LECTURE NOTES ON

ELECTRONIC DEVICES & CIRCUITS

II B.TECH I SEMESTER

ELECTRONICS AND COMMUNICATION ENGINEERING

(ACADEMIC YEAR-2022-2023)

(R20A0401)



DEPARTMENT OF ELECTRONICS & COMMUNICATION ENGINEERING

MALLA REDDY COLLEGE OF ENGINEERING & TECHNOLOGY

Autonomous Institution – UGC, Govt. of India

(Affiliated to JNTU, Hyderabad, Approved by AICTE - Accredited by NBA & NAAC – 'A' Grade - ISO 9001:2008 Certified)

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MALLA REDDY COLLEGE OF ENGINEERING AND TECHNOLOGY

II Year B.Tech. ECE- I Sem **L/T/P/C**

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(R20A0401) ELECTRONIC DEVICES AND CIRCUITS

COURSE OBJECTIVES:

1) To learn how pn diode is used as a rectifier and various types of filter design
2) To know different types of transistor biasing techniques
3) To learn BJT Hybrid model and how to design transistor amplifier
4) To learn about feedback amplifiers and different types of oscillators.
5) To learn about FET amplifiers and special purpose diodes.

UNIT I

Rectifiers: P-N Junction diode as a rectifier, half wave rectifier, Full wave rectifier, Bridge rectifier, their ripple factor, efficiency and %regulation.

Filters: Capacitor filter, Inductor Filter, L-Filter,

UNIT II

Biasing and Stabilization: Operating point, the D.C Load line, Fixed bias, Collector to base bias, Self-bias techniques for stabilization, Stabilization factors, (s, s^{I}), Bias Compensation using diode and transistor , (Compensation against variation in V_{BE}, I_{CO}). Thermal runaway and Thermal stability

UNIT III

BJT Hybrid Model and Transistor Amplifier:H-parameter representation of a transistor, Conversion of h-parameters**,** Analysis of single stage transistor amplifier using h-parameters: voltage gain, current gain, Input impedance and Output impedance. Comparison of transistor configurations in terms of A_i, R_i , A_V,and R_O ,

UNIT IV

FEEDBACK AMPLIFIERS:

Concept of Feedback and types, Effects of negative feedback on amplifiers characteristics, voltage series, current series, current shunt, and voltage shunt feedback amplifiers.

OSCILLATORS: Classification of oscillators, Barkhausen criterion, RC phase shift oscillator, Wein-bridge oscillator, LC oscillators- Hartley and Colpitts oscillator.

UNIT V:

FET Amplifiers: FET Biasing, Common source Amplifier, Common Drain Amplifier.

Special purpose Devices: Principal of operation and characteristics of Tunnel Diode, Varactor Diode, photo Diode and UJT.

TEXT BOOKS

1) "Electronic Devices & Circuits", Special Edition – MRCET, McGraw Hill Publications,2017.
2) Integrated Electronics Analog Digital Circuits, Jacob Millman and D. Halkias, McGrawHill.
3) Electronic Devices and Circuits, S.Salivahanan,N.Sureshkumar, McGrawHill.

REFERENCE BOOKS

1) Electronic Devices and Circuits,K.Lal Kishore B.SPublications
2) Electronic Devices and Circuits, G.S.N. Raju, I.K. International Publications, New Delhi,2006.

COURSE OUTCOMES:

After the course completion the students will be able

1) To design pn diode based rectifiers with filters
2) To design different types of transistor biasing circuits
3) To design transistor amplifier using hybrid model.
4) To design and analyze feedback amplifiers and different types of oscillators.
5) To analyze and understand FET amplifiers and special purpose diodes.

UNIT I:

RECTIFIERS

P-N Junction diode as a rectifier, half wave rectifier, Full wave rectifier, Bridge rectifier,Their ripple factor, efficiency and %regulation.
Filters: Capacitor filter, Inductor Filter, L-Filter,

RECTIFIERS & FILTERS

INTRODUCTION

For the operation of most of the electronics devices and circuits, a d.c. source is required. So it is advantageous to convert domestic a.c. supply into d.c.voltages. The process of converting a.c. voltage into d.c. voltage is called as rectification. This is achieved with i) Step-down Transformer, ii) Rectifier,

iii) Filter and iv) Voltage regulator circuits.

These elements constitute d.c. regulated power supply shown in the fig 1 below.

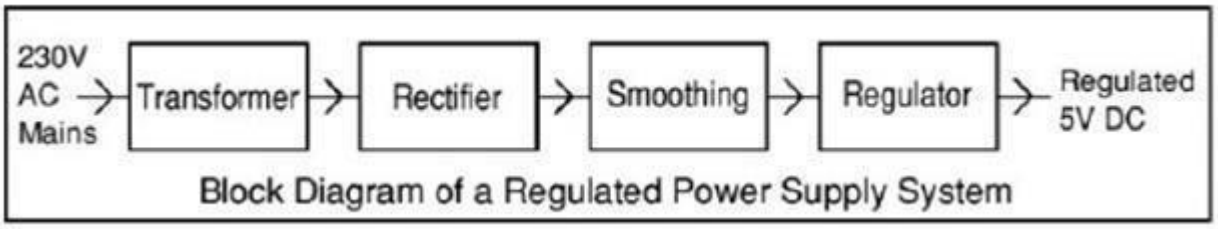


Fig 1.20: Block Diagram of regulated D.C Power Supply

- ✓ Transformer – steps down 230V AC mains to low voltageAC.
- ✓ Rectifier – converts AC to DC, but the DC output isvarying.
- ✓ Smoothing – smooth the DC from varying greatly to a smallripple.
- ✓ Regulator – eliminates ripple by setting DC output to a fixedvoltage.

The block diagram of a regulated D.C. power supply consists of step-down transformer, rectifier, filter, voltage regulator and load. An ideal regulated power supply is an electronics circuit designed to provide a predetermined d.c. voltage Vo which is independent of the load current and variations in the input voltage ad temperature. If the output of a regulator circuit is a AC voltage then it is termed as voltage stabilizer, whereas if the output is a DC voltage then it is termed as voltage regulator.

RECTIFIER

Any electrical device which offers a low resistance to the current in one direction but a high resistance to the current in the opposite direction is called rectifier. Such a device is capable of converting a sinusoidal input waveform, whose average value is zero, into a unidirectional Waveform, with a non-

zero average component. A rectifier is a device, which converts a.c. voltage (bi-directional) to pulsatingd.c. voltage (Unidirectional).

Characteristics of a Rectifier Circuit:

Any electrical device which offers a low resistance to the current in one direction but a high resistance to the current in the opposite direction is called rectifier. Such a device is capable of converting a sinusoidal input waveform, whose average value is zero, into a unidirectional waveform, with a non-zero average component.

A rectifier is a device, which converts a.c. voltage (bi-directional) to pulsating d.c..Load currents: They are two types of output current. They are average or d.c. current and RMS currents.

Average or DC current: The average current of a periodic function is defined as the area of one cycle of the curve divided by the base.

It is expressed mathematically as

Average value/dc value/mean value= $\frac{Area \quad over \quad one \quad period}{Total\ time\ period}$

$$V_{dc} = \frac{1}{T}\int_0^T V d(wt)$$

i) Effective (or) R.M.Scurrent:

The effective (or) R.M.S. current squared ofa periodic function of time is given by the area of one cycle of the curve, which represents the square of the function divided by the base.

$$V_{rms} = \sqrt{\frac{1}{T}\int_0^T V^2 d(wt)}$$

ii) Peakfactor:

It is the ratio of peak value to Rms value

$$\text{Peak factor} = \frac{peakvalue}{rmsvalue}$$

iii) Form factor:

It is the ratio of Rms value to average value

$$\text{Form factor} = \frac{Rmsvalue}{averagevalue}$$

iv) Ripple Factor (Γ) :

It is defined as ration of R.M.S. value of a.c. component to the d.c. component in the output is known as “Ripple Factor”.

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

$$V_{ac} =$$

$$\eta = \frac{o/p\ power}{i/p\ power}$$

v) Efficiency (η):

$$\sqrt{V_{rms}^2 - V_{dc}^2}$$

It is the ratio of d.c output power to the a.c. input power. It signifies, how efficiently the rectifier circuit converts a.c. power into d.c. power.

vi) Peak Inverse Voltage(PIV):

It is defined as the maximum reverse voltage that a diode can withstand without destroying the junction.

vii) Transformer Utilization Factor(UTF):

The d.c. power to be delivered to the load in a rectifier circuit decides the rating of the Transformer used in the circuit. So, transformer utilization factor is defined as

$$TUF = \frac{P_{dc}}{p_{ac(rated)}}$$

viii) %Regulation:

The variation of the d.c. output voltage as a function of d.c. load current is called regulation. The percentage regulation is defined as

$$\%\ \mathrm{Re}\,gulation = \frac{V_{NL} - V_{FL}}{V_{FL}} * 100$$

For an ideal power supply, % Regulation is zero.

CLASSIFICATION OFRECTIFIERS

Using one or more diodes in the circuit, following rectifier circuits can be designed.

1) Half - WaveRectifier
2) Full – WaveRectifier
3) Bridge Rectifier

HALF-WAVERECTIFIER:

A Half – wave rectifier as shown in **fig 1.21**is one, which converts a.c. voltage into a pulsating voltage using only one half cycle of the applied a.c. voltage.

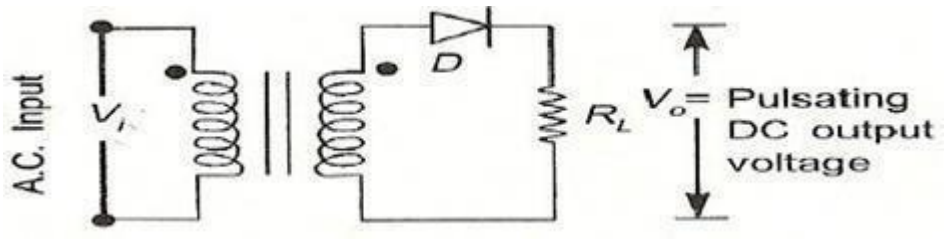
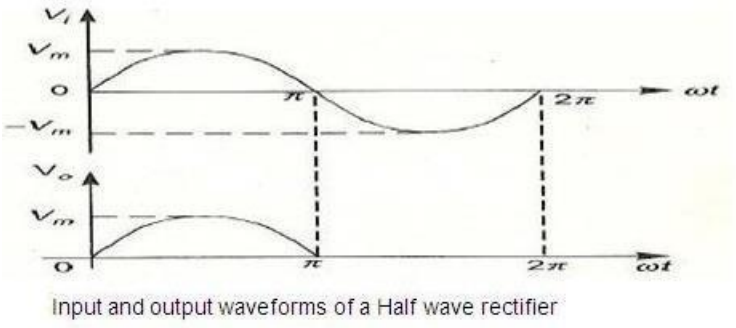


Fig 1.21: Half-Wave Rectifier

The a.c. voltage is applied to the rectifier circuit using step-down transformer-rectifying element i.e., p-n junction diode and the source of a.c. voltage, all connected is series. The a.c. voltage is applied to the rectifier circuit using step-down transformer



Input and output waveforms of a Half wave rectifier

Fig 1.22: Input Vs Output waveforms of Half-Wave Rectifier

$V=V_m \sin(wt)$

The input to the rectifier circuit, Where V_m is the peak value of secondary a.c. voltage.

Operation:

For the positive half-cycle of input a.c. voltage, the diode D is forward biased and hence it conducts. Now a current flows in the circuit and there is a voltage drop across RL. The waveform of the diode current (or) load current is shown in **fig 1.22**.

For the negative half-cycle of input, the diode D is reverse biased and hence it does not Conduct. Now no current flows in the circuit i.e., i=0 and Vo=0. Thus for the negative half- cycle no power is delivered to the load.

Analysis:

In the analysis of a HWR, the following parameters are to be analyzed.

1. DC outputcurrent
2. DC Outputvoltage
3. R.M.S.Current
4. R.M.S.voltage
5. Rectifier Efficiency (η)
6. Ripple factor (γ)
7. PeakFactor
8. %Regulation
9. Transformer Utilization Factor(TUF)

10. formfactor

11. o/pfrequency

Let a sinusoidal voltage Vi be applied to the input of the rectifier.

Then $V=V_m$ sin (wt) Where V_m is the maximum value of the secondary voltage. Let the diode be idealized to piece-wise linear approximation with resistance Rf in the forward direction i.e., in the ON state and Rr (=∞) in the reverse direction i.e., in the OFF state. Now the current 'i' in the diode (or) in the load resistance RL isgivenby $V=V_m \sin(wt)$

i) AVERAGE VOLTAGE

$$V_{dc} = \frac{1}{T}\int_0^T Vd(wt)$$

$$V_{dc} = \frac{1}{T}\int_0^{2\Pi} V(\alpha)d\alpha$$

$$V_{dc} = \frac{1}{2\Pi}\int_{\Pi}^{2\Pi} V(\alpha)d\alpha$$

$$V_{dc} = \frac{1}{2\Pi}\int_0 V_m \sin(wt)$$

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

ii).AVERAGE CURRENT:

$$I_{dc} = \frac{I_m}{\Pi}$$

iii) RMS VOLTAGE:

$$V_{rms} = \sqrt{\frac{1}{T}\int_0^T V^2 \, d(wt)}$$

$$V_{rms} = \sqrt{\frac{1}{2\Pi}\int_0^{2\Pi} (V_m sim(wt))\, d(wt)}$$

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

IV) RMS CURRENT

V) PEAK FACTOR

$$\boxed{I_{rms} = \frac{I_m}{\Pi}}$$

Peak factor = $\frac{peakvalue}{rmsvalue}$

Peak Factor = $\frac{V_m}{(V_m/2)}$

Peak Factor =2

Peak Factor =2

vi) FORM FACTOR

$$\text{Form factor} = \frac{Rmsvalue}{averagevalue}$$

$$\text{Form factor} = \frac{(V_m/2)}{V_m/\Pi}$$

Form Factor =1.57

vii) Ripple Factor: $\Gamma = \frac{V_{ac}}{V_{dc}}$

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

$$\Gamma = \frac{\sqrt{V_{rms}^2 - V_{dc}^2}}{V_{ac}}$$

$$\Gamma = \sqrt{\frac{V_{rms}^2}{V_{dc}^2} - 1}$$

$$\Gamma = 1.21$$

viii) Efficiency (η):

$$\eta = \frac{o/p\ power}{i/p\ power} * 100$$

$$\eta = \frac{P_{ac}}{P_{dc}} * 100$$

η =40.8

ix)Transformer Utilization Factor(TUF):

The d.c. power to be delivered to the load in a rectifier circuit decides the rating of the transformer used in the circuit. Therefore, transformer utilization factor is defined as

$$TUF = \frac{p_{dc}}{P_{ac(rated)}}$$

TUF =0.286.

The value of TUF is low which shows that in half-wave circuit, the transformer is not fully utilized.

If the transformer rating is 1 KVA (1000VA) then the half-wave rectifier can deliver

1000 X 0.287 = 287 watts to resistance load.

vi)Peak Inverse Voltage(PIV):

It is defined as the maximum reverse voltage that a diode can withstand without destroying the junction. The peak inverse voltage across a diode is the peak of the negative half- cycle. For half-wave rectifier, PIV is Vm.

DISADVANTAGES OF HALF-WAVE RECTIFIER:

1. The ripple factor ishigh.
2. The efficiency is low.
3. The Transformer Utilization factor islow.

Because of all these disadvantages, the half-wave rectifier circuit is normally not used as a power rectifier circuit.

FULL WAVERECTIFIER:

A full-wave rectifier converts an ac voltage into a pulsating dc voltage using both half cycles of the applied ac voltage. In order to rectify both the half cycles of ac input, two diodes are used in this circuit. The diodes feed a common load RL with the help of a center-tap transformer. A center-tap transformer is the one, which produces two sinusoidal waveforms of same magnitude and frequency butoutofphasewithrespecttothegroundinthesecondarywindingofthetransformer.Thefullwave rectifier is shown in the **fig 1.23.**

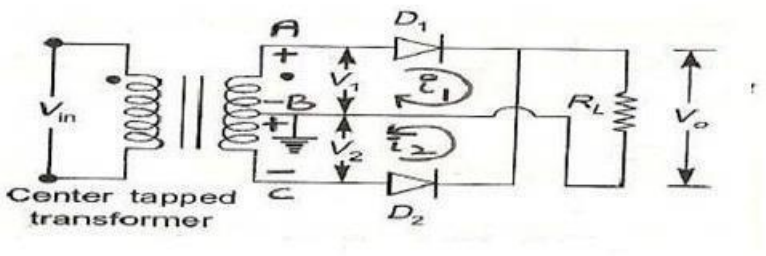


Fig 1.23: Center Tapped Full Wave Rectifier

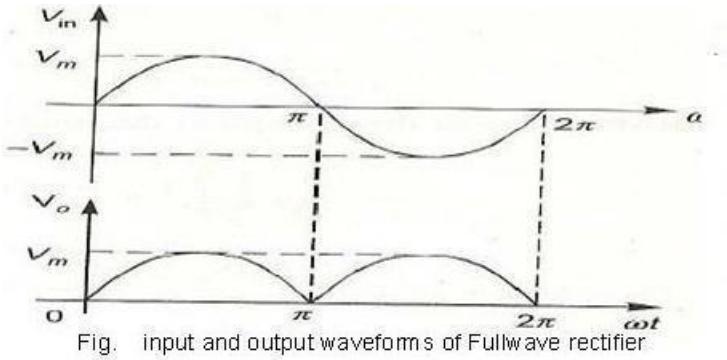


Fig. input and output waveforms of Fullwave rectifier

Fig. 1.24Input and output wave forms of Center Tapped Full Wave Rectifier

Duringpositivehalfoftheinputsignal,anodeofdiodeD1becomespositiveandatthe same time the anode of diode D2 becomes negative. Hence D1 conducts and D2 doesnot conduct.TheloadcurrentflowsthroughD1andthevoltagedropacrossRLwillbeequaltotheinput voltage.

Duringthenegativehalfcycleoftheinput,theanodeofD1becomesnegativeandtheanodeof D2 becomes positive. Hence, D1 does not conduct and D2 conducts. The load current flows through D2 and the voltage drop across RL will be equal to the input voltage. It is noted that the load current flows in the both the half cycles of ac voltage and in the same direction through the loadresistance.

i) AVERAGEVOLTAGE

$$V_{dc} = I_{dc}.R_L = \frac{2I_m}{\pi}.R_L \quad \text{We know } I_m = \frac{V_m}{R_S + R_f + R_L}$$

$$\therefore V_{dc} = \frac{2V_m R_L}{\pi(R_S + R_f + R_L}$$

$$If\,(R_s + R_f) << R_L$$

$$V_{dc} = \frac{2V_m}{\pi} = 0.637V_m.$$

ii) AVERAGE CURRENT

$$\frac{1}{2\pi}\int_0^{2\pi} id\theta = \frac{1}{2\pi}\int_0^{2\pi} I_m \sin\theta d\theta$$

$$I_{dc} = \frac{I_m}{2\pi}\left[\int_0^{\pi} \sin\theta d\theta - \int_{\pi}^{2\pi} \sin\theta d\theta\right]$$

$$= \frac{I_m}{2\pi}[(-2)(-2)]$$

$$= \frac{I_m}{2\pi}.4 = \frac{2I_m}{\pi} = 0.637\, I_m.$$

$$\boxed{I_{dc} = 0.637 I_m.}$$

$$\therefore I_{DC}\ FWR = 2\ I_{DC}\ HWR.$$

iii) RMSVOLTAGE:

$$V_{rms} = \sqrt{\frac{1}{T}\int_0^T V^2 d\,(wt)}$$

$$V_{rms} = \sqrt{\frac{1}{2\Pi}\int_0^{2\Pi} (V_m sim(wt))\, d\,(wt)}$$

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

IV) RMSCURRENT

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

V) PEAKFACTOR

Peak factor **=** $\dfrac{peakvalue}{rmsvalue}$

Peak Factor = $\frac{V_m}{(V_m/2)}$

Peak Factor =2

vi) FORMFACTOR

Form factor= $\frac{Rms\ value}{average value}$

Form factor= $\frac{(V_m/\sqrt{2})}{2V_m/\Pi}$

Form Factor =1.11

vii) RippleFactor:

$$\gamma = \sqrt{\left(\frac{I_{rms}}{I_{dc}}\right)^2 - 1}$$

for FWR,

$$I_{rms} = \frac{I_m}{\sqrt{2}} \quad \& \quad I_{DC} = \frac{2I_m}{\pi}$$

$$\therefore \gamma_{FWR} = \sqrt{\left(\frac{I_m}{\sqrt{2}} / \frac{2I_m}{\pi}\right)^2 - 1}$$

$$= \sqrt{\left(\frac{\pi}{2\sqrt{2}}\right)^2 - 1}$$

$$= \sqrt{\left(\frac{3.1416}{2\times 1.414}\right)^2 - 1} = 0.483$$

viii) Efficiency (η):

$$\eta = \frac{o/ppower}{i/ppower} * 100$$

$$\eta = \frac{P_{dc}}{P_{ac}} \times 100\%$$

For FWR, $p_{dc} = I_{dc}^2 . R_L = \left(\frac{2}{\pi} . I_m\right)^2 . R_L$

$P_{ac} = I^2_{rms} (R_f + R_S + R_L)$

$$\left(\frac{I_m}{\sqrt{2}}\right)^2 (R_f + R_S + R_L)$$

$$\eta = \frac{\frac{I^2_m 4}{\pi^2} . R_L}{\frac{I^2 m^2}{2} . (R_f + R_s + R_L)}$$

$$If\ (R_f + R_S) << R_L$$

$$\eta = \frac{4}{\pi^2} . \frac{2}{1} = \frac{8}{\pi^2} = 0.812 = 81.2\%$$

ix) Transformer Utilization Factor(TUF):

The d.c. power to be delivered to the load in a rectifier circuit decides the rating of the transformer used in the circuit. So, transformer utilization factor is defined as

$$TUF = \frac{p_{dc}}{P_{ac(rated)}}$$

a) TUF (Secondary) = $\frac{P_{dc}\ delivered\ to\ load}{AC\ power\ rating\ of\ transformer\ secondary}$

b) Since both the windings are used $TUF_{FWR} = 2\ TUF_{HWR}$

$= 2 \times 0.287 = 0.574$

c) TUF primary = Rated efficiency = $\frac{P_{dc}}{P_{ac}} \times 100 = 81.2\%$

d) Average = $\frac{0.812 + 0.574}{2} = 0.693$

x) Peak Inverse Voltage(PIV):

It is defined as the maximum reverse voltage that a diode can withstand without destroying the junction. The peak inverse voltage across a diode is the peak of the negative half- cycle. For half- wave rectifier, PIV is 2Vm

xi) % Regulation

$$\text{Voltage regulation} = \frac{I_{dc}(R_s + R_f)}{\frac{2V_m}{\pi} - I_{DC}(R_f + R_S)}$$

.

Advantages

1) Ripple factor = 0.482 (against 1.21 forHWR)
2) Rectification efficiency is 0.812 (against 0.405 forHWR)
3) Better TUF (secondary) is 0.574 (0.287 forHWR)
4) No core saturationproblem

Disadvantages:

1) Requires center tappedtransformer.

BRIDGERECTIFIER.

Another type of circuit that produces the same output waveform as the full wave rectifier circuit above, is that of the **Full Wave Bridge Rectifier**. This type of single phase rectifier uses four individual rectifying diodes connected in a closed loop "bridge" configuration to produce the desired output. The main advantage of this bridge circuit is that it does not require a special centre tapped transformer, thereby reducing its size and cost. The single secondary winding is connected to one side of the diode bridge network and the load to the other side as shown below.

The Diode Bridge Rectifier

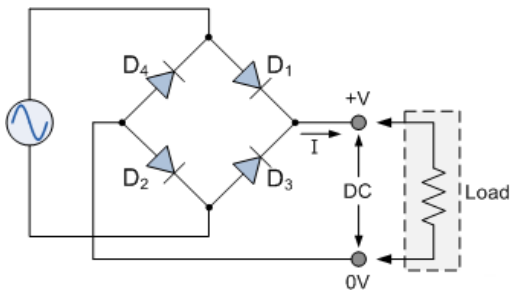
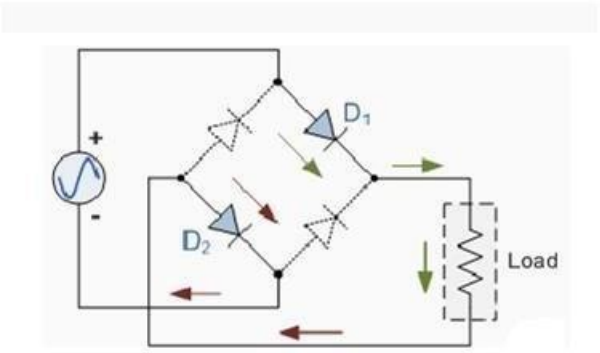


Fig 1.25: Bridge Rectifier

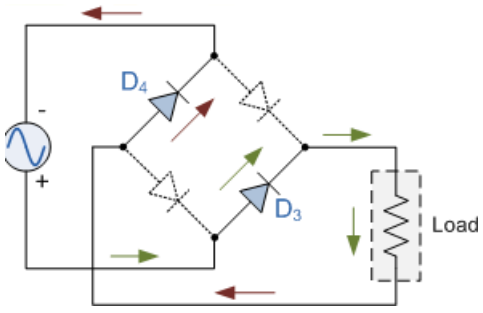
The four diodes labelled D_1 to D_4 are arranged in "series pairs" with only two diodes conducting current during each half cycle. During the positive half cycle of the supply, diodes D1 and D2 conduct in series while diodes D3 and D4 are reverse biased and the current flows through the load as shown below.

The Positive Half-cycle



The Negative Half-cycle

During the negative half cycle of the supply, diodes D3 and D4 conduct in series , but diodes D1 and D2 switch "OFF" as they are now reverse biased. The current flowing through the load is the same direction as before.



