B.TECH. COMPUTER SCIENCE AND ENGINEERING,
SEMESTER II
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Practical File

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ECL-119: BASIC ELECTRICAL AND ELECTRONICS ENGINEERING

Contents

Activity 1

Familiarisation with Resistor

1.1 Aim

The main objectives are as per following:

- Explain the function and unit of Resistor
- Measure the value of a Resistor
- Measure the Tolerance of a Resistor
- Explain the types of Resistors

1.2 Apparatus

- Metal-Film Resistor (220 Ω)
- Carbon-Film Resistor (220 Ω)
- Wire-wound Resistor (10k Ω)
- Potentiometer (10k Ω)

1.3 Theory

A resistor is a passive two-terminal electrical component that implements electrical resistance as a circuit element. In electronic circuits, resistors are used to reduce current flow, adjust signal levels, to divide voltages, bias active elements, and terminate transmission lines, among other uses. High-power resistors that can dissipate many watts of electrical power as heat, may be used as part of motor controls, in power distribution systems, or as test loads for generators. Fixed resistors have resistances that only change slightly with temperature, time or operating voltage. Variable resistors can be used to adjust circuit elements (such as a volume control or a lamp dimmer), or as sensing devices for heat, light, humidity, force, or chemical activity.

1.3.1 Types of Resistors

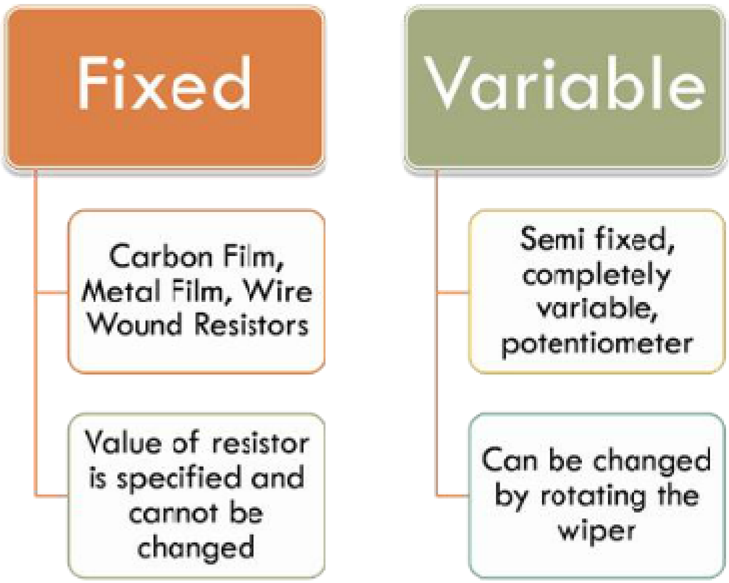


Figure 1.3.1

Carbon Film Resistors (Figure 1.3.2a)

- Most general purpose, cheap resistor
- Tolerance of Resistance value is usually +/- 5%
- Power ratings of 1/8 W ,1/4 W and ½ W are usually used
- Con: Tend to be electrically noisy

Metal Film Resistors (Figure 1.3.2b)

- Used when higher tolerance is needed, i.e. more value.
- They have about +/- 0.05% tolerance

Wire Wound Resistors (Figure 1.3.2c)

- A wire wound resistor is made of metal resistance wire, and because of this they can be manufactured to precise values
- Also, high wattage resistors can be made by thick wire material
- Wire wound resistors in a ceramic case are called as ceramic resistors

Figure 1.3.2

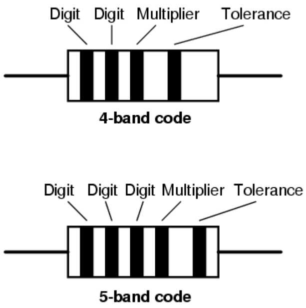
1.4 Procedure

1.4.1 Reading Value of Fixed Resistors

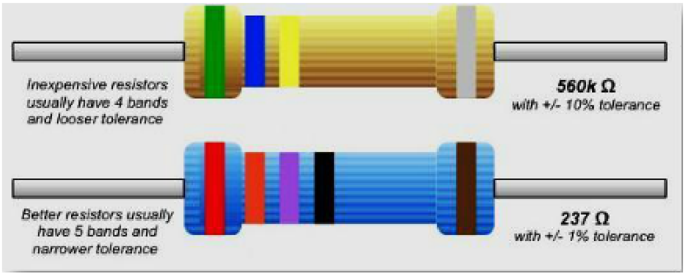
Resistors are color-coded as they are too small for the value to be written on them. There are 4 or 5 bands of color . Value of a Resistor is decoded from these band of colors. (Refer Figure 1.4.1a and 1.4.1b)

Procedure

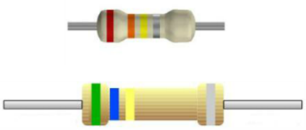
1. If your resistor has four color bands, turn the resistor so that the gold or silver band is on right hand side or the end with more bands should point left. (see Figure 1.4.1c)
2. The first band is now on the left hand side. This represents the first digit .Based on the color make a note of the digit (Figure 1.4.1d).
3. The second band represents the second digit. The colors represent the same numbers as did the first digit (Figure 1.4.1d)
4. The third band divulges how many zeros to add/divide to the first two numbers – for a 4 band Resistor (Figure 1.4.1d)
5. The third band denotes the 3rd digit – for a 5 band Resistor (Figure 1.4.1d).



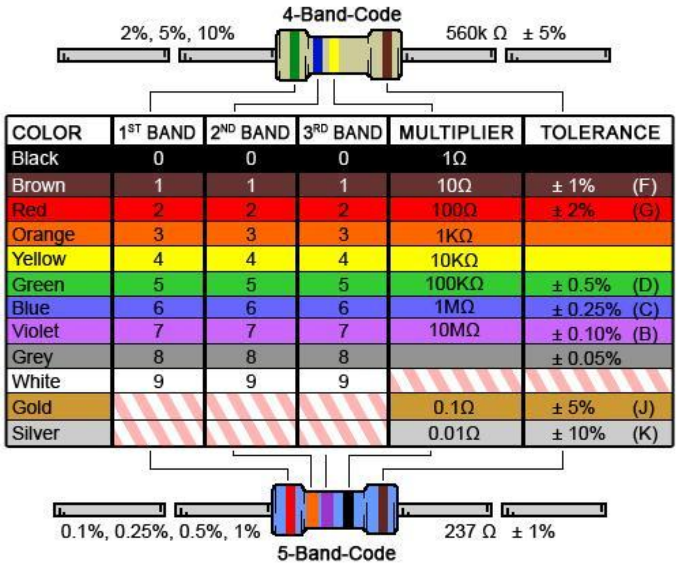
(a) Band coding on resistors



(b) 4-band/5-band resistors



(c) Correct method to hold resistor



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				0.1Ω	± 5% (J)
Silver				0.01Ω	± 10% (K)

(d) Resistor Value table

Figure 1.4.1: *Resistors have bands on them, showing the resistor value and tolerances in a color-coded format.*

Tolerance

The last band denotes the tolerance . So the value of the 4 band resistor it is +/- 5% while for the 5 band resistor it is +/- 1%.

- Tolerance of a Resistor is also an important property to consider .
- A 100 ohm resistor with a 10 % tolerance can mean its value can be any fixed value between 90 to 110 Ohms.
- A 120 Ohm resistor with a 10 % tolerance can mean its value can be any fixed value between 108 and 132 Ohms.
- So there is some overlap between 100 Ohm and 120 Ohm resistance in terms of its limits.

1.5 Conclusion

Resistors are common elements of electrical networks and electronic circuits and are ubiquitous in electronic equipment. The electrical function of a resistor is specified by its resistance: common commercial resistors are manufactured over a range of more than nine orders of magnitude. The nominal value of the resistance falls within the manufacturing tolerance, indicated on the component.

Activity 2

Familiarisation with Capacitor

2.1 Aim

The main objectives are as per following:

- Provide a definition of capacitor and name its units
- Explain how a capacitor can be constructed to give a particular value of capacitance
- Determine experimentally the energy stored in a capacitor
- Identify the value and type of capacitor
- Identify the polarity of terminals

2.2 Apparatus

- Ceramic Capacitor ($1000\mu F$)
- Electrolytic Capacitor ($1000\mu F$)
- Ammeter
- Bulb
- Switch
- 12V Battery

2.3 Theory

2.3.1 What is a Capacitor

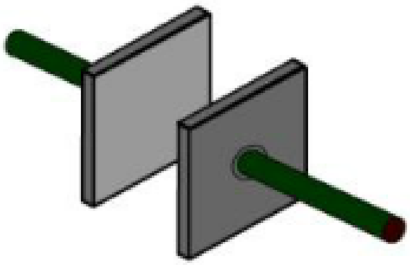
Figure 2.3.1: A simple ceramic capacitor

It is one of the passive components like resistor. Capacitor is also known as condenser. Capacitor is generally used to store the charge. The charge is stored in the form of “electrical field”. Capacitors play a major role in many electrical and electronic circuits.

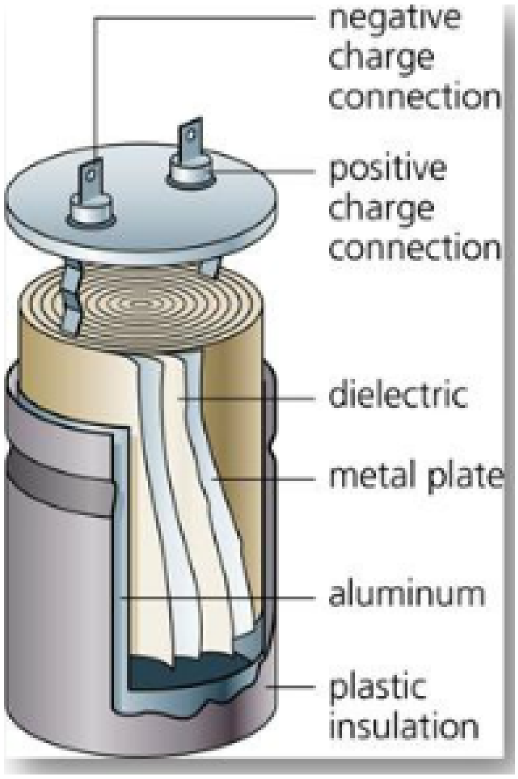
2.3.2 Construction of a Capacitor

The basic construction of all capacitors is of two parallel metal plates separated by an insulating material (Figure 2.3.2a). An insulator is a material which is non-conducting i.e. it shows a high resistance to letting to electric used is air, other types are oil or paper. Real capacitors are made by taking thin strips of metal foil and the appropriate dielectric material and sandwiching them together.

Capacitor achieve large area (thus large capacitance) by doing something tricky, such as putting a dielectric between 2 layers of metal foil and rolling it up like in Figure 2.3.2b.



(a) Metallic plates of a capacitor



(b) Increasing the area of capacitor by wounding

Figure 2.3.2: *Internal view of a simple capacitor*

2.3.3 Capacitance

A capacitor is so called because it has the capacity to store charge- just like a beaker storing a liquid. Capacitors are marked with a value which indicates their capacitance – their ability to store charge . Capacitance can be thought of as the “electrical capacity” of that body. It is measured in Farads.

Figure 2.3.3: A capacitor with $100\mu F$ capacitance

2.3.4 Maximum Working Voltage

If the voltage across a capacitor is too high, the insulator between the plates fails to insulate and charge passes from one plate to the other . Capacitor are usually marked with the maximum working voltage to help the user avoid situation.
A good rule of thumb is to never place a voltage across the capacitor which exceeds about two thirds of this value, especially for alternating current circuits.

2.3.5 Mathematical Notation

A static description of the way a capacitor behaves would be to say $Q = C \times V$, where Q is the total charge, C is a measure of how big the capacitor is and V is the voltage across it.

A dynamic description ,ie one that changes with time would be to say $I = C \times \frac{dV}{dt}$. This is just the time derivative of the static description.C is constant wrt time, I is the rate at which charge flows . This essentially says – the bigger the current , the faster the capacitor's voltage changes.

2.3.6 Classification of Capacitor

Polarized: They have positive and negative electrode.
Un-Polarized: They don't have positive and negative electrode

UN-POLARIZED	POLARIZED
Ceramic	Electrolytic
Multilayer	Tantalum
Polystyrene Film	Super
Polyster Film	
Polypropylene	
Mica	

Table 2.3.1: Examples of Polarized and Un-Polarized Capacitors

Ceramic Capacitors

Ceramic capacitors (Figure 2.3.4) are the most used capacitors in the electronics industry. Ceramic capacitors are fixed capacitance type capacitors and they are

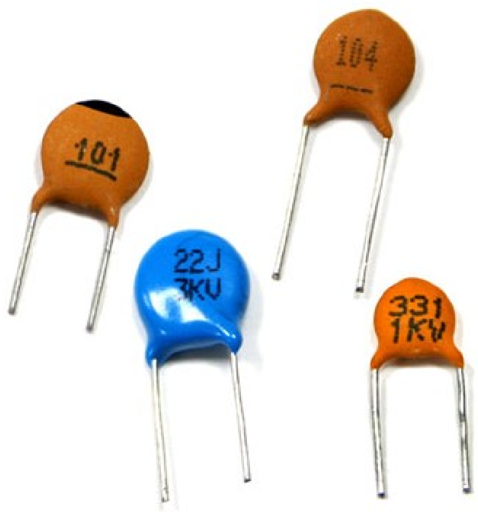


Figure 2.3.4: Differet Ceramic Capacitors

usually very small (in terms of both physical dimensions and capacitance). The capacitance of ceramic capacitors is usually in the range of picofarads to few micro farads (less than 10µF). They are non-polarised type capacitors and hence can be used in both DC as well as AC circuits.

Electrolytic Capacitor

Figure 2.3.5: Electrolytic Capacitor

Electrolytic capacitors (Figure 2.3.5) are polarized and they must be connected the correct way round , atleast one of their leads will be marked + or −. It is very easy to find the values of electrolytic capacitors because they are clearly printed with their capacitance and voltage rating.

Tantalum Capacitor

Figure 2.3.6: Tantalum Capacitor

Tantalum bead capacitors (Figure 2.3.6) are polarized and have low voltage ratings like electrolytic capacitors . Usually , the + symbol is used to show the positive component lead . Modern tantalum bead capacitors are printed with their capacitance voltage and polarity in full. However older ones use a color–code system which has two stripes (for the two digits) and a spot of color for the number of zeros to give the value in μF.

Un-polarized Capacitors - small values (upto $1\mu F$)

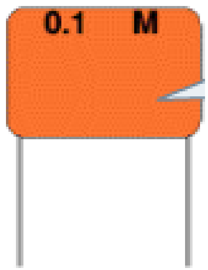
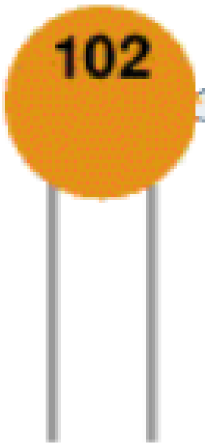


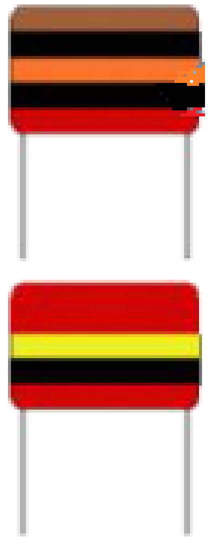
Figure 2.3.7: Numbers printed on un-polarized capacitor

The value printed but without a multiplier, so you need to use experience to work out what the multiplier should be! For example 0.1 means $0.1pF$. Sometimes the multiplier is used in place of the decimal point: For example: $4n7$ means $4.7nF$.

Un-polarized Capacitors - Capacitor Number Code



(a) Codes printed on un-polarized capacitor



(b) Color coded un-polarized capacitors

Figure 2.3.8: *Different ways of printing its capacitance on capacitors*

A number code (Figure 2.3.8a) is often used on small capacitors where printing is difficult: The 1st number is the 1st digit, the 2nd number is the 2nd digit, the 3rd number is the number of zeros to give the capacitance in pF. Ignore any letters - they just indicate tolerance and voltage rating. For example: 102 means $1000pF$ (not $102pF$) For example: $472J$ means $4700pF$ (J means 5% tolerance).

A color code was used on polyester capacitors for many years (Figure 2.3.8b). It is now obsolete, but of course there are many still around. The colors should be read like the resistor code, the top three color bands giving the value in pF. Ignore the 4^{th} band (tolerance) and 5^{th} band (voltage rating). For example: brown, black, orange means $10000pF$. Note that there are no gaps between the color bands, so 2 identical bands actually appear as a wide band. For example: wide red, yellow means $220nF$.

2.3.7 Capacitors in series

Capacitors in series means two or more capacitors connected in a single line. Positive plate of the one capacitor is connected to the negative plate of the next

Figure 2.3.9: Capacitor in series

capacitor.

$$Q_T = Q_1 = Q_2 = \ldots = Q$$
$$I_C = I_1 = I_2 = \ldots = I$$

where,
Q_T is the total charge,
I_C is the capacitive current

When the capacitors are connected in series Charge and current is same on all the capacitors.

For series capacitors same quantity of electrons will flow through each capacitor because the charge on each plate is coming from the adjacent plate. So, coulomb charge is same. As current is nothing but flow of electrons, current is also same.

Equivalent Capacitance for two capacitors in series,

$$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2}$$
$$\frac{1}{C_{eq}} = \frac{C_1 C_2}{C_1 + C_2}$$

2.3.8 Capacitors in parallel

When the capacitors are connected in parallel the total capacitance value is increased. There are some applications where higher capacitance values are required.

All the capacitors which are connected in parallel have the same voltage and is

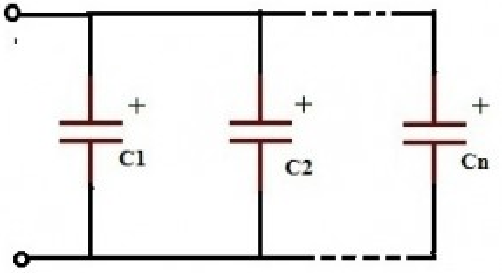


Figure 2.3.10: Capacitor in parallel

equal to the V_T applied between the input and output terminals of the circuit.

