13/1/2020 Electronics

Communication Systems:

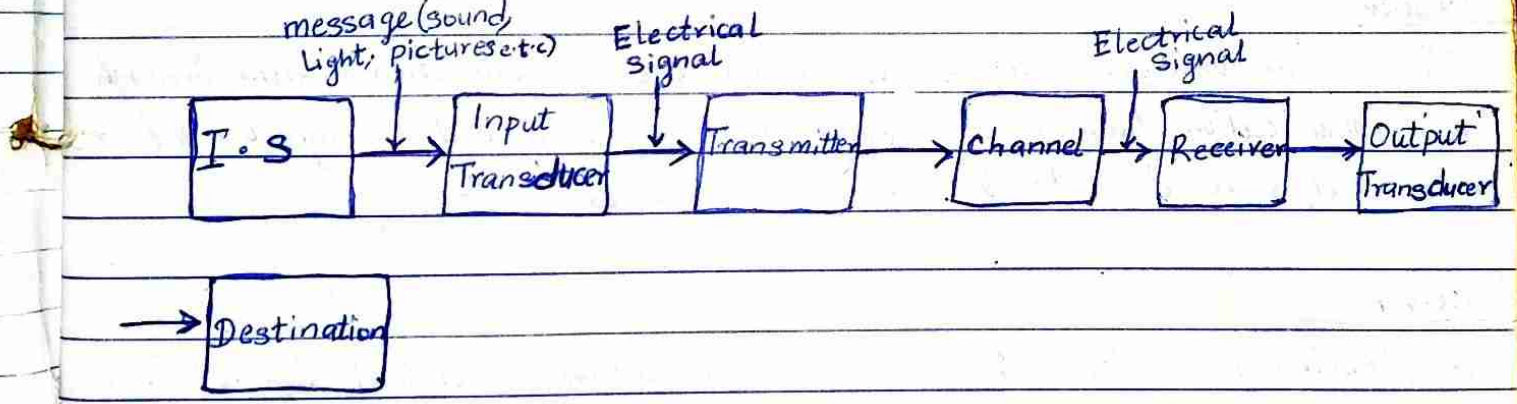
This is the process of information transfer across space & time. The collection of all the element & devices. Communication system is the collection of all elements & devices for the achievement of communication.

Examples are radio broadcasting, Mobile communication, Television broadcasting, computer communication

Block diagram of Communication System

The basic element of communication system are

a) Information source
b) Transmitter
c) Information Channel
d) Receiver & Destination



Information Source

This is the first step in communication system

Input Transducer

A Transducer is a device which convert one form of energy or signal to another energy or signal form. It is present in the input side & the output side of the communications system.

Generally, the input Tranducer convert the non-electrical signal (sound, light, pictures e.t.c) into an electrical signal. e.g microphone

Transmitter

The transmitter is a device which converts a signal produced by a source into a form that is suitable for transmission over a given channel or medium. This uses a technique called modulation to convert electrical signal into a form that is suitable for transmission over a given channel or medium.

Modulation increases the strength of the signal

In order to send the signal a long distance without interference & loss in strength a process called modulation is brought into play.

Communication Channel:

It is a medium through which the signals travels from the source to receiver

We have the wired medium & wireless medium

Examples of wired medium are co-axial cables, fibre optic cables e.t.c

Examples of wireless medium are Air, water & vacuum

Noise

This is an unwanted signal that enter the communication system through the communication channel & interfers with the transmitted signal. The noise helps to degrade the signal's strength

Receiver

The Receiver is a device that receives the signal (electrical signal) from the channel & convert the signal back to its original form (e.g light, sound e.t.c) which is understandable by human at the destination.

This technique is called **Modulation**

Output Transducer:

This converts electrical signal into non-electrical signal (e.g sound, picture, light). The transducer is also impended in the receiver

Destination:

This is the final stage in the communication system. The human beings are the destination listening to the channel.

Basic Operation in the Transmitter

1) Modulation
2) Coding

Modulation:

This is the process of encoding information into a signal that can be transmitted over a channel of interest. Modulation is extremely necessary in communication system due to the following reasons

a) Antenna length:

In order to transmit a wave effectively, the length of the antenna should be approximately equal to the wave of the signal.

b) ~~Wireless Communi~~ Operation range: Because signal can be transmitted over a large distance, modulation is needed

c) Wireless Communication: An important feature of radio transmission is that it can be carried without wires i.e radiated into space.

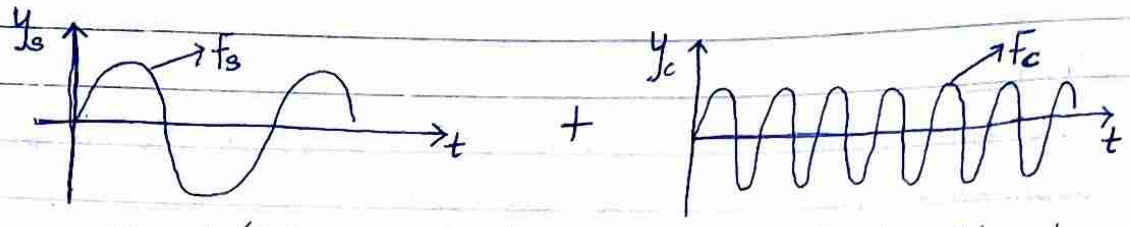
Therefore effective radiation of electrical energy is possible at high frequency.

Types of Modulation

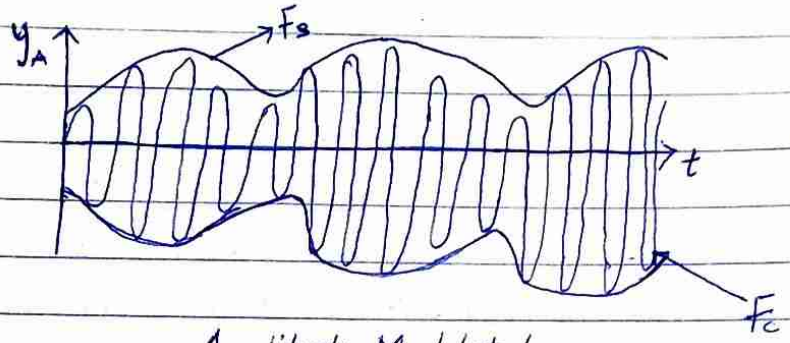
a) Amplitude Modulation (AM)

Here only the amplitude of the carrier wave is changed in accordance with the intensity of the signal. However the frequency of the modulated wave remains the same.

Illustration of the Principle of Amplitude Modulation



Signal (Information signal) Carrier Signal



Amplitude Modulated wave

27/1/2020

Modulation Factor:

An important consideration in amplitude modulation is to describe the depth of modulation i.e the extent to which a amplitude of carrier wave is changed by the signal. This is described by a factor called modulation factor.

Modulation factor (M) is the ratio of change of amplitude of carrier wave to the amplitude of normal carrier wave

$$M = \frac{\text{Amplitude change of carrier wave}}{\text{Amplitude of Normal carrier wave}} \quad \text{—— (2)}$$

$$M = \frac{A_m - A_c}{A_c} \quad \text{—— (2a)}$$

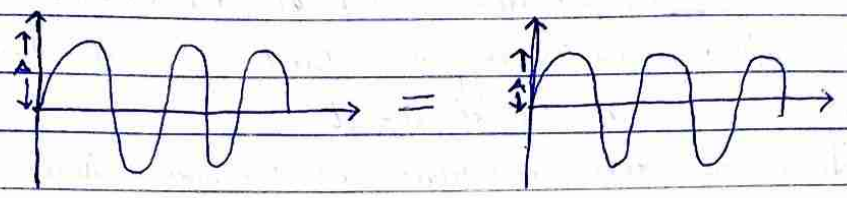
where A_m = Amplitude of modulated wave

A_c = Amplitude of carrier wave

Amplitude modulation for different value of modulation factor

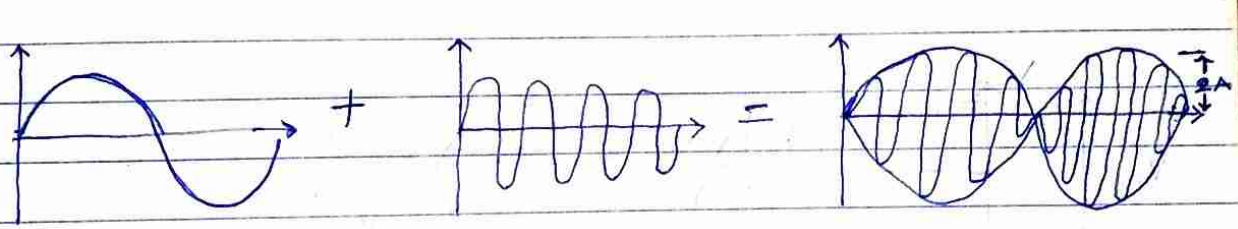
1) When the signal amplitude is zero, the carrier wave cannot be modulated, therefore the amplitude of the carrier wave remains unchanged

No signal +

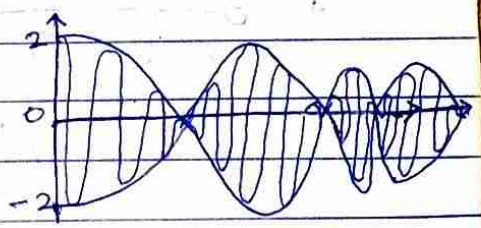


$$M = \frac{A_m - A_c}{A_c} = \frac{A - A}{A} = 0/A = 0 \text{ or } 0\%$$

2) When the signal amplitude is equal to carrier amplitude

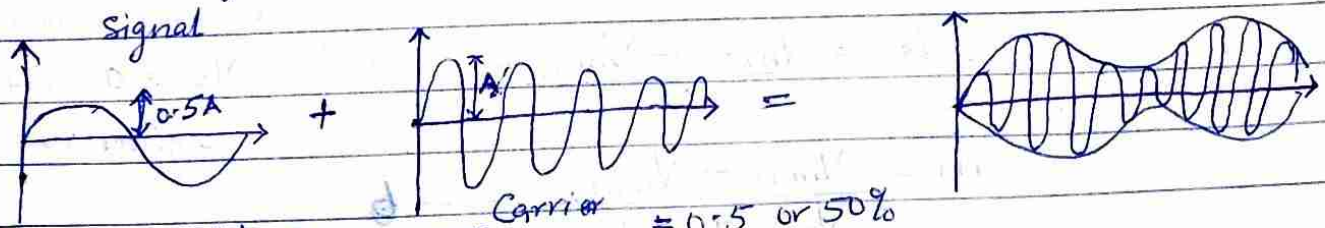


signal carrier



$$m = \frac{A_m - A_c}{A_c} = \frac{A}{A} = 1 \text{ or } 100\%$$

3) When the signal amplitude is half the carrier amplitude

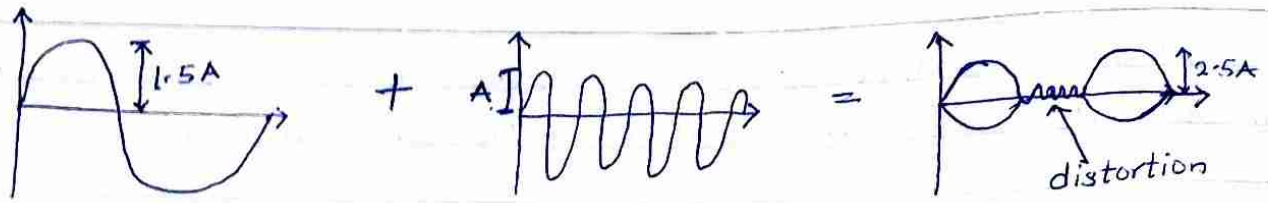


Carrier

$$m = \frac{A_m - A_c}{A_c} = \frac{1.5A - A}{A} = \frac{0.5A}{A} = 0.5 \text{ or } 50\%$$

4) When the signal amplitude is 1.5 the carrier amplitude

$$m = \frac{A_m - A_c}{A_c} = \frac{2.5A - A}{A} = \frac{1.5\cancel{A}}{\cancel{A}} = 1.5 \text{ or } 150\%$$



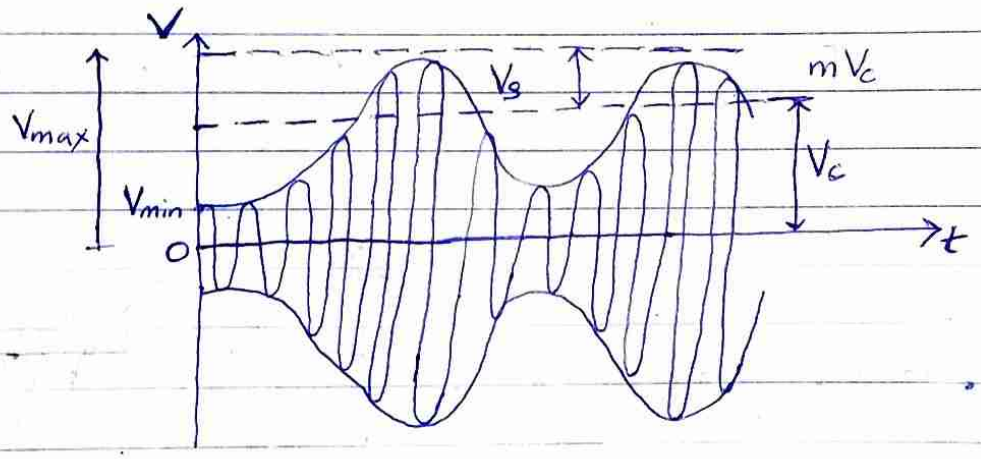
Importance of the Modulation Factor

Modulation factor is very important since it determine the strength & quality of the transmitted signal

When the carrier amplitude is modulated to a small degree (i.e m is small) the amount of carrier amplitude variation is small. Therefore the audio been transmitted will not be strong.

The greater the degree the modulation factor (M) the stronger & clearer the audio signal will be. However the carrier amplitude is over modulated (i.e $M > 1$), distortion will occur during reception.

Therfore the degree of modulation should never exceed 100%



~~Modulation~~

$$V_c = \frac{V_{max} + V_{min}}{2} \quad --- 1)$$

where V_c = ~~Signal~~ amplitude carrier voltage

$$V_s = \frac{V_{max} - V_{min}}{2} \quad --- 2)$$

V_s = amplitude signal voltage

$$m = \frac{V_{max} - V_{min}}{V_{max} + V_{min}} \quad --- 3)$$

Question 1

a) The maximum peak-peak voltage is 12mV & the minimum peak-peak voltage is 2mV. Calculate the

1) modulation factor

2) carrier voltage & signal voltage

b) A carrier wave of 50V & 600KHz is modulated by a 10V, 200Hz sine wave signal. Find the

1) Modulation factor

Continuation

$$V_{max} = V_c + V_s \quad \text{——— (1)}$$

$$V_{min} = V_c - V_s \quad \text{——— (2)}$$

Subtract (2) from (1)

$$V_s = \frac{1}{2}(V_{max} - V_{min}) \quad \text{——— (3)}$$

Add (1) & (2)

$$V_c = \frac{1}{2}(V_{max} + V_{min}) \quad \text{——— (4)}$$

The modulation factor is used to describe the amount of amplitude change present in an amplitude waveform

$$\therefore m = \frac{V_s}{V_c} \quad \text{——— (5)}$$

Substituting (3) & (4) into (5) we have,

$$m = \frac{V_{max} - V_{min}}{V_{max} + V_{min}} \quad \text{——— (6)}$$

Question (solutions)

1) $m = \frac{V_{max} - V_{min}}{V_{max} + V_{min}} = \frac{12-2}{12+2} = \frac{10}{14} = 0.71$

2) $V_c = \frac{1}{2}(V_{max} + V_{min}) = (12+2)/2 = 14/2 = 7mV$

$V_s = \frac{1}{2}(V_{max} - V_{min}) = (12-2)/2 = 10/2 = 5mV$

b) $m = \frac{V_{max} - V_{min}}{V_{max} + V_{min}}$

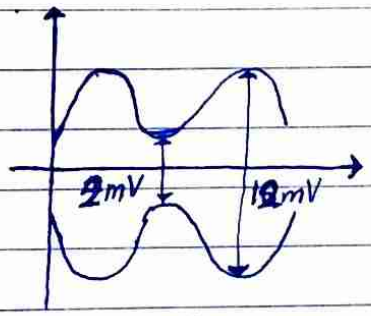
$V_c = 50V$, $V_s = 10V$

$V_{max} = 50 + 10 = 60V$

$V_{min} = 50 - 10 = 40V$

$m = \frac{60 - 40}{60 + 40} = \frac{20}{100} = 0.2$

Solving again !!!



$V_{max} = \frac{12}{2} = 6mV$

$V_{min} = \frac{2}{2} = 1mV$

a) $m = \frac{V_{max} - V_{min}}{V_{max} + V_{min}} = \frac{6-1}{6+1} = \frac{5}{7} = 0.7$

b) $V_s = \frac{V_{max} - V_{min}}{2} = \frac{6-1}{2} = \frac{5}{2} = 2.5V$

$V_c = \frac{V_{max} + V_{min}}{2} = \frac{6+1}{2} = \frac{7}{2} = 3.5V$

2) $m = \frac{V_s}{V_c} = \frac{10}{50} = \frac{1}{5} = 0.2$

Analysis of Amplitude Wave

1) The carrier wave is represented as

$$U_c = V_c \cos \omega_c t \quad \text{——— (2)}$$

where U_c = inst. Carrier voltage

V_c = Amplitude of carrier voltage

ω_c = Angular velocity

2) The signal wave is represented as,

$$U_s = V_s \cos \omega_s t \quad \text{——— (2)}$$

Recall from fig (1), $V_s = m V_c$ ——— (3)

(3) into (2)

$$U_s = m V_c \cos \omega_s t \quad \text{——— (4)}$$

where U_s = Inst. Signal voltage

mV_c = Amplitude of signal voltage

ω_s = Angular

$$V_{AM} = V_c + U_s \quad \text{——— (5)}$$

(4) into (5)

$$V_{AM} = V_c + mV_c \cos \omega_s t$$

$$V_{AM} = V_c (1 + m \cos \omega_s t) \quad \text{——— (6)}$$

3) The inst. Voltage of the Amplitude modulated wave

$$U_{AM} = V_{AM} \cos \omega_c t \quad \text{——— (7)}$$

(6) into (7)

$$U_{AM} = V_c (1 + m \cos \omega_s t) \cos \omega_c t \quad \text{——— (8)}$$

$$= V_c \cos \omega_c t + mV_c \cos \omega_c t \cos \omega_s t$$

$$U_{AM} = V_c \cos \omega_c t + \frac{mV_c}{2} \left[\cos(\omega_c + \omega_s)t + \cos(\omega_c - \omega_s)t \right]$$

$$= V_c \cos 2\pi f_c t + \frac{mV_c}{2} \left[\cos 2\pi (f_c + f_s)t + \cos 2\pi (f_c - f_s)t \right]$$

$$= V_c \cos 2\pi f_c t + \frac{mV_c}{2} \cos 2\pi (f_c + f_s)t + \frac{mV_c}{2} \cos 2\pi (f_c - f_s)t \quad \text{——— (15)}$$

The following can be noted from the above equation,

1) The Amplitude modulated wave is equivalent to the summation of three sinusodial wave. One having amplitude (V_c) & f_c - the second fourth having amplitude $\frac{mV_c}{2}$ & $f_c + f_s$ & the third having amplitude $\frac{mV_c}{2}$ & $f_c - f_s$

2) The A-M wave has 3 frequencies, f_c, $f_c + f_s$, $f_c - f_s$. This means that the process of modulation does not change the original carrier frequency but produces two new frequencies, $f_c + f_s$ & $f_c - f_s$ which are called Side band frequency.