As the current flowing through the load is unidirectional, so the voltage developed across the load is also unidirectional the same as for the previous two diode full-wave rectifier, therefore the average DC

voltage across the load is $0.637V_{max}$. However in reality, during each half cycle the current flows through two diodes instead of just one so the amplitude of the output voltage is two voltage drops (2 x 0.7 = 1.4V) less than the input V_{MAX} amplitude. The ripple frequency is now twice the supply frequency (e.g. 100Hz for a 50Hz supply)

Therefore, the following expressions are same as that of full wave rectifier.

a) Average current $I_{dc} = \frac{2I_m}{\pi}$

b) RMS current $I_{rms} = \frac{I_m}{\sqrt{2}}$

c) DC output voltage (no.load) V_{DC} $\frac{2V_m}{\pi}$

d) Ripple factor $\gamma = 0.482$

e) Rectification efficiency = $\eta = 0.812$

f) DC output voltage full load.

= $V_{DCFL} = \frac{2V_m}{\pi} - I_{dc}(R_S + 2R_f)$; i.e., less by one diode loss.

TUF of both primary & secondary are 0.812 therefore TUF overall is 0.812 (better than FWR with 0.693)

Comparison:

Sl. No.	Parameter	HWR	FWR	BR
1	No. of diodes	1	2	4
2	PIV of diodes	V_m	2 V_m	V_m
3	Secondary voltage (rms)	V	V-0-V	V
4	DC output voltage at no load	$\frac{V_m}{\pi}$ =0.318 V_m	$\frac{2V_m}{\pi}$ =0.636 V_m	$\frac{2V_m}{\pi}$ =0.636 V_m
5	Ripple factor γ	1.21	0.482	0.482
6	Ripple frequency	f	2f	2f
7	Rectification efficiency η	0.406	0.812	0.812
8	TUF	0.287	0.693	0.812

FILTERS

The output of a rectifier contains dc component as well as ac component. Filters are used to minimize the undesirable ac i.e., ripple leaving only the dc component to appear at the output.

Some important filters are:

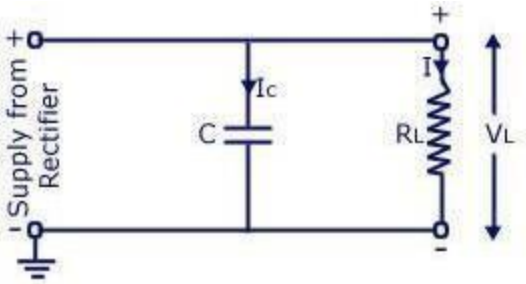
1. Inductorfilter
2. Capacitorfilter
3. LC or L sectionfilter
4. CLC or Π-typefilter

CAPACITORFILTER

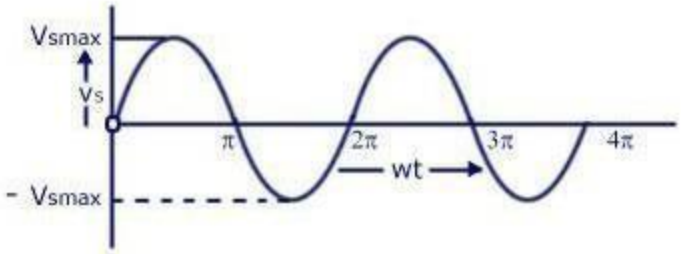
This is the most simple form of the **filter circuit**and in this arrangement a high value capacitor C is placed directly across the output terminals, as shown in figure. During the conduction period it gets charged and stores up energy to it during non-conduction period. Through this process, the time duration during which Ft is to be noted here that the capacitor C gets charged to the peak because there is no resistance (except the negligible forward resistance of diode) in the charging path. But the discharging time is quite large (roughly 100 times more than the charging time depending upon the value of RL) because it discharges through load resistance RL.

The function of the capacitor filter may be viewed in terms of impedances. The large value capacitor C offers a low impedance shunt path to the ac components or ripples but offers high impedance to the dc component. Thus ripples get bypassed through capacitor C and only dc component flows through the load resistanceRL

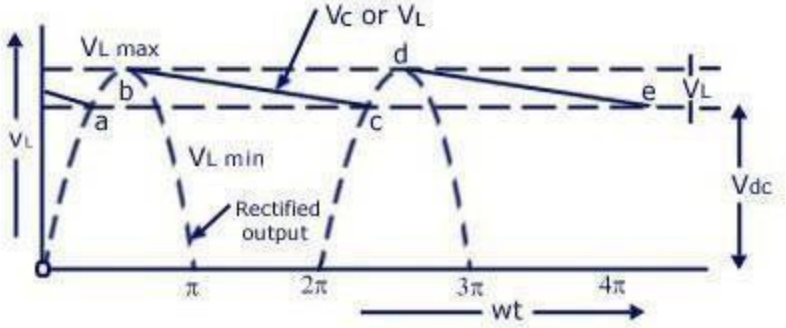
Capacitor filter is very popular because of its low cost, small size, light weight and good characteristics.



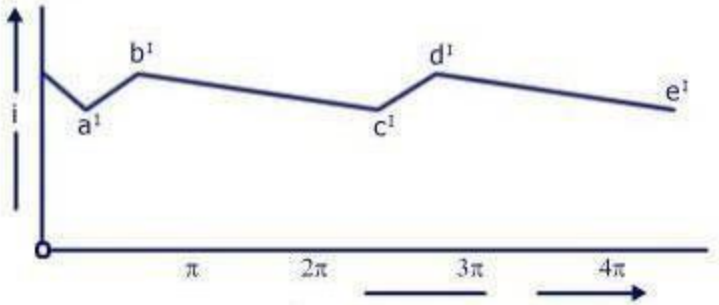
Circuit Diagram



Input voltage Waveform to Rectifier



Rectified and filtered Output Voltage Waveform



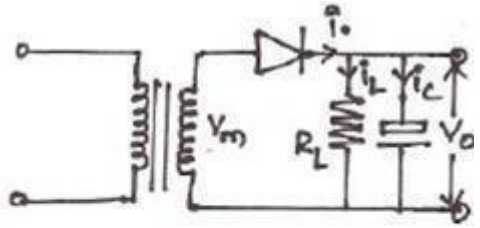
Load Current Waveform

Half-wave Rectifier With Shunt Capacitor Filter

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Fig 1.26: Shunt Capacitor Filter

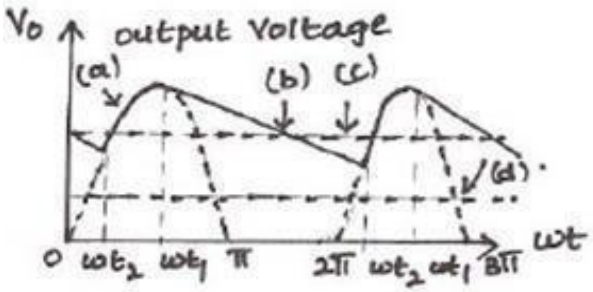
CAPACITOR FILTER WITH HWR



Cut In angle – wt_2

Cut out angle = Wt_1

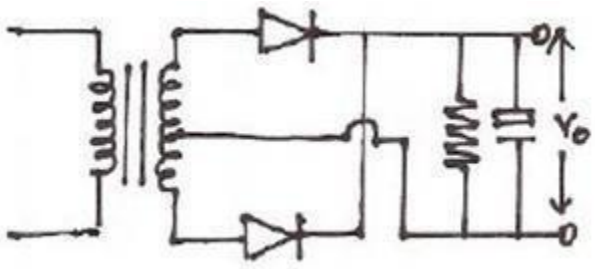
$Wt_1 = \pi - \tan^{-1} WCR_L$

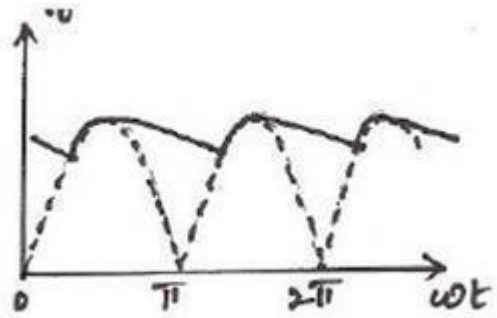


(a) Capacitor charging through diode ($Wt_2 - Wt_1$)
(b) Capacitor discharging through R_L (Wt_1 to Wt_2)
(c) Average (DC) voltage with fitter
(d) Average (DC) voltage without fitter.

Fig 1.27: Half Wave Rectifier with Shunt capacitor Filter

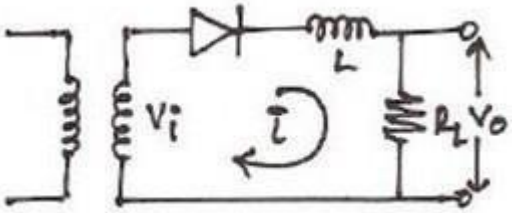
CAPACITOR FILTER WITH FWR





$$\text{Ripple factor } r = \frac{1}{4\sqrt{3}fCR_L}$$

$$\text{Ripple freq}_{FWR} = 2 \text{ ripple freq}_{HWR}.$$



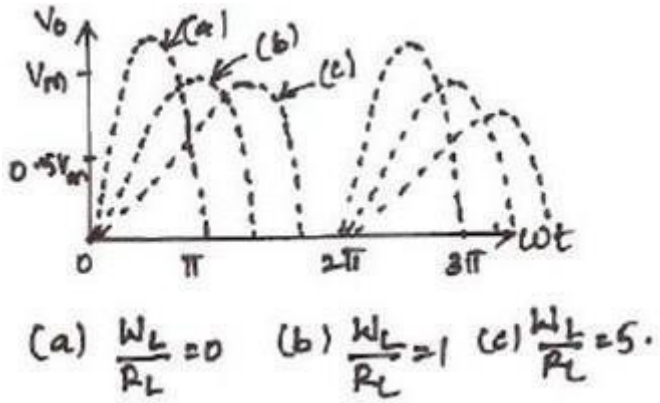


Fig 1.28: Full Wave Rectifier with Shunt capacitor Filter

Important points about shunt capacitor filter are:

1. For a fixed-value filter capacitance larger the load resistance RL larger will be the discharge time constant CRL and therefore, lower the ripples and more the output voltage. On the other hand lower the load resistance (or more the load current), lower will be the outputvoltage.

2. Similarly smaller the filter capacitor, the less charge it can hold and more it will discharge. Thus the peak-to-peak value of the ripple will increase, and the average dc level will decrease. Larger the filter capacitor, the more charge it can hold and the less it will discharge. Hence the peak-to-peak value of the ripple will be less, and the average dc level will increase. But, the maximum value of the capacitance that can be employed is limited by another factor. The larger the capacitance value, the greater is the current required to charge the capacitor to a given voltage. The maximum current that can be handled by a diode is limited by the figure quoted by the manufacturer. Thus the maximum value of the capacitance, that can be used in the shunt filter capacitor islimited.

Series InductorFilter.

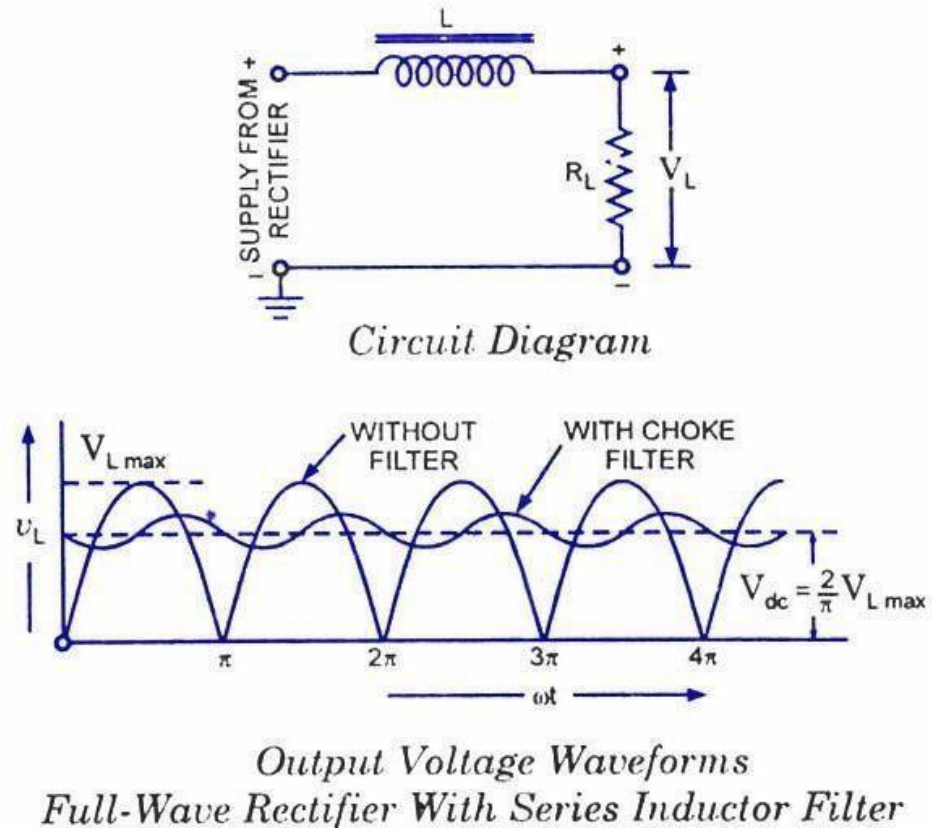


Fig 1.29: Full Wave Rectifier with Series Inductor Filter

In this arrangement a high value inductor or choke L is connected in series with the rectifier element and the load, as illustrated in figure. The filtering action of an inductor filter depends upon its property of opposing any change in the current flowing through it. When the output current of the rectifierincreases above a certain value, energy is stored in it in the form of magnetic field and this

energy is given up when the output current falls below the average value. Thus by placing a choke coil in series with the rectifier output and load, any sudden change in current that might have occurred in the circuit without an inductor is smoothed out by the presence of the inductor L.

The function of the inductor filter may be viewed in terms of impedances. The choke offers high impedance to the ac components but offers almost zero resistance to the desired dc components. Thus ripples are removed to a large extent. Nature of the output voltage without filter and with choke filter is shown in figure.

For dc (zero frequency), the choke resistance R_c in series with the load resistance R_L forms a voltage divider and dc voltage across the load is given as

where V_{dc} is dc voltage output from a full-wave rectifier. Usually choke coil resistance Rc, is much small than R_L and, therefore, almost entire of the dc voltage is available across the load resistance R_L.

Since the reactance of inductor increases with the increase in frequency, better filtering of the higher harmonic components takes place, so effect of third and higher harmonic voltages can be neglected.

As obvious from equation , if choke coil resistance R_c is negligible in comparison to load resistance R_L, then the entire dc component of rectifier output is available across 2 R_L and is equal to — V_{Lmax}. The ac voltage partly drops across X_L and partly over R_L.

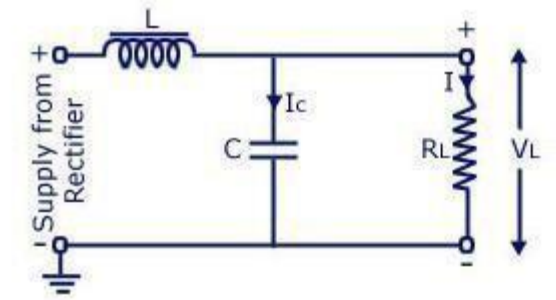
L-SECTIONFILTER:

A simple series inductor reduces both the peakand effective values of the output current and output voltage. On the other hand a simple **shunt capacitor filter**reduces the ripple voltage but increases the diode current. The diode may get damaged due to large current and at the same time it causes greater heating of supply transformer resulting in reduced efficiency.

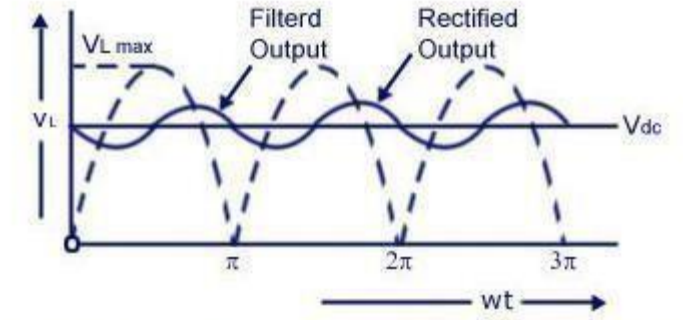
In an inductor filter, ripple factor increases with the increase in load resistance RL while in a capacitor filter it varies inversely with load resistance RL.

From economical point of view also, neither series inductor nor shunt capacitor type filters are suitable.

Practical **filter-circuits**are derived by combining the voltage stabilizing action of shunt capacitor with the current smoothing action of series choke coil. By using combination of inductor and capacitor ripple factor can be lowered, diode current can be restricted and simultaneously ripple factor can be made almost independent of load resistance (or load current). Two types of most commonly used combinations are choke-input or L-section filter-and capacitor-input orPi-Filter.



Circuit Digram



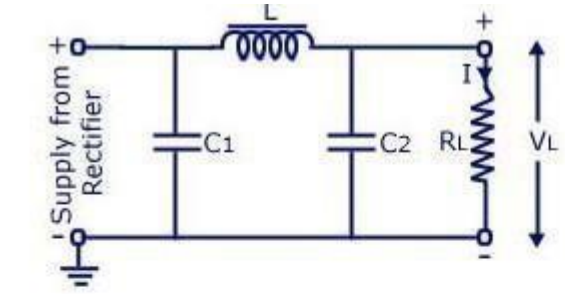
Rectified and Filtered Output Voltage Waveform
Full-wave Rectifier With Choke-Input Filter

Fig 1.30: Full Wave Rectifier with Choke Input Filter

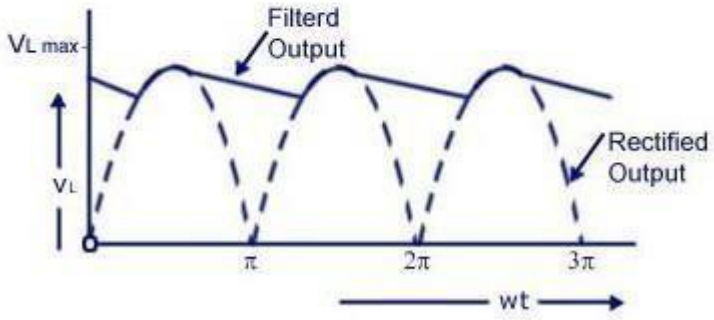
Choke-input filter is explained below:

Choke-input filter consists of a choke L connected in series with the rectifier and a capacitor C connected across the load . This is also sometimes called the L-section filter because in this arrangement inductor and capacitor are connected, as an inverted L. ln figure only one filter section is shown. But several identical sections are often employed to improve the smoothing action. (The choke L on the input side of the filter readily allows dc to pass but opposes the flow of ac components because its dc resistance is negligibly small but ac impedance is large. Any fluctuation that remains in the current even after passing through the choke are largely by-passed around the load by the shunt capacitor because Xc is much smaller than RL. Ripples can be reduced effectively by making XL greater than Xc at ripple frequency. However, a small ripple still remains in the filtered output and this is considered negligible if it than l%. The rectified and filtered output voltage waveforms from a full-wave re with choke-input filter are shown in figure.

Π-SECTION FILTER:



Circuit Digram



Rectified and Filtered Output Voltage Waveform
Full-wave Rectifier With capacitor Input Filter

Fig 1.31: Full Wave Rectifier with Capacitor Input Filter

Capacitor-Input or Pi-Filter.

Such a filter consists of a shunt capacitor C1 at the input followed by an L-section filter formed by series inductor L and shunt capacitor C_2. This is also called the *n-filter* because the shape of the circuit diagram for this filter appears like Greek letter *n (pi)*. Since the rectifier feeds directly into the capacitor so it is also called *capacitor inputfilter.*

As the rectified output is fed directly into a capacitor C1. Such a filter can be used with a half-wave rectifier (series inductor and L-section filters cannot be used with half-wave rectifiers). Usually electrolytic capacitors are used even though their capacitances are large but they occupy minimum space. Usually both capacitors C1 and C_2 are enclosed in one metal container. The metal container serves as, the common ground for the two capacitors.

A capacitor-input or *pi*- filter is characterized by a high voltage output at low current drains. Such a filter is used, if, for a given transformer, higher voltage than that can be obtained from an L-section filter is required and if low ripple than that can be obtained from a shunt capacitor filter or L-section filter is desired. In this filter, the input capacitor C1 is selected to offer very low reactance to the ripple frequency. Hence major part of filtering is accomplished by the input capacitor *C1.* Most of the remaining ripple is removed by the L-section filter consisting of a choke L and capacitorC_2.)

The action of this filter can *best* be understood by considering the action of L-section filter, formed by L and C_2, upon the triangular output voltage wave from the input capacitor C_1 The charging and discharging action of input capacitor C1 has already been discussed. The output voltage is roughly the same as across input capacitor C1 less the dc voltage drop in inductor. The ripples contained in this output are reduced further by L-section filter. The output voltage of pi-filter falls off rapidly with the increase in load-current and, therefore, the voltage regulation with this filter is very poor.

SALIENT FEATURES OF L-SECTION AND PI-FILTERS.

1. In pi-filter the dc output voltage is much larger than that can be had from an L-section filter with the same inputvoltage.

2.In pi-filter ripples are less in comparison to those in shunt capacitor or L-section filter. So smaller valued choke is required in a pi-filter in comparison to that required in L-sectionfilter.

3.In pi-filter, the capacitor is to be charged to the peak value hence the rms current in supply transformer is larger as compared in case of L-sectionfilter.

4.Voltage regulation in case of pi-filter is very poor, as already mentioned. So n-filters are suitable for fixed loads whereas L-section filters can work satisfactorily with varying loads provided a minimum current is maintained.

5.In case of a pi-filter PIV is larger than that in case of an L-sectionfilter.

COMPARISON OF FILTERS

1) A capacitor filter provides Vm volts at less load current. But regulation ispoor.

2) An Inductor filter gives high ripple voltage for low load currents. It is used for

high loadcurrents

3) L – Section filter gives a ripple factor independent of load current.Voltage

Regulation can be improved by use of bleederresistance

4) Multiple L – Section filter or π filters give much less ripple than the single L –

Section Filter.

UNIT II: Biasing and Stabilization:

Biasing and Stabilization: Operating point, the D.C Load line, Fixed bias, Collector to base bias, Self-bias techniques for stabilization, Stabilization factors, (s, s^{I}), Bias Compensation using diode and transistor , (Compensation against variation in V_{BE}, I_{CO}). Thermal runaway and Thermal stability

TRANSISTOR BIASING AND STABILIZATION

NEED FOR TRANSISTORBIASING

If the o/p signal must be a faithful reproduction of the i/p signal, the transistor must be operated in active region. That means an operating point has to be established in this region . To establish an operating point (proper values of collector current $I_c$and collector to emitter voltage V_{CE}) appropriate supply voltages and resistances must be suitably chosen in the ckt. This process of selecting proper supply voltages and resistance for obtaining desired operating point or Q point is called as biasing and the ckt used for transistor biasing is called as biasingckt.

There are four conditions to be met by a transistor so that it acts as a faithful ampr:

1) Emitter base junction must be forward biased (V_{BE}=0.7Vfor Si, 0.2V for Ge) and collector base junction must be reverse biased for all levels of i/psignal.
2) V_{ce} voltage should not fall below $V_{CE(sat)}$ (0.3V for Si, 0.1V for Ge) for any part of the i/p signal. For V_{CE} less than $V_{CE(sat)}$ the collector base junction is not probably reverse biased.
3) The value of the signal I_c when no signal is applied should be at least equal to the max. collector current t due to signalalone.
4) Max. rating of the transistor $I_{c(max)}$, $V_{CE(max)}$ and $P_{D(max)}$ should not be exceeded at any value of i/p signal.

Consider the fig shown in fig 2.12. If operating point is selected at A, A represents a condition when no bias is applied to the transistor i.e, I_c=0, V_{CE} =0. It does not satisfy the above said conditions necessary for faithful amplification.

Point C is too close to $P_{D(max)}$ curve of the transistor. Therefore the o/p voltage swing in the positive direction is limited.

Point B is located in the middle of active region .It will allow both positive and negative half cycles in the o/p signal. It also provides linear gain and larger possible o/p voltages andcurrents

Hence operating point for a transistor amplifier is selected to be in the middle of active region.

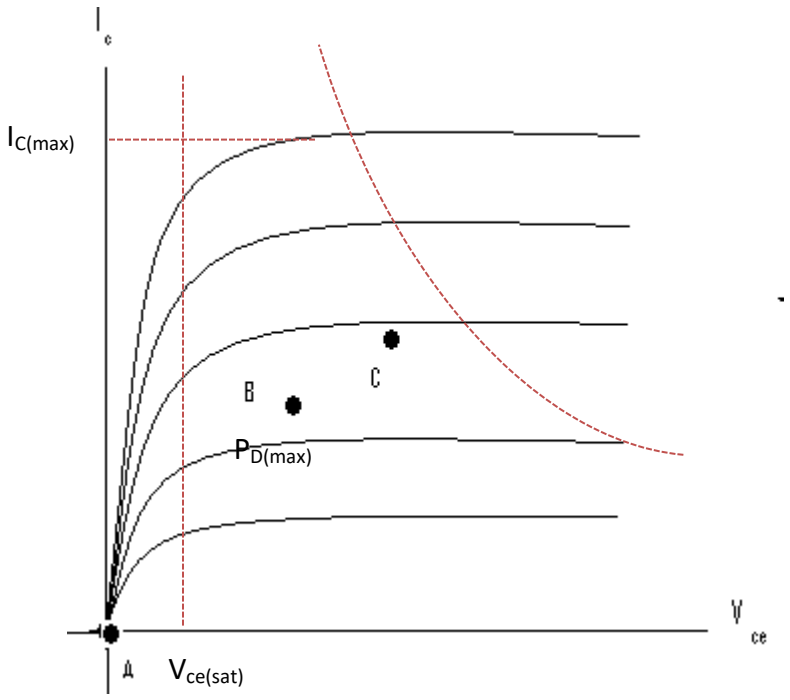


Fig 2.12 CE Output Characteristics

DC LOADLINE

Referring to the biasing circuit of fig 2.13 a, the values of V_{CC} and R_C are fixed and Ic and V_{CE} are dependent on R_B.

