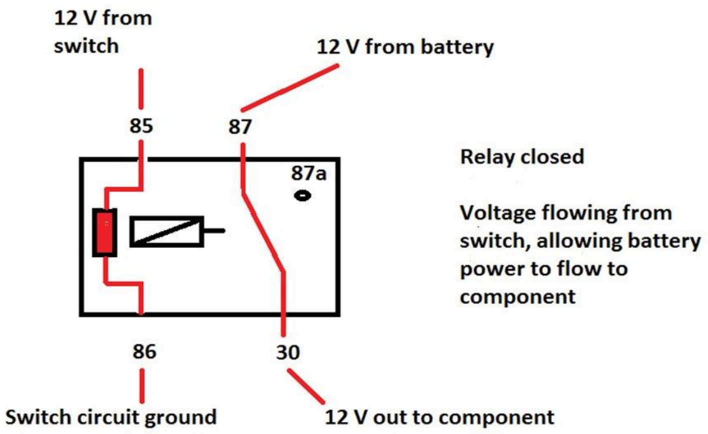


Many electrical components in a vehicle or machine are controlled by a relay. So if a component isn't working because electricity isn't getting to it, there is a possibility the relay may be faulty. But determining whether or not a relay is defective requires a little basic investigation. Here's how to go about it.

First, though, it's important to know how relays work.

Relays have an internal electromagnet that opens and closes a circuit to stop and start the flow of electricity. They help extend the life of switches by making it unnecessary to route the high amperage flow of electricity needed by a system directly through a switch. That can burn its contact points over time. Instead, a switch activated by a driver or machine operator simply sends a low-amperage current through a relay, which activates the electromagnet inside it. The magnet then closes a second, independent electrical circuit, allowing high amperage to flow through it directly to a component. Relays also allow for simpler routing of electrical circuits by making it unnecessary to route high amperage wires into and out of a machine cab.



