UNIT 1

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Regulated Power Supply: Block Diagram, Bridge Rectifier with filter, Zener diode as Voltage Regulator, Photo diode, LED.**Amplifiers**: CE Amplifier with and without feedback, Multistage amplifier, BJT as a switch, Cutoff and Saturation modes.(Text 5: 3.3,3.7.3)

Regulated power Supply:

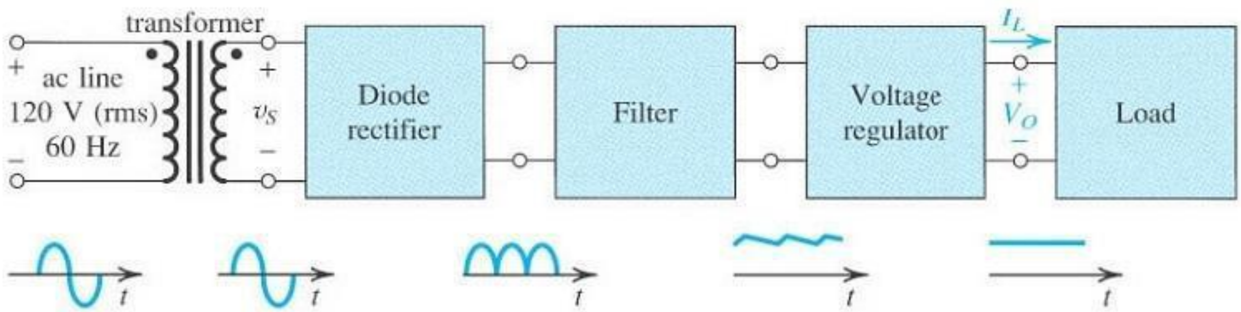


Fig 1: Regulated Power Supply

The AC voltage is connected to the primary of the transformer.

The transformer steps down to the AC voltage for the desired DC output.

Pulsating DC voltage means a unidirectional voltage containing large vary in component called ripple in it.

To reduce the ripple, filter is used after the rectifier circuit, which reduces the ripple content in the pulsating DC and tries to make it smoother. But still the output of filter contains some ripples and this output is called unregulated DC.

A circuit used after the filter is a regulator circuit which is not only makes the dc voltage smooth and almost ripple free but it also keeps the dc output voltage constant though input dc voltage varies under certain conditions.

The regulator also keeps dc voltage constant under variable load conditions.

The output of the regulator is pure DC and to which the load can be connected.

Power Supply Performance parameters:

The DC output voltage in a DC Supply varies due to two parameters.

Line Regulation Load
Regulation

The input to the unregulated power supply i.e. rectifier circuit is 230V AC supply. This is called Line Voltage.

The Line Voltage may change under different load conditions.

A +/- 10% variation in the AC supply voltage V_s also called as Line voltage is very common.

There is some variation in the DC output voltage when the line voltage varies.

The output voltage change ΔV_0 due to a change in the line voltage is called source effect.

Source Effect= ΔV_0 for a 10% change in V_s

The source effect expresses as a % of DC output voltage V_0 is called Line Regulation.

Line Regulation = =(ΔV_0 for a 10% change in $V_{s)}/V_0$ x100

For a good DC power supply ΔV_0 should be very small.

Ideally ΔV_0 should be equal to 0. Therefore Line Regulation is 0% for an ideal

The load regulation is the change in the regulated output voltage when the load current is changed from minimum (no load) to maximum (full load).

The DC output voltage V_0 is a function of load current I_L. If the load current I_L increases V_0 decreases and vice-versa.

The output voltage change ΔV_0 due to the load current change I_{Lmax} is called the load effect.

Load effect= ΔV_0 for ΔI_{Lmax}.

The load effect expressed as a percentage of the output voltage V_0 is called the load regulation.

Load regulation=(ΔV_0 for ΔI_{Lmax}.)/V_0 x 100

Diode Applications

Rectification: Rectification is a process of converting alternating current into direct current. We know that semiconductor diodes conduct current in the forward direction and blocks current in the other direction; they can be used for rectification. The source available for us is single phase 230V,ac at 50Hz,as we know that most of the electronics circuits such as amplifiers, oscillators etc require a DC voltage in the range of 5V to 25V for their operation. Hence it is essential to convert ac into dc.

Rectifier: is a device that converts alternating current into direct current. Rectifier circuits use semiconductor diodes as rectifying elements.

Following are the different types of rectifiers used:

a)Half Wave Rectifier

b)Full Wave Rectifier

Full Wave Rectifier can be built in the following ways:

a)Full Wave Rectifier using 2 diodes and a centre tapped transformer

b)Full Wave Bridge Rectifier using 4 diodes and an ordinary transformer

Bridge Rectifier

The construction diagram of a bridge rectifier is shown in the below figure. The bridge rectifier is made up of four diodes namely D1, D2, D3, D4 and load resistor RL. The four diodes are connected in a closed loop (Bridge) configuration to efficiently convert the Alternating Current (AC) into Direct Current (DC). The main advantage of this bridge circuit configuration is that we do not require an expensive center tapped transformer, thereby reducing its cost and size.

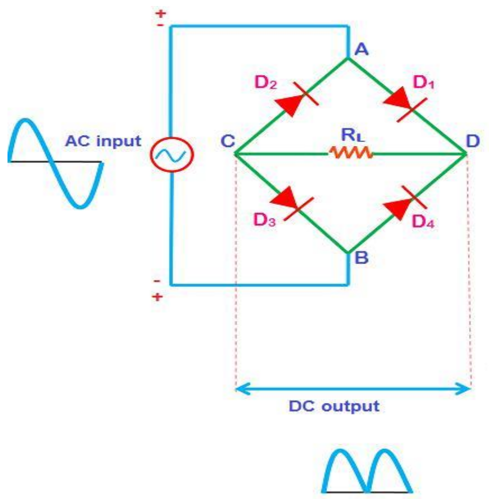


Fig 2: Bridge rectifier Circuit

The input AC signal is applied across two terminals A and B and the output DC signal is obtained across the load resistor RL which is connected between the terminals C and D.

The four diodes D_1, D_2, D_3, D_4 are arranged in series with only two diodes allowing electric current during each half cycle. For example, diodes D_1 and D_3 are considered as one pair which allows electric current during the positive half cycle whereas diodes D_2 and D_4 are considered as another pair which allows electric current during the negative half cycle of the input AC signal.

When input AC signal is applied across the bridge rectifier, during the positive half cycle diodes D_1 and D_3 are forward biased and allows electric current while the diodes D_2 and $D_4$are reverse biased and blocks electric current. On the other hand, during the negative half cycle diodes D_2 and D_4 are forward biased and allows electric current while diodes D_1 and D_3 are reverse biased and blocks electric current.

During the positive half cycle, the terminal A becomes positive while the terminal B becomes negative. This causes the diodes D_1 and D_3 forward biased and at the same time, it causes the diodes D_2 and D_4 reverse biased. The current flow direction during the positive half cycle is shown in the figure A (i.e. A to D to C to B).

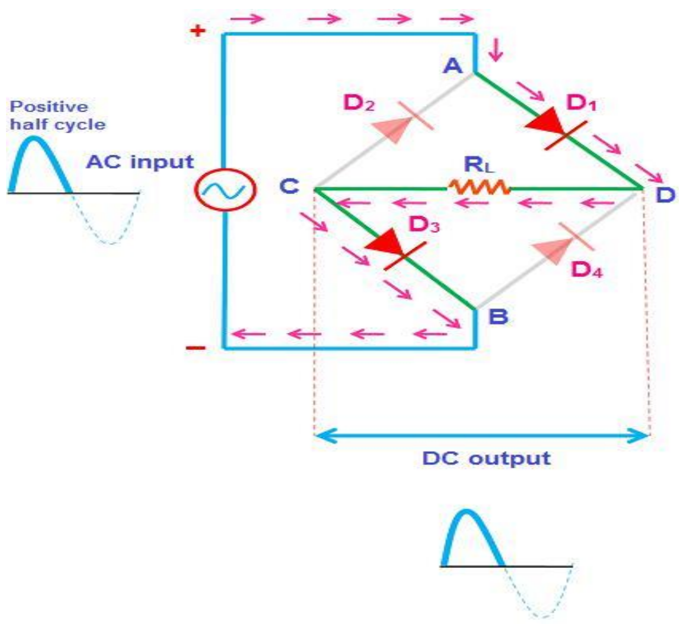


Fig 3: Bridge rectifier operation during Positive cycle

During the negative half cycle, the terminal B becomes positive while the terminal A becomes negative. This causes the diodes D_2 and D_4 forward biased and at the same time, it causes the diodes D_1 and D_3 reverse biased.