Applying Kirchhoff's voltage law to the collector circuit in fig. 2.13, we get

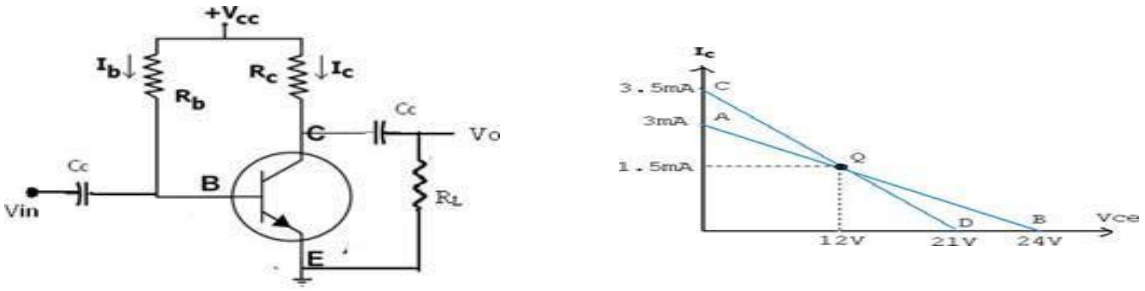


Fig 2.13(a) CE Amplifier Circuit (b) Load line

$$Vcc = IcRc + Vce$$

The straight line represented by AB in fig2.13b is called the dc load line. The coordinates of the end point A are obtained by substituting V_{CE} =0 in the above equation. Then $Ic = \frac{Vcc}{Rc}$. Therefore The coordinates of A are V_{CE} =0 and $Ic = \frac{Vcc}{Rc}$.

The coordinates of B are obtained by substituting Ic=0 in the above equation. Then Vce = Vcc. Therefore the coordinates of B are V_{CE} =Vcc and Ic=0. Thus the dc load line AB can be drawn if the values of Rc and Vcc are known.

As shown in the fig2.13b, the optimum POINT IS LOCATED AT THE MID POINT OF THE MIDWAY BETWEEN a AND b. In order to get faithful amplification, the Q point must be well within the active region of the transistor.

Even though the Q point is fixed properly, it is very important to ensure that the operating point remains stable where it is originally fixed. If the Q point shifts nearer to either A or B, the output voltage and current get clipped, thereby o/p signal is distorted.

In practice, the Q-point tends to shift its position due to any or all of the following three main factors.

1) Reverse saturation current, Ico, which doubles for every 10°C raise intemperature
2) Base emitter Voltage ,VBE, which decreases by 2.5 mV per°C
3) Transistor current gain, h_{FE} or β which increases withtemperature.

If base current I_B is kept constant since I_B is approximately equal to Vcc/RB. If the transistor is replaced by another one of the same type, one cannot ensure that the new transistor will have identical parameters as that of the first one. Parameters such as β vary over a range. This results in the variation of collector current Ic for a given I_B. Hence , in the o/p characteristics, the spacing between the curves might increase or decrease which leads to the shifting of the Q-point to a location which might be completelyunsatisfactory.

AC LOADLINE

After drawing the dc load line, the operating point Q is properly located at the center of the dc load line. This operating point is chosen under zero input signal condition of the circuit. Hence the ac load line should also pas through the operating point Q. The effective ac load resistance R_{ac}, is a combination of R_C parallel toR_L i.e. $R_{ac} = R_L||R_C$. So the slope of the ac load line CQD will be $\left(\frac{-1}{R_{ac}}\right)$. To draw the ac load line, two end points, I.e. $V_{CE(max)}$ and $I_{C(max)}$ when the signal is applied arerequired.

$V_{CE(\max)} = V_{CEQ} + I_{CQ}R_{ac}$, which locates point D on the Vce axis.

$I_{c(\max))} = I_{CQ} + \frac{V_{CEQ}}{R_{ac}}$, which locates the point C on the I_C axis.

By joining points c and D, ac load line CD is constructed. As $R_C > R_{ac}$, The dc load line is less steep than ac load line.

STABILITY FACTOR(S):

The rise of temperature results in increase in the value of transistor gain β and the leakage current Ico. So, I_C also increases which results in a shift in operating point. Therefore, The biasing network should be provided with thermal stability. Maintenance of the operating point is specified by S, which indicates the degree of change in operating point due to change intemperature.

The extent to which I_C is stabilized with varying I_C is measured by a stability factor S

$$S = \frac{\partial I_c}{\partial I_{co}} \approx \frac{dI_c}{dI_{co}} \approx \frac{\Delta I_c}{\Delta I_{co}}, \ \beta \text{ and } I_B \text{ constant}$$

For CEconfiguration $I_C = \beta I_B + (1+\beta) I_{CO}$

Differentiate the above equation w.r.t I_C , We get

$$1 = \beta \frac{dI_B}{dI_C} + (1+\beta) \frac{dI_{co}}{dI_c}$$

$$\therefore \left(1 - \beta \frac{dI_B}{dI_C}\right) = \frac{(\beta+1)}{S}$$

$$\therefore S = \frac{1+\beta}{1-\beta \frac{dI_B}{dI_C}}$$

S should be small to have better thermal stability.

Stability factor S' and S'':

S' is defined as the rate of change of I_C with V_{BE}, keeping I_C and V_{BE} constant.

$$S' = \frac{\partial I_c}{\partial V_{BE}}$$

S'' is defined as the rate of change of I_C with β, keeping I_{CO} and V_{BE}constant.

$$S'' = \frac{\partial I_c}{\partial \beta}$$

METHODS OF TRANSISTORBIASING

1) Fixed bias (basebias)

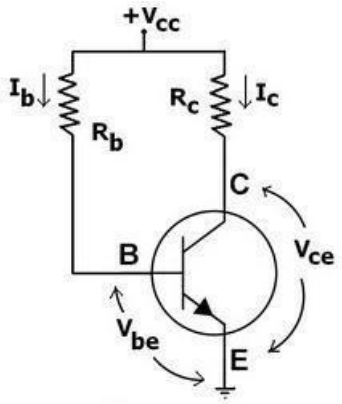


Fig 2.14 Fixed Biasing Circuit

This form of biasing is also called *base bias*. In the fig 4.3 shown, the single power source (for example, battery) is used for both collector and base of a transistor, although separate batteries can also be used.

In the given circuit,

$V_{cc} = I_B R_B + V_{be}$

Therefore, $I_B = (V_{cc} - V_{be})/R_B$

Since the equation is independent of current $I_C R$, $dI_B/dI_C R = 0$ and the stability factor is given by the equation….. reduces to

$S = 1+\beta$

Since β is a large quantity, this is very poor biasing circuit. Therefore in practice the circuit is not used fo biasing.

For a given transistor, V_{be} does not vary significantly during use. As V_{cc} is of fixed value, on selection of R the base current I_B is fixed. Therefore this type is called *fixed bias* type ofcircuit.

Also for given circuit, $V_{cc} = I_C R_C + V_{ce}$

Therefore, $V_{ce} = V_{cc} - I_C R_C$

Merits:

- It is simple to shift the operating point anywhere in the active region bymerely changing the base resistor(R_B).
- A very small number of components arerequired.

Demerits:

- The collector current does not remain constant with variation in temperature orpower supply voltage. Therefore the operating point isunstable.
- Changes in V_{be} will change I_B and thus cause R_E to change. This in turn will alter the gain of thestage.
- When the transistor is replaced with another one, considerable change in the value ofβ can be expected. Due to this change the operating point willshift.

2) EMITTER-FEEDBACKBIAS:

The emitter feedback bias circuit is shown in the fig 2.15. The fixed bias circuit is modified by attaching an external resistor to the emitter. This resistor introduces negative feedback that stabilizes the Q-point. From Kirchhoff's voltage law, the voltage across the base resistor is

$V_{Rb} = V_{CC} - I_e R_e - V_{be}$.

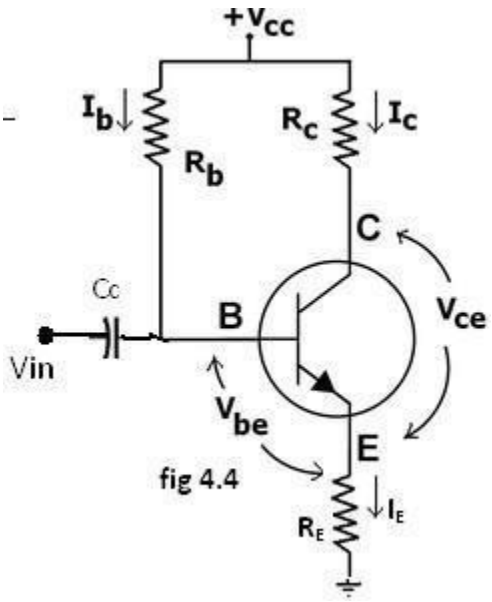


fig 4.4

Fig 2.15 Self Biasing Circuit

From Ohm's law, the base current is

$I_b = V_{Rb} / R_b$.

The way feedback controls the bias point is as follows. If V_{be} is held constant and temperature increases, emitter current increases. However, a larger I_e increases the emitter voltage $V_e = I_e R_e$, which in turn reduces the voltage V_{Rb} across the base resistor. A lower base-resistor voltage drop reduces the base current, which results in less collector current because I_c = ß I_B. Collector current and emitter current are related by $I_c = \alpha I_e$ with $\alpha \approx 1$, so increase in emitter current with temperature is opposed, and operating point is kept stable.

Similarly, if the transistor is replaced by another, there may be a change in I_C (corresponding to change in β-value, for example). By similar process as above, the change is negated and operating point kept stable.

For the given circuit,

$I_B = (V_{CC} - V_{be})/(R_B + (\beta+1)R_E)$.

Merits:

The circuit has the tendency to stabilize operating point against changes in temperature and β-value.

Demerits:

- In this circuit, to keep I_C independent of β the following condition must bemet:

$$I_C = \beta I_B = \frac{\beta(V_{CC} - V_{be})}{R_B + (\beta + 1)R_E} \approx \frac{(V_{CC} - V_{be})}{R_E}$$

which is approximately the case if $(\beta + 1)R_E >> R_B$.

- Asβ-valueisfixedforagiventransistor,thisrelationcanbesatisfiedeitherbykeeping R_E very large, or making R_B verylow.

- If R_E is of large value, high V_{CC} is necessary. This increases cost as well as precautions necessary whilehandling.
- If R_B is low, a separate low voltage supply should be used in the base circuit. Using two supplies of different voltages isimpractical.

- In addition to the above, R_E causes ac feedback which reduces the voltage gain of theamplifier.

3)COLLECTOR TO BASE BIAS OR COLLECTOR FEED-BACKBIAS:

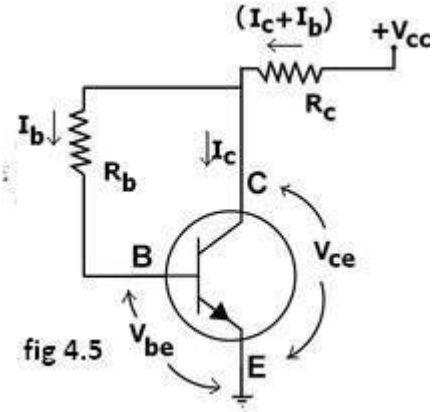


Fig 2.16 Collector to Base Biasing Circuit

This configuration shown in fig 2.16 employs negative feedback to prevent thermal runaway and stabilize the operating point. In this form of biasing, the base resistor $R_B$is connected to the collector instead of connecting it to the DC source V_{cc}. So any thermal runaway will induce a voltage drop across the $R_C$resistor that will throttle the transistor's base current.

From Kirchhoff's voltage law, the voltage V_{R_b}across the base resistor $R_b$is

$$V_{R_b} = V_{cc} - \overbrace{(I_c + I_b)R_c}^{\text{Voltage drop across } R_c} - \overbrace{V_{be}}^{\text{Voltage at base}}.$$

By the Ebers–Moll model, $I_c = \beta I_b$, and so

$$V_{R_b} = V_{cc} - (\overbrace{\beta I_b}^{I_c} + I_b)R_c - V_{be} = V_{cc} - I_b(\beta + 1)R_c - V_{be}.$$

From Ohm's law, the base current $I_b = V_{R_b}/R_b$, andso

$$\overbrace{I_b R_b}^{V_{R_b}} = V_{cc} - I_b(\beta + 1)R_c - V_{be}.$$

Hence, the base current $I_b$is

$$I_b = \frac{V_{cc} - V_{be}}{R_b + (\beta + 1)R_c}$$

If $V_{be}$is held constant and temperature increases, then the collector current $I_c$increases. However, a larger $I_c$causes the voltage drop across resistor $R_c$to increase, which in turn reduces the

voltage V_{R_b}across the base resistor R_b. A lower base-resistor voltage drop reduces the base current I_b, which results in less collector current I_c. Because an increase in collector current with temperature is opposed, the operating point is keptstable.

Merits:

- Circuit stabilizes the operating point against variations in temperature and β(i.e. replacement oftransistor)

Demerits:

- In this circuit, to keep $I_c$independent of β, the following condition must bemet:

$$I_c = \beta I_b = \frac{\beta(V_{cc} - V_{be})}{R_b + R_c + \beta R_c} \approx \frac{(V_{cc} - V_{be})}{R_c}$$

which is the case when

$$\beta R_c \gg R_b.$$

- As β-value is fixed (and generally unknown) for a given transistor, this relation can be satisfied either by keeping $R_c$fairly large or making $R_b$verylow.

- If $R_c$is large, a high $V_{cc}$is necessary, which increases cost as well as precautions necessary whilehandling.
- If $R_b$is low, the reverse bias of the collector–base region is small, which limits the range of collector voltage swing that leaves the transistor in activemode.

- The resistor $R_b$causes an AC feedback, reducing thevoltage gainof the amplifier. This undesirable effect is a trade-off for greaterQ-pointstability.

Usage: The feedback also decreases the input impedance of the amplifier as seen from the base, which can be advantageous. Due to the gain reduction from feedback, this biasing form is used only when the trade-off for stability iswarranted.

4) COLLECTOR –EMITTER FEEDBACKBIAS:

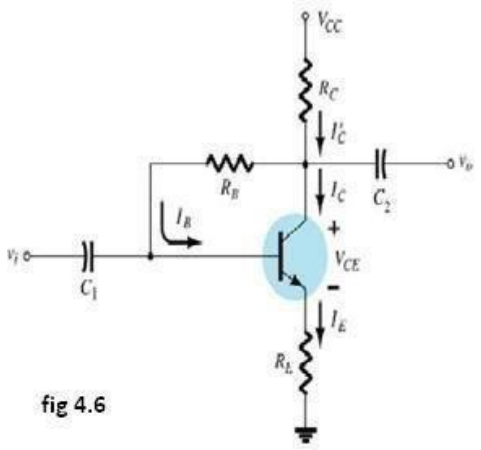


Fig 2.17 Collector-Emitter Biasing Circuit

The above fig 2.17shows the collector –emitter feedback bias circuit that can be obtained by applying both the collector feedback and emitter feedback. Here the collector feedback is provided by connecting a resistance RB from the collector to the base and emitter feedback is provided by connecting an emitter Re from emitter to ground. Both feed backs are used to control collector current and base current IB in the opposite direction to increase the stability as compared to the previous biasingcircuits.

5) VOLTAGE DIVIDER BIAS OR SELF BIAS OR EMITTERBIAS

The voltage divider as shown in the fig 2.18 is formed using external resistors R_1 and R_2. The voltage across R_2 forward biases the emitter junction. By proper selection of resistors R_1 and R_2, the operating point of the transistor can be made independent of β. In this circuit, the voltage divider holds the base voltage fixed independent of base current provided the divider current is large compared to the base current. However, even with a fixed base voltage, collector current varies with temperature (for example) so an emitter resistor is added to stabilize the Q-point, similar to the above circuits with emitter resistor.

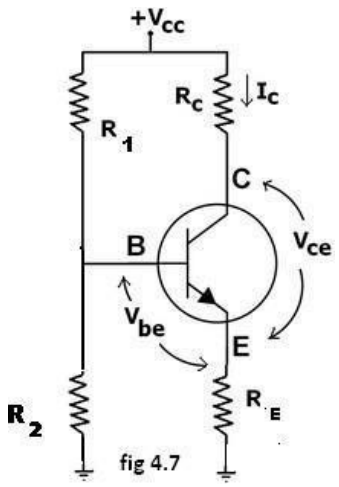


Fig 2.18 Voltage Divider Biasing Circuit

In this circuit the base voltage is given by:

$$V_B = \text{voltageacross } R_2 = V_{cc}\frac{R_2}{(R_1+R_2)} - I_B\frac{R_1R_2}{(R_1+R_2)}$$

$$\approx V_{cc}\frac{R_2}{(R_1+R_2)} \text{provided } I_B << I_2 = V_B/R_2.$$

Also $V_B = V_{be} + I_E R_E$

For the given circuit,

$$I_B = \frac{\frac{V_{CC}}{1+R_1/R_2} - V_{be}}{(\beta+1)R_E + R_1 \parallel R_2}.$$

Let the current in resistor R1 is I1 and this is divided into two parts – current through base and resistor R2. Since the base current is very small so for all practical purpose it is assumed that I1 also flows through R2, so we have

$$I_1 = \frac{V_{CC}}{R_1+R_2}$$

$$V_2 = \frac{V_{CC}}{R_1+R_2}\cdot R_2$$

Applying KVL in the circuit, we have

$$V_2 = V_{BE} + V_E$$

$$V_2 = V_{BE} + I_E R_E$$

$$I_E = \frac{V_2 - V_{BE}}{R_E}$$

$$I_C = \frac{V_2 - V_{BE}}{R_E} \quad \because I_C \cong I_E$$

$$I_C = \frac{\frac{V_{CC}}{R_1 + R_2} \cdot R_2 - V_{BE}}{R_E}$$

It is apparent from above expression that the collector current is independent of ? thus the stability is excellent. In all practical cases the value of VBE is quite small in comparison to the V2, so it can be ignored in the above expression so the collector current is almost independent of the transistor parameters thus this arrangement provides excellent stability.

Again applying KVL in collector circuit, we have

$$V_{CC} = I_C R_C + V_{CE} + I_E R_E$$

$$\because I_C \cong I_E$$

$$\therefore V_{CC} = I_C R_C + V_{CE} + I_C R_E$$

$$V_{CE} = V_{CC} - I_C (R_C + R_E)$$

The resistor RE provides stability to the circuit. If the current through the collector rises, the voltage across the resistor RE also rises. This will cause VCE to increase as the voltage V2 is independent of collector current. This decreases the base current, thus collector current increases to its formervalue.

Stability factor for such circuit arrangement is given by

$$S = \frac{(1+\beta)(R_{eq} + R_E)}{R_{eq} + R_E(1+\beta)}$$

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

$$S = \frac{(1+\beta)\left(1 + \frac{R_{eq}}{R_E}\right)}{\frac{R_{eq}}{R_E} + 1 + \beta}$$

If Req/RE is very small compared to 1, it can be ignored in the above expression thus we have

$$S = \frac{1+\beta}{1+\beta} = 1$$

Which is excellent since it is the smallest possible value for the stability. In actual practice the value of stability factor is around 8-10, since Req/RE cannot be ignored as compared to 1.

Merits:

- Unlike above circuits, only one dc supply isnecessary.
- Operating point is almost independent of βvariation.
- Operating point stabilized against shift intemperature.

Demerits:

- In this circuit, to keep I_C independent of β the following condition must bemet:

$$I_C = \beta I_B = \beta \frac{\frac{V_{CC}}{1+R_1/R_2} - V_{be}}{(\beta+1)R_E + R_1 \parallel R_2} \approx \frac{\frac{V_{CC}}{1+R_1/R_2} - V_{be}}{R_E},$$

which is approximately the caseif $(\beta+1)R_E >> R_1 \parallel R_2$

where R_1 || R_2 denotes the equivalent resistance of R_1 and R_2 connected in parallel.

- As β-value is fixed for a given transistor, this relation can be satisfied either by keeping R_E fairly large, or making R_1||R_2 verylow.

- If R_E is of large value, high V_{CC} is necessary. This increases cost as well as precautions necessary whilehandling.
- If R_1 || R_2 is low, either R_1 is low, or R_2 is low, or both are low. A low R_1 raises V_B closer to V_C, reducing the available swing in collector voltage, and limiting how large $R_C$can be made without driving the transistor out of active mode. A low R_2 lowers V_{be}, reducing the allowed collector current. Lowering both resistor values draws more current from the power supply and lowers the input resistance of the amplifier as seen from thebase.

- AC as well as DC feedback is caused by R_E, which reduces the AC voltage gain of the amplifier. A method to avoid AC feedback while retaining DC feedback is discussedbelow.

Usage: The circuit's stability and merits as above make it widely used for linear circuits.

BIAS COMPENSATION USING DIODE ANDTRANSISTOR

The various biasing circuits considered use some type of negative feedback to stabilize the operation point. Also, diodes, thermistors and sensistors can be used to compensate for variations in current.

DIODE COMPENSATION:

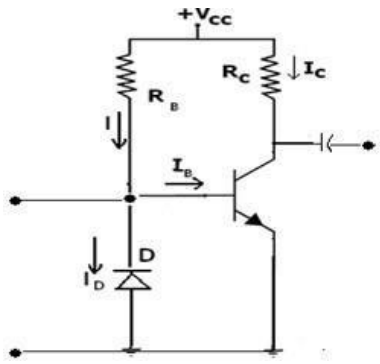


Fig 2.19Diode Compensation Circuit

The following fig 2.19 shows a transistor amplifier with a diode D connected across the base-emitter junction for compensation of change in collector saturation current I_{CO}. The diode is of the same material as the transistor and it is reverse biased by e the emitter-base junction voltage V_{BE}, allowing the diode reverse saturation current I_O to flow through diode D. The base currentI_B=I-I_O.

As long as temperature is constant, diode D operates as a resistor. As the temperature increases, I_{CO} of the transistor increases. Hence, to compensate for this, the base current I_B should be decreased.

The increase in temperature will also cause the leakage current I_O through D to increase and thereby decrease the base current I_B. This is the required action to keep Ic constant.

This type of bias compensation does not need a change in Ic to effect the change in I_C, as both I_O and I_{CO} can track almost equally according to the change intemperature.

THERMISTOR COMPENSATION:

The following fig2.20 a thermistor R_T, having a negative temperature coefficient is connected in parallel with R_2. The resistance of thermistor decreases exponentially with increase of temperature. An increase of temperature will decrease the base voltage V_{BE}, reducing I_B and I_C.

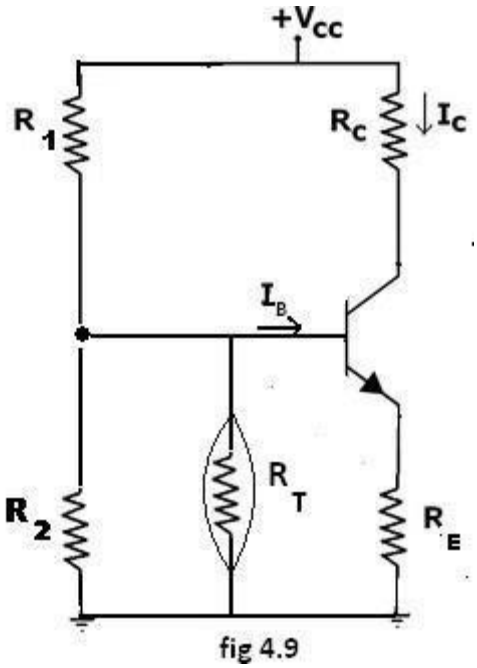


Fig 2.20 Thermistor Compensation

SENSISTOR COMPENSATION:

In the following fig2.21 shown a sensistor Rs having a positive temperature coefficient is connected across R_1 or R_E. Rs increases with temperature. As the temperature increases, the equivalent resistance of the parallel combination of R1 and Rs also increases and hence V_{BE}decreases, reducing I_B and Ic. This reduced Ic compensates for increased Ic caused by the increase in V_{BE}, I_{CO} and β due totemperature.

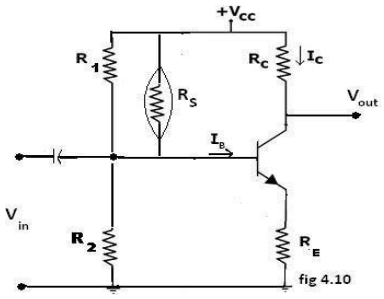


Fig 2.21 Sensistor Compensation

UNIT III

BJT Hybrid Model and Transistor Amplifier

BJT Hybrid Model and Transistor Amplifier's-parameter representation of a transistor, Conversion of h-parameters**,** Analysis of single stage transistor amplifier using H-parameters: voltage gain, current gain, Input impedance and Output impedance. Comparison of transistor configurations in terms of A_i, R_i , A_v,and R_o ,

BJT HYBRID MODEL

Small signal low frequency transistor Models:

All the transistor amplifiers are two port networks having two voltages and two currents. The positive directions of voltages and currents are shown in **fig. 1**.

