UNIT-I

SYLLABUS

Semiconductor Diodes: P and N type semiconductors. Energy Level Diagram. Conductivity and Mobility, Concept of Drift velocity. PN Junction Fabrication (Simple Idea). Barrier Formation in PN Junction Diode. Static and Dynamic Resistance. Current Flow Mechanism in Forward and Reverse Biased Diode. Drift Velocity. Derivation for Barrier Potential, Barrier Width and Current for Step Junction. Current Flow Mechanism in Forward and Reverse Biased Diode.

Conductor

A material that allows electricity to pass through it is known as conductor. Charges are allowed to move freely in the conductor. E.g.: Usually metals are conductors.

Insulator

A material which does not allow electricity to pass through it is known as insulator. Charges are not allowed to move in insulator. E.g.: Plastic, wood are insulators.

Semiconductors

A material that can behave as a conductor as well as an insulator is known as semiconductor.

E.g.: germanium, silicon etc.

Conductivity

The measurement of charges which are allowed to flow in a material is known as conductivity of the material.

Resistivity

The measurement of the resisting power i.e. restriction to the flow of charge in the material, is called as resistivity.

	Resistivity	Conductivity
Conductors	$10^{\text{-2}}$ to $10^{\text{-8}}\Omega\text{m}$	10^2 to 10^8 Sm ⁻¹
Semiconductors	10^{-5} to $10^{6} \Omega m$	10^5 to 10^{-6} Sm ⁻¹
Insulators	10^{11} to $10^{19}\Omega m$	10^{-11} to 10^{-19} Sm ⁻¹

conductivity = 1/resistivity

Observations

- Conductors have high conductivity and very low resistivity.
- Insulator have low conductivity and high resistivity.
- Semiconductors have conductivity and resistivity in between the conductor and insulator.

Types of Semiconductors

• Elemental Semiconductors: Silicon (Si), Germanium (Ge)

- Compound Semiconductors: There can be three types of Compound semiconductors
 - Inorganic semiconductors: Cadmium sulphide (Cd S), Gallium arsenide (Ga As), Cadmium selenide (Cd Se), Indium phosphide (In P).
 - Organic semiconductors: Anthracene, Phthalocyanine.
 - Organic Polymers: Polypyrrole, Polyaniline, Polythiophene.

Energy Level

In an isolated atom, the energy processed by the electrons in the same orbit is almost equal. When the atoms are placed in a crystal form the energy level of each electron changes due to the effect of other closely placed atoms. There are two types of electrons present in an atom

- Valence electron An atom requires eight electrons in the outer most orbit to be stable. So the atom shares electrons with another atom to attain stability, this is known as valence fulfilment. In valence fulfilment the electron that is shared between the two atoms is known as valence electron.
- Free electron If an electron receives energy externally such as due to heat the electron moves out of the valence band and becomes free. The free electron has a greater energy than the valence electron.

When electric current is passed through the material the free electrons move towards the positive direction of current resulting in conduction of current through the material. In crystal formation the energy level of electron can be categorised into two distinct energy levels or energy bands.

Valence Band – Valence band contains valence electrons. The valence band can be completely filled with electrons or sometimes partially filled with electrons but it is never empty. As these are valence electrons they are not affected by the electric filled.

Conduction Band – Conduction band contains free electrons. It can be empty or partially filled with electrons. As these are free electrons they conduct electricity through the material.

Forbidden Band / **Energy Gap** (E_g) – The forbidden band is completely empty as there are no electrons in it. To move an electron from the valence band to the conduction band an energy equal to the energy gap is required.

N type Semiconductors

When Si or Ge crystal is doped with pentavalent impurity we get n type semiconductor.

Example of pentavalent atom: Phosphorous (P), Arsenic (As), Antimony (Sb).

Pentavalent atom has 5 electrons in its valence shell. Figure shows the structure of n type semiconductor. Every pentavalent dopant atom finds 4 neighboring Si atoms. It shares its 4 valence electrons with four Si atoms to form octet and Si atoms become stable.

Since valence orbit can hold maximum 8 electrons, the 1 extra electron of dopant atom is not the part of covalent bonding and hence it becomes free electron. The free electron of phosphorous atom has energy 0.01eV less than the conduction band energy of Silicon. At room temperature these free electrons move to the conduction band and are available for conduction of electricity.

Due to these extra free electrons in the crystal structure, the number of electrons become greater than the number of holes in the crystal.

Note – Number of holes will decrease but will never become zero, there would be a small number of holes present in the crystal.

Relationship between the number of electrons and number of holes is given by $n_e \times n_h = n_i^2$

 $n_e =$ number of electrons.

 n_h = number of holes.

 n_i = total number of charge carriers.

Conduction band is crowded by electrons and holes in the valence band are decreased in N type semiconductor. In N type semiconductor electrons are majority charge carriers and holes are minority charge carriers. Since every pentavalent dopant atom donates 1 electron for conduction; it is called donor type dopant. As we can control the number of dopant i.e. we can control the number of free electrons and hence control the conductivity of semiconductor.

P-Type Semiconductors

Where,

When Si or Ge crystal or intrinsic semiconductor is doped with measured quantity of trivalent impurity such as indium(In), boron (B), aluminum (Al), we get p type semiconductor. The trivalent atom has three electrons in valence shell. Every trivalent dopant atom shares its 3 electrons with 3 neighboring Si atoms to form covalent bond. But, the bond between dopant atom and 4^{th} neighbor is not completed as trivalent atom has no more electron to share. Hence creating a vacancy that acts as a hole. This hole has tendency to accept any electron in its close vicinity. For this reason, trivalent impurity is called as an acceptor type dopant. At room temperature, an electron from neighboring atom can jump into the hole. This hole disappears and new hole is created at the position of displaced electron.

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As this semiconductor has large number of holes and conductivity is because of positively charged holes, it is called p type semiconductor. In P type semiconductor holes are majority charge carriers and electrons are minority charge carriers. The number of holes is comparatively very large than the number of electrons.

$n_h >> n_e$

Though P type semiconductor has large numbers of holes, its net charge is zero.

P-N Junction

When half part of a Si crystal is doped with trivalent impurity and half with pentavalent impurity, we get P-N junction diode. The border where p-region meets with

n-region is called the junction.



P and N type junction develops a depletion-layer around it due to the recombination of electrons from N-side and holes on P-side. No charge carriers are present in this region as combination of holes and electrons create neutral atoms, hence depletion-layer has high resistance. No charge carriers from either side is allowed to cross the depletion layer. Due to losing electrons 'N' develops a positive charge layer, and 'P' develops a negative charge layer. Hence an electric field or potential difference is developed between the two. This potential difference prevents the flow of majority charge carriers across the junction, hence called as potential barrier. When no external source is connected to diode it is said to be unbiased diode. Majority charge carriers i.e. holes in the P side and electrons in the N side cannot flow through the depletion-layer, but minority charge carriers i.e. electrons in P side and holes in N side can flow through depletion-layer. P-N junction diode acts as an insulator.

Biasing of P-N Junction

Biasing in the process of applying potential difference to the semiconductor. Biasing is achieved by applying EMF across the P-N junction diode. Biasing can be of two types –

- Forward biasing
- Reverse biasing

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Forward biasing

When positive terminal of the battery is connected to P-side and negative terminal to N-side it is called forward biasing and the diode is said to be forward biased.



When forward biased, electrons from N-side and holes from P-side are pushed towards the junction. The depletion layer's width decreases. As depletion layer decreases, potential barrier also decreases. The potential difference within the P-N junction diode is known as induced potential ($V_{induced}$) and potential difference applied externally is called applied potential ($V_{applied}$).

Total Potential Difference = $V_{Induced} + V_{Applied}$

The direction of both the potential are opposite to each other therefore, as the applied potential increases it reduces the effect of induced potential. When the applied potential is equal to the induced potential then, the net potential equals to zero and the depletion layer vanishes.

As there is no depletion layer, large number of electrons and holes cross the junction. They recombine and large current flows through the diode. After recombining, the electrons travel as valence electrons then leave the Pregion and enter positive terminal of the source. A continuous current flows in the diode. That is, on forward biasing, P-N junction diode acts as conductor.

Reverse Biasing Of P-N Junction

When positive terminal of the battery is connected to N-side and negative terminal to P-side, it is known as reverse biasing and the diode is said to be reversed biased.



In reverse biasing, free electrons and holes move away from the junction. Hence, increasing the width of depletion layer. As the depletion layer increases, potential barrier also increases.

In reverse biasing the induced and applied potential are in the same direction i.e. the net potential will increase with the increasing applied potential. Higher will be the net potential in the diode, higher will be the resistance. Majority charge carriers cannot move across the junction, hence current will not be allowed to flow across the diode. That is, on reverse biasing, P-N junction diode acts as insulator. The current flowing in the reverse biased circuit due to the minority charge carrier is known as reverse current.

Characteristic Of P-N Junction

To study V-I characteristic of diode the external source is connected to diode through rheostat so that variable voltage can be applied to diode. A voltmeter is connected parallel to diode to read diode voltage and current meter is connected in series with diode to measure resulting current. Characteristics can be studied separately for forward biasing and reverse biasing.

Forward characteristic

When forward biased (Si diode), initially current does not flow until biasing is less than potential barrier (0.7 V) but it increases suddenly beyond 0.7 V and current is directly proportional to voltage.



Resistance in forward biasing is dynamic resistance which is given by -

$$\mathbf{R} = \Delta \mathbf{v} / \Delta \mathbf{i}$$

Resistance in forward biasing in the range of few ohm to ten kilo ohm.

Reverse characteristic

When the diode is reverse biased, there is no crossing of majority carriers and current is approximately zero.



A very small current of the order nA flows because of minority carriers in depletion region. This current is called reverse current. When reverse biasing increases, at a particular high value, the reverse current increases suddenly and a large amount of atoms are broken down in the depletion layer. This is called breakdown of diode. If this reverse current is not controlled, p-n junction gets damaged due to excess heating. The reverse voltage, at which the diode breakdown occur is called breakdown voltage (V_{BR}). For general purpose diode, the reverse voltage is always kept below the breakdown voltage. Resistance in forward biasing is in the range of thousand kilo ohm.

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Symbol for P-N junction



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Analog Systems and Applications (17PHU202)

UNIT-I

QUESTI OPTIC	ON OPTION	OPTION	OPTION	ANSWE	
ONS I	2	3	4	ĸ	
A crystal one pn	two pn	three pn	four	one pn	
diode nas junctio	n junctions	junctions	Junction	junction	
•••••					
A crystal kΩ diode has forward resistance of	Ω	ΜΩ	KV	Ω	
If the forwar arrow of crystal diode symbol is positive w.r.t. bar,	rd reverse	opposite	rotating	forward	
then diode is biased The reverse current in a diode is of the order	kA mA	μΑ	А	μΑ	

The	2.5 V	3 V		0.7 V	0.7 V
forward			10 V		
voltage					
drop					
across a					
silicon					
diode is					
about					
••••					
•••					
A crystal	an	а	an	a voltage	а
diode is	amplifier	rectifier	oscillator	regulator	rectifier
used as	-			-	
The d.c.	the same	more	less	equal	less
resistance	as	than	than	1	than
of a					
crystal					
diode is					
its					
a.c.					
resistance					
An ideal				inductor	
crystal	conducto	insulator	resistance	maaevor	conducto
diode is	r	mbulutor	material		r
one	1		material		1
which					
behaves					
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nerfect					
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when					
forward					
biased					

The ratio 1:1 100:140,000 : of reverse 1000:1 40,000: 1 resistance 1 and forward resistance of a germaniu m crystal d The junction ions minority . minority leakage carriers majority capacitan carriers current in carriers ce a crystal diode is due to If the remains increases temperat the same decreases increases becomes ure of a zero crystal diode increases, then leakage current The PIV the same lower equal more rating of as lower than than a crystal than diode is

equal . If the remains . is is doping decreased decreased the same is level of a increased crystal diode is increased the , breakdow n voltage... The knee applied barrier forward barrier voltage voltage breakdow voltage potential potential of n voltage а crystal diode is approxim ately When the linear passive . active linear graph nonlinear between current through and voltage across a device is a straight line, the device is referred to as

When the forward forward reverse crystal inverse poor current diode current is large, the is bias A crystal unilateral nonnondiode is a linear linear bilateral linear device forward forward opposite A crystal reverse forward diode or reverse utilises the remains If is is equal in doping the same decreased increased increased level in a crystal diode is increased the , width of depletion layer..... the diode In a the diode the diode there is diode semicond is in its is in its is in its is no uctor forward potential noncondu forward reverse diode, the conductin nondifferenc cting conductin depletion g state g state conductin e region is between g state removed the anode when: and

cathode

The 0.2 V 0.4 V 0.6 V .8V 0.2V forward threshold voltage for а germaniu m diode is about: The term the the the recombin the 'covalent introducti sharing generatio ation sharing bonding' on of an of n of of refers to: impurity valence surplus valence electrons electrons electrons Why is due to the due to due to due to due to heat power voltage the PN current current produced rating of across the junction passing passing a the diode diode in of the through through diode? diode the diode the diode Since more higher current higher current diodes limiting dopants voltage limiting current resistors are sources resistors sources destroyed by excessive current, circuits must have: The the nthe pthe pthe nthe parrow in type type type type type material, material, material, material, material, the schemati which is which is which is which is which is c symbol called the called the called the called the of a anode anode cathode cathode anode diode points to

The characteri stic curve for the complex model of a silicon diode shows that	the barrier potential increases slightly with an increase in current	the barrier potential decreases slightly with an increase in current	the barrier potential stays fixed at 0.7 V	the barrier potential is 0 V	the barrier potential stays fixed at 0.7 V
A pn junction allows current flow when	both the n-type and p- type materials have the same potential	the p- type material is more positive than the n- type material	there is no potential on the n- type or p- type materials	the n- type material is more positive than the p- type material	the p- type material is more positive than the n- type material
When a diode is forward biased, the voltage across it	is inversely proportio nal to the current	is directly proportio nal to the source voltage	is directly proportio nal to the current	remains approxim ately the same	remains approxim ately the same
The peak inverse voltage (PIV) across a noncondu cting diode in a bridge rectifier equals approxim ately:	the peak value of the secondar y voltage	twice the peak secondar y voltage	half the peak secondar y voltage	four times the peak value of the secondar y voltage	the peak value of the secondar y voltage

Testing a	high	high	low	high	high
good	resistance	resistance	resistance	resistance	resistance
diode	when	when	when	when	when
with an	forward	reverse	forward	forward	reverse
ohmmete	or reverse	biased	or reverse	biased	biased
r should	biased	and low	biased	and low	and low
indicate		resistance		resistance	resistance
		when		when	when
		forward		reverse	forward
		biased		biased	biased
What	higher	higher	lower	lower	higher
circuit	power	resistance	current	voltage	resistance
activity	(heat)				
may shift					
a					
characteri					
stic curve					
so that					
diode					
operating					
points are					
different?					
The	is the	has	is a two-	lower	is a two-
diode	simplest	characteri	terminal	current	terminal
	of	stics that	device	device	device

conducto closely

r devices match

those of a oscillator

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What does a high resistance reading in both forward- and reverse- bias directions indicate?	A good diode	An open diode	A shorted diode	A defective ohmmete r	An open diode
Which capacitan ce dominate s in the reverse- bias region?	depletion	conversio n	ີ Diffu sion	Poupling	depletion
What is the state of an ideal diode in the region of noncondu ction?	An open circuit	A short circuit	Unpredic table	Undefine d	An open circuit
How many orbiting electrons does the germaniu m atom have?	4	12	32	45	32
How many terminals does a diode have?	2	3	4	6	2