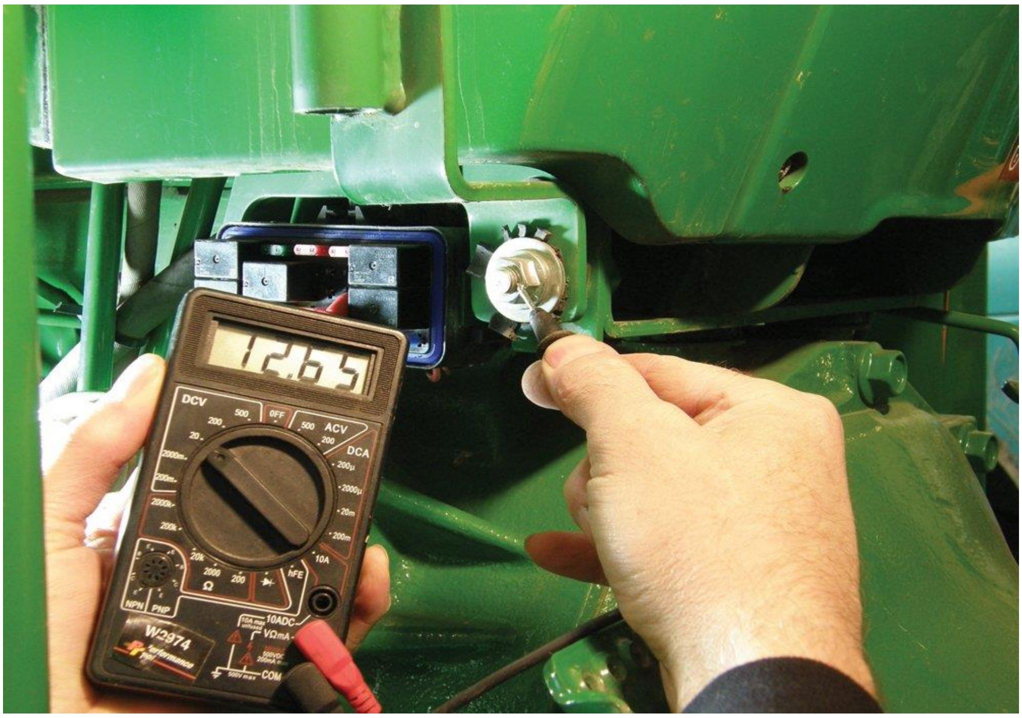


Using a multimeter

The only tool required to check a relay is a multimeter. With the relay removed from the fuse box, the multimeter set to measure DC voltage and the switch in the cab activated, first check to see if there are 12 volts at the 85 position in the fuse box where the relay plugs in (or wherever the relay is located). If there isn't, check to see if the appropriate fuse has blown. If the fuse is intact, ensure the switch is allowing current to flow to the relay.

Once you can confirm there is voltage at the 85 position, set the multimeter to the continuity mode and check to see if the 86 slot has a good ground connection.

If voltage is able to flow through that side of the relay, move on to the 87 connection point and determine if battery voltage is present there. If it isn't, that also suggests a blown fuse or circuit breaker.



Checking the connection points in the fuse box with a multimeter will confirm if battery voltage is available at the relay terminals. The 12.65 reading indicates voltage is available at the 87 connection

LO 3.4: Apply integrated circuits

Content/Topic1: Identification and general description of main IC chips based types , model,

An Integrated circuit is a special component that is fabricated with thousands of transistors, resistors, diodes, and other electronic components on a tiny silicon chip. These are the building blocks of current electronic devices like cell phones, computers, etc. These can be analog or digital integrated circuits. Mostly used ICs in electronic circuits are Op-amps, timers, comparators, switches ICs, and so on. These can be classified as linear and nonlinear ICs.
An integrated circuit or monolithic integrated circuit (also referred to as an IC, a chip, or a microchip) is a set of electronic circuits on one small flat piece (or "chip") of semiconductor material that is normally silicon. The integration of large numbers of tiny MOS transistors into a small chip results in circuits that are orders of magnitude smaller, faster, and less expensive than those constructed of discrete electronic components. The IC's mass production capability, reliability, and building-block approach to integrated circuit design has ensured the rapid adoption of standardized ICs in place of designs using discrete transistors. ICs are now used in virtually all electronic equipment and have revolutionized the world of electronics. Computers, mobile phones, and other digital home appliances are now inextricable parts of the structure of modern societies, made possible by the small size and low cost of ICs.

Integrated circuits were made practical by technological advancements in metal–oxide–silicon (MOS) semiconductor device fabrication. Since their origins in the 1960s, the size, speed, and capacity of chips have progressed enormously, driven by technical advances that fit more and more MOS transistors on chips of the same size – a modern chip may have many billions of MOS transistors in an area the size of a human fingernail. These advances, roughly following Moore's law, make computer chips of today possess millions of times the capacity and thousands of times the speed of the computer chips of the early 1970s.

ICs have two main advantages over discrete circuits: cost and performance. Cost is low because the chips, with all their components, are printed as a unit by photolithography rather than being constructed one transistor at a time. Furthermore, packaged ICs use much less material than discrete circuits. Performance is high because the IC's components switch quickly and consume comparatively little power because of their small size and proximity. The main disadvantage of ICs is the high cost to design them and fabricate the required photomasks. This high initial cost means ICs are only commercially viable when high production volumes are anticipated.

Integrated circuits can be classified into analog,[66] digital[67] and mixed signal,[68] consisting of both analog and digital signaling on the same IC.

Digital integrated circuits can contain anywhere from one[69] to billions[46] of logic gates, flip-flops, multiplexers, and other circuits in a few square millimeters. The small size of these circuits allows high speed, low power dissipation, and reduced manufacturing cost compared with board-level integration. These digital ICs, typically microprocessors, DSPs, and microcontrollers, work using boolean algebra to process "one" and "zero" signals.