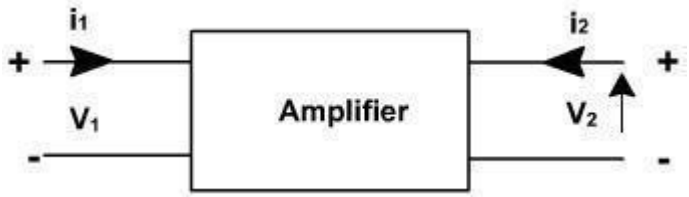


Fig. 3.1: Transistor as a two port Network

A two-port network is represented by four external variables: voltage V_1 and current I_1 at the input port, and voltage V_2 and current I_2 at the output port, so that the two-port network can be treated as a black box modeled by the relationships between the four variables,V_1,V_2, I_1,I_2 . Out of four variables two can be selected as are independent variables and two are dependent variables.The dependent variables can be expressed interns of independent variables. This leads to various two port parameters out of which the following three are important:

1. Impedance parameters(z-parameters)
2. Admittance parameters(y-parameters)
3. Hybrid parameters(h-parameters)

z-parameters

A two-port network can be described by z-parameters as

$$V_1 = Z_{11}I_1 + Z_{12}I_2$$
$$V_2 = Z_{21}I_1 + Z_{22}I_2$$

In matrix form, the above equation can be rewritten as

$$\begin{bmatrix} V_1 \\ V_2 \end{bmatrix} = \begin{bmatrix} z_{11} & z_{12} \\ z_{21} & z_{22} \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \end{bmatrix}$$

Where

$$z_{11} = \left.\frac{V_1}{I_1}\right|_{I_2=0}$$

Input impedance with output port open circuited

$$z_{12} = \left.\frac{V_1}{I_2}\right|_{I_1=0}$$

Reverse transfer impedance with input port open circuited

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

Forward transfer impedance with output port open circuited

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

Output impedance with input port open circuited

Y-parameters

A two-port network can be described by Y-parameters as

$$I_1 = Y_{11}V_1 + Y_{12}V_2$$
$$I_2 = Y_{21}V_1 + Y_{22}V_2$$

In matrix form, the above equation can be rewritten as

$$\begin{bmatrix} I_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} y_{11} & y_{12} \\ y_{21} & y_{22} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \end{bmatrix}$$

$$y_{11} = \left. \frac{I_1}{V_1} \right|_{V_2=0}$$

Input admittance with output port short circuited

$$y_{12} = \left. \frac{I_1}{V_2} \right|_{V_1=0}$$

Reverse transfer admittance with input port short circuited

$$y_{21} = \left. \frac{I_2}{V_1} \right|_{V_2=0}$$

Forward transfer admittance with output port short circuited

$$y_{22} = \left. \frac{I_2}{V_2} \right|_{V_1=0}$$

Output admittance with input port short circuited

Hybrid parameters (h-parameters)

If the input current I1 and output voltage V2 are taken as independent variables, the dependent variables V1 and I2 can be written as

$$\begin{bmatrix} V_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} \begin{bmatrix} I_1 \\ V_2 \end{bmatrix}$$

Where h_{11}, h_{12}, h_{21}, h_{22} are called as hybrid parameters.

$$h_{11} = \left. \frac{V_1}{I_1} \right|_{V_2=0}$$

Input impedence with o/p port short circuited

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

Reverse voltage transfer ratio with i/p port open circuited

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

Forward voltage transfer ratio with o/p port short circuited

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

output impedence with i/p port open circuited

THE HYBRID MODEL FOR TWO PORT NETWORK:

Based on the definition of hybrid parameters the mathematical model for two pert networks known as h-parameter model can be developed. The hybrid equations can be written as:

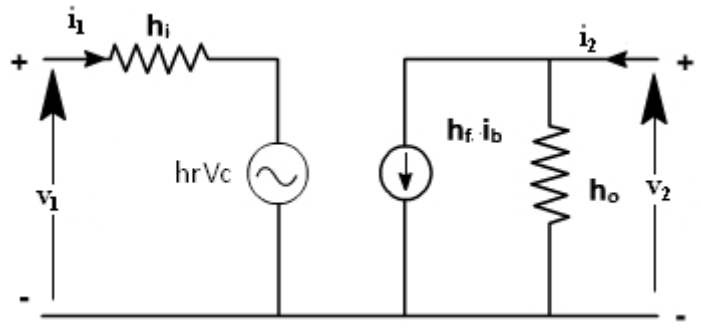
$$V_1 = h_i I_1 + h_r V_2$$

$$I_2 = h_f I_1 + h_o V_2$$

(The following convenient alternative subscript notation is recommended
by the **IEEE Standards**:
***i*=11=input** ***o* = 22 =output**

***f* =21 = forward transfer *r* = 12 = reverse transfer)**

We may now use the four h parameters to construct a mathematical model of the device of Fig.(1). The hybrid circuit for any device indicated in Fig.(2). We can verify that the model of Fig.(2) satisfies above equations by writing Kirchhoff'svoltage and current laws for input and output ports.



If these parameters are specified for a particular configuration, then suffixes e,b or c are also included, e.g. h_{fe} ,h_{ib} are h parameters of common emitter and common collector amplifiers

Using two equations the generalized model of the amplifier can be drawn as shown in fig. 3.2.

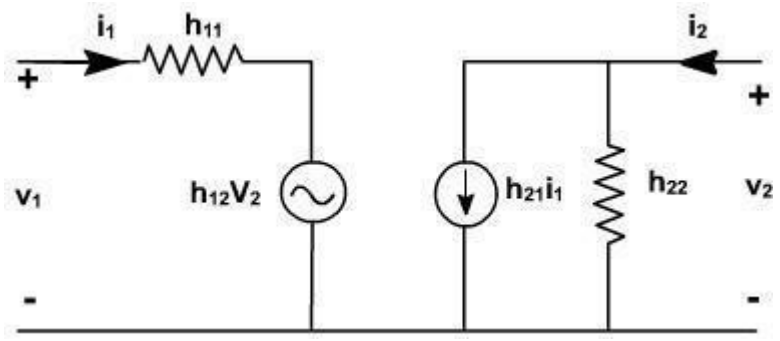


Fig.3.2:-h-parameter equivalent of Transistor

TRANSISTOR HYBRID MODEL:

The hybrid model for a transistor amplifier can be derived as follow:

Let us consider CE configuration as show in fig. 3.3. The variables, i_B, i_C ,v_C, and v_B represent total instantaneous currents and voltages i_B and v_C can be taken as independent variables and v_B, I_C as dependent variables.

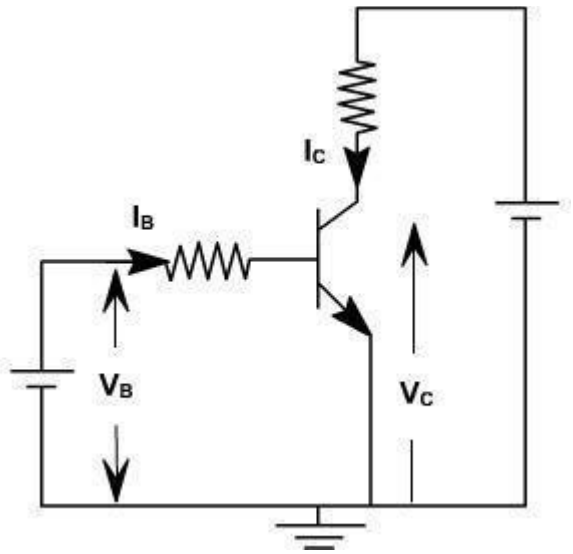


Fig. 3.3 CE Transistor Amplifier

$V_B = f1\ (i_B\ , v_C\ )$

$I_C = f2\ (i_B\ , v_C)$.

Using Taylor 's series expression, and neglecting higher order terms we obtain.

$$\Delta v_B = \left.\frac{\partial f_1}{\partial i_B}\right|_{v_C} \Delta i_B + \left.\frac{\partial f_1}{\partial v_C}\right|_{i_B} \Delta v_C$$

$$\Delta i_C = \left.\frac{\partial f_2}{\partial i_B}\right|_{v_C} \Delta i_B + \left.\frac{\partial f_2}{\partial v_C}\right|_{i_B} \Delta v_C$$

The partial derivatives are taken keeping the collector voltage or base current constant. The Δv_B, Δv_C, Δi_B, Δi_C represent the small signal (incremental) base and collector current and voltage and can be represented as v_B, i_C, i_B ,v_C

$$\therefore v_b = h_{ie}\, i_B + h_{re}\, v_C$$

$$i_C = h_{fe}\, i_B + h_{oe}\, v_b$$

where

$$h_{ie} = \left.\frac{\partial f_1}{\partial i_B}\right|_{v_C} = \left.\frac{\partial v_B}{\partial i_B}\right|_{v_C}; \qquad h_{re} = \left.\frac{\partial f_1}{\partial v_C}\right|_{i_B} = \left.\frac{\partial v_B}{\partial v_C}\right|_{i_B}$$

$$h_{fe} = \left.\frac{\partial f_2}{\partial i_B}\right|_{v_C} = \left.\frac{\partial i_C}{\partial i_B}\right|_{v_C}; \qquad h_{oe} = \left.\frac{\partial f_2}{\partial v_C}\right|_{i_B} = \left.\frac{\partial v_B}{\partial v_C}\right|_{i_B}$$

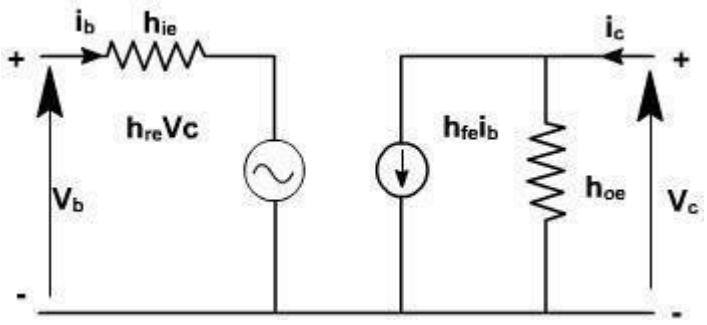


Fig. 3.4:h-parameter model of CE Configuration

To determine the four h-parameters of transistor amplifier, input and output characteristic are used. Input characteristic depicts the relationship between input voltage and input current with output voltage as parameter. The output characteristic depicts the relationship between output voltage and output current with input current as parameter. Fig. 5, shows the output characteristics of CE amplifier.

$$h_{fe} = \left.\frac{\partial i_C}{\partial i_B}\right|_{V_C} = \frac{i_{C2} - i_{C1}}{i_{b2} - i_{b1}}$$

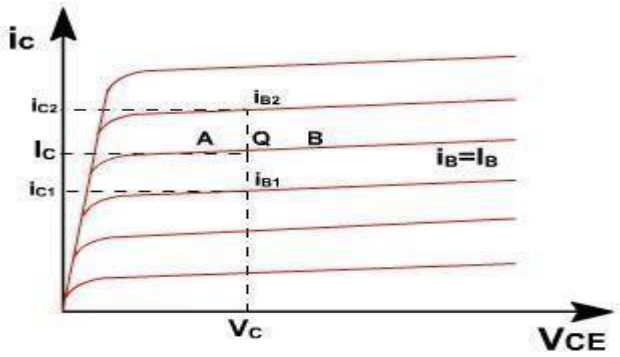


Fig. 3.5Transistor CE Configuration output characteristics

The current increments are taken around the quiescent point Q which corresponds to $i_B = I_B$ and to the collector voltage $V_{CE} = V_C$

$$h_{oe} = \left.\frac{\partial i_C}{\partial V_C}\right|_{i_B}$$

The value of h_{oe} at the quiescent operating point is given by the slope of the output characteristic at the operating point (i.e. slope of tangent AB).

$$h_{ie} = \frac{\partial V_B}{\partial i_B} \approx \left.\frac{\Delta V_B}{\Delta i_B}\right|_{V_C}$$

h_{ie} is the slope of the appropriate input on fig. 3.6, at the operating point (slope of tangent EF at Q).

$$h_{re} = \frac{\partial V_B}{\partial V_C} = \left.\frac{\Delta V_B}{\Delta V_C}\right|_{I_B} = \frac{V_{B2} - V_{B1}}{V_{C2} - V_{C1}}$$

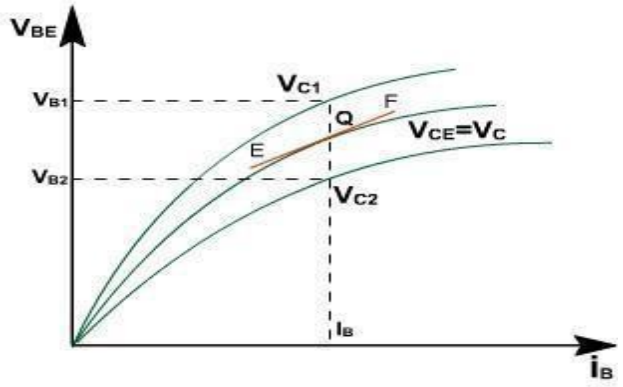


Fig. 3.6 Calculation of h-parameters from output characteristics

A vertical line on the input characteristic represents constant base current. The parameter hre can be obtained from the ratio (V_{B2}– V_{B1}) and (V_{C2}– V_{C1}) for at Q.

Typical CE h-parametersof transistor 2N1573 are given below:

h_{ie} = 1000 ohm.
h_{re} = 2.5 * 10 –4
h_{fe} = 50
h_{oe} =25μA/V

ANALYSIS OF A TRANSISTOR AMPLIFIER USING H-PARAMETERS:

To form a transistor amplifier it is only necessary to connect an external load and signal source as indicated in **fig. 3.7**and to bias the transistor properly.

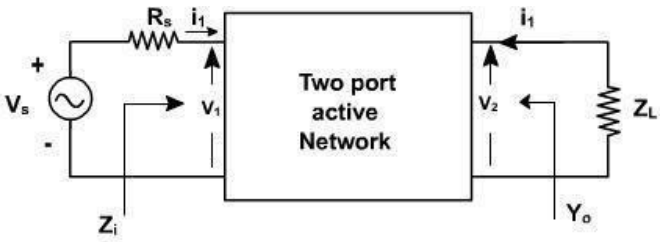


Fig. 3.7 Transistor two port Network

Consider the two-port network of CE amplifier. R_S is the source resistance and Z_L is the load impedence h-parameters are assumed to be constant over the operating range. The ac equivalent circuit is shown in fig. 2. (Phasor notations are used assuming sinusoidal voltage input). The quantities of interest are the current gain, input impedence, voltage gain, and output impedence.

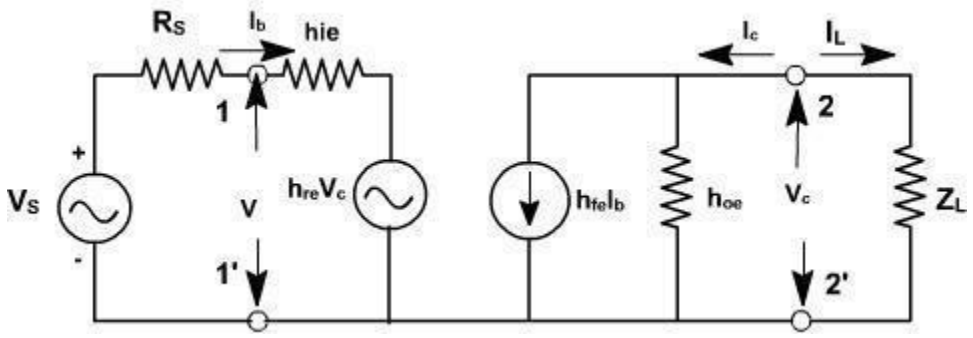


Fig 3.8:h parameter equivalent of Transistor in CE configuration

Current gain:

For the transistor amplifier stage, A_i is defined as the ratio of output to input currents.

$$A_I = \frac{I_L}{I_1} = \frac{-I_2}{I_1}$$

Input impedence:

The impedence looking into the amplifier input terminals (1,1') is the input impedance Z_i

$$Z_i = \frac{V_b}{I_b}$$

$$V_b = h_{ie} I_b + h_{re} V_c$$

$$\frac{V_b}{I_b} = h_{ie} + h_{re} \frac{V_c}{I_b}$$

$$= h_{ie} - \frac{h_{re} I_c Z_L}{I_b}$$

$$\therefore Z_i = h_{ie} + h_{re} A_I Z_L$$

$$= h_{ie} - \frac{h_{re} h_{fe} Z_L}{1 + h_{oe} Z_L}$$

$$\therefore Z_i = h_{ie} - \frac{h_{re} h_{fe}}{Y_L + h_{oe}} \qquad (\text{since } Y_L = \frac{1}{Z_L})$$

Voltage gain:

The ratio of output voltage to input voltage gives the gain of the transistors.

$$A_v = \frac{V_C}{V_b} = -\frac{I_C Z_L}{V_b}$$

$$\therefore A_v = \frac{I_B A_i Z_L}{V_b} = \frac{A_i Z_L}{Z_i}$$

Output Admittance:

$$Y_0 = \left.\frac{I_c}{V_c}\right|_{V_s} = 0$$

$$I_c = h_{fe} I_b + h_{oe} V_c$$

$$\frac{I_c}{V_c} = h_{fe}\frac{I_b}{V_c} + h_{oe}$$

when $V_s = 0$, $\quad R_s . I_b + h_{ie} . I_b + h_{re} V_c = 0.$

$$\frac{I_b}{V_c} = -\frac{h_{re}}{R_s + h_{ie}}$$

$$\therefore Y_0 = h_{oe} - \frac{h_{re}\, h_{fe}}{R_s + h_{ie}}$$

Voltage amplification taking into account source impedance (R_S) is given by

$$A_{VS} = \frac{V_c}{V_s} = \frac{V_c}{V_b} * \frac{V_b}{V_S} \qquad \left(V_b = \frac{V_s}{R_s + Z_i} * Z_i\right)$$

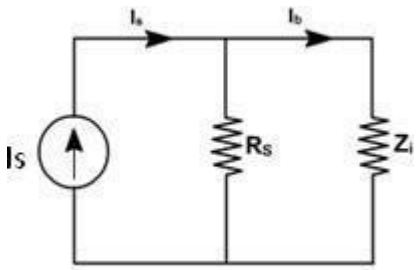
$$= A_V \cdot \frac{Z_i}{Z_i + R_s}$$

$$= \frac{A_i Z_L}{Z_i + R_s}$$

It is defined as

A_v is the voltage gain for an ideal voltage source ($R_v = 0$).

Consider input source to be a current source I_S in parallel with a resistance R_S as shown in <u>fig. 3</u>.



In this case, overall current gain A_{IS} is defined as

$$A_{I_s} = \frac{I_L}{I_s}$$

$$= -\frac{I_c}{I_s}$$

$$= -\frac{I_c}{I_b} * \frac{I_b}{I_s} \qquad \left(I_b = \frac{I_s * R_s}{R_s + Z_i}\right)$$

$$= A_I * \frac{R_s}{R_s + Z_i}$$

If $R_s \to \infty$, $A_{Is} \to A_I$

h-parameters

To analyze multistage amplifier the h-parameters of the transistor used are obtained from manufacture data sheet. The manufacture data sheet usually provides h-parameter in CE configuration. These parameters may be converted into CC and CB values. For example fig. 4hrc in terms of CE parameter can be obtained as follows.

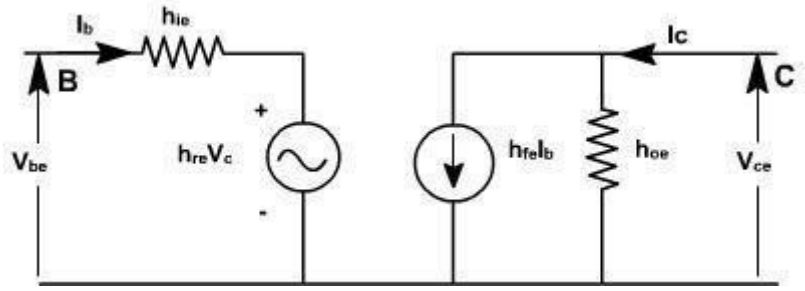


Fig. 3.9 CE h-parameter model

For CE transistor configuaration

Vbe = hie Ib + hre Vce

Ic = h fe Ib + hoe Vce

The circuit can be redrawn like CC transistor configuration as shown in fig. 5.

Vbc = hie Ib + hrc Vec

Ic = hfe Ib + hoe Vec

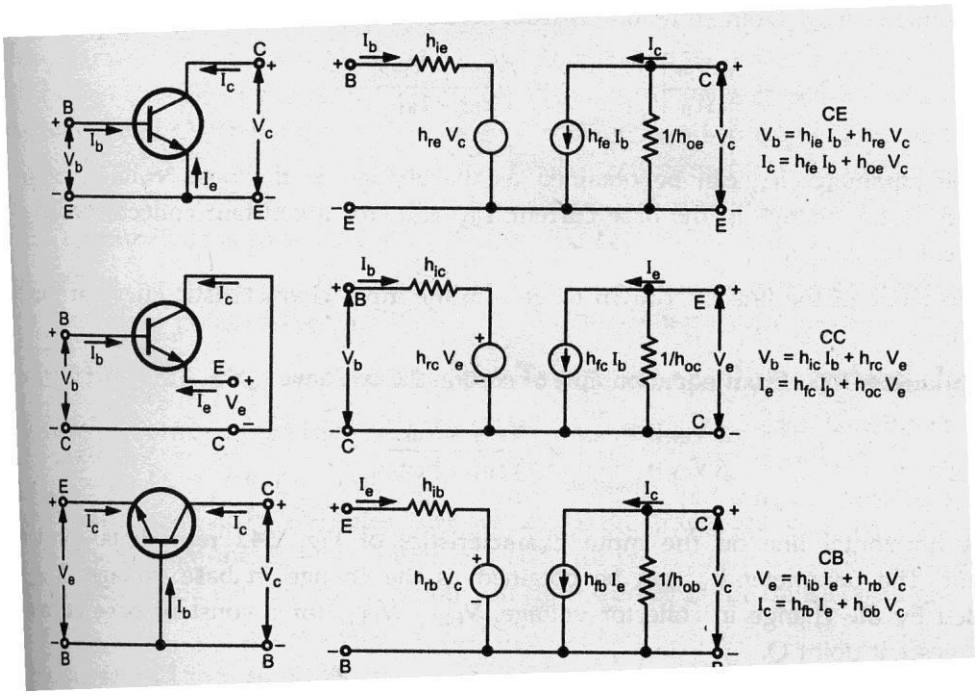


Fig 3.10 hybrid model for transistor in three different configurations

Typical h-parameter values for a transistor

Parameter	CE	CC	CB
h_i	1100 Ω	1100 Ω	22 Ω
h_r	2.5×10^{-4}	1	3×10^{-4}
h_f	50	-51	-0.98
h_o	25 µA/V	25 µA/V	0.49 µA/V

Analysis of a Transistor amplifier circuit using h-parameters

A transistor amplifier can be constructed by connecting an external load and signal source and biasing the transistor properly.

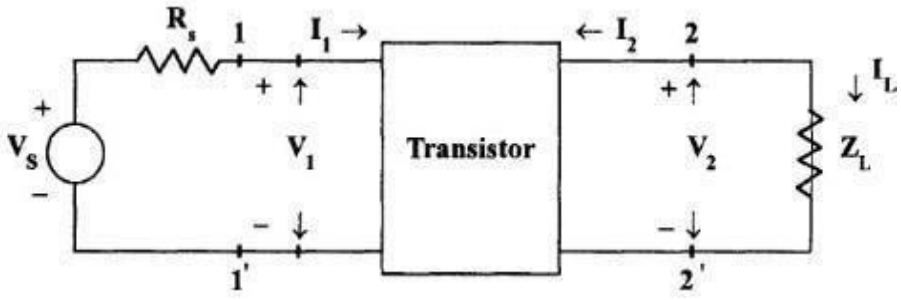


Fig.3.11 Basic Amplifier Circuit

The two port network of Fig. 3.11 represents a transistor in any one of its configuration. It is assumed that h-parameters remain constant over the operating range.The input is sinusoidal and I_1,V_1,I_2 and V_2 are phase quantities

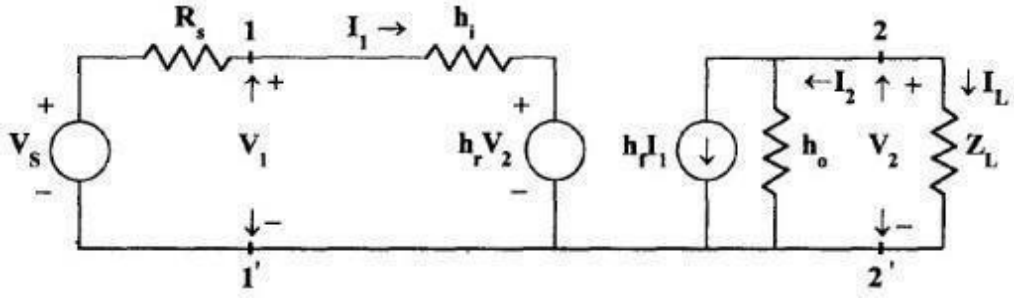


Fig. 3.12 Transistor replaced by its Hybrid Model

Current Gain or Current Amplification (A_i)

For transistor amplifier the current gain A_i is defined as the ratio of output current to input current,i.e,

$$A_i = I_L / I_1 = -I_2 / I_1$$

From the circuit of Fig

$$I_2 = h_f I_1 + h_o V_2$$

Substituting $V_2 = I_L Z_L = -I_2 Z_L$

$$I_2 = h_f I_1 - I_2 Z_L h_o$$

$I_2 + I_2 Z_L h_o = h_f I_1$

$I_2(1+ Z_L h_o) = h_f I_1$

$A_i = -I_2 / I_1 = - h_f / (1+ Z_L h_o)$

Therefore,

$A_i = - h_f / (1+ Z_L h_o)$

Input Impedence (Z_i)

In the circuitof Fig ,$R_S$isthesignalsourceresistance.Theimpedenceseenwhenlookingintothe amplifier terminals (1,1′) is the amplifier input impedenceZ_i,

$Z_i = V_1 / I_1$

From the input circuit of Fig $V_1 = h_i I_1 + h_r V_2$

$Z_i = (h_i I_1 + h_r V_2) / I_1$

$= h_i + h_r V_2 / I_1$

Substituting

$V_2 = -I_2 Z_L = A_1 I_1 Z_L$

$Z_i = h_i + h_r A_1 I_1 Z_L / I_1$

$= h_i + h_r A_1 Z_L$

Substituting for A_i

$Z_i = h_i - h_f h_r Z_L / (1+ h_o Z_L)$

$= h_i - h_f h_r Z_L / Z_L(1/Z_L+ h_o)$

Taking the Load admittance as $Y_L = 1/ Z_L$

$Z_i = h_i - h_f h_r / (Y_L + h_o)$

Voltage Gain or Voltage Gain Amplification Factor(A_v)

The ratio of output voltage V_2 to input voltage V_1 give the voltage gain of the transistor i.e,

$$A_v = V_2 / V_1$$

Substituting

$$V_2 = -I_2 Z_L = A_1 I_1 Z_L$$

$$A_v = A_1 I_1 Z_L / V_1 = A_i Z_L / Z_i$$

Output Admittance (Y_o)

Y_o is obtained by setting V_S to zero, Z_L to infinity and by driving the output terminals from a generator V_2. If the current V_2 is I_2 then $Y_o = I_2/V_2$ with $V_S=0$ and $R_L = \infty$.

From the circuit of fig

$$I_2 = h_f I_1 + h_o V_2$$

Dividing by V_2,

$$I_2 / V_2 = h_f I_1/V_2 + h_o$$

With $V_2 = 0$, by KVL in input circuit,

$$R_S I_1 + h_i I_1 + h_r V_2 = 0$$

$$(R_S + h_i) I_1 + h_r V_2 = 0$$

Hence, $I_2 / V_2 = -h_r / (R_S + h_i)$

$$= h_f (-h_r/(R_S + h_i)+h_o$$

$$Y_o = h_o - h_f h_r/(R_S + h_i)$$

The output admittance is a function of source resistance. If the source impedence is resistive then Y_o is real.