What unit is used to represent the level of a diode forward current I_F ?	A	mA	v	mV	mA
The diffused impuritie s with	4	3	5	0	5
valence electrons are called donor atoms.					
Which of the following devices can check the condition of a semicond uctor diode?	Digital display meter (DDM)	Multimet er	galvanom eter	DDM and Multimet er	DDM and Multimet er
Which of the following is an atom compose d of?	Electrons	neutinos	Neutrons	electrons ,neutron , protons	electrons ,neutron , protons

How many valence electrons does a silicon atom have?	1	2	3	4	4
What is the resistor value of an ideal diode in the region of conductio n?	0 ohm	5 k ohm	15 Kohm	9 K ohm	0 0hm
Which of the following elements is most frequentl y used for doping pure Ge or Si?	Boron	Gallium	Indium	boron,ind ium and galium	boron,ind ium and galium
Which of the following ratings is true?	Si diodes have higher PIV and narrower temperat ure ranges than Ge diodes.	Si diodes have higher PIV and wider temperat ure ranges than Ge diodes	Si diodes have lower PIV and narrower temperat ure ranges than Ge diodes.	Si diodes have lower PIV and wider temperat ure ranges than Ge diodes.	Si diodes have higher PIV and wider temperat ure ranges than Ge diodes

The ideal open closed virtual neutal open diode is a(n) circuit the in region of noncondu ction. Diffusion Transitio Depletion absorptio Diffusion Which capacitan n n ce dominate s in the forwardbias region? what No bias Zener Forward In Forward Reverse state is a bias bias region bias silicon diode if the voltage drop across it is about 0.7 V? А Positive Zero Negative no Negative polarity semicond uctor has temperat ure coefficien of t resistance •

The most commonl y used semicond uctor is	silicon	Bermaniu m	carbon	copper	silicon
When a pentavale nt impurity is added to a pure semicond uctor, it becomes	An insulator	An intrinsic semicond uctor	p-type semicond uctor	n-type semicond uctor	n-type semicond uctor
Addition of pentavale nt impurity to a semicond uctor creates many 	Free electrons	Holes	Valence electrons	Bound electrons	Free electrons
. A pentavale nt impurity has	3	2	5	4	5
An n- type semicond uctor is	Positively charged	Negativel y charged	Electrical ly neutral	no polarity	Negativel y charged

A	3	4	5	6	3
trivalent					
impurity					
has					
valence					
electrons					
Addition	Free	Holes	Valence	Bound	Holes
of	electrons		electrons	electrons	
trivalent					
impurity					
to a					
semicond					
uctor					
creates					
many					
•••••					
A hole in	A free	The	A free	A free	The
а	electron	incomple	proton	neutron	incomple
semicond		te part of			te part of
uctor is		an			an
defined		electron			electron
as		pair bond			pair bond
In a	Only	Only	Holes	ions	Holes
semicond	holes	free	and free		and free
uctor,		electrons	electrons		electrons
current					
conductio					
n is due					
to					
The	positive	-ve	-ve	positive	+ve
battery	terminal	terminal	terminal	teminal	terminal
connectio	to p and	to p and	to p and	to	to p and
ns	-ve	+ve	-ve	positive	-ve
required	terminal	terminal	terminal		terminal
to	to n	to n	to n		to n
forward					
bias a pn					
junction					
are					

the Acceptor Holes electrons . Holes In Donor depletion ions and and ions , neutron, region of protons electrons electrons а pn junction, there is a shortage of pn oscillator Unidirect А junction Controlle Bidirecti Unidirect ional acts as a d switch onal ional switch switch switch

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TORE-21

UNIT-II

SYLLABUS

Two-terminal Devices and their Applications: Rectifier Diode: Half-wave Rectifiers. Centre-tapped and Bridge Full-wave Rectifiers, Calculation of Ripple Factor and Rectification Efficiency, C-filter, Zener Diode and Voltage Regulation. Principle and structure of LEDs, Photodiode and Solar Cell.

Bipolar Junction transistors: n-p-n and p-n-p Transistors. Characteristics of CB, CE and CC Configurations. Current gains α and β Relations between α and β . Load Line analysis of Transistors. DC Load line and Q-point. Physical Mechanism of Current Flow. Active, Cutoff and Saturation Regions.

Rectifier-Principle

Majority of electronic devices require direct current sources for their operations. But domestic electric supply is available in alternating current form. Therefore, it has to be converted in direct current.Rectifier is a device which coverts alternating current to direct or steady current is known a rectifier.



Half wave rectifier

Half wave rectifier converts only half cycle of alternating current to direct current, the remaining half cycle is wasted.



The input current is bidirectional and output current is unidirectional. The current obtained is pulsated or bumpy. Only a single diode is used in half wave rectifier.



An A.C supply is provided to the transformer. The diode is connected in series with load (electronic device) resistance R_L . During every positive half cycle of the A.C input, point A becomes positive w.r.t. point B, and diode becomes forward biased and current is allowed to flow. During every negative half cycle of the A.C input, point A becomes negative w.r.t. point B, and diode becomes reverse biased and current is not allowed to flow.

Full Wave-Rectifier

Full wave rectifier converts the complete cycle of alternating current to direct current. No input current is wasted.



The input current is bidirectional and output current is unidirectional. Two diode are required for full wave rectifier.



This rectifier requires centre tapped secondary transformer. During positive half cycle of A.C input, point A is positive w.r.t point C and point B is negative w.r.t. point C, therefore the diode D_1 is forward biased and diode D_2 is reverse biased. The current flows through diode D_1 and passes through the load R_L , path of current is AMPQCA. During negative half cycle of A.C input, point B is positive w.r.t point C and point A is negative w.r.t point C, therefore the diode D_2 is forward biased and diode D_1 is reverse biased. The current flows through diode D_2 is forward biased and diode D_1 is reverse biased. The current flows through diode D_2 , and passes through the load R_L , path of current is BNPQCB.

Zener-Diode

Zener diode is P-N junction diode. It is used for regulation of voltage supplied. It is highly doped and used in reverse biasing. Zener diode is designed to operate in breakdown region.



When reverse bias reaches a particular value, the current increases suddenly. This voltage is called Zener breakdown voltage or simply Zener voltage (V_Z). Breakdown for a given Zener diode depends upon doping level of P and N regions. Generally, this value is small, such as 1.5V, 2V. It is clear from characteristic that, in breakdown region, voltage across Zener diode remains almost constant even when current through it changes by large amount.

Photo Diode

Photo diode converts light energy to electrical energy, hence they can detect presence of light. For photo diode reverse biasing is used. Initially the rheostat is adjusted such that there is no reading shown in ammeter though there is current flowing through the circuit this current is known as dark current. In depletion layer only atoms are present. When light is incident on atoms in depletion layer it supplies energy to electron of that atom and this electron becomes a free electron. The free electron is pulled towards the N region and this helps in the conduction of current. This current flowing through the circuit is indicated by the ammeter and is known as photo current. Photo current indicates the intensity/presence of light.



Light Emitting Diode(LED)

Light emitting diode is a special type of P-N junction diode that has energy gap greater than 1.8eV.



When the free electrons fall from conduction band to valence band, the energy equal to band gap (E_g) is released in the form of photons. The photon has energy E = hv, for the photon to be visible to human eye it should have a frequency v greater than visible light hence, the energy gap should have a value greater than 1.8eV hence, Silicon and Germanium cannot be used. Light emitting diodes are used in forward bias. This results in reduction of depletion layer allowing the free electrons to recombine with the holes i.e. minority charge carriers recombine and release energy slightly less than energy gap. This gives light of different colors. Gallium-Arsenide LED emits infrared light. Ga-As-P LED emits red and yellow light. Ga-P LEDs emit red, green light. LEDs cannot be used in reverse biased because if we reach the breakdown voltage a large amount of current will flow through it and the LED will burn out. Their reverse breakdown voltage is low about 5V.



Solar-Cell

Solar cell, which is also known as photovoltaic cell, converts solar (light) energy directly into electrical energy.



Solar cell is a P-N junction diode that has very thin layer of P-type semiconductor (thickness is in μ m) so that light can reach the junction. The photon that is reaching the junction should have energy greater than the energy gap. Metallic contacts are formed on both the layers for external circuit connections. At the top silver fingers are used, as silver is the best conductor and they are used to absorb photo electrons. This displacement of charges sets up a potential difference across two regions, with P-side as positive and N-side as negative. If external load RL is connected, current flows through it and we get electrical energy. Typically, a solar cell can generate photo voltage from 0.5 V to 1.2 V.

V-I characteristic of solar cell



Applications of solar cell

- Charging storage batteries.
- Charging satellite batteries.
- Pumps and other electronic appliances in the far-off areas use solar cell.
- Radiophones.

Transistor

If we now join together two individual signal diodes back-to-back, this will give us two PNjunctions connected together in series that share a common **P** or **N** terminal. The fusion of these two diodes produces a three layer, two junction, three terminal device forming the basis of a **Bipolar Junction Transistor**, or **BJT** for short. Transistors are three terminal active devices made from different semiconductor materials that can act as either an insulator or a conductor by the application of a small signal voltage. The transistor's ability to change between these two states enables it to have two basic functions: "switching" (digital electronics) or "amplification"

(analogue electronics). Then bipolar transistors have the ability to operate within three different regions:

- 1) Active Region the transistor operates as an amplifier and $Ic = \beta Ib$
- 2) Saturation the transistor is "Fully-ON" operating as a switch and Ic = I(saturation)
- 3) Cut-off the transistor is "Fully-OFF" operating as a switch and Ic = 0
- 4)



A Typical Bipolar Transistor

The word Transistor is an acronym, and is a combination of the words Transfer aristorused to describe their mode of operation way back in their early days of development. There are two basic types of bipolar transistor construction, PNP and NPN, which basically escribes the physical arrangement of the P-type and N-type semiconductor materials from which they are made. The **Bipolar Transistor** basic construction consists of two PN-junctions producing three connecting terminals with each terminal being given a name to identify it from the other two. These three terminals are known and labelled as the Emitter (E), the Base (B) and the Collector (C) respectively. Bipolar Transistors are current regulating devices that control the amount of current flowing through them in proportion to the amount of biasing voltage applied to their base terminal acting like a current-controlled switch. The principle of operation of the two transistor types PNP andNPN, is exactly the same the only difference being in their biasing and the polarity of the power supply for each type.



The construction and circuit symbols for both the PNP and NPN bipolar transistor are given above with the arrow in the circuit symbol always showing the direction of "conventional current flow" between the base terminal and its emitter terminal. The direction of the arrow always points from the positive P-type region to the negative N-type region for both transistor types, exactly the same as for the standard diode symbol.

Bipolar Transistor Configurations

As the **Bipolar Transistor** is a three terminal device, there are basically three possible ways to connect it within an electronic circuit with one terminal being common to both the input and output. Each method of connection responding differently to its input signal within a circuit as the static characteristics of the transistor vary with each circuit arrangement.

- 1) Common Base Configuration has Voltage Gain but no Current Gain.
- 2) Common Emitter Configuration has both Current and Voltage Gain.
- 3) Common Collector Configuration has Current Gain but no Voltage Gain.

The Common Base (CB) Configuration

As its name suggests, in the **Common Base** or grounded base configuration, the BASE connection is common to both the input signal AND the output signal with the input signal being applied between the base and the emitter terminals. The corresponding output signal is taken from between the base and the collector terminals as shown with the base terminal grounded or connected to a fixed reference voltage point.

The input current flowing into the emitter is quite large as its the sum of both the base current and collector current respectively therefore, the collector current output is less than the emitter current input resulting in a current gain for this type of circuit of "1" (unity) or less, in other words the common base configuration "attenuates" the input signal.

The Common Base Transistor Circuit



This type of amplifier configuration is a non-inverting voltage amplifier circuit, in that the signal voltages Vin and Vout are "in-phase". This type of transistor arrangement is not very common due to its unusually high voltage gain characteristics. Its input characteristics represent that of a forward biased diode while the output characteristics represent that of an illuminated photo-diode.

Also this type of bipolar transistor configuration has a high ratio of output to input resistance or more importantly "load" resistance (RL) to "input" resistance (Rin) giving it a value of "Resistance Gain". Then the voltage gain (Av) for a common base configuration is therefore given as:

Common Base Voltage Gain

$$A_{V} = \frac{Vout}{Vin} = \frac{I_{C} \times R_{L}}{I_{E} \times R_{IN}}$$

Where: Ic/Ie is the current gain, alpha (α) and RL/Rin is the resistance gain. The common base circuit is generally only used in single stage amplifier circuits such as microphone pre-amplifier or radio frequency (Rf) amplifiers due to its very good high frequency response.

The Common Emitter (CE) Configuration

In the **Common Emitter** or grounded emitter configuration, the input signal is applied between the base and the emitter, while the output is taken from between the collector and the emitter as shown. This type of configuration is the most commonly used circuit for transistor based amplifiers and which represents the "normal" method of bipolar transistor connection. The common emitter amplifier configuration produces the highest current and power gain of all the three bipolar transistor configurations. This is mainly because the input impedance is LOW as it is connected to a forward biased PN-junction, while the output impedance is HIGH as it is taken from a reverse biased PN-junction.

The Common Emitter Amplifier Circuit



In this type of configuration, the current flowing out of the transistor must be equal to the currents flowing into the transistor as the emitter current is given as Ie = Ic + Ib.

As the load resistance (RL) is connected in series with the collector, the current gain of the common emitter transistor configuration is quite large as it is the ratio of Ic/Ib. A transistors current gain is given the Greek symbol of Beta, (β). As the emitter current for a common emitter configuration is defined asIe = Ic + Ib, the ratio of Ic/Ie is called Alpha, given the Greek symbol of α . Note: that the value of Alpha will always be less than unity. Since the electrical relationship between these three currents, Ib, Ic and Ieis determined by the physical construction of the transistor itself, any small change in the base current (Ib), will result in a much larger change in the collector current (Ic). Then, small changes in current flowing in the base will thus control the current in the emitter-collector circuit. Typically, Beta has a value between 20 and 200 for most general purpose transistors. So if a transistor has a Beta value of say 100, then one electron will flow from the base terminal for every 100 electrons flowing between the emitter-collector

terminal. By combining the expressions for both Alpha, α and Beta, β the mathematical relationship between these parameters and therefore the current gain of the transistor can be given as:

Alpha,(
$$\alpha$$
) = $\frac{I_{C}}{I_{E}}$ and Beta,(β) = $\frac{I_{C}}{I_{B}}$
 $\therefore I_{C} = \alpha . I_{E} = \beta . I_{B}$
as: $\alpha = \frac{\beta}{\beta + 1}$ $\beta = \frac{\alpha}{1 - \alpha}$
 $I_{E} = I_{C} + I_{B}$

Where: "Ic" is the current flowing into the collector terminal, "Ib" is the current flowing into the base terminal and "Ie" is the current flowing out of the emitter terminal. Then to summarise a little. This type of bipolar transistor configuration has a greater input impedance, current and power gain than that of the common base configuration but its voltage gain is much lower. The common emitter configuration is an inverting amplifier circuit. This means that the resulting output signal is 180° "out-of-phase" with the input voltage signal.