The current flow direction during negative half cycle is shown in the figure B (I.e. B to D to C to A).

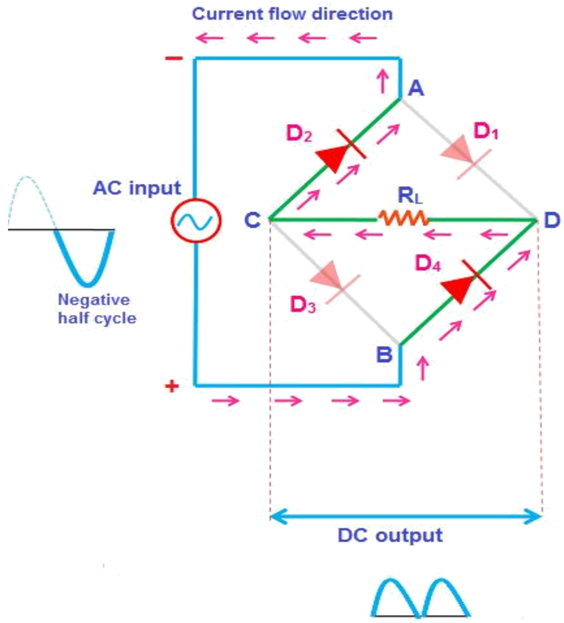


Fig 4: Bridge rectifier operation during Negative cycle

From the above two figures we can observe that the direction of current flow across load resistor R_L is same during the positive half cycle and negative half cycle. Therefore, the polarity of the output DC signal is same for both positive and negative half cycles. In our case, it is completely positive.

If the direction of diodes is reversed then we get a complete negative DC voltage. Thus, a bridge rectifier allows electric current during both positive and negative half cycles of the input AC signal. The output waveforms of the bridge rectifier is shown in the below figure.

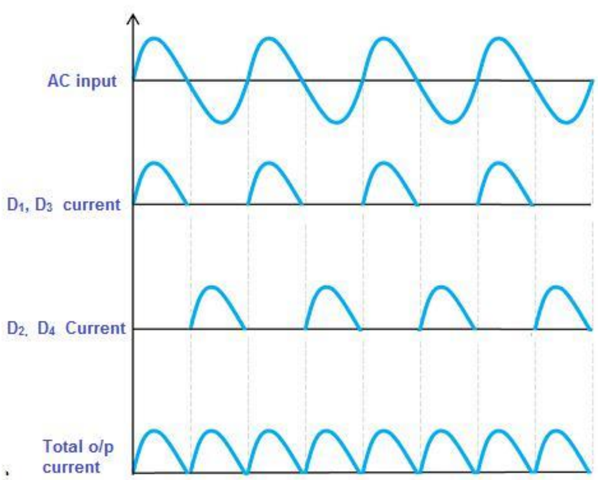


Fig 5: Output waveforms of bridge rectifier

From the equivalent circuit of bridge rectifier during positive cycle, Applying KVL to equivalent circuit we get,

$$V_2 - i_o R_f - i_o R_f - i_o R_L = 0$$

$$i_o = V_2/(2R_f + R_L)$$

$$\text{WKT} \quad V_2 = V_m \sin\omega t$$

$$i_o = V_m \sin\omega t /(2R_f + R_L)$$

$$i_o = I_m \sin\omega t$$

$$\text{where } I_m = V_m/(2R_f + R_L)$$

Sl. No.	Parameter	Equation
1	DC Load Current	$I_{dc}=2\ I_m/\pi$
2	DC Load Voltage	$V_{dc}=2V_m/\ \pi\ (1+2\ R_f/\ R_L)$
3	RMS Load Current	$I_{rms}=I_m/\sqrt{2}$
4	RMS Load Voltage	$V_{rms}=V_m/\ \sqrt{2}\ (1+2\ R_f/\ R_L)$
5	Regulation	$2\ R_f/\ R_L$
6	Effiency of rectification	$\eta=0.812/1+2\ R_f/\ R_L$
7	Ripple factor	0.483
8	PIV	V_m

Bridge rectifier with capacitor filter:

The pulsating DC output obtained across the load resistor R_L contains small ripples. To reduce these ripples, we use a filter at the output.The filter normally used in the bridge rectifier is a capacitor filter. In the below circuit diagram, the capacitor filter is connected across the load resistor R_L..

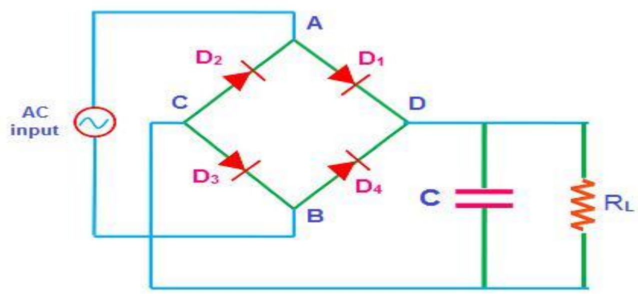


Fig 6: Bridge rectifier with filter capacitor

When input AC signal is applied, during the positive half cycle both diodes D_1 and D_3 are forward biased. At the same time, diodes D_2 and D_4 are reverse biased.

On the other hand, during the negative half cycle, diodes D_2 and D_4 are forward biased. At the same time, diodes D_1 and D_3 are reverse biased.Thus, the bridge rectifier allows both positive and negative half cycles of the input AC signal.The DC output produced by the bridge rectifier is not a pure DC but a pulsating DC. This pulsating DC contains both AC and DC components.

The AC components fluctuate with respect to time while the DC components remain constant with respect to time. So the AC components present in the pulsating DC is an unwanted signal. .The output waveforms of the bridge rectifier with filter is shown in the below figure.

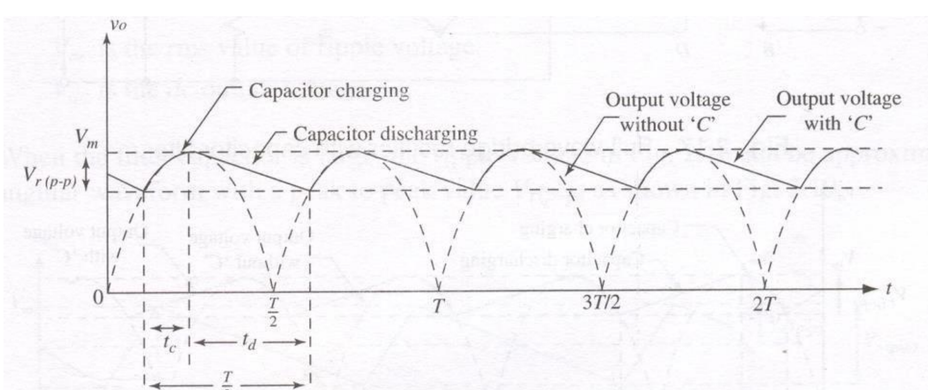


Fig 7: Output waveforms of bridge rectifier with filter capacitor

Ripple factor, DC voltage and load regulation for FWR with capacitor filter is given below:

$\gamma = 1/4\sqrt{3}fCR_L$

$V_{dc} = V_m/(1+1/4fCR_L)$

Load regulation $= 1/4fCR_L$

Zener diode:

The zener diode is a silicon PN junction semiconductor diode, which is generally operated in reverse break down region.

The zener diodes are fabricated with précised break down voltages by controlling the doping level , during the manufacturing process. When a junction is reverse biased normally only a very small reverses saturation current Is flows.