Voltage Amplification Factor(A_{vs}) taking into account the resistance (R_s) of the source

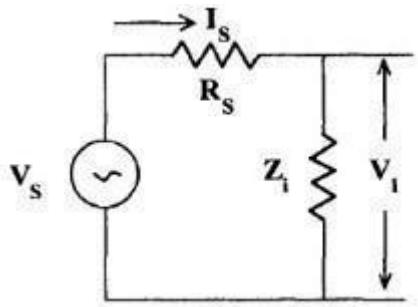


Fig. 3.13 Thevenin's Equivalent Input

Circuit This overall voltage gain A_{vs} is given by

$$A_{vs} = V_2 / V_S = V_2V_1 / V_1V_S = A_v V_1 / V_S$$

From the equivalent input circuit using Thevenin's equivalent for the source shown in Fig. 5.6

$V_1 = V_S Z_i / (Z_{i+} R_S)$

$V_1 / V_S = Z_i / (Z_i + R_S)$

Then, $A_{vs} = A_v Z_i / (Z_i + R_S)$

Substituting $A_v = A_i Z_L / Z_i$

$A_{vs} = A_i Z_L / (Z_i + R_S)$

$A_{vs} = A_i Z_L R_S / (Z_i + R_S) R_S$

$A_{vs} = A_{is} Z_L / R_S$

Current Amplification (A_{is}) taking into account the source Resistance(R_S)

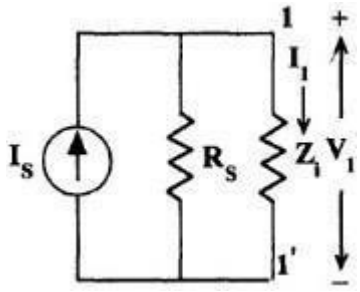


Fig. 3.14 Norton's Equivalent Input Circuit

The modified input circuit using Norton's equivalent circuit for the calculation of A_{is} is shown in Fig. 1.7

Overall Current Gain, $A_{is} = -I_2 / I_S = - I_2 I_1 / I_1 I_S = A_i I_1 / I_S$

FromFig.1.7 $I_1 = I_S R_S / (R_S + Z_i)$

$I_1 / I_S = R_S / (R_S + Z_i)$

andhence, $A_{is} = A_i R_S / (R_S + Z_i)$

Operating Power Gain (A_P)

The operating power gain A_P of the transistor is defined as

$A_P = P_2 / P_1 = -V_2 I_2 / V_1 I_1 = A_v A_i = A_i A_i Z_L / Z_i$

$A_P = A_i^2 (Z_L / Z_i)$

Small Signal analysis of a transistor amplifier

$A_i = - h_f / (1 + Z_L h_o)$	$A_v = A_i Z_L / Z_i$
$Z_i = h_i + h_r A_1 Z_L = h_i - h_f h_r / (Y_L + h_o)$	$A_{vs} = A_v Z_i / (Z_i + R_S) = A_i Z_L / (Z_i + R_S)$ $= A_{is} Z_L / R_S$
$Y_o = h_o - h_f h_r / (R_S + h_i) = 1 / Z_o$	$A_{is} = A_i R_S / (R_S + Z_i) = A_{vs} = A_{is} R_S / Z_L$

UNIT IV

FEEDBACK AMPLIFIERS:

Concept of Feedback and types, Effects of negative feedback on amplifiers characteristics, voltage series, current series, current shunt, and voltage shunt feedback amplifiers.
OSCILLATORS: Classification of oscillators, Barkhausen criterion, RC phase shift oscillator, Wein-bridge oscillator, LC oscillators- Hartley and Colpitts oscillator.

A practical amplifier has a gain of nearly one million *i.e.* its output is one million times the input. Consequently, even a casual disturbance at the input will appear in the amplified form in the output. There is a strong tendency in amplifiers to introduce *hum* due to sudden temperature changes or stray electric and magnetic fields. Therefore, every high gain amplifier tends to give noise along with signal in its output. The noise in the output of an amplifier is undesirable and must be kept to as small a level as possible. The noise level in amplifiers can be reduced considerably by the use of *negative feedback i.e*. by injecting a fraction of output in phase opposition to the input signal. The object of this chapter is to consider the effects and methods of providing negative feedback in transistoramplifiers.

Ideally an amplifier should reproduce the input signal, with change in magnitude and with or without change in phase. But some of the short comings of the amplifier circuit are

1. Change in the value of the gain due to variation in supplying voltage, temperature or due to components.
2. Distortion in wave-form due to non linearities in the operating characters of the Amplifying device.
3. The amplifier may introduce noise (undesired signals)

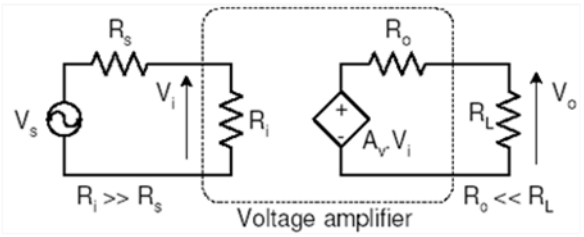
The above drawbacks can be minimizing if we introduce feedback.

CLASSIFICATION OF AMPLIFIERS

Amplifiers can be classified broadly as:

1. Voltage amplifiers.
2. Current amplifiers.
3. Tran conductance amplifiers.
4. Tran resistance amplifiers.

1.1 Voltage amplifier



if $R_i >> R_s$

then $V_i \approx V_s$

and if $R_o << R_L$

then

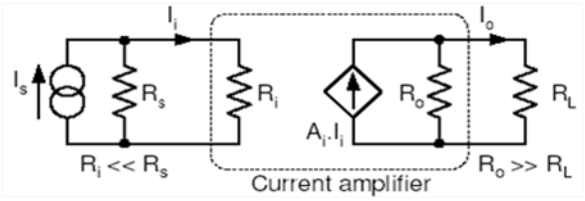
$$V_o \approx A_v V_i \approx A_v V_s$$

hence $A_v \equiv \frac{V_o}{V_i}$

with $R_L = \infty$

represent the open circuit voltage gain.

1.2 Current amplifier



if $R_i << R_s$

then $I_i \approx I_s$

and if $R_o >> R_L$

then

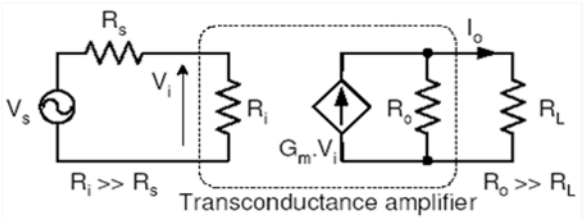
$$I_o \approx A_i I_i \approx A_i I_s$$

hence $A_i \equiv \frac{I_o}{I_i}$

with $R_L = 0$

represent the short circuit current gain.

1.3 Transconductance amplifier



if $R_i >> R_s$

then $V_i \approx V_s$

and if $R_o >> R_L$

then

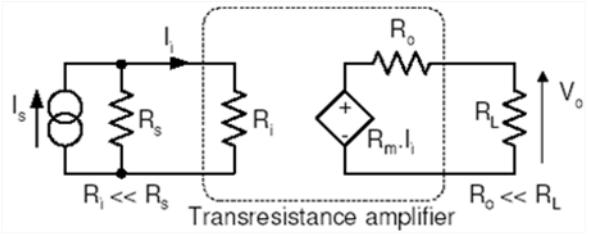
$$I_o \approx G_m V_i \approx G_m V_s$$

hence $G_m \equiv \frac{I_o}{V_i}$

with $R_L = 0$

represent the short circuit mutual or transfer conductance

1.4 Transresistance amplifier



if $R_i << R_s$

then $I_i \approx I_s$

and if $R_o << R_L$

then

$$V_o \approx R_m I_i \approx R_m i_s$$

hence $R_m \equiv \frac{V_o}{I_i}$

with $R_L = \infty$

represent the open circuit mutual or transfer resistance.

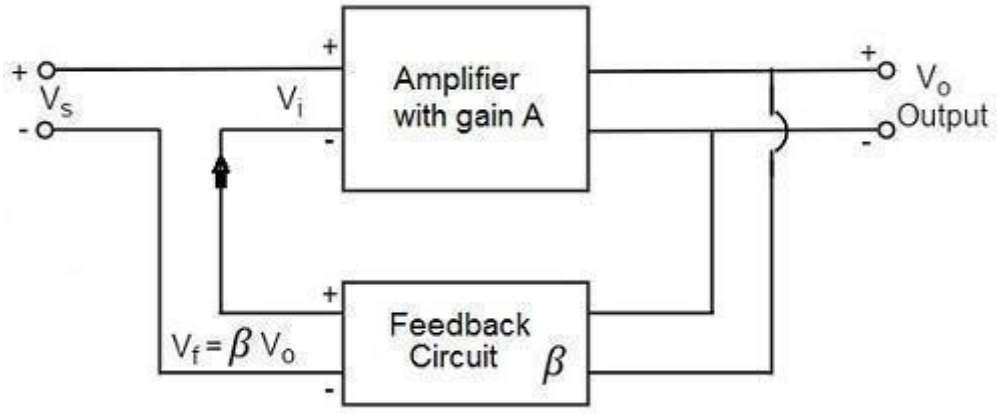
Concept of Feedback

An amplifier circuit simply increases the signal strength. But while amplifying, it just increases the strength of its input signal whether it contains information or some noise along with information. This noise or some disturbance is introduced in the amplifiers because of their strong tendency to introduce hum due to sudden temperature changes or stray electric and magnetic fields. Therefore, every high gain amplifier tends to give noise along with signal in its output, which is very undesirable.

The noise level in the amplifier circuits can be considerably reduced by using negative feedback done by injecting a fraction of output in phase opposition to the input signal.

Principle of Feedback Amplifier

A feedback amplifier generally consists of two parts. They are theamplifier and the feedback circuit. The feedback circuit usually consists of resistors. The concept of feedback amplifier can be understood from the following figure.



From the above figure, the gain of the amplifier is represented as A. the gain of the amplifier is the ratio of output voltage V_o to the input voltage V_i. the feedback network extracts a voltage $V_f = \beta V_o$ from the output V_o of the amplifier.

This voltage is added for positive feedback and subtracted for negative feedback, from the signal voltage V_s. Now,

$Vi=Vs+Vf=Vs+\beta Vo$
$Vi=Vs-Vf=Vs-\beta Vo$

The quantity $\beta = V_f/V_o$ is called as feedback ratio or feedback fraction.

Let us consider the case of negative feedback. The output $V_o$must be equal to the input voltage ($V_s - \beta V_o$) multiplied by the gain A of the amplifier.

Hence,

$$(V_s - \beta V_o)A = V_o$$

Or

$$AV_s - A\beta V_o = V_o$$

Or

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

Therefore,

$$\frac{Vo}{Vs} = \frac{A}{1 + A\beta}$$

Let A_f be the overall gain (gain with the feedback) of the amplifier. This is defined as the ratio of output voltage V_o to the applied signal voltage V_s, i.e.,

$$Af = \frac{A}{1 + A\beta}$$

The equation of gain of the feedback amplifier, with positive feedback is given by

$$Af = \frac{A}{1 - A\beta}$$

These are the standard equations to calculate the gain of feedback amplifiers.

Types of Feedbacks

The process of injecting a fraction of output energy of some device back to the input is known as Feedback. It has been found that feedback is very useful in reducing noise and making the amplifier operation stable.

Depending upon whether the feedback signal aids or opposes the input signal, there are two types of feedbacks used.

Positive Feedback

The feedback in which the feedback energy i.e., either voltage or current is in phase with the input signal and thus aids it is called asPositive feedback.

Both the input signal and feedback signal introduces a phase shift of 180^o thus making a 360^o resultant phase shift around the loop, to be finally in phase with the input signal.

Though the positive feedback increases the gain of the amplifier, it has the disadvantages such as

- Increasing distortion
- Instability

It is because of these disadvantages the positive feedback is not recommended for the amplifiers. If the positive feedback is sufficiently large, it leads to oscillations, by which oscillator circuits are formed.

Negative Feedback

The feedback in which the feedback energy i.e., either voltage or current is out of phase with the input and thus opposes it, is called as negative feedback.

In negative feedback, the amplifier introduces a phase shift of 180^o into the circuit while the feedback network is so designed that it produces no phase shift or zero phase shift. Thus the resultant feedback voltage V_f is 180^o out of phase with the input signal V_{in}.

Though the gain of negative feedback amplifier is reduced, there are many advantages of negative feedback such as

- Stability of gain is improved
- Reduction in distortion
- Reduction in noise
- Increase in input impedance
- Decrease in output impedance
- Increase in the range of uniform application

It is because of these advantages negative feedback is frequently employed in amplifiers.

Negative feedback in an amplifier is the method of feeding a portion of the amplified output to the input but in opposite phase. The phase opposition occurs as the amplifier provides 180^o phase shift whereas the feedback network doesn't.

While the output energy is being applied to the input, for the voltage energy to be taken as feedback, the output is taken in shunt connection and for the current energy to be taken as feedback, the output is taken in series connection.

There are two main types of negative feedback circuits. They are –

- Negative Voltage Feedback
- Negative Current Feedback

Negative Voltage Feedback

In this method, the voltage feedback to the input of amplifier is proportional to the output voltage. This is further classified into two types −

- Voltage-series feedback
- Voltage-shunt feedback

Negative Current Feedback

In this method, the voltage feedback to the input of amplifier is proportional to the output current. This is further classified into two types.

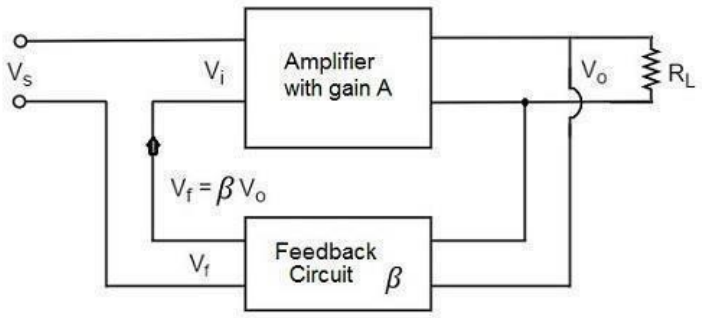
- Current-series feedback
- Current-shunt feedback

Let us have a brief idea on all of them.

Voltage-Series Feedback

In the voltage series feedback circuit, a fraction of the output voltage is applied in series with the input voltage through the feedback circuit. This is also known as shunt-driven series-fed feedback, i.e., a parallel-series circuit.

The following figure shows the block diagram of voltage series feedback, by which it is evident that the feedback circuit is placed in shunt with the output but in series with the input.

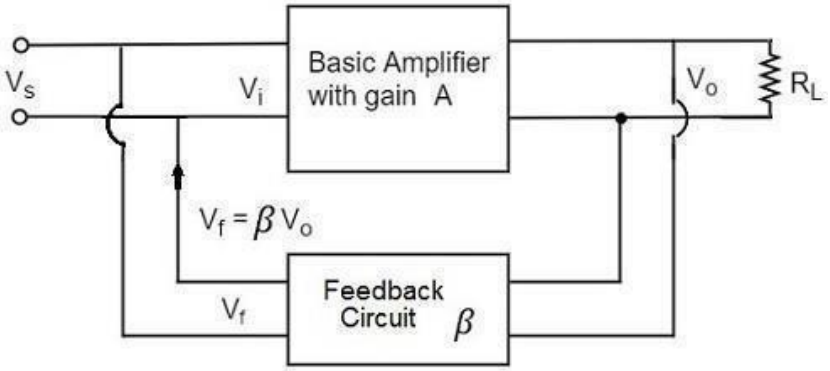


As the feedback circuit is connected in shunt with the output, the output impedance is decreased and due to the series connection with the input, the input impedance is increased.

Voltage-Shunt Feedback

In the voltage shunt feedback circuit, a fraction of the output voltage is applied in parallel with the input voltage through the feedback network. This is also known as shunt-driven shunt-fed feedback i.e., a parallel-parallel proto type.

The below figure shows the block diagram of voltage shunt feedback, by which it is evident that the feedback circuit is placed in shunt with the output and also with the input.

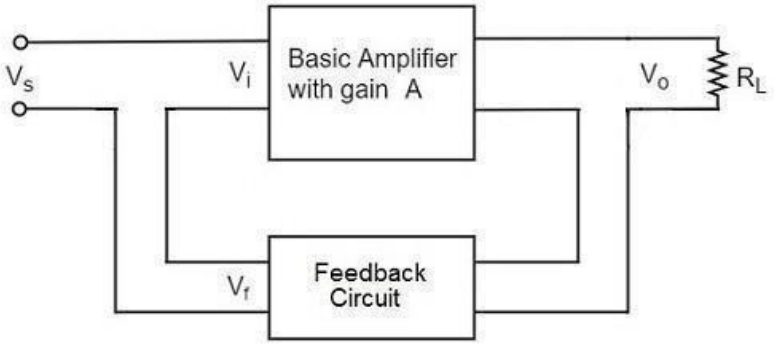


As the feedback circuit is connected in shunt with the output and the input as well, both the output impedance and the input impedance are decreased.

Current-Series Feedback

In the current series feedback circuit, a fraction of the output voltage is applied in series with the input voltage through the feedback circuit. This is also known as series-driven series-fed feedback i.e., a series-series circuit.

The following figure shows the block diagram of current series feedback, by which it is evident that the feedback circuit is placed in series with the output and also with the input.

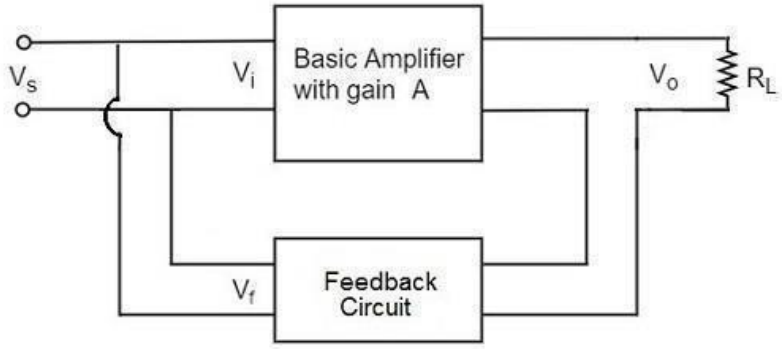


As the feedback circuit is connected in series with the output and the input as well, both the output impedance and the input impedance are increased.

Current-Shunt Feedback

In the current shunt feedback circuit, a fraction of the output voltage is applied in series with the input voltage through the feedback circuit. This is also known as series-driven shunt-fed feedback i.e., a series-parallel circuit.

The below figure shows the block diagram of current shunt feedback, by which it is evident that the feedback circuit is placed in series with the output but in parallel with the input.



As the feedback circuit is connected in series with the output, the output impedance is increased and due to the parallel connection with the input, the input impedance is decreased.

Let us now tabulate the amplifier characteristics that get affected by different types of negative feedbacks.

Characteristics	**Types of Feedback**			
	Voltage-Series	**Voltage-Shunt**	**Current-Series**	**Current-Shunt**
Voltage Gain	Decreases	Decreases	Decreases	Decreases
Bandwidth	Increases	Increases	Increases	Increases
Input resistance	Increases	Decreases	Increases	Decreases
Output resistance	Decreases	Decreases	Increases	Increases
Harmonic distortion	Decreases	Decreases	Decreases	Decreases
Noise	Decreases	Decreases	Decreases	Decreases

Advantages of Negative Feedback

1. Stabilization of gain
   - Make the gain less sensitive to changes in circuit components e.g. due to changes in temperature.
2. Reduce non-linear distortion
   - Make the output proportional to the input, keeping the gain constant, independent of signal level.
3. Reduce the effect of noise
   - Minimize the contribution to the output of unwanted signals generated in circuit components or extraneous interference.
4. Extend the bandwidth of the amplifier
   - Reduce the gain and increase the bandwidth
5. Modification the input and output impedances
   - Raise or lower the input and output impedances by selection of the appropriate feedback topology.

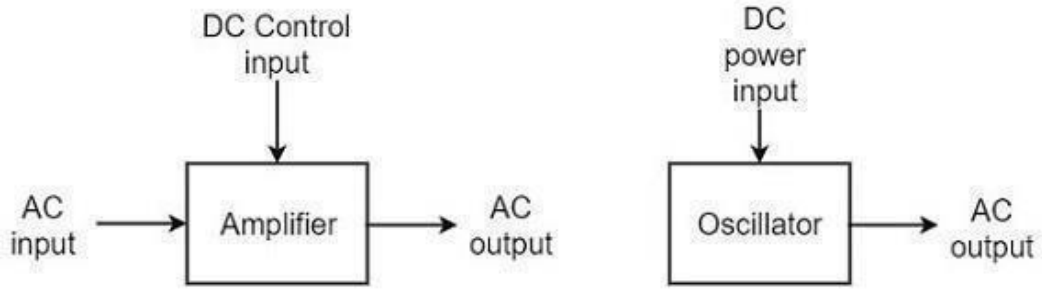
Oscillators

An **oscillator** generates output without any ac input signal. An electronic oscillator is a circuit which converts dc energy into ac at a very high frequency. An amplifier with a positive feedback can be understood as an oscillator.

Amplifier vs. Oscillator

An **amplifier** increases the signal strength of the input signal applied, whereas an **oscillator** generates a signal without that input signal, but it requires dc for its operation. This is the main difference between an amplifier and anoscillator.

Take a look at the following illustration. It clearly shows how an amplifier takes energy from d.c. power source and converts it into a.c. energy at signal frequency. An oscillator produces an oscillating a.c. signal on its own.



The frequency, waveform, and magnitude of a.c. power generated by an amplifier, is controlled by the a.c. signal voltage applied at the input, whereas those for an oscillator are controlled by the components in the circuit itself, which means no external controlling voltage is required.

Alternator vs. Oscillator

An **alternator** is a mechanical device that produces sinusoidal waves without any input. This a.c. generating machine is used to generate frequencies up to 1000Hz. The output frequency depends on the number of poles and the speed of rotation of thearmature.

The following points highlight the differences between an alternator and an oscillator −

- An alternator converts mechanical energy to a.c. energy, whereas the oscillator converts d.c. energy into a.c. energy.
- An oscillator can produce higher frequencies of several MHz whereas an alternator cannot.
- An alternator has rotating parts, whereas an electronic oscillator doesn't.
- It is easy to change the frequency of oscillations in an oscillator than in an alternator.

Oscillators can also be considered as opposite to rectifiers that convert a.c. to d.c. as these convert d.c. to a.c.

Classification of Oscillators

Electronic oscillators are classified mainly into the following two categories −

- **Sinusoidal Oscillators** − The oscillators that produce an output having a sine waveform are called **sinusoidal** or **harmonic oscillators**. Such oscillators can provide output at frequencies ranging from 20 Hz to 1 GHz.
- **Non-sinusoidal Oscillators** − The oscillators that produce an output having a square, rectangular or saw-tooth waveform are called **non-sinusoidal** or **relaxation oscillators**. Such oscillators can provide output at frequencies ranging from 0 Hz to 20 MHz.

Sinusoidal Oscillators

Sinusoidal oscillators can be classified in the following categories −

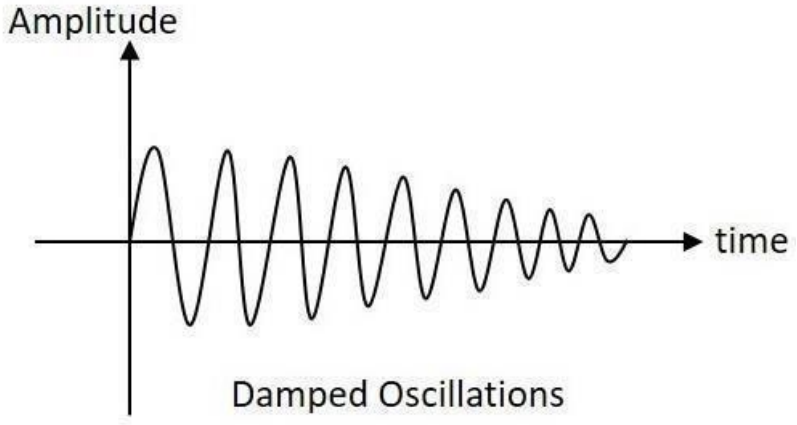
- **Tuned Circuit Oscillators** − These oscillators use a tuned-circuit consisting of inductors (L) and capacitors (C) and are used to generate high-frequency signals. Thus they are also known as radio frequency R.F. oscillators. Such oscillators are Hartley, Colpitts, Clapp-oscillators etc.
- **RC Oscillators** − There oscillators use resistors and capacitors and are used to generate low or audio-frequency signals. Thus they are also known as audio-frequency (A.F.) oscillators. Such oscillators are Phase –shift and Wein-bridge oscillators.
- **Crystal Oscillators** − These oscillators use quartz crystals and are used to generate highly stabilized output signal with frequencies up to 10 MHz. The Piezo oscillator is an example of a crystal oscillator.
- **Negative-resistance Oscillator** − These oscillators use negative-resistance characteristic of the devices such as tunnel devices. A tuned diode oscillator is an example of a negative-resistance oscillator.

Nature of Sinusoidal Oscillations

The nature of oscillations in a sinusoidal wave is generally of two types. They are **damped** and **undamped oscillations**.

Damped Oscillations

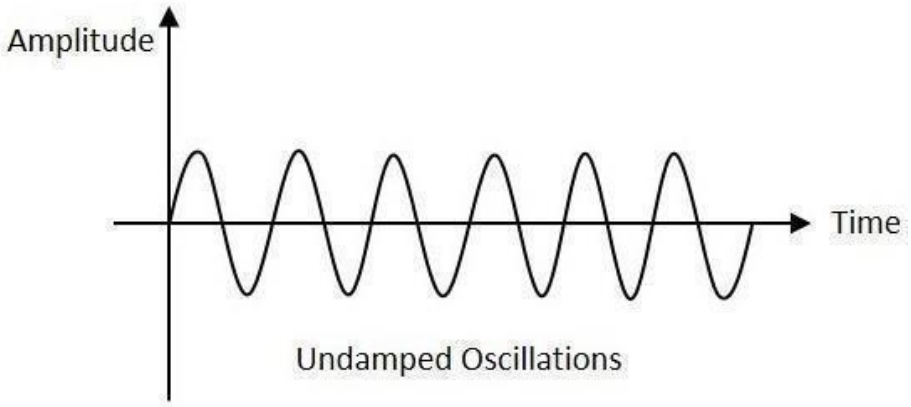
The electrical oscillations whose amplitude goes on decreasing with time are called as **Damped Oscillations**. The frequency of the damped oscillations may remain constant depending upon the circuit parameters.