The Common Collector (CC) Configuration

In the **Common Collector** or grounded collector configuration, the collector is now common through the supply. The input signal is connected directly to the base, while the output is taken from the emitter load as shown. This type of configuration is commonly known as a**Voltage Follower** or **Emitter Follower** circuit. The common collector, or emitter follower configuration is very useful for impedance matching applications because of the very high input impedance, in the region of hundreds of thousands of Ohms while having a relatively low output impedance.

The Common Collector Transistor Circuit



The common emitter configuration has a current gain approximately equal to the β value of the transistor itself. In the common collector configuration the load resistance is situated in series with the emitter so its current is equal to that of the emitter current. As the emitter current is the combination of the collector AND the base current combined, the load resistance in this type of transistor configuration also has both the collector current and the input current of the base flowing through it. Then the current gain of the circuit is given as:

The Common Collector Current Gain

$$\mathbf{I}_{E} = \mathbf{I}_{C} + \mathbf{I}_{B}$$
$$\mathbf{A}_{i} = \frac{\mathbf{I}_{E}}{\mathbf{I}_{B}} = \frac{\mathbf{I}_{C} + \mathbf{I}_{B}}{\mathbf{I}_{B}}$$
$$\mathbf{A}_{i} = \frac{\mathbf{I}_{C}}{\mathbf{I}_{B}} + 1$$
$$\mathbf{A}_{i} = \frac{\mathbf{I}_{C}}{\mathbf{I}_{B}} + 1$$

This type of bipolar transistor configuration is a non-inverting circuit in that the signal voltages of Vin and Vout are "in-phase". It has a voltage gain that is always less than "1" (unity). The load resistance of the common collector transistor receives both the base and collector currents giving a large current gain (as with the common emitter configuration) therefore, providing good current amplification with very little voltage gain.

We can now summarise the various relationships between the transistors individual DC currents flowing through each leg and its DC current gains given above in the following table.

Relationship between DC Currents and Gains

Bipolar Transistor Summary

Then to summarise, the behaviour of the bipolar transistor in each one of the above circuit configurations is very different and produces different circuit characteristics with regards to input impedance, output impedance and gain whether this is voltage gain,

current gain or power gain and this is summarised in the table below. The most commonly used transistor configuration is the **NPN Transistor**. We also learnt that the junctions of the bipolar transistor can be biased in one of three different ways – **Common Base, Common Emitter** and **Common Collector**. In this tutorial about bipolar transistors we will look more closely at the "Common Emitter" configuration using the **Bipolar NPN Transistor** with an example of the construction of a NPN transistor along with the transistors current flow characteristics is given below.

A Bipolar NPN Transistor Configuration



(Note: Arrow defines the emitter and conventional current flow, "out" for a Bipolar NPN Transistor.)

The construction and terminal voltages for a bipolar NPN transistor are shown above. The voltage between the Base and Emitter (V_{BE}), is positive at the Base and negative at the Emitter because for an NPN transistor, the Base terminal is always positive with respect to the Emitter. Also the Collector supply voltage is positive with respect to the Emitter (V_{CE}). So for a bipolar NPN transistor to conduct the Collector is always more positive with respect to both the Base and the Emitter.



NPN Transistor Connection

Then the voltage sources are connected to an NPN transistor as shown. The Collector is connected to the supply voltage V_{CC} via the load resistor, RL which also acts to limit the maximum current flowing through the device. The Base supply voltage V_B is connected to the Base resistor R_B , which again is used to limit the maximum Base current. So in a NPN Transistor it is the movement of negative current carriers (electrons) through the Base region that constitutes

transistor action, since these mobile electrons provide the link between the Collector and Emitter circuits. This link between the input and output circuits is the main feature of transistor action because the transistors amplifying properties come from the consequent control which the Base exerts upon the Collector to Emitter current. Then we can see that the transistor is a current operated device (Beta model) and that a large current (Ic) flows freely through the device between the collector and the emitter terminals when the transistor is switched "fully-ON". However, this only happens when a small biasing current (Ib) is flowing into the base terminal of the transistor at the same time thus allowing the Base to act as a sort of current control input.

The transistor current in a bipolar NPN transistor is the ratio of these two currents (Ic/Ib), called the *DC Current Gain* of the device and is given the symbol of hfe or nowadays Beta, (β). The value of β can be large up to 200 for standard transistors, and it is this large ratio between Ic and Ib that makes the bipolar NPN transistor a useful amplifying device when used in its active region as Ib provides the input and Ic provides the output. Note that Beta has no units as it is a ratio. Also, the current gain of the transistor from the Collector terminal to the Emitter terminal, Ic/Ie, is called Alpha, (α), and is a function of the transistor itself (electrons diffusing across the junction). As the emitter current Ie is the sum of a very small base current plus a very large collector current, the value of alpha α , is very close to unity, and for a typical low-power signal transistor this value ranges from about 0.950 to 0.999

α and β Relationship in a NPN Transistor

DC Current Gain = $\frac{\text{Output Current}}{\text{Input Current}} = \frac{I_C}{I_B}$ $I_E = I_B + I_C \dots (\text{KCL}) \text{ and } \frac{I_C}{I_E} = \alpha$ Thus: $I_B = I_E - I_C$ $I_B = I_E - \alpha I_E$ $I_B = I_E (1 - \alpha)$ $\therefore \beta = \frac{I_C}{I_B} = \frac{I_C}{I_E(1 - \alpha)} = \frac{\alpha}{1 - \alpha}$

By combining the two parameters α and β we can produce two mathematical expressions that gives the relationship between the different currents flowing in the transistor.

$$\alpha = \frac{\beta}{\beta + 1} \text{ or } \alpha = \beta(1 - \alpha)$$
$$\beta = \frac{\alpha}{1 - \alpha} \text{ or } \beta = \alpha(1 + \beta)$$
If $\alpha = 0.99$ $\beta = \frac{0.99}{0.01} = 99$
The values of Beta vary from about 20 for high current power transistors to well over 1000 for high frequency low power type bipolar transistors. The value of Beta for most standard NPN transistors can be found in the manufactures data sheets but generally range between 50 - 200.

The equation above for Beta can also be re-arranged to make Ic as the subject, and with a zero base current (Ib = 0) the resultant collector current Ic will also be zero, ($\beta \ge 0$). Also when the base current is high the corresponding collector current will also be high resulting in the base current controlling the collector current. One of the most important properties of the **Bipolar Junction Transistor** is that a small base current can control a much larger collector current.

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OPTION	OPTION	OPTION	OPTION	ANSWE
1	2	3	4	R
one pn junction	two pn junctions	three pn junctions	four junction	one pn junction
an amplifier	a voltage regulator	a rectifier	a multivibr ator	voltage regulator
the same as	less than	more than	equal	more than
reverse	forward	both forward and reverse	opposite	reverse
	operion 1 one pn junction an amplifier the same as reverse	OPTION 1OPTION OPTION junctionone pn junctionstwo pn junctionsan amplifiera voltage regulatorthe the same asless thanthe reverseless than	OPTIONOPTIONOPTION 123one pn junctiontwo pn junctionsan amplifiera voltage regulatora rectifierthe same asless thanmore thanthe same asless thanmore than	OPTION 1234one pn junctiontwo pn pn junctionsthree pn

In the constant constant variable breakdow voltage resistance voltage current constant n region, voltage a zener didoe behaves like а source.

A zener	is	is	carrier	carrier is	carrier
diode is	forward	reverse	more	less than	more
destroyed	biased	biased	than rated	rated	than rated
if			current	current	current
it					
A zener	a non-	а	an	unilateral	a non-
diode is	linear	linear	amplifyin		linear
			g		
			0		
device					
If the PIV	the	the	the	diode	the
rating of	diode	diode is	diode	conducts	diode is
a diode is	conducts	destroyed	behaves	normally	destroyed
exceeded,	poorly	·	like a		-
			zener		
			diode		
The	choke			inductanc	choke
	input	capacitor	resistance	e input	input
		input	input		
filter					
circuit					
results in					
the best					
voltage					
regulatio					
n					

The	40.6 %	50.00%	35%	80%	40.60%
maximu					
m					
efficiency					
of a half-					
wave					
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The most	half-	centre-	bridge	filter	bridge
widely	wave	tap full-	full-wave		full-wave
used	rectifier	wave	rectifier		rectifier
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The LED	GaAs	CU	С	Al	GaAS
is usually					
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like:					
What	Light	Light	light	light	
does	emitting	emitting	energy	emitting	
LED	doide	detector	disply	disply	
stands for					

The most Silicon Aluminiu galium Silicon commonl germaniu m used m у semicond uctor in the manufact ure of a transistor is electron electron hole The hole donor arrow in current in current in ion current in the the the the current the emitter collector emitter emitter symbol of а transistor indicates the direction of In a high low high . low low transistor, resistance resistance resistance resistance to high signal is to low to high to low to high transferre resistance resistance resistance resistance d from a circuit propotion the Decrease Increases same As decreases temperat s al ure of a transistor goes up, the baseemitter resistance

The CE CB CCCBE CE voltage gain in a transistor connecte in d . arrangem ent is the highest The CBE CE CE CBCCpower gain in a transistor connecte d in arrangem ent is the highest The most CE CB CC CBE CE commonl у used transistor arrangem ent is arrangem ent moderate lightly heavily The no doping moderate ly collector ly of а transistor is doped

heavily lightly heavily The no emitter of moderate doping ly а transistor is doped The input low very high high 0 low impedanc e of a transistor is • • • • voltage both resistan А current current transistor voltage ce and is а current operated device collector The collector base emitter, emitter element and that has collector the biggest size in a transistor is . The base heavily lightly lightly no doping of а moderate transistor ly is doped

The 3 2 1 2 4 number of depletion layers in а transistor is high very low very high high It is low generally desired that а transistor should have input impedanc e The 180 0 90 270 180 phase differenc e between the output and input voltages of a CE amplifier is .

The dc load line on a family of collector characteri stic curves of a transistor shows the	saturation region.	cutoff region.	saturation , cuttoff region.	depletion region	saturation , cuttoff region.
A transistor data sheet usually identifies β_{DC} as	h _{re} .	h _{fe} .	I _C .	V _{CE} .	h _{fe}
When a transistor is used as a switch, it is stable in which two distinct regions?	saturation and active	active and cutoff	saturation and cutoff	active	saturation and cutoff
For a silicon transistor, when a base- emitter junction is forward- biased, it has a nominal voltage drop of	0.7 V.	0.3 V.	0.2 V.	V _{CC} .	0.7 V

The value of β_{DC}	is fixed for any particular transistor.	varies with temperat ure.	varies with I _C .	varies with temperat ure and $I_{\rm C}$.	varies with temperat ure and I _C .
The term BJT is short for	base junction transistor.	binary junction transistor.	both junction transistor.	bipolar junction transistor.	bipolar junction transistor
A BJT has an I_B of 50 μ A and a β DC of 75; I_C is:	375 mA	37.5 mA	3.75 mA	0.375 mA	3.75 mA
A certain transistor has I_C 15 mA and I_B 167 μ A; β_{DC} is:	15	167	0.011	90	90
For normal operation of a pnp BJT, the base must be with respect to the emitter and with respect to the	positive, negative	positive, positive	negative, positive	negative, negative	negative, positive
collector.					

7.5 V 1.33 V 7.5 V 13.3 V 15 V А transistor amplifier has а voltage gain of 100. If the input voltage is 75 mV, the output voltage is: A 35 mV 3.5 V 28.57 V 4.375 V 4.375 4.375 V signal is mV applied to the base of а properly biased transistor with an $r'_e = 8 \Omega$ and $R_{\rm C}$ = kΩ. 1 The output signal voltage at the collector is: emitter, emitter, What is base, emitter, collector, collector, the order collector, collector, base, emitter, of emitter base collector base base doping, from heavily to lightly doped, for each region?

What are npn and the two pnp types of bipolar junction transistor s ²	pnn and nnp	ppn and nnp	pts and stp	npn and pnp
Which of $I_E = I_B + I_C$ following is true for an npn or pnp transistor ?	$I_{\rm B} = I_{\rm C} + I_{\rm E}$	$I_{\rm C} = I_{\rm B} + I_{\rm E}$	IC = IB	$I_{\rm E} = I_{\rm B} + I_{\rm C}$
What is β_{DC} the ratio of I_C I_B ?	h _{FE}	α_{DC}	either β_{DC} or h_{FE} , but not α_{DC}	either β_{DC} or h_{FE} , but not α_{DC}
What is β_{DC} the ratio of I_C I_E ?	β_{DC} / (β_{DC} + 1)	α _{DC}	either β_{DC} / $(\beta_{DC} + 1)$ or α_{DC} , but not β_{DC}	either β_{DC} / $(\beta_{DC} + 1)$ or α_{DC} , but not β_{DC}
In what $0 < V_{CE}$ range of voltages is the transistor in the linear region of its operation ?	$0.7 < V_{CE} < V_{CE(max)}$	V _{CE(max)} > V _{CE}	Vce.	$0.7 < V_{CE} < V_{CE(max)}$
What I _C does DC vary with?	°C	both I_C and °C	I _{C'} , but not °C	both I_C and °C

What is TO-18 TO-TO-TO-92 TO-39 92,TO-18 92,TO-18 (are) general-,TO-39 ,TO-39 purpose/s mallsignal transistor case S type(s)? The μΑ nA pА nA mA magnitud e of dark current in a phototran sistor usually in falls what range? Jefferson Charles First Fornster Charles George solar cell Fritts. Fritts. Fritts. Fritts. Fritts. was invented in 1883 by Most of recombin pass recombin pass recombin e in the through e in through the majority e in the emitter the base collector the base carriers base region to region to from the the the collector collector emitter . The electron hole donor acceptor electron ion current current current current ion IB is current current a IC = IE + IB = IC + IE = IC - IE =IE =In transistor IB IE IB IC + IBIC + IB. . .

The value of α of a transistor is	1	>1	<1	0	<1
The output impedanc e of a transistor	low	high	0	very low	high
If the value of α is 0.9, then value of β is	90	10	30	55	90
The leakage current in CE arrangem ent is that in CB	more than	less than	the same as	equal	more than
arrangem					
The collector- base junction in a transistor has	forward bias at all times	reverse bias at all times	low resistance	high resistance	reverse bias at all times
The emitter- base junction in a transistor has	forward bias at all times	reverse bias at all times	low resistance	high resistance	forward bias at all times

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<u>UNIT-III</u>

SYLLABUS

Amplifiers: Transistor Biasing and Stabilization Circuits. Fixed Bias and Voltage Divider Bias. Transistor as 2-port Network. h-parameter Equivalent Circuit. Analysis of a single-stage CE amplifier using Hybrid Model. Input and Output Impedance. Current, Voltage and Power Gains. Classification of Class A, B & C Amplifiers. Coupled Amplifier: Two stage RC-coupled amplifier and its frequency response. **Feedback in Amplifiers:** Effects of Positive and Negative Feedback on Input Impedance, Output Impedance, Gain, Stability, Distortion and Noise.