The die from an Intel 8742, an 8-bit NMOS microcontroller that includes a CPU running at 12 MHz, 128 bytes of RAM, 2048 bytes of EPROM, and I/O in the same chip
Among the most advanced integrated circuits are the microprocessors or "cores", which control everything from personal computers and cellular phones to digital microwave ovens. Digital memory chips and application-specific integrated circuits (ASICs) are examples of other families of integrated circuits that are important to the modern information society.

In the 1980s, programmable logic devices were developed. These devices contain circuits whose logical function and connectivity can be programmed by the user, rather than being fixed by the integrated circuit manufacturer. This allows a single chip to be programmed to implement different LSI-type functions such as logic gates, adders and registers. Programmability comes in at least four forms - devices that can be programmed only once, devices that can be erased and then re-programmed using UV light, devices that can be (re)programmed using flash memory, and field-programmable gate arrays (FPGAs) which can be programmed at any time, including during operation. Current FPGAs can (as of 2016) implement the equivalent of millions of gates and operate at frequencies up to 1 GHz.

Analog ICs, such as sensors, power management circuits, and operational amplifiers (op-amps), work by processing continuous signals. They perform analog functions such as amplification, active filtering, demodulation, and mixing. Analog ICs ease the burden on circuit designers by having expertly designed analog circuits available instead of designing and/or constructing a difficult analog circuit from scratch.

ICs can also combine analog and digital circuits on a single chip to create functions such as analog-to-digital converters and digital-to-analog converters. Such mixed-signal circuits offer smaller size and lower cost, but must carefully account for signal interference. Prior to the late 1990s, radios could not be fabricated in the same low-cost CMOS processes as microprocessors. But since 1998, a large number of radio chips have been developed using RF CMOS processes. Examples include Intel's DECT cordless phone, or 802.11 (Wi-Fi) chips created by Atheros and other companies.

Modern electronic component distributors often further sub-categorize the huge variety of integrated circuits now available:

Digital ICs are further sub-categorized as logic ICs (such as microprocessors and microcontrollers), memory chips (such as MOS memory and floating-gate memory), interface ICs (level shifters, serializer/deserializer, etc.), power management ICs, and programmable devices.
Analog ICs are further sub-categorized as linear integrated circuits and RF circuits (radio frequency circuits).
Mixed-signal integrated circuits are further sub-categorized as data acquisition ICs (including A/D converters, D/A converters, digital potentiometers), clock/timing ICs, switched capacitor (SC) circuits, and RF CMOS circuits.
Three-dimensional integrated circuits (3D ICs) are further sub-categorized into through-silicon via (TSV) ICs and Cu-Cu connection ICs.

Generations

In the early days of simple integrated circuits, the technology's large scale limited each chip to only a few transistors, and the low degree of integration meant the design process was relatively simple. Manufacturing yields were also quite low by today's standards. As metal–oxide–semiconductor (MOS) technology progressed, millions and then billions of MOS transistors could be placed on one chip,[87] and good designs required thorough planning, giving rise to the field of electronic design automation, or EDA.

Name	Signification	Year	Transistor count[88]	Logic gates number[89]
ULSI	*ultra-large-scale integration*	1984	1 000 000 and more	100 000 and more
SSI	*small-scale integration*	1964	1 to 10	1 to 12
MSI	*medium-scale integration*	1968	10 to 500	13 to 99
VLSI	*very large-scale integration*	1980	20 000 to 1 000 000	10 000 to 99 999
LSI	*large-scale integration*	1971	500 to 20 000	100 to 9999

IC Classifications

Four basic types of constructions are employed in the manufacture of integrated circuits, namely ; (*i*) mono-lithic (*ii*) thin-film (*iii*) thick-film (*iv*) hybrid.

Advantages :

Integrated circuits possess the following advantages over discrete circuits :

(*i*) Increased reliability due to lesser number of connections.

(*ii*) Extremely small size due to the fabrication of various circuit elements in a single chip of semi-conductor material.