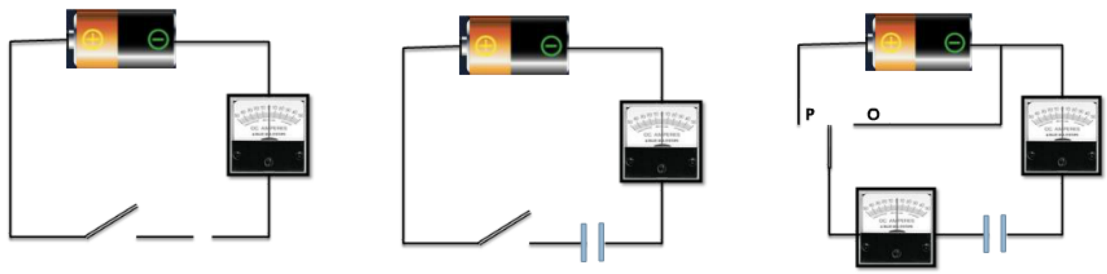
$$V_T = V_1 = V_2$$

Equivalent Capacitance for two capacitors in parallel,

$$C_{eq} = C_1 + C_2$$

2.4 Procedure

2.4.1 Functioning of Capacitor



(a) Circuit with no capacitor

(b) Circuit with 2-step key and 1 ammeter

(c) Circuit with 2-step key and 2 ammeter

Figure 2.4.1: *Understanding of working of capacitor using different circuits*

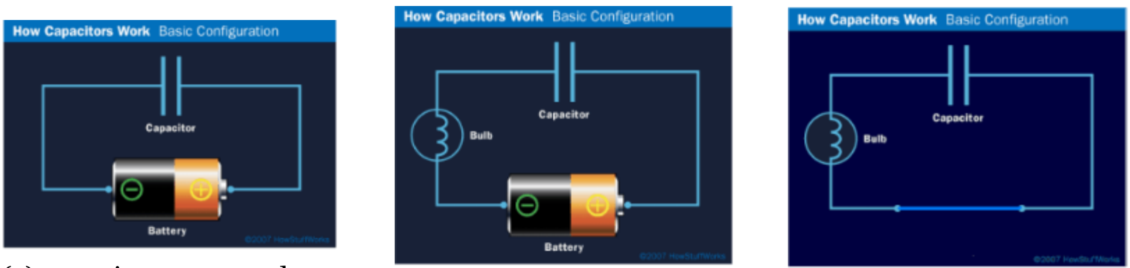
1. Consider a circuit set up like in the Figure 2.4.1a. The Ammeter will show a reading of 0.
2. Now let's place large metal plate at each of the connectors a few millimetres apart as in Figure 2.4.1b. The Ammeter will flick on one side and come back

to 0.

3. Let us extend this by placing a galvanometer on both sides of the capacitor and using a two-way switch as in Figure 2.4.1c. When the switch is connected to P, both the ammeters flick briefly to right.
4. After moving to P now the switch is moved to O. For both of the Ammeters, both flick briefly to left.
5. Instead of moving to P the first time, if the switch is first moved to O, neither Ammeters moves.
6. The behaviour of the ammeter needles in the previous experiment suggests that a current flow firstly one way, then the other as the switch is moved from P to O. So, this suggests equal amounts of charge flows off one plate and onto the other

2.4.2 Charging and Discharging

We say that the capacitor is charged up when connected to P and discharged when moved to O.



(a) capacitor connected to a battery

(b) charging of a capacitor

(c) discharging of a capacitor

Figure 2.4.2: *Understanding of charging and discharging of a capacitor using different circuits*

Charging

The plate on the capacitor that attaches to the negative terminal of the battery accepts electrons that the battery is producing .The plate on the capacitor that attaches to the positive terminal of the battery loses electrons to the battery. Once it's charged , the capacitor has the sam voltage as the battery. (This is in reference to Figure 2.4.2a)

Now, we connect a bulb to the circuit as per Figure 2.4.2b. The bulb will first glow and then keep dimming and finally turn off.

Discharging

If you then remove the battery and replace it with a wire , current will flow from one plate of the capacitor to the other. The bulb will light initially and then dim as the capacitor discharges , until it is completely out. (This is in reference to Figure 2.4.2c)

2.5 Conclusion

Capacitors are common elements of electrical networks and electronic circuits and are ubiquitous in electronic equipment. The electrical function of a capacitor is specified by its capacitance: common commercial capacitors are manufactured over a wide variety of types. The nominal value of the capacitance falls within the manufacturing tolerance, indicated on the component.

Activity 3

Familiarisation with Inductor

3.1 Aim

- Explain Function of Inductor
- Explain the factors influencing inductance

3.2 Apparatus

- Resistor
- Inductor of different forms
- 12V Battery

3.3 Theory

3.3.1 Function of an Inductor

The function of a valve is to control the amount of fluid that flows through a pipe. In an electronic circuit, the resistor is used to control the amount of current that flows through a conductor. Another device that controls the current is the inductor. However unlike the resistor that affects the current uniformly at all times, the inductor only affects currents when thy are changing in value.

(a) A valve

(b) A resistor

(c) An Inductor

Figure 3.3.1: *Functioning of an Inductor*

3.3.2 Similarity with Capacitor

- Rate of change of voltage in a capacitor depends upon the current through it. Rate of change of current in an inductor depends upon the voltage applied across it.
- Like capacitive current , inductive current is not simply proportional to voltage.
- Unlike the situation in a resistor, the power associated with inductive current (V times I) is not turned into heat but is stored as energy in the inductor's magnetic field.

3.3.3 Equation of an Inductor

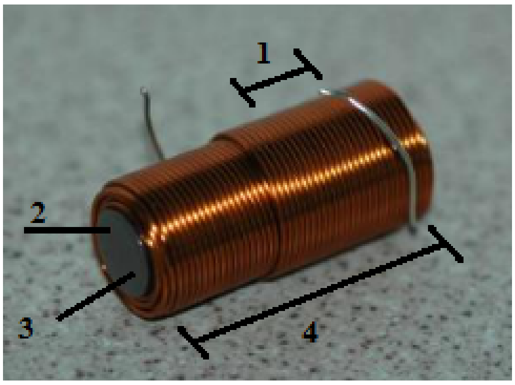
$$V = L\frac{dI}{dt}$$

- L is the inductance and is measured in henry.
- Putting a voltage across an inductor causes the current to rise as a ramp.
- 1 volt across 1 henry produces a current that increases at 1 amp per second

3.3.4 Structure of an Inductor

It consists of a wire wound as a coil around a core. The core may consist of a air filled hollow tube or solid material. (See Figure 3.3.2a)

(a) Structure of different types of Inductors



(b) Internal view of an inductor

Figure 3.3.2: *Inductor*

3.3.5 Inductance

The amount of inductance in henries a coil has, is determined by the following factors (See Figure 3.3.2b)-

1. No of turns of wire wound around the coil
2. Cross sectional area of the coil
3. The material type of the coil
4. The Length of the coil

3.3.6 Inductive Kick

An Inductive is capable of producing a momentary voltage that is much higher than the voltage of th power source that supplied the current to create its magnetic field . This temporary voltage is called an inductive kick.

Example of applications of inductive devices to provide an inductive kick is a Combustion Engine ignition system that creates the spark across the gap of the spark plug (see Figure 3.3.3).

Figure 3.3.3: Inductive Kick creating a spark in the spark-plug

3.4 Conclusion

An inductor, also called a coil, choke, or reactor, is a passive two-terminal electrical component that stores energy in a magnetic field when electric current flows through it. An inductor typically consists of an insulated wire wound into a coil. Inductor is an important component of any electronic circuit. Inductance is always present in any circuit, where Inductor is present or not.

Activity 4

Experiments based on Ohm's Law

4.1 Aim

- Explain Ohm's Law
- Explain Ohm's Law for Resistance in series
- Explain Ohm's Law for Resistance in parallel
- Explain Non-Ohmic Device
- Measure and confirm Ohm's Law

4.2 Apparatus

Ammeter, Voltmeter, Resistors, Battery, Wires

4.3 Theory

4.3.1 Ohm's Law

1. The law states that the current through a conductor between two points is directly proportional to the voltage across the two points. Such a conductor is characterized by its 'Resistance' – R measured in Ohms.

2. $V = IR$
   - V is the Voltage in Volts across the conductor.
   - I is the current in Amperes through the conductor.
   - Voltage(V) is directly proportional to current(I) i.e. $V \propto I$
   - Resistance(R) in inversely proportional to current(I) i.e. $I \propto R$

4.3.2 Explanation of Ohm's Law

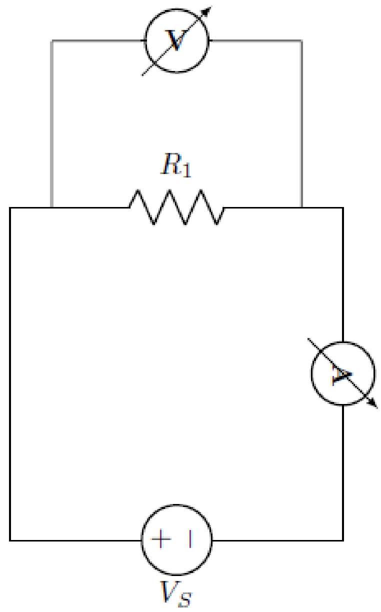


Figure 4.3.1: Current Through Resistor

From the circuit:

The voltage across resistor is equal to source voltage:

$$V_R = V_S$$

The current through the resistance is given by:

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

4.3.3 Explaination of Ohm's Law for Resistance in series

Series circuits are sometimes called current-coupled or daisy chain-coupled. The current in a series circuit goes through every component in the circuit. Therefore, all of the components in a series connection carry the same current. There is only one path in a series circuit in which the current can flow.

Current:

$$I = I_1 = I_2 = I_3$$

Resistance:

$$R_{eq} = R_1 + R_2 + R_3$$

Voltage:

$$V_S = V_{R1} + V_{R2} + V_{R3}$$

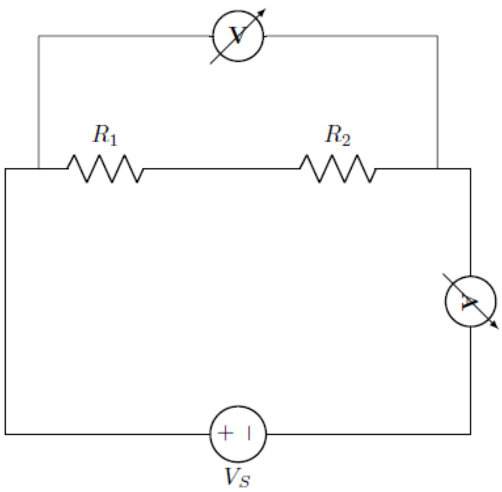


Figure 4.3.2: Series Resistors

From the circuit:

The equivalent resistance,

$$R_{eq} = R_1 + R_2$$

The total current of the circuit,

$$I_T = \frac{V_S}{R_{eq}}$$

Voltage across each resistance are, For resistance R_1,

$$V_{R1} = R_1 \times I_T$$

For resistance R_2,

$$V_{R2} = R_2 \times I_T$$

In a series circuit, the current through each of the resistors is the same, and the voltage across the circuit is the sum of the voltages across each resistor.

4.3.4 Explaination of Ohm's Law for Resistance in parallel

If two or more components are connected in parallel they have the same potential difference (voltage) across their ends. The potential differences across the components are the same in magnitude, and they also have identical polarities. The same voltage is applicable to all circuit components connected in parallel. The total current is the sum of the currents through the individual components, in accordance with Kirchhoff's current law.

Voltage:

$$V = V_1 = V_2 = V_3$$

Resistance:

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

Current:

$$I_T = I_{R1} + I_{R2} + I_{R3}$$

From the circuit:

The equivalent resistance,

$$R_{eq} = \frac{R_1 \times R_2}{R_1 + R_2}$$

The total current of the circuit,

$$I_T = \frac{V_S}{R_{eq}}$$

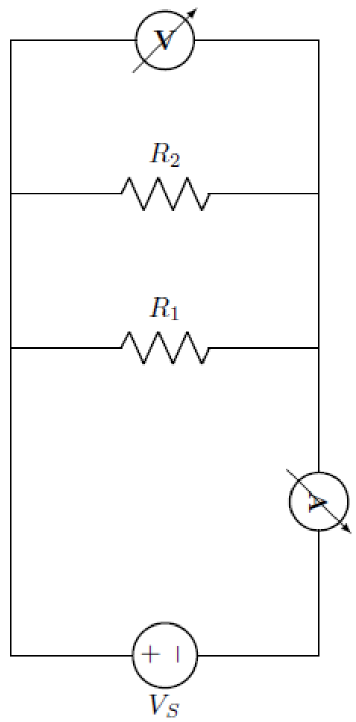


Figure 4.3.3: Parallel Resistors

Current across each resistance are, For resistance R_1,

$$I_{R1} = \frac{V_S}{R_1}$$

For resistance R_2,

$$I_{R2} = \frac{V_S}{R_2}$$

In a parallel circuit, the voltage across each of the resistors is the same, and the total current is the sum of the currents through each resistor.

4.3.5 Explaination of Non-Ohmic Device

A Non ohmic device is a device that does not obey Ohm's Law i.e. the resistance is not constant, but changes in a way that depends on the voltage across it.The device is said to be non-Ohmic. In this case V versus I graph is not a straight line, but has some curvy shape. Such devices do not have a constant value of resistance and the resistance is called dynamic resistance because it is constantly changing.Examples of such devices are tungsten filament (bulb), diode,thermistor etc.

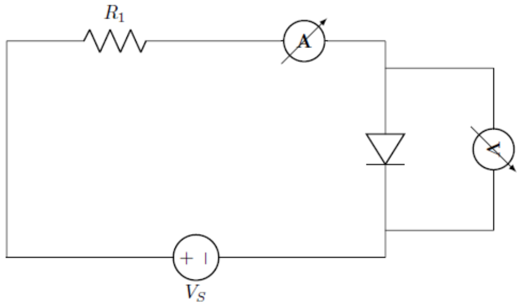


Figure 4.3.4: Non-Ohmic Devices

4.4 Procedure

4.4.1 Experiment of confirming Ohm's Law

1. Set DC voltage $0 - 30V$.
2. Set the Resistance Value $(1K\Omega - 100K\Omega)$.
3. Voltmeter is placed parallel to resistor and ammeter series with resistor.
4. Now note the Voltmeter and Ammeter reading for DC voltage.
5. Increase the DC voltage by 2 factor and note Voltmeter and Ammeter Readings. Keep resistance value constant

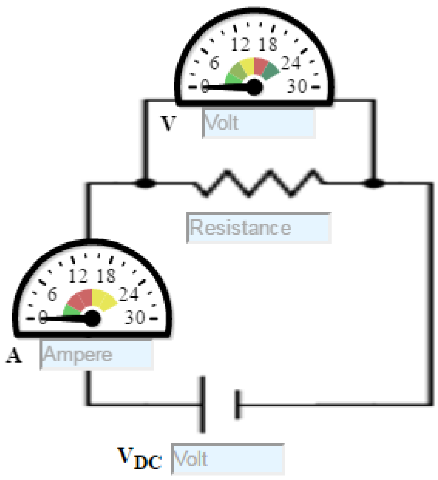


Figure 4.4.1

6. Plot the $V - I$ graph to verify Ohm's Law.
7. Repeat step 2 to 6 for another set of resistance value.
8. V versus I graph is a straight line.
9. Therefore from the graph we see that the resistance do adhere to Ohm's law.

Thus resistance is said to be an Ohmic device.

4.4.2 Experiment with Resistance in series

1. Set DC voltage $0 - 30V$.
2. Here resistance are kept in series. Set the resistance $R_1(1K\Omega - 100K\Omega)$ value and set resistance $R_2(5K\Omega - 15K\Omega)$.
3. Voltmeter is placed parallel with resistor and ammeter series with resistor.
4. Now note the Voltmeter and Ammeter reading for DC voltage.

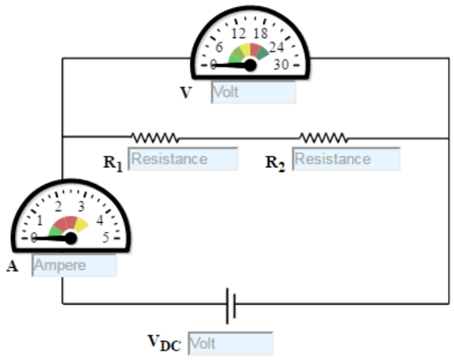


Figure 4.4.2

5. Increase the DC voltage by 2 factor and note Voltmeter and Ammeter Readings. Keeping resistance value constant
6. Plot the $V - I$ graph to verify Ohm's Law
7. Repeat step 2 to 6 for another set of resistance value.

4.4.3 Experiment with Resistance in parallel

1. Set DC voltage $0 - 30V$.
2. Here Resistances are kept parallelly. Set the resistance $R_1(100\Omega - 2K\Omega)$ value and set resistance $R_2(1K\Omega - 30K\Omega)$.
3. Voltmeter is placed parallel to resistor and ammeter series with resistor.
4. Now note the Voltmeter and Ammeter reading for DC voltage.
5. Increase the DC voltage by 2 factor and note Voltmeter and Ammeter Readings. Keeping Resistance value constant
6. Plot the $V - I$ graph to verify Ohm's Law.
7. Repeat step 2 to 6 for another set of resistance value.

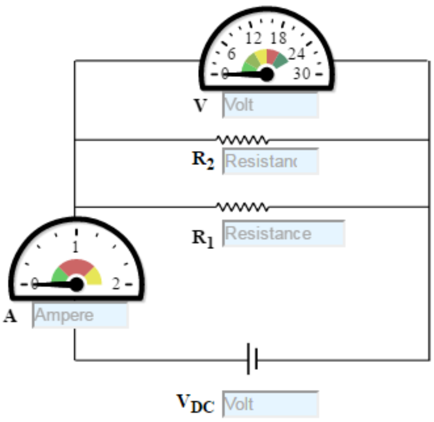


Figure 4.4.3

4.4.4 Experiment with Non-Ohmic Device

1. Set DC voltage to $5V$.
2. Use the resistor of $100K\Omega$ and a diode.
3. Voltmeter is placed parallel to Silicon diode and ammeter series with resistor.
4. Now note the Voltmeter and Ammeter reading for DC voltage $5V$.

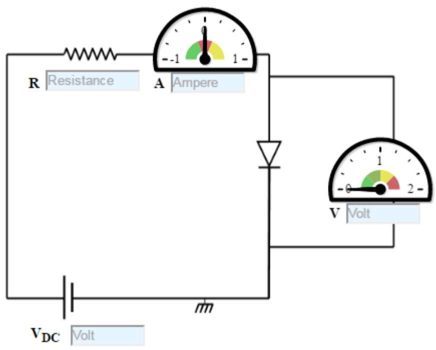


Figure 4.4.4

5. Decrease the Resistance as $75K\Omega$, $51K\Omega$, $24K\Omega$ and $10K\Omega$ and take the readings and note Voltmeter reading across Silicon diode and Ammeter reading.
6. Plot the $V - I$ graph and observe the change.
7. The Change is not simply proportional. V versus I graph is not a straight line.
8. Therefore from the graph we see that the diode does not adhere to Ohms law.Thus diode is said to be non-Ohmic device.