A transistors steady state of operation depends a great deal on its base current, collector voltage, and collector current and therefore, if a transistor is to operate as a linear amplifier, it must be properly biased to have a suitable operating point.

Establishing the correct operating point requires the proper selection of bias resistors and load resistors to provide the appropriate input current and collector voltage conditions. The correct biasing point for a bipolar transistor, either NPN or PNP, generally lies somewhere between the two extremes of operation with respect to it being either "fully-ON" or "fully-OFF" along its load line. This central operating point is called the "Quiescent Operating Point", or Q-point for short. When a bipolar transistor is biased so that the Q-point is near the middle of its operating range, that is approximately halfway between cut-off and saturation, it is said to be operating as a Class-A amplifier. This mode of operation allows the output current to increase and decrease around the amplifiers Q-point without distortion as the input signal swings through a complete cycle. In other words, the output current flows for the full 360° of the input cycle. The function of the "DC Bias level" or "no input signal level" is to correctly set the transistors Q-point by setting its Collector current ($I_{\rm C}$) to a constant and steady state value without an input signal applied to the transistors Base. This steady-state or DC operating point is set by the values of the circuits DC supply voltage (Vcc) and the value of the biasing resistors connected the transistors Base terminal.

Since the transistors Base bias currents are steady-state DC currents, the appropriate use of coupling and bypass capacitors will help block bias current setup for one transistor stage affecting the bias conditions of the next. Base bias networks can be used for Common-base (CB), common-collector (CC) or common-emitter (CE) transistor configurations. In this simple transistor biasing tutorial we will look at the different biasing arrangements available for a Common Emitter Amplifier.

Common Emitter Amplifier

One of the most frequently used biasing circuits for a transistor circuit is with the selfbias of the emitter-bias circuit where one or more biasing resistors are used to set up the initial DC values of transistor currents, (I_B), (I_C) and (I_E).

The two most common forms of transistor biasing are: *Beta Dependent* and *Beta Independent*. Transistor bias voltages are largely dependent on transistor beta, (β) so the biasing set up for one

transistor may not necessarily be the same for another transistor. Transistor biasing can be achieved either by using a single feed back resistor or by using a simple voltage divider network to provide the required biasing voltage.

The following are five examples of transistor Base bias configurations from a single supply (Vcc).

Fixed Base Biasing a Transistor



The circuit shown is called as a "fixed base bias circuit", because the transistors base current, I_B remains constant for given values of Vcc, and therefore the transistors operating point must also remain fixed. This two resistor biasing network is used to establish the initial operating region of the transistor using a fixed current bias.

This type of transistor biasing arrangement is also beta dependent biasing as the steady-state condition of operation is a function of the transistors beta β value, so the biasing point will vary over a wide range for transistors of the same type as the characteristics of the transistors will not be exactly the same.

The emitter diode of the transistor is forward biased by applying the required positive base bias voltage via the current limiting resistor $R_{\rm B}$. Assuming a standard bipolar transistor, the forward base-emitter voltage drop will be 0.7V. Then the value of R_B is simply: (V_{CC} – V_{BE} /I_B where I_B is defined as I_C/ β .

With this single resistor type of biasing method the biasing voltages and currents do not remain stable during transistor operation and can vary enormously. Also the temperature of the transistor can adversely effect the operating point. Collector Feedback Biasing a Transistor



This self biasing collector feedback configuration is another beta dependent biasing method that requires only two resistors to provide the necessary DC bias for the transistor. The collector to base feedback configuration ensures that the transistor is always biased in the active region regardless of the value of Beta (β) as the DC base bias voltage is derived from the collector voltage, V_C providing good stability.

In this circuit, the base bias resistor, R_B is connected to the transistors collector C, instead of to the supply voltage rail, Vcc. Now if the collector current increases, the collector voltage drops, reducing the base drive and thereby automatically reducing the collector current to keep the transistors Q-point fixed. Then this method of collector feedback biasing produces negative feedback as there is feedback from the output to the input through resistor, R_B .

The biasing voltage is derived from the voltage drop across the load resistor, R_L . So if the load current increases there will be a larger voltage drop across R_L , and a corresponding reduced collector voltage, V_C which will cause a corresponding drop in the base current, I_B which in turn, brings I_C back to normal.

The opposite reaction will also occur when transistors collector current becomes less. Then this method of biasing is called self-biasing with the transistors stability using this type of feedback bias network being generally good for most amplifier designs. Dual Feedback Transistor Biasing



Adding an additional resistor to the base bias network of the previous configuration improves stability even more with respect to variations in Beta, (β) by increasing the current flowing through the base bias resistors. The current flowing through R_{B1} is generally set at a value equal to about 10% of collector current, I_C . Obviously it must also be greater than the base current required for the minimum value of Beta, β .One of the advantages of this type of self biasing configuration is that the resistors provide both automatic biasing and Rf feedback at the same time.

Transistor Biasing with Emitter Feedback



This type of transistor biasing configuration, often called self-emitter biasing, uses both emitter and collector-base feedback to stabilize the collector current even more as resistors R_B and R_E as well as the emitter-base junction of the transistor are all effectively connected in series with the supply voltage, V_{CC} .

The downside of this emitter feedback configuration is that the output has reduced gain because of the base resistor connection as the collector voltage determines the current flowing through the feedback resistor, R_B producing what is called "degenerative feedback". The current flowing from the emitter, I_E (which is a combination of $I_C + :I_B$) causes a voltage drop to appear across R_E in such a direction, that it forward biases the emitter-base junction. So if the emitter current increases, voltage drop IR_E also increases.

Since the polarity of this voltage reverse biases the emitter-base junction, I_B automatically decrease. Therefore the emitter current increase less than it would have done had there been no self biasing resistor. Resistor values are generally set so that the voltage drop across emitter resistor R_E is approximately 10% of V_{CC} and the current flowing through resistor R_{B1} is 10% of the collector current I_C . This type of transistor biasing configuration works best at relatively low power supply voltages.

Voltage Divider Transistor Biasing



The common emitter transistor is biased using a voltage divider network to increase stability. The name of this biasing configuration comes from the fact that the two resistors R_{B1} and R_{B2} form a voltage or potential divider network with their center point connecting the transistors base terminal directly across the supply. This voltage divider configuration is the most widely used transistor biasing method, as the emitter diode of the transistor is forward biased by the voltage dropped across resistor R_{B2} . Also, voltage divider network biasing makes the transistor circuit independent of changes in beta as the voltages at the transistors base, emitter, and collector are dependent on external circuit values.

To calculate the voltage developed across resistor R_{B2} and therefore the voltage applied to the base terminal we simply use the voltage divider formula for resistors in series Generally the voltage drop across resistor R_{B2} is much less than for resistor R_{B1} . Then clearly the transistors base voltage V_B with respect to ground, will be equal to the voltage across R_{B2} . The current flowing through resistor R_{B2} is generally set at 10 times the value of the required base current I_B so that it has no effect on the voltage divider current or changes in Beta.

The goal of Transistor Biasing is to establish a known Q-point in order for the transistor to work efficiently and produce an undistorted output signal. Correct biasing of the transistor also establishes its initial AC operating region with practical biasing circuits using either a two or four-resistor bias network. In bipolar transistor circuits, the Q-point is represented by (V_{CE} , I_C) for the NPN transistors or (V_{EC} , I_C) for PNP transistors.

The stability of the base bias network and therefore the Q-point is generally assessed by considering the collector current as a function of both Beta (β) and temperature. Here we have looked briefly at five different configurations for "biasing a transistor" using resistive networks. But we can also bias a transistor using either silicon diodes, zener diodes or active networks all connected to the base terminal of the transistor or by biasing the transistor from a dual power supply.

Amplifier Classes

The classification of an amplifier as either a voltage or a power amplifier is made by comparing the characteristics of the input and output signals by measuring the amount of time in relation to the input signal that the current flows in the output circuit.For the transistor to operate within its "Active Region" some form of "Base Biasing" was required. This small Base Bias

voltage added to the input signal allowed the transistor to reproduce the full input waveform at its output with no loss of signal. However, by altering the position of this Base bias voltage, it is possible to operate an amplifier in an amplification mode other than that for full waveform reproduction.

With the introduction to the amplifier of a Base bias voltage, different operating ranges and modes of operation can be obtained which are categorized according to their classification. These various mode of operation are better known as Amplifier Class.Audio power amplifiers are classified in an alphabetical order according to their circuit configurations and mode of operation. Amplifiers are designated by different classes of operation such as class "A", class "B", class "C", class "AB", etc. These different amplifier classes range from a near linear output but with low efficiency to a non-linear output but with a high efficiency.

No one class of operation is "better" or "worse" than any other class with the type of operation being determined by the use of the amplifying circuit. There are typical maximum efficiencies for the various types or class of amplifier, with the most commonly used being:

- 1) Class A Amplifier has low efficiency of less than 40% but good signal reproduction and linearity.
- 2) Class B Amplifier is twice as efficient as class A amplifiers with a maximum theoretical efficiency of about 70% because the amplifying device only conducts (and uses power) for half of the input signal.
- 3) Class AB Amplifier has an efficiency rating between that of Class A and Class B but poorer signal reproduction than class A amplifiers.
- 4) Class C Amplifier is the most inefficient amplifier class as only a very small portion of the input signal is amplified therefore the output signal bears very little resemblance to the input signal. Class C amplifiers have the worst signal reproduction.



Class A Amplifier



To achieve high linearity and gain, the output stage of a class A amplifier is biased "ON" (conducting) all the time. Then for an amplifier to be classified as "Class A" the zero signal idle current in the output stage must be equal to or greater than the maximum load current (usually a loudspeaker) required to produce the largest output signal.As a class A amplifier operates in the linear portion of its characteristic curves, the single output device conducts through a full 360 degrees of the output waveform. Then the class A amplifier is equivalent to a current

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source.Since a class A amplifier operates in the linear region, the transistors base (or gate) DC biasing voltage should by chosen properly to ensure correct operation and low distortion.

However, as the output device is "ON" at all times, it is constantly carrying current, which represents a continuous loss of power in the amplifier. Due to this continuous loss of power class A amplifiers create tremendous amounts of heat adding to their very low efficiency at around 30%, making them impractical for high-power amplifications. Also due to the high idling current of the amplifier, the power supply must be sized accordingly and be well filtered to avoid any amplifier hum and noise. Therefore, due to the low efficiency and over heating problems of Class A amplifiers, more efficient amplifier classes have been developed.

Class B Amplifier

Class B amplifiers were invented as a solution to the efficiency and heating problems associated with the previous class A amplifier. The basic class B amplifier uses two complimentary transistors either bipolar of FET for each half of the waveform with its output stage configured in a "push-pull" type arrangement, so that each transistor device amplifies only half of the output waveform. In the class B amplifier, there is no DC base bias current as its quiescent current is zero, so that the dc power is small and therefore its efficiency is much higher than that of the class A amplifier. However, the price paid for the improvement in the efficiency is in the linearity of the switching device.

Class B Amplifier



When the input signal goes positive, the positive biased transistor conducts while the negative transistor is switched "OFF". Likewise, when the input signal goes negative, the positive transistor switches "OFF" while the negative biased transistor turns "ON" and conducts the negative portion of the signal. Thus the transistor conducts only half of the time, either on positive or negative half cycle of the input signal.

Then we can see that each transistor device of the class B amplifier only conducts through one half or 180 degrees of the output waveform in strict time alternation, but as the output stage has devices for both halves of the signal waveform the two halves are combined together to produce the full linear output waveform.

This push-pull design of amplifier is obviously more efficient than Class A, at about 50%, but the problem with the class B amplifier design is that it can create distortion at the zerocrossing point of the waveform due to the transistors dead band of input base voltages from -0.7V

to +0.7.. Then in a class B amplifier, the output transistor is not "biased" to an "ON" state of operation until this voltage is exceeded. This means that the the part of the waveform which falls within this 0.7 volt window will not be reproduced accurately making the class B amplifier unsuitable for precision audio amplifier applications.

Class AB Amplifier

As its name suggests, the Class AB Amplifier is a combination of the "Class A" and the "Class B" type amplifiers we have looked at above. The AB classification of amplifier is currently one of the most common used types of audio power amplifier design. The class AB amplifier is a variation of a class B amplifier as described above, except that both devices are allowed to conduct at the same time around the waveforms crossover point eliminating the crossover distortion problems of the previous class B amplifier.

The two transistors have a very small bias voltage, typically at 5 to 10% of the quiescent current to bias the transistors just above its cut-off point. Then the conducting device, either bipolar of FET, will be "ON" for more than one half cycle, but much less than one full cycle of the input signal. Therefore, in a class AB amplifier design each of the push-pull transistors is conducting for slightly more than the half cycle of conduction in class B, but much less than the full cycle of conduction of class A.

In other words, the conduction angle of a class AB amplifier is somewhere between 180° and 360° depending upon the chosen bias point as shown. Class AB Amplifier



The advantage of this small bias voltage, provided by series diodes or resistors, is that the crossover distortion created by the class B amplifier characteristics is overcome, without the inefficiencies of the class A amplifier design. So the class AB amplifier is a good compromise between class A and class B in terms of efficiency and linearity, with conversion efficiencies reaching about 50% to 60%.

Class C Amplifier

The Class C Amplifier design has the greatest efficiency but the poorest linearity of the classes of amplifiers mentioned here. The previous classes, A, B and AB are considered linear amplifiers, as the output signals amplitude and phase are linearly related to the input signals

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amplitude and phase. However, the class C amplifier is heavily biased so that the output current is zero for more than one half of an input sinusoidal signal cycle with the transistor idling at its cutoff point. In other words, the conduction angle for the transistor is significantly less than 180 degrees, and is generally around the 90 degrees area.

While this form of transistor biasing gives a much improved efficiency of around 80% to the amplifier, it introduces a very heavy distortion of the output signal. Therefore, class C amplifiers are not suitable for use as audio amplifiers.

Class C Amplifier



Due to its heavy audio distortion, class C amplifiers are commonly used in high frequency sine wave oscillators and certain types of radio frequency amplifiers, where the pulses of current produced at the amplifiers output can be converted to complete sine waves of a particular frequency by the use of LC resonant circuits in its collector circuit.

Due to this continuous loss of power class A amplifiers create tremendous amounts of heat adding to their very low efficiency at around 30%, making them impractical for high-power amplifications. Also due to the high idling current of the amplifier, the power supply must be sized accordingly and be well filtered to avoid any amplifier hum and noise. Therefore, due to the low efficiency and over heating problems of Class A amplifiers, more efficient amplifier classes have been developed.

Common emitter RC coupled amplifier.

The common emitter RC coupled amplifier is one of the simplest and elementary transistor amplifier that can be made. Don't expect much boom from this little circuit, the main purpose of this circuit is pre-amplification i.e to make weak signals strong enough for further processing or amplification. If designed properly, this amplifier can provide excellent signal characteristics. The circuit diagram of a single stage common emitter RC coupled amplifier using transistor is shown below.