As the voltage across the diode increases in the reverse bias region, the velocity of minority carrier responsible for the reverse saturation current Is will also increase.

The symbol for zener diode is shown below.

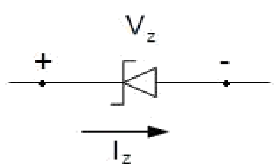


Fig 8: Symbol for Zener diode

Characteristics of Zener diode:

The forward and reverse characteristics are similar to that of a conventional diode until break down occurs in reverse bias.

In reverse biased condition, the diode carries reverse saturation current till the reverse voltage applied is less than the reverse break down voltage.

When the reverse voltage exceeds the reverse break down voltage, the current through it changes very drastically but the voltage across it, remains almost constant.

The break down characteristics for a Zener diode is significantly important as it is operating region for the zener diode.

At a certain reverse voltage, current through zener diode increases rapidly.

The change from a low value to large value of current is very sharp. Such a sharp change

in the reverse characteristics is called knee/ zener knee of the curve.

At this knee point breakdown is set to occur in the device. The reverse biased voltage at which the break down occurs is called zener break down voltage which is dented by V_Z.

The current corresponding to knee point is called zener knee current and it is a minimum current zener must carry to operate in reverse break down region. It is denoted as $I_{z(min)}$.

The maximum current a zener diode can carry safely is called zener maximum current and is denoted as $I_{z(max)}$.

As current increases, the power dissipation increases. If the dissipation increases beyond certain value, the diode may get damaged. So the current should be less than Iz(max).

In practical circuits to limit the zener current between Iz(min) and Iz(max) a current limiting resistor is used in series with the zener diode.

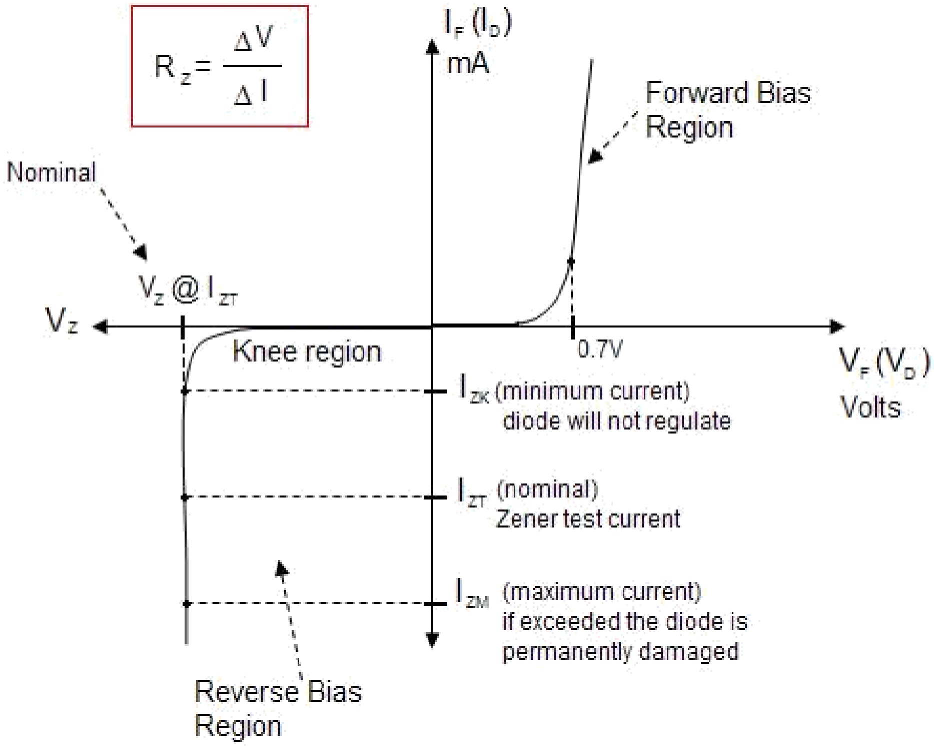


Fig 9: Zener diode characteristics

Breakdown mechanisms in Zener Diode:

1. There are two distinct mechanisms due to which breakdown may occur in the zener diode.

   Zener breakdown

   Avalanche breakdown

2. If the breakdown voltage is between 5 and 8 v both avalanche and zener mechanisms are involved and if it is above 8v, only avalanche mechanisms takes over.

1. Zener breakdown

The electric field strength can be very high when the depletion region is very narrow because WKT electric field is expressed in terms of volts/distance.

The application of reverse bias voltage causes a field across the depletion region may be of the order 3×10^5 V/cm.

An electric field of such high magnitude exerts a large force on the valence electrons of the atom, tending them to separate from their separate atom. After breaking covalent bonds large carriers are generated and a sudden increase of current is observed.

To protect the diode a limiting resistance is used in the circuit.

In zener breakdown, the value of breakdown voltage decreases as PN junction temperature increases. Thus such diodes have negative temperature co-efficient.

2. Avalanche breakdown:

This breakdown happens when the depletion region is not narrow enough for zener breakdown.

WKT, in reverse biased condition there will be a small reverse saturation current due to minority charge carriers i.e. electrons in P type material and holes in N type material.

As the applied reverse bias voltage becomes larger the minority charge carriers increasingly accelerate.

There will be collisions between these particles and electrons involved in the covalent bonds of crystal structure.

When the applied voltage is increased, the velocity and hence the kinetic energy of the electron increases.

If such an electron hits an electron involved in covalent bond, then the collision gives bond valence electron enough energy to enable it to break its covalent bond thus one electron by colliding the other atom creates electron hole pair.

Then these new electrons will bombard the other and again generates new electron hole pair. This phenomenon is called carrier multiplication or avalanche multiplication.

At this stage junction is said to be in break down and current starts increasing rapidly. To limit the current, we require a current limit in resistor.

Zener diode with zener voltage above 6V exhibits avalanche breakdown. Such diodes will have positive temperature co-efficient.

Differences between Zener and Avalanche breakdown:

Sl No	**Zener breakdown**	**Avalanche breakdown**
1.	Breakdown occurs for zener diode with Vz < 6V	Breakdown occurs for zener diode with Vz > 6V
2.	Temperature coefficient is negative	Temperature coefficient is positive
3.	Breakdown occurs due to high electric field	Breakdown occurs due to high kinetic energy
4.	The VI curve is very sharp.	The VI curve is not as sharp as zener.

Design of Zener Regulator:

1. **Regulation with varying input voltage:**

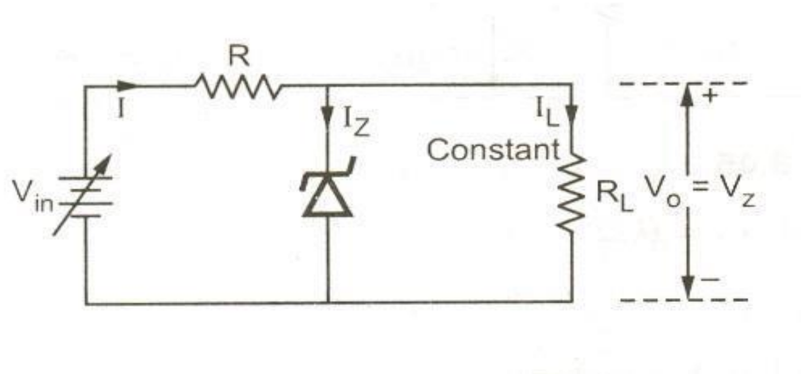


Fig 10: Varying input condition

From the above figure V0 = Vz= constant. IL = V0/RL=VZ/RL= constant.

We can write I=IL+IZ

If we increase input voltage Vin then the current I increases, but WKT current through the load is constant. Hence current through Zener increases to keep IL constant.

As long as Iz is in between Iz(min) and Iz(max) the Vz i.e. the ouput voltage V0 is constant i.e. how the change in input voltage is getting compensated and constant output is maintained.

When Vin decreases the current I decrease. But WKT the current through load is constant the current through zener decreases.

Iz will be in between Iz(max) to Iz(min) to keep the output voltage constant.