4.5 Observations

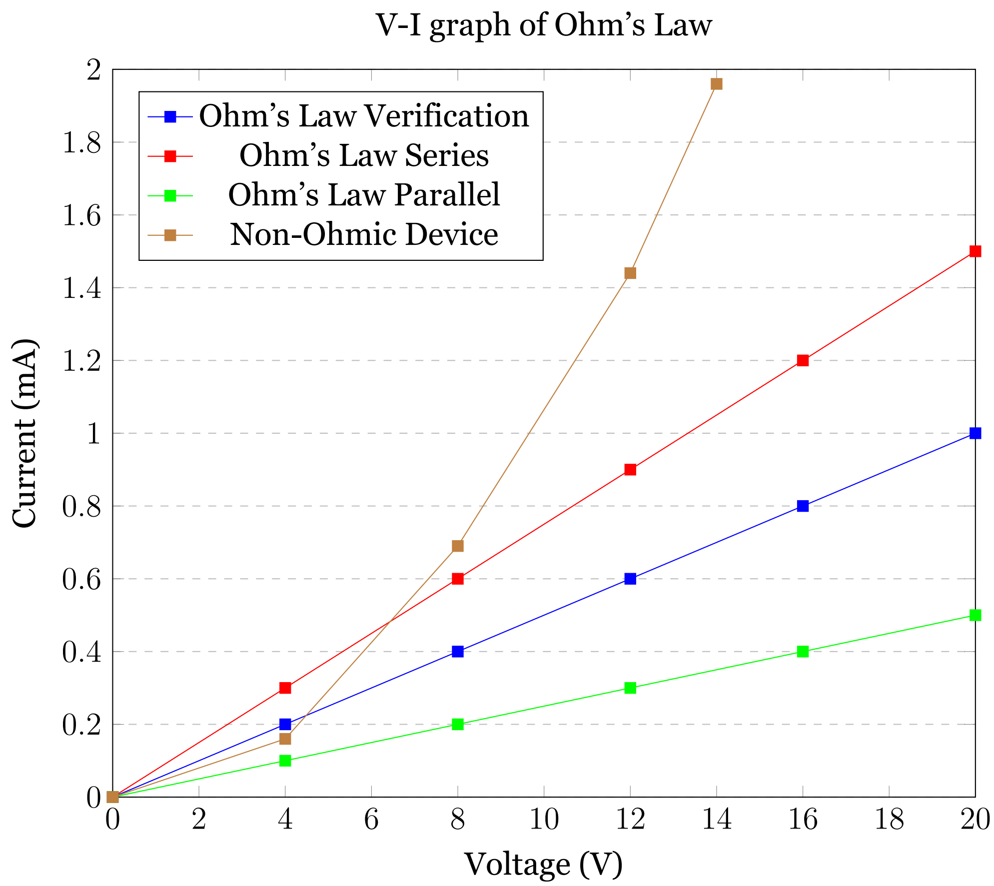


Figure 4.5.1: Observation $V - I$ Graph

Sr No.	Voltage(V)	Ohm's Exp (I)	Series (I mA)	Parallel (I mA)	Non-Ohmic (I mA)
1	0	0	0	0	0
2	4	0.2	0.3	0.1	0.16
3	8	0.4	0.6	0.2	0.69
4	12	0.6	0.9	0.3	1.44
5	16	0.8	1.2	0.4	2.56
6	20	1	1.5	0.5	4

Figure 4.5.2: Observation Values

4.6 Result

V versus I graph is a straight line. Which means voltage is directly proportional to current. Therefore, Ohm's law is verified for Ohmic-devices.

Activity 5

V-I Characteristics of a Diode

5.1 Aim

- Explain the structure of a P-N junction diode
- Explain the function of a P-N junction diode
- Explain forward and reverse biased characteristics of a Silicon diode
- Explain forward and reverse biased characteristics of a Germanium diode

5.2 Apparatus

- Silicon Diode
- Germanium Diode
- DC Battery Source
- Ammeter
- Volmeter
- Resistor

5.3 Theory

5.3.1 Structure of P-N junction diode

The diode is a device formed from a junction of n-type and p-type semiconductor material. The lead connected to the p-type material is called the anode and the lead connected to the n-type material is the cathode. In general, the cathode of a diode is marked by a solid line on the diode.

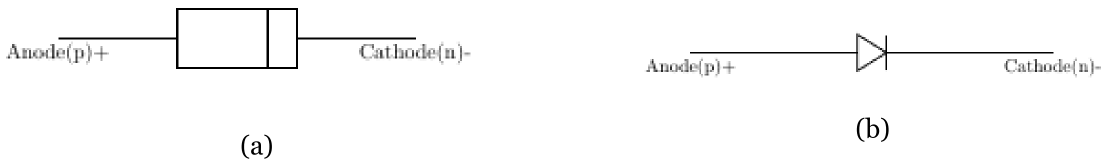


Figure 5.3.1: *(a) A diode (b) Symbol of a diode*

5.3.2 Function of a P-N junction diode in Forward Bias

The positive terminal of battery is connected to the P side(anode) and the negative terminal of battery is connected to the N side(cathode) of a diode, the holes in the p-type region and the electrons in the n-type region are pushed toward the junction and start to neutralize the depletion zone, reducing its width. The positive potential applied to the p-type material repels the holes, while the negative potential applied to the n-type material repels the electrons. The change in potential between the p side and the n side decreases or switches sign. With increasing forward-bias voltage, the depletion zone eventually becomes thin enough that the zone's electric field cannot counteract charge carrier motion across the p–n junction, which as a consequence reduces electrical resistance. The electrons that cross the p–n junction into the p-type material (or holes that cross into the n-type material) will diffuse into the nearby neutral region. The amount of minority diffusion in the near-neutral zones determines the amount of current that may flow through the diode.

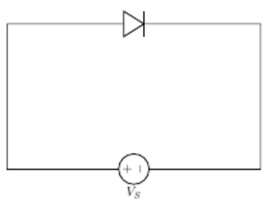


Figure 5.3.2: Forward biased diode

5.3.3 Function of a P-N junction diode in Reverse Bias

The positive terminal of battery is connected to the N side(cathode) and the negative terminal of battery is connected to the P side(anode) of a diode. Therefore, very little current will flow until the diode breaks down. The positive

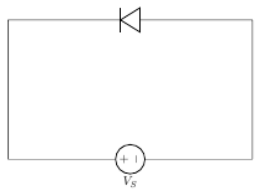


Figure 5.3.3: Reverse biased diode

terminal of battery is connected to the N side(cathode) and the negative terminal of battery is connected to the P side(anode) of a diode, the 'holes' in the p-type material are pulled away from the junction, leaving behind charged ions and causing the width of the depletion region to increase. Likewise, because the n-type region is connected to the positive terminal, the electrons will also be pulled away from the junction, with similar effect. This increases the voltage barrier causing a high resistance to the flow of charge carriers, thus allowing minimal electric current to cross the p–n junction. The increase in resistance of the p–n junction results in the junction behaving as an insulator.

The strength of the depletion zone electric field increases as the reverse-bias voltage increases. Once the electric field intensity increases beyond a critical level, the p–n junction depletion zone breaks down and current begins to flow, usually by either the Zener or the avalanche breakdown processes. Both of these breakdown processes are non-destructive and are reversible, as long as the amount of current flowing does not reach levels that cause the semiconductor material to overheat and cause thermal damage.

5.3.4 Forward and reverse biased characteristics of a Silicon diode

In forward biasing, the positive terminal of battery is connected to the P side and the negative terminal of battery is connected to the N side of the diode. Diode will conduct in forward biasing because the forward biasing will decrease the depletion region width and overcome the barrier potential. In order to conduct, the forward biasing voltage should be greater than the barrier potential. During forward biasing the diode acts like a closed switch with a potential drop of nearly 0.6 V across it for a silicon diode. The forward and reverse bias characteristics of a silicon diode. From the graph, you may notice that the diode starts conducting when the forward bias voltage exceeds around 0.6 volts (for Si diode). This voltage is called cut-in voltage.

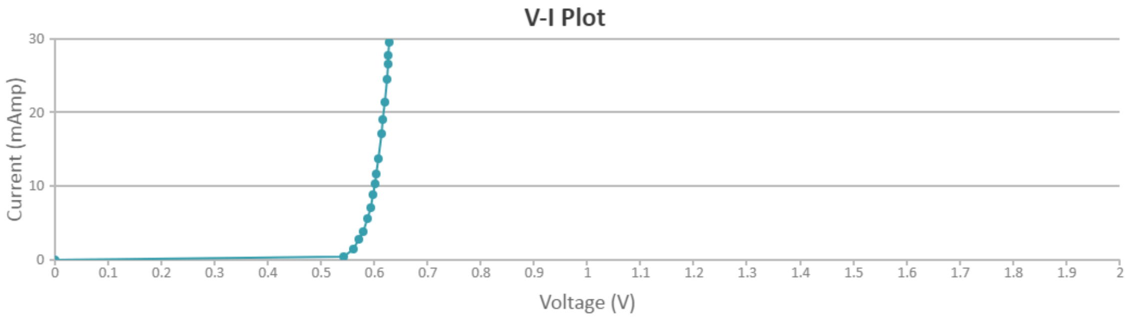


Figure 5.3.4: Forward Biased Silicon diode VI plot

In reverse biasing, the positive terminal of battery is connected to the N side and the negative terminal of battery is connected to the P side of a diode. In reverse biasing, the diode does not conduct electricity, since reverse biasing leads to an increase in the depletion region width; hence current carrier charges find it more difficult to overcome the barrier potential. The diode will act like an open switch and there is no current flow.

5.3.5 Forward and reverse biased characteristics of a Germanium diode

In forward biasing, the positive terminal of battery is connected to the P side and the negative terminal of battery is connected to the N side of the diode. Diode will conduct in forward biasing because the forward biasing will decrease the depletion region width and overcome the barrier potential. In order to conduct, the forward biasing voltage should be greater than the barrier potential. During forward biasing the diode acts like a closed switch with a potential drop of nearly 0.3 V across it for a germanium diode. The forward and reverse bias characteristics of a germanium diode. From the graph, you may notice that the diode starts conducting when the forward bias voltage exceeds around 0.3 volts (for Ge diode). This voltage is called cut-in voltage.

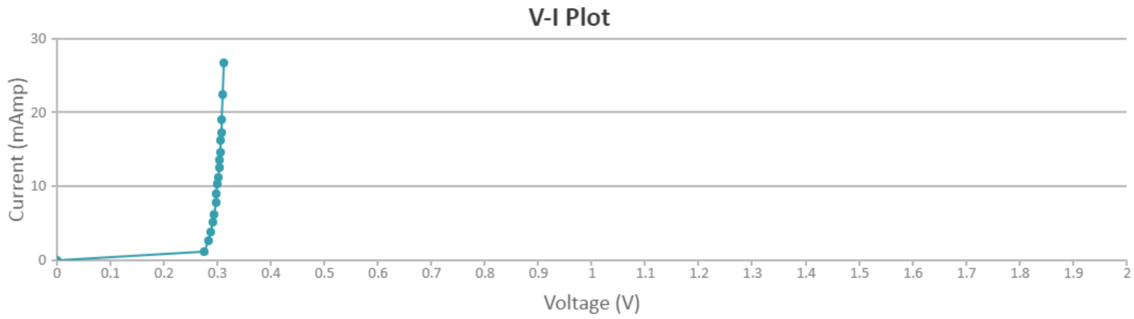


Figure 5.3.5: Forward Biased Germanium diode VI plot

In reverse biasing, the positive terminal of battery is connected to the N side and the negative terminal of battery is connected to the P side of a diode. In reverse biasing, the diode does not conduct electricity, since reverse biasing leads to an increase in the depletion region width; hence current carrier charges find it more difficult to overcome the barrier potential. The diode will act like an open switch and there is no current flow.

5.3.6 Diode Equation

In the forward-biased and reversed-biased regions, the current (I_f), and the voltage (V_f), of a semiconductor diode are related by the diode equation:

$$I_f = I_s \times (exp^{\frac{V_f}{n \times V_T}} - 1)$$

where, I_s is reverse saturation current or leakage current,
I_f is current through the diode(forward current),
V_f is potential difference across the diode terminals(forward voltage)
V_T is thermal voltage, given by

$$V_T = \frac{k \times T}{q}$$

and

k is *Boltzmann's constant = 1.38x10−23 J /Kelvin*,
q is the electronic charge = *1.6x10−19 joules/volt(Coulombs)*,
T is the *absolute temperature in Kelvin(K = 273 + temperature in °C)*,
At room temperature (25 °C), the thermal voltage is about 25.7 mV,
n is an *empirical constant* between 0.5 and 2

The empirical constant, n, is a number that can vary according to the voltage and current levels. It depends on electron drift, diffusion, and carrier recombination in the depletion region. Among the quantities affecting the value of n are the diode manufacture, levels of doping and purity of materials.

If n=1, the value of $\frac{k \times T}{q}$ is 26 mV at 25°C. When n=2, the value of $\frac{k \times T}{q}$ becomes 52 mV. For germanium diodes, n is usually considered to be close to 1. For silicon diodes, n is in the range of 1.3 to 1.6.

5.4 Procedure

5.4.1 Forward Bias-Si Diode

1. Set DC voltage to 0.2 V .
2. Select the diode.
3. Set the resistor.
4. Voltmeter is placed parallel to Silicon diode and ammeter series with resistor.
5. The positive side of battery to the P side(anode) and the negative of battery to the N side(cathode) of the diode.
6. Now vary the voltage upto 5V and note the Voltmeter and Ammeter reading for particular DC voltage.
7. Take the readings and note Voltmeter reading across Silicon diode and Ammeter reading.
8. Plot the V-I graph and observe the change.
9. Calculate the dynamic resistance of the diode. $R_d = \frac{\Delta V}{\Delta I}$
10. Therefore from the graph we see that the diode starts conducting when the forward bias voltage exceeds around 0.6 volts (for Si diode). This voltage is

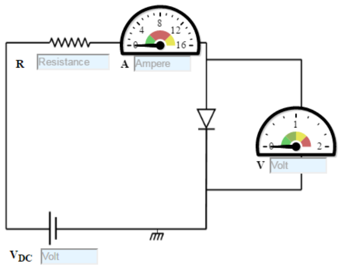


Figure 5.4.1

called cut-in voltage.

5.4.2 Reverse Bias-Si Diode

1. Set DC voltage to 0.2 V .
2. Select the diode.
3. Set the resistor.
4. Voltmeter is placed parallel to Silicon diode and ammeter series with resistor.
5. The positive terminal of battery is connected to the N side(cathode) and the negative terminal of battery is connected to the P side(anode) of a diode.

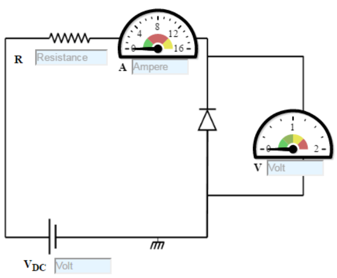


Figure 5.4.2

6. Now vary the voltage upto 30V and note the Voltmeter and Ammeter reading for DC voltage .
7. Take the readings and note Voltmeter reading across Silicon diode and Ammeter reading.
8. Plot the V-I graph and observe the change.

5.4.3 Forward Bias-Ge Diode

1. Set DC voltage to 0.2 V .

2. Use the resistor of 1K ohms and a Germanium diode.
3. Voltmeter is placed parallel to Germanium diode and ammeter series with resistor.
4. The positive terminal of battery is connected to the P side(anode) and the negative terminal of battery is connected to the N side(cathode) of the diode.

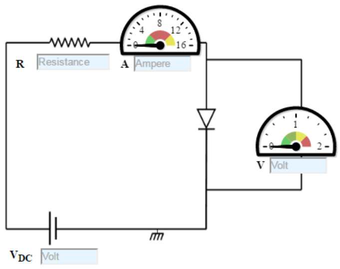


Figure 5.4.3

5. Now vary the voltage upto 30V and note the Voltmeter and Ammeter reading for particular DC voltage .
6. Take the readings and note Voltmeter reading across Germanium diode and Ammeter reading.
7. Plot the V-I graph and observe the change.
8. Therefore from the graph we see that the diode starts conducting when the forward bias voltage exceeds around 0.3 volts (for Ge diode). This voltage is called cut-in voltage.

5.4.4 Reverse Bias-Ge Diode

1. Set DC voltage to 0.2 V .
2. Use the resistor of 1K ohms and a Germanium diode.
3. Voltmeter is placed parallel to Germanium diode and ammeter series with resistor.
4. The positive terminal of battery is connected to the N side(cathode) and the negative terminal of battery is connected to the P side(anode) of a diode.
5. Now vary the voltage upto 30V and note the Voltmeter and Ammeter reading for DC voltage .
6. Take the readings and note Voltmeter reading across Silicon diode and

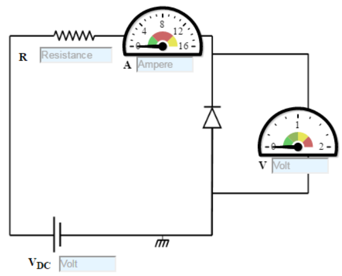


Figure 5.4.4

Ammeter reading.