RC coupled amplifier

Capacitor Cin is the input DC decoupling capacitor which blocks any DC component if present in the input signal from reaching the Q1 base. If any external DC voltage reaches the base of Q1, it will alter the biasing conditions and affects the performance of the amplifier.R1 and R2 are the biasing resistors. This network provides the transistor O1's base with the necessary bias voltage to drive it into the active region.

The region of operation where the transistor is completely switched of is called cut-off region and the region of operation where the transistor is completely switched ON (like a closed switch) is called saturation region. The region in between cut-off and saturation is called active region. Refer Fig 2 for better understanding. For a transistor amplifier to function properly, it should operate in the active region.

Let us consider this simple situation where there is no biasing for the transistor. As we all know, a silicon transistor requires 0.7 volts for switch ON and surely this 0.7 V will be taken from the input audio signal by the transistor. So all parts of there input wave form with amplitude $\leq 0.7V$ will be absent in the output waveform. In the other hand if the transistor is given with a heavy bias at the base, it will enter into saturation (fully ON) and behaves like a closed switch so that any further change in the base current due to the input audio signal will not cause any change in the output. The voltage across collector and emitter will be 0.2V at this condition (Vce sat = 0.2V). That is why proper biasing is required for the proper operation of a transistor amplifier.



BJT output characteristics

Cout is the output DC decoupling capacitor. It prevents any DC voltage from entering into the succeeding stage from the present stage. If this capacitor is not used the output of the amplifier (Vout) will be clamped by the DC level present at the transistors collector. Rc is the collector resistor and Re is the emitter resistor.

Values of Rc and Re are so selected that 50% of Vcc gets dropped across the collector & emitter of the transistor. This is done to ensure that the operating point is positioned at the center of the load line. 40% of Vcc is dropped across Rc and 10% of Vcc is dropped across Re. A higher voltage drop across Re will reduce the output voltage swing and so it is a common practice to keep the voltage drop across Re = 10%Vcc . Ce is the emitter by-pass capacitor. At zero signal condition (i.e, no input) only the quiescent current (set by the biasing resistors R1 and R2 flows through the Re).

This current is a direct current of magnitude few milli amperes and Ce does nothing. When input signal is applied, the transistor amplifies it and as a result a corresponding alternating current flows through the Re. The job of Ce is to bypass this alternating component of the emitter current. If Ce is not there, the entire emitter current will flow through Re and that causes a large voltage drop across it. This voltage drop gets added to the Vbe of the transistor and the bias settings will be altered. It reality, it is just like giving a heavy negative feedback and so it drastically reduces the gain.



Feedback in Amplifiers

Feedback.

A feedback system is one in which the output signal is sampled and then fed back to the input to form an error signal that drives the system. Feedback is comprised of a sub-circuit that allows a fraction of the output signal from a system to modify the effective input signal in such a way as to produce a response that can differ substantially from the response produced in the absence of such feedback.Feedback.

Systems are very useful and widely used in amplifier circuits, oscillators, process control systems as well as other types of electronic systems. But for feedback to be an effective tool it must be controlled as an uncontrolled system will either oscillate or fail to function. The basic model of a feedback system is given as:



This basic feedback loop of sensing, controlling and actuation is the main concept behind a feedback control system and there are several good reasons why feedback is applied and used in electronic circuits:

- 1) Circuit characteristics such as the systems gain and response can be precisely controlled.
- 2) Circuit characteristics can be made independent of operating conditions such as supply voltages or temperature variations.
- 3) Signal distortion due to the non-linear nature of the components used can be greatly reduced.
- 4) The Frequency Response, Gain and Bandwidth of a circuit or system can be easily controlled to within tight limits.

Whilst there are many different types of control systems, there are just two main types of feedback control namely: Negative Feedback and Positive Feedback.

Positive Feedback Systems

In a "positive feedback control system", the set point and output values are added together by the controller as the feedback is "in-phase" with the input. The effect of positive (or regenerative) feedback is to "increase" the systems gain, ie, the overall gain with positive feedback applied will be greater than the gain without feedback. For example, if someone praises you or gives you positive feedback about something, you feel happy about yourself and are full of energy, you feel more positive.

However, in electronic and control systems to much praise and positive feedback can increase the systems gain far too much which would give rise to oscillatory circuit responses as it increases the magnitude of the effective input signal.

An example of a positive feedback systems could be an electronic amplifier based on an operational amplifier, or op-amp as shown. Positive Feedback System





Positive feedback control of the op-amp is achieved by applying a small part of the output voltage signal at Vout back to the non-inverting (+) input terminal via the feedback resistor, $R_{\rm F}$. If the input voltage Vin is positive, the op-amp amplifies this positive signal and the

output becomes more positive. Some of this output voltage is returned back to the input by the feedback network. Thus the input voltage becomes more positive, causing an even larger output voltage and so on. Eventually the output becomes saturated at its positive supply rail.

Likewise, if the input voltage Vin is negative, the reverse happens and the op-amp saturates at its negative supply rail. Then we can see that positive feedback does not allow the circuit to function as an amplifier as the output voltage quickly saturates to one supply rail or the other, because with positive feedback loops "more leads to more" and "less leads to less". Then if the loop gain is positive for any system the transfer function will be: Av = G / (1 - GH). Note that if GH = 1 the system gain Av = infinity and the circuit will start to self-oscillate, after which no input signal is needed to maintain oscillations, which is useful if you want to make an oscillator.

Although often considered undesirable, this behaviour is used in electronics to obtain a very fast switching response to a condition or signal. One example of the use of positive feedback is hysteresis in which a logic device or system maintains a given state until some input crosses a preset threshold. This type of behaviour is called "bi-stability" and is often associated with logic gates and digital switching devices such as multivibrators.

Negative Feedback Systems

In a "negative feedback control system", the set point and output values are subtracted from each other as the feedback is "out-of-phase" with the original input. The effect of negative (or degenerative) feedback is to "reduce" the gain. For example, if someone criticises you or gives you negative feedback about something, you feel unhappy about yourself and therefore lack energy, you feel less positive.Because negative feedback produces stable circuit responses, improves stability and increases the operating bandwidth of a given system, the majority of all control and feedback systems is degenerative reducing the effects of the gain.An example of a negative feedback system is an electronic amplifier based on an operational amplifier as shown. Negative Feedback System



Negative feedback control of the amplifier is achieved by applying a small part of the output voltage signal at Vout back to the inverting (-) input terminal via the feedback resistor, Rf.If the input voltage Vin is positive, the op-amp amplifies this positive signal, but because its connected to the inverting input of the amplifier, and the output becomes more negative.

Some of this output voltage is returned back to the input by the feedback network of Rf.Thus the input voltage is reduced by the negative feedback signal, causing an even smaller

output voltage and so on. Eventually the output will settle down and become stabilised at a value determined by the gain ratio of $Rf \div Rin.Likewise$, if the input voltage Vin is negative, the reverse happens and the op-amps output becomes positive (inverted) which adds to the negative input signal. Then we can see that negative feedback allows the circuit to function as an amplifier, so long as the output is within the saturation limits.

So we can see that the output voltage is stabilised and controlled by the feedback, because with negative feedback loops "more leads to less" and "less leads to more".

Then if the loop gain is positive for any system the transfer function will be: Av = G / (1 + GH). The use of negative feedback in amplifier and process control systems is widespread because as a rule negative feedback systems are more stable than positive feedback systems, and a negative feedback system is said to be stable if it does not oscillate by itself at any frequency except for a given circuit condition. Another advantage is that negative feedback also makes control systems more immune to random variations in component values and inputs. Of course nothing is for free, so it must be used with caution as negative feedback significantly modifies the operating characteristics of a given system. KARPAGAM ACADEMY OF HIGHER EDUCATION, COIMBATORE-21 DEPARTMENT OF PHYSICS I B.SC PHYSICS Analog Systems and Applications (18PHU202)

UNIT-III

QUESTION	OPTION 1	OPTION 2	OPTION 3	OPTION 4	ANSWER
When	Is	Is	Remains	equal	Is
negative	increased	reduced	the same		reduced
voltage					
feedback					
is applied					
to an					
amplifier,					
its					
voltage					
gain					
The value	<1	>1	0	1	<1
of			-		
negative					
feedback					
fraction					
is always					
10 11 10 10 5					
There	2	3	5	6	2
are	_	-	-	•	_
<i>h</i> p					
arameters					
of a					
transistor					
The <i>h</i> na	Large	Small	Both	no signal	Small
rameter	signals	sionals	small and	no signar	sionals
approach	only	only	large		only
approach	omy	omy	signals		omy
correct			signais		
rogulta					
for					
	Mha	Ohm	Formad	A <i>mm</i> and	Ohm
limonaia	IVIIIO	Unin	гагаа	Ampere	Onm
dimensio					
115 of his ma					
or nie pa					
rameter					
are					

May or stable Also If the Also Do not change operating change change may not point change changes, the h par ameters of transistor If Also Do not Also May or stable temperat change change may not change change ure changes, h parame ters of a transistor transform Resistive А Resistive feedback Capacitiv Inductive er circuit e usually employs network The gain Resonant Open Closed short Closed loop loop of an loop circuit amplifier with feedback is known as gain

Remains equal When Is Is Is voltage increased reduced the same increased feedback (negative is) applied to an amplifier, its input impedanc e When Remains equal Is Is Is current increased reduced the same reduced feedback (negative is) applied to an amplifier, its input impedanc e Negative Oscillator filter Amplifier **Rectifiers Amplifier** feedback s is S S employed in Impedanc Voltage Impedanc Emitter Current resistance e matchin gain e matchin follower gain is used for ... Quiescen with no with no under full along the with no t power is signal load. load. dc load signal the power input. line. input dissipatio n of a transistor

A class B slightly amplifier more operates than 180° in the of the linear input region for cycle.	360° of the input cycle.	slightly less than 180° of the input cycle.	much less than 180° of the input cycle.	slightly less than 180° of the input cycle
In a class a current AB mirror. amplifier, if the V_{BE} drop s are not matched to the diode drops or if the diodes are not in thermal equilibriu m with the transistor s, this can result in	diode separatio n.	crossover distortion	thermal runaway.	thermal runaway
Which class A amplifier is commonl y used as a frequency multiplier 2	class B	class C	Class D	class C

The least c efficient amplifier among all classes is	elass B.	class A.	class AB.	class C.	class B
A class A 3 amplifier has a voltage gain of 30 and a current gain of 25. What is the power gain?	80	25	1.2	750	750
You have c an applicatio n for a power amplifier to operate on FM radio frequenci es. The most likely choice would be a amplifier.	elass A	class B	class C	class AB	class C

A class A 4.4 mA	6.1 mA	16.7 mA	20 mA	4.4 mA
amplifier				
with $R_{\rm C} =$				
3.3 kΩ				
and R_E =				
1.2 kΩ				
has a				
$V_{CC} = 20$				
V. Find				
I _{C(sat)} .				

A class C 0 V. amplifier has a tank circuit in the output. The amplifier is conductin g only 28°. The output voltage is	a dc value equal to V _{CC} .	a sine wave.	a square wave with a frequency determin ed by the tank.	a sine wave.	
In 25 practice, the efficiency of a capacitiv ely coupled class A amplifier	40	70	10	10	
<u> </u>					
The Q- point is at cutoff for class	A	В	С	AB	В
---	----	----	----	----	----
operation					
Class	A	В	С	AB	AB
amplifier s are normally operated in a push- pull configura tion in order to produce an output that is a replica of the input.					
The maximu m efficiency of a class B amplifier is	50	25	70	79	79

A class A	В	С	AB	AB
amplifier is biased slightly above cutoff and operates in the linear region for slightly more than 180° of the input cycle.				
Which A class of amplifier operates in the linear region for only a small part of the input cycle?	В	C	AB	C
Class D 90% operation can achieve power efficiency of over	78.50%	50%	25%	90%

____·

less than 0 less than The beta more 100 to a than 200 200 of 100 100 power transistor is generally A form 90% 78.50% 50% 50% 25% of class А amplifier having maximu m efficiency of _____ uses a transform er to couple the output signal to ${{{\left({{N_1}}/{N_2}} \right)}^2} \quad {{N_1} imes {N_2}} \ {{\left({{N_1}}/{{N_2}} \right)}^{{1/3}}}$ The N_1/N_2 $(N_1/N_2)^2$ reflected impedanc e seen from one side of the transform er to the other side is _____.

neither the dc In a class the ac the dc the ac and dc the ac nor А dc transform ercoupled power amplifier, winding resistance of the transform er determin e(s) the dc load line for the circuit. The slope $-1/R_L$ (lo $1/(a^2R_L) -1/(a^2R_L) 1/R_L$ $-1/(a^2 R_L)$ of the ac ad load line resistor) in the class А transform ercoupled transistor is _____.

The product amount	differenc e	average	sum of	differenc e
of power				
dissipate				
d by the				
transistor				
is the				
of				
that				
drawn				
from the				
dc supply				
(set by				
the bias				
point)				
and the				
amount				
delivered				
to the ac				
load.				
A class A the least	about the	the most	equal	the least
amplifier	same			
dissipates				
power				
when the				
load is				
drawing				
maximu				
m power				
from the				

circuit.

In a class larger,	larger,	smaller,	larger	larger,
A smaller,	smaller,	larger,		smaller,
transform farther	closer	closer		closer
er-				
coupled				
amplifier,				
the				
the value				
of				
V_{CEmax} an				
d the				
the				
value of				
V _{CEmin} ,				
the				
the				
efficiency				
to (from)				
the				
theoretica				
l limit of				
50%.				

In class B a full- operation wave , the current drawn from a single power supply has the form of rectified signal.	a half- wave	both a full-wave and a half wave	diode <u>-</u>	a full- wave
0				

The highest efficiency is obtained in class B operation when the level of $V_L(p)$ is equal to	0.25V _{CC}	0.50V _{CC}	V _{cc}	2V _{CC}	V _{CC}
transistor s can be used to build a class B amplifier.	npn and pnp	nMOS and pMOS	Both npn and pnp or nMOS and pMOS	npn	Both npn and pnp or nMOS and pMOS
The complem entary Darlingto n- connecte d transistor for a class B amplifier provides output current and output resistance	higher, higher	higher, lower	lower, lower	lower, higher	higher, lower

The larger the same smaller larger equal fundame than than than as ntal compone nt is typically any harmonic compone nt. 10db 30db 20 db An 0 db 20db amplifier has а power of gain 100. Its db gain is In order Thin base Thin Wide Thin wide collector collector emitter base to get more voltage gain from а transistor amplifier, the transistor used should have The Increase Protect Pass a.c. Provide Pass a.c. and block biasing and block the the purpose a output of transistor d.c. d.c. coupling impedanc capacitor e of a transistor in transistor amplifier is to

The Avoid Avoid Forward Reduce reverse voltage purpose bias the noise in bias voltage gain drop of emitter gain drop emitter the emitter capacitor amplifier (i.e. capacitor across RE) is to The ratio About 1 Low high moderate moderate of output impedanc e of a CE amplifier is ... If a . About 1 Low high moderate Low transistor amplifier feeds a load of low resistance (e.g. speaker), then voltage gain will be ... If the Biasing Signal no signal Biasing Transisto condition will not condition input capacitor r will be s will s will reach the of a destroyed change change base transistor amplifier is shortcircuited, then... А CE Grounde Grounde signal at amplifier d emitter Grounde d Grounde base collector is also d base d emitter called circuit

The value The equal Less More Less than of same as than than collector load RC in a transistor amplifier is the ... output impedanc e of the transistor. The d.c. The equal Less More More load of a same as than than than transistor amplifier is generally that of a a.c. load In Mica Paper Air Electrolyt transistor Electrolyt amplifier ic ic s, we generally use capacitor s.