1. **Regulation with varying load:**

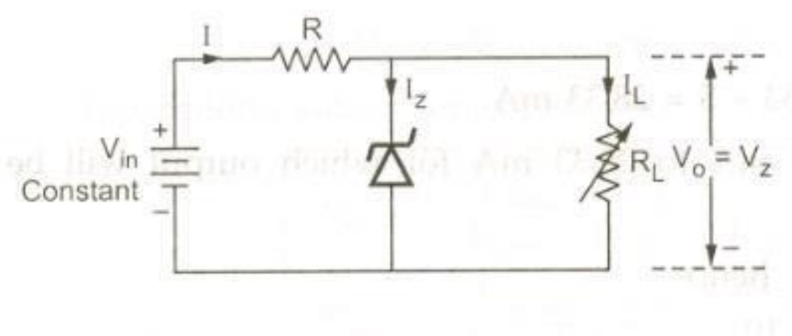


Fig 11: Varying load condition

In the above figure the input voltage V_{in} is kept constant whereas load is varying. Her V_{in} is constant and V_0 is also constant. Current I can be calculated as $I=(V_{in}-Vz)/R$. WKT $I_L = V_0/R_L=V_Z/R_L=$ constant.

If R_L increases then current through load I_L decreases, to keep constant I, I_z increases but as long as I_z is in between $I_{z(min)}$ and $I_{z(max)}$ output voltage will be constant.

If R_L decreases then current through load I_L increases, to keep constant I, I_z decreases but as long as I_z is in between $I_{z(min)}$ and $I_{z(max)}$ output voltage will be constant.

3. **Design of Zener regulator when both voltage and load are varying:**

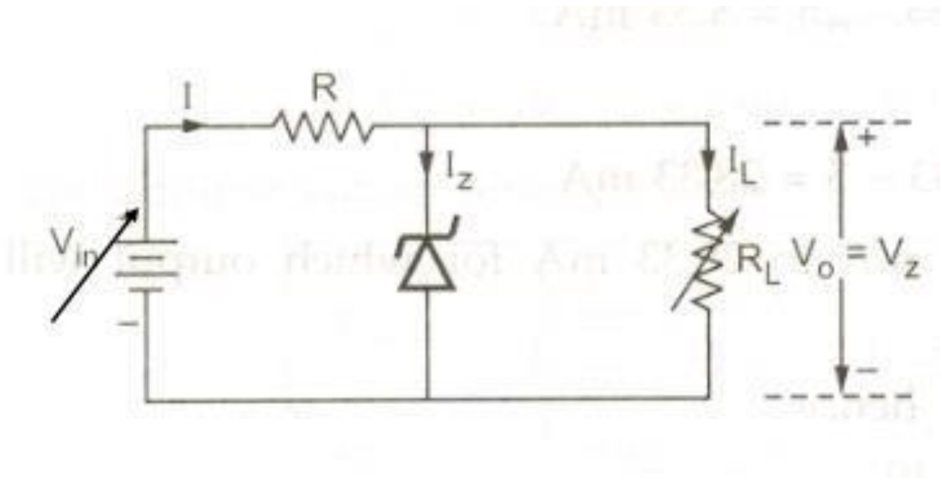


Fig 12: Zener regulator when both voltage and load are varying

In the above figure both input voltage V_{in} and load R_L are varying.

When we need to design a zener regulator, the parameters like R,V_{in} I_L has to be considered.

Here V_{in} varies between $V_{in(min)}$ to $V_{in(max)}$ and the load current I_L varies from $I_{L(min)}$ to $I_{L(max)}$.

The calculation of R should be such that zener should operate between $I_{Z(min)}$ and $I_{Z(max)}$.

The current through zener must be more than $I_{Z(min)}$,where $I_{Z(min)}$ is the minimum zener current required to operate in the breakdown region.

$$\boxed{[(V_{in(min)} - V_Z)/R] - I_{L(max)} > I_{Z(min)}}$$

Maximum zener current flows when $V_{in} = V_{in(max)}$ and $I_L = I_{L(min)}$.the current through zener must be less than $I_{Z(max)}$.where $I_{Z(max)}$ is the maximum allowable zener current for safe operation.

$$[(V_{in(max)} - V_Z)/R] - I_{L(min)} < I_{Z(max)}$$

Where $I_{Z(max)} = P_D/V_Z$

P_D is the maximum allowable power dissipation in zone.

PHOTO DIODE

A photodiode is a kind of light detector, which involves the conversion of light into voltage or current, based on the mode of operation of the device.

It consists of built-in lenses and optical filters, and has small or large surface areas. With an increase in their surface areas, photodiodes have a slower response time. Conventional solar cells, used for generating electric solar power, are a typical photodiode with a large surface area.

A photodiode is a semi-conductor device, with a p-n junction and an intrinsic layer between p and n layers. It produces photocurrent by generating electron-hole pairs, due to the absorption of light in the intrinsic or depletion region. The photocurrent thus generated is proportional to the absorbed light intensity.

Working Principle of Photodiodes

When photons of energy greater than 1.1 eV hit the diode, electron-hole pairs are created. The intensity of photon absorption depends on the energy of photons – the lower the energy of photons, the deeper the absorption is. This process is known as the inner photoelectric effect.

If the absorption occurs in the depletion region of the p-n junction, these hole pairs are swept from the junction - due to the built-in electric field of the depletion region. As a result, the holes move toward the anode and the electrons move toward the cathode, thereby producing photocurrent. The sum of photocurrents and dark currents, which flow with or without light, is the total current passing through the photodiode. The sensitivity of the device can be increased by minimizing the dark current.

Modes of Operation

Photodiodes can be operated in different modes, which are as follows:

Photovoltaic mode – It is also known as zero bias mode, in which a voltage is generated by the illuminated photodiode. It provides a very small dynamic range and non-linear dependence of the voltage produced

Photoconductive mode - The diode used in this mode is more commonly reverse biased. The application of reverse voltage increases the width of the depletion layer, which in turn reduces the response time and capacitance of the junction. This mode is very fast, and exhibits electronic noise

Avalanche diode mode - Avalanche photodiodes are operated in a high reverse bias condition, which allow multiplication of an avalanche breakdown to each photo-generated electron-hole pair. This results in internal gain within the photodiode, which gradually increases the responsivity of the device

Applications

Photodiodes find application in the following:

Cameras

Medical devices

Safety equipment

Optical communication
devices Position sensors

Bar code
scanners
Automotive
devices

Surveying instruments

Light-Emitting Diode(LED)

A light-emitting diode (LED) is a two-lead semiconductor light source. It is a p–n junction diode, which emits light when activated.[4] When a suitable voltage is applied to the leads, electrons are able to recombine with electron holes within the device, releasing energy in the form of photons. This effect is called electroluminescence, and the color of the light (corresponding to the energy of the photon) is determined by the energy band gap of the semiconductor.

An LED is often small in area (less than 1 mm2) and integrated optical components may be used to shape its radiation pattern.[5]

Appearing as practical electronic components in 1962,[6] the earliest LEDs emitted low-intensity infrared light. Infrared LEDs are still frequently used as transmitting elements in remote-control circuits, such as those in remote controls for a wide variety of consumer electronics. The first visible-light LEDs were also of low intensity, and limited to red. Modern LEDs are available across the visible, ultraviolet, and infrared wavelengths, with very high brightness.

Early LEDs were often used as indicator lamps for electronic devices, replacing small incandescent bulbs. They were soon packaged into numeric readouts in the form of seven-segment displays, and were commonly seen in digital clocks.

Recent developments in LEDs permit them to be used in environmental and task lighting. LEDs have many advantages over incandescent light sources including lower energy consumption, longer lifetime, improved physical robustness, smaller size, and faster switching. Light-emitting diodes are now used in applications as diverse as aviation lighting, automotive headlamps, advertising, general lighting, traffic signals, camera flashes and lighted wallpaper. As of 2015[update], LEDs powerful enough for room lighting remain somewhat more expensive, and require more precise current and heat management than compact fluorescent lamp sources of comparable output.

LEDs have allowed new text, video displays, and sensors to be developed, while their high switching rates are also used in advanced communications technology.