(*iii*) Lesser weight and **space requirement

due to miniaturized circuit

(*iv*) Low power requirements.

(*v*) Greater ability to operate at extreme values of temperature.

(*vi*) Low cost because of simultaneous production of hundreds of alike circuits on a small semiconductor wafer.

(*vii*) The circuit lay out is greatly simplified because integrated circuits are constrained to use minimum number of external connections

Disadvantages

The disadvantages of integrated circuits are :

(*i*) If any component in an *IC* goes out of order, the whole *IC* has to be replaced by the new one.

(*ii*) In an *IC*, it is neither convenient nor economical to fabricate capacitances exceeding 30 *pF*. Therefore, for high values of capacitance, discrete components exterior to *IC* chip are connected.

(*iii*) It is not possible to fabricate inductors and transformers on the surface of semi-conductor chip. Therefore, these components are connected exterior to the semi-conductor chip.

(*iv*) It is not possible to produce high power *ICs* (greater than 10 W).

(*v*) There is a lack of flexibility in an *IC i.e.*, it is generally not possible to modify the parameters within which an integrated circuit will operate.

The following points are worth noting about integrated circuits :

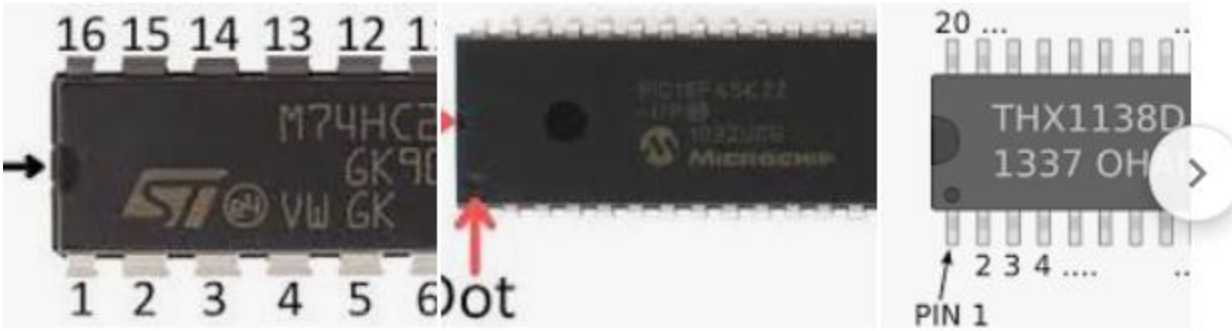
(*i*) In an *IC*, the various components are automatically part of a small semi-conductor chip and the individual components cannot be removed or replaced

(*ii*) The size of an **IC* is extremely small. In fact, *ICs* are so small that you normally need a microscope to see the connections between the components

(*iii*) No components of an *IC* are seen to project above the surface of the chip. This is because all the components are formed within the chip

- **Identification of IC pins**

The **pins** are numbered anti-clockwise around the **IC** (chip) starting near the notch or dot. The diagrams show the numbering for 8-**pin** and 14-**pin ICs**, but the principle is the same for all sizes.



Topic 3: Selection of ICs

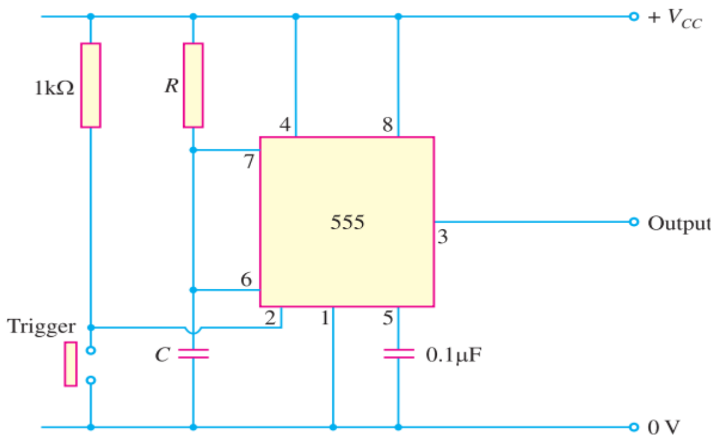
- **Some application of Circuits Using ICs**