The output power of a transistor amplifier is more than the input power because the additiona l power is supplied	Transisto r	Biasing circuit	Collector supply VCC	filter	Collector supply VCC
by A transistor amplifier has high output impedanc e because 	Emitter is heavily doped	Collector has reverse bias	Collector is wider than emitter or base	collector forward bias	Collector has reverse bias
For highest power gain, one would use configura tion	CC	Сь	CE	CBE	CE
RC coupling is used for amplifica tion	Voltage	Current	Power	resistance	Voltage

In an RC Changes Is Changes change Is uniformly with time coupled abruptly constant constant amplifier, with with frequency the frequency voltage gain over midfrequency range An Good High good Economy advantag impedanc Economy efficiency resistance e of RC e coupling matching scheme is the The best RC Direct indirect Direct Transfor frequency response mer is of coupling Transfor Voltage Current Power capacitan Power mer ce coupling is used for amplifica tion In an RC To pass Not to То То Not to coupling d.c. attenuate dissipate dissipate attenuate scheme, between the low high high heat the low the the stages frequenci power frequenci coupling es es capacitor CC must be large enough . . .

The noise factor of an ideal amplifier expressed in db is	0	1	10	20	0
When a multistag e amplifier is to amplify d.c. signal, then one must use	RC	Transfor mer	Direct	indirect	Direct
coupling coupling provides the maximu m voltage gain	RC	Transfor mer	Direct	indirect	Transfor mer
RC coupling is not used to amplify extremely low frequenci es because	There is considera ble power loss	There is hum in the output	Electrical size of coupling capacitor becomes very large	there ia a hum in output	Electrical size of coupling capacitor becomes very large

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UNIT-IV

SYLLABUS

Sinusoidal Oscillators: Barkhausen's Criterion for self-sustained oscillations. RC Phase shift oscillator, determination of Frequency. Hartley & Colpitt oscillators.

Operational Amplifiers (Black Box approach): Characteristics of an Ideal and practical Op-Amp. (IC 741) Open-loop and Closed-loop Gain. Frequency Response. CMRR. Slew Rate and concept of Virtual ground.

An oscillator is an electronic device which generates sinusoidal waves when excited by a DC input supply voltage. There are two types of approaches to generate sine waves.

- 1) Using resonance phenomena (This can be implemented with a separate circuit or using the non linearity of the device itself)
- 2) By appropriately shaping a triangular waveform.

Multivibrator is a circuit which generate non sinusoidal wave forms such as square, triangular, pulse e.t.c.Oscillators are circuits which generates sinusoidal wave forms. Multi vibrators are basic building blocks in function generators and nonlinear oscillators whereas oscillators are basic building blocks in inverters.

Barkhausen criterion

The frequency of oscillation at which sinusoidal oscillator operates is the frequency for which the total shift introduced, as the signal proceeds from the input terminals, through the amplifier and feedback network, and back again to the input, is precisely zero(or an integral multiple of $2^{*}\Pi$).

Stated simply the condition $A^*\beta = -1$ at $\omega = \omega_0$, i.e. the magnitude of loop gain should be one and phase of loop gain should be unity (the feedback network introduces 180^0 phase shift, the other 180^0 phase shift is provided by mixer) is called Barkhausen criterion.

A closed loop system with negative feedback can be represented by a

Transfer function = $A/(1+A*\beta)$.

Often feedback network consists of only resistive elements and is independent of frequency but amplifier gain is a function of frequency. Hence the loop gain $A^*\beta$ is a function of frequency. There may exist a frequency ω_o at which its magnitude is one and phase is 180^0 i.e. $A^*\beta = -1$ (Barkhausen criterion).

At that frequency overall gain of system is very large theoretically infinite. Noise at the input of amplifier consists of all frequencies with negligible amplitudes. For all frequencies other than the oscillator frequencies the amplifier gain will not be enough to elevate them to significant amplitudes. But at that frequency where oscillator oscillates it provides very large gain and the amplitude of corresponding sine wave will be limited by the nonlinearity of the active device. The frequency of oscillation depends mostly on few circuit parameters such as passive elements such

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as resistance, inductance, and capacitance e.t.c. The principle cause of drift of these circuit parameters is temperature. Therefore compensation measures should be taken for balancing temperature induced variations.

Basic Hartley Oscillator Design



When the circuit is oscillating, the voltage at point X (collector), relative to point Y (emitter), is 180° out-of-phase with the voltage at point Z (base) relative to point Y. At the frequency of oscillation, the impedance of the Collector load is resistive and an increase in Base voltage causes a decrease in the Collector voltage. Then there is a 180° phase change in the voltage between the Base and Collector and this along with the original 180° phase shift in the feedback loop provides the correct phase relationship of positive feedback for oscillations to be maintained.

The amount of feedback depends upon the position of the "tapping point" of the inductor. If this is moved nearer to the collector the amount of feedback is increased, but the output taken between the Collector and earth is reduced and vice versa. Resistors, R1 and R2 provide the usual stabilizing DC bias for the transistor in the normal manner while the capacitors act as DC-blocking capacitors. In this Hartley Oscillator circuit, the DC Collector current flows through part of the coil and for this reason the circuit is said to be "Series-fed" with the frequency of oscillation of the Hartley Oscillator being given as.

$$f = \frac{1}{2\pi\sqrt{L_{\rm T}C}}$$

where:
$$L_T = L_1 + L_2 + 2M$$

The frequency of oscillations can be adjusted by varying the "tuning" capacitor, C or by varying the position of the iron-dust core inside the coil (inductive tuning) giving an output over a wide range of frequencies making it very easy to tune. Also the Hartley Oscillator produces an output amplitude which is constant over the entire frequency range.

Basic Colpitts Oscillator Circuit



The emitter terminal of the transistor is effectively connected to the junction of the two capacitors, C1 and C2 which are connected in series and act as a simple voltage divider. When the power supply is firstly applied, capacitors C1 and C2 charge up and then discharge through the coil L. The oscillations across the capacitors are applied to the base-emitter junction and appear in the amplified at the collector output.Resistors, R1 and R2 provide the usual stabilizing DC bias for the transistor in the normal manner while the additional capacitors act as a DC-blocking bypass capacitors.

A radio-frequency choke (RFC) is used in the collector circuit to provide a high reactance (ideally open circuit) at the frequency of oscillation, (fr) and a low resistance at DC to help start the oscillations. The required external phase shift is obtained in a similar manner to that in the Hartley oscillator circuit with the required positive feedback obtained for sustained undamped oscillations. The amount of feedback is determined by the ratio of C1 and C2. These two capacitances are generally "ganged" together to provide a constant amount of feedback so that as one is adjusted the other automatically follows. The frequency of oscillations for a Colpitts oscillator is determined by the resonant frequency of the LC tank circuit and is given as:

$$f_{\rm T} = \frac{1}{2\pi\sqrt{\rm L\,C_{\rm T}}}$$

where C_T is the capacitance of C1 and C2 connected in series and is given as:

$$\frac{1}{C_{T}} = \frac{1}{C_{1}} + \frac{1}{C_{2}} \quad \text{or} \quad C_{T} = \frac{C_{1} \times C_{2}}{C_{1} + C_{2}}$$

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The configuration of the transistor amplifier is of a Ce amplifier with the output signal 180° out of phase with regards to the input signal. The additional 180° phase shift require for oscillation is achieved by the fact that the two capacitors are connected together in series but in parallel with the inductive coil resulting in overall phase shift of the circuit being zero or 360° . The amount of feedback depends on the values of C1 and C2. We can see that the voltage across C1 is the the same as the oscillators output voltage, Vout and that the voltage across C2 is the oscillators feedback voltage. Then the voltage across C1 will be much greater than that across C2.

Therefore, by changing the values of capacitors, C1 and C2 we can adjust the amount of feedback voltage returned to the tank circuit. However, large amounts of feedback may cause the output sine wave to become distorted, while small amounts of feedback may not allow the circuit to oscillate. Then the amount of feedback developed by the Colpitts oscillator is based on the capacitance ratio of C1 and C2 and is what governs the the excitation of the oscillator. This ratio is called the "feedback fraction" and is given simply as:

Feedback Fraction =
$$\frac{C_1}{C_2}$$
%

Operational Amplifiers

Opamp is a short form of operational amplifier which is capable of performing mathematical operations and signal conditioning(opamp is the heart of Instrumentation amplifier which is the front end signal conditioner of all data acquisition systems). Opamp is a DC coupled amplifier which amplifies even DC signals. Signetics µa741 series Opamp is one of the most successful opamp series. If input is given to inverting terminal with non inverting terminal grounded output will be exactly 180 degrees out of phase with input, hence the name inverting terminal. Similarly if input is given to Non inverting terminal with inverting terminal grounded, output will be exactly in phase with input. Above arguments are true provided they are no storage elements in the circuit with opamp.

Differential amplifier stage: Differential amplifier stage provides the following main functions:

(1)**High input impedance**: Generally differential amplifier stage is employed with constant current source in the emitter circuit; this ensures irrespective of input voltage fluctuations emitter current remains constant and provides high resistance to any fluctuations in the collector current(alternatively you can thought of a transistor biased at some quiescent point now if input voltage at base changes small signal input resistance is given by Δ Vbe/ Δ Ib where Δ Ib is approximately zero as we have biased emitter current at a fixed current dictated by constant current source so input resistance will be very high). Even multiple differential stages are employed.

(2)**High Common Mode Rejection Ratio**: This is one of most desirable future essential to filter out the noise (noise will be common to both input terminals). By employing high resistance in the emitter circuit as CMMR is inversely related to emitter circuit resistance (constant current source provides high resistance when connected in series) and by carefully matching the transistors(very

difficult even with highly advanced technology) high CMMRs can be achieved. After rejecting a lot of noise in the input signal is amplified in the next stage.

a) Gain stages: This intermediate stage will be provided with number of gain modules which are responsible for high gain of opamp. These modules are generally common emitter stages .Often level shifter module is also used to force the output voltage to ground potential i.e reference ground.

b) Output stage: This is generally a push pull amplifier (Power amplifier stage to drive more current or in turn more power) or common collector stage (which acts as buffer) which provides unit voltage gain with very low output resistance and high current gain. Ideal Opamp characteristics

Ideal operational amplifier are characterized by

- 1) Infinite gain
- 2) Infinite input resistance
- 3) Zero output resistance (order of 10's of ohms)
- 4) Infinite bandwidth (practically restricted by slew rate)
- 5) Linear irrespective of entire analog signal range No offsets and, so on
- 6)

A real Opamp exhibits imperfections from ideal characteristics of an opamp due to practical limitations such as improper matching of transistors in differential stages, due to bulk and parasitic capacitance's e.t.c. Some of dc error voltages, currents and bandwidth limitations of an opamp are as follow

Slew rate of opamp

It is the maximum rate at which output can change in an opamp. It is one of the major limitations in an opamp. It is expressed in volt/second. The output gets distorted if the rate at which output changes exceeds slew rate.

CMRR

CMRR is acronym for Common Mode Rejection Ration which is used to quantify how good a differential amplifier is. Let V1=V1d+Vn and V2=V2d+Vn where differential input signal is Vd = V1d-V2d and Vn is the common input signal. The output of differential amplifier will be of the form Vo = Ad*(Vd) +Ac*Vn, then the Common Mode Rejection Ratio of an differential amplifier is defined as the

Where Ad is differential mode signal gain and Ac is common mode signal gain.

741 Opamp Pin configuration

The pin configuration of opamp is as follows

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Where pins 1 and 5showing Offset Null's along with potentiometer arrangement are used to nullify offset voltages. Positive offsets are nullified with pin 1 and negative offsets are nullified using pin 5.+Vcc and -Vcc are positive and negative supply voltages respectively generally within a range of + or $_12$ to + or $_24$. Pins 2 and 3 are inverting and non inverting input terminals respectively. Maximum differential input voltages will be specified in datasheets which should be exceeded, Opamp may get damaged due to high power dissipation. Pin 6 is single ended output terminal from which output will be taken.

Virtual ground

As the name indicates it is virtual, not real ground. For some purposes we can consider it as equivalent to ground. In opamps the term virtual ground means that the voltage at that particular node is almost equal to ground voltage (0V). It is not physically connected to ground. This concept is very useful in analysis of <u>opamp</u> circuits and it will make a lot of calculations very simple.





As gain is infinite, Vin = 0

- 1) Vin = V2 V1
- 2) In the above circuit V1 is connected to ground, so V1 = 0. Thus V2 also will be at ground potential.
- 3) V2 = 0.