3) The summation of the carrier frequency & signal frequency is called the $f_c + f_s$ Upper side band frequency while $f_c - f_s$ is called Lower side band frequency

Exam question

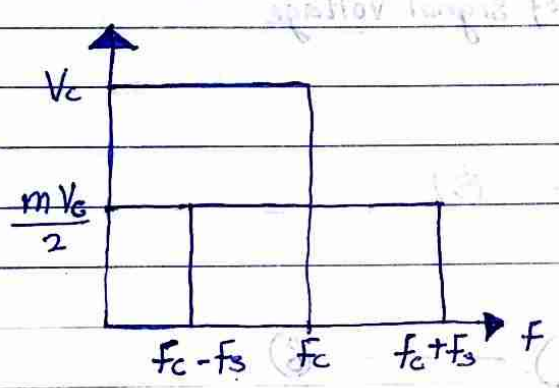


fig 8 : This shows the frequency spectrum of an amplitude modulated wave

Bandwidth

In an A-M wave, the bandwidth is from $f_c - f_s$ to $f_c + f_s$ i-e $2f_s$

$$(f_c + f_s) - (f_c - f_s) = 2f_s$$

Thus in A-M wave, the bandwidth is twice the frequency.

1) An Amplitude modulated is represented by

$$V = 2(1 + 0.2\cos 320t)\sin 2\times10^3 t \text{ Volts}$$

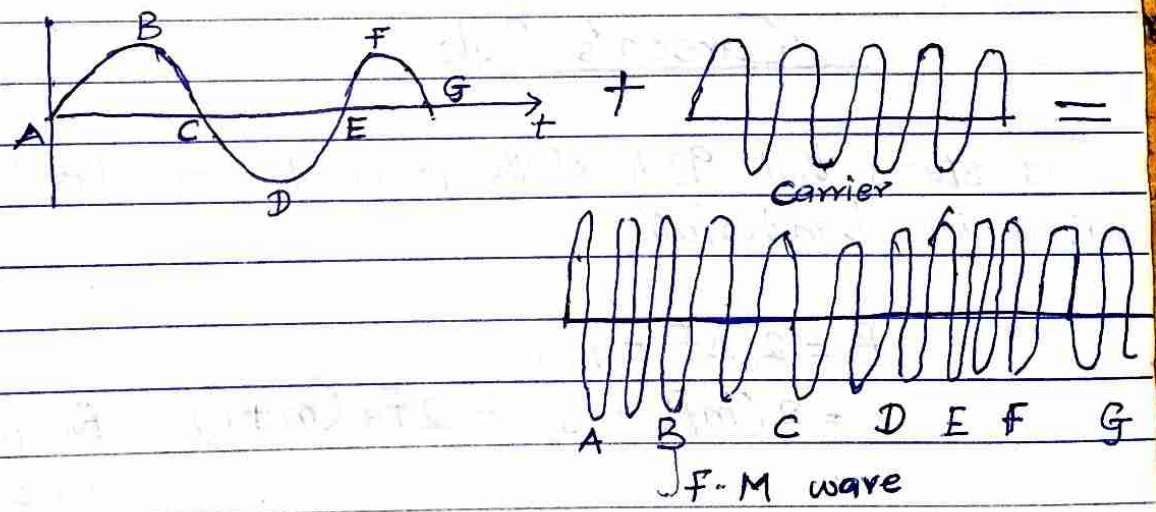
a) What are the maximum & minimum amplitude of the A.M wave

b) What frequency component are contained in the modulated wave & what is the amplitude of each component

2) A sinusodial carrier wave of frequency 5 MHz & amplitude of 200V is amplitude modulated by sinusodial voltage of frequency 2 kHz producing 50% modulation. Cal. the frequency & amplitude of lower & upper side band term.

Frequency Modulation

In frequency modulation, only the frequency of the carrier wave is changed in accordance with the signal. However the amplitude of the modulated wave remains the same i.e the carrier wave amplitude.



When the signal voltage is zero at A, C, E, G, the carrier frequency remain the same. When the signal approaches its positive peak as at B & F, the carrier frequency is increased to maximum, as shown by the closely spaced cycle.

However during the +ve peak of signal at D, the carrier frequency is reduced to the minimum as shown by the widely spaced cycle

Modulation Factor

The frequency modulated factor is given as

$$m = \frac{\Delta F_{max}}{F_s} = \frac{F_{max} - F_c}{F_s}$$

It is the ratio of the maximum frequency deviation to the original frequency signal unlike amplitude modulation, the modulation factor for frequency modulation can be greater than 1

The instantaneous voltage of a frequency modulated wave can be given as

$$U_{fm} = V_c \sin\left[2\pi F_c t - m\cos(2\pi F_s t)\right]$$

The side band frequency can be obtained using Bessel's function & has been found to be infinite.

Upper side band frequency $= F_c + F_s,\ F_c + 2F_s,\ F_c + 3F_s \ldots$

Lower sid band frequency $= F_c - F_s,\ F_c - 2F_s,\ F_c - 3F_s \ldots$

Carson's Rule

This states that 98% of the power of a modulated signal lies within the bandwidth

$$B = 2(\Delta F + F_s)$$
$$= 2(mF_s + F_s) = 2F_s(m+1)$$ For frequency modulated wave

Assignment

1) A frequency modulated wave

$$U_{fm} = 6\sin(3\times10^4 t - 2\cos 150t)$$

find the

a) Carrier frequency
b) Signal frequency
c) Modulation factor
d) Maximum frequency deviation
e) Bandwidth
f) first three Upper & lower side band frequencies

Solution

$$U_{F.M} = 6\sin(3\times10^4 t - 2\cos 150t)$$

Comparing with

$$U_{F.M} = V_c \sin(\omega_c t - m\cos\omega_s t)$$

a) Carrier frequency, $f_c = \frac{3\times10^4}{2\pi} = 4774.6\,Hz$

b) Signal frequency, $f_s = \frac{150}{2\pi} = 23.87\,Hz$

c) $m = 2$

d) $m = \frac{\Delta f_{max}}{f_s} \Rightarrow \Delta f_{max} = 2\times 23.87 = 47.74\,Hz$

e) $B = 2f_s(m+1) = 2\times 23.87(2+1) = 148.22\,Hz$

f) 1st three Upper side band frequencies

$f_c + f_s = 4774.6 + 23.87 = 4798.47\,Hz$

$f_c + 2f_s = 4774.6 + 2(23.87) = 4822.34\,Hz$

$f_c + 3f_s = 4774.6 + 3(23.87) = 4846.21\,Hz$

1st three lower side band frequency

$f_c - f_s = 4774.6 - 23.87 = 4750.73$

$f_c - 2f_s = 4774.6 - 2(23.87) = 4726.86\,Hz$

$f_c - 3f_s = 4774.6 - 3(23.87) = 4702.99\,Hz$

Differences between Frequency Modulation & Amplitude Modulation

Amplitude Modulation	Frequency Modulation
1) Amplitude of the carrier wave varies, frequency & phase are constant	Frequency is varied, Amplitude & phase are constant.
2) More susceptible to noise because noise affect amplitude	Less susceptible to noise because noise does not affect frequency.
3) Here bandwidth (B) = $2f_s$	Bandwidth (B) = $2(\Delta f + f_s)$
4) Poor signal quality	Better signal quality
5) Modulation factor less or equal to 1 ($m \leq 1$)	Modulation factor is greater than 1 ($m > 1$)

De Modulation

The process of recovering the audio signal from the modulated wave is known as demodulation. At the broadcasting station, modulation is done to transmit the audio signal over a large distance to the receiver.

When the modulated wave is picked up by the radio receiver, it is necessary to recover the audio signal from it. This process of recovering is called demodulation

Types of Demodulation

1) Amplitude Modulation Demodulation
2) Frequency Modulation Demodulation

Solution

1) AM of wave equ

$$V = 2(1 + 0.2\cos 320t)\sin 2\times10^3 t \text{ volts}$$

Comparing with the A.M wave equation,

$$V = V_c(1 + m\cos\omega_s t)\sin\omega_c t$$

$V_c = 2V$

$m = 0.2$

$f_s = \frac{\omega_s}{2\pi} = \frac{320}{2\pi} = 50.93Hz$ $\quad [\omega = 2\pi f]$

$f_c = \frac{\omega_c}{2\pi} = \frac{2\times10^3}{2\pi} = 318.3Hz$ $\quad \boxed{m = \frac{V_s}{V_c}}$

i) Minimum amplitude $= V_c - V_s = V_c - mV_c$
$= 2 - (0.2\times2) = 1.6V$

Maximum amplitude $= V_c + V_s = V_c + mV_c$
$= 2 + (0.2\times2) = 2.4V$

ii) $f_c = 318.3Hz$; $f_c - f_s = (318.3 - 50.93)Hz = 267.37Hz$; $f_c + f_s = (318.3 + 50.93) = 369.23Hz$

The amplitude of each above

$V_c = 2V$; $\frac{mV_c}{2} = \frac{0.2\times2}{2} = 0.2V$; $\frac{mV_c}{2} = \frac{0.2\times2}{2} = 0.2V$

2) frequency of Carrier wave, $f_c = 5MHz$
frequency of signal wave, $f_s = 2kHz$
Modulation, $m = 50\% = 0.5$
$V_c = 200V$

Upper band frequency $= f_c - f_s = 5\times10^3 kHz - 2kHz = 4998kHz$
Lower band frequency $= f_c + f_s = 5\times10^3 kHz + 2kHz = 5002kHz$

Amplitude of Each side band $= \frac{mV_c}{2} = \frac{0.5\times200}{2} = 50V$

Elements of Logic Circuitry

Logic Gates

A Logic gate is an arrangement of ~~controlled~~ used to calculate operation in digital circuit. It is a circuit that contains one or more input signal

Properties or Characteristics of Logic Gate

1) In digital system, the binary information is represented by 2 Voltage Level generally plus 5 volt & 0 volt
The 5 Volt is used to represent binary 1 which stands for high input or output while 0 Volt is used to represent binary 0 which stands for low input or output.

2) A Logic gate has only 1 output signal. The Output depends on the input signal & the type of gate

3) The operation of a logic gate may be described by Truth table or Boolean Algebra

4

Truth Table

A	B	y
0	0	0
0	1	1
1	0	1
1	1	1

Boolean Algebra

A+B = y
0+0 = 0
0+1 = 1
1+0 = 1
1+1 = 1

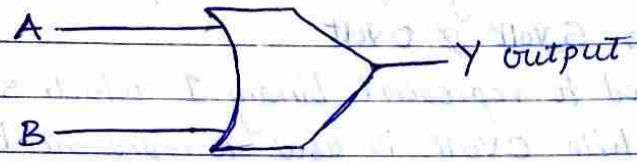
Boolean logic is a form of algebra in which all value are reduced to either true or false

Three basic Logic Gate

1) OR - Gate
2) AND - "
3) NOT - Gate or Inverter

OR - Gate:

This is a logic gate that has 2 or more input but only one output. The output 'Y' of an OR - Gate is low, when all the input are low. ~~The Output of~~ The output 'Y' of an OR - Gate is high, if



Truth table

A	B	Y
0	0	0
0	1	1
1	0	1
1	1	1

Boolean Algebra

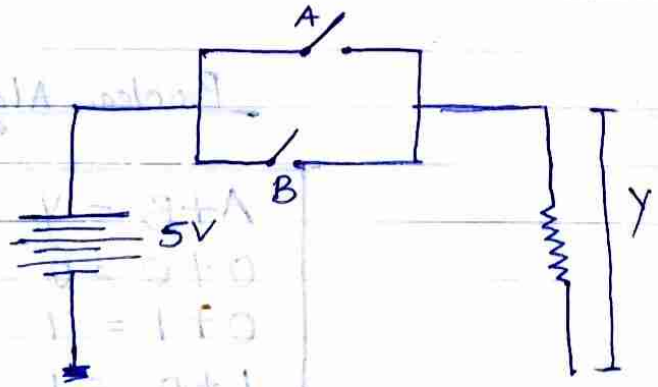
A + B = Y

0 + 0 = 0

0 + 1 = 1

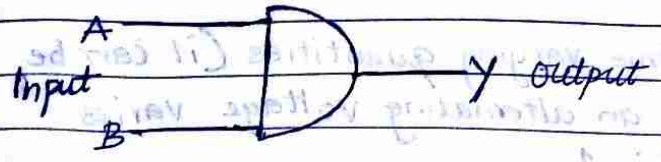
1 + 0 = 1

1 + 1 = 1



AND - Gate:

This is a logic gate that two or more input but only one output. The output Y is high when all the input are high. The output Y is low if any or all the input are low. This gate works on multiplication Rule



Truth Table

A	B	Y
0	0	0
0	1	0
1	0	0
1	1	1

Boolean Algebra

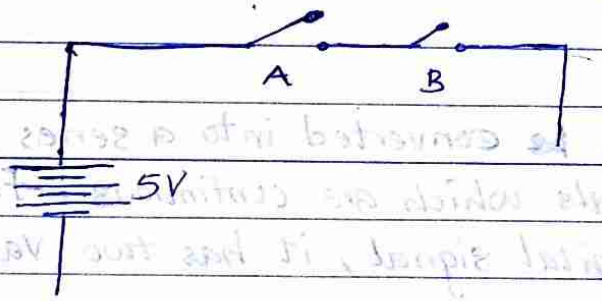
$A \cdot B = Y$

$0 + 0 = 0$

$0 + 1 = 0$

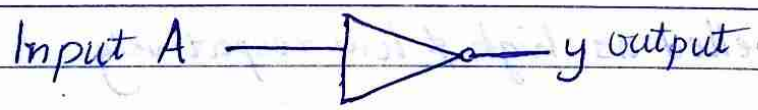
$1 + 0 = 0$

$1 + 1 = 1$



NOT- Gate:

This has only one input & one output where the input is opposite of the output



Truth Table

A	Y
0	1
1	0

Combination of Basic Logic gates

1) NAND
2) NOR
3) XOR
4) XNOR

Analog to Digital Conversion

Analog Signal

This is a signal that contains time varying quantities (it can be voltage or current) - For example, an alternating voltage varies sinusodially in an analog signal fig 1.

The output voltage can have an infinite number of values due to mainly valued output - The analog operation is less reliable

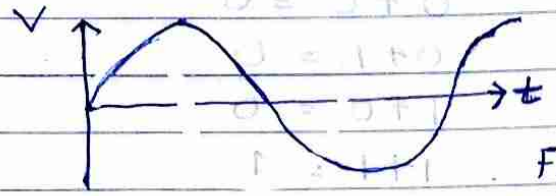


Fig 1

Digital Signal:

This is an electric signal ~~is~~ converted into a series of binary digits unlike analog signals which are continuous. For example a square wave is a digital signal, it has two values +5V & 0V & no other values

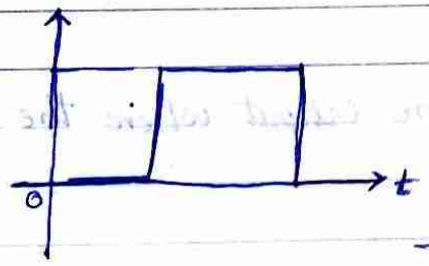
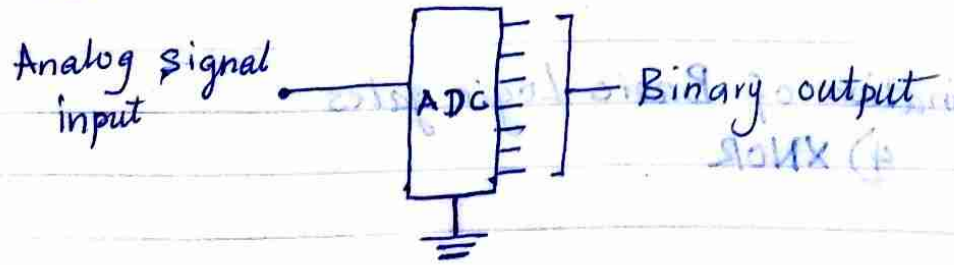


Fig 2

This values are labelled as high & low respectively

Analog to digital Converter (ADC)

This is an electronic integrated circuit used to convert analog signals such as voltages to digital or binary form consisting of 1s or 0s



In order to convert an analog signal to a digital signal, two main process is involved. They are;

a) Sampling
b) Quantization

Sampling:

This is the reduction of a continuous signal to a discrete signal e.g the conversion of sound wave into a sequence of samples.

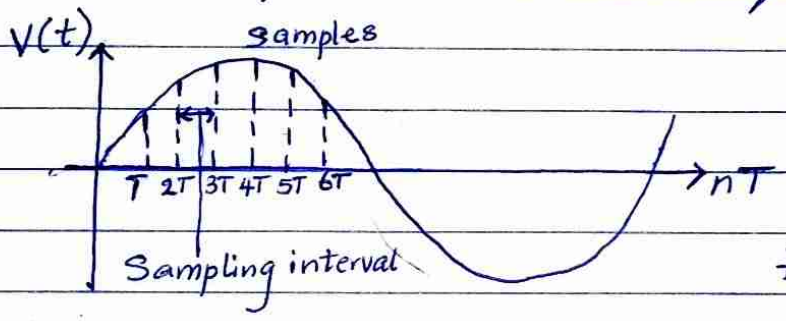


Fig 4

Phy 351

Opto Electronic Devices

Examples: Led, photo diode, Photo transistor, light dependent resistant, Photo voltaic cell, Opto coupler.

Electronics is the science of how to control electric energy in which the electron have fundamental roles. Electronics deals with electrical circuit that involve active electrical components like diodes, integrated circuits & associated passive electrical component. Non-linear behaviour of active components & their ability to control electron flow makes amplification of weak signal possible. Electronics is used in information processing, telecommunication, signal processing e.t.c

An electronic component is any physical entity in an electronic system used to affect the electron or their associated field in a manner consistent with the intended function of the electronic system. Components are intended to be connected together to create an electronic circuit with a particular function e.g an amplifier, radio

Components can be packaged singly or in more complexed groups e.g integrated circuits.