Working:

A light emitting diode (LED) is known to be one of the best optoelectronic devices out of the lot. The device is capable of emitting a fairly narrow bandwidth of visible or invisible light when its internal diode junction attains a forward electric current or voltage. The visible lights that an LED emits are usually orange, red, yellow, or green. The invisible light includes the infrared light.

The biggest advantage of this device is its high power to light conversion efficiency. That is, the efficiency is almost 50 times greater than a simple tungsten lamp. The response time of the LED is also known to be very fast in the range of 0.1 microseconds when compared with 100 milliseconds for a tungsten lamp. Due to these advantages, the device wide applications as visual indicators and as dancing light displays.

We know that a P-N junction can connect the absorbed light energy into its proportional electric current. The same process is reversed here. That is, the P-N junction emits light when energy is applied on it. This phenomenon is generally called electroluminance, which can be defined as the emission of light from a semi-conductor under the influence of an electric field.

The charge carriers recombine in a forward P-N junction as the electrons cross from the N-region and recombine with the holes existing in the P-region. Free electrons are in the conduction band of energy levels, while holes are in the valence energy band. Thus the energy level of the holes will be lesser than the energy levels of the electrons. Some part of the energy must be dissipated in order to recombine the electrons and the holes. This energy is emitted in the form of heat and light.

The electrons dissipate energy in the form of heat for silicon and germanium diodes. But in Galium- Arsenide-phosphorous (GaAsP) and Galium-phosphorous (GaP) semiconductors, the electrons dissipate energy by emitting photons.

Amplifiers:

Common Emitter configuration (CE)

Emitter is common to both i/p and o/p terminals as shown in fig 13.

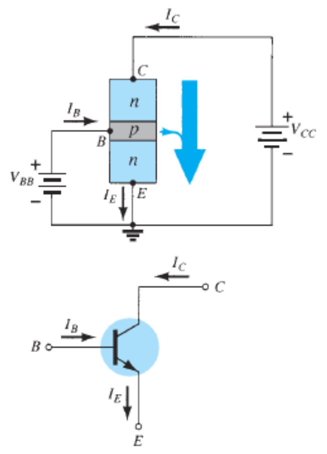


Fig 13: CE configuration

- **Input characteristics:** A plot of the variation of i/p base current I_B with variation in the EB voltage V_{BE} (i/p) for different values of collector emitter voltage V_{CE} (o/p) is the i/p characteristics as seen in Fig 14.To obtain the i/p characteristics, V_{CE} is kept constant, V_{BE} is varied and value of I_B is recorded. For fixed value of V_{BE}, I_B decreases with increase in V_{CE}. This is due to the fact that with increase in V_{CE}, the depletion region of the reverse bias collector base junction widens, reducing base width.

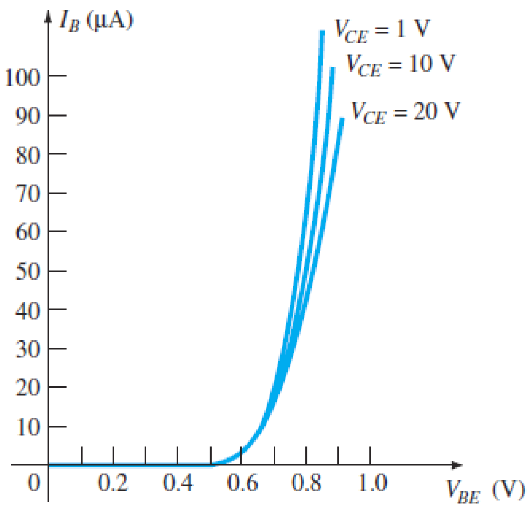


Fig 14 Input characteristics for CE mode

- **Output characteristics**: Relates to o/p current I_C to an o/p voltage V_{CE} for various levels of input current I_B as seen in Fig 15. The three region of interest are :-
  Active region:-In this region, the collector current responds more readily to any input signal since I_C is more sensitive. So the transistor can be used as an amplifier. The characteristics are not horizontal lines due to fixed I_B, the magnitude of I_C increases with increases in V_{CE} due to early effect.
  The collector current I_C can be derived in active region as before.
  In common base mode
  $I_C = -\alpha I_E + I_{CO}$
  $I_C = \alpha(I_B + I_C) + I_{CO}$
  $I_C = \alpha I_B + \alpha I_C + I_{CO}$
  $I_C(1-\alpha) = \alpha I_B + I_{CO}$
  $I_C = \alpha I_B/(1-\alpha) + I_{CO}/(1-\alpha)$
  Substituting $\beta = \alpha/(1-\alpha)$ and $1/(1-\alpha) = 1+\beta$ yields
  $Ic = \beta I_B + I_{CO}(1+\beta)$
  Cutoff region: the region to the right of the $V_{CE} = 0$ and below $I_B = 0$ is the cutoff region. If $I_B = 0$ then $I_C = I_E = (1+\beta)Ico$.
  Saturation region: This region lies extremely close to the zero voltage axis, where all the curves merge and fall rapidly towards the origin. In this region I_C is almost independent of I_B.

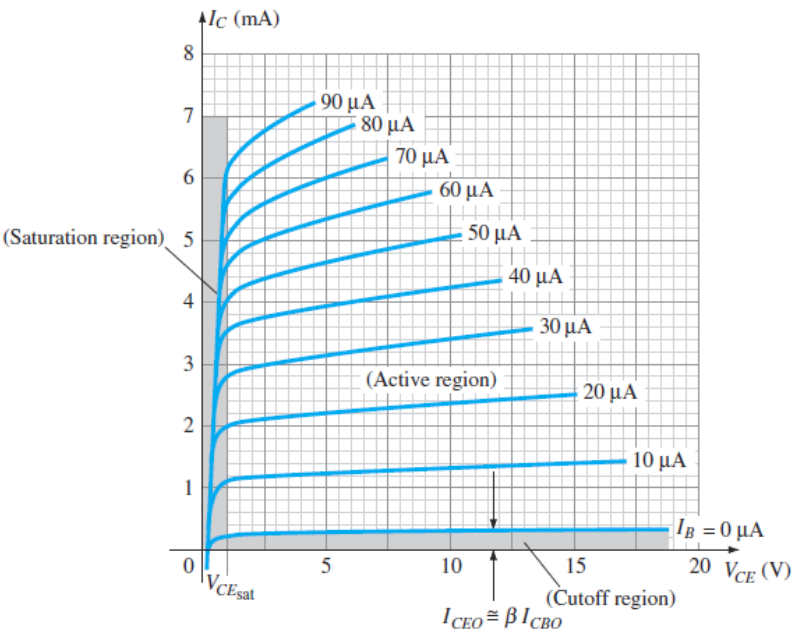


Fig 15 Output characteristics for CE mode

- **DC load line:** Biasing is application of external dc voltages of correct polarity and magnitude across the two junctions of the transistor. Since dc biasing is essentially required for proper operation of the transistor. If the transistor is to be used as an amplifier then the device should be operated in active region. Similarly if the device is required to be operated as an electronic switch then it should be operated in saturation and cut off regions.

- **Operating point:** Consider the common emitter circuit as shown below. The transistor EB junction is forward biased by external dc voltage V_{BB} and CB junction is reverse biased by V_{CC}. When the signal is zero, there exists dc collector current I_C and the output voltage V_{CE}. Consider the common emitter circuit as shown in Fig 16.