Damped oscillations are generally produced by the oscillatory circuits that produce power losses and doesn't compensate if required.

Undamped Oscillations

The electrical oscillations whose amplitude remains constant with time are called as **Undamped Oscillations**. The frequency of the undamped oscillations remains constant.



Undamped oscillations are generally produced by the oscillatory circuits that produce no power losses and follow compensation techniques if any power losses occur.

An amplifier with positive feedback produces its output to be in phase with the input and increases the strength of the signal. Positive feedback is also called as **degenerative feedback** or**direct feedback**. This kind of feedback makes a feedback amplifier, an oscillator.

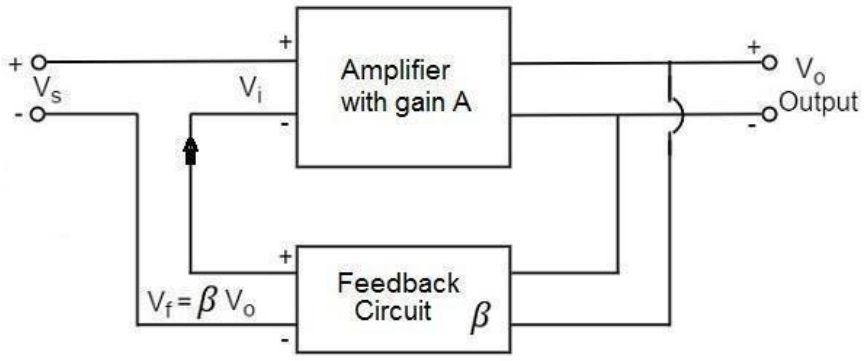
The use of positive feedback results in a feedback amplifier having closed-loop gain greater than the open-loop gain. It results in **instability** and operates as an oscillatory circuit. An oscillatory circuit provides a constantly varying amplified output signal of any desired frequency.

The Barkhausen Criterion

With the knowledge we have till now, we understood that a practical oscillator circuit consists of a tank circuit, a transistor amplifier circuit and a feedback circuit. so, let us now try to brush up the concept of feedback amplifiers, to derive the gain of the feedback amplifiers.

Principle of Feedback Amplifier

A feedback amplifier generally consists of two parts. They are the **amplifier** and the **feedback circuit**. The feedback circuit usually consists of resistors. The concept of feedback amplifier can be understood from the following figure below.



From the above figure, the gain of the amplifier is represented as A. The gain of the amplifier is the ratio of output voltage Vo to the input voltage V_i. The feedback network extracts a voltage $V_f = \beta V_o$ from the output V_o of the amplifier.

This voltage is added for positive feedback and subtracted for negative feedback, from the signal voltage V_s.

So, for a positivefeedback,

$$V_i = V_s + V_f = V_s + \beta V_o$$

The quantity $\beta = V_f/V_o$ is called as feedback ratio or feedback fraction.

The output V_o must be equal to the input voltage $(V_s + \beta V_o)$ multiplied by the gain A of the amplifier.

Hence,

$(Vs+\beta Vo)A=Vo$

Or

$AVs+A\beta Vo=Vo$

Or

$AVs=Vo(1-A\beta)$

Therefore

$$\frac{V_o}{V_s} = \frac{A}{(1-A\beta)}$$

Let A_f be the overall gain (gain with the feedback) of the amplifier. This is defined as the ratio of output voltage V_o to the applied signal voltage V_s, i.e.,

$$A_f = \frac{V_o}{V_s}$$

from the above two equations, we can understand that, the equation of gain of the feedback amplifier with positive feedback is given by

$$Af = \frac{A}{1 - A\beta}$$

Where **Aβ** is the **feedback factor** or the **loop gain**.

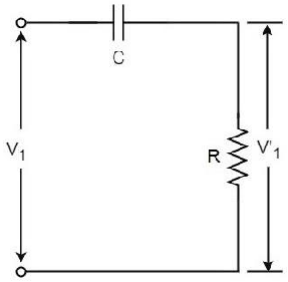
If Aβ = 1, $A_f = \infty$. Thus the gain becomes infinity, i.e., there is output without any input. In another words, the amplifier works as an Oscillator.

The condition Aβ = 1 is called as **Barkhausen Criterion of oscillations**. This is a very important factor to be always kept in mind, in the concept of Oscillators

RC-Phase–shift Oscillators

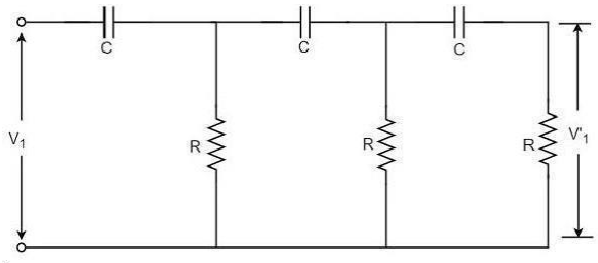
PrincipleofPhase-shiftoscillators

We know that the output voltage of an RC circuit for a sinewave input leads the input voltage. The phase angle by which it leads is determined by the value of RC components used in the circuit. The following circuit diagram shows a single section of an RC network.



The output voltage V_1' across the resistor R leads the input voltage applied input V_1 by some phase angle ϕ^o. If R were reduced to zero, V_1' will lead the V_1 by 90° i.e., ϕ^o=90°.

However, adjusting R to zero would be impracticable, because it would lead to no voltage across R. Therefore, in practice, R is varied to such a value that makes V_1' to lead V_1 by 60°. The following circuit diagram shows the three sections of the RC network.



Each section produces a phase shift of 60°. Consequently, a total phase shift of 180° is produced, i.e., voltage V_2 leads the voltage V_1 by 180°.

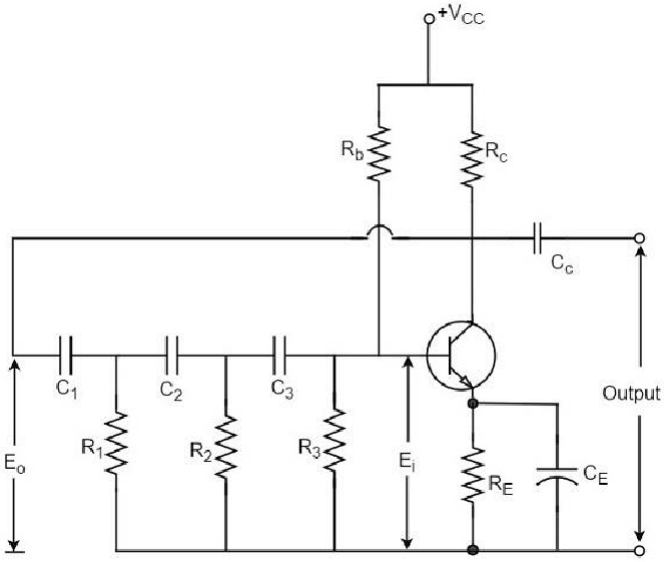
Phase-shift Oscillator Circuit

The oscillator circuit that produces a sine wave using a phase-shift network is called as a Phase-shift oscillator circuit. The constructional details and operation of a phase-shift oscillator circuit are as given below.

Construction

The phase-shift oscillator circuit consists of a single transistor amplifier section and a RC phase-shift network. The phase shift network in this circuit, consists of three RC sections. At the resonant frequency f_o, the phase shift in each RC section is 60^o so that the total phase shift produced by RC network is 180^o.

The following circuit diagram shows the arrangement of an RC phase-shift oscillator.



The frequency of oscillations is given by

$$f_o = \frac{1}{2\pi RC\sqrt{6}}$$

Where

$$R_1 = R_2 = R_3 = R$$

$$C_1 = C_2 = C_3 = C$$

Operation

The circuit when switched ON oscillates at the resonant frequency f_o. The output E_o of the amplifier is fed back to RC feedback network. This network produces a phase shift of 180^o and a voltage E_i appears at its output. This voltage is applied to the transistor amplifier.

The feedback applied will be

$$m=Ei/Eo$$

The feedback is in correct phase, whereas the transistor amplifier, which is in CE configuration, produces a 180^o phase shift. The phase shift produced by network and the transistor add to form a phase shift around the entire loop which is 360^o.

Advantages

The advantages of RC phase shift oscillator are as follows −

- It does not require transformers or inductors.
- It can be used to produce very low frequencies.
- The circuit provides good frequency stability.

Disadvantages

The disadvantages of RC phase shift oscillator are as follows −

- Starting the oscillations is difficult as the feedback is small.
- The output produced is small.

Another type of popular audio frequency oscillator is the Wien bridge oscillator circuit. This is mostly used because of its important features. This circuit is free from the **circuit fluctuations** and the **ambient temperature**.

The main advantage of this oscillator is that the frequency can be varied in the range of 10Hz to about 1MHz whereas in RC oscillators, the frequency is not varied.

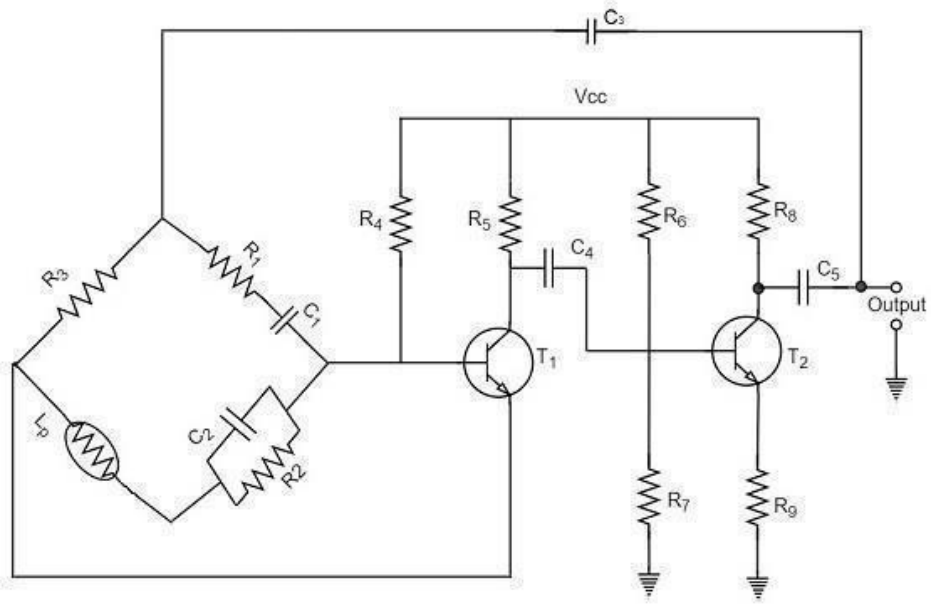
Wienbridge

oscillator

Construction

The circuit construction of Wien bridge oscillator can be explained as below. It is a two-stage amplifier with RC bridge circuit. The bridge circuit has the arms R_1C_1, R_3, R_2C_2 and the tungsten lamp L_p. Resistance R_3 and the lamp L_p are used to stabilize the amplitude of the output.

The following circuit diagram shows the arrangement of a Wien bridge oscillator.



The transistor T_1 serves as an oscillator and an amplifier while the other transistor T_2 serves as an inverter. The inverter operation provides a phase shift of 180°. This circuit provides positive feedback through R_1C_1, C_2R_2 to the transistor T_1 and negative feedback through the voltage divider to the input of transistor T_2.

The frequency of oscillations is determined by the series element R_1C_1 and parallel element R_2C_2 of the bridge.

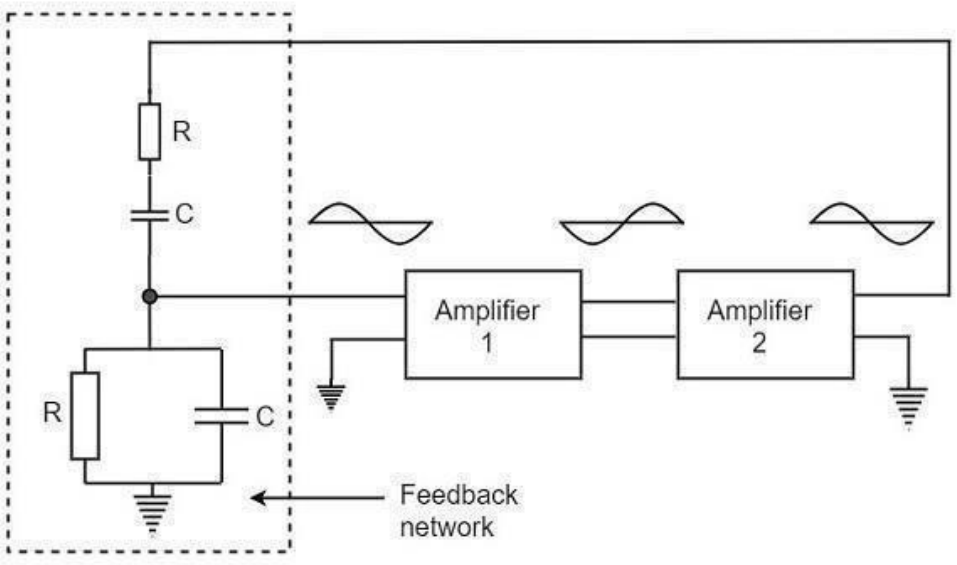
$$f = \frac{1}{2\pi\sqrt{R_1C_1R_2C_2}}$$

If $R_1 = R_2$ and $C_1 = C_2 = C$

Then,

$$f = \frac{1}{2\pi RC}$$

Now, we can simplify the above circuit as follows −



The oscillator consists of two stages of RC coupled amplifier and a feedback network. The voltage across the parallel combination of R and C is fed to the input of amplifier 1. The net phase shift through the two amplifiers is zero.

The usual idea of connecting the output of amplifier 2 to amplifier 1 to provide signal regeneration for oscillator is not applicable here as the amplifier 1 will amplify signals over a wide range of frequencies and hence direct coupling would result in poor frequency stability. By adding Wien bridge feedback network, the oscillator becomes sensitive to a particular frequency and hence frequency stability is achieved.

Operation

When the circuit is switched ON, the bridge circuit produces oscillations of the frequency stated above. The two transistors produce a total phase shift of 360° so that proper positive feedback is ensured. The negative feedback in the circuit ensures constant output. This is achieved by temperature sensitive tungsten lamp L_p. Its resistance increases with current.

If the amplitude of the output increases, more current is produced and more negative feedback is achieved. Due to this, the output would return to the original value. Whereas, if the output tends to decrease, reverse action would take place.

Advantages

The advantages of Wien bridge oscillator are as follows −

- The circuit provides good frequency stability.

- It provides constant output.
- The operation of circuit is quite easy.
- The overall gain is high because of two transistors.
- The frequency of oscillations can be changed easily.
- The amplitude stability of the output voltage can be maintained more accurately, by replacing R_2 with a thermistor.

Disadvantages

The disadvantages of Wien bridge oscillator are as follows −

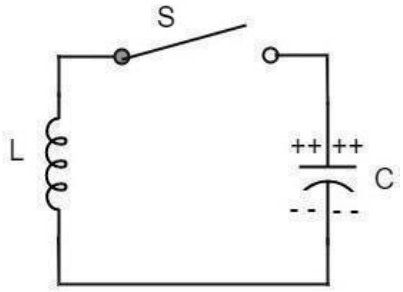
- The circuit cannot generate very high frequencies.
- Two transistors and number of components are required for the circuit construction.

LC Oscillators

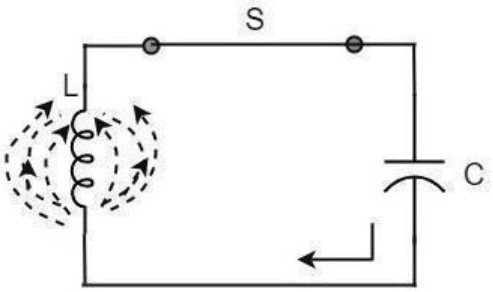
An oscillatory circuit produces electrical oscillations of a desired frequency. They are also known as **tank circuits**.

A simple tank circuit comprises of an inductor L and a capacitor C both of which together determine the oscillatory frequency of the circuit.

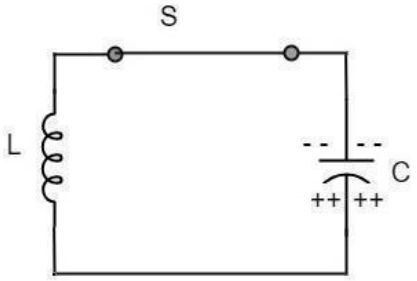
To understand the concept of oscillatory circuit, let us consider the following circuit. The capacitor in this circuit is already charged using a dc source. In this situation, the upper plate of the capacitor has excess of electrons whereas the lower plate has deficit of electrons. The capacitor holds some electrostatic energy and there is a voltage across the capacitor.



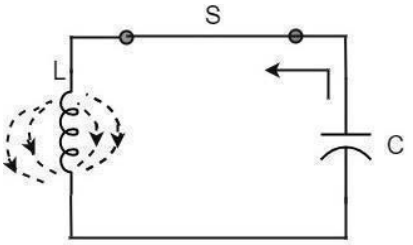
When the switch **S** is closed, the capacitor discharges and the current flows through the inductor. Due to the inductive effect, the current builds up slowly towards a maximum value. Once the capacitor discharges completely, the magnetic field around the coil is maximum.



Now, let us move on to the next stage. Once the capacitor is discharged completely, the magnetic field begins to collapse and produces a counter EMF according to Lenz's law. The capacitor is now charged with positive charge on the upper plate and negative charge on the lower plate.



Once the capacitor is fully charged, it starts to discharge to build up a magnetic field around the coil, as shown in the following circuit diagram.



This continuation of charging and discharging results in alternating motion of electrons or an **oscillatory current**. The interchange of energy between L and C produce continuous **oscillations**.

In an ideal circuit, where there are no losses, the oscillations would continue indefinitely. In a practical tank circuit, there occur losses such as **resistive** and **radiation losses** in the coil and **dielectric losses** in the capacitor. These losses result in damped oscillations.

Frequency of Oscillations

The frequency of the oscillations produced by the tank circuit are determined by the components of the tank circuit, **the L** and **the C**. The actual frequency of oscillations is the **resonant frequency** (or natural frequency) of the tank circuit which is given by

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

Capacitance of the capacitor

The frequency of oscillation f_o is inversely proportional to the square root of the capacitance of a capacitor. So, if the value of the capacitor used is large, the charge and discharge time periods will be large. Hence the frequency will be lower.

Mathematically, the frequency,

$$f_o \propto \frac{1}{\sqrt{C}}$$

Self-Inductance of the coil

The frequency of the oscillation f_o is proportional to the square root of the self-inductance of the coil. If the value of the inductance is large, the opposition to change of current flow is greater and hence the time required to complete each cycle will be longer, which means time period will be longer and frequency will be lower.

Mathematically, the frequency,

$$f_o \propto \frac{1}{\sqrt{L}}$$

Combining both the above equations,

$$f_o \propto \frac{1}{\sqrt{LC}}$$

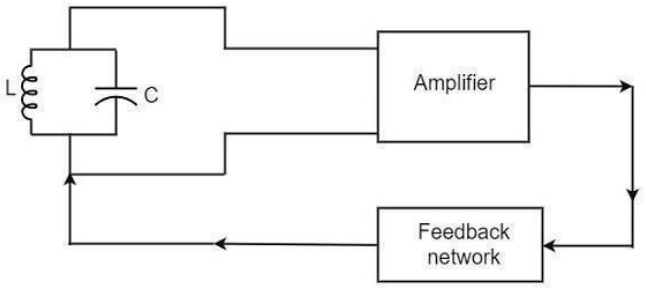
$$f_o = \frac{1}{2\pi\sqrt{LC}}$$

The above equation, though indicates the output frequency, matches the **natural frequency** or **resonance frequency** of the tank circuit.

An Oscillator circuit is a complete set of all the parts of circuit which helps to produce the oscillations. These oscillations should sustain and should be Undamped as just discussed before. Let us try to analyze a practical Oscillator circuit to have a better understanding on how an Oscillator circuit works.

Practical Oscillator Circuit

A Practical Oscillator circuit consists of a tank circuit, a transistor amplifier, and a feedback circuit. The following circuit diagram shows the arrangement of a practical oscillator.



Let us now discuss the parts of this practical oscillator circuit.

Tank Circuit − The tank circuit consists of an inductance L connected in parallel with capacitor **C**. The values of these two components determine the frequency of the oscillator circuit and hence this is called as **Frequency determining circuit**.

- **Transistor Amplifier** − The output of the tank circuit is connected to the amplifier circuit so that the oscillations produced by the tank circuit are amplified here. Hence the output of these oscillations are increased by the amplifier.
- **Feedback Circuit** − The function of feedback circuit is to transfer a part of the output energy to LC circuit in proper phase. This feedback is positive in oscillators while negative in amplifiers.

Frequency Stability of an Oscillator

The frequency stability of an oscillator is a measure of its ability to maintain a constant frequency, over a long time interval. When operated over a longer period of time, the oscillator frequency may have a drift from the previously set value either by increasing or by decreasing.

The change in oscillator frequency may arise due to the following factors −

- Operating point of the active device such as BJT or FET used should lie in the linear region of the amplifier. Its deviation will affect the oscillator frequency.
- The temperature dependency of the performance of circuit components affect the oscillator frequency.
- The changes in d.c. supply voltage applied to the active device, shift the oscillator frequency. This can be avoided if a regulated power supply is used.
- A change in output load may cause a change in the Q-factor of the tank circuit, thereby causing a change in oscillator output frequency.
- The presence of inter element capacitances and stray capacitances affect the oscillator output frequency and thus frequency stability.

Tuned circuit oscillators are the circuits that produce oscillations with the help of tuning circuits. The tuning circuits consists of an inductance L and a capacitor C. These are also known as **LC oscillators, resonant circuit oscillators** or **tank circuit oscillators**.

The tuned circuit oscillators are used to produce an output with frequencies ranging from 1 MHz to 500 MHz Hence these are also known as **R.F. Oscillators**. A BJT or a FET is used as an amplifier with tuned circuit oscillators. With an amplifier and an LC tank circuit, we can feedback a signal with right amplitude and phase to maintain oscillations.

Types of Tuned Circuit Oscillators

Most of the oscillators used in radio transmitters and receivers are of LC oscillators type. Depending upon the way the feedback is used in the circuit, the LC oscillators are divided as the following types.

- **Hartley Oscillator** − It uses inductive feedback.
- **Colpitts Oscillator** − It uses capacitive feedback.
- **Clapp Oscillator** − It uses capacitive feedback.

Hartley Oscillator

A very popular **local oscillator** circuit that is mostly used in **radio receivers** is the **Hartley Oscillator** circuit. The constructional details and operation of a Hartley oscillator are as discussed below.

Construction

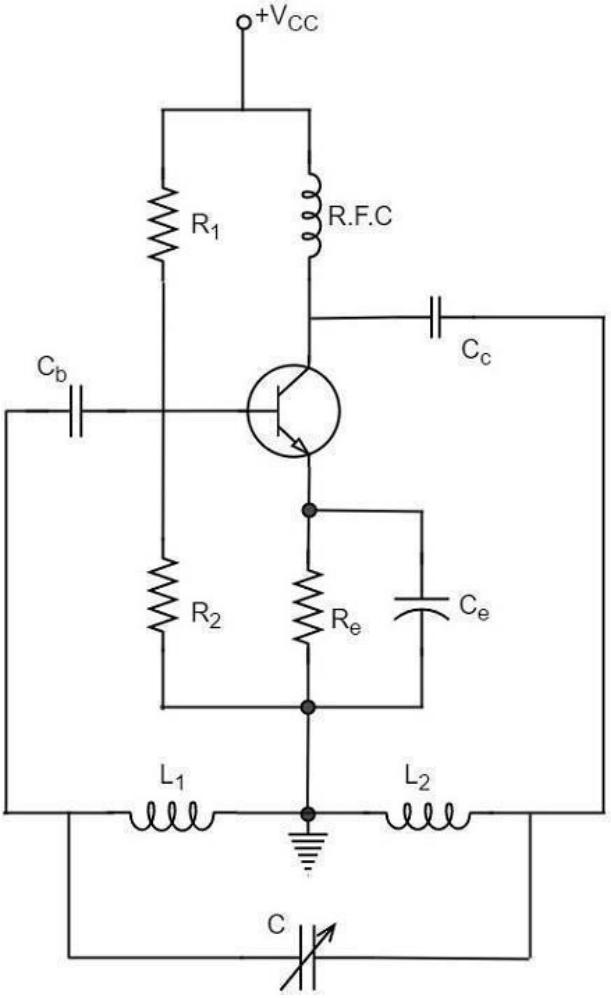
In the circuit diagram of a Hartley oscillator shown below, the resistors R_1, R_2 and R_e provide necessary bias condition for the circuit. The capacitor C_e provides a.c. ground thereby providing any signal degeneration. This also provides temperature stabilization.

The capacitors C_c and C_b are employed to block d.c. and to provide an a.c. path. The radio frequency choke (R.F.C) offers very high impedance to high frequency currents which means it shorts for d.c. and opens for a.c. Hence it provides d.c. load for collector and keeps a.c. currents out of d.c. supply source

Tank Circuit

The frequency determining network is a parallel resonant circuit which consists of the inductors L_1 and L_2 along with a variable capacitor C. The junction of L_1 and L_2 are earthed. The coil L_1 has its one end connected to base via C_c and the other to emitter via C_e. So, L_2 is in the output circuit. Both the coils L_1 and L_2 are inductively coupled and together form an **Auto-transformer**.

The following circuit diagram shows the arrangement of a Hartley oscillator. The tank circuit is **shunt fed** in this circuit. It can also be a **series-fed**.



Operation

When the collector supply is given, a transient current is produced in the oscillatory or tank circuit. The oscillatory current in the tank circuit produces a.c. voltage across L_1.