7. Plot the V-I graph and observe the change.

5.5 Observations

Sr No.	Forward Voltage(V)	Forward Current (mA)
1	0.557	0.507
2	0.570	1.78
3	0.575	2.54
4	0.580	3.30
5	0.582	3.80
6	0.586	4.57
7	0.589	5.33
8	0.592	6.09
9	0.594	6.85
10	0.605	11.2

Figure 5.5.1: Forward biased Silicon Diode

Sr No.	Reverse Voltage(V)	Reverse Current (mA)
1	0.170	0.100
2	1.79	0.100
3	4.21	0.100
4	6.23	0.100
5	9.26	0.100
6	11.9	0.100
7	15.2	0.100
8	18.2	0.100
9	20.7	0.100
10	30.4	31.39

Figure 5.5.2: Reverse biased Silicon Diode

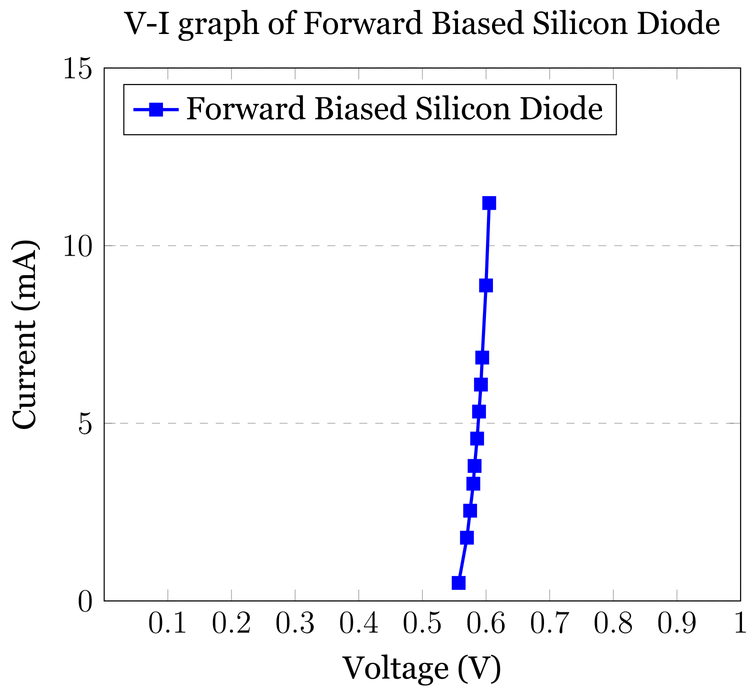


Figure 5.5.3: Observation $V - I$ Graph of Silicon Forward Biased Diode

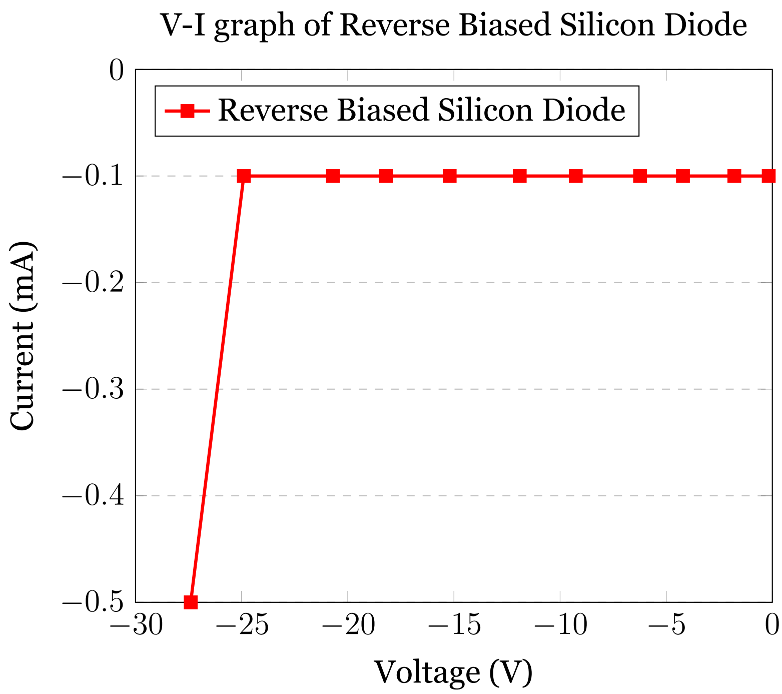


Figure 5.5.4: Observation $V - I$ Graph of Reverse Biased Silicon Diode

5.6 Result

A diode is a semiconductor device that essentially acts as a one-way switch for current. It allows current to flow easily in one direction, but severely restricts current from flowing in the opposite direction.

When a diode allows current flow, it is forward-biased. When a diode is reverse-biased, it acts as an insulator and does not permit current to flow.

Activity 6

Half Wave Rectification

6.1 Aim

- Explain Rectification
- Explain Half Wave Rectification
- Explain Half Wave Rectification:For Positive Half Cycle
- Explain Half Wave Rectification:For Negative Half Cycle

6.2 Apparatus

- Silicon/Germanium Diode
- Resistor
- AC Power Source
- Oscilloscope

6.3 Theory

6.3.1 Rectification

A rectifier is a device that converts alternating current (AC) to direct current (DC), a process known as rectification. Rectifiers are essentially of two types – a half wave rectifier and a full wave rectifier.

Figure 6.3.1: Function of a Rectifier

6.3.2 Half Wave Rectification

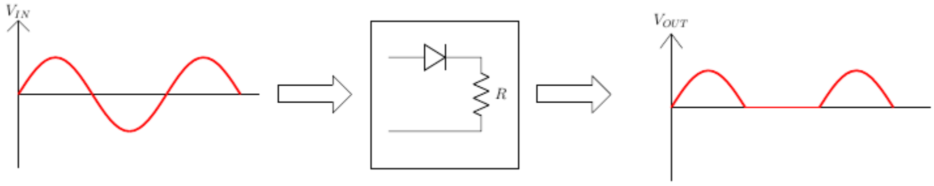


Figure 6.3.2: Half Wave Rectification

On the positive cycle the diode is forward biased and on the negative cycle the diode is reverse biased. By using a diode we have converted an AC source into a pulsating DC source. In summary we have 'rectified' the AC signal. The

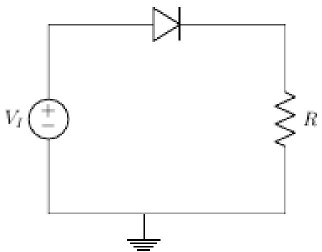


Figure 6.3.3: Half Wave Rectification Circuit

simplest kind of rectifier circuit is the half-wave rectifier.The half-wave rectifier is a circuit that allows only part of an input signal to pass. The circuit is simply the combination of a single diode in series with a resistor, where the resistor is acting as a load.

6.3.3 Half Wave Rectifiers – Waveforms

The output DC voltage of a half wave rectifier can be calculated with the following two ideal equations.

$$V_{peak} = V_{rms} \times \sqrt{2}$$

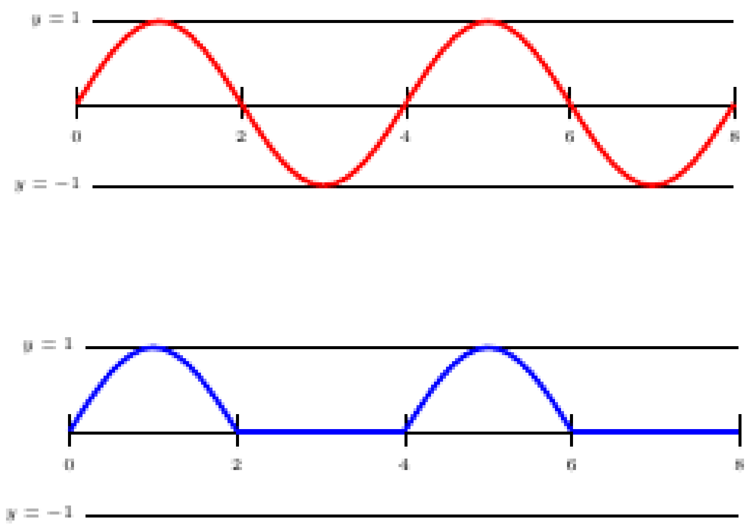


Figure 6.3.4: Half Wave Rectification Wave Form

$$V_{dc} = \frac{V_{peak}}{\pi}$$

6.3.4 Half Wave Rectification: For Positive Half Cycle

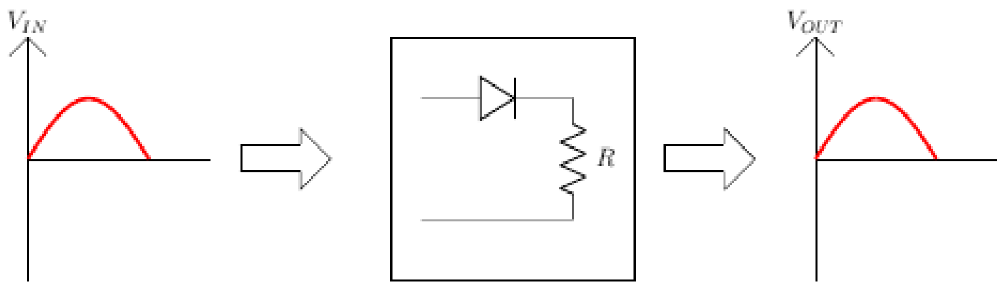


Figure 6.3.5: Half Wave Rectification - Positive Half Cycle

Diode is forward biased, acts as a short circuit, passes the waveform through.

For positive half cycle:

$$V_I - V_b - I \times r_d - I \times R = 0$$

where, V_I is the input voltage,
V_b is barrier potential,
r_d is diode resistance,

I is total current,

R is resistance

$$I = \frac{V_I - V_b}{r_d + R}$$

$$V_O = I \times R$$

$$V_O = \frac{V_I - V_b}{r_d + R} \times R$$

For $r_d << R$,

$$V_O = V_I - V_b$$

V_b is 0.3 for Germanium , V_b is 0.7 for Silicon

For $V_I < V_b$,

The diode will remain OFF.The Output voltage will be,

$$V_O = 0$$

For $V_I > V_b$,

The diode will be ON.The Output voltage will be,

$$V_O = V_I - V_b$$

6.3.5 Half Wave Rectification: For Negative Half Cycle

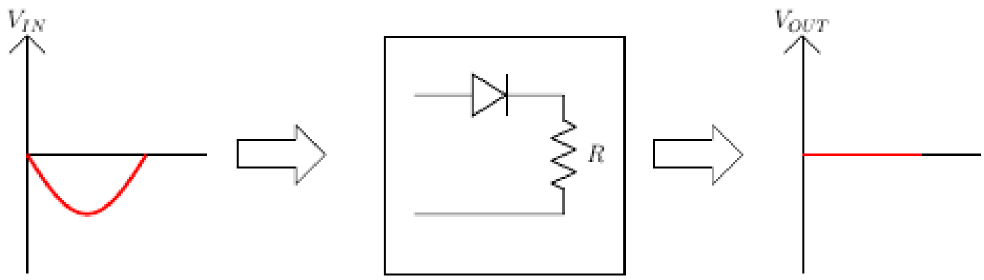


Figure 6.3.6: Half Wave Rectification - Negative Half Cycle

Diode is reverse biased, acts as a open circuit, does not pass the waveform through.

For negative half cycle:

$$V_O = 0 \quad Since, \quad I = 0$$

6.3.6 Half wave Rectification: For an Ideal Diode

For Ideal Diode,

$$V_b = 0$$

For positive half cycle,

$$V_O = V_I$$

For negative half cycle,

$$V_O = 0$$

6.3.7 Average output voltage

$$V_O = \begin{cases} V_m \sin wt, & 0 \leq wt \leq \pi \\ 0, & \pi \leq wt \leq 2\pi \end{cases}$$

$$V_{av} = \frac{V_m}{\pi} = 0.318 V_m$$

6.3.8 RMS load voltage

$$V_{rms} = I_{rms} \times R = \frac{V_m}{2}$$

6.3.9 Average load current

$$I_{av} = \frac{V_{av}}{R} = \frac{\frac{V_m}{\pi}}{R}$$

$$I_{av} = \frac{V_m}{\pi \times R} = \frac{I_m}{\pi}$$

6.3.10 RMS load current

$$I_{rms} = \frac{I_m}{2}$$

6.3.11 Form factor

It is defined as the ratio of rms load voltage and average load voltage.

$$\begin{aligned} F.F &= \frac{V_{rms}}{V_{av}} \\ &= \frac{\frac{V_m}{2}}{\frac{V_{av}}{2}} = \frac{\pi}{2} = 1.57 \end{aligned}$$

$$F.F \geq 1$$

$$rms \geq av$$

6.3.12 Ripple Factor

$$\begin{aligned} \gamma &= \sqrt{F.F^2 - 1} \times 100\% \\ &= \sqrt{1.57^2 - 1} \times 100\% \\ &= 1.21\% \end{aligned}$$

6.3.13 Efficiency

It is defined as ratio of dc power available at the load to the input ac power.

$$\begin{aligned} n\% &= \frac{P_{load}}{P_{in}} \times 100\% \\ &= \frac{I_{dc}^2 \times R}{I_{rms}^2 \times R} \times 100\% \\ &= \frac{\frac{I_m^2}{\pi^2}}{\frac{I_m^2}{4}} \times 100\% \\ &= \frac{4}{\pi^2} \times 100\% \\ &= 40.56\% \end{aligned}$$

6.3.14 Peak Inverse Volatge

For rectifier applications, peak inverse voltage (PIV) or peak reverse voltage (PRV) is the maximum value of reverse voltage which occurs at the peak of the input cycle when the diode is reverse-biased.The portion of the sinusoidal waveform which repeats or duplicates itself is known as the cycle. The part of the cycle above the horizontal axis is called the positive half-cycle, the part of the cycle below the horizontal axis is called the negative half cycle. With reference to the amplitude of the cycle, the peak inverse voltage is specified as the maximum negative value of the sine-wave within a cycle's negative half cycle.

$$V_{PIV} = V$$

$$-V_m + V = 0 \Rightarrow V = V_m$$

$$V_{PIV} \geq V_m$$

6.4 Procedure

1. Set the resistor R_L.
2. Click on 'ON' button to start the experiment.
3. Click on 'Sine Wave' button to generate input waveform
4. Click on 'Oscilloscope' button to get the rectified output.
5. Vary the Amplitude, Frequency, volt/div using the controllers.

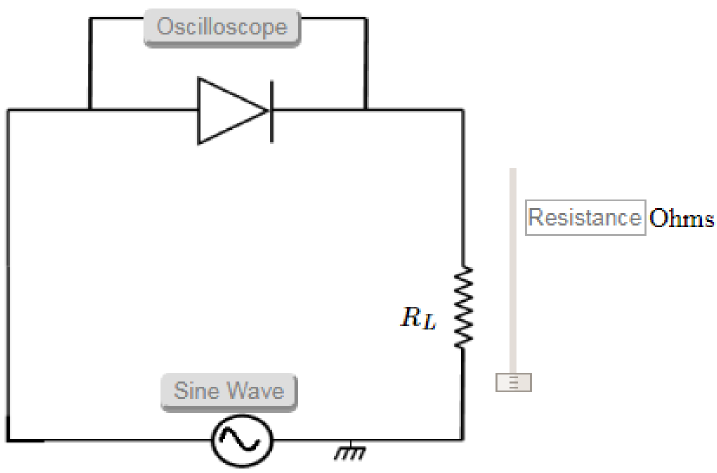


Figure 6.4.1

6. Click on "Dual" button to observe both the waveform.
7. Channel 1 shows the input sine waveform, Channel 2 shows the output rectified waveform.

8. Calculate the Ripple Factor.Theoretical Ripple Factor= 1.21.

6.5 Calculations

Measure the V_m

$$V_{rms} = \frac{V_m}{2}$$

$$V_{dc} = \frac{V_m}{\pi}$$

Ripple Factor(RP)

$$RP = \frac{V_{ac}}{V_{dc}}$$

Since,

$$V_{ac} = \sqrt{(V_{rms}^2 - V_{dc}^2)}$$

Peak Current: $0.74999999mA$

6.6 Observations

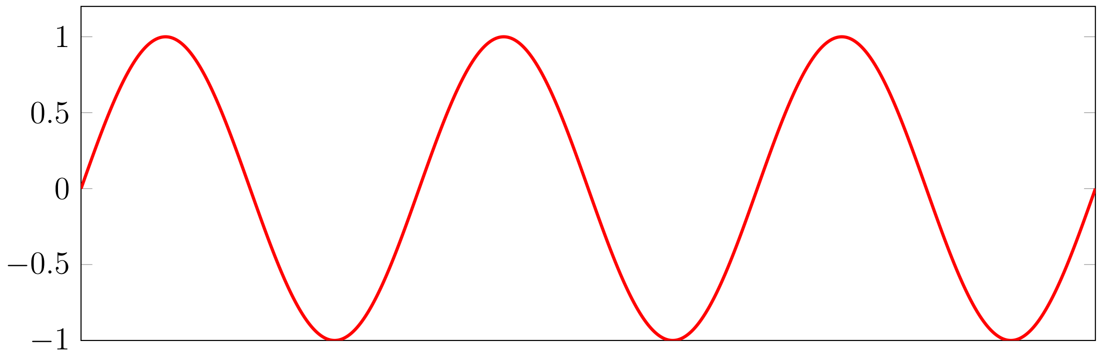


Figure 6.6.1: Un-Rectified AC Waveform

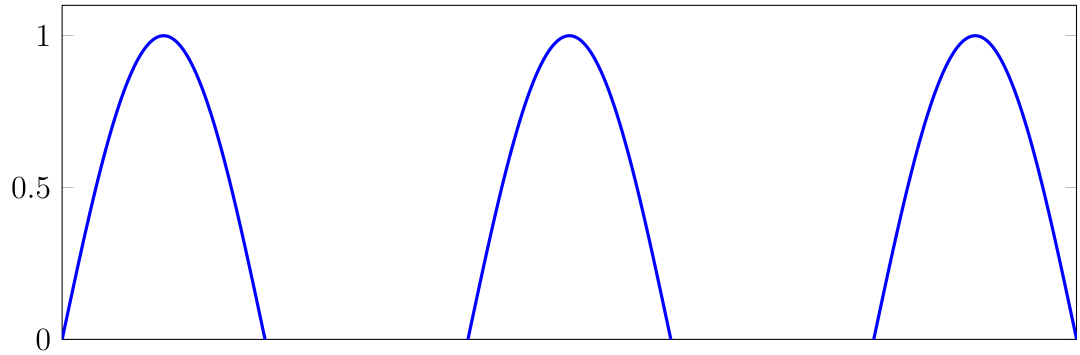


Figure 6.6.2: Half Wave Rectified Waveform

6.7 Result

A rectifier is a device that converts alternating current (AC) to direct current (DC). It is done by using a diode or a group of diodes. Half wave rectifiers use one diode, while a full wave rectifier uses multiple diodes.

The working of a half wave rectifier takes advantage of the fact that diodes only allow current to flow in one direction.

Activity 7

Full Wave Rectification

7.1 Aim

- Explain Rectification
- Explain Center Tapped Full Wave Rectification
- Explain Bridge Full Wave Rectification

7.2 Apparatus

- Center Tapped Transformer
- Silicon Diodes
- AC Power Source
- Resistors
- Ammeter
- Voltmeter

7.3 Theory

7.3.1 Rectification

A rectifier is a device that converts alternating current (AC) to direct current (DC), a process known as rectification. Rectifiers are essentially of two types – a half wave rectifier and a full wave rectifier.

Figure 7.3.1: Function of a Rectifier

7.3.2 Full Wave Rectifier

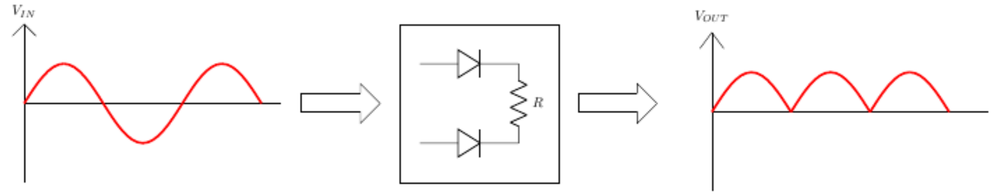
A full-wave rectifier is exactly the same as the half-wave, but allows unidirectional current through the load during the entire sinusoidal cycle (as opposed to only half the cycle in the half-wave). A full-wave rectifier converts the whole of the input waveform to one of constant polarity (positive or negative) at its output. Let us see our half wave rectifier example and deduce the circuit. For a half wave Rectifier this is what we have observed as in Figure 6.3.2. If we change the phase of the input waveform by 180 degrees, we get Figure 7.3.2b. Now if we add these two circuits, we would get Figure 7.3.2c.