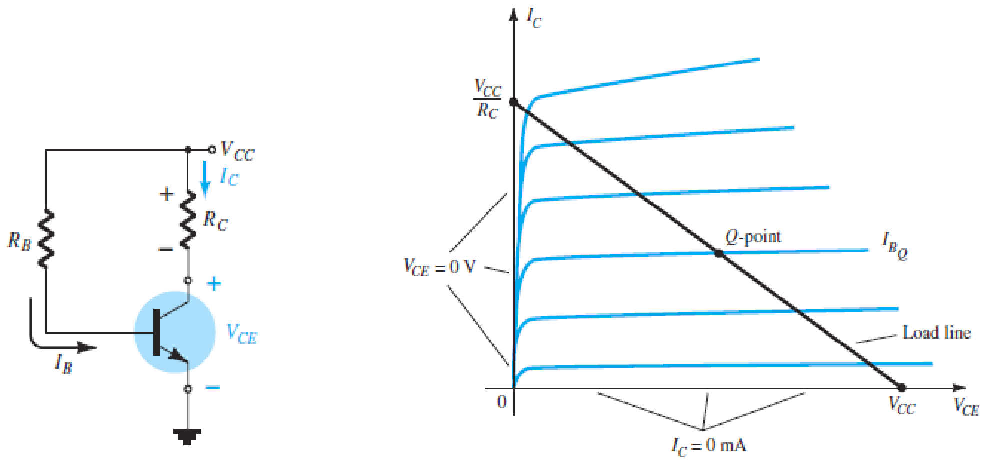


Fig 16 Load line analysis

By applying KVL to the o/p circuit

$V_{CC}=I_CR_C+V_{CE}$

$V_{CE}=V_{CC} - I_CR_C$

Therefore $I_C= (-1/R_C)\ V_{CE} + V_{CC}/R_C$

The above equation represents a straight line with the slope of $(-1/R_C)$. To draw the DC load line on the o/p characteristics, two points are required. In the below equation if $V_{CE}=0$,

$I_C=(-1/R_C)\ V_{CE} + V_{CC}/R_C$,

then $I_C=\ V_{CC}/R_C$……………………….(a)

Similarly if $I_C=0$ then $V_{CC}=V_{CE}$………… (b)

Using (a) and (b) a straight line is drawn on the output characteristics. The line between (a) and (b) is called dc load line. The word dc indicates that only dc condition is considered with no input signal. During the operation of the transistor for fixed values of V_{CC} and R_C, the values of V_{CE} and I_C at different values of I_B are given by the intersection of load line with I_B lines as shown in figure. The intersection points on the load line are called operating point or quiescent point (Q-point). Usually Q point is said typically near the middle of dc load line for faithful amplification. If Q point is placed in saturation or cutoff, results in distortion in the o/p w/f.

Selection of Q-point

When a line is drawn joining the saturation and cut off points, such a line can be called as **Load line**. This line, when drawn over the output characteristic curve, makes contact at a point called as **Operating point**. This operating point is also called as **quiescent point** or simply **Q-point**. There can be many such intersecting points, but the Q-point is selected in such a way that irrespective of AC signal swing, the transistor remains in the active region.

The fig 17 shows how to represent the operating point.

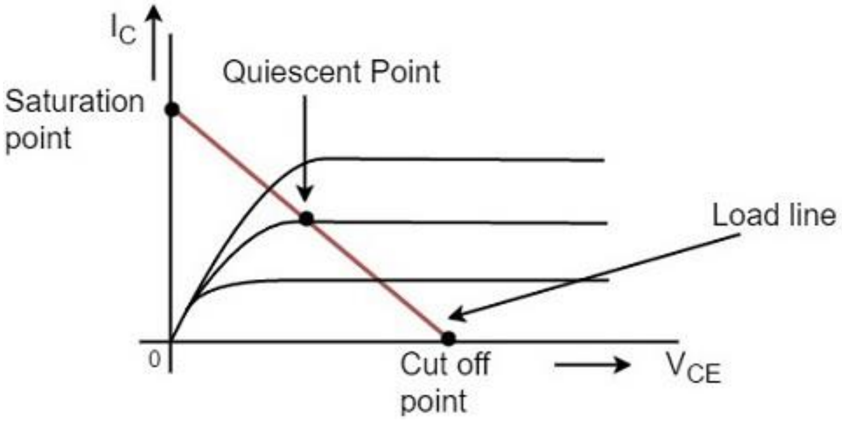


Fig 17: Regions of operations of CE configuration

The operating point should not get disturbed as it should remain stable to achieve faithful amplification. Hence the quiescent point or Q-point is the value where the Faithful Amplification is achieved.

Faithful Amplification

The process of increasing the signal strength is called as Amplification. This amplification when done without any loss in the components of the signal, is called as Faithful amplification. Faithful amplification is the process of obtaining complete portions of input signal by increasing the signal strength. This is done when AC signal is applied at its input.

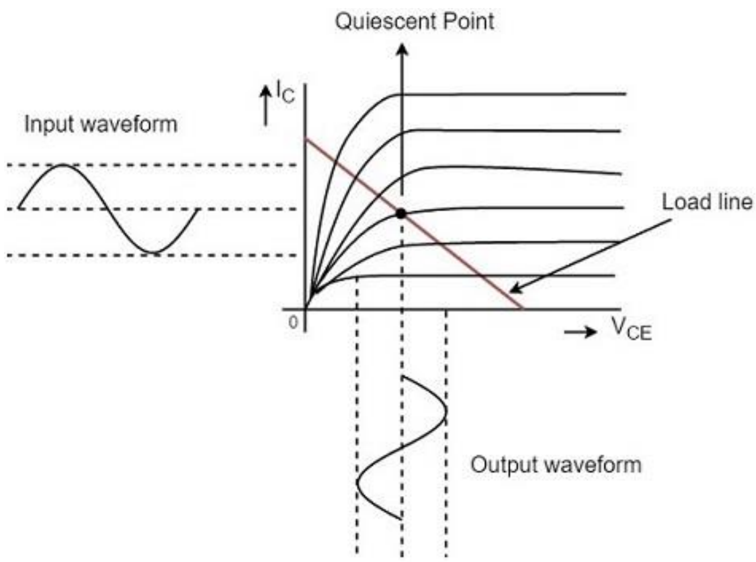


Fig 18: Operating point is in the middle of active region

In the above graph fig 18, the input signal applied is completely amplified and reproduced without any losses. This can be understood as Faithful Amplification. The operating point is so chosen such that it lies in the active region and it helps in the reproduction of complete signal without any loss. If the operating point is considered near saturation point, then the amplification is as shown in fig 19.

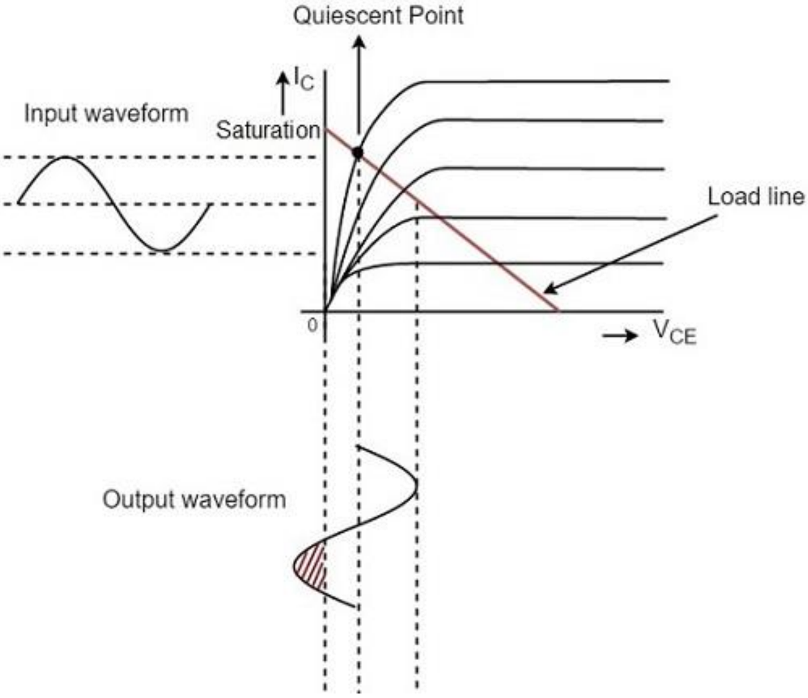


Fig 19: operating point is considered near saturation point

If the operation point is considered near cut off point, then the amplification is shown in fig 20.