Active components are transistors while passive ones are resistors, diode, inductors & capacitors e.t.c

Active components take part in the transfomation of energy e.g rectifer, transistors. Passive elements dissipate or store energy e.g capacitance, inductor. A passive device is one in which is incapable of augmenting the input power. An active device is one in which a gain in power is possible e.g amplifier.

N.B

Electronic components are classified in various ways e.g linear or non-linear active or passive, two, three or n-terminal. Passive linear two terminal devices include resistors, inductors or capacitors.

Avalanche effect
Zener effect

Types of Circuit

Circuits & components can be divided into two groups; analog & digital.

Analog circuit uses a continuous range of voltage or current as applied to discrete levels in digital circuits. Digital circuits are electric circuits based on a number of discrete voltage levels

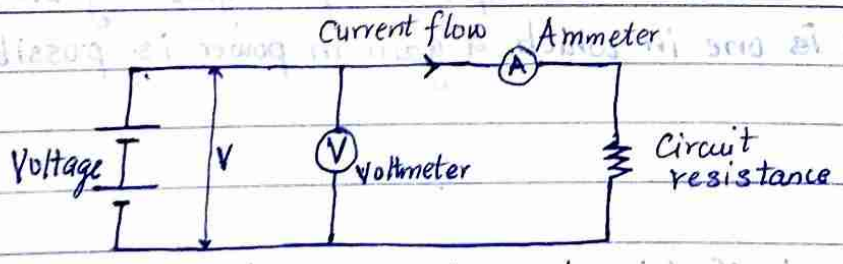
Current - Voltage Characteristic

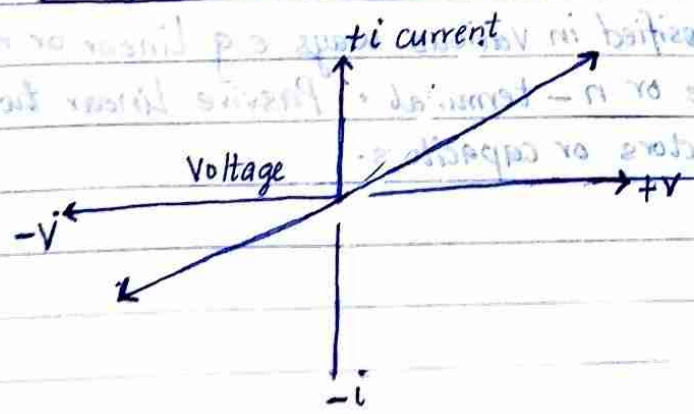
A current - voltage characteristic or I-V curve is a relationship between the electric current through a circuit, device or material & the corresponding voltage or p.d across it.

In electronic components with more than two terminals e.g transistors. The current - voltage relationship at one pair of terminals may depend on the current or voltage of a third terminal. The simplest IV characteristic involves a resistor which obeys ohms law resulting in a linear relationship. I-V characteristic may be non-linear e.g thermistors, diodes e.t.c

The I-V Characteristic curves are used to determine & understand the basic parameters of a component or device which can be used to model mathematically its behaviour within an electronic circuit.

IV Characteristic Curves of an ideal Resistor





In a pure resistance the relationship between voltage & current is linear & constant at a constant temperature.

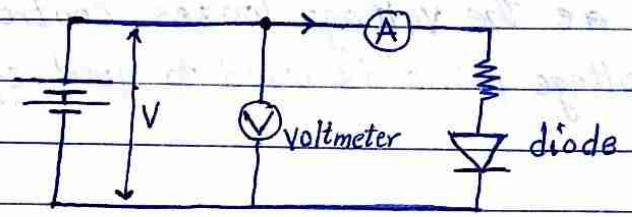
$I \propto V$

$I = \frac{1}{R} V \Rightarrow V = IR$.

I-V characteristic curves of semiconductors

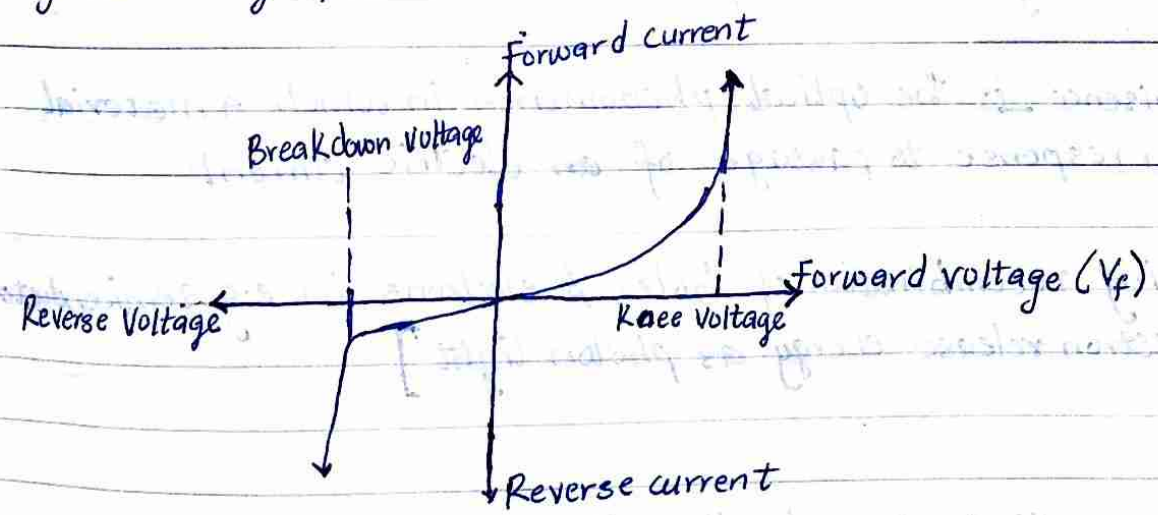
Semiconductor devices such as diodes, transistors are all constructed using semiconductor PN junction connected together hence their IV characteristics reflect the operation of these pn junction. They have non-linear I-V characteristic

I-V Characteristic of a Diode



A pn junction diode allows electric charge to flow in one direction but not in the opposite. Negative charges can easily flow through the junction from n to p but not p to n.

When forward biased, electric charges flow freely due to reduced resistance. When reverse biased, the junction barrier or resistance become large & charge flow is reduced.



When the diode is forward biased, anode is +ve with respect to the cathode a forward or positive current passes through the diode as seen in the top right quadrant. The curve increases gradually unto the forward

quadrant.

When the forward voltage exceeds the p-n internal barrier voltage = 0.7V for silicon, avalanche occurs & forward current increases rapidly for a very small increase in voltage producing a non-linear curve.

When reverse biased, the cathode positive with respect to the anode, the diode blocks current expect for an extremely small leakage current & operates in the lower left quadrant. The diode continues to block current flow through it until the reverse voltage across the diode becomes greater than its breakdown voltage point resulting in a sudden increase in reverse current producing a fairly striaght line downward curve as the voltage looses control.

The reverse breakdown voltage point is used to good effect with Zener diodes.

Note:

In a p-n junction without an external applied voltage an equilibrum condition is reached in which a potential difference is formed across the junction. The p.d is called built-in potential

Light Emitting Diodes Structure

[Electroluminisence is the optical phenomenon in which a material emits light in response to passage of an electric current

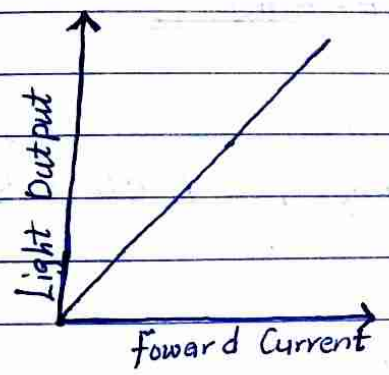
It is a resulting recombination of holes & electrons in e.g semiconductor The excited electron release energy as photon light]

Read up Zener effect & Avalanche effect

One way to construct a LED is to deposit 3 semiconductor layers on a substrate. Between p-type & n-type semiconductor layers an active region emits light when an electron & a hole recombine. Considering the p-n combination to be a diode. when forward biased, the hole from P-region & electron from n-region are driven into the active region, the light is produced by a solid state process called electroluminisence (This has been discussed above).

The LED structure is placed in a tiny reflective cup so that the light from the active layer will be reflected towards the

LED Characteristics



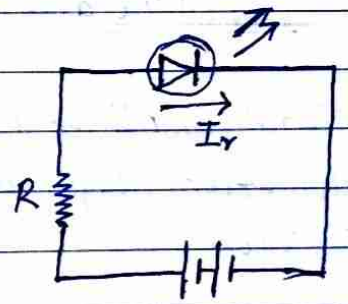
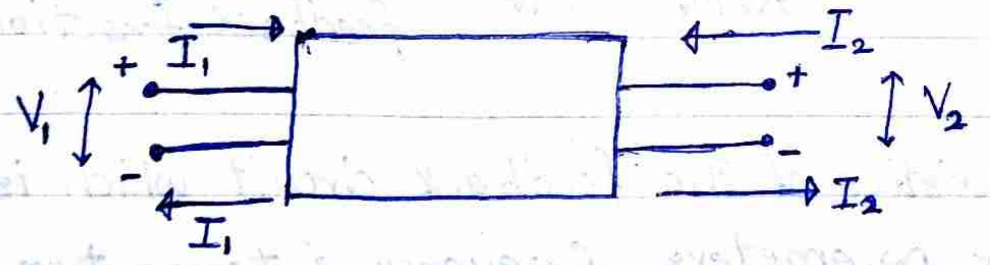


fig: Typical output characteristic for LED

Four - Terminal Networks

Electrical circuit having 4 terminals is called four terminal network or two port. In acoustic electrochemical or optical devices such networks can be called a quadripole. Two terminals or poles are the input terminals & the other two output. Laws like Ohm's law, Kirchoff can be applied in accessing such circuits. A port is a terminal pair where energy can be supplied or extracted. Current at a terminal is regarded as +ve if it flows in & -ve if it flows out as shown in the diagram below. A two port network is called a black box.

Primary parameters of the Four terminal networks



Standard Four Terminal Network Configuration having four external Variables

The symbol of the four terminal network & possible direction of the voltage & current are shown above. The properties of the four terminal network depend on the relation between input voltages & currents. Two of the voltages & currents are called Excitation or Reaction. The other two voltages & currents are called response or action.

Port Condition

Two terminals constitute a port if the current applied to them satisfy the essential requirement known as port condition. The condition is that the electric current entering one terminal must equal the current emerging from the other terminal on the same port.

Port 1 is normally called the input port & Port 2 the output port. V_1 = Voltage across port 1, I_1 = Current into port 1, V_2 = Voltage across port 2, I_2 = current into port 2.

Plots of I_2 versus V_2 = Output Characteristics while plots of I_1 versus V_1 = input characteristics. Plots of input variable against output variable is called Transfer or Mutual characteristics.

The Primary Parameters

There are six combinations of the reaction & excitations in a four terminal network. The coefficients of these equation are called primary parameters of the network. In two port mathematical models, the network is called by a 2 by 2 sq matrix of complex numbers. The common models are Z-parameter, B-parameter, Y-parameter, H-parameter, T-parameter

Version	1	2	3	4
Action Variables	$I_1 I_2$	$V_1 V_2$	$I_1 V_2$	$V_2 I_2$
Reaction Variables	$V_1 V_2$	$I_1 I_2$	$I_2 V_1$	$V_1 I_1$
System of parameters	Z	Y	H	T

Expressing the reaction variables in terms of action variables, we have,

$$\left.\begin{aligned} V_1 &= Z_{11} I_1 + Z_{12} I_2 \\ V_2 &= Z_{21} I_1 + Z_{22} I_2 \end{aligned}\right\} \text{Z-parameters}$$

Electronics
- Active
  - Linear Resistor
  - Non Linear
- Passive
  - one port Network or 2 Terminal
  - two port Network or 4 terminal Network

$$\left.\begin{aligned} I_1 &= Y_{11} V_1 + Y_{12} V_2 \\ I_2 &= Y_{21} V_1 + Y_{22} V_2 \end{aligned}\right\} \text{Y - parameters}$$

$$\left.\begin{aligned} V_1 &= h_{11} I_1 + h_{12} V_2 \\ I_2 &= h_{21} I_1 + h_{22} V_2 \end{aligned}\right\} \text{H - parameters}$$

$$\left.\begin{aligned} V_1 &= t_{11} V_2 + t_{12} I_2 \\ I_1 &= t_{21} V_2 + t_{22} I_2 \end{aligned}\right\} \text{T - parameters}$$

The first two set of equations relate network voltage & current. Their coefficients are in ohm's Law. They have dimensions of impedance or admittance. Admittance is the inverse of impedance. The 3rd equation has 'h' coefficient because the equation has mixture of variables (hybrid). In the 4th equation, the coefficient relate output variable with input variable & are called transmission or t variables.

The double subscripted parameters are explained as follows;

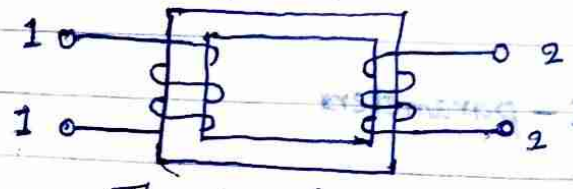
1st subscript = port at which the dependent variable appears

2nd subscript = The port at which the independent variable appears

Examples of 2 port network devices include bridge circuits, electric filters transformer

General Properties of the Network

i) Reciprocal: A network is reciprocal, if the voltage appearing at port 2 due to current appearing at port 1 is the same as the voltage appearing at port 1 when the same current appears at port 2. Active components like transistors & generators are not reciprocal. Any two port who fails the above test is non-reciprocal. Circuit containing passive elements like capacitors, resistors & inductors are reciprocal. e.g. $Z_{12} = Z_{21}$



The transformer

The input terminals are used to connect the source of electrical energy, the output to a Load

2) Linear Network:
If the relationship between current flowing & voltage is linear, the network is linear, if not is non-linear

3) Symmetrical Network: A network is symmetric, if the input impedance is equal to its output impedance. e.g $Z_{11} = Z_{22}$

4) Lossless Network: A Lossless network contain no resistors or other dissipative elements

Matrix Forms of 4-Types of Primary Network Parameters in Circuit Theory

$$\begin{pmatrix} V_1 \\ V_2 \end{pmatrix} = |Z| \cdot \begin{vmatrix} I_1 \\ I_2 \end{vmatrix} \quad \text{where } |Z| = \begin{vmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{vmatrix}$$

$$\begin{vmatrix} I_1 \\ I_2 \end{vmatrix} = |Y| \cdot \begin{vmatrix} V_1 \\ V_2 \end{vmatrix} \quad \text{where } |Y| = \begin{vmatrix} Y_{11} & Y_{12} \\ Y_{21} & Y_{22} \end{vmatrix}$$

$$\begin{vmatrix} V_1 \\ I_2 \end{vmatrix} = |H| \cdot \begin{vmatrix} I_1 \\ V_2 \end{vmatrix} \quad \text{where } |H| = \begin{vmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{vmatrix}$$

$$\begin{vmatrix} V_1 \\ I_1 \end{vmatrix} = |T| \cdot \begin{vmatrix} V_2 \\ I_2 \end{vmatrix} \quad \text{where } |T| = \begin{vmatrix} t_{11} & t_{12} \\ t_{21} & t_{22} \end{vmatrix}$$

General Relations between Primary Parameters

All the parameters are interrelated & each can be expressed in terms of the other. e.g expressing Z-parameters through T-parameters. The goal of such expression is to obtain V_1 & V_2 in terms of I_1 & I_2

Recall, initial system of equations with T-parameters

$$V_1 = t_{11} V_2 + t_{12} I_2 \quad \text{--- (1)}$$
$$I_1 = t_{21} V_2 + t_{22} I_2 \quad \text{--- (2)}$$

Transforming 2nd equation & substituting the value of V_2 into the 1st eqn yields,

$$V_2 = \frac{I_1 - t_{22} I_2}{t_{21}}$$

$$V_1 = t_{11}\left(\frac{I_1 - t_{22} I_2}{t_{21}}\right) + t_{12} I_2 \quad \text{--- (3)}$$

from the above equation;

$$V_1 = \frac{t_{11}}{t_{21}} I_1 + \left(t_{12} - \frac{t_{11} t_{22}}{t_{21}}\right) I_2 = Z_{11} I_1 + Z_{12} I_2 \quad \text{--- (4)}$$

Making V_2 the subject in eqn (2) gives eqn (5)

$$V_2 = \frac{1}{t_{21}} I_1 - \frac{t_{22}}{t_{21}} I_2 = Z_{21} I_1 + Z_{22} I_2 \quad \text{--- (5)}$$

$$\therefore Z_{11} = \frac{t_{11}}{t_{21}} ; \quad Z_{12} = t_{12} - \frac{t_{11} t_{22}}{t_{21}} ; \quad Z_{21} = \frac{1}{t_{21}}$$

$$Z_{22} = \frac{-t_{22}}{t_{21}}$$

Exp.tal Definition of the Primary Parameters

The primary parameters could be found experimentally one of the excitation (input variable is equal to zero) or Shorted circuit (voltage or equal to zero)

a) If network output is open, $I_2 = 0$, the network equation could be written in more simple form

$V_1 = t_{11} V_2$; $V_1 = Z_{11} I_1$; $I_1 = t_{21} V_2$; $V_2 = Z_{21} I_1$

Hence $t_{11} = \left.\frac{V_1}{V_2}\right|_{I_2=0}$; $Z_{11} = \left.\frac{V_1}{I_1}\right|_{I_2=0}$; $t_{21} = \left.\frac{I_1}{V_2}\right|_{I_2=0}$

$Z_{21} = \left.\frac{V_2}{I_1}\right|_{I_2=0}$

b) When network output is shorted ($V_2 = 0$), then

$V_1 = t_{12} I_2$, $I_1 = Y_{11} V_1$, $V_1 = h_{11} I_1$, $I_1 = t_{21} I_2$

$I_2 = Y_{21} V_1$, $I_2 = h_{21} I_1$

So

$t_{12} = \left.\frac{V_1}{I_2}\right|_{V_2=0}$; $Y_{11} = \left.\frac{I_1}{V_1}\right|_{V_2=0}$; $h_{11} = \left.\frac{V_1}{I_1}\right|_{V_2=0}$

$t_{21} = \left.\frac{I_1}{I_2}\right|_{V_2=0}$; $Y_{21} = \left.\frac{I_2}{V_1}\right|_{V_2=0}$; $h_{21} = \left.\frac{I_2}{I_1}\right|_{V_2=0}$

c) When network input is open ($I_1 = 0$) then

$V_1 = Z_{12} I_2$, $V_1 = h_{12} V_2$, $V_2 = Z_{22} I_2$, $I_2 = h_{22} V_2$

Therefore,

$Z_{12} = \left.\frac{V_1}{I_1}\right|_{I_1=0}$; $h_{12} = \left.\frac{V_1}{V_2}\right|_{I_1=0}$; $Z_{22} = \left.\frac{V_2}{I_2}\right|_{I_1=0}$

$h_{22} = \left.\frac{I_2}{V_2}\right|_{I_1=0}$

d) And when network input is shorted ($V_1 = 0$), then

$I_1 = Y_{12} V_2$; $I_2 = Y_{22} V_2$ ∴ So

$$y_{12} = \frac{I_1}{V_2}\Big|_{V_1=0} \quad ; \quad y_{22} = \frac{I_2}{V_2}\Big|_{V_1=0}$$

The formular of the primary parameters could be used as mathemical definition. They show physical meaning of the parameters e.g

$$t_{11} = \frac{V_1}{V_2}\Big|_{I_2=0} = \frac{1}{\frac{V_2}{V_1}}\Big|_{I_2=0} =$$

Is the reverse function of the voltage transfer function in the open four terminal network e.g t_{21} relates input current & output voltage in the open network. t_{21} can be known as feedback-coupling admittance, t_{12} — shorted network crossing (direct coupling impedance), t_{22} — reverse function of the current transfer in the shorted network.