7.3.3 Full Wave Rectifier - Circuit

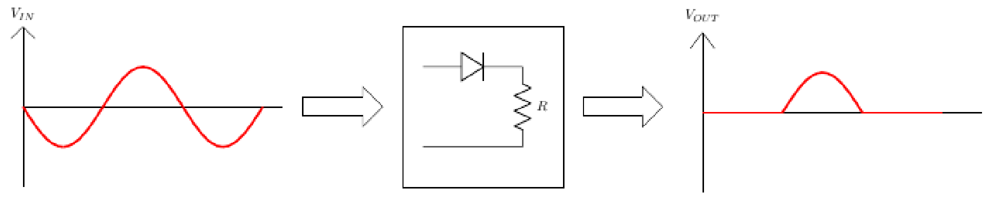
So, we have seen that this rectifier circuit consists of two sources which have a phase difference along with two diodes(see Figure 7.3.3) When V_1 is positive, V_2 is negative. Hence the top diode(D_1) will be a short and the bottom diode(D_2) will be an open. On the other hand, when V_1 is negative, V_2 is positive. Hence the bottom diode(D_2) will be on and the top diode(D_1) will be an open circuit.

7.3.4 Full Wave Rectifier – Waveforms

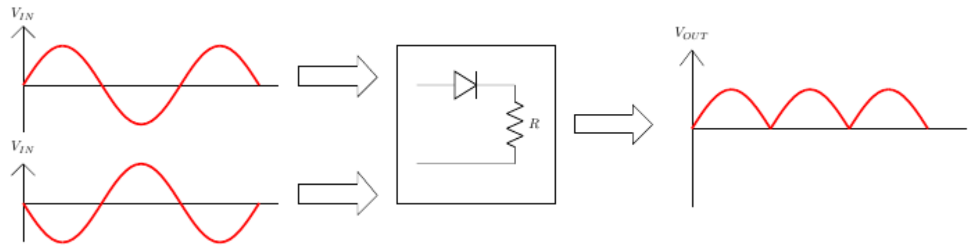
The resulting waveform of the schematic is shown in 7.3.4a. This configuration is rarely used because sometimes it may be impractical to obtain two voltage sources and it is difficult to SYNC the sources. Let us see how a single source can be used.



(a) Full Wave Rectification



(b) Half Wave Rectification with Waveform changed by 180°



(c) 2 different Half Wave Rectifications

Figure 7.3.2: *How Full Wave Rectification can be obtained from Half-Wave Rectification*

7.3.5 Full Wave Rectifier – Center Tapped Transformer

A Full-Wave Rectifier can be constructed using Center-Tapped transformer (see Figure 7.3.5a) – which give us two shifted sinusoids so that exactly one of the waveforms is positive at one time and two diodes. As compared to the half wave rectifier we use two diodes instead of one, one of the two diodes remains in conduction in both of the half cycles. At any point in time, only one of the diodes is forward biased. This allows for continuous conduction through load.

$$\frac{N_P}{N_S} = \frac{V_P}{V_S} = \frac{1}{2}$$

$$\Rightarrow V_S = 2 \times V_I$$

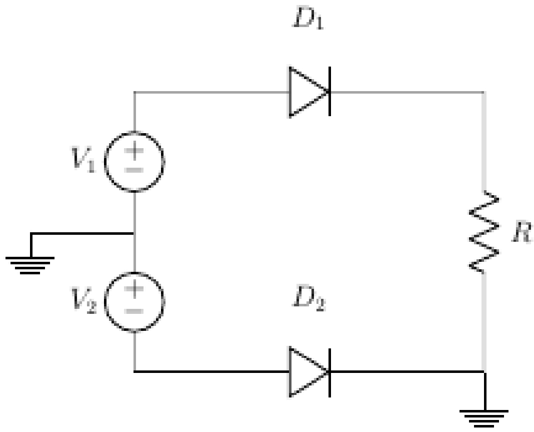


Figure 7.3.3: Circuit of Full Wave Rectifier

Center Tapped Transformer – Positive cycle

For Positive Cycle D_1 is Forward Biased and D_2 is Reverse Biased (See Figure 7.3.6)

$$V_I - V_O = 0$$

$$\Rightarrow V_O = V_I$$

Center Tapped Transformer– Negative cycle

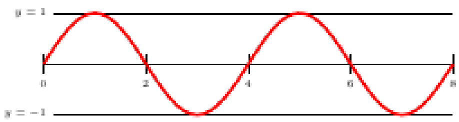
For Negative Cycle D_1 is Reverse Biased and D_2 is Forward Biased (See Figure 7.3.7)

$$V_I - V_O = 0$$

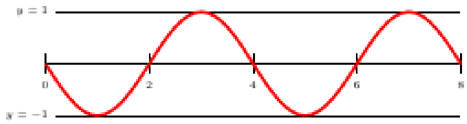
$$\Rightarrow V_O = V_I$$

7.3.6 Bridge Rectifier

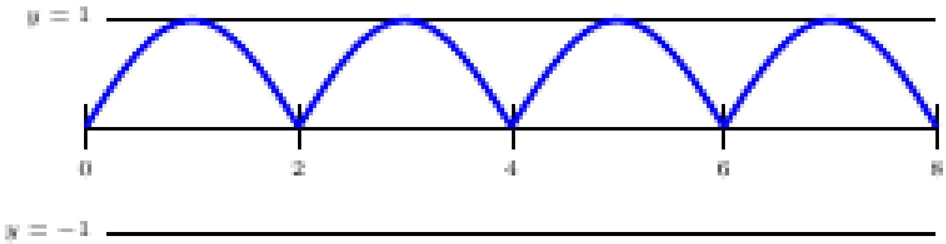
Bridge rectifier uses 4 rectifying diodes connected in a ”bridged” configuration(see Figure 7.3.8) to produce the desired output but does not require a special centre tapped transformer, thereby reducing its size and cost. The single secondary winding is connected to one side of the diode bridge network and the load to the other side as shown below.



(a) Simple $sinx$ wave



(b) 180° inverted $sinx$ wave



(c) Rectified $|sinx|$ wave

Figure 7.3.4: *Waveforms Resulting from Full Wave Rectifier*

Bridge Rectifier – Positive Half Cycle

During the positive half cycle of the supply diodes D_1 and D_2 conduct in series while diodes D_3 and D_4 are reverse biased (ideally they can be replaced with open circuits) and the current flows through the load as shown in Figure 7.3.9a. For Positive Half Cycle D_1 and D_2 is Forward Biased and D_3 and D_4 is Reverse Biased.

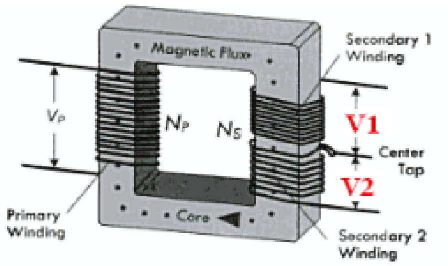
$$V_I - V_O = 0$$

$$\Rightarrow V_O = V_I$$

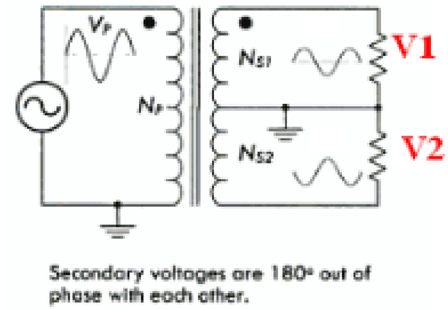
$$V_O = V_I - 2 \times V_b$$

$$V_O = V_I - 2 \times V_b - 2 \times I_{rd}$$

where, V_I is the input voltage, V_b is barrier potential, r_d is diode resistance



(a) Center-Tapped Transformer



(b) Symbol of Center-Tapped Transformer

Figure 7.3.5: *An AC Wave can be rectified with a center-tapped transformer*

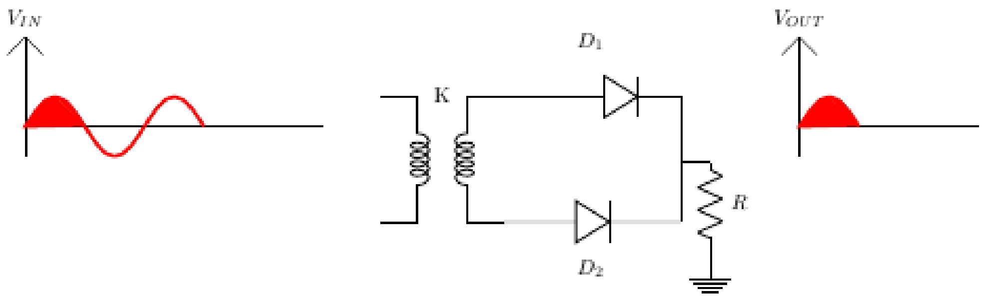


Figure 7.3.6: Center Tapped Transformer – Positive cycle

Bridge Rectifier – Negative Half Cycle

During the negative half cycle of the supply, diodes D_3 and D_4 conduct in series, but diodes D_1 and D_2 switch of as they are now reverse biased. The current flowing through the load is the same direction as before. (see Figure 7.3.9b) For Negative Half Cycle D_1 and D_2 is Reverse Biased and D_3 and D_4 is Forward Biased.

$$V_I - V_O = 0$$

$$\Rightarrow V_O = V_I$$

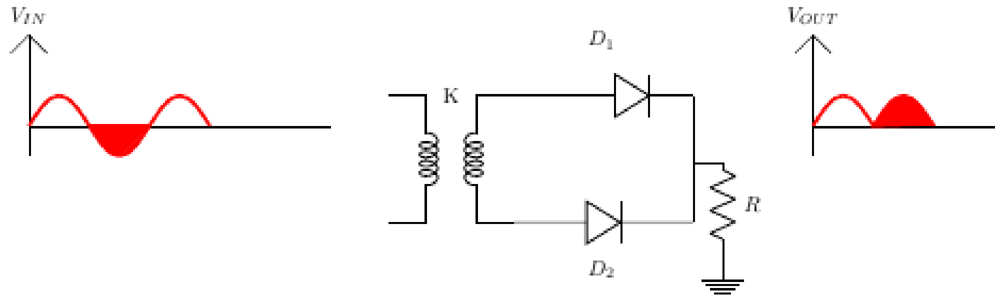


Figure 7.3.7: Center Tapped Transformer – Negative cycle

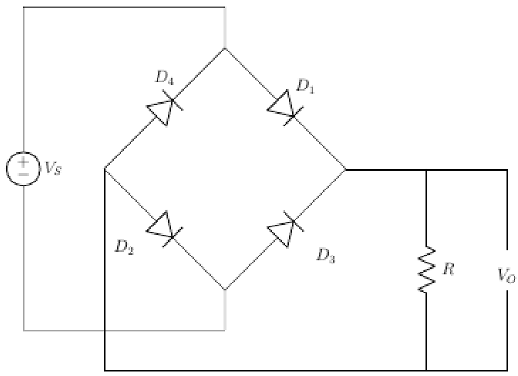


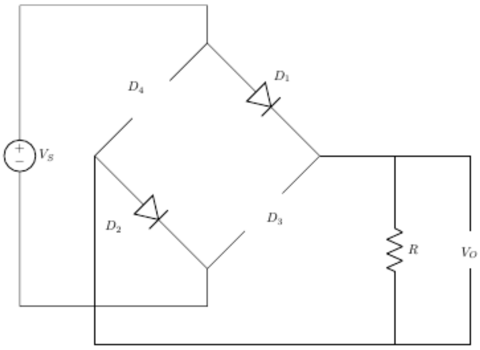
Figure 7.3.8: A Bridge Rectifier

7.3.7 Average DC Load Voltage

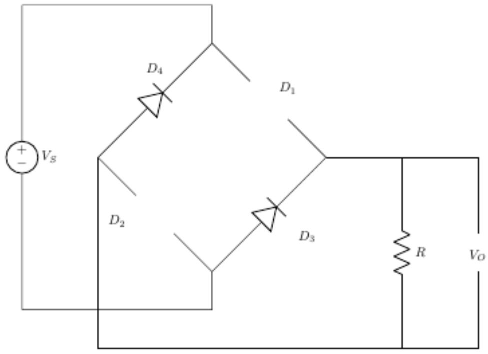
$$V_O = V_m \times \sin wt \quad for \quad 0 \leq wt \leq \pi$$
$$V_{av} = V_{dc} = \frac{2 \times V_m}{\pi}$$

7.3.8 Average Load Current

$$\begin{aligned} I_{av} &= \frac{V_{av}}{R} \\ &= \frac{2 \times V_m}{\pi \times R} \\ &= \frac{2 \times I_m}{R} \end{aligned}$$



(a) Center-Tapped Transformer



(b) Symbol of Center-Tapped Transformer

Figure 7.3.9: *Bridge Rectifier with positive and negative halves*

7.3.9 RMS Load Current

$$I = I_m \times \sin wt \quad for \quad 0 \leq wt \leq \pi$$

$$I_{rms} = \frac{I_m}{\sqrt{2}}$$

7.3.10 RMS Load Voltage

$$\begin{aligned} V_{rms} &= I_{rms} \times R \\ &= \frac{I_m}{\sqrt{2}} \times R \\ &= \frac{V_m}{\sqrt{2}} \end{aligned}$$

7.3.11 Form factor

It is defined as the ratio of rms load voltage and average load voltage.

$$
\begin{aligned}
FF &= \frac{V_{rms}}{V_{av}} \\
&= \frac{\frac{V_m}{\sqrt{2}}}{\frac{2\times V_m}{\pi}} \\
&= \frac{\pi}{2\sqrt{2}} \\
&= 1.11 \\
FF &\geq 1
\end{aligned}
$$

7.3.12 Ripple Factor

$$
\begin{aligned}
\gamma &= \sqrt{FF^2 - 1} \times 100\% \\
&= \sqrt{1.11^2 - 1} \times 100\% \\
&= 48.1\%
\end{aligned}
$$

7.3.13 Efficiency

It is defined as ratio of DC power available at the load to the input AC power.

$$
\begin{aligned}
n\% &= \frac{P_{load}}{P_{in}} \times 100\% \\
&= \frac{I_{dc}^2 \times R}{I_{rms}^2 \times R} \times 100\% \\
&= \frac{\frac{4\times I_m^2}{\pi^2}}{\frac{I_m^2}{2}} \times 100\% \\
&= \frac{8}{\pi^2} \times 100\% \\
&= 81.13\%
\end{aligned}
$$

7.3.14 Peak Inverse Volatge

For rectifier applications, peak inverse voltage (PIV) or peak reverse voltage (PRV) is the maximum value of reverse voltage which occurs at the peak of the input cycle when the diode is reverse-biased.The portion of the sinusoidal waveform which repeats or duplicates itself is known as the cycle. The part of the cycle above the horizontal axis is called the positive half-cycle, the part of the cycle below the horizontal axis is called the negative half cycle. With reference to the amplitude of the cycle, the peak inverse voltage is specified as the maximum negative value of the sine-wave within a cycle's negative half cycle.

For Bridge Rectifier,
D_1 and D_2 is Forward Biased
D_3 and D_4 is Reverse Biased

$$V_m - V_O = 0$$

$$\Rightarrow V_O = V_m$$

$$-V_O + PIV = 0$$

$$\Rightarrow PIV = V_m$$

$$PIV \geq V_m$$

For Center Tapped Rectifier,
D_2 is Forward Biased,
PIV at D_1,

$$V_m - V_O = 0$$

$$\Rightarrow V_O = V_m$$

$$V_O - PIV + V_m$$

$$\Rightarrow PIV = 2V_m$$

$$PIV \geq 2V_m$$

7.4 Procedure

1. Set the resistor R_L.
2. Click on 'ON' button to start the experiment.
3. Click on 'Sine Wave' button to generate input waveform
4. Click on 'Oscilloscope' button to get the rectified output.

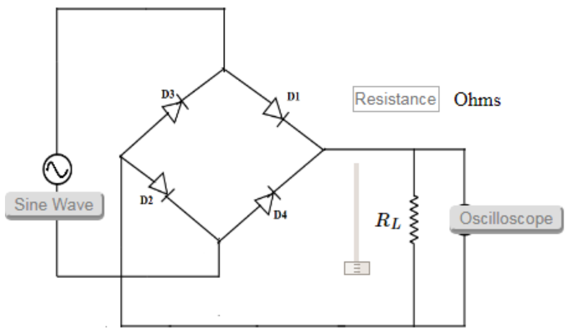


Figure 7.4.1: Full Bridge Rectifier

5. Vary the Amplitude, Frequency, volt/div using the controllers.
6. Click on "Dual" button to observe both the waveform.
7. Channel 1 shows the input sine waveform, Channel 2 shows the output rectified waveform.
8. Calculate the Ripple Factor.Theoretical Ripple Factor=0.483.

7.5 Calculation

Measure the V_m

$$V_{rms} = \frac{V_m}{\sqrt{2}}$$
$$V_{dc} = \frac{2 \times V_m}{\pi}$$
$$RippleFactor(RF) = \frac{V_{ac}}{V_{dc}}$$
$$Since, V_{ac} = \sqrt{(V_{rms}^2 - V_{dc}^2)}$$

Peak Current: $0.599999mA$

7.6 Observations

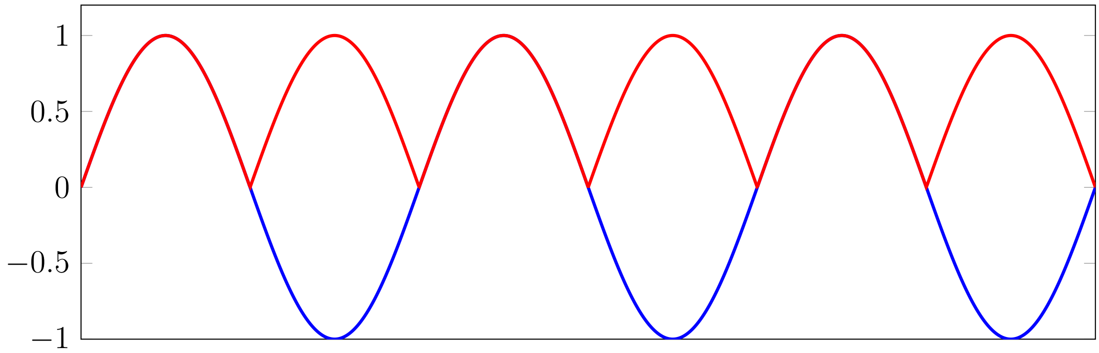


Figure 7.6.1: AC Wave Form (Blue), Full Wave Rectified Wave (Red)

7.7 Result

A full wave rectifier is defined as a type of rectifier that converts both halves of each cycle of an alternating wave (AC signal) into a pulsating DC signal. Full-wave rectifiers are used to convert AC voltage to DC voltage, requiring multiple diodes to construct. Full wave rectification is the process of converting an AC signal to a DC signal.