1. IC Fixed 5-volt Voltage Regulator. The *IC* voltage regulator is a device that is used to hold the output voltage from a dc power supply constant as the input voltage or load current changes

2.**The 555 Timer** is consist of The *R* and *C* are the external components whose values determine the time *T* (in seconds) for which the circuit is ON or OFF They are two types of N555

1. The 555 Timer as monostable multivibrator. Fig below shows the circuit of the 555 timer as a monostable multivibrator. The *R* and *C* are the external components whose values determine the time *T* (in seconds) for which the circuit is on. This time is given by ;

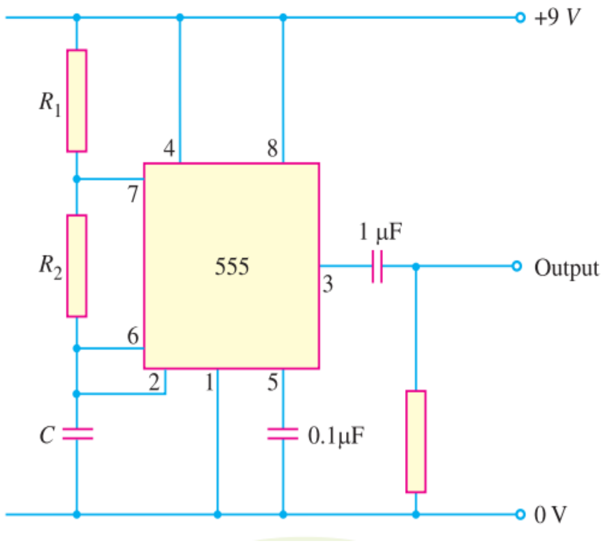
$T = 1.1\ RC$



1. The 555 Timer as astablemultivibrator.

Fig below shows the 555 timer as an astable

multibrator. Note that the circuit contains *two resistors (R1 and R2) and one capacitor (C)* and *does not have an input from any other circuit.* The lack of a triggering signal from an external source is the circuit recognition feature of the astablemultivibrator.



The time T for which the output is 'high' is given by ;

$T1 = 0.694\ (R1 + R2)\ C$

The time

T 2 for which the output is 'low' is given by

$T2$

$= 0.694\ R2C$

∴Total period T for the oscillation is

$T = T1 + T2 = 0.694\,(R1 + 2\,R2)\,C$

The frequency *f* of the astable multivibrator is given by

$$f = \frac{1}{T} = \frac{1}{0.694\,(R_1 + 2R_2)\,C} = \frac{1.44}{(R_1 + 2R_2)\,C}$$

- **Proper testing of IC devices using various related techniques**

One common testing technique for the testing of semiconductor integrated circuits (ICs) is a scan testing technique. This essentially involves launching a test pattern (termed "vector") into the pins of a device package and monitoring an output response at a specific time, dependent on the clock speed of the device.

Reference(s):

- Smith, M. & Pringle, D. (2007) Global Mobile Communication is 20 years old, URL http://www.gsmworld.com/index.shtml, Accessed 28 September 2007
- Tarica, E. (2007) Trouble in Cyberia, URL http://www.theage.com.au/news/education-news/trouble-in-cyberia/2007/10/19/1192301048347.html?page=fullpage#contentSwap3, Accessed 28 September 2007
- https://www.elprocus.com/different-types-of-integrated-circuits/
- Electronic Instrument Handbook, Third Edition, Clyde F. coombs Jr
- http://circuit-zone.com/index.php?cat=LC_Meter
- Electronic Devices (Electron Flow Version) (9th Edition) 9th Edition by Thomas L. Floy