All Z parameters has impedance dimension & y-parameters has admittance dimension.

Z_{11} — input impedance of the open network, Z_{21} - direct coupling impedance, Z_{12} - network with open input feedback coupling resistance; Z_{22} — output impedance with open input.

h_{11} — input impedence of the open network, h_{21} - current transfer coefficient for open circuit.

y_{22} — output admittance of circuit with the open input &

h_{12} — voltage freedback coefficient in the network with open input

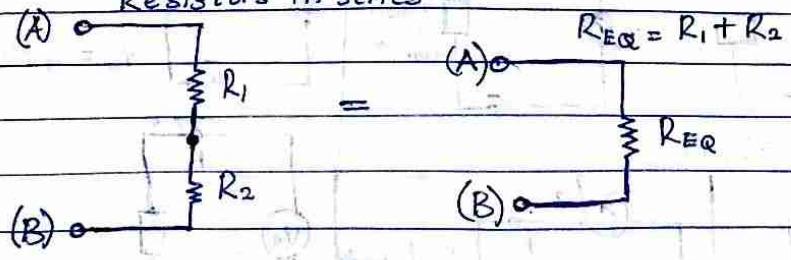
Equivalent Circuits

Circuit Equivalence :- Two circuits are equivalent if they have the same I-V characteristics at a specified pair of terminals.

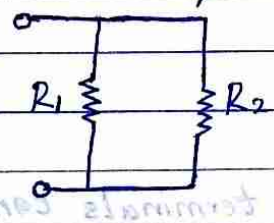
Terminal = external connection to two nodes = port.

The aim is to simplify analysis replacing complicated sub circuits by simpler equivalent circuits.

Resistors in series

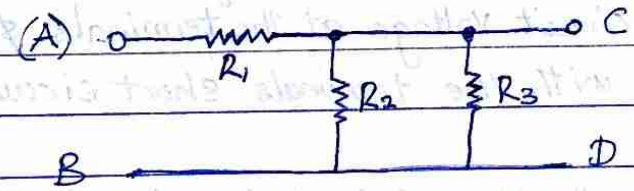


Resistors in parallel



$$= \frac{1}{\frac{1}{R_1} + \frac{1}{R_2}} = \frac{R_1 R_2}{R_1 + R_2}$$

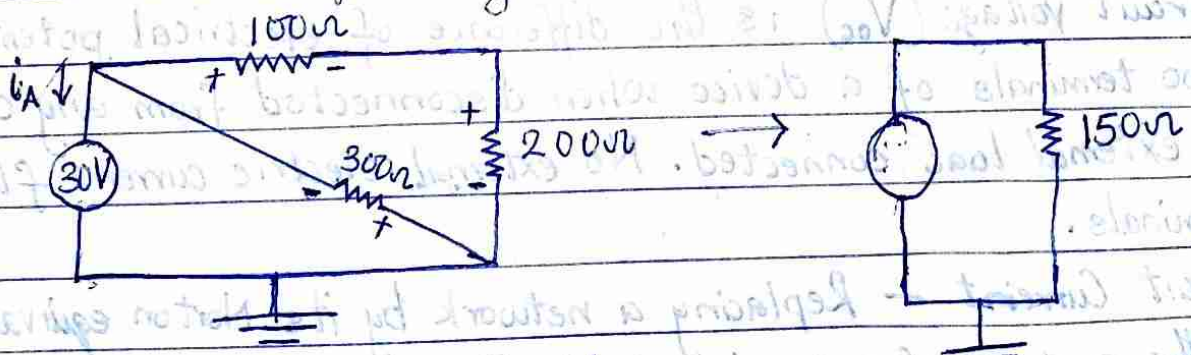
Consider the circuit,



$$R_{EQ_{CD}} = R_2 \| R_3 = \left[\frac{1}{R_2} + \frac{1}{R_3}\right]^{-1} = \frac{R_2 R_3}{R_2 + R_3}$$

$$R_{EQ_{AB}} = R_1 + R_2 \| R_3 = R_1 + \frac{R_2 R_3}{R_2 + R_3}$$

Find i_A in the following circuit if $V_A = 30V$

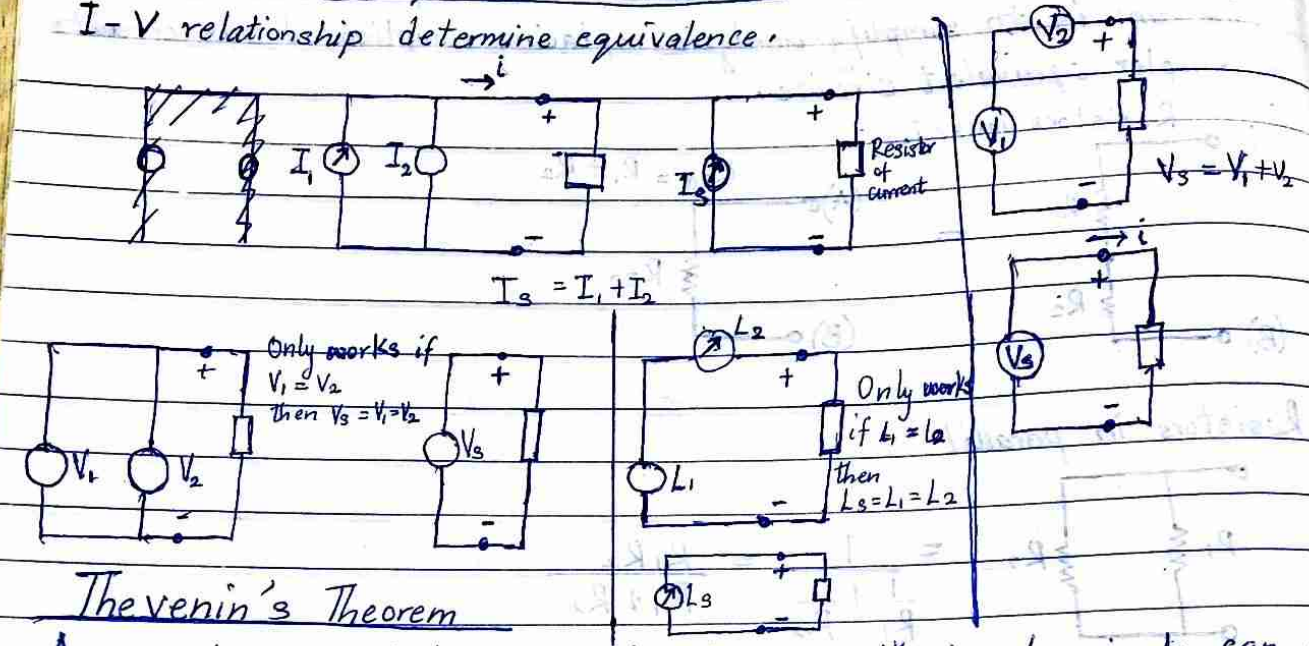


$$i_A = -\frac{V_A}{R} = -\frac{30}{150} = -200mA$$

Equivalent circuits for resistive networks are familiar reductions of parallel & series connections.

Equivalent Sources

I-V relationship determine equivalence.



Thevenin's Theorem

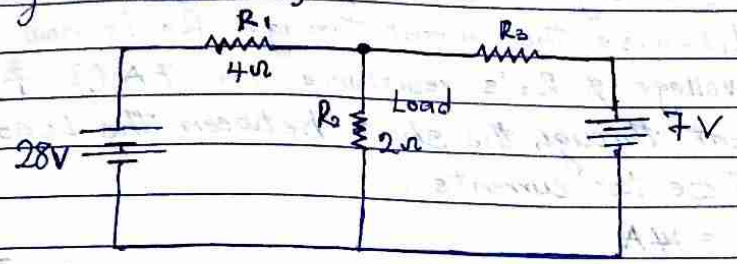
Any combination of batteries & resistance with two terminals can be replaced by a single voltage source 'e' & a single series resistor 'r'. The value of 'e' is the open circuit voltage at the terminals & the value 'r' is 'e' divided by the current with the terminals short circuited.

Nortons Theorem :- Any collection of batteries & resistances with two terminals is electrically equivalent to an ideal current source 1 in parallel with a single resistor 'r'. The value of 'r' is the same as that in the Thevenin equivalent & the current 'i' can be found by dividing the open circuit voltage by 'r'.

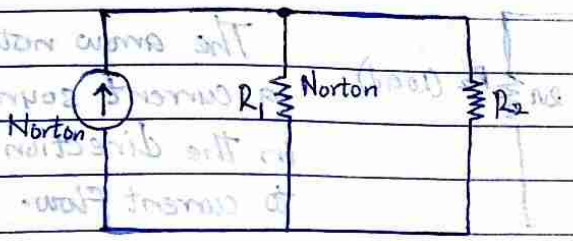
Open circuit voltage (V_{oc}) is the difference of electrical potential between two terminals of a device when disconnected from any circuit. There is no external load connected. No external electric current flows between terminals.

Equivalent Current – Replacing a network by its Norton equivalent can simplify the analyses of a complex circuit. In this example the Norton current is obtained from the open circuit voltage (The Thevenin voltage

divided by the resistance).



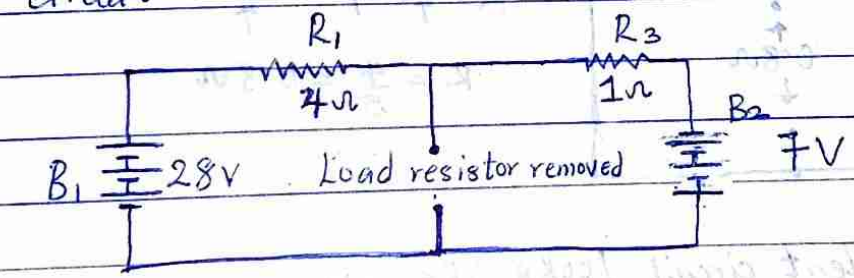
After Norton Conversion



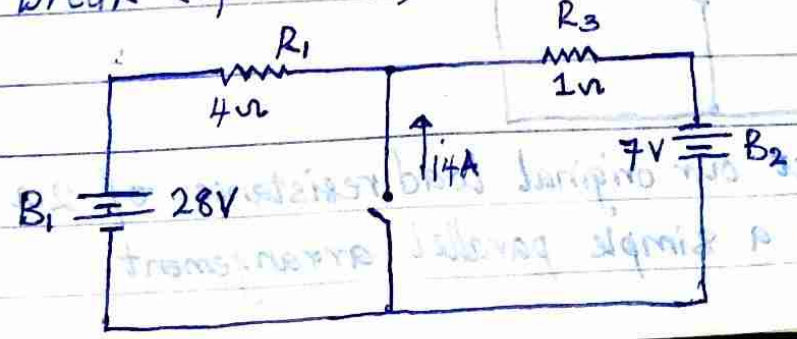
Remember that a current source provides a constant amount of current.

Thevenin theorem everything in the original circuit expect the load resistance has been reduced to an equivalent circuit that is simpler to analyze.

i) 1st step — Identify the Load resistance & remove it from the original circuit.



To find the Norton current, place a short between the load points & determine the resultant current (In thevenin, you replace the Load resistor with a break (Open Circuit)

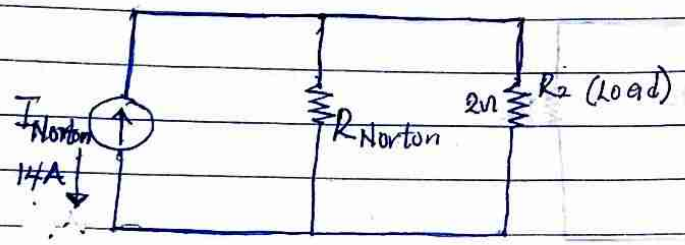


With zero voltage dropped between the Load resistor connection point the current through R_1 is strictly a function of B_1 voltage & R_1's resistance i.e 7A ($I = \frac{28}{4}$). Likewise the current through R_3 is now strictly a function of B_2's voltage & R_3's resistance i.e 7A ($I = \frac{7}{1}$)

∴ The total current through the short between the Load connection points is the sum of these two currents

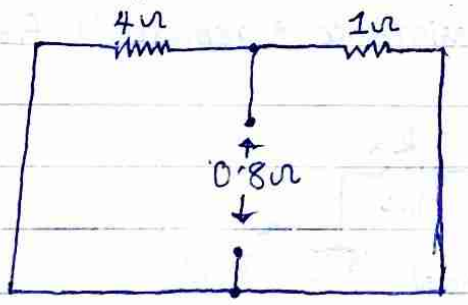
$$7A + 7A = 14A$$

This figure of 14A becomes the Norton source current I_{Norton} in our equivalent current



The arrow notation for a current source, points in the direction opposite to current flow.

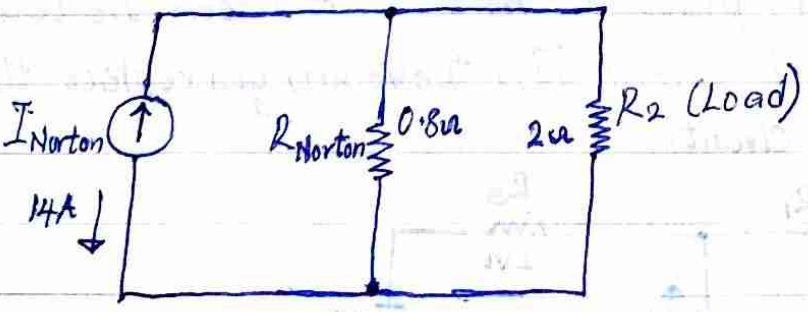
To calculate the Norton Resistance do the same thing as calculating Thevenin resistance. Take the original circuit (with the load resistor still removed) remove the power source, voltage source replaced with wires & current sources replaced with breaks & figure total resistance from one Load connection point to the other.



$$\frac{1}{R} = \frac{1}{4} + \frac{1}{1} = \frac{5}{4}$$

$$R = \frac{4}{5} = 0.8\Omega$$

The Norton equivalent circuit looks like this



If we re-connect our original load resistance of 2Ω we analyze the Norton current as a simple parallel arrangement.

	R_{Norton}	R_{Load}	Total	
E	8	8	8	Volts
I	10	4	14	Ampere
R	0.8	2	571.43m	Ohms

Review :- Norton's Theorem is a way to reduce an equivalent current composed of a single current source, parallel resistance & parallel load.

Steps to follow;

1) Find the Norton source current by removing the Load resistor from the original circuit & calculating current through a short (wire) jumping across the open connection points where the Load resistor used to be.

2) Find the Norton resistance by removing all power source in the original circuit (voltage source shorted & current source open) & calculate total resistance between the open connection points.

3) Draw the Norton equivalent current with the Norton current source in parallel with the Norton resistance. The Load resistor attached between the two open points of the equivalent circuit.

4) Analyze voltage & current for the load resistor following the rules for parallel circuits.

Thevenin Theorem

Any Linear electric network or complex circuit with current & voltage source can be replaced by an equivalent circuit containing of a single independent voltage source V_{TH} & a series resistance R_{TH}.

Simple Steps to analyze Electric Circuit through Thevenin Theorem

1) Open the Load resistor
2) Calculate/measure the open circuit voltage. This is the Thevenin voltage (V_{TH})
3) Open current source & short voltage source.

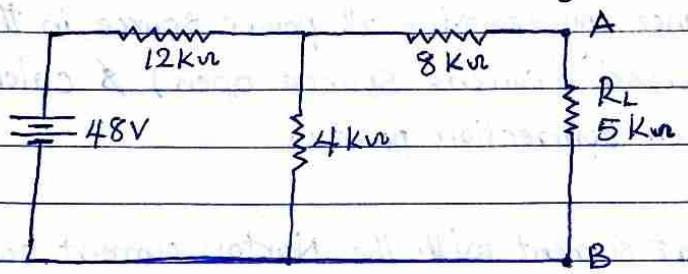
4) Calculate/measure the open circuit resistance. This is the Thevenin Resistance (R_{TH})

5) Now, redraw the circuit with measured open circuit voltage (V_{TH}) in Step 2 as voltage source & measured open circuit resistance (R_{TH}) in Step 4 as a series resistance & connect the load resistor which we had removed in step (1).

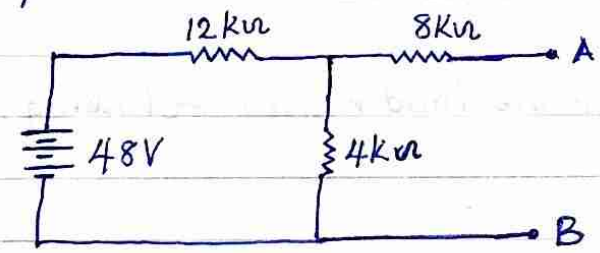
6) Now find the Total current flowing through Load resistor by using the Ohm's law.

$$I_T = \frac{V_{TH}}{(R_{TH} + R_L)}$$

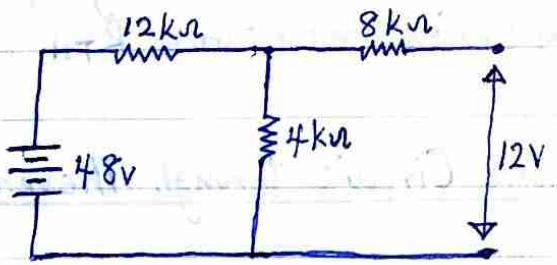
Example: Find V_{TH}, R_{TH} & the Load current flowing through & Load voltage across the load resistor in the fig. below using Thevenin theorem



Step 1: Open the 5kΩ resistor



Step 2: Calculate/measure the open circuit voltage - This is the Thevenin voltage (V_{TH}).



Removing the load resistance make the circuit open circuit. Now the Thevenin voltage has to be calculated.