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QUESTI	OPTION	OPTION	OPTION	OPTION	ANSWE
ONS	1	2	3	4	R

An	ideal	Unity	Zero	Infinite	Infinite	Infinite
oper	ation	open loop	input	output	bandwidt	bandwidt
al		gain	impedanc	impedanc	h	h
amp	lifier		e	e		
has_	<u> </u>					

The gain of an operation al	Decrease s	Increases	Zero	Infinite	Decrease s
amplifier					
at					
high					
frequenci					
es					
because					
of					
capacitan					
ces					
within					
operation					
al					
amplifier					
An operation al amplifier can amplify_	Only AC	Only DC	AC and DC	Any current	AC and DC

The two Positive Differenti Inverting High & Inverting al & Non & Non & Non input & low terminals Negative differenti inverting inverting of an al operation al amplifier are known as The Inverting Non Differenti Summing Differenti Inverting al operation al al amplifier input is a amplifier The gain 1,000 10,000 1,00,000 10,00,00 10,00,00 of 0 0 an actual operation al amplifier is around IC 741 is Frequenc Amplitud Time Pulse Frequenc compens Compens e y y operation compens compens ated ated compens al ated ated ated amplifier IC 741 15mV 10 mV 12 mV 14 mV 15mV offset Voltage adjustme nt range is Common CMRR Common Common Collector Collector stands for Modulati Mode Mode Mode Mode Rejection Rejection Resictor Rejection on **Rejection Ratio** Ratio Ratio Ratio Ratio

The 13V 12V 14V 10V 13V range of the input commonmode voltage is Output 60 Ohm 50 Ohm 75 Ohm 80 Ohm 75 Ohm Resistanc e of IC 741____ **PSRR** Power Pulse Power Power Power Signal Stands Sector Supply Supply Supply Resistanc Rejetion Resictor Rejection Rejection for Ratio e Range Ratio Ratio Ratio CMRR is 100dB 90dB 75dB 60dB 90dB typically d В Built in 10 mA 50mA 25mA 100mA 25mA short circuit protectio n is guarantee d to withstand of current Supply 1.5 2.8 3.17 5.2 2.8 current in IC 741 is m А Power 85mW 75mW 50mW 100mW 85mW consumpt ion in operation al amplifier is_____

The slew rate of operation al amplifier	Zero	5V/uS	1.5V/uS	0.5V/uS	0.5V/uS
The small voltage applied at the input terminals to make output voltage zero is called	Input bias current	Thermal drift	Input offset voltage	Input offset current	Input offset voltage
The total number of Inputs in IC741	1	2	3	4	2
The power supply voltage to op-amp may ranges from	5v to 12v	5v to 22v	9v to 12v	5v to 30v	5v to 22v
In operation al amplifier pin 2 is called	Power supply terminal	Inverting input terminal	Non inverting input terminal	Output treminal	Inverting input terminal

_

In operation al amplifier pin 3 is called	Power supply terminal	Inverting input terminal	Non inverting input terminal	Output treminal	Non inverting input terminal
In operation al amplifier pin 6 is called	Power supply terminal	Inverting input terminal	Non inverting input terminal	Output treminal	Output treminal
In operation al amplifier pin 7 and 4 are connecte d to	Power supply terminal	Inverting input terminal	Non inverting input terminal	Output treminal	Power supply terminal
In operation al amplifier pin 1 and 5 are used for	dc offset	ac offset	Connect with AFO	Connect with power supply	dc offset
Operatio nal amplifier have basic	Two	Three	eight	one	eight

terminals

Operatio High Infinite Low Zero Zero nal amplifier have out put impedanc e Operatio Infinite Zero High Infinite Low nal amplifier have ope loop n voltage gain Operatio Current Voltage Amplifier Converto Voltage nal r amplifier is а voltage controlle d source Single widely The Multi Duel Multi operation al amplifier is а terminal device The 0*C to 70*c to 0*C to >100*c <0*c operating 70*c 70*c 100*c temperat ure range of IC 741 is___

An ideal Vol op-amp has no current from source and its response is independ ent of	tage Noise	Current	Temperat ure	Temperat
An op- 70d amp with open loop gain of 90dB with dc signal has gain oft hrough audio and radio frequenci	B 80dB	90dB	100dB	90dB
es The rate I/C of which the voltage across the capacitor in operation al amplifier is given by	C/I	V/I	I/V	I/C

The input offset voltage is measured is	V	KV	mV	uV	mV
The common mode rejection ratio is measured in	V	mV	dB	uV	dB
The unit of slew rate is	mV/sec	dB	V/uS	uV/Sec	V/uS
Op-amp IC 741 has a	Low	High	Moderate	Unity	Low
slew rate The open- loop gain of the op- amp decreases at the rate of	(-10)dB decade	(-20)dB decade	(-30)dB decade	(-40)dB decade	(-20)dB decade
. An oscillator produces oscillatio	Damped	Undampe d	Modulate d	unmodul ated	Undampe d
An oscillator employs feedback	Positive	Negative	Neither positive nor negative	Data insufficie nt	Positive

Hartley oscillator is commonl y used in	Radio receivers	Radio transmitt ers	TV receivers	transmitt ers	Radio receivers
In a phase shift oscillator, we use RC sections	1	23	2	3	3
In a phase shift oscillator, the frequency determini ng elements are	L and C	R, L and C	R and C	R and L	R and C
An oscillator differs from an amplifier because it	Has more gain	Requires no input signal	Requires no d.c. supply	Always has the same input	Requires no input signal
One condition for oscillatio n is	A phase shift around the feedback loop of 1800	A gain around the feedback loop of one-third	A phase shift around the feedback loop of 00	A gain around the feedback loop of less than 1	A phase shift around the feedback loop of 00

A second condition for oscillatio ns is	A gain of 1 around the feedback loop	No gain around the feedback loop	The attention of the feedback circuit must be one-third	The feedback circuit must be capacitiv e	A gain of 1 around the feedback loop
For an oscillator to properly start, the gain around the feedback loop must initially be	1	>1	<1	0	>1
In Colpitt's oscillator, feedback is obtained 	By magnetic induction	By a tickler coil	. From the centre of split capacitor s	by self induction	From the centre of split capacitor s
is a fixed frequency oscillator	Phase- shift oscillator	Hartely- oscillator	Colpitt's oscillator	Crystal oscillator	Crystal oscillator
An oscillator converts 	dc. power into d.c. power	.d c. power into a.c. power	mechanic al power into a.c. power	ac to ac	.d c. power into a.c. power

In an LC transistor oscillator, the active device is 	LC tank circuit	Biasing circuit	Transisto r	transform er	Transisto r
In an LC circuit, when the capacitor is maximu m, the inductor energy is	Minimu m	Maximu m	Half-way between maximu m and minimum	moderate	Minimu m
In an LC oscillator, the frequency of oscillator is L	Proportio nal to square of	Directly proportio nal to	Independ ent of the values of	Inversely proportio nal to square root of	Inversely proportio nal to square root of
or C. An LC oscillator cannot be used to produce frequenci es	High	Audio	Very low	Very high	Very low

It has It is It has Quartz It is very crystal is superior easily quite costly superior electrical available inexpensi electrical most commonl propertie propertie ve y used in s S crystal oscillator S because Wien-The Wien-Hartely Crystal Phase signal bridge shift bridge generator generally used in the laboratori is es oscillator Its low An Its low Its high Its high Less important output availabili output Q output limitation ty of of quartz a crystal crystal oscillator is ... In an LC Decrease Increased Decrease oscillator, Increased d 4 time 4 times d 2 times Decrease the 2 times d 2 times if value of L is increased four times, the frequency of oscillatio ns is

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<u>UNIT-V</u>

SYLLABUS

Applications of Op-Amps: Inverting and non-inverting amplifiers, Adder, Subtractor, Differentiator, Integrator, Log amplifier, Zero crossing detector, Wein bridge oscillator. **Conversion:** Resistive network (Weighted and R-2R Ladder). Accuracy and Resolution. A/D Conversion (successive approximation)

Inverting amplifier

Definition

Inverting amplifier is one in which the output is exactly 180° out of phase with respect to input(i.e. if you apply a positive voltage, output will be negative). Output is an inverted(in terms of phase) amplified version of input.

Circuit operation



Applying KCL at inverting node we get

$$(0-V_i)/R_i+(0-V_o)/R_f=0$$

By rearranging the terms we will get

Voltage gain
$$A_v = V_o/V_i = -R_f/R_i$$
.

<u>Gain</u>

Gain of inverting amplifier $A_v = -R_f/R_i$.

Non Inverting amplifier

Definition

Non Inverting amplifier is one in which the output is in phase with respect to input(i.e. if you apply a positive voltage, output will be positive). Output is an Non inverted(in terms of phase) amplified version of input.

Circuit operation

The inverting amplifier using opamp is shown in the figure below



Assuming the opamp is ideal and applying the concept of virtual short, the voltage at the inverting terminal is equal to non inverting terminal. Applying KCL at inverting node we get

$$(V_i - V_o)/R_2 + (V_o - 0)/R_1 = 0$$

By rearranging the terms we will get

Voltage gain $A_v = V_o/V_i = (1 + R_f/R_i)$

Gain

Gain of non inverting amplifier $A_v = (1 + R_f/R_i)$.

Op-amp Integrator Circuit



As its name implies, the **Op-amp Integrator** is an operational amplifier circuit that performs the mathematical operation of **Integration**, that is we can cause the output to respond to changes in the input voltage over time as the op-amp integrator produces an output voltage which is proportional to the integral of the input voltage.

In other words the magnitude of the output signal is determined by the length of time a voltage is present at its input as the current through the feedback loop charges or discharges the capacitor as the required negative feedback occurs through the capacitor.

When a step voltage, Vin is firstly applied to the input of an integrating amplifier, the uncharged capacitor C has very little resistance and acts a bit like a short circuit allowing maximum current to flow via the input resistor, Rin as potential difference exists between the two plates. No current flows into the amplifiers input and point X is a virtual earth resulting in zero output. As the impedance of the capacitor at this point is very low, the gain ratio of Xc/Rin is also very small giving an overall voltage gain of less than one, (voltage follower circuit).

As the feedback capacitor, C begins to charge up due to the influence of the input voltage, its impedance Xc slowly increase in proportion to its rate of charge. The capacitor charges up at a rate determined by the RC time constant, (τ) of the series RC network. Negative feedback forces the op-amp to produce an output voltage that maintains a virtual earth at the op-amp's inverting input.

Since the capacitor is connected between the op-amp's inverting input (which is at earth potential) and the op-amp's output (which is negative), the potential voltage, Vc developed across the capacitor slowly increases causing the charging current to decrease as the impedance of the capacitor increases. This results in the ratio of Xc/Rin increasing producing a linearly increasing ramp output voltage that continues to increase until the capacitor is fully charged.

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Op-amp Differentiator Circuit



The input signal to the differentiator is applied to the capacitor. The capacitor blocks any DC content so there is no current flow to the amplifier summing point, X resulting in zero output voltage. The capacitor only allows AC type input voltage changes to pass through and whose frequency is dependent on the rate of change of the input signal.

At low frequencies the reactance of the capacitor is "High" resulting in a low gain (Rf/Xc) and low output voltage from the op-amp. At higher frequencies the reactance of the capacitor is much lower resulting in a higher gain and higher output voltage from the differentiator amplifier.

However, at high frequencies an op-amp differentiator circuit becomes unstable and will start to oscillate. This is due mainly to the first-order effect, which determines the frequency response of the op-amp circuit causing a second-order response which, at high frequencies gives an output voltage far higher than what would be expected. To avoid this the high frequency gain of the circuit needs to be reduced by adding an additional small value capacitor across the feedback resistor Rf.

Since the node voltage of the operational amplifier at its inverting input terminal is zero, the current, i flowing through the capacitor will be given as:

$$I_{IN} = I_F$$
 and $I_F = -\frac{V_{OUT}}{R_F}$

The charge on the capacitor equals Capacitance x Voltage across the capacitor

$$Q = C \times V_{IN}$$

The rate of change of this charge is:

$$\frac{\mathrm{dQ}}{\mathrm{dt}} = \mathrm{C} \, \frac{\mathrm{dV}_{\mathrm{IN}}}{\mathrm{dt}}$$

but dQ/dt is the capacitor current,i

$$I_{IN} = C \frac{dV_{IN}}{dt} = I_F$$
$$\therefore -\frac{V_{OUT}}{R_F} = C \frac{dV_{IN}}{dt}$$

from which we have an ideal voltage output for the op-amp differentiator is given as:

$$V_{OUT} = -R_F C \frac{dV_{IN}}{dt}$$

Therefore, the output voltage Vout is a constant -Rf.C times the derivative of the input voltage Vin with respect to time. The minus sign indicates a 180° phase shift because the input signal is connected to the inverting input terminal of the operational amplifier.

One final point to mention, the **Op-amp Differentiator** circuit in its basic form has two main disadvantages compared to the previous operational amplifier integrator circuit. One is that it suffers from instability at high frequencies as mentioned above, and the other is that the capacitive input makes it very susceptible to random noise signals and any noise or harmonics present in the source circuit will be amplified more than the input signal itself. This is because the output is proportional to the slope of the input voltage so some means of limiting the bandwidth in order to achieve closed-loop stability is required.

Op-amp Differentiator Waveforms

If we apply a constantly changing signal such as a Square-wave, Triangular or Sine-wave type signal to the input of a differentiator amplifier circuit the resultant output signal will be changed and whose final shape is dependent upon the RC time constant of the Resistor/Capacitor combination.


Summing Amplifier Circuit



In this simple summing amplifier circuit, the output voltage, (Vout) now becomes proportional to the sum of the input voltages, V1, V2, V3, etc. Then we can modify the original equation for the inverting amplifier to take account of these new inputs thus:

$$I_F = I_1 + I_2 + I_3 = -\left\lfloor \frac{V1}{Rin} + \frac{V2}{Rin} + \frac{V3}{Rin} \right\rfloor$$

_

Inverting Equation: Vout =
$$-\frac{Rf}{Rin} \times Vin$$

then, -Vout =
$$\left[\frac{R_F}{Rin}V1 + \frac{R_F}{Rin}V2 + \frac{R_F}{Rin}V3\right]$$

However, if all the input impedances, (Rin) are equal in value, we can simplify the above equation to give an output voltage of:

Summing Amplifier Equation

-Vout =
$$\frac{R_F}{R_{IN}} (V1 + V2 + V3....etc)$$

We now have an operational amplifier circuit that will amplify each individual input voltage and produce an output voltage signal that is proportional to the algebraic "SUM" of the three individual input voltages V_1 , V_2 and V_3 . We can also add more inputs if required as each individual input "see's" their respective resistance, Rin as the only input impedance.

This is because the input signals are effectively isolated from each other by the "virtual earth" node at the inverting input of the op-amp. A direct voltage addition can also be obtained when all the resistances are of equal value and Rf is equal to Rin.

A Scaling Summing Amplifier can be made if the individual input resistors are "NOT" equal.

Then the equation would have to be modified to:

$$-\text{Vout} = \text{V1}\left(\frac{\text{Rf}}{\text{R1}}\right) + \text{V2}\left(\frac{\text{Rf}}{\text{R2}}\right) + \text{V3}\left(\frac{\text{Rf}}{\text{R3}}\right) \dots \text{etc}$$

To make the math's a little easier, we can rearrange the above formula to make the feedback resistor R_F the subject of the equation giving the output voltage as:

-Vout =
$$\operatorname{Rf}\left(\frac{\operatorname{V1}}{\operatorname{R1}} + \frac{\operatorname{V2}}{\operatorname{R2}} + \frac{\operatorname{V3}}{\operatorname{R3}}\right) \dots \operatorname{etc}$$

This allows the output voltage to be easily calculated if more input resistors are connected to the amplifiers inverting input terminal. The input impedance of each individual channel is the value of their respective input resistors, ie, $R_1, R_2, R_3 \dots$ etc.

Differential Amplifier



By connecting each input in turn to 0v ground we can use superposition to solve for the output voltage Vout.

$$I_1 = \frac{V_1 - V_a}{R_1}, \quad I_2 = \frac{V_2 - V_b}{R_2}, \quad I_f = \frac{V_a - (V_{out})}{R_3}$$

Summing point $V_a = V_b$

and
$$V_b = V_2 \left(\frac{R_4}{R_2 + R_4} \right)$$

If
$$V_2 = 0$$
, then: $V_{out(a)} = -V_1 \left(\frac{R_3}{R_1}\right)$

If
$$V_1 = 0$$
, then: $V_{out(b)} = V_2 \left(\frac{R_4}{R_2 + R_4}\right) \left(\frac{R_1 + R_3}{R_1}\right)$

$$V_{\text{out}} \, = \, - V_{\text{out}(a)} \, + \, V_{\text{out}(b)}$$

$$\therefore V_{\text{out}} = -V_1 \left(\frac{R_3}{R_1}\right) + V_2 \left(\frac{R_4}{R_2 + R_4}\right) \left(\frac{R_1 + R_3}{R_1}\right)$$

When resistors, R1 = R2 and R3 = R4 the above transfer function for the differential amplifier can be simplified to the following expression:

Differential Amplifier Equation

$$\mathbf{V}_{\text{OUT}} = \frac{\mathbf{R}_3}{\mathbf{R}_1} \left(\mathbf{V}_2 - \mathbf{V}_1 \right)$$

If all the resistors are all of the same ohmic value, that is: R1 = R2 = R3 = R4 then the circuit will become a **Unity Gain Differential Amplifier** and the voltage gain of the amplifier will be exactly one or unity. Then the output expression would simply be Vout = V2 – V1. Also note that if inputV1 is higher than input V2 the output voltage sum will be negative, and ifV2 is higher than V1, the output voltage sum will be positive.