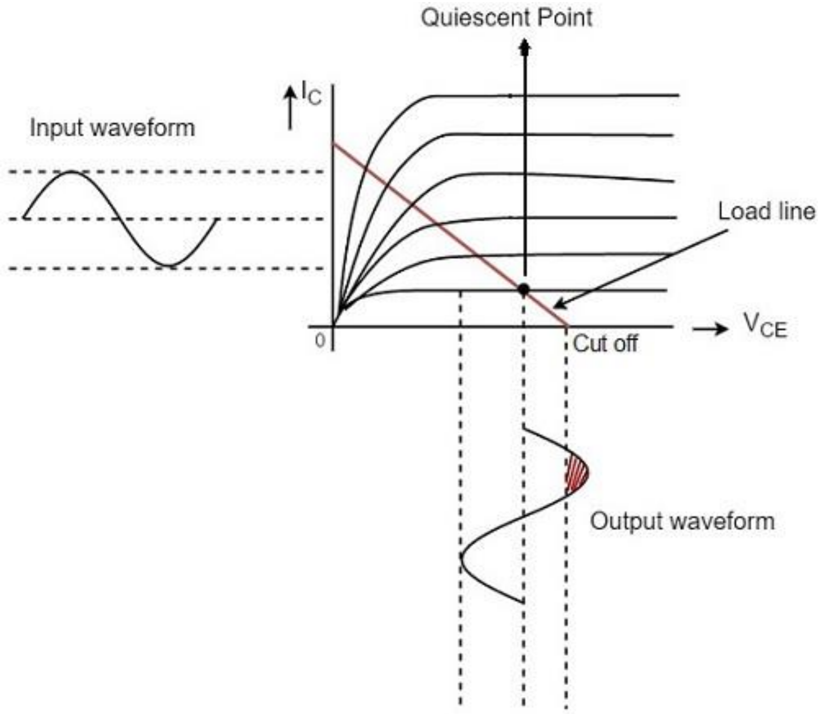


Fig 20: operating point is considered near cutoff point

Hence the placement of operating point is an important factor to achieve faithful amplification. But for the transistor to function properly as an amplifier, its input circuit (i.e., the base-emitter junction) remains forward biased and its output circuit (i.e., collector-base junction) remains reverse biased.

The amplified signal thus contains the same information as in the input signal whereas the strength of the signal is increased.

Key factors for Faithful Amplification

To ensure faithful amplification, the following basic conditions must be satisfied.

- Proper zero signal collector current
- Minimum proper base-emitter voltage (V_{BE}) at any instant.
- Minimum proper collector-emitter voltage (V_{CE}) at any instant.

The fulfillment of these conditions ensures that the transistor works over the active region having input forward biased and output reverse biased.

- **Amplifiers**

An amplifier is an electronic circuit that amplifies or magnifies or strengthens the amplitude of input signal without any distortion. Basic amplifier circuit is shown in Figure 21.

Figure 21: Basic amplifier circuit

Let us assume a small sinusoidal signal is applied to the amplifier at the output of the amplifier the signal must remain sinusoidal in waveform and the frequency of the signal must remain same as the input.

The ratio of output voltage to the input voltage of the amplifier is called the gain of the amplifier which is denoted by A_V.

The ratio of output current to the input current is called the current gain of the amplifier which is denoted as A_I.

- **Decibels:**

The term bel is derived from the name of scientist Alexander Graham bell. It was found that the bel was too large for the unit of measurement, so the decibel (dB) is defined such that 10 decibels = 1 bel. Gain is generally expressed in dB because the ear responds to the sound intensities on a logarithmic scale rather than linear scale. It is easy to express the gain in dB rather than actual numbers

Voltage gain = A_V = (o/p voltage) / (i/p voltage)

$A_V = Vo / Vi$

Current gain = A_I = (o/p current) / (i/p current)

$A_I = Io / Ii$

Power gain = Ap = (o/p power) / (i/p power)

$A_P = Po / Pi$

Decibel power gain

$(A_P)dB = 10 \log(Po/Pi)$

$\Delta Po = 10 \log (P_2/P_1)$ dB

Decibel voltage gain

$(Ap)dB = 10 \log (P_o/P_i)$

Wkt $P_o = V_o^2 / RL$ and $Pi = V_i^2 /Ri$

$P_o/P_i = (V_o^2/RL) /(V_o^2/Ri) = V_0^2 / V_i^2$ if RL= Ri

$(A_P)dB = 10 \log (V_o^2 / V_i^2)$

(A_P) dB = $20 \log (V_o/V_i)$

Decibel voltage gain (A_V) dB = $20 \log (V_o/ V_i)$

Decibel current gain $(A_I)dB = 20 \log(I_o/I_i)$

(A_P) dB= $20 \log (I_o/I_i)$

Need for cascading of amplifiers:

The current gain or voltage gain obtainable from a single transistor amplifier stage is usually in adequate for most of the applications. Hence several amplifiers stage is connected in cascade.

The amplifiers are connected such that the output of one stage forms the input of the next stage. Such cascade amplifiers permit realization of any desired voltage or current.

In the cascading of amplifiers an important consideration is the choice of elements coupling one stage to the next one. Different coupling methods are used in the different type of cascade amplifier such as RC coupled amplifier and transformer coupled amplifier.

Cascaded stages: Figure 22 shows N amplifiers connected in cascade.

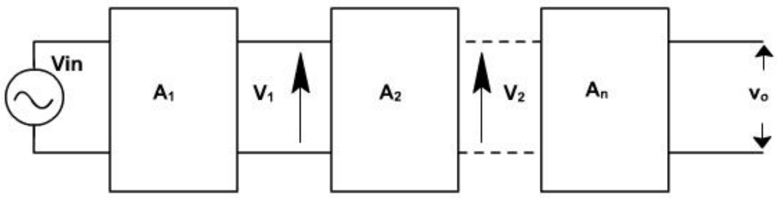


Fig 22: Amplifiers connected in cascade

Voltage of 1st stage $AV_1 = V_1/V_i$

Voltage of 2nd stage $AV_2= V_2/V_1$

Voltage gain of Nth stage $AV_n = (V_o)/(V_{n-1})$

Overall voltage gain $AV = V_o/V_i$

$AV= V_o/V_{n-1}* \ldots\ldots V_3/V_2 * V_2/V_1*V_1/V_i$

$= AV_n*AV_2*AV_3*\ldots\ldots AV_n$

Overall voltage gain in dB

$(AV)dB = 20 \log (AV)$

$= 20 \log(AV_1*AV_2*AV_3\ldots\ldots\ldots AV_n)$

$= 20 \log(AV_1)+20\log(AV_2)+\ldots\ldots\ldots+20\log(AV_N)$

$(AV)dB = AV_1dB + AV_2dB + \ldots\ldots..+AV_ndB$

<u>RC coupled amplifier</u>: The circuit diagram of RC coupled amplifier is shown in fig 23.

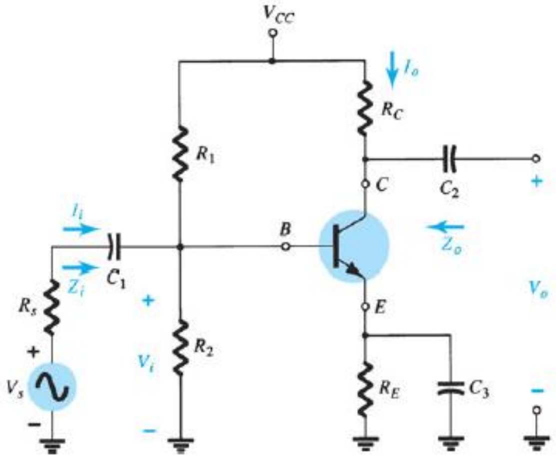
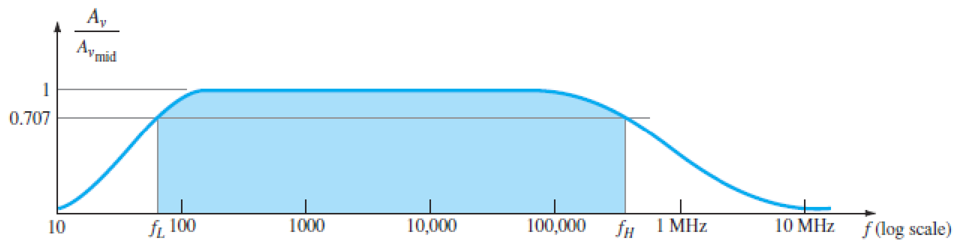