The **auto-transformer** made by the inductive coupling of L_1 and L_2 helps in determining the frequency and establishes the feedback. As the CE configured transistor provides 180^o phase shift, another 180^o phase shift is provided by the transformer, which makes 360^o phase shift between the input and outputvoltages.

This makes the feedback positive which is essential for the condition of oscillations. When the **loop gain |βA| of the amplifier is greater than one**, oscillations are sustained in the circuit.

Frequency

The equation for **frequency of Hartley oscillator** is given as

$$f = \frac{1}{2\pi\sqrt{L_T C}}$$

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

Here, L_T is the total cumulatively coupled inductance; L_1 and L_2represent inductances of 1st and 2nd coils; and **M** represents mutual inductance.

Mutual inductance is calculated when two windings are considered.

Advantages

The advantages of Hartley oscillator are

- Instead of using a large transformer, a single coil can be used as an auto-transformer.
- Frequency can be varied by employing either a variable capacitor or a variable inductor.
- Less number of components are sufficient.
- The amplitude of the output remains constant over a fixed frequencyrange.

Disadvantages

The disadvantages of Hartley oscillator are

- It cannot be a low frequency oscillator.
- Harmonic distortions are present.

Applications

The applications of Hartley oscillator are

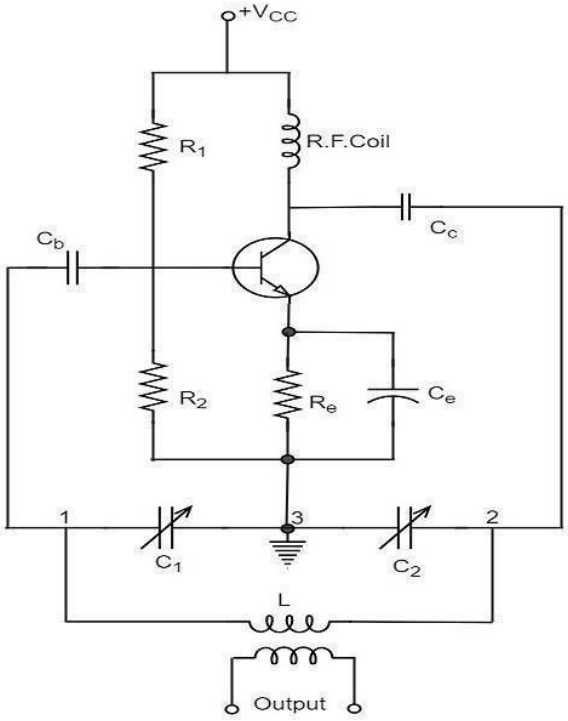
- It is used to produce a sine wave of desired frequency.
- Mostly used as a local oscillator in radio receivers.
- It is also used as R.F. Oscillator.

Colpitts oscillator

A Colpitts oscillator looks just like the Hartley oscillator but the inductors and capacitors are replaced with each other in the tank circuit. The constructional details and operation of a colpitts oscillator are as discussed below.

Construction

Let us first take a look at the circuit diagram of a Colpitts oscillator.



The resistors R_1, R_2 and R_e provide necessary bias condition for the circuit. The capacitor C_e provides a.c. ground thereby providing any signal degeneration. This also provides temperature stabilization.

The capacitors C_c and C_b are employed to block d.c. and to provide an a.c. path. The radio frequency choke (R.F.C) offers very high impedance to high frequency currents which means it shorts for d.c. and opens for a.c. Hence it provides d.c. load for collector and keeps a.c. currents out of d.c. supply source.

Tank Circuit

The frequency determining network is a parallel resonant circuit which consists of variable capacitors C_1 and C_2 along with an inductor L. The junction of C_1 and C_2 are earthed. The capacitor C_1 has its one end connected to base via C_c and the other to emitter via C_e. the voltage developed across C_1 provides the regenerative feedback required for the sustained oscillations.

Operation

When the collector supply is given, a transient current is produced in the oscillatory or tank circuit. The oscillatory current in the tank circuit produces a.c. voltage across C_1 which are

applied to the base emitter junction and appear in the amplified form in the collector circuit and supply losses to the tank circuit.

If terminal 1 is at positive potential with respect to terminal 3 at any instant, then terminal 2 will be at negative potential with respect to 3 at that instant because terminal 3 is grounded. Therefore, points 1 and 2 are out of phase by 180°.

As the CE configured transistor provides 180° phase shift, it makes 360° phase shift between the input and output voltages. Hence, feedback is properly phased to produce continuous Undamped oscillations. When the **loop gain |βA| of the amplifier is greater than one, oscillations are sustained** in the circuit.

Frequency

The equation for **frequency of Colpitts oscillator** is given as

$$f = \frac{1}{2\pi\sqrt{LC_T}}$$

C_T is the total capacitance of C_1 and C_2 connected in series.

$$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2}$$

$$C_T = \frac{C_1 \times C_2}{C_1 + C_2}$$

Advantages

The advantages of Colpitts oscillator are as follows −

- Colpitts oscillator can generate sinusoidal signals of very highfrequencies.
- It can withstand high and low temperatures.
- The frequency stability is high.
- Frequency can be varied by using both the variable capacitors.
- Less number of components are sufficient.
- The amplitude of the output remains constant over a fixed frequency range.

The Colpitts oscillator is designed to eliminate the disadvantages of Hartley oscillator and is known to have no specific disadvantages. Hence there are many applications of a colpitts oscillator.

The operation of Clapp oscillator circuit is in the same way as that of Colpitts oscillator. The frequency of oscillator is given by the relation,

$$2\pi\sqrt{L.C}$$

Where $\frac{1}{\frac{1}{C_1}+\frac{1}{C_2}+\frac{1}{C_3}}$

Usually, the value of C_3 is much smaller than C_1 and C_2. As a result of this, **C** is approximately equal to C_3. Therefore, the frequency of oscillation,

$$f_o = \frac{1}{2\pi\sqrt{L.C_3}}$$

It is understood that the Clapp oscillator is similar to the Colpitts oscillator, however they differ in the way the inductances and capacitances are arranged. The frequency stability though is good, can be variable in a Clapp oscillator.

A Clapp oscillator is sometimes preferred over a Colpitts oscillator for constructing a variable frequency oscillator. The Clapp oscillators are used in receiver tuning circuits as a frequency oscillator.

One of the important features of an oscillator is that the feedback energy applied should be in correct phase to the tank circuit. The oscillator circuits discussed so far has employed inductor (L) and capacitor (C) combination, in the tank circuit or frequency determining circuit.

We have observed that the LC combination in oscillators provide 180° phase shift and transistor in CE configuration provide 180° phase shift to make a total of 360° phase shift so that it would make a zero difference in phase.

Drawbacks of LC circuits

Though they have few applications, the **LC** circuits have few **drawbacks** such as

- Frequency instability
- Waveform is poor
- Cannot be used for low frequencies
- Inductors are bulky and expensive

Whenever an oscillator is under continuous operation, its **frequency stability** gets affected. There occur changes in its frequency. The main factors that affect the frequency of an oscillator are

- Power supply variations
- Changes in temperature
- Changes in load or output resistance

In RC and LC oscillators the values of resistance, capacitance and inductance vary with temperature and hence the frequency gets affected. In order to avoid this problem, the piezo electric crystals are being used in oscillators.

UNIT V:

FET Amplifiers: FET Biasing, Common source Amplifier, Common Drain Amplifier.
Special purpose Devices: Principal of operation and characteristics of Tunnel Diode, Varactor Diode, Photo Diodeand UJT

BIASING FET:-

For the proper functioning of a linear FET amplifier, it is necessary to maintain the operating point Q stable in the central portion of the pinch off region The Q point should be independent of device parameter variations and ambient temperature variations

This can be achieved by suitably selecting the gate to source voltage VGS and drain current ID which is referred to as biasing

JFET biasing circuits are very similar to BJT biasing circuits The main difference between JFET circuits and BJT circuits is the operation of the active components themselves

There are mainly two types of Biasing circuits

1) Self bias
2) Voltage divider-bias.

SELFBIAS

Self bias is a JFET biasing circuit that uses a source resistor to help reverse bias the JFET gate. A self bias circuit is shown in the fig. Self bias is the most common type of JFET bias. This JFET must be operated such that gate source junction is always reverse biased. This condition requires a negative VGS for an N channel JFET and a positive VGS for P channel JFET. This can be achieved using the self bias arrangement as shown in Fig. The gate resistor RG doesn't affect the bias because it has essentially no voltage drop across it, and: the gate remains at 0V .RG is necessary only to isolate an ac signal from ground in amplifier applications. The voltage drop across resistor RS makes gate source junction reverse biased.

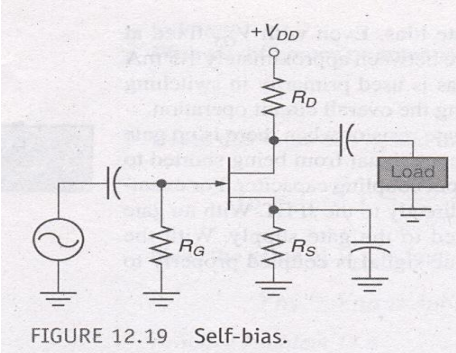


FIGURE 12.19 Self-bias.

For the dc analysis coupling capacitors are open circuits.

For the N channel FET in Fig (a)

IS produces a voltage drop across RS and makes the source positive w.r.t ground. In any JFET circuit all the source current passes through the device to the drain circuit .This is due to the fact that there is no significant gate current.

We can define source current as IS = ID

(VG =0 because there is no gate current flowing in RG So VG across RG is zero)

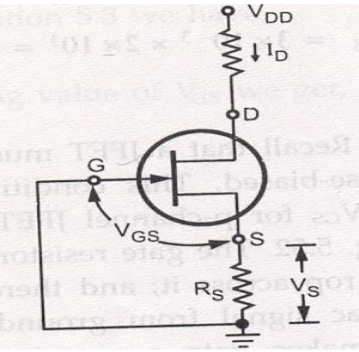
VG =0 then VS= ISRS =ID RS

VGS = VG-VS =0-ID RS=- ID RS

DC analysis of self Bias:-

In the following DC analysis, the N channel J FET shown in the fig. is used for illustration.

For DC analysis we can replace coupling capacitors by open circuits and we can also replace the resistor RG by a short circuit equivalent.:. IG = 0.The relation between ID and VGS is given by



$$Id=Idss[1-\frac{Vgs}{Vp}]^2$$

VGS for N channel JFET is =-idRs

Substuting this value in the above equation

$$Id=Idss[1-\frac{(-IdRs)}{Vp}]^2$$

$$Id=Idss[1+\frac{(IdRs)}{Vp}]^2$$

For the N-chanel FET in the above figure

Is produces a voltage drop across Rs and makes the source positive w.r.t ground in any JFET circuit all the source current passes through the device to drain circuit this is due to the fact that there is no significant gate current. Therefore we can define source current as Is=Id and Vg=0 then

Vs= Is Rs =IdRs

Vgs=Vg-Vs=0-IdRs=-IdRs

Drawing the self bias line:-

Typical transfer characteristics for a self biased JFET are shown in the fig.

The maximum drain current is 5mA and the gate source cut off voltage is -3V. This means the gate voltage has to be between 0 and -3V.

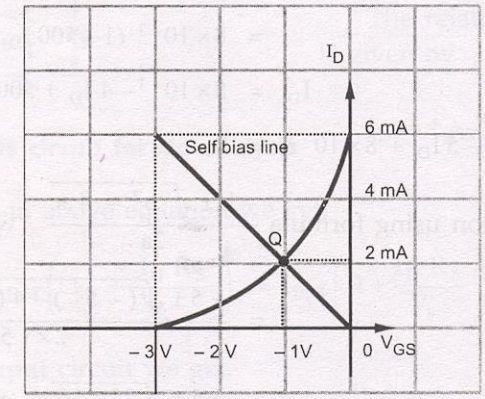


Fig. 5.55 Transfer characteristics

Now using the equation VGS = -IDRS and assuming RS of any suitable value we can draw the self bias line.

Let us assume RS = 500Ω

With this Rs , we can plot two points corresponding to ID = 0 and Id = IDSS

for ID =0

VGS = -ID RS

VGS = 0X (500.Ω) = 0V

So the first point is (0 ,0)

(I_d, VGS)

For ID= IDSS=5mA

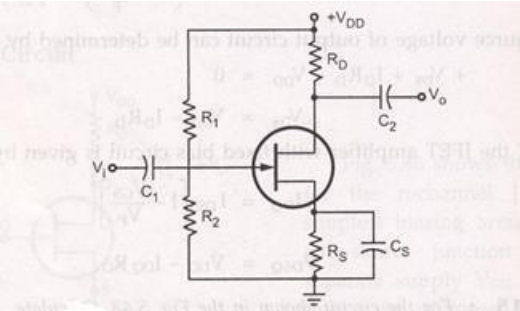
VGS = (-5mA) (500 Ω) = -3V

So the 2nd Point will be (5mA,-3V)

By plotting these two points, we can draw the straight line through the points. This line will intersect the transconductance curve and it is known as self bias line.The intersection point gives the operating point of the self bias JFET for the circuit.

At Q point , the ID is slightly > than 2mA and VGS is slightly > -1V. The Q point for the self bias JFET depends on the value of Rs.If Rs is large, Q point far down on the transconductance curve ,ID is small, when Rs is small Q point is far up on the curve , ID is large.

VOLTAGE DIVIDERBIAS:-



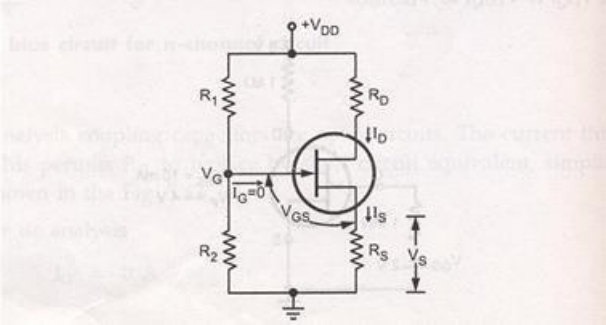
The fig. shows N channel JFET with voltage divider bias. The voltage at the source of JFET must be more positive than the voltage at the gate in order to keep the gate to source junction reverse biased. The source voltage is

VS = IDRS

The gate voltage is set by resistors R1 and R2 as expressed by the following equation using the voltage divider formula.

$$Vg=\left(\frac{R2}{(R1+R2)}\right)Vdd$$

For dc analysis



Applying KVL to the input circuit

VG-VGS-VS =0

:: VGS = VG-Vs=VG-ISRS

VGS=VG-IDRS :: IS =ID

Applying KVL to the input circuit we get

VDS+IDRD+VS-VDD =0

::VDS = VDD-IDRD-IDRS

VDS = VDD-ID (RD +RS)

The Q point of a JFET amplifier , using the voltage divider bias is

IDQ = IDSS[1-VGS/VP]2

VDSQ = VDD-ID (RD+RS)

COMPARISON OF MOSFET WITH JFET

a. In enhancement and depletion types of MOSFET, the transverse electricfield induced across an insulating layer deposited on the semiconductor material controls the conductivity of thechannel.

b. In the JFET the transverse electric field across the reverse biased PN junction controls the conductivity of thechannel.

c. The gate leakage current in a MOSFET is of the order of 10^{-12}A. Hence the input resistance of a MOSFET is very high in the order of 10^{10} to 10^{15} Ω. The gate leakage current of a JFET is of the order of 10^{-9}A., and its input resistance is of the order of10^{8}Ω.

d. TheoutputcharacteristicsoftheJFETareflatterthanthoseoftheMOSFET,andhencethe drain resistance of a JFET (0.1 to 1MΩ) is much higher than that of a MOSFET (1 to50kΩ).

e. JFETs are operated only in the depletion mode. The depletion type MOSFET may be operated in both depletion and enhancementmode.

f. Comparing to JFET, MOSFETs are easier tofabricate.

g. Special digital CMOS circuits are available which involve near zero power dissipation and very low voltage and current requirements. This makes them suitable for portable systems.

FET AMPLIFIERS

INTRODUCTION

Field Effect Transistor (FET) amplifiers provide an excellent voltage gain and high input impedence. Because of high input impedence and other characteristics of JFETs they are preferred over BJTs for certain types of applications.

There are 3 basic FET circuit configurations:

i) Common Source

ii)Common Drain

iii)Common Gain

Similar to BJT CE,CC and CB circuits, only difference is in BJT large output collector current is controlledbysmallinputbasecurrentwhereasFETcontrolsoutputcurrentbymeansofsmallinput voltage. In both the cases output current is controlledvariable.

FET amplifier circuits use voltage controlled nature of the JFET. In Pinch off region, I_D depends only on V_{GS}.

Common Source (CS)Amplifier

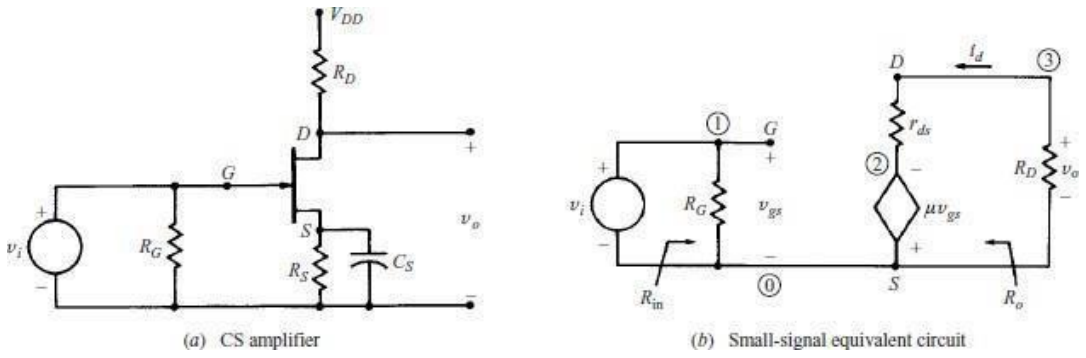


Fig. 5.1 (a) CS Amplifier (b) Small-signal equivalent circuit

A simple Common Source amplifier is shown in Fig. 5.1(a) and associated small signal equivalent circuit using voltage-source model of FET is shown in Fig. 5.1(b)

Voltage Gain

Source resistance (R_S) is used to set the Q-Point but is bypassed by C_S for mid-frequency operation.

From the small signal equivalent circuit ,the output voltage

$$V_O = -R_D \mu V_{gs}(R_D + r_d)$$

Where $V_{gs} = V_i$, the input voltage,

Hence, the voltage gain,

$$A_V = V_O / V_i = -R_D \mu (R_D + r_d)$$

Input Impedence

From Fig. 5.1(b) Input Impedence is

$$Z_i = R_G$$

For voltage divider bias as in CE Amplifiers of BJT

$$R_G = R_1 \| R_2$$

Output Impedance

Output impedance is the impedance measured at the output terminals with the input voltage $V_I = 0$

From the Fig. 5.1(b) when the input voltage $V_i = 0$, $V_{gs} = 0$ and hence

$$\mu V_{gs} = 0$$

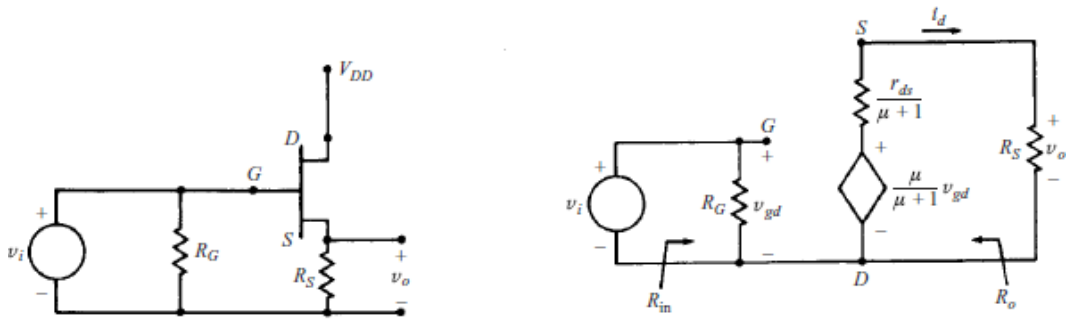
The equivalent circuit for calculating output impedence is given in Fig. 5.2.

Output impedence $Z_o = r_d \| R_D$

Normally r_d will be far greater than R_D . Hence $Z_o \approx R_D$

Common DrainAmplifier

A simple common drain amplifier is shown in Fig. 5.2(a) and associated small signal equivalent circuit using the voltage source model of FET is shown in Fig. 5.2(b).Since voltage V_{gd} is more easily determined than V_{gs}, the voltage source in the output circuit is expressed in terms of V_{gs} and Thevenin's theorem.



(a) CD or SF amplifier (b) Small-signal equivalent circuit

Fig. 5.2 (a)CD Amplifier (b)Small-signal equivalent circuit

Voltage Gain

The output voltage,

$$V_O = R_S \mu V_{gd} / (\mu + 1) R_S + r_d$$

Where $V_{gd} = V_i$ the input voltage.

Hence, the voltage gain,

$$A_v = V_O / V_i = R_S \mu / (\mu + 1) R_S + r_d$$

Input Impedence

From Fig. 5.2(b), Input Impedence $Z_i = R_G$

Output Impedence

From Fig. 5.2(b), Output impedence measured at the output terminals with input voltage $V_i = 0$ can be calculated from the following equivalent circuit.

As $V_i = 0$: $V_{gd} = 0$: $\mu v_{gd} / (\mu + 1) = 0$

Output Impedence

$$Z_O = r_d / (\mu + 1) \parallel R_S$$

When $\mu \gg 1$

$$Z_O = (r_d / \mu) \parallel R_S = (1/g_m) \parallel R_S$$

BIASING FET

For the proper functioning of a linear FET amplifier, it is necessary to maintain the operating point Q stable in the central portion of the pinch off region The Q point should be independent of device parameter variations and ambient temperature variations

This can be achieved by suitably selecting the gate to source voltage VGS and drain current ID which is referred to as biasing

JFET biasing circuits are very similar to BJT biasing circuitsThe main difference between JFET circuits and BJT circuits is the operation of the active components themselves

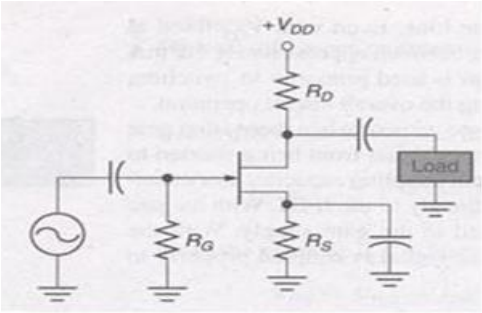
There are mainly two types of Biasing circuits

1. Selfbias
2. Voltage dividerbias.

5.13.1. SELF BIAS:-

Self bias is a JFET biasing circuit that uses a source resistor to help reverse bias the JFET gate.

A self bias circuit is shown in the fig 5.3



Self bias is the most common type of JFET bias.
This JFET must be operated such that gate source junction is always reverse biased.
This condition requires a negative VGS for an N channel JFET and a positive VGS for P channel JFET.
This can be achieved using the self bias arrangement as shown in Fig 5.3.
The gate resistor RG doesn't affect the bias because it has essentially no voltage drop across it, and :
the gate remains at 0V .RG is necessary only to isolate an ac signal from ground in amplifier applications.
The voltage drop across resistor RS makes gate source junction reverse biased.

DC analysis of self Bias:-

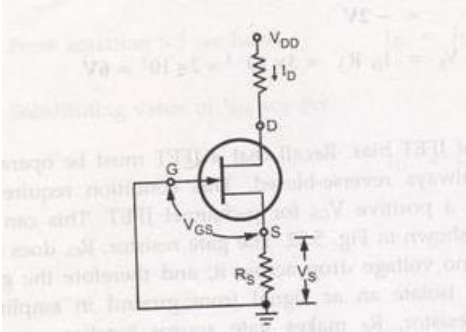
In the following DC analysis , the N channel J FET shown in the fig5.4. is used for illustration.

ForDCanalysiswecanreplacecouplingcapacitorsbyopencircuitsand we canalsoreplace the resistor RG by a short circuitequivalent.

:. IG = 0

The relation between ID and VGS is given by

$$Id=Idss[1-\frac{Vgs}{Vp}]^2$$



VGS for N channel JFET is =-id Rs

Substuting this value in the above equation

$$Id=Idss[1-\frac{(-IdRs)}{Vp}]^2$$

$$Id=Idss[1+\frac{(IdRs)}{Vp}]^2$$

For the N-chanel FET in the above figure

Is produces a voltage drop across Rs and makes the source positive w.r.t ground

in any JFET circuit all the source current passes through the device to drain circuit this is due to the fact that there is no significant gate current

therefore we can define source current as Is=Id and Vg=0 then

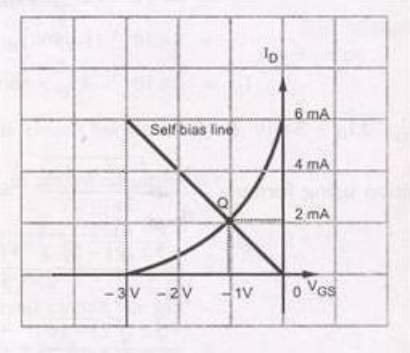
Vs= Is Rs =IdRs

Vgs=Vg-Vs=0-IdRs=-IdRs

Drawing the self bias line:-

Typical transfer characteristics for a self biased JFET are shown in the figure 5.5 below:

The maximum drain current is 6mA and the gate source cut off voltage is -3V. This means the gate voltage has to be between 0 and -3V.



Now using the equation VGS = -IDRS and assuming RS of any suitable value we can draw the self bias line.

Let us assume RS = 500Ω

With this Rs , we can plot two points corresponding to ID = 0 and Id =IDSS

for ID =0

VGS = -ID RS

VGS = 0X (500.Ω) = 0V

So the first point is (0 ,0)

(I_d, VGS)

For ID= IDSS=6mA

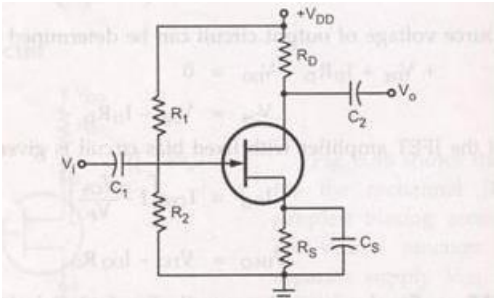
VGS = (-6mA) (500 Ω) = -3V

So the 2nd Point will be (6mA,-3V)

By plotting these two points, we can draw the straight line through the points. This line will intersect the transconductance curve and it is known as self bias line. The intersection point gives the operating point of the self bias JFET for the circuit.