Circuits that convert alternating current (AC) into direct current (DC) are known as rectifiers. If such rectifiers rectify both the positive and negative half cycles of an input alternating waveform, the rectifiers are full-wave rectifiers.

Activity 8

Zener Diode-Voltage Regulator

8.1 Aim

- Explain the function of a Zener diode
- Explain Zener Diode as Voltage Regulator

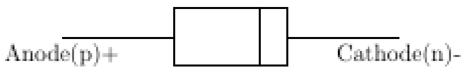
8.2 Apparatus

- Zener Diode
- Resistors
- Ammeter
- Voltmeter
- DC Battery Source

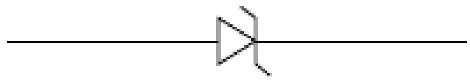
8.3 Theory

8.3.1 Zener Diode

A Zener Diode is a special kind of diode which permits current to flow in the forward direction as normal, but will also allow it to flow in the reverse direction when the voltage is above the breakdown voltage or 'zener' voltage. Zener diodes are designed so that their breakdown voltage is much lower - for example just 2.4 Volts.



(a) Zener Diode



(b) Symbol of Zener Diode

Figure 8.3.1: *Zener Diode image and symbol*

8.3.2 Function of Zener Diode

1. Zener diodes are a special kind of diode which permits current to flow in the forward direction.
2. Zener diodes will also allow current to flow in the reverse direction when the voltage is above a certain value. This breakdown voltage is known as the Zener voltage. In a standard diode, the Zener voltage is high, and the diode is permanently damaged if a reverse current above that value is allowed to pass through it.
3. In the reverse bias direction, there is practically no reverse current flow until the breakdown voltage is reached. When this occurs there is a sharp increase in reverse current. Varying amount of reverse current can pass through the diode without damaging it. The breakdown voltage or zener voltage (V_Z) across the diode remains relatively constant.

8.3.3 Zener Diode As A Voltage Regulator

A voltage regulator is an electronic circuit that provides a stable DC voltage independent of the load current, temperature and AC line voltage variations. A Zener diode of break down voltage V_Z is reverse connected to an input voltage source V_I across a load resistance R_L and a series resistor R_S. The voltage across the zener will remain steady at its break down voltage V_Z for all the values of zener current I_Z as long as the current remains in the break down region. Hence a regulated DC output voltage $V_0 = V_Z$ is obtained across R_L, whenever the input voltage remains within a minimum and maximum voltage. Basically there are two type of regulations such as:

Line Regulation: In this type of regulation, series resistance and load resistance are fixed, only input voltage is changing. Output voltage remains the same as long as the input voltage is maintained above a minimum value.

Load Regulation: In this type of regulation, input voltage is fixed and the load resistance is varying. Output volt remains same, as long as the load resistance is maintained above a minimum value.

Line Regulation

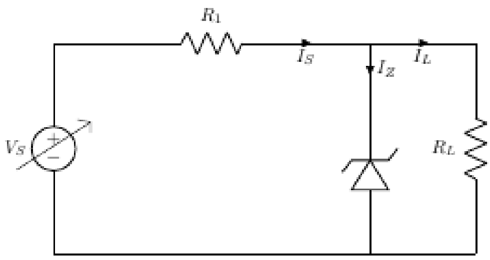


Figure 8.3.2: Zener Diode for Line Regulation

In Line Regulation, Load resistance is constant and input voltage varies. V_I must be sufficiently large to turn the Zener Diode ON.

$$V_L = V_Z = \frac{V_{Imin} \times R_L}{(R_S + R_L)}$$

So, the minimum turn-on voltage V_{Imin} is :

$$V_{Imin} = \frac{V_Z \times (R_S + R_L)}{R_L}$$

The maximum value of V_I is limited by the maximum zener current I_{Zmax}

$$I_{Rmax} = I_{Zmax} + I_L$$

I_L is fixed at :

$$\frac{V_Z}{R_L} \qquad Since, V_L = V_Z$$

So maximum V_I is

$$V_{Imax} = V_{Rmax} + V_Z$$

or,

$$V_{Imax} = I_{Rmax} \times R + V_Z$$

For $V_I < V_Z$,

$$V_O = V_I$$

For $V_I > V_Z$,

$$V_O = V_I - I_S \times R_S$$

8.3.4 Load Regulation

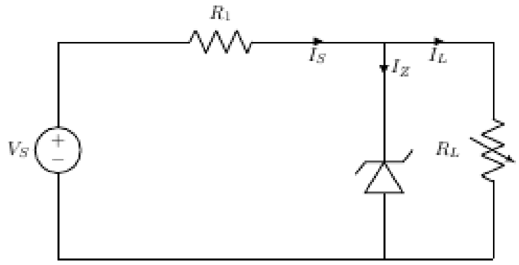


Figure 8.3.3: Zener Diode for Load Regulation

In Load Regulation , input voltage is constant and Load resistance varies. Too small a Load Resistance R_L ,will result in $V_{Th} < V_Z$ and Zener Diode will be OFF.

$$V_L = V_Z = \frac{V_{Imin} \times R_L}{(R_S + R_L)}$$

So the minimum load resistance R_L

$$R_{Lmin} = \frac{V_Z \times R_S}{V_I - V_Z}$$

Any load resistance greater than R_{Lmin} will make Zener Diode ON

$$I_S = I_L + I_Z$$

R_{Lmin} will establish maximum I_L as

$$I_{Lmax} = \frac{V_L}{R_{Lmin}} = \frac{V_Z}{R_{Lmin}} \qquad Since, V_L = V_Z$$

$V_S$is the voltage drop across R_S

$$V_S = V_{Imin} - V_Z$$

$$I_S = \frac{V_{Imin} - V_Z}{R_S}$$

For $R_L < R_{Lmin}$,

$$V_O = V_I$$

For $R_L > R_{Lmin}$,

$$V_O = V_I - I_S \times R_S$$

8.4 Procedure

8.4.1 Zener Diode - Line Regulation

1. Set the Zener Voltage(V_Z)
2. Set the Series Resistance (R_S) value.
3. Set the Load Resistance (R_L) value.
4. Vary DC voltage.
5. Voltmeter is placed parallel to load resistor and ammeter series with the series resistor.

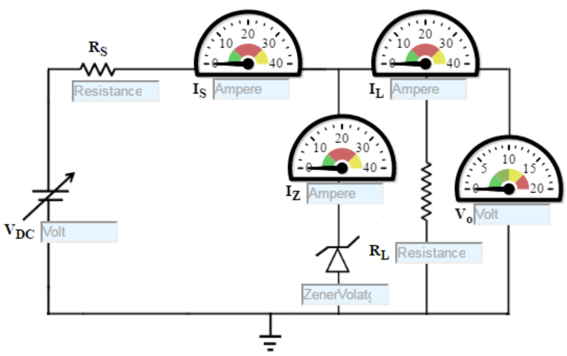


Figure 8.4.1: Simulation of Zener Diode for Line Regulation

6. Choose appropriate DC voltage such that zener diode is 'on'.
7. Now note the Voltmeter and Ammeter reading for various DC voltage.
8. Note the Load current(I_L), zener current(I_Z), Output voltage(V_O)
9. Calculate the voltage regulation.

8.4.2 Zener Diode - Load Regulation

1. Set DC voltage.
2. Set the Series Resistance (R_S) value.
3. 1W D0-41 Glass Zener Diode 1N4740A, Zener voltage is 10 V.
4. Vary the Load Resistance (R_L).
5. Voltmeter is placed parallel to load resistor and ammeter series with the series resistor.

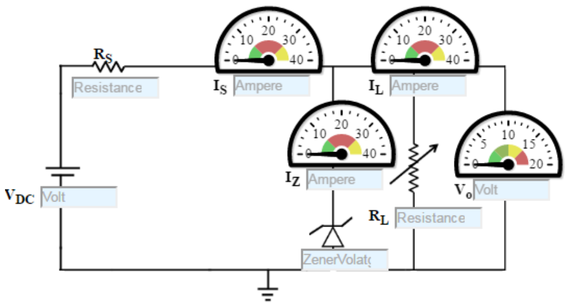


Figure 8.4.2: Simulation of Zener Diode for Load Regulation

6. Choose Load Resistance in such a manner, such that the Zener diode is 'on'.
7. Now note the Voltmeter and Ammeter reading for various Load Resistance.
8. Increase the load resistance (R_L).
9. Note the Load current(I_L), zener current(I_Z), Output voltage(V_O)
10. Calculate the voltage regulation.

8.4.3 Zener Characteristics

1. Select the diode.
2. Set the rheostat $R_h = 1\Omega$
3. By adjusting the rheostat, voltmeter reading is increased from 0 and in each time note the corresponding reading in milliammeter.

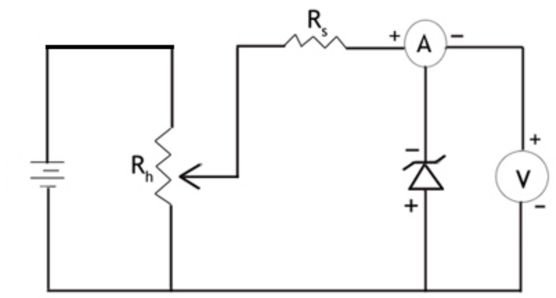


Figure 8.4.3: Circuit using Zener Diode for knowing its Characteristics

4. Take the readings and note Voltmeter reading across Zener diode and Ammeter reading.
5. Plot the V-I graph and observe the change.

8.5 Observations

8.5.1 Zener Diode - Line Regulator

Zener Voltage (V_Z): $5.1V$

Series Resistance(R_S): $1K\Omega$

Load Resistance (R_L): $2K\Omega$

Sr No.	UnRegulated Supply Voltage (V_S) (V)	Load Current (I_L) (mA)	Zener Current (I_Z)(mA)	Regulated Output Voltage (V_O) (V)	% Voltage Regulation
1	0	2.55	0	0	NaN
2	2.4	2.55	0	2.4	100
3	5.6	2.55	-2.050	5.10	100
4	9.6	2.55	1.950	5.10	55.6
5	12.8	2.55	5.150	5.10	41.7
6	16	2.55	8.350	5.10	31.3
7	18.2	2.55	10.550	5.10	27.8
8	22	2.55	14.350	5.10	22.7
9	26	2.55	18.350	5.10	19.2
10	29.2	2.55	21.550	5.10	17.2
11	30	2.55	22.350	5.10	16.7

Figure 8.5.1: Zener Diode Line Regulation Observations

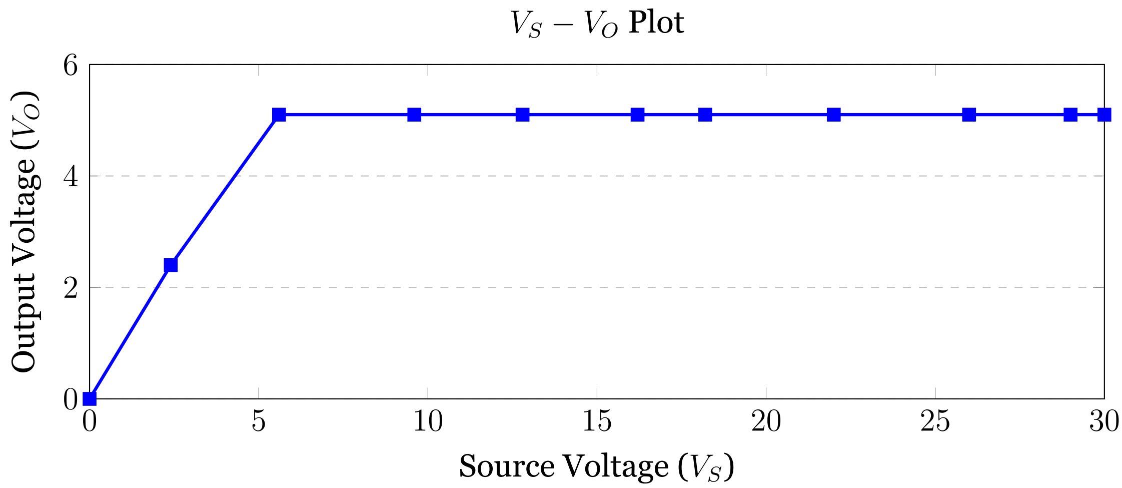


Figure 8.5.2: $V_S - V_O$ Plot of Zener Diode - LINE Regulator

8.5.2 Zener Diode - Load Regulator

Zener Voltage (V_Z): $5.1V$

Series Resistance(R_S): $0.1K\Omega$

DC Voltage (V_{DC}): $6V$

Sr No.	Load Resistance (R_L) (Ω)	Load Current (I_L) (mA)	Zener Current (I_Z)(mA)	Regulated Output Voltage (V_O) (V)	% Voltage Regulation
1	150	34.0	0	6	40.0
2	266	19.2	0	6	27.3
3	395	12.9	0	6	20.2
4	505	10.1	0	6	16.5
5	609	8.37	0.626	5.10	14.1
6	749	6.81	2.19	5.10	11.8
7	865	5.90	3.10	5.10	10.4
8	969	5.26	3.74	5.10	9.35
9	1073	4.75	4.25	5.10	8.53
10	1195	4.27	4.73	5.10	7.72
11	1250	4.08	4.92	5.10	7.41

Figure 8.5.3: Zener Diode Load Regulator Observations

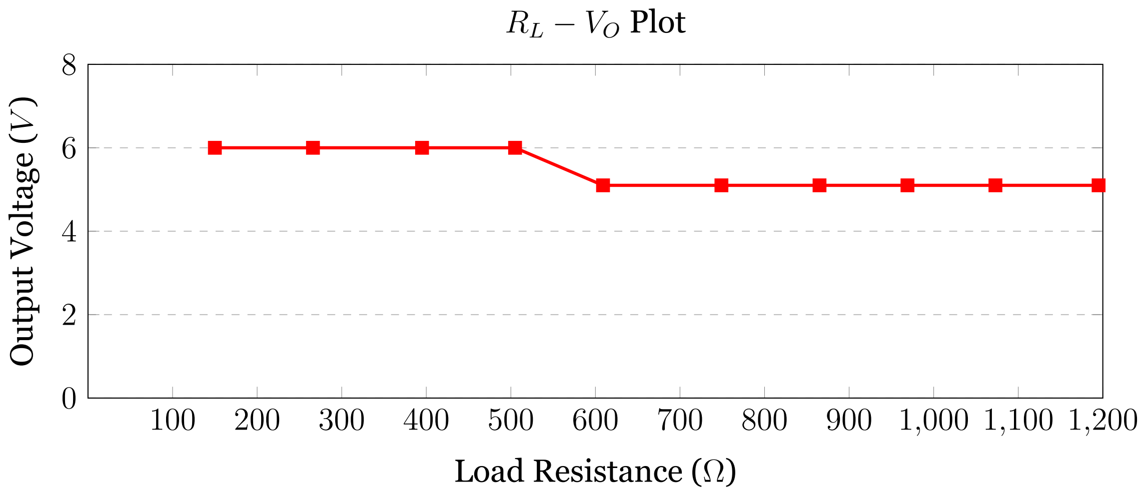


Figure 8.5.4: $R_L - V_O$ Plot of Zener Diode - LOAD Regulator

8.5.3 Zener Characteristics

Sr No.	Zener Voltage (V)	Current (mA)
1	0.120	0.000
2	1.911	0.000
3	3.620	0.000
4	4.724	0.001
5	6.354	0.002

Figure 8.5.5: Zener Diode Characteristics

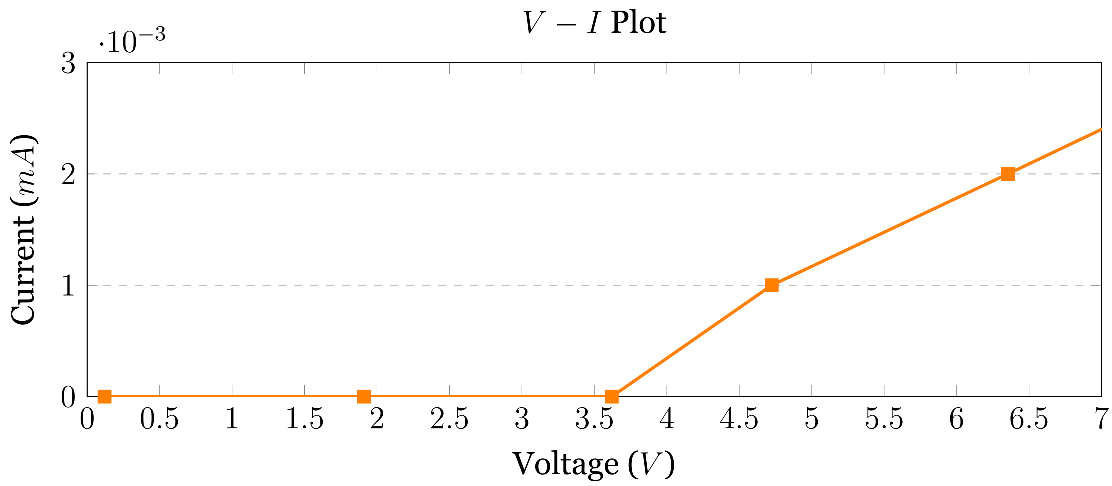


Figure 8.5.6: $V - I$ Plot of Zener Characteristics

8.6 Result

A Zener Diode is a special kind of diode which permits current to flow in the forward direction as normal, but will also allow it to flow in the reverse direction when the voltage is above the breakdown voltage or 'zener' voltage. Zener diodes are designed so that their breakdown voltage is much lower e.g. 2.4 Volts.

Activity 9

BJT Common Emitter Characteristics

9.1 Aim

- Explain structure of Bipolar Junction Transistor
- Explain Operation of Bipolar Junction Transistor
- Explain Common Emitter characteristics of a BJT

9.2 Apparatus

- A Bipolar Junction Transistor
- Voltmeter
- Ammeter
- Rheostat
- Battery

9.3 Theory

9.3.1 Structure of Bipolar Junction Transistor

A bipolar junction transistor, BJT, is a single piece of silicon with two back-to-back P-N junctions.BJTs can be made either as PNP or as NPN.

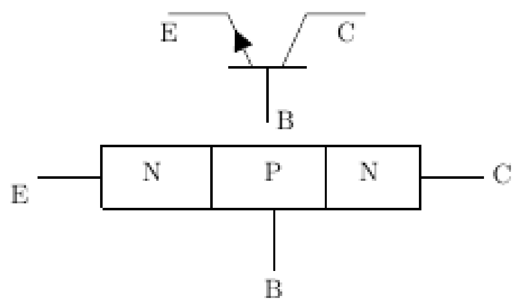


Figure 9.3.1: Structures, layers and circuit symbol of NPN transistor

They have three regions and three terminals, emitter, base, and collector represented by E, B, and C respectively. The direction of the arrow indicates the direction of the current in the emitter when the transistor is conducting normally. An easy way to remember this is NPN stands for ”Not Pointing iN”.