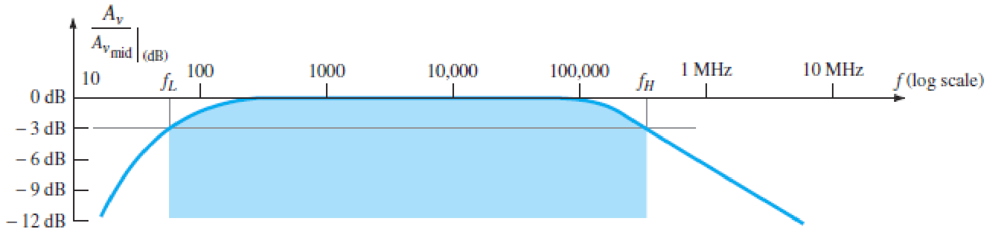
Fig 23: RC Coupled amplifier

The resistors R1, R2, RC, RE forms the voltage divider biasing circuit. The values of resistors are chosen such that they set proper operating point for the CE amplifier. The operating point is chosen such that the device works in active region and it acts as an amplifier. In the fig23, the coupling capacitors C1, C2 and bypass capacitor CE. The impedance of capacitor is given by XC = 1/2πfC. For dc signals f=0. The impedance XC = ∞. For DC signals capacitor acts as open circuit. In the circuit the signal source VS and the source is associated with source resistance RS. Note that source resistance RS is in parallel with R2 this reduces the bias voltage at the base of the transistor and this intern alters the collector current which is not desired. The dc signal which in the input of the source signal alters the biasing condition of the transistor. The capacitor C1 blocks any dc signals entering into the transistor. Similarly by connecting RL directly to the amplifier, the dc levels of VC and VCE will change which again alters the operating conditions of transistor. The output coupling capacitor C2 blocks dc signals entering the load or entering the next stage of the amplifier and it allows only ac signals to enter the next stage. The resistance RE provides bias stabilization to the transistor. But it also reduces the voltage gain of the amplifier. The bypass capacitor acts as a short circuit for ac signals and allows to create an ac ground in an amplifier without disturbing its Q-point.

Frequency response:



a) Normalized plot



b) Decibel plot

Fig 24: Frequency response

The frequency response of an RC coupled amplifier is shown in fig 24 can be divided into 3 regions:

1. Low frequency region: Reactance of a capacitor is given as XC = 1/2πfC

   At low frequencies XC increases, this increase in XC drops the signal voltage across the capacitor and in turn reduces the circuit gain.

2. Mid frequency region: As the frequency range increases, XC becomes very small and the voltage gain will be maximum and it will be almost constant for a certain range of frequencies.

3. High frequency range: At higher frequencies the voltage gain decreases due to the influence of junction capacitances of the transistor. At higher frequencies the reactance of junction capacitance falls. When the reactance becomes small enough, they provide shunting effect as they are in parallel with junctions. This reduces the current gain and in turn reduces the voltage gain.

- **Bandwidth (BW) of an amplifier:**

  Bandwidth of an amplifier is the difference between fC2(higher cutoff freq) and fC1 (lower cutoff freq)

  BW of an amplifier = $f_H – f_L$.

  The BW specifies the range of frequencies over which the gain does not deviate more than 70.7% of the maximum gain at mid frequency range. The two frequencies fC1 and fC2 are referred as half power frequencies or half power points or cut off frequencies. Because the gain or output voltage drops to 70.7% of maximum value and this represents a power level to one half the power at the reference frequency in mid frequency range.

Transistor as a switch

The application of transistors is not limited solely to the amplification of signals. Through proper design, transistors can be used as switches for computer and control applications. The network of Fig. 25 can be employed as an *inverter* in computer logic circuitry. Note that the output voltage *V C* is opposite to that applied to the base or input terminal. In addition, note the absence of a dc supply connected to the base circuit. The only dc source is connected to the collector or output side, and for computer applications is typically equal to the magnitude of the “high” side of the applied signal—in this case 5 V. The resistor R_B will ensure that the full applied voltage of 5 V will not appear across the base-to-emitter junction. It will also set the I_B level for the “on” condition.

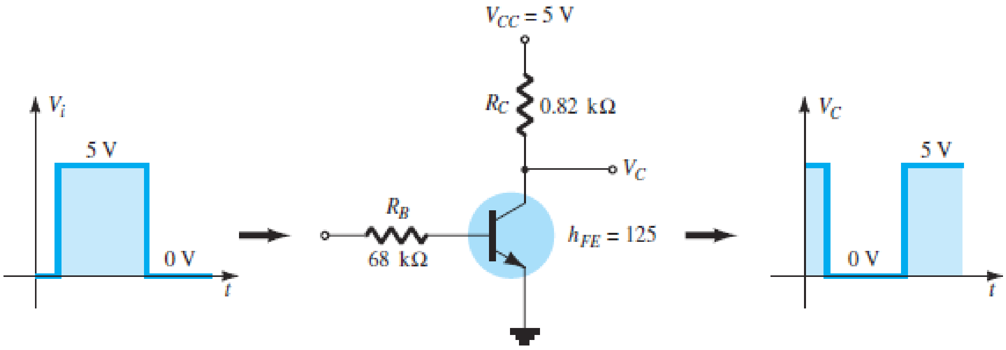


Fig. 25: Inverter circuit

Negative Feedback:

The block diagram of a feedback amplifier is shown in fig 26.

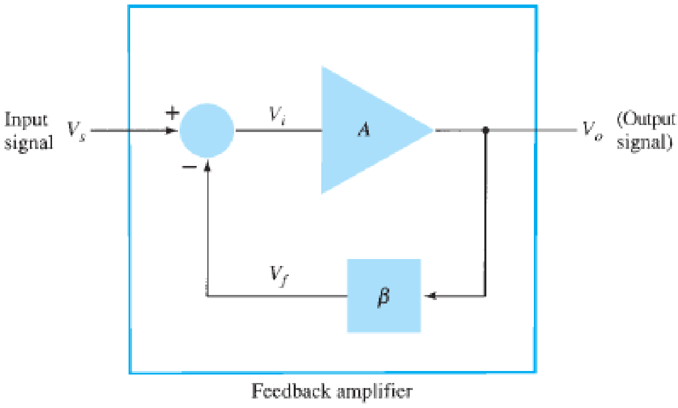


Fig 26: Simple block diagram of feedback amplifier.

Gain with feedback:

$$A = \frac{V_o}{V_s} = \frac{V_o}{V_i}$$

If a feedback signal V_f is connected in series with the input, then

$$V_i = V_s - V_f$$

Since $\quad V_o = AV_i = A(V_s - V_f) = AV_s - AV_f = AV_s - A(\beta V_o)$

then $\quad (1 + \beta A)V_o = AV_s$

so that the overall voltage gain *with* feedback is

$$\boxed{A_f = \frac{V_o}{V_s} = \frac{A}{1 + \beta A}}$$

Gain stability with feedback:

$$\left|\frac{dA_f}{A_f}\right| = \frac{1}{|1 + \beta A|}\left|\frac{dA}{A}\right|$$

$$\left|\frac{dA_f}{A_f}\right| \cong \left|\frac{1}{\beta A}\right|\left|\frac{dA}{A}\right| \qquad \text{for } \beta A \gg 1$$

This shows that magnitude of the relative change in gain $\left|\frac{dA_f}{A_f}\right|$ is reduced by the factor $|\beta A|$ compared to that without feedback $\left(\left|\frac{dA}{A}\right|\right)$.

Advantages of negative feedback amplifiers:

1. Input impedance increases by a factor of $1+A\beta$
2. Output impedance decreases by a factor of $1+A\beta$
3. Bandwidth increases by a factor of $1+A\beta$
4. Distortion decreases by a factor of $1+A\beta$
5. Noise decreases by a factor of $1+A\beta$
6. Stability of the gain improves by a factor of $1+A\beta$