At Q point , the ID is slightly > than 2mA and VGS is slightly > -1V. The Q point for the self bias JFET depends on the value of Rs.If Rs is large, Q point far down on the transconductance curve ,ID is small, when Rs is small Q point is far up on the curve , ID is large.

5.13.2 VOLTAGE DIVIDER BIAS:-



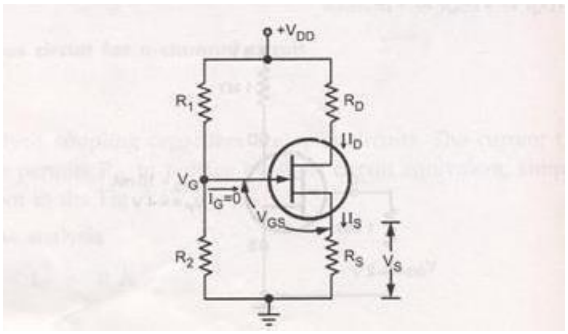
The fig5.6 shows N channel JFET with voltage divider bias. The voltage at the source of JFET must be more positive than the voltage at the gate in order to keep the gate to source junction reverse biased. The source voltage is

VS = IDRS

The gate voltage is set by resistors R1 and R2 as expressed by the following equation using the voltage divider formula.

Vg= $Vdd\left(\frac{R2}{(R1+R2)}\right)$

For dc analysis fig 5.5



Applying KVL to the input circuit

VG-VGS-VS =0

:: VGS = VG-Vs=VG-ISRS

VGS=VG-IDRS :: IS =ID

Applying KVL to the input circuit we get

VDS+IDRD+VS-VDD =0

::VDS = VDD-IDRD-IDRS

VDS = VDD-ID (RD +RS)

The Q point of a JFET amplifier , using the voltage divider bias is

IDQ = IDSS[1-VGS/VP]2

VDSQ = VDD-ID (RD+RS)

SPECIAL PURPOSE ELECTRONIC DEVICES

PRINCIPLE OF OPERATION AND CHARACTERISTICS OF TUNNELDIODE

A **tunnel diode** or **Esaki diode** is a type of semiconductor diode which is capable of very fast operation, well into the microwave frequency region, by using quantum mechanical effects.

It was invented in August 1957 by Leo Esaki when he was with Tokyo Tsushin Kogyo, now known as Sony. In 1973 he received the Nobel Prize in Physics, jointly with Brian Josephson, for discovering the electron tunneling effect used in these diodes. Robert Noyce independently came up with the idea of a tunnel diode while working for William Shockley, but was discouraged from pursuing it.



Fig 5.8 : Tunnel diode schematic symbol

These diodes have a heavily doped p–n junction only some 10 nm (100 Å) wide. The heavy doping results in a broken bandgap, where conduction band electron states on the n-side are more or less aligned with valence band hole states on the p-side. Tunnel diodes were manufactured by Sony for the first time in 1957 followed by General Electric and other companies from about 1960, and are still made in low volume today. Tunnel diodes are usually made from germanium, but can also be made in gallium arsenide and silicon materials. They can be used as oscillators, amplifiers, frequency converters and detectors.TunnellingPhenomenon:

In a conventional semiconductor diode, conduction takes place while the p–n junction is forward biased and blocks current flow when the junction is reverse biased. This occurs up to a point known as the “reverse breakdown voltage” when conduction begins (often accompanied by destruction of the device). In the tunnel diode, the dopant concentration in the p and n layers are increased to the point where the **reverse breakdown voltage** becomes **zero** and the diode conducts in the reverse direction. However, when forward-biased, an odd effect occurs called “quantum mechanical tunnelling” which gives rise to a region where an *increase* in forward voltage is accompanied by a *decrease* in forward current. This negative resistance region can be exploited in a solid state version of the dynatron oscillator which normally uses a tetrode thermionic valve (ortube).

Forward bias operation

Under normal forward bias operation, as voltage begins to increase, electrons at first tunnel through the very narrow p–n junction barrier because filled electron states in the conduction band on the n-

side become aligned with empty valence band hole states on the p-side of the p-n junction. As voltage increases further these states become more misaligned and the current drops – this is called *negative resistance* because current decreases with increasing voltage. As voltage increases yet further, the diode begins to operate as a normal diode, where electrons travel by conduction across the p–n junction, and no longer by tunneling through the p–n junction barrier. Thus the most important operating region for a tunnel diode is the negative resistance region.

Reverse bias operation

When used in the reverse direction they are called **back diodes** and can act as fast rectifiers with zero offset voltage and extreme linearity for power signals (they have an accurate square law characteristic in the reverse direction).

Under reverse bias filled states on the p-side become increasingly aligned with empty states on the n-side and electrons now tunnel through the pn junction barrier in reverse direction – this is the Zener effect that also occurs in zener diodes.

Technical comparisons

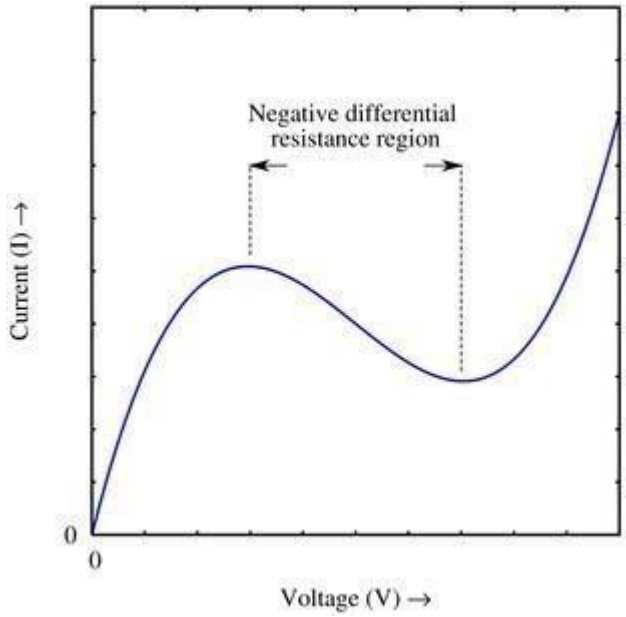


Fig5.9: current-voltage characteristic of tunnel diode

A rough approximation of the VI curve for a tunnel diode, showing the negative differential resistance region. The Japanese physicist Leo Esaki invented the tunnel diode in 1958.It consists of a p-n junction with highly doped regions. Because of the thinness of the junction, the electrons can pass through the potential barrier of the dam layer at a suitable polarization, reaching the energy states on the other sides of the junction. The current-voltage characteristic of the diode is represented in Figure 1.20a. In this sketch *i p* and *Up* are the peak, and *iv* and *Uv* are the valley values for the current and voltage

respectively. The form of this dependence can be qualitatively explained by considering the tunneling processes that take place in a thin p-n junction.

Energy band structure of tunnel diode:

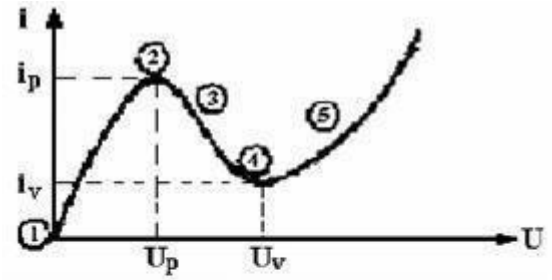


Figure 1.

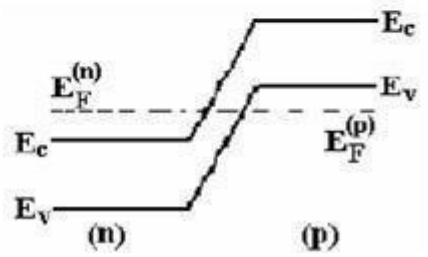
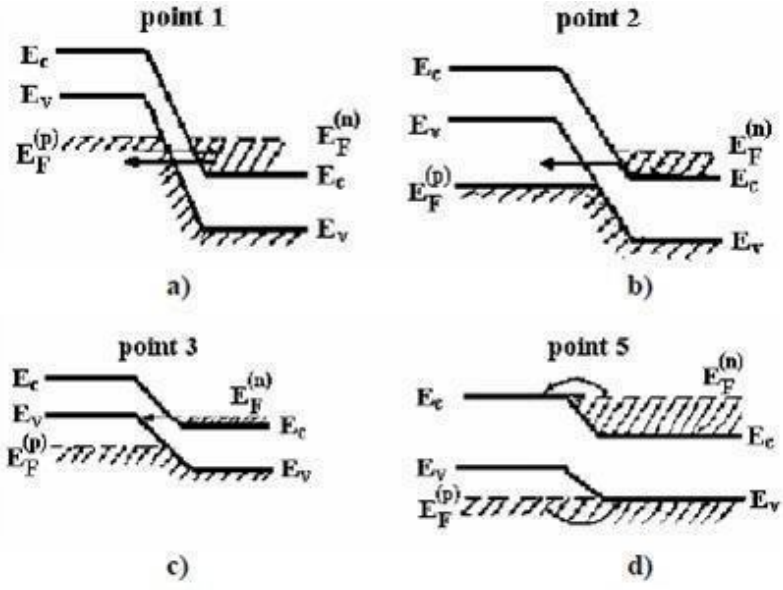


Fig 5.10 Energy band structure of tunnel diode

For the degenerated semiconductors, the energy band diagram at thermal equilibrium is presented in Figure 5.10b.

In Figure 5.11c the tunneling processes in different points of the current voltage characteristic for the tunnel diode are presented.



Advantages of tunnel diodes:

- Environmental immunity i.e. peak point is not a function oftemperature.
- Lowcost.
- Lownoise.
- Low power consumption.
- High speed i.e. tunneling takes place very fast at the speed of light in the order ofnanoseconds
- Simplicity i.e. a tunnel diode can be used along with a d.c supply and a few passive elements to obtain various applicationcircuits.

Applications for tunnel diodes:

- local oscillators for UHF televisiontuners
- Trigger circuits inoscilloscopes
- High speed counter circuits and very fast-rise time pulse generatorcircuits
- The tunnel diode can also be used as low-noise microwaveamplifier.

VARACTORDIODE

Varactor diode is a special type of diode which uses transition capacitance property i.e voltage variable capacitance .These are also called as varicap,VVC(voltage variable capacitance) or tuning diodes.

The varactor diode symbol is shown below with a diagram representation.



Fig 5.12:symbol of varactor diode

When a reverse voltage is applied to a PN junction, the holes in the p-region are attracted to the anode terminal and electrons in the n-region are attracted to the cathode terminal creating a region where there is little current. This region ,the depletion region, is essentially devoid of carriers and behaves as the dielectric of a capacitor.

The depletion region increases as reverse voltage across it increases; and since capacitance varies inversely as dielectric thickness, the junction capacitance will decrease as the voltage across the PN junction increases. So by varying the reverse voltage across a PN junction the junction capacitance can be varied .This is shown in the typical varactor voltage-capacitance curve below.

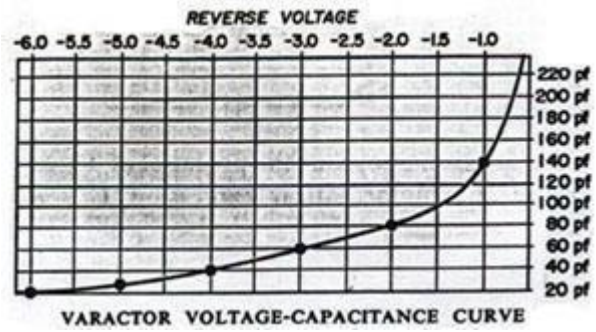


Fig 5.13voltage- capacitance curve

Notice the nonlinear increase in capacitance as the reverse voltage is decreased. This nonlinearity allows the varactor to be used also as a harmonic generator.

Major varactor considerations are:
(a) Capacitance value
(b) Voltage
(c) Variation in capacitance withvoltage.
(d) Maximum workingvoltage
(e) Leakage current

Applications:

- Tuned circuits.
- FM modulators
- Automatic frequency controldevices
- Adjustable bandpassfilters
- Parametricamplifiers
- Television receivers.

PHOTODIODE

The photo diode is a semiconductor p-n junction device whose region of operation is limited to the reverse biased region.The figure below shows the symbol of photodiode



Fig 5.18:Symbol of photodiode.

Principle of operation:

A photodiode is a type of photo detector capable of converting light into either current or voltage, depending upon the mode of operation. The common, traditional solar cell used to generate electric solar power is a large area photodiode. A photodiode is designed to operate in reverse bias. The deletion region width is large. Under normal conditions it carries small reverse current due to minority charge carriers. When light is incident through glass window on the p-n junction, photons in the light bombard the p-n junction and some energy s imparted to the valence electrons. So valence electrons

break covalent bonds and become free electrons. Thus more electron-hole pairs are generated. Thus total number of minority charge carriers increases and hence reverse current increases.This is the basic principle of operation of photo diode.

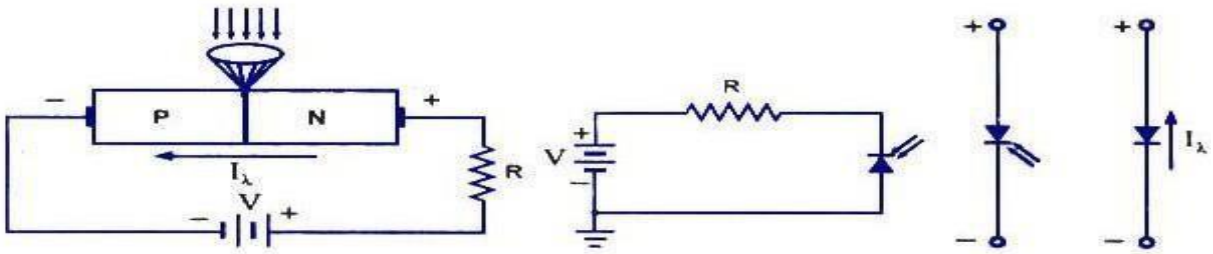


Fig 5.19: Basic Biasing Arrangement and construction of photodiode and symbols

Characteristics of photodiode:

When the P-N junction is reverse-biased, a reverse saturation current flows due to thermally generated holes and electrons being swept across the junction as the minority carriers. With the increase in temperature of the junction more and more hole-electron pairs are created and so the reverse saturation current I_0 increases. The same effect can be had by illuminating the junction. When light energy bombards a P-N junction, it dislodges valence electrons.

The more light striking the junction the larger the reverse current in a diode. It is due to generation of more and more charge carriers with the increase in level of illumination. This is clearly shown in ‘figure for different intensity levels. The dark current is the current that exists when no light is incident. It is to be noted here that current becomes zero only with a positive applied bias equals to V_Q. The almost equal spacing between the curves for the same increment in luminous flux reveals that the reverse saturation current I_0 increases linearly with the luminous flux as shown in figure. Increase in reverse voltage does not increase the reverse current significantly, because all available charge carriers are already being swept across the junction. For reducing the reverse saturation current I_0 to zero, it is necessary to forward bias the junction by an amount equal to barrier potential. Thus the photodiode can be used as a photoconductive device.

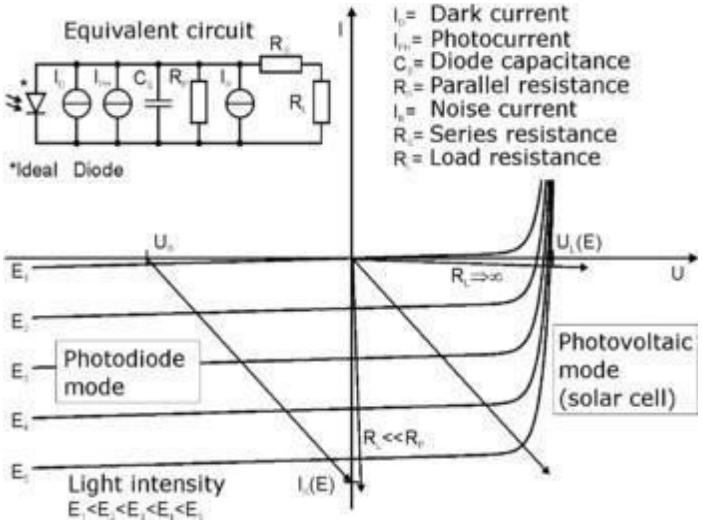


Fig 5.20: characteristics of photodiode

On removal of reverse bias applied across the photodiode, minority charge carriers continue to be swept across the junction while the diode is illuminated. This has the effect of increasing the concentration of holes in the P-side and that of electrons in the N-side But the barrier potential is negative on the P-side and positive on the N-side, and was created by holes flowing from P to N-side and electrons from N to P-side during fabrication of junction. Thus the flow of minority carriers tends to reduce the barrier potential.

When an external circuit is connected across the diode terminals, the minority carrier; return to the original side via the external circuit. The electrons which crossed the junction from P to N-side now flow out through the N-terminal and into the P-terminal This means that the device is behaving as a voltage cell with the N-side being the negative terminal and the P-side the positive terminal. Thus, the photodiode is & photovoltaic device as well as photoconductive device.

Advantages:

The advantages of photodiode are:

1. It can be used as variable resistance device. 2. Highly sensitive to the light.
3. The speed of operation is very high.

Disadvantages:

1. Temperature dependent dark

current. 2. Poor temperature stability.
3. Current needs amplification for driving other circuits.

Applications:

1. Alarm system. 2. Counting system

UNIJUNUCTION TRANSISTOR (UJT)

It is a three-terminal silicon diode. As its name indicates, ithas only one *P-N* junction.

- It differs from an ordinary diode in that it has three leadsand it differs from a FET in that it has no ability to amplify.

- However, it has the ability to control a large ac power with asmall signal. It is a three-terminal silicon diode. As its name indicates, it has only one *P-N* junction.

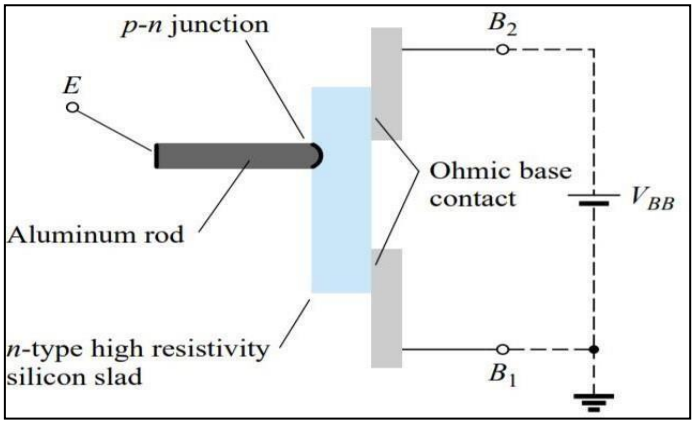
- It differs from an ordinary diode in that it has three lead sand it differs from a FET in that it has no ability to amplify.

However, it has the ability to control a large ac power with asmall signal.

Construction

- A slab of lightly doped (increased resistance characteristic) n-type silicon material has two base contacts attached to both ends of one surface and an aluminum rod alloyed to the opposite surface.

- The p-n junction of the device is formed at the boundary of the aluminum rod and the n-type silicon slab. The single p-n junction accounts for the terminology unijunction. It was originally called a duo (double) base diode due to the presence of two base



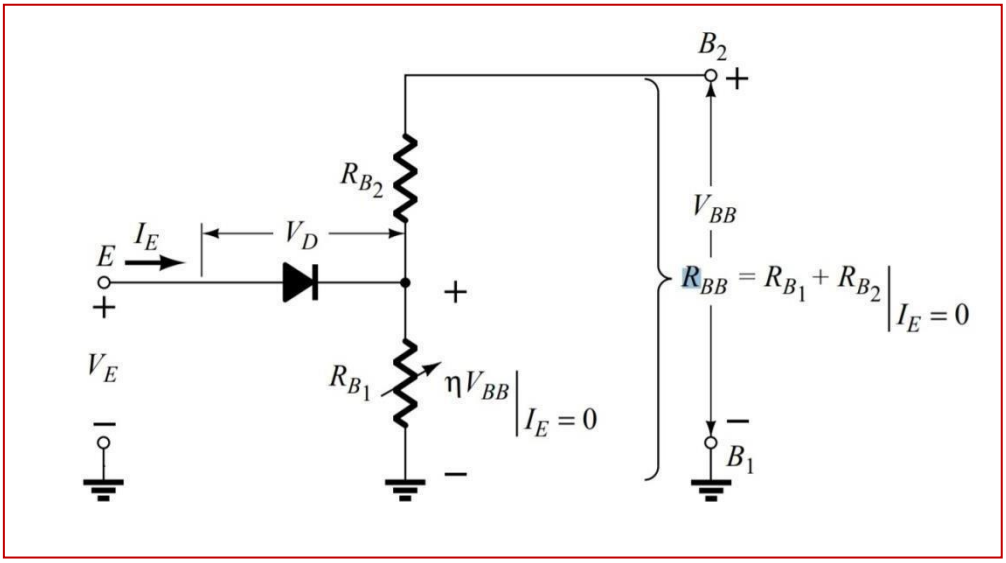
INTER-BASE RESISTANCE (R_{BB})

- It is the resistance between $B_2$and B_1 *i.e*. it is the total resistance of the silicon bar from one end to the other with emitter terminal open.

- It should also be noted that point

A is such that $R_{B1} > R_{B2}$. Usually, R_{B1} = 60% of $_{RB1}$

- The resistance R_{B1} has been shown as a variable resistor because its value varies
inversely as *I*
E.



INTRINSICSTAND-OFFRATIO

- As seen from Fig, when a battery of 30 V is applied across B_2 B_1 , there is a progressive `fallof voltage over R_{BB} provided *E* is open.

It is obvious from Fig. that emitter acts as a voltage-divider tap on fixed resistance*RBB*.

- With emitter open, $I_1 = I_2$, the interbase current is given by Ohm's Law.

  $I_1 = I_2 = V_{BB} / R_{BB}$

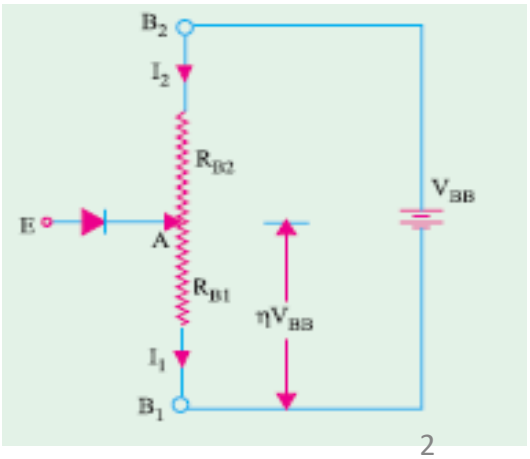
- It may be noted that part of *VBB* is dropped over R_{B2} and part on R_{B1}. Let uscall the voltage drop across R_{B1} as V_A.

- Using simple voltage divider relationship, The voltage division factor is given a special symbol (η) and the name of '**intrinsic standoff ratio**'

$$V_{R_{B_1}} = \frac{R_{B_1}}{R_{B_1} + R_{B_2}} \cdot V_{BB} = \eta V_{BB}\Big|_{I_E=0}$$

$$\eta = \frac{R_{B_1}}{R_{B_1} + R_{B_2}}\Big|_{I_E=0} = \frac{R_{B_1}}{R_{BB}}$$

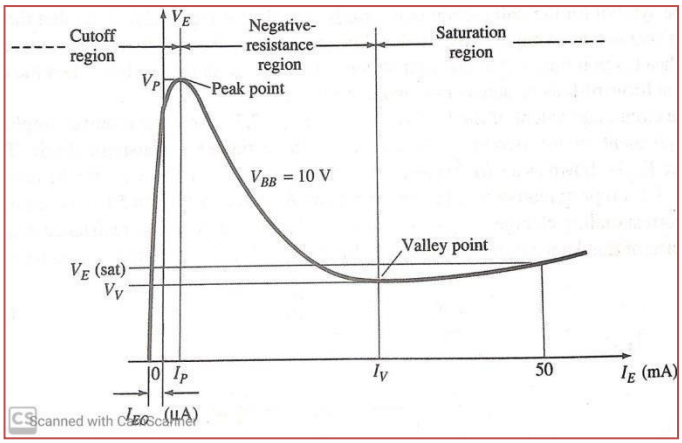
Therefore, $V_{RB1} = \eta V_{BB}$



UJT Static Emitter Characteristics

- The decrease in resistance in the active region is due to the holes injected into the n-type slab from the aluminum p-type rod when conduction is established.

- The increased hole content in the n-type material will result in an increase in the numberof free electrons in the slab, producing an increase in conductivity (G) and a corresponding drop in resistance (R ↓ 1/G ↑). Three other important parameters for the unijunction transistor are IP, VV, and IV. Each is indicated on Fig.



- When *VBB* is switched on, *VA* is developed and ***reverse-biases the junction*.** If V_B is the barrier voltage of the *P-N* junction, then total reverse bias voltage is = V_{RB1} +*VB* = ηV_{BB} + V*B* Value of *VB* for Si is 0.7 V.

- It is obvious that emitter junction will not become forward-biased unless itsapplied voltage *V*E exceeds (ηV_{BB}+ *VB*). This value of *VE* is **called peakpoint voltage VP** .

- When *VE* = *VP,* emitter (peak current), *IP* starts to flow through *RB1* to ground(*i.e*. *B1*). The UJT is then said to have been ***fired*** or turned ON. Beyond the valleypoint, UJT is in

Saturation and *V*E increases very little with an increasing *IE*.

- It is seen that only terminals *E* and *B*1 are the active terminals whereas *B*2 is the Bias terminal *i.e*. it is meant only for applying external voltage across the UJT.

- Generally, UJT is triggered into conduction by applying a suitable positive pulse at its emitter.

- It can be brought back to OFF state by applying a negative trigger pulse.

2.3 APPLICATIONS

- One unique property of UJT is that it can be triggered by (or an output can be taken from) *any one of its three terminals***.**