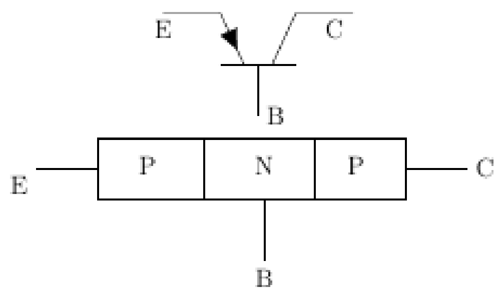


Figure 9.3.2: Structures, layers and circuit symbol of PNP transistor

Emitter (E):It is the region to the left end which supply free charge carriers i.e., electrons in n-p-n or holes in p-n-p transistors.These majority carriers are injected to the middle region i.e. electrons in the p region of n-p-n or holes in the n region of p-n-p transistor. Emitter is a heavily doped region to supply a large number of majority carriers into the base.

Base (B):It is the middle region where either two p-type layers or two n-type layers are sandwiched. The majority carriers from the emitter region are injected into this rgion.This region is thin and very lightly doped.

Collector (C):It is the region to right end where charge carriers are collected.The area of this region is largest compared to emitter and base region . The doping level of this region is intermediate between heavily doped emitter region and lightly doped base region.

9.3.2 Operation of Bipolar Junction Transistor

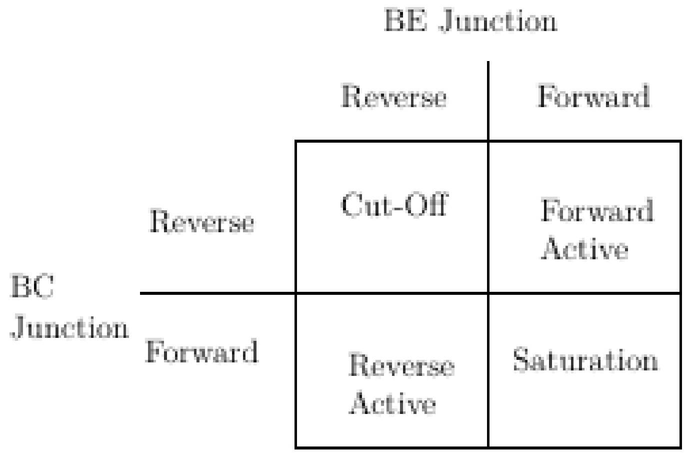


Figure 9.3.3: Four Operating Conditions

Cutoff Region: Base-emitter junction is reverse biased. No current flow.

Saturation Region: Base-emitter junction is forward biased and Collector-base junction is forward biased.

Active Region: Base-emitter is junction forward biased and Collector-base junction is reverse biased.

Breakdown Region: I_C and V_{CE} exceed specifications and can cause damage to the transistor.

9.3.3 Cut-Off Region

In Cut-Off region both junctions are reverse biased, Base-emitter junction is reverse biased ($V_{BE} < 0$)and also Collector-Base junction is reverse biased($V_{CB} > 0$).With reverse biasing, all currents are zero.There are some leakage currents associated with reverse biased junctions,but these currents are small and therefore can be neglected.

9.3.4 Forward Active Region

In Forward Active region Base-emitter junction is forward biased($V_{BE} > 0$) and Collector-Base junction is reverse biased($V_{CB} > 0$). In this case, the forward bias of the BE junction will cause the injection of both holes and electrons across the junction. The holes are of little consequence because the doping levels are adjusted to minimize the hole current. The electrons are the carriers of interest. The electrons are injected into the base region where they are called the minority carrier even though they greatly outnumber the holes. Application:Amplifier in analog circuits

$$I_C = -\alpha_F \times I_E + I_{CO}$$

where, α_F is the forward current transfer ratio I_{CO} is Collector reverse saturation current

9.3.5 Saturation Region

In Saturation region both junctions are Forward biased,Base-emitter junction is forward biased($V_{BE} > 0$) and also Collector-Base junction is forward biased($V_{CB} < 0$). Maximum currents flows through the transistor with only a small voltage drop across the collector junction.The transistor also does not respond to any change in emitter current or base-emitter voltage.

9.3.6 Reverse Active Region

In Reverse Active region Base-emitter junction is reverse biased($V_{BE} < 0$) and Collector-Base junction is forward biased($V_{CB} < 0$).The operation is just the same as the forward active region, except all voltage sources, and hence collector and emitter currents, are the reverse of the forward bias case. The current gain in this mode is smaller than that of forward active mode for which this mode in general unsuitable for amplification. Application:In digital circuits and analog switching circuits.

$$I_E = -\alpha_R * I_C + I_{EO}$$

where, α_R is the reverse current transfer ratio
I_{EO} is the Emitter reverse saturation current

This configuration is rarely used because most transistors are doped selectively to give forward current transfer ratios very near unity, which automatically causes the reverse current transfer ratio to be very low.

9.3.7 BJT - Common Emitter Circuit

The DC behavior of the BJT can be described by the Ebers-Moll Model. The equations for the model are:

$$I_F = I_{ES} \times (exp^{\frac{V_{BE}}{V_T}} - 1)$$

$$I_R = I_{CS} \times (exp^{\frac{V_{CB}}{V_T}} - 1)$$

where, I_{ES} is base-emitter saturation currents,
I_{CS} is base-collector saturation currents

$$V_T = \frac{k \times T}{q}$$

where, k is the Boltzmann's constant (k = 1.381 e-23 V.C/ K),
T is the absolute temperature in degrees Kelvin, and
q is the charge of an electron (q = 1.602 e-19 C).

$$\beta_F = \frac{\alpha_F}{1 - \alpha_F}$$

$$\beta_R = \frac{\alpha_R}{1 - \alpha_R}$$

where,
β_F is large signal forward current gain of common-emitter configuration,
β_R is the large signal reverse current gain of the common-emitter configuration

$$\alpha_F = \frac{\beta_F}{1 + \beta_F}$$

$$\alpha_R = \frac{\beta_R}{1 + \beta_R}$$

where,
α_R is large signal reverse current gain of a common-base configuration,

α_F is large signal forward current gain of the common-base configuration.

$$I_C = \alpha_F \times I_F - I_R$$

$$I_E = -I_F + \alpha_R * I_R$$

$$I_B = (1 - \alpha_F) \times I_F + (1 - \alpha_R) \times I_R$$

The forward and reverse current gains are related by the expression

$$\alpha_R \times I_{CS} = \alpha_F \times I_{ES} = I_S$$

where,
I_S is the BJT transport saturation current.
The parameters α_R and α_F are influenced by impurity concentrations and junction depths.
The saturation current, I_S , can be expressed as

$$I_S = J_S \times A$$

where,
A is the area of the emitter and
J_S is the transport saturation current density

9.3.8 Input Characteristics

The most important characteristic of the BJT is the plot of the base current, I_B, versus the base-emitter voltage,V_{BE}, for various values of the collector-emitter voltage,V_{CE}

$$I_B = \phi(V_{BE}, V_{CE}) \qquad for \quad constant \quad V_{CE}$$

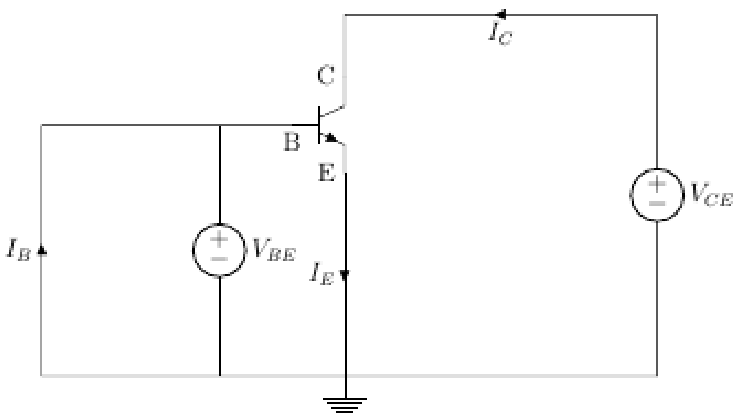


Figure 9.3.4: Input Characteristics Circuit

9.3.9 Output Characteristics

The most important characteristic of the BJT is the plot of the collector current, I_C, versus the collector-emitter voltage, V_{CE}, for various values of the base current, I_B as shown on the circuit on the right.

$$I_C = \phi(V_{CE}, I_B) \qquad for \quad constant \quad I_B$$

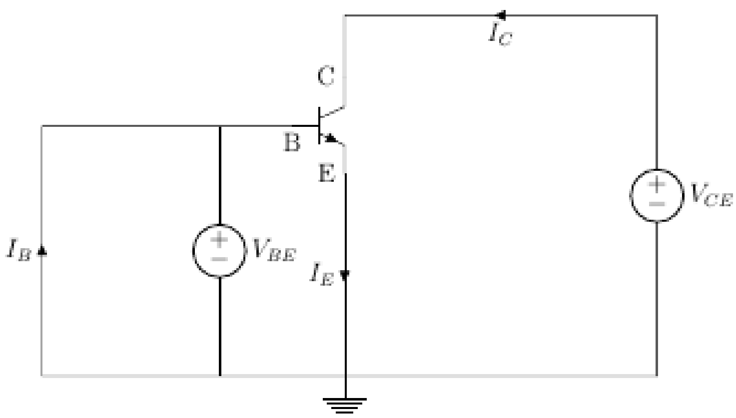


Figure 9.3.5: Output Characteristics Circuit

9.4 Procedure

9.4.1 BJT Common Emitter - Input Characteristics

1. Initially set rheostat $R_{h1} = 1\Omega$ and rheostat $R_{h2} = 1\Omega$
2. Set the Collector-Emitter Voltage(V_{CE}) to 1V by adjusting the rheostat R_{h2}
3. Base Emitter Voltage(V_{BE}) is varied by adjusting the rheostat R_{h1}.

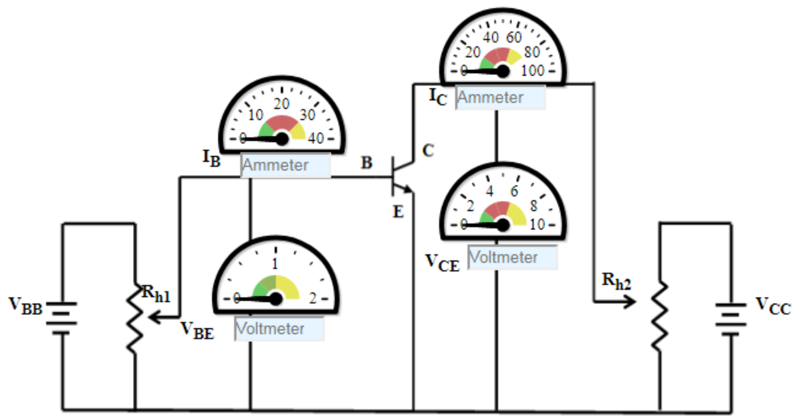


Figure 9.4.1: Simulation for BJT Common Emitter - Input Characteristics

4. Note the reading of Base current(I_B)in micro Ampere.
5. Click on 'Plot' to plot the I-V characteristics of Common - Emitter configuration. A graph is drawn with VBE along X-axis and I_B along Y-axis.
6. Click on 'Clear' button to take another sets of readings
7. Now set the Collector-Emitter Voltage(V_{CE}) to 2V, 3V, 4V

9.4.2 BJT Common Emitter - Output Characteristics

1. Initially set rheostat $R_{h1} = 1\Omega$ and rheostat $R_{h2} = 1\Omega$
2. Set the Base current(I_B) $15\mu A$ by adjusting the rheostat R_{h1}
3. Vary the Collector-Emitter Voltage(V_{CE})is varied by adjusting the rheostat R_{h2}.
4. Note the reading of Collector current(I_C).
5. Click on 'Plot' to plot the I-V characteristics of Common - Emitter configuration. A graph is drawn with V_{CE} along X-axis and I_C along Y-axis.
6. Click on 'Clear' button to take another sets of readings
7. Now set the Base Current(I_B) to $20\mu A$

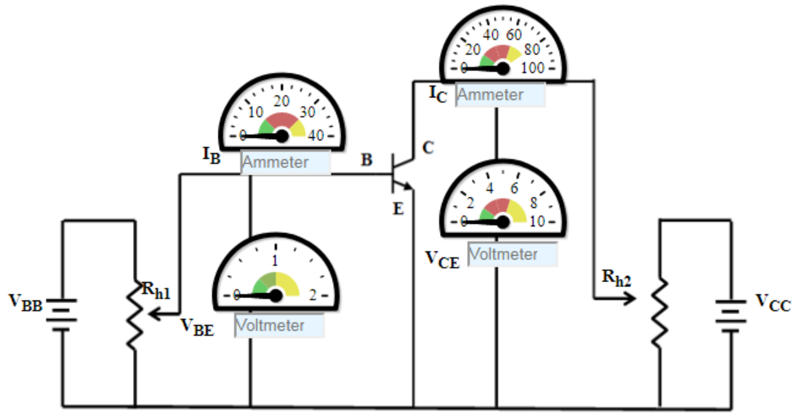


Figure 9.4.2: Simulation for BJT Common Emitter - Output Characteristics

9.5 Observations

9.5.1 BJT Common Emmiter - Input Characteristics

Sr No.	Base-Emitter Voltage (V)	Base Current (μA)
1	0.06000	2.179
2	0.2400	2.818
3	0.5000	4.085
4	0.8400	6.640
5	1.240	11.76
6	1.560	18.57
7	1.800	26.17
8	2.000	34.82

Figure 9.5.1: BJT Common Emmiter - Input Characteristics Table at $V_{CE} = 1V$

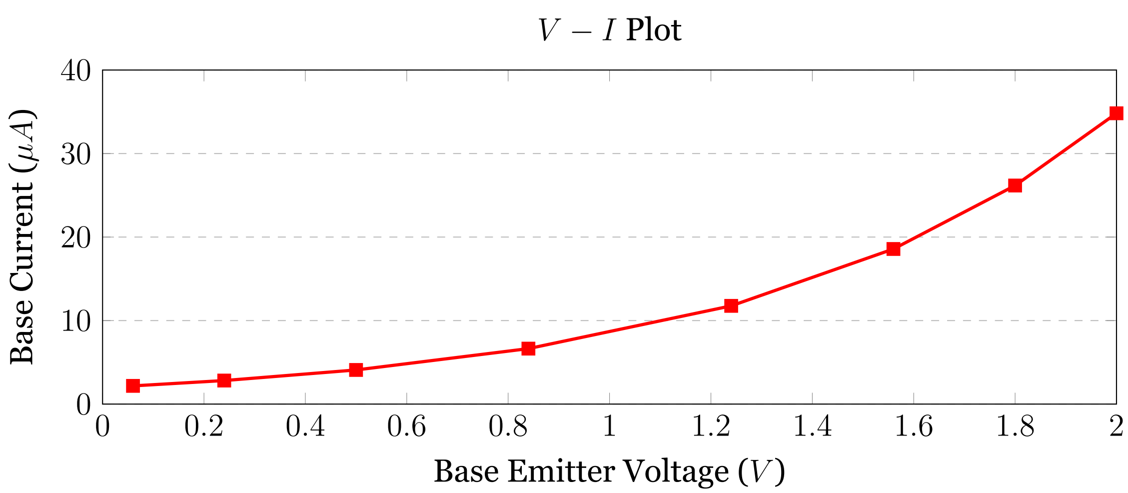


Figure 9.5.2: $V - I$ Plot of BJT Common Emitter - Input Characteristics at $V_{CE} = 1V$

9.5.2 BJT Common Emitter - Output Characteristics

Sr No.	Collector Voltage (V)	Collector Current (mA)
1	0.1000	7.427
2	1.500	67.45
3	2.800	73.97
4	3.900	74.46
5	5.000	74.51
6	6.000	74.52
7	7.800	74.52
8	9.000	74.52
9	10.00	74.52

Figure 9.5.3: BJT Common Emmiter - Output Characteristics Table at $I_B = 15\mu A$

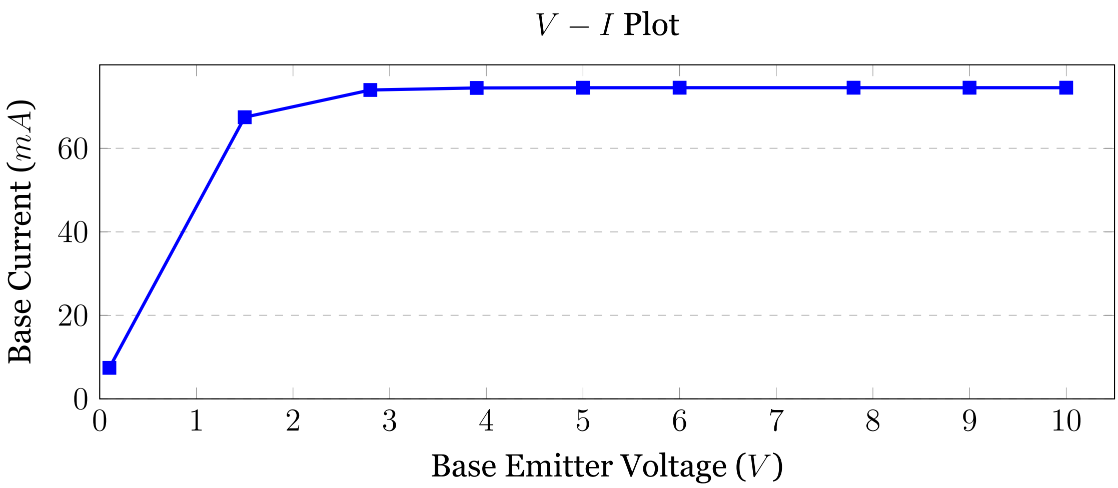


Figure 9.5.4: $V - I$ Plot of BJT Common Emitter - Output Characteristics at $I_B = 15\mu A$

9.6 Result

A bipolar transistor allows a small current injected at one of its terminals to control a much larger current flowing between two other terminals, making the device capable of amplification or switching.The collector–emitter current can be viewed as being controlled by the base–emitter current (current control), or by the base–emitter voltage (voltage control). These views are related by the current–voltage relation of the base–emitter junction, which is the usual exponential current–voltage curve of a p–n junction (diode).

Activity 10

BJT Common Base Characteristics

10.1 Aim

- Explain structure of Bipolar Junction Transistor
- Explain Operation of Bipolar Junction Transistor
- Explain Common Base characteristics of a BJT

10.2 Apparatus

- A Bipolar Junction Transistor
- Voltmeter
- Ammeter
- Rheostat
- Battery

10.3 Theory

10.3.1 Structure of Bipolar Junction Transistor

A bipolar junction transistor, BJT, is a single piece of silicon with two back-to-back P-N junctions.BJTs can be made either as PNP or as NPN.