Wien Bridge Oscillator



The output of the operational amplifier is fed back to both the inputs of the amplifier. One part of the feedback signal is connected to the inverting input terminal (negative feedback) via the resistor divider network of R1 and R2 which allows the amplifiers voltage gain to be adjusted within narrow limits. The other part is fed back to the non-inverting input terminal (positive feedback) via the RC Wien Bridge network.

The RC network is connected in the positive feedback path of the amplifier and has zero phase shift a just one frequency. Then at the selected resonant frequency, (fr) the voltages applied to the inverting and non-inverting inputs will be equal and "in-phase" so the positive feedback will cancel out the negative feedback signal causing the circuit to oscillate.

The voltage gain of the amplifier circuit MUST be equal too or greater than three "Gain = 3" for oscillations to start because as we have seen above, the input is 1/3 of the output. This value, (Av ≥ 3) is set by the feedback resistor network, R1 and R2 and for a non-inverting amplifier this is given as the ratio 1+(R1/R2).

Also, due to the open-loop gain limitations of operational amplifiers, frequencies above 1MHz are unachievable without the use of special high frequency op-amps.

Wien Bridge Oscillator Frequency

$$f_{\rm r} = \frac{1}{2\pi\,{
m RC}}$$

Where:

- 1) fr is the Resonant Frequency in Hertz
- 2) R is the Resistance in Ohms
- 3) C is the Capacitance in Farads

Op amp zero crossing detector

Definition

In opamp zero crossing detectors the output responds almost discontinuously every time the input passes through zero. It consists of a comparator circuit followed by differentiator and diode arrangement.

Circuit operation

The circuit of zero crossing detector is shown in the figure below



Since the opamp is in open loop configuration $V_o = A_v^*(V_i - 0)$ the output of opamp i.e. V_o will be at Positive saturation voltage $+V_{cc}$ when ever $V_i > 0$ V and is at negative saturation voltage $-V_{cc}$ when $V_i < 0$ V. whenever the output of opamp transits from $+V_{cc}$ to $-V_{cc}$ the capacitor C charges to $+V_{cc}$ if the output of opamp changes from $-V_{cc}$ to $+V_{cc}$ and it discharges

through R to $-V_{cc}$ if the output of opamp changes from $-V_{cc}$ to $+V_{cc}$. The differentiator circuit(combination of capacitor and resistor) provides an output V' = R*C*dV_o/dt consisting of peaks at times where the square wave crosses zero voltage. The diode is kept to filter off the zero crossings where input voltage crosses zero voltage in rising fashion.

Digital to Analogue Converters (DAC)

1) A Binary Weighted Ladder:



Starting from V_1 and going through V_3 , this would give each input voltage exactly half the effect on the output as the voltage before it. In other words, input voltage V_1 has a 1:1 effect on the output voltage (gain of 1), while input voltage V_2 has half that much effect on the output (a gain of 1/2), and V_3 half of that (a gain of 1/4). These ratios are the same ratios corresponding to position weights in the binary system. If we drive the inputs of this circuit with digital gates so that each input is either 0 volts or full supply voltage, the output voltage will be an analog representation of the binary value of these three bits.

2) A R-2R Ladder:



A 4-bit R-2R Ladder DAC

The basic theory of the R-2R ladder network is that current flowing through any input resistor (2R) encounters two possible paths at the far end. The effective resistances of both paths are the same (also 2R), so the incoming current splits equally along both paths. The half-current that flows back towards lower orders of magnitude does not reach the op amp, and therefore has no effect on the output voltage. The half that takes the path towards the op amp along the ladder can affect the output. The inverting input of the op-amp is at virtual earth. Current flowing in the network is therefore unaffected by switch elements of the ladder positions. If we label the bits (or inputs) bit 1 to bit N the output voltage caused by connecting a particular with all grounded is: Vout bit to Vr other bits = Vr/2Nwhere N is the bit number. For bit 1, Vout =Vr/2, for bit 2, Vout = Vr/4 etc. Since an R/2R ladder is a linear circuit, we can apply the principle of superposition to calculate Vout. The expected output voltage is calculated by summing the effect of all bits connected to An R/2R ladder of 4 bits would have a full-scale output voltage of 1/2 + 1/4 + 1/8 + 1/16 = 15Vr/16 or 0.9375 volts (if Vr=1 volt) while a 10bit R/2R ladder would have a full-scale output voltage of 0.99902 (if Vr=1 volt).

Performance Characteristics of DAC

The performance characteristics of a DAC include resolution, accuracy, linearity, monotonicity, and settling time:

• Resolution.

The resolution of a DAC is the reciprocal of the number of discrete steps in the output. This, of course, is dependent on the number of input bits. For example, a 4-bit DAC has a resolution of one part in 2" - 1 (one part in fifteen).Expressed as a percentage, this is (1/15)100 = 6.67%. The total number of discrete steps equals 2" - 1, where *n* is the number of bits. Resolution can also be expressed as the number of bits that are converted.

• Accuracy.

Accuracy is a comparison of the actual output of a DAC with the expected output. It is expressed as a percentage of a full-scale, or maximum, output voltage. For example, if a converter has a full-scale output of 10V and the accuracy is ± 0.1 %, then the maximum error for any output voltage is (10 V)(0.001) =10 rnV. Ideally, the accuracy should be, at most, $\pm 1/2$ of an LSB. For an 8-bit converter, 1 LSB is 1/256 = 0.0039 (0.39% of full scale). The accuracy should be approximately $\pm 0.2\%$,

• Linearity.

A linear error is a deviation from the ideal straight-line output of a DAC. A special case is an offset error, which is the amount of output voltage when the input bits are all zeros.

• Monotonicity.

A DAC is monotonic if it does not take any reverse steps when it is sequenced over its **entire** range of input bits.

• Settling time.

Settling time is normally defined as the time it takes a DAC to settle within $\pm \frac{1}{2}$ LSB of its final value when a change occurs in the input code.

Successive Approximation Type Analog to Digital Converter:

A successive approximation A/D converter consists of a comparator, a successive approximation register (SAR), output latches, and a D/A converter. The circuit diagram is shown below



Successive Approximation Type Analog to Digital Converter

The main part of the circuit is the 8-bit SAR, whose output is given to an 8-bit D/A converter. The analog output V_a of the D/A converter is then compared to an analog signal V_{in} by the comparator. The output of the comparator is a serial data input to the SAR. Till the digital

output (8 bits) of the SAR is equivalent to the analog input V_{in} , the SAR adjusts itself. The 8-bit latch at the end of conversation holds onto the resultant digital data output.

Working

At the start of a conversion cycle, the SAR is reset by making the start signal (S) high. The MSB of the SAR (Q7) is set as soon as the first transition from LOW to HIGH is introduced. The output is given to the D/A converter which produces an analog equivalent of the MSB and is compared with the analog input V_{in} . If comparator output is LOW, D/A output will be greater than V_{in} and the MSB will be cleared by the SAR.

If comparator output is HIGH, D/A output will be less than V_{in} and the MSB will be set to the next position (Q7 to Q6) by the SAR. According to the comparator output, the SAR will either keep or reset the Q6 bit. This process goes on until all the bits are tried. After Q0 is tried, the SAR makes the conversion complete (CC) signal HIGH to show that the parallel output lines contain valid data. The CC signal in turn enables the latch, and digital data appear at the output of the latch. As the SAR determines each bit, digital data is also available serially. As shown in the figure above, the CC signal is connected to the start conversion input in order to convert the cycle continuously.The biggest advantage of such a circuit is its high speed. It may be more complex than an A/D converter, but it offers better resolution.

KARPAGAM ACADEMY OF HIGHER EDUCATION,COIMBATORE-21 DEPARTMENT OF PHYSICS SC PHYSICS Analog Systems and Applications (17PHU202)

UNIT-V

QUESTI ONS	OPTION 1	OPTION 2	OPTION 3	OPTION 4	ANSWE R
The is_a miniature	Integrate d Resistor	Integrate d Capacitor	Integrate d Circuit	Integrate d Inductor	Integrate d Circuit
, low cost electronic circuit consistin					
g of active and passive					
compone nts that are joined					
on a single crystal chip.					
GSI stands for	Giant Scale Integratio n	Gun Scale Integratio n	Greater Scale Integratio n	Geometri c Scale Integratio n	Giant Scale Integratio n
A small single crystal rod of silicon is	Ingot	wafer	plasma	seed crystal	seed crystal

called

Commun Compute Electroni industrial The industrial Instrume ication c circuits and and r ntation based applicatio consumer consumer applicatio applicatio amplifier circuits ns is used ns ns in Comparat Encoder Peak The Clipper Peak function or detector detector of а is used to compare the peak values of the input Derivativ NonDeri Multiplie Derivativ In Equal differenti vative e r e ator the output wavefor m is the of input wavefor m we Integrate Summing Non-Integrate If Inverting interchan d inverting d ge the resistor and capacitor of the differenti ator the circuit is

V-I I-V V-I Peak Comparat Α is used convertor converter detector convertor or for low voltage dc and ac volt meter, LED and zener diode tester The Window Zero Peak Level Zero reference detector crossing detector detector crossing voltage is detector detector set to zero in The other Triangula Sine Square Square Sine name of r wave to wave to wave to wave to wave to zero square square triangular sine wave square crossing wave wave wave generator wave detector generator generator generator generator is The sine Window Zero Peak Level Zero wave to detector crossing detector detector crossing square detector detector wave generator is other wise known

as____

The type Zero of circuit cross in which dete unknown input is marked between 2 threshold levels is known as	b Level sing detector	Peak detector	Window detector	Window detector
The Sine output of way schmitt trigger circuit is	e Square ve wave	Triangula r	saw tooth wave	Square wave
Hysteresi Pha s in met schmitt tigger is also known as	se Timer er	Backlash	Regenara tive	Backlash
Backlash Pha refers to met	se Timer er	Regenara tive	Hysteresi s	Hysteresi s
non In astable Bist multivibr ator,both the states are state	able Monosta ble	Quasi stable	Tri stable	Quasi stable

A is a circuit which compares a signal voltage applied at one input of an op- amp with known reference voltage.	Rectifier	amplifier	Op-amp	Comparat or	Comparat or
The smallest amount of differenc e in voltage required at the inputs of comparat or to make the output change its state is known as	Response time	Threshol d	Accuracy	Resolutio n	Accuracy
Which converter s uses integratin g op-amp	Parallel A/D	Single slope A/D	Dual slop A/D	triple A/D	Dual slop A/D

A differenti al amplifier	is a part of an Op- amp	has one input and one output	has two outputs	is a part of an Op- amp& has one input and one output	is a part of an Op- amp& has one input and one output
When a differenti al amplifier is operated single-ended	the output is grounded	one input is grounded and signal is applied to the other	both inputs are connecte d together	the output is not inverted	one input is grounded and signal is applied to the other
In differenti al-mode,	opposite polarity signals are applied to the inputs	the gain is one	the outputs are of different amplitud es	only one supply voltage is used	opposite polarity signals are applied to the inputs
In the common mode,	both inputs are grounded a.c. signals only current source	the outputs are connecte d together d.c. signals only active filter	an identical signal appears on both the inputs a.c. and d.c. signals nonlinear circuit	the output signal are in-phase neither d.c. nor a.c. signals linear circuit	an identical signal appears on both the inputs a.c. and d.c. signals nonlinear circuit
of a(n)					

The ramp voltage at the output of an op- amp integrator	increases or decreases exponenti ally	increases or decreases at a linear rate	is constant	is always increasin g and never decreasin g	increases or decreases at a linear rate
Another name for a unity gain amplifier is:	differenc e amplifier	comparat or	single ended	voltage follower	voltage follower
A noninvert ing closed- loop op- amp circuit generally has a gain factor:	<1	>1	0	1	>1
In order for an output to swing above and below a zero reference, the op- amp circuit	a resistive feedback network	zero offset	a wide bandwidt h	a negative and positive supply	a negative and positive supply

requires:

Input R_i $R_f + R_i \propto R_f - R_i$ R_i impedance $[Z_{in}(I)]$ of an inverting amplifieris approximately equal to:

The	the ratio	the open-	the	the input	the
closed-	of the	loop	feedback	resistance	feedback
loop	input	voltage	resistance		resistance
voltage	resistance	gain	divided		divided
gain of an	to the		by the		by the
inverting	feedback		input		input
amplifier	resistance		resistance		resistance
equals:					
All of the	inverting	common-	double-	single-	inverting
following	mode	mode	ended	ended	mode
are basic					
op-amp					
input					
modes of					
operation					
EXCEPT					

```
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signals is
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amplifier
?
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filtering The pulse pulse peak input detection noise Schmitt shaping shaping trigger is rejection twoа state device that is used for: When a open- or integratio saturation addition integratio capacitor closedn or or cutoff or n or is used in loop gain differenti subtractio differenti place of a ation ation n resistor in an opamp network, its placemen t determin es: An differenti differenc summing analog summing subtracto output ator e that is r proportio nal to the addition of two or more inputs is from which type of amplifier ? An ideal high high moderate zero zero amplifier input gain offset output offset impedanc should current have: e

Which of nonmono incorrect offset nonmono nonmono the tonic output error tonic and tonic and following error codes offset offset is a type error error of error associate with d digital-toanalog converter S (DACs)? A 4-bit 3.125 0.3125 30.12 312.5 3.125 R/2Rdigital-toanalog (DAC) converter has а reference of 5 volts. What is the analog output for the input code 0101.

A binary- 50 micro 5000A 50mA 5mA 50 micro weighted A А digital-toanalog converter has an input resistor of 100 k. If the resistor is connecte d to a 5 V source, the current through the resistor is: R/2R 4-bit D/A The 4-bit D/A 8-bit D/A op-amp practical ladder converter converter comparat converter of D/A use ors S S S converter binaryweighted s digital-toanalog converter S is limited to:

The differenc	quantizati on	accuracy	resolutio n	monotoni city	resolutio n
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analog					
voltage					
represent					
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adjacent					
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codes, or					
the					
analog					
step size,					
is the:					
					_
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primary	requires	conversio	number	number	number
disadvant	the input	n time is	of output	of	of
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(DAC),				understan	
as				d and	
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to a				oot.	
binary-					
weighted					
digital-to-					
analog					
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converter					
?					
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resolutio					
n of a					
0-5 V 6-					
bit digital					
to-analog					
converter					
(DAC) 18:					
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which is	allerenti	niissing	ando	onset	allerenti
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digital	ity				ity
(ADC)	ity				ity
conversio					
n error?					

Prepared by Dr.A.Nagamani Prabu, Assistant Professor, Department of physics, KAHE.