Current flows through 12kΩ & 4kΩ and not is 8kΩ because it is open.

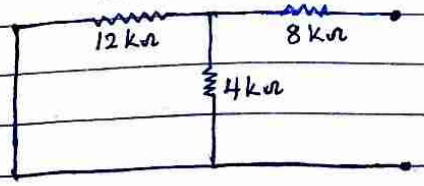
Hence, Total series resistance = 12kΩ + 4kΩ = 16kΩ

$\therefore$ Current $= \frac{48}{16000} = 3mA$. But 4kΩ is parallel to 8kΩ

The same voltage will appear across the 8kΩ resistor as 4kΩ resistor

$\therefore 3mA \times 4k\Omega = 12V$

Step 3: Open current sources & short voltage source



Step 4: Calculate/measure the open circuit resistance. This is the Thevenin resistance (R_{TH}). The 48V DC source is reduced to zero which is the same as replacing it with a short

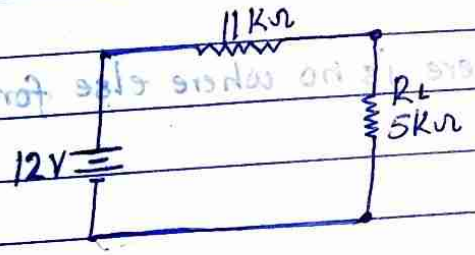
$\therefore$ 8kΩ resistor is in series with a parallel connection of 4kΩ resistor & 12kΩ resistor i.e

$8k\Omega + 4k\Omega // 12k\Omega$

$R_{TH} = 8k\Omega + [(4k\Omega \times 12k\Omega)/(4k\Omega + 12k\Omega)]$

$= 8k\Omega + 3k\Omega = 11k\Omega$

Step 5: Connect the R_{TH} in series with voltage source V_{TH} & reconnect the Load resistor. This is the Thevenin equivalent circuit.



Thevenin's equivalent circuit

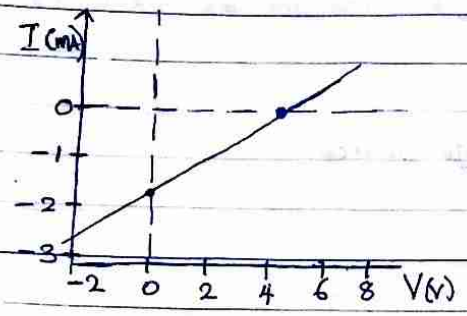
Step 6: Calculate the total Load current & Load voltage as shown according to ohm's Law

$I_L = V_{TH}/(R_{TH} + R_L) = 12V/(11k\Omega + 5k\Omega) = 12V/16k\Omega = 0.75mA$

& $V_L = I_L \times R_L = 0.75mA \times 5k\Omega = 3.75V$

Thevenin Circuit Properties

A Thevenin equivalent circuit has a straight line characteristic with the equation.



$$V = R_{TH} I + V_{TH}$$

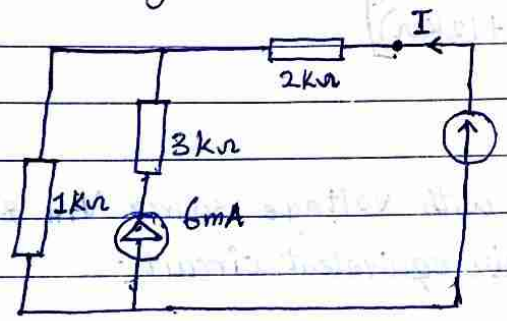
Divide all through by R_{TH}

$$I = \frac{1}{R_{TH}} V - \frac{V_{TH}}{R_{TH}}$$

3 important quantities are

- Open circuit voltage; If $I = 0$ then $V_{oc} = V_{TH}$
- Short circuit voltage if $V = 0$ then $I_{sc} = -V_{Th}/R_{TH}$
- Thevenin Resistance : The slope of the characteristic is $du/dv = \frac{1}{R_{TH}}$

To detemine Thevenin value any two of the following have to be known
Open circuit voltage, short circuit current, Thevenin resistance



Open circuit voltage $1k\Omega = 6$ because there is no where else for the current to go.

$$\text{So } V_{oc} = 6 \times 1 = 6V = V_{TH}$$

2kΩ & 1kΩ are in parallel & so form a current divide in which current are proportional to conductance

$$\text{So } I_{sc} = -\frac{1/2}{3/2} \times 6 = -2mA = -\frac{V_{TH}}{R_{TH}}$$

Thevenin Resistance

Set all the independent sources to zero voltage source → Short circuit, current source → open circuit.

Find eqn. resistor between the two terminal. The 3kΩ resistor has

no effect - so

$R_{TH} = 2k\Omega + 1k\Omega = 3k\Omega$

Semi Conductor Basic

Resistance of a material is generally defined as being the ratio of the voltage difference across it to the current flowing through it → Ohm's Law. Resistance of a material to current flow depends on the physical size of the material & the material of which it is made - To avoid this dependence the term resistivity is used. It is the inverse of conductivity & is measured in ohm-metres. If the resistivity of various material is compared, they can be grouped into conductors, insulator & semiconductor

Resistivity Chart

10^{-8}	Silver — 1.6×10^{-8}	Conductors
10^{-6}	Gold — 2.4×10^{-8}	
10^{-4}	Carbon — 3.5×10^{-5}	
10^{-2}		
10^{0}	Germanium — 4.6×10^{-1}	Semi conductors
10^{2}	Silicon — 6.4×10^{2}	
10^{4}		
10^{6}		
10^{12}	Glass — 1.0×10^{10}	Insulators
10^{14}		
10^{16}	Quartz — 7.5×10^{18}	

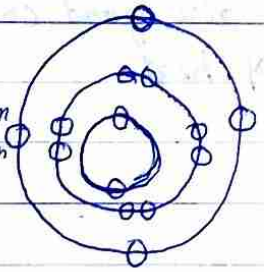
Note: The resistivity (ρ) of a material at one time depends upon their ambient temperature because metals are also good conductors of heat.

Conductors:- Materials have low values of resistivity usually micro-ohm per metre. This low value allows them to easily pass an electric current due to their being plenty of free electrons floating about within their basic atomic structure. When a positive voltage potential is applied to the material these free electron leave their parent atom & travel together through the material forming an electron drift - current. Cu, Al, Ar or non-metals such as carbon are good example. They have fewer electron that can easily be knocked off - The energy which is lost in the process

of passing an electric current appears in the form of heat which is why conductors & especially resistors become hot.

Insulators: They are opposite of conductors made of materials generally non-metals with few or no free electron within the basic atomic structure. The electrons in the outer valence shell are strongly attracted by the positively charged inner nucleus. When a p.d is applied there is no current flow as there are no electrons to move & which gives the material their insulating properties. Examples are glass, porcelain e.t.c

Semiconductors: Semiconductors materials such as silicon, germanium, gallium Arsenide have electrical properties somewhere in the middle between those of conductors & insulators. They are no good insulators nor good conductors, hence the name semiconductors. They have very few electrons because their atoms are grouped together in a crystalline pattern called crystal lattice. Their ability to conduct electrically can be improved by adding impurities to the structure, thereby creating free electrons than holes or vice versa. This process of adding impurity atom to semiconductor of 1 impurity atom per 10million atom of the semiconductor is called doping.



Silicon atom showing 4 electron in its outer Valence shell

N-type Semiconductor basics

In order for our silicon crystal to conduct electricity we need to introduce an impurity atom such as arsenic, antimony or phosphorus into the crystalline structure making it extrinsic (impurities are added)

4 out of 5 orbital electrons to bond with its neighbouring silicon atoms leaving one free electron to become mobile when an electrical voltage is applied (electron flow). Each impurity atom donates one electron. Pentavalent atom are generally known as donors.

Antimony (Sb) or Phosphorus (P) are frequently used as a pentavalent

additive to the silicon.

The resulting semiconductor basic material has an excess of current-carrying electrons each with a negative charge. It is therefore referred to as N-type material with the electron called majority carriers while the resulting holes are called minority carriers.

A semiconductor material is as N-type when its donor density is greater than its acceptor density. It has more electrons than holes thereby creating a negative pole.

An antimony atom
Atomic number = 51

P - Type Semiconductor basics

Introducing trivalent (3 electron) impurity into the crystalline such as Aluminum, Boron or indium which have only 3 valence electron available in their outermost orbital. The fourth closed band cannot be formed. With a hole in the silicon crystal, a neighbouring electron is attracted into it & tries to move into the hole to fill it. The electron filling the hole leaves a hole behind it & so on, giving appearance that the hole are moving as the charges.

The movement of holes results in shortage of electron in the silicon turning the entire doped crystal into a positive pole. Trivalent impurities are called acceptors. Boron atom is a trivalent atom with 3 electrons in the outer shell. The doping with boron atom causes conduction to consist mainly of +ve charge carriers resulting in a p-type material

with the positive holes called majority carriers while the free electron are called minority carriers. A semiconductor basic material is p-type when its acceptor density is greater then its donor density

Boron atom & Doping

Dr E. B. I. Ugwu [Part]

Coordinator

Semi-conductor theory & Devices

- Characteristics
- Electronic devices, Amplifiers, types
- Lasers & Masers
- Four terminal Network
- Equivalent Circuits
- Transistor
- Op-Amp

Semi Conductor

Semiconductors are substances like germanium, silicon, carbon e.t.c that are neither good conductors of electricity like copper or bad conductors like glass. Their restivity lies between conductors & insulators. They are extensively used in making transistors.

Semi-conductors have negative temperature coefficient of resistance i.e their resistance decrease with increase in temperature & vice-versa. Also, when a suitable impurity (e.g arsenic, gallium e.t.c) is added to them, their current conducting properties change appreciably. The third property is that their restivity is less than that of an insulator but more than that of a conductor.

Bonds in Semiconductors & theory of its conduction

Semiconductors are crystals (substances in which the atoms or molecules are arranged in orderly pattern that form covalent bonds in order to attain octet state, i.e complete their last orbit. They have four (4) Valence electrons which they share with neighbouring atoms to reach octet state. Hence, valence electrons in an atom of germanium or silicon are not free. The energy required to break these covalent bonds in a semiconductor is very small ($\sim 1eV$). In other words, the forbidden energy gap, i.e the energy between the valence bond & conduction band is very small & can easily be reached by a valence electron for it to enter the conduction band from the valence band. At room temperature, free electrons in the conduction band is very

few in number, hence a semiconductor at this temperature is neither a good conductor or an insulator.

As more thermal energy is supplied, more valence electrons are set free & migrate to the conduction band. These free electrons constitute a tiny electric current of p.d is applied across the semi-conductor. Therefore the resistance of a semiconductor decreases with increase in temperature.

As an electron leaves for the conduction band, a hole which acts as a positive charge is formed where the missing electron was. Hence, there is a hole-electron pair; & there as many holes as there are electrons. The movement of holes creates a hole current. Holes moves towards the negative terminal while electrons drift towards the positive terminal.

Types of Semiconductor

A semi-conductor in its pure form is known as intrinsic semiconductor. Even at room temperature, hole-electron pairs are created. Adding a small amount of impurity to a semi-conductor (this is termed doping) will improve the amount of current produced. The semiconductor is now called Extrinsic Semiconductor. If a pentavalent impurity e.g arsenic or antimony is added, the semiconductor becomes an n-type semi-conductor is formed but if a trivalent atom (element) is added as impurity, a p-type semi-conductor is formed.

Four out of the five valence electrons pair covalently with the semi-conductor; (e.g Ge) valence electrons leaving the fifth electron as free electron. The free electron moves to the conduction band & a small amount of arsenic (As) provides millions of free electrons. Thermal energy of even room temperature will still provide a few electrons ~~over~~ holes pairs. The predominance of free electrons over holes makes the n-type (negative type) more conducting when a p.d is applied. An n-type impurity is called a donor impurity because it donates electron.

If a trivalent impurity (e.g Gallium) is added, its three valence electrons combine covalently with three or four valence electrons of

Germanium (Ge) leaving out one Ge valence electron uncombined. This missing electron is called hole & for a very small amount of impurity, there are millions of holes. This extrinsic semi-conductor is a p-type (positive) semiconductors. The majority carrier of current in an n-type semiconductor are free electrons & for a p-type, holes.

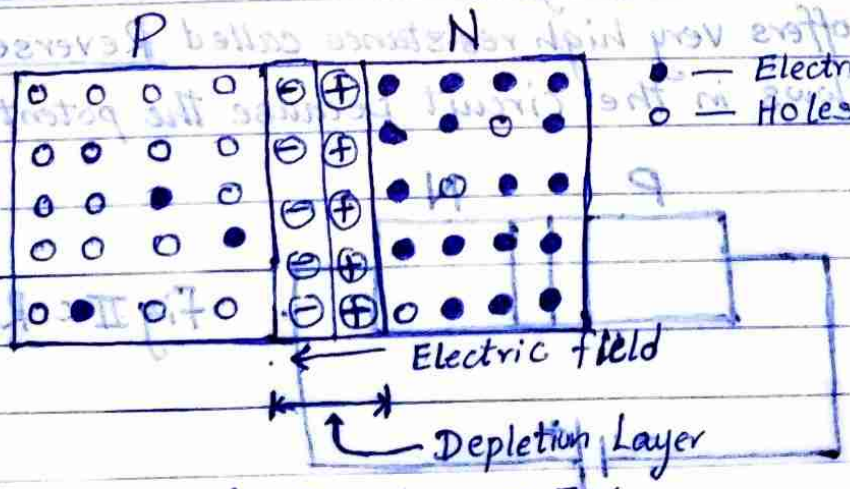
The minority carriers in n-type are holes while electrons are minority carriers in p-type.

The Properties of p-n Junction

When a p-type semiconductor is suitably joined to n-type, the contact surface is called pn junction. One method of formation of pn junction is called alloying.

At the point of formation, free electrons move from the n-region to the p-region where they combine with holes near the junction. This creates a region of positive charges (pentavalent ions) near the junction. As the electrons combine with holes in the p-region, the p-region loses holes & a layer of trivalent (negative charges) is formed near the junction. The two layers of positive & negative charges form the Depletion Layer.

Once the depletion layer is formed, electron diffusion stops. Hence, the depletion layer acts as a barrier since it sets up an electric field with a potential called Barrier Potential, V_0. The barrier potential is a function of amount of doping, temperature & the nature of the material.



For Ga, $V_0 = 0.3V$, & Si, $V_0 = 0.7V$

Biasing

The term bias refers to the use of d.c. voltage to establish certain operating conditions. There are two bias conditions;

1) Forward Biasing
2) Reverse Biasing

Forward Biasing:

If a p.d is applied such that it cancels the potential barrier, permitting current to flow, it is forward biasing. In this case, positive terminal of the battery is connected to the p-type & negative terminal to the n-type. A small p.d is enough to cancel the barrier potential, Vo & a forward Current flows.

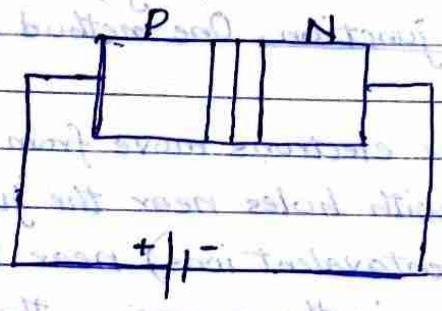


Fig 1: forward Bias

In the forward Bias,

i) The potential barrier is reduced at some forward voltage
ii) The junction offers low resistance i.e the forward resistance is low.
iii) Current flows due to low forward resistance.

Reverse Biasing:

If the positive terminal is connected to the n-type & negative terminal connected to the p-type, it is reverse biased. In this case,

i) the junction offers very high resistance called Reverse Resistance
ii) No current flows in the circuit because the potential barrier is increased.

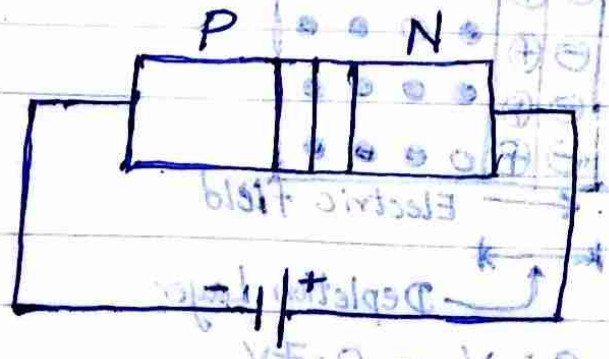
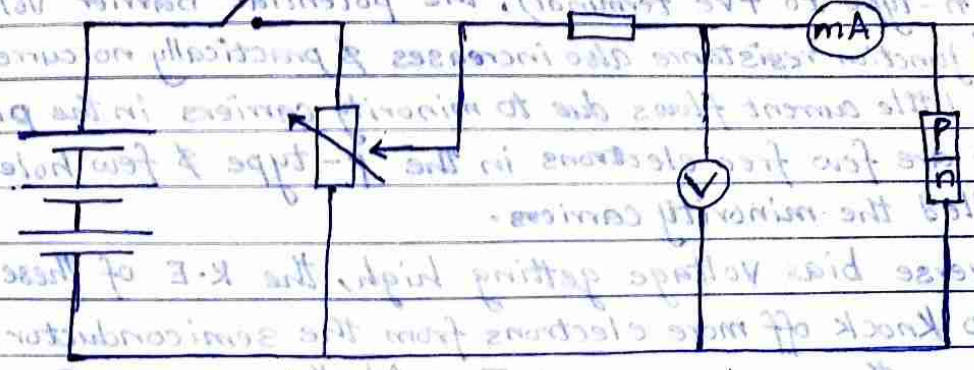


Fig II: Reverse bias

Volt - Ampere Characteristics of PN Junction

A pn junction is also called a semiconductor diode or crystal diode. The V-I Characteristic is the curve between V across the junction & I in the circuit.

The Circuit below can be used to investigate V-I characteristics of a pn junction.



The behaviour is studied under three conditions,

a) Zero voltage b) Forward bias c) Reverse bias

a) Zero Voltage: With a zero external voltage (Key open) the potential barrier prevents current from flowing.

b) Forward bias: With forward bias (i-e +ve connected to p-type & -ve to the n-type), the potential barrier is reduced or even totally eliminated at certain external voltage & current flows.

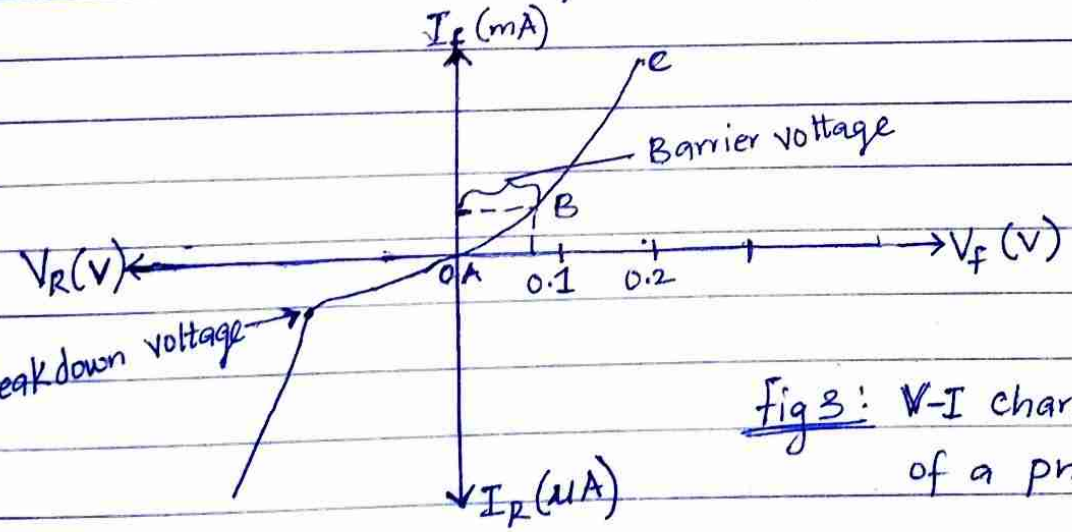


fig 3: V-I characteristics of a pn junction

An increase in voltage leads to increase in I (Curve AC). With the region 'AB', the current increases very slowly, thus a non-linear curve. With 'AB', the forward bias voltage is used in overcoming the potential barrier

voltage, V_0 - Once external voltage is greater than V_0, a linear curve BC is obtained as increase in forward bias voltage leads to sharp rise in forward current, I_f.

c) Reverse bias: With reverse bias (P-type is connected to -ve terminal & n-type to +ve terminal), the potential barrier voltage is increased & junction resistance also increases & practically no current flows. However, very little current flows due to minority carriers in the pn junction. Recall there are few free electrons in the p-type & few holes in the n-type called the minority carriers.

With reverse bias voltage getting high, the K.E of these electrons is enough to knock off more electrons from the semiconductor atoms which increases the reverse current I_R. At this stage, Breakdown of the junction occurs & a sudden rise in reverse current, I_R is seen. This may cause a permanent damage to the pn junction.

Topics

1) Various types of amplifiers
2) Frequency & phase response
3) Distortion
4) Feedback, oscillators

Naming terminals

i) Emitter: The section on one side that supplies charge carriers (electrons or holes), it is always forward biased w.r.t the base so that it can supply a large number of majority carriers (ie holes for p-type emitter & electrons for n-type.

ii) Collector: The section on the other side that collects the charges. Collector is always reverse biased. It's function is to remove charges from its junction with the base.

iii) Base: Is the middle section which forms two pn junction between the emitter & collector. The base-emitter (BE) is always forward biased allowing Low resistance for the emitter circuit. The base-collector (BC) is reverse biased & provides high resistance in the collector circuit

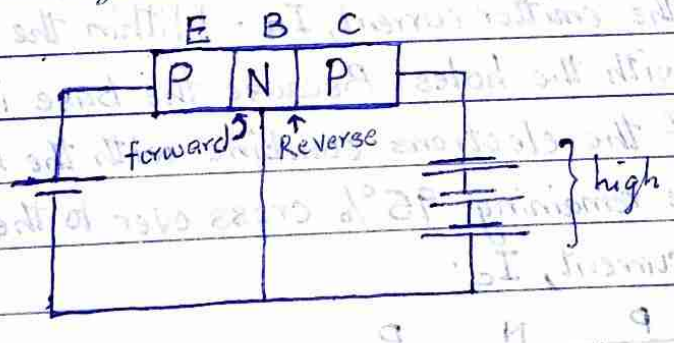


Fig I

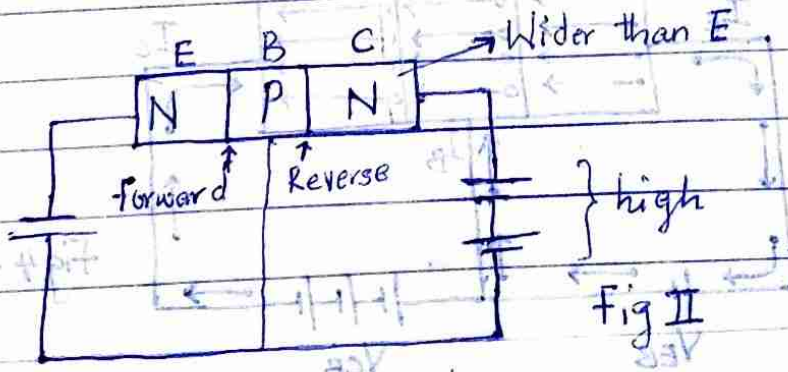


Fig II

B-E → always forward biased
B-C → always reverse biased

Note:

1) The base is much thinner than the emitter while the collector is wider than both the emitter & base. For convenience, the collector & emitter are diagramatically shown to be the same.

2) The emitter is heavily doped so as to have much carrier of charge. (holes for P & electrons for n-type). The collector is moderately doped.

3) The resistance of the emitter-base (emitter diode) - - - - - is always low (forward biasing) while that of collector base (collector diode) is very high (reverse biasing)

Transistor Action

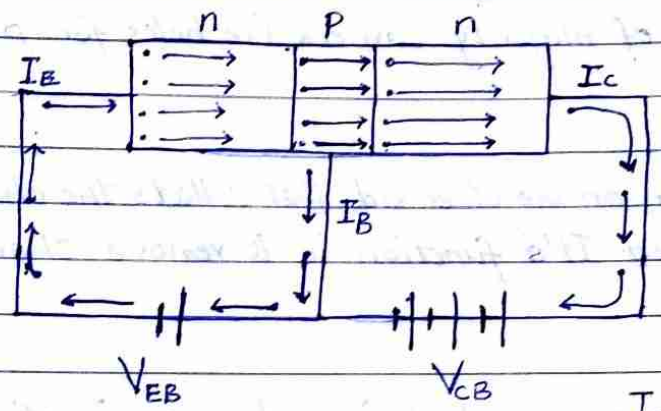


Fig 3: n-pn transistor

$$I_E = I_B + I_C$$

The emitter-base is forward biased (Low resistance) while the collector base is reversed biased (high resistance). Electrons flow from the emitter to the base. This constitutes the emitter current, I_E. Within the p-type base, few electrons combine with the holes. Because the base is thin & lightly doped, only about 5% of the electrons combine with the holes to constitute the base current, I_B. The remaining 95% cross over to the collector to constitute the collector current, I_C.

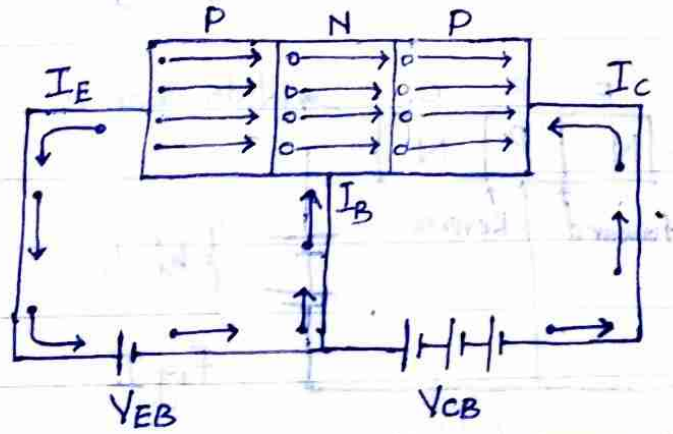


Fig 4: P-n-P transistor

$$I_E = I_E + I_C$$

In fig IV, the emitter-base is forward biased & collector base is reversed biased.

Holes flow from p-type emitter to n-type base where about 5% combine with electrons due to high doping of the base & its thin size. About 95% flows to the collector. Remember, in the wires outside the transistor, only electrons flows to constitute the outside current.

Note: Almost all the current (95%) of the EB current flows in the CB. Therefore, a transistor transfers current from Low resistance input (E.B) to high resistance output (CB). This is responsible for the AMPLIFICATION capability of a transistor.

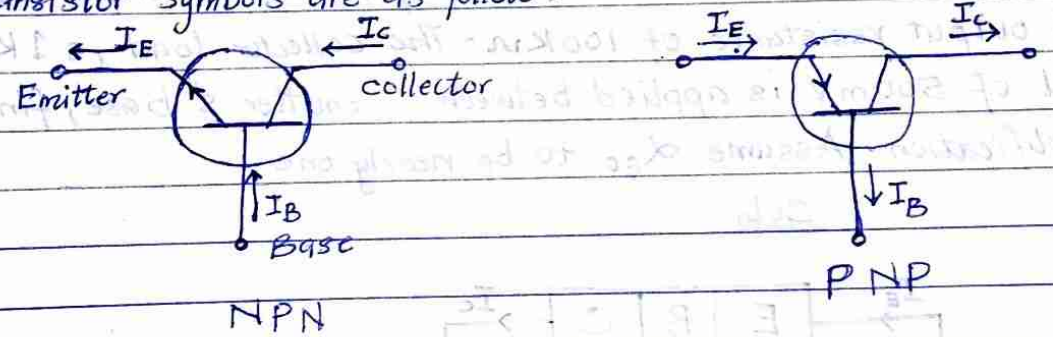
Basically, there are two types of transistor;

i) Bipolar junction transistor (BJT)

ii) Field effect transistor (FET)

All our discussions will be on BJT

Transistor symbols are as follow :-



$$I_E = I_B + I_C$$

Emitter is shown by an arrow which indicates the direction of flow of conventional current with forward bias.

Transistor as an Amplifier

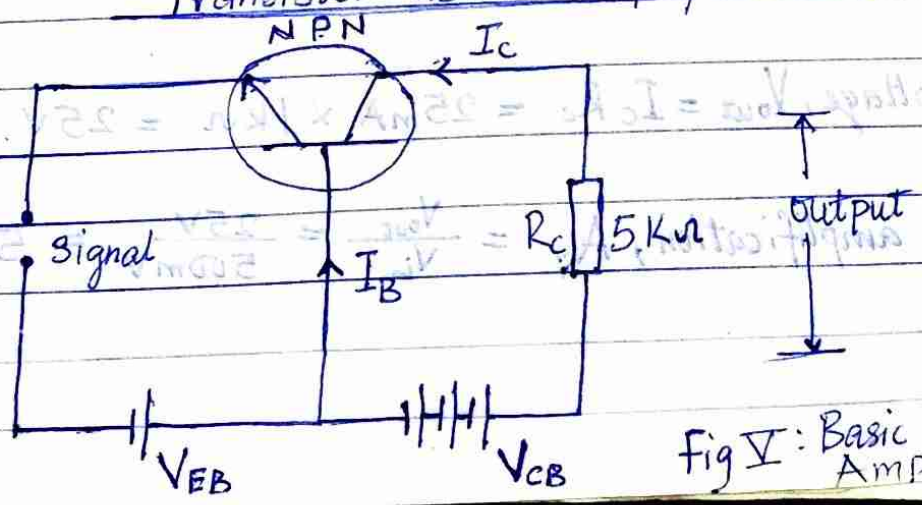


Fig V: Basic circuit of transistor Amplifier

The input circuit (EB) is always forward biased no matter the polarity of the signal with the aid of a d.c voltage. Since the EB circuit, has Low resistance, a small change in the signal voltage causes an appreciable change in the emitter current. This causes an almost the same change (~95%) in the collector (output) current due to transistor action. With Large current in the collector, current coupled with large resistance the output voltage is very large.

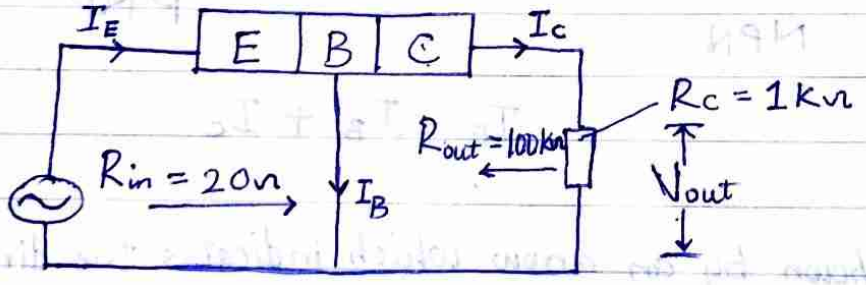
Therefore, a weak signal in the INPUT has appeared (been amplified) as large OUTPUT voltage.

Assuming R_c (Load across collector) is 5kΩ & a change of 0.1V in signal voltage produces a change of 1mA in emitter current, the 1mA flowing through 5kΩ will produce a voltage of $V = IR = 1mA \times 5k\Omega = 5V$

Therefore a change of 0.1V in input produces a change of 5V in output

Example: A common base transistor amplifier has an input resistance of 20Ω & output resistance of 100kΩ. The collector load is 1kΩ. If a signal of 500mV is applied between emitter & base, find the voltage amplification. Assume α_{GC} to be nearly one

Soln



$$\text{Input current, } I_E = \frac{\text{Input Voltage (signal)}}{\text{Input Resistance } (R_{in})} = \frac{500mV}{20\Omega} = 25mA \approx \text{output current } I_c$$

$$\text{Output Voltage, } V_{out} = I_c R_c = 25mA \times 1k\Omega = 25V$$

$$\text{Voltage amplification, } A_V = \frac{V_{out}}{V_{in}} = \frac{25V}{500mV} = 50V$$

Transistor Connections

There are only three leads in a transistor; emitter, base & collector terminals. In a circuit we need four terminals for connection : two for input & two for output. Therefore one terminal has to be made common to both input & output. Hence, transistor has to be connected in either of these three ways;

i) Common base (CB) Connection
ii) Common emitter (CE) connection
iii) Common collector (CC) connection

Each has its advantages & disadvantages but whichever method is used, the emitter is always forward biased & the collector is always reverse biased.

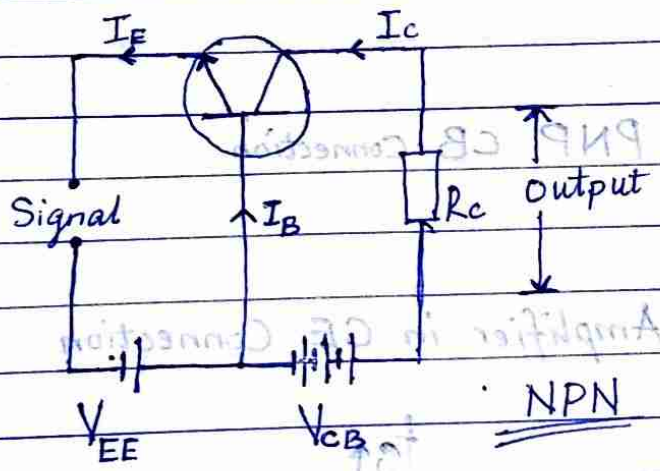


Fig VI a

NPN

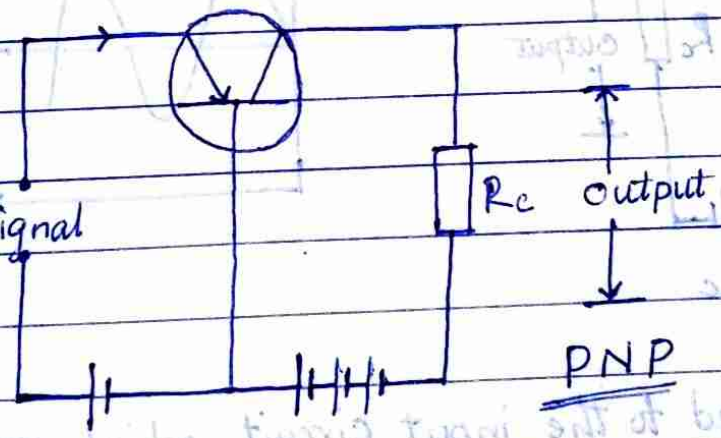
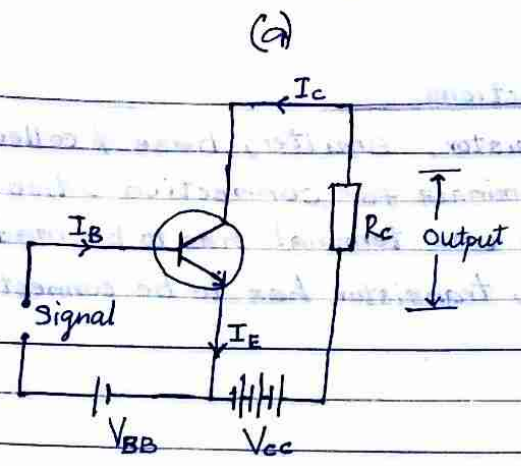


Fig VI b

PNP

CB TRANSISTOR



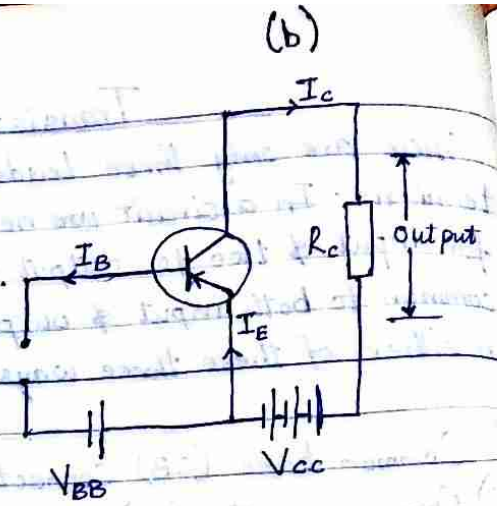
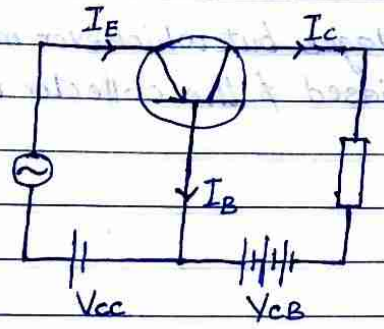


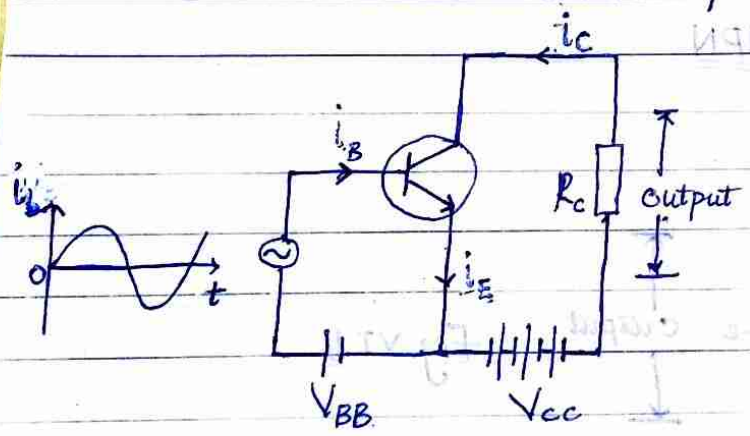
Fig VII a : NPN CE transistor

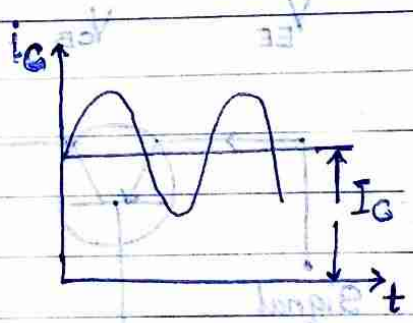
Fig VII b : PNP CE transistor



PNP CB Connection

Transistor as Amplifier in CE Connection





A battery V_{BB} is connected to the input circuit which magnitude always keeps the emitter-base circuit forward biased. It is the base voltage, V_{BB}.

During one-half (positive) of the cycle, the forward bias is increased. Therefore more electrons flow from emitter to base collector via the base. This causes increase in the collector current which produces a greater voltage drop across R_C.

During the negative half cycle, the forward bias emitter - base junction is decreased. This leads to decreased collector current which produces a less voltage drop in the R_c in the opposite direction.

Fig(b): When no signal is applied, there is still current I_c due to the forward bias voltage, V_{BB}. This current flows through the base to the collector & is called the zero signal collector current. When signal is applied, the total collector current, i_C is increased/decreased during the positive/negative half of the cycle.

Total collector current, $i_C = i_c + I_c$ where i_c is the voltage drop across the R_c or collector load which is the useful current

Performance of Transistor Amplifier

This depends on input resistance (R_i), Output resistance (R_o), effective collector Load (R_{AC}), Current gain (β), Voltage gain (A_v) & power gain (A_p).

We use the CE connection which is universally adopted in our explanations.

i) Input Resistance, R_i: Ratio of change in base-emitter voltage ΔV_{BE} to change in base current, ΔI_B

$$R_i = \frac{\Delta V_{BE}}{\Delta I_B}$$

NB:

It is always small due to forward biasing (5Ω to 500Ω for high powered to low powered transistors). It is the total opposition offered to the flow of current by the base - emitter junction.

ii) Output Resistance, $R_o = \frac{\Delta V_{CE}}{\Delta I_c}$ at constant I_B

This is the ratio of change in the collector-emitter voltage to change in the collector current at constant base current. It is always high because I_c changes slightly with change in V_{CE}. This is due to reverse biasing.

iii) Effective Collector Load, R_{AC}: It is the total load as seen by the a.c collector current. In a single stage amplifier, R_{AC} is a parallel combination of R_C & R_o

$$\therefore R_{AC} = \frac{R_C \times R_o}{R_C + R_o}$$

Since R_o is several times R_C, R_C can be neglected as compared to R_o.

In several stage amplification (mutistage amplifer), R_i of the next stage comes into play

$$\therefore R_{AC} = \frac{R_C \times R_o}{R_o} = R_C$$

$$= \frac{R_C \times R_i}{R_C + R_i} \quad \text{since } R_C \parallel R_o = R_C$$

But since R_i is quite small, R_{AC} is reduced.

iv) Current gain, β: is the ratio of change in collector current (ΔI_C) to change in base current (ΔI_B)

$$\beta = \frac{\Delta I_C}{\Delta I_B} \quad \text{ranges from 20 to 500}$$

v) Voltage gain, A_V: is the ratio of change in output voltage (ΔV_{CE}) to change in input voltage (ΔV_{BE}) i.e

$$A_V = \frac{\Delta V_{CE}}{\Delta V_{BE}}$$

$$= \frac{\text{Change in output current} \times \text{Eff. Load}}{\text{Change in input current} \times R_i}$$

$$= \frac{\Delta I_C \times R_{AC}}{\Delta I_B \times R_i} = \frac{\Delta I_C}{\Delta I_B} \times \frac{R_{AC}}{R_i} = \beta \times \frac{R_{AC}}{R_i}$$

vi) Power gain, A_P: is the ratio of output signal power to input signal power i-e

$$A_P = \frac{(\Delta I_C)^2 \times R_{AC}}{(\Delta I_B)^2 \times R_i} = \frac{\Delta I_C}{\Delta I_B} \times \frac{\Delta I_C \times R_{AC}}{\Delta I_B \times R_i}$$

$$= \text{current gain} \times \text{voltage gain}$$

$$= \beta A_V$$

Ex1: A change of 200mV in base-emitter voltage causes a change of 100μA in the base current. Find the input resistance of the transistor.

Soln

$\Delta V_{BE} = 200mV$

$\Delta I_B = 100\mu A$

$$R_i = \frac{\Delta V_{BE}}{\Delta I_B} = \frac{200mV}{100\mu A} = 2k\Omega$$

Ex2: If the collector current changes from 2mA to 3mA in a transistor when collector-emitter voltage increase from 2V to 10V, what is the output resistance?

Soln

$\Delta V_{CE} = 10 - 2 = 8V$

$\Delta I_C = 3 - 2 = 1mA$

$$R_o = \frac{\Delta V_{CE}}{\Delta I_C} = \frac{8V}{1mA} = 8k\Omega$$

Ex3: For a single stage transistor amplifier, the collector load is 2kΩ & input resistance 1kΩ. If the current gain is 50, calculate, the voltage gain of the amplifier-

Soln

$R_C = 2k\Omega$, $R_i = 1k\Omega$, $\beta = 50$

$$A_V = \beta \times \frac{R_{AC}}{R_i} = \beta \times \frac{R_C}{R_i}$$ $\left.\right\}$ $R_{AC} = R_C$ for single stage

$$= 50 \times \frac{2}{1} = 100$$

Faithful Amplification

The process of raising the strength of a weak signal without any change in its general shape is faithful amplification. This is achieved by ensuring that the emitter-base (input) is always forward biased while the base-collector circuit is always reverse biased. To achieve this the following basic conditions must be satisfied-

i) Proper zero signal collector current (a d.c source)

ii) Minimum proper base-emitter voltage V_{BE} at any instant

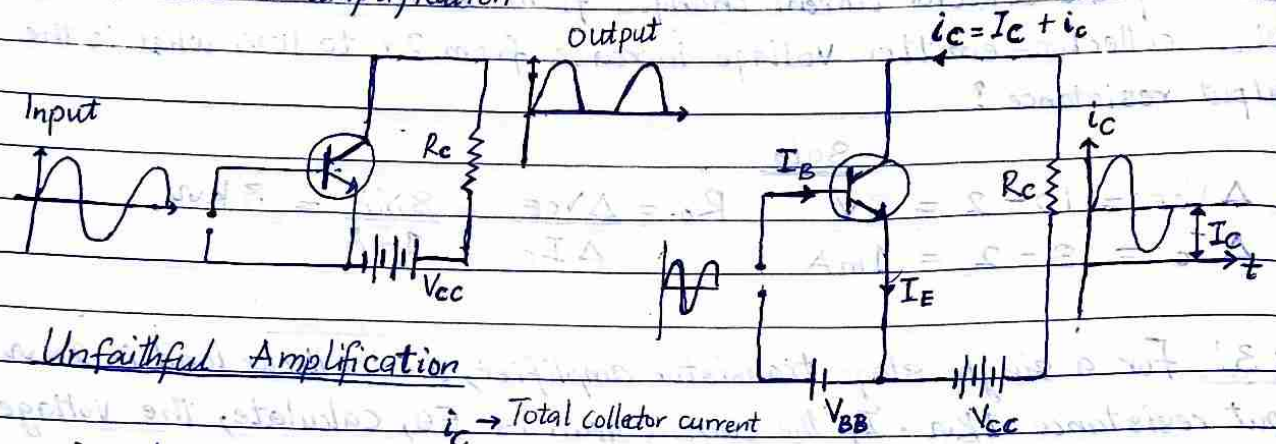
iii) Minimum collector-emitter voltage V_{CE} at any instant

Conditions (i) & (ii) ensures that there is always forward bias at the base-emitter junction & reverse bias at base-collector junction is satisfied by (iii).

1)

Proper Zero signal collector

Fig (1) below : During the positive half cycle of the signal, the base is +ve w.r.t to the emitter (forward bias), a large base current flows to the collector & because of R_c there will be a large voltage output. However, during the 2nd half (-ve), the base is negative w.r.t to the emitter (reverse biased) & no current flows in the collector circuit. Thus, there will be no output & hence no amplification



Unfaithful Amplification

$i_C \rightarrow$ Total collector current

$i_c \rightarrow$ A.C current

$I_C \rightarrow$ Zero Signal collector current

Faithful Amplification

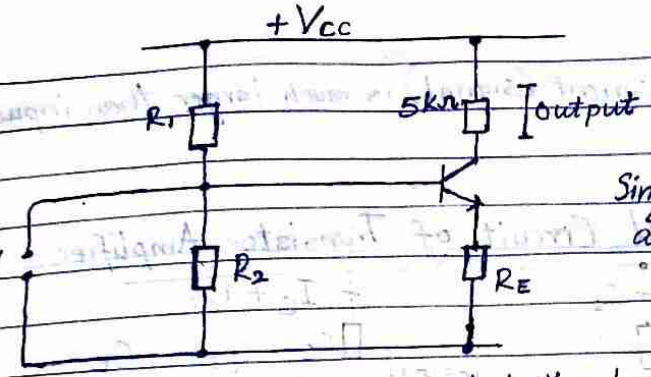
With a battery introduced (V_{BB}), there is always forward biasing in the base-emitter junction & even when there is no signal, a d.c current, I_C flows in the collector due to V_{BB}. This is the zero collector current, I_C. During the +ve half cycle, there is more current in the collector due to the more forward biasing. During the 2nd half (-ve half) cycle, there is less forward biasing & collector current, i_C decreases.

The value of the zero signal collector current should be at least equal to the maximum collector current due to signal alone i.e

Zero signal collector current $\geq$ max. collector current due to signal alone

Single Stage Transistor Amplifier

When only a single transistor with associated circuitry is used for amplification of a weak signal, the circuit is a single stage transistor amplifier. A practical amplifier consists of a number of stages, which can still be split up into seperate single stage



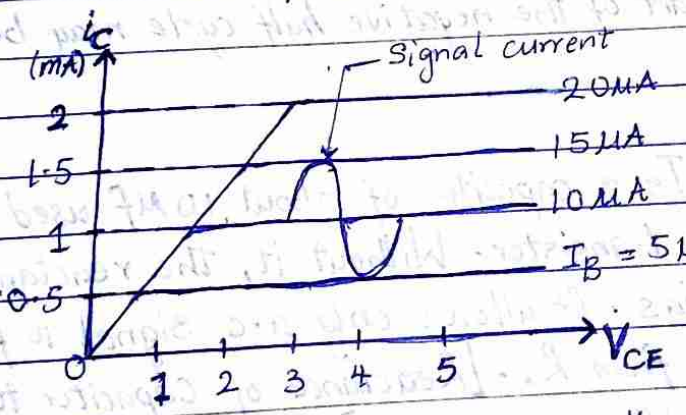
Single Stage transistor amplifier

When a weak a.c source is applied to the base, a small base current (a.c) flows. Due to transistor action, a much larger (times base current) flows in the collector through the Load, Rc because Rc is quite large, a large voltage appears across Rc. This is row amplification.

For instance, if a change of 0.1V in base (signal) voltage produces a change of 2mA in the collector current, then the output voltage V_o $= 2mA \times 5k\Omega = 10V$. This is amplification

Graphical Demonstration of Transistor Amplifier

The function of an amplifier can be explained graphically. The figure below is the characteristics of a transistor in CE configuration.



Suppose the zero signal current is 10μA i.e the base current I_B for which the transistor is biased by the signal network. When there is extra biasing by an a.c, then the base current I_B increases/decreases during the +ve/-ve half cycle by 5μA. That is, rising to 15μA during the positive half cycle & decreasing to 5μA during the negative half cycle. The total collector current increases/decreases corresponding from 1mA to 1.5mA/0.5mA, an increase or decrease of 0.5mA.

Before a base current variation of 10μA results in a variation of 1mA (1000μA) in collector current, i_C i.e by a factor of 100. This current flows through the

output resistance, R_C

Conclusion: Output current (signal) is much larger than input signal (amplification).

Practical Circuit of Transistor Amplifier:

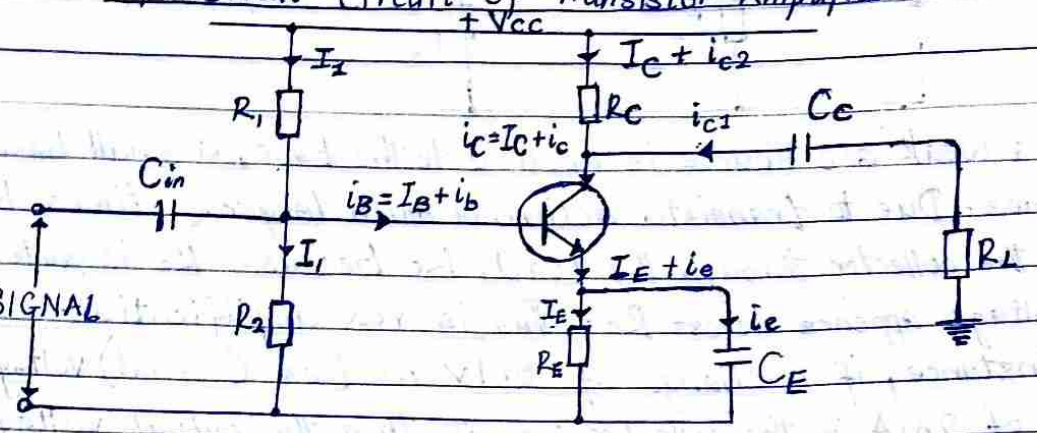


Fig A: Proper single stage transistor amplifier

The above circuit can be used to achieve faithful amplification. The various circuit elements are described below;

i) Biasing Circuit: This consists of R_1, R_2 & R_E which form the biasing & stabilisation circuit. The biasing circuit must establish a proper operating point else a part of the negative half cycle may be cut off in the output.

ii) Input Capacitor, C_{in}: Is a capacitor of about 10 μF used to couple the signal to the base of the transistor. Without it, the reactance will come across R_2 & change the bias. It allows only a.c signal to flow but isolates the signal source from R_2. [Reactance of capacitor to d.c is infinite, it blocks d.c but allows a.c to flow]

iii) Emitter bypass Capacitor, C_E: A capacitor of about 100 μF in parallel with emitter 1rad R_E to provide low reactance path to the amplified a.c signal. Without it, there will be voltage drop across R_E thereby reducing the amplified signal.

i) Coupling Capacitor C_C: About 10μF, couples one stage of the amplification to the next stage. Without it, the next stage biasing will be drastically

changed due to shunting effect of R_c (R_c is in parallel with resistance R_1 of the upper or next stage. It involves d·c of one stage from the next stage but allows a·c to flow through it.

Base Current:
With no signal applied, d·c base current I_B flows due to biasing. With signal applied, a-c base current i_b also flows.
Therefore with signal, total base current $i_B = I_B + i_b$

Collector Current:
Without signal, collector current (d·c) = I_C due to biasing
With a·c signal, a·c current flows = i_c
But $I_C = \beta I_B$ = Zero signal collector current
$i_c = \beta i_b$ = collector current due to signal

Emitter Current:
Without signal, a d·c emitter current = I_E
With signal, emitter current (a·c) = i_e
Total emitter current, $i_E = I_E + i_e$
Recall that,

$$I_E = I_B + I_C$$
$$i_e = i_b + i_c$$

Since base current is usually very small, then
$I_E \simeq I_C$ & $i_e \simeq i_c$

Ques 1: What is the role of
a) Emitter bypass capacitor, C_E
b) Coupling capacitor, C_c &
c) Input capacitor, C_{in}

Phase Reversal

In a CE configuration, when the input voltage increases in the positive direction, the output voltage increases in the negative direction & vice-versa. This is called phase reversal. Simply put, there is a phase voltage in CE connection. The input & output current are in phase.

If the signal (input) voltage increases in the positive half cycle, the base current also increases. As a result both the collector current, i_c & voltage drop across R_c increase. But since the voltage across the coupling capacitor is constant, the output voltage, V_{CE} decreases. Put differently the output voltage increases in the negative direction or is 180° out of phase with input voltage. Therefore in a CE configuration, the positive half cycle of the signal appears as amplified negative half cycle in the output & vice-versa.

Mathematically,

$$V_{CE} = V_{cc} - i_c R_c$$

differentiating

$$dV_{CE} = 0 - di_c R_c$$

$$\therefore dV_{CE} = -di_c R_c \quad (180° \text{ out of phase})$$

Illustration

a) When signal current = 0 (i.e absence of signal), $i_c = 1mA$

$\therefore V_{CE} = V_{cc} - i_c R_c = 10 - 1mA \times 4k\Omega = 6V$

b) When signal reaches +ve peak value, $i_c = 1.5mA$

$V_{CE} = 10V - 1.5mA \times 4k\Omega = 4V$ i.e decrease from 6V to 4V but i_c increases from 1mA to 1.5mA. V_c is 180° out of phase with i_c.

c) When signal reaches -ve peak, $i_c = 0.5mA$

$V_c = 10V - (0.5mA \times 4k\Omega) = 8V$ i.e as i_c decrease from 1.5mA to 0.5mA, V_c increases from 4V to 8V or 180° out of phase while i_c decreases from 1.5mA to 0.5mA.

Note:

i) For every amplifier type (CE, CB, CC), the input & output current are in phase. As i_{in} increases, i_{out} decreases & vice versa

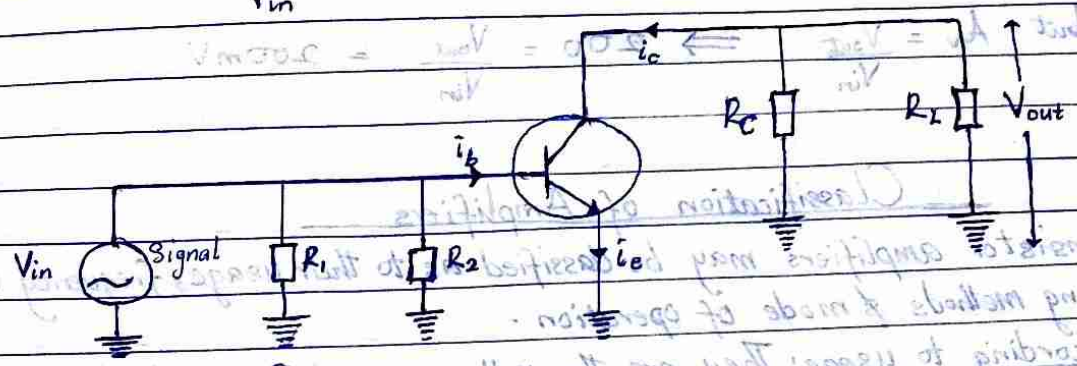
ii) For CE, input voltage V_{in} is 180° out of phase with output voltage, V_{out}

iii) For CB & CC, the V_{in} is in phase with V_{out}

Voltage Gain

The basic function of an amplifier is to raise the strength of an a-c input signal. The voltage gain is the ratio of the a-c voltage output to the a-c input voltage.

$$A_V = \frac{V_{out}}{V_{in}}$$



R_C is parallel with R_L

$\therefore$ Effective Load for a-c $R_{AC} = \frac{R_C \times R_L}{R_C + R_L}$

$V_{out} = i_c R_{AC}$; $V_{in} = i_b R_{in}$

Voltage Gain $A_V = \frac{V_{out}}{V_{in}} = \frac{i_c \times R_{AC}}{i_b \times R_{in}} = \beta \times \frac{R_{AC}}{R_{in}}$

Power gain $A_p = \frac{i_c^2 \times R_{AC}}{i_b^2 \times R_{in}} = \beta^2 \times \frac{R_{AC}}{R_{in}}$

Question 1 : In a transistor amplifier, when the signal changes by 0.02V, the base current changes by 10μA & collector current by 1mA. Assuming the collector Loader is 5kΩ & R_L = 10kΩ, find,

i) Current gain ii) Input impedence, R_{in} iii) A-c load, R_{AC} iv) Voltage gain, A_V

v) Power gain, A_p

Soln

$\Delta I_B = 10\,\mu A$, $\Delta I_C = 1mA$, $\Delta V_{BE} = 0.02V$, $R_C = 5k\Omega$, $R_L = 10k\Omega$

i) $\beta = \frac{\Delta I_C}{\Delta I_B} = \frac{1mA}{10\mu A} = 100$

ii) $R_{in} = \frac{\Delta V_{BE}}{\Delta I_B} = \frac{0.02V}{10\mu A} = 2k\Omega$

iii) $R_{AC} = \frac{R_C \times R_L}{R_C + R_L} = \frac{5 \times 10}{5+10} = 3.3k\Omega$

iv) $A_V = \beta \times \frac{R_{AC}}{R_{in}} = 100 \times \frac{3.3}{2} = 165$

v) $A_p = \beta \times A_V = 100 \times 165 = 16,500$

Q2: In a transistor, if the collector Load $R_C = 10k\Omega$ & $R_L = 10k\Omega$, while the input Load $R_{in} = 2.5k\Omega$ & current gain β is 10 - Find the output voltage for an input voltage of $1mV_{rms}$.

Soln

Effective Load, $R_{AC} = \frac{R_C \times R_L}{R_C + R_L} = \frac{10 \times 10}{10+10} = 5k\Omega$

Voltage gain, $A_V = \beta \times \frac{R_{AC}}{R_{in}} = \frac{100 \times 5}{2.5} = 200$

but $A_V = \frac{V_{out}}{V_{in}} \Rightarrow 200 = \frac{V_{out}}{V_{in}} = 200mV$

Classification of Amplifiers

Transistor amplifiers may be classified as to their usage, frequency capabilities, coupling methods & mode of operation.

i) According to usage: They are the voltage amplifiers which increases the voltage & the power amplifiers that increase the power level of the signal.

ii) According to frequency capabilities:

They are the audio amplifiers & radio frequency amplifiers. Audio amplifiers boost signals within the audio range i.e 20Hz to 20kHz while radio frequency amplifiers boost signal with high frequency.

iii) According to Coupling methods:

Usually, a single stage amplifier is insufficient to meet practical requirements, so the output from one stage is coupled to another stage. We may then have R-C coupled amplifers, transformer coupled amplifier, direct coupled amplifier e.t.c

iv) According to Mode of Operation:

E.g Class A, Class B, Class C amplifiers - This depends on the portion of the input signal cycle during which the collector current is expected to flow.

Class A ⇒ Collector current flows for the entire input a.c signal

Class B ⇒ Collector current flows for half-cycle of input a.c signal

Class C ⇒ Collector current flows for less than half-cycle input a.c signal.

Questions: What do you understand by
a) Class A voltage amplifier b) Audio voltage amplifier c) Class B power amplifier d) Class A transformer coupled power amplifier?

Solutions
a) The amplifier boosts the signal voltage & the collector current flows for the whole input signal.
b) Raises the audio voltage (20Hz to 20KHz) of the input signal.
c) It raises power level of the signal & its mode of operation is such that collector current flows for only half-cycle of the signal only
d) It raises the power level of the signal & is coupled by transformer while the collector current flows for the entire cycle of the signal

Gain & Transistor Configuration

Amplification is the process of boosting a.c signal & the circuit used to achieve it is amplifier. There are only three types of gain; current gain, voltage gain & power gain.

i) The CE configuration has the three gains; Current gain, voltage gain & gain.
ii) The CB configuration has voltage & power gain but no current gain. The current gain is 1 (one)
iii) The CC amplifier has current & power gain but no voltage gain

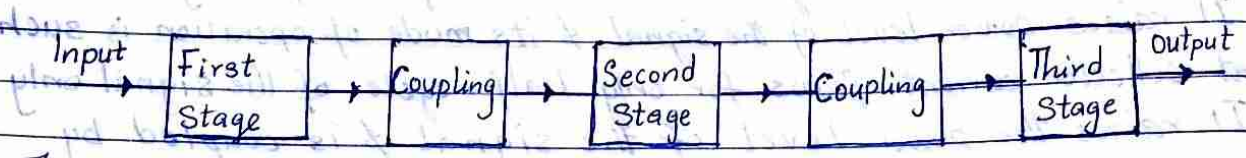
Note:
The choice of amplifier for a given application often depends on the type of gain desired. Since CE amplifiers have all the gains, it is widely used in about 90% of all applications. All our discussion is based on CE.

Multistage Transistor Amplifier

A single stage amplifier is usually insufficient to drive an output device. The gain is usually inadequate for practical purposes. Therefore, two three or more stages of amplification is necessary. That is, each amplifier stage is coupled to another stage until the desired output is got.

A circuit containing more than one stage of amplification is known as mutistage transistor amplifier. A number of single stage amplifiers are cascaded (connected in series). The output of first stage is connected to the input of the second through a suitable coupling device.

Below is the block diagram of a ~~four~~ 3 stage amplifier.



The coupling device e.g capacitor, transformer e.t.c is to

i) transfer a.c output of one stage to the input of the next stage.

ii) isolates the d.c conditions of one stage from the next stage.

a) In RC coupling, a capacitor is the coupling device. The capacitor blocks d.c bias voltages from one stage to the next while transfering the a.c output of one stage to the next.

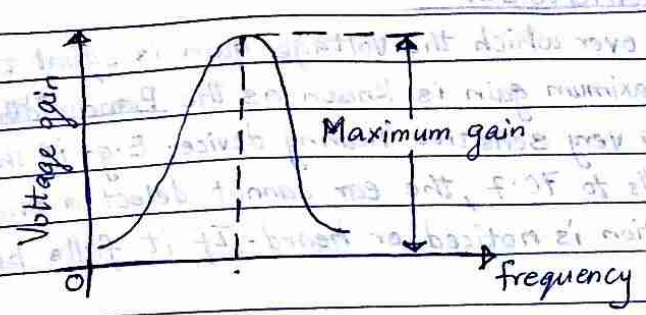
b) In transformer coupling, a transformer is the coupling device. The transformer performs the two functions above & also permits impedance matching.

c) In direct coupling or d.c coupling, the individual amplifier stage bias conditions are so designed that the two stages may be directly connected without the necessity for d.c isolation.

Frequency Response

The voltage gain of an amplifier varies with the signal frequency due to the relationship between reactance, X_c & frequency, f $[X_c = 1/2\pi fC]$.

That is, reactance changes with change in frequency which is turn effects voltage output. A graph of voltage gain against signal frequency is called FREQUENCY RESPONSE.



The voltage gain increases with frequency of the signal into a maximum frequency called the RESONANT FREQUENCY after which it decreases with increase in frequency.

The performance of a amplifier depends to a large extent on its frequency response. In an amplifier design, care must be taken to ensure that the gain is uniform over a specific frequency range. E.g in an audio amplifier, the frequency range of 20Hz to 20KHz (i.e sound spectrum), should be uniformly amplified else a distorted sound will be got at the output end (the speaker).

Decibel Gain

The gain of an amplifier can be expressed as a number but for practical purposes, the bel or decibel (db) is used as a unit.

The Logarithm to base ten (Log_{10}) of power gain is the bel power gain.

$$\text{Power Gain} = Log_{10} \frac{P_{out}}{P_{in}} \text{ bel}$$

$$1 \text{ bel} = 10 \text{ db}$$

There are some advantages in expressing the gain in decibel (db);

1) The db is a Logarithmic unit just like our ear response is a Logarithmic i.e Loudness of sound heard by the ear is NOT according to the intensity of sound but according to the Log of the intensity. E.g if intensity increases by 100times, our ear hears it as doubling effect ($Log_{10} 100 = 2$). This means that the ear hears it as doubled NOT as 100times.

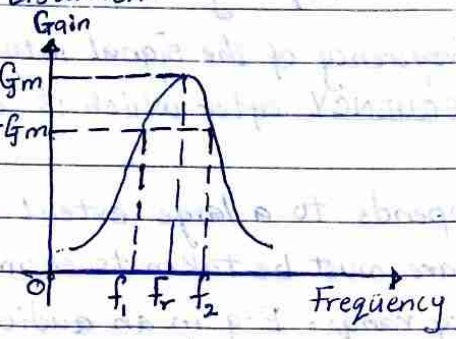
2) The gain of a multistage amplifier is easier to calculate if expressed in decibel (db) as it is the sum of gains of individual stage in db

Gain in db = 1st stage Gain in db + 2nd stage Gain in db

Bandwidth

The range of frequency over which the voltage gain is equal to or greater than 70.7% of the maximum gain is known as the Bandwidth.

The human ear is not a very sensitive hearing device. E.g. if the gain of an amplifier is 100, if it falls to 70.7, the ear cannot detect a change in intensity & hence, no distortion is noticed or heard. If it falls below 70.7, it can hear clear distortion.



$f_1 - f_2$ is the bandwidth, where,

f_1 = Lower cut-off frequency ; f_2 = Upper cut-off frequency

Between f_1 & f_2, the gain $\geq$ 70.7% of maximum gain, G_m, & for distortionless amplification. Notice that f_1 & f_2 are the limiting frequencies.

Bandwidth can also be expressed in db

Ex1: Suppose the maximum voltage gain 100. Then 70.7% of it is 70.7

$\therefore$ fall in voltage gain from G_m = $20 \log 10 - 20 \log 70.7$

$= 20 \log \frac{100}{70.7} = 3 db$

Hence Bandwidth of an amplifier is a range of frequency at the limits of which its voltage gain falls by 3db from G_m.

The frequency f_1 or f_2 is also called 3db frequency or half-power frequency. The 3db designation is because the voltage gain at those frequency is 3db below the maximum voltage gain, (G_m) value. The half power is because the voltage is down to 0.707 of G_m (the power is proportional to V^2) is down to $(0.707)^2$ or one half of its maximum value.

Question: Find the gain in db in the following cases;

i) Voltage gain of 30 b) power gain of 100

Soln

i) Voltage gain = $20 \log_{10} 30$ db = 29.54db

ii) Power gain = $10 \log_{10} 100$ = 20db

Recall

Voltage gain in db $= 20 \text{ Log } \frac{V_{out}/R}{V_{in}/R} = 20 \text{ Log } \frac{V_{out}}{V_{in}}$

and

Power gain in db $= 10 \text{ Log } \frac{I_{out}^2 R}{I_{in}^2 R} = 20 \text{ Log } \frac{I_{out}}{I_{in}}$

Question: Express the following gains as a number i) power gain of 40db ii) Power gain of 43db

soln

i) Power gain = 40db or 4 bel

P-Gain = Antilog 4 $= 10^4 = \underline{10,000}$

ii) Power gain = Antilog 4·3 $= 2 \times 10^4 = \underline{20,000}$

OR

$10 \text{ Log}_{10} \frac{P_{out}}{P_{in}} = 43\text{db} \Rightarrow \text{Log}_{10} \frac{P_{out}}{P_{in}} = \frac{43}{10} = 4.3$

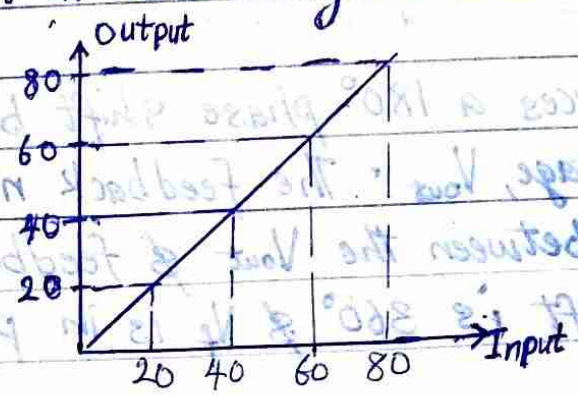
$\frac{P_{out}}{P_{in}} = 10^{4.3} = 20,000$

Generally, $V_{out}/V_{in} = (10)^{\text{gain in db}/20}$ & $\frac{P_{out}}{P_{in}} = 10^{\text{gain in db}/20}$

Distortion

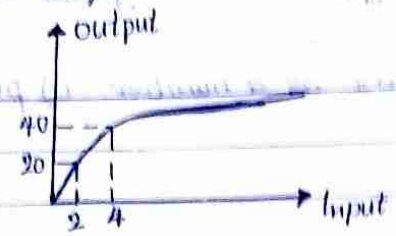
The change of output wave shape from input wave shape of an amplifier is called DISTORTION.

A transistor is not a linear device. So any input signal applied to it will not be exactly like the output signal. Hence distortion occurs in a transistor. For small variations of the signal about the operating point, the transistor behaves as a linear device & can handle such small variations effectively. Eg. in a voltage amplifier that has Low input voltage (a few mV), it reproduces a flat or linear response. That is, it reproduces the varing input signal at constant gain.



Gain $= \frac{\text{output}}{\text{Input}}$

A power amplifier handles large signal & at above certain frequency, it boosts some frequencies better than others. There is no perfect linear response - The response is now 'clipped' i.e increase in input leads to a small increase in output.



This Leads to distortion which is caused by increasing amplitude of the input signal. This could be minimized by feedback.

Feedback

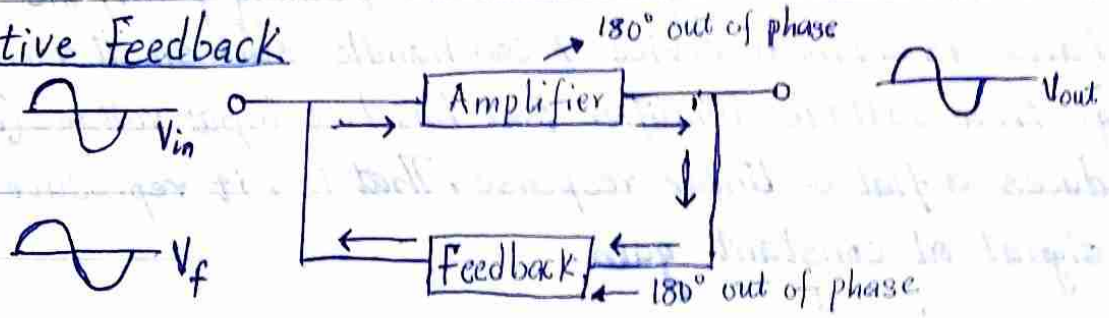
A pratical amplifier has a gain of nearly one million. As a result, a casual disturbance at the input will appear in the amplified output. There may be due to temperature changes or even stray electric & magnetic fields. Every high amplifier has noise in the signal output which is very undesirable. This can be reduced by negative feedback i.e injecting a fraction of the output in phase opposition to the input signal.

Feedback is the process of injecting a fraction of output energy of a device to the input.

There are two types of feedback. namely;

i) Positive Feedback ii) Negative feedback

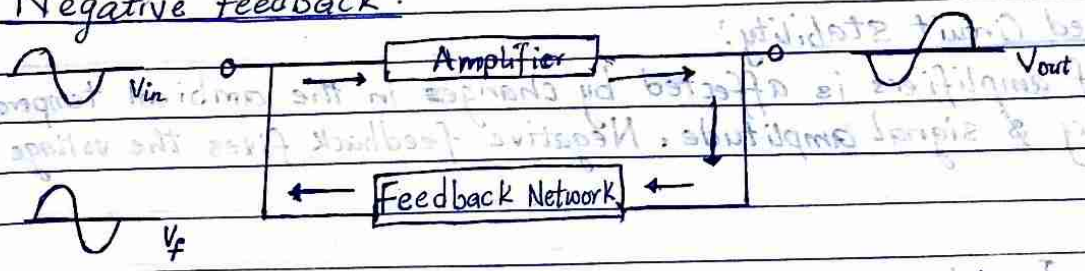
Postive Feedback



The amplifier introduces a 180° phase shift between the input voltage, V_{in} & output voltage, V_{out}. The feedback network introduces another 180° phase shift between the V_{out} & feedback voltage, V_f. Thus the total phase shift is 360° & V_f is in phase with V_{in}.

This is positive feedback which increases the gain of the amplifier but causes distortion & instability. It is rarely used except in oscillators. Oscillators convert d.c power to a.c power.

Negative Feedback:



The amplifier introduces 180° phase shift while the feedback network introduces a zero phase shift between V_{out} & V_f. Therefore, V_f is 180° out of phase with V_{in}. This is Negative Feedback which reduces gain but has the advantages of reduced distortion, reduced instability (stability in gain), increased bandwidth & improved output & input impedances. It is usually employed in amplifiers.

Advantages of Negative Feedback

i) Gain stability: The resultant gain A_{vf} is made independent of transistor parameters or the supply voltage variation

$$A_{vf} = \frac{A_v}{1 + A_v M_v}$$

For negative feedback in amplifier to be effective, $A_v M_v >> 1$. Therefore 1 is neglected &

$$A_{vf} = \frac{A_v}{A_v M_v} = \frac{1}{M_v}$$

i.e the reciprocal of the feedback fraction, M_v

M_v is the characteristics of the feedback circuit which is unaffected by variation in transistor parameters, frequency & temperature changes. This gain is very stable

ii) Reduces non-linear distorties:

Because voltage gain changes at various points in the cycle, a large

signal has non-linear distortion.

iii) Improved frequency response:

Voltage gain of the amplifier is independent of signal frequency. The frequency response is improved.

iv) Increased Circuit stability:

Output of amplifiers is affected by changes in the ambient temperature, frequency & signal amplitude. Negative feedback fixes the voltage gain.

v) Improved Impedance:

It increases the input impedance & decreases the output impedance. This helps in impedance matching.