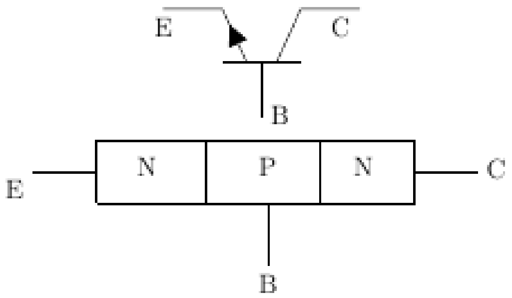


Figure 10.3.1: Structures, layers and circuit symbol of NPN transistor

They have three regions and three terminals, emitter, base, and collector represented by E, B, and C respectively. The direction of the arrow indicates the direction of the current in the emitter when the transistor is conducting normally. An easy way to remember this is NPN stands for ”Not Pointing iN”.

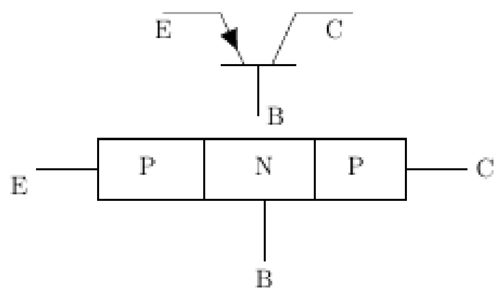


Figure 10.3.2: Structures, layers and circuit symbol of PNP transistor

Emitter (E):It is the region to the left end which supply free charge carriers i.e., electrons in n-p-n or holes in p-n-p transistors.These majority carriers are injected to the middle region i.e. electrons in the p region of n-p-n or holes in the n region of p-n-p transistor. Emitter is aheavily doped region to supply a large number of majority carriers into the base.

Base (B):It is the middle region where either two p-type layers or two n-type layers are sandwiched. The majority carriers from the emitter region are injected into this rgion.This region is thin and very lightly doped.

Collector (C):It is the region to right end where charge carriers are collected.The area of this region is largest compared to emitter and base region . The doping level of this region is intermediate between heavily doped emitter region and lightly doped base region.

10.3.2 Operation of Bipolar Junction Transistor

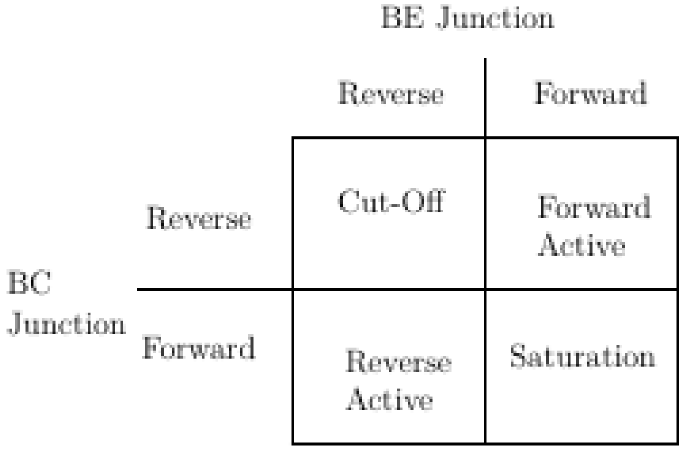


Figure 10.3.3: Four Operating Conditions

Cutoff Region: Base-emitter junction is reverse biased. No current flow.

Saturation Region: Base-emitter junction is forward biased and Collector-base junction is forward biased.

Active Region: Base-emitter is junction forward biased and Collector-base junction is reverse biased.

Breakdown Region: IC and VCE exceed specifications and can cause damage to the transistor.

Cutoff Region: Base-emitter junction is reverse biased. No current flow.

Saturation Region: Base-emitter junction is forward biased and Collector-base junction is forward biased.

Active Region: Base-emitter is junction forward biased and Collector-base junction is reverse biased.

Breakdown Region: I_C and V_{CE} exceed specifications and can cause damage to the transistor.

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In Cut-Off region both junctions are reverse biased, Base-emitter junction is reverse biased ($V_{BE} < 0$)and also Collector-Base junction is reverse biased($V_{CB} > 0$).With reverse biasing, all currents are zero.There are some leakage currents associated with reverse biased junctions,but these currents are small and therefore can be neglected.

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$$I_C = -\alpha_F \times I_E + I_{CO}$$

where, α_F is the forward current transfer ratio I_{CO} is Collector reverse saturation current

10.3.5 Saturation Region

In Saturation region both junctions are Forward biased,Base-emitter junction is forward biased($V_{BE} > 0$) and also Collector-Base junction is forward biased($V_{CB} < 0$). Maximum currents flows through the transistor with only a small voltage drop across the collector junction.The transistor also does not respond to any change in emitter current or base-emitter voltage.

10.3.6 Reverse Active Region

In Reverse Active region Base-emitter junction is reverse biased($V_{BE} < 0$) and Collector-Base junction is forward biased($V_{CB} < 0$).The operation is just the same as the forward active region, except all voltage sources, and hence collector and emitter currents, are the reverse of the forward bias case. The current gain in this mode is smaller than that of forward active mode for which this mode in general unsuitable for amplification.

$$I_E = -\alpha_R * I_C + I_{EO}$$

where, α_R is the reverse current transfer ratio
I_{EO} is the Emitter reverse saturation current

This configuration is rarely used because most transistors are doped selectively to give forward current transfer ratios very near unity, which automatically causes the reverse current transfer ratio to be very low.

10.3.7 BJT - Common Emitter Circuit

The DC behavior of the BJT can be described by the Ebers-Moll Model. The equations for the model are:

$$I_F = I_{ES} \times (exp^{\frac{V_{BE}}{V_T}} - 1)$$

$$I_R = I_{CS} \times (exp^{\frac{V_{CB}}{V_T}} - 1)$$

where,
I_{ES} is base-emitter saturation currents, I_{CS} is base-collector saturation currents

$$V_T = \frac{k \times T}{q}$$

where,
k is the Boltzmann's constant (k = 1.381 e-23 V.C/ K),
T is the absolute temperature in degrees Kelvin, and
q is the charge of an electron (q = 1.602 e-19 C).

$$\beta_F = \frac{\alpha_F}{1 - \alpha_F}$$

$$\beta_R = \frac{\alpha_R}{1 - \alpha_R}$$

where,

β_F is large signal forward current gain of common-emitter configuration,

β_R is the large signal reverse current gain of the common-emitter configuration

$$\alpha_F = \frac{\beta_F}{1 + \beta_F}$$

$$\alpha_R = \frac{\beta_R}{1 + \beta_R}$$

where,

α_R is large signal reverse current gain of a common-base configuration,

α_F is large signal forward current gain of the common-base configuration.

$$I_C = \alpha_F \times I_F - I_R$$

$$I_E = -I_F + \alpha_R * I_R$$

$$I_B = (1 - \alpha_F) \times I_F + (1 - \alpha_R) \times I_R$$

The forward and reverse current gains are related by the expression

$$\alpha_R \times I_{CS} = \alpha_F \times I_{ES} = I_S$$

where,

I_S is the BJT transport saturation current.

The parameters α_R and α_F are influenced by impurity concentrations and junction depths.

The saturation current, I_S , can be expressed as

$$I_S = J_S \times A$$

where,

A is the area of the emitter and

J_S is the transport saturation current density

10.3.8 Input Characteristics

The most important characteristic of the BJT is the plot of the emitter current, I_E, versus the base-emitter voltage, V_{BE}, for various values of the collector-base voltage, V_{CB}

$$I_E = \phi(V_{BE}, V_{CB}) \qquad for \quad constant \quad V_{CB}$$

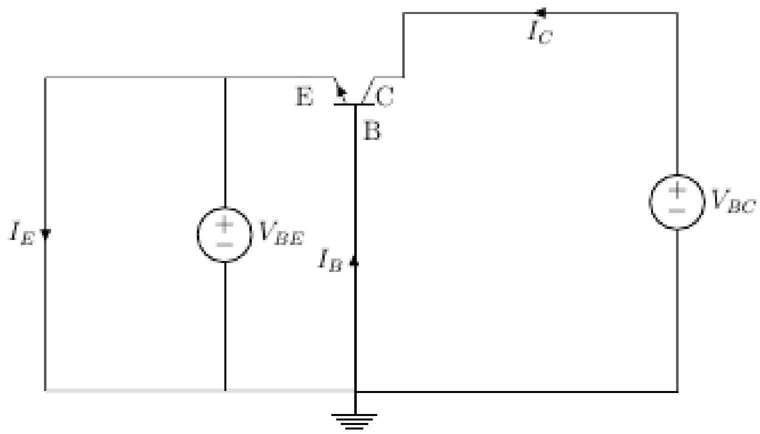

Figure 10.3.4: Input Characteristics Circuit

10.3.9 Output Characteristics

The most important characteristic of the BJT is the plot of the collector current, I_C, versus the collector-base voltage, V_{CB}, for various values of the emitter current, I_E as shown on the circuit on the right.

$$I_C = \phi(V_{CB}, I_E) \qquad for \quad constant \quad I_E$$

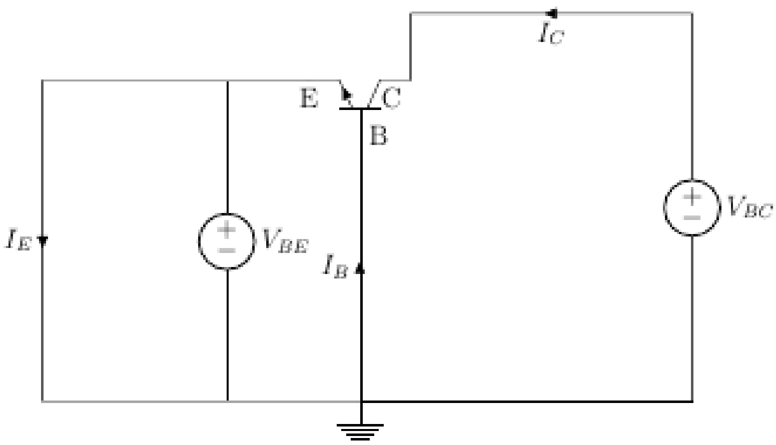

Figure 10.3.5: Output Characteristics Circuit

10.4 Procedure

10.4.1 BJT Common Base - Input Characteristics

1. Initially set rheostat $R_{h1} = 1\Omega$ and rheostat $R_{h2} = 1\Omega$
2. Set the Collector-Base Voltage(V_{CB}) to 1V by adjusting the rheostat R_{h2}
3. Base Emitter Voltage(V_{BE}) is varied by adjusting the rheostat R_{h1}.

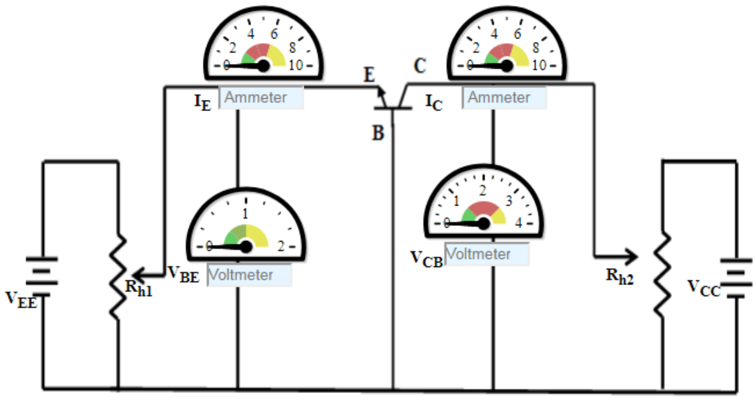

Figure 10.4.1: Simulation for BJT Common Base - Input Characteristics

4. Note the reading of emitter current(I_E)in m-Ampere.
5. Click on 'Plot' to plot the I-V characteristics of Common-Base configuration. A graph is drawn with V_{BE} along X-axis and I_E along Y-axis.
6. Click on 'Clear' button to take another sets of readings
7. Now set the Collector-Emitter Voltage(V_{CB}) to 2V, 3V, 4V

10.4.2 BJT Common Base - Output Characteristics

1. Initially set rheostat $R_{h1} = 1\Omega$ and rheostat $R_{h2} = 1\Omega$.
2. Set the Emitter current(I_E)1 mA by adjusting the rheostat R_{h1}
3. Vary the Collector-Base Voltage(V_{CB})is varied by adjusting the rheostat R_{h2}.

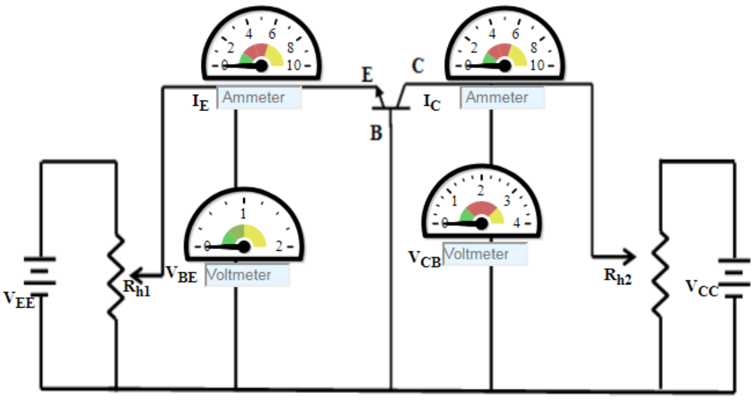

Figure 10.4.2: Simulation for BJT Common Base - Output Characteristics

4. Note the reading of Collector current(I_C).
5. Click on 'Plot' to plot the I-V characteristics of Common-Base configuration. A graph is drawn with V_{CB} along X-axis and I_C along Y-axis.
6. Click on 'Clear' button to take another sets of readings
7. Now set the Emitter Current(I_E) to 2 mA

10.5 Observations

10.5.1 BJT Common Base - Input Characteristics

Sr No.	Base-Emitter Voltage (V)	Emitter Current (mA)
1	0.02000	0.76
2	0.2000	0.98
3	0.4000	1.3
4	0.7400	2.1
5	0.9600	2.9
6	1.200	4.1
7	1.420	5.6
8	1.620	7.4
9	1.880	11
10	2.000	13

Figure 10.5.1: BJT Common Base - Input Characteristics Table at $V_{CB} = 1V$

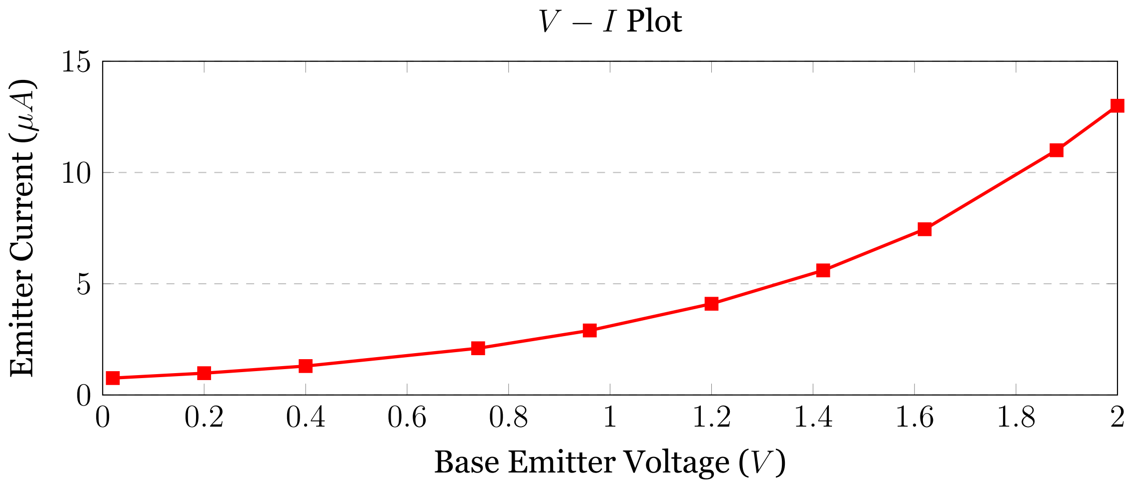

Figure 10.5.2: $V - I$ Plot of BJT Common Base - Input Characteristics at $V_{CB} = 1V$

10.5.2 BJT Common Base - Output Characteristics

Sr No.	Base-Collector Voltage (V)	Collector Current (mA)
1	-0.3000	-0.3795
2	0.9000	0.9332
3	2.100	1.264
4	3.500	1.300
5	5.000	1.303
6	6.100	1.303
7	7.300	1.303
8	8.600	1.303
9	9.600	1.303

Figure 10.5.3: BJT Common Base - Output Characteristics Table at $I_E = 1mA$

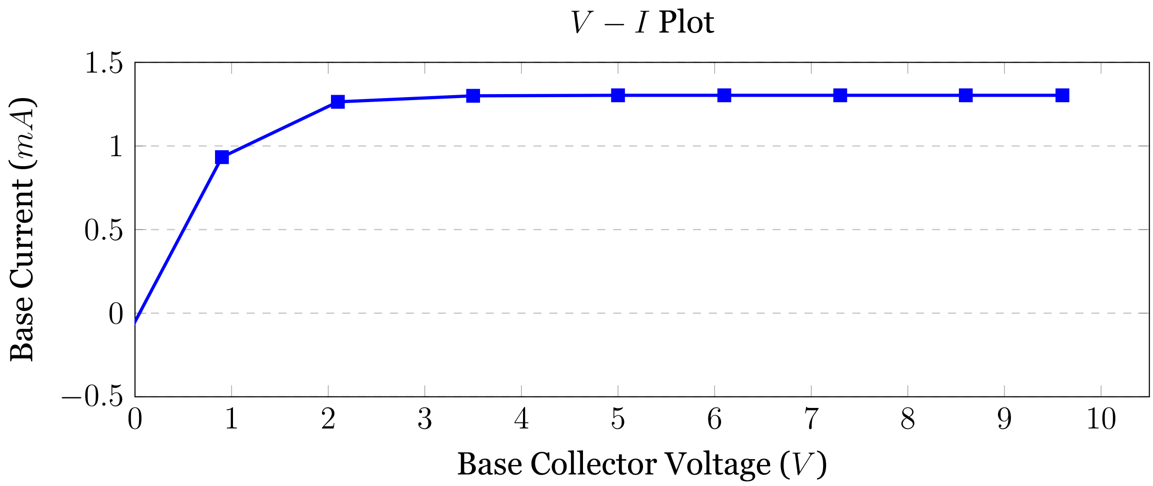

Figure 10.5.4: $V - I$ Plot of BJT Common Base - Output Characteristics at $I_E = 1mA$

10.6 Result

A bipolar transistor allows a small current injected at one of its terminals to control a much larger current flowing between two other terminals, making the device capable of amplification or switching.The collector–emitter current can be viewed as being controlled by the base–emitter current (current control), or by the base–emitter voltage (voltage control). These views are related by the current–voltage relation of the base–emitter junction, which is the usual exponential current–voltage curve of a p–n junction (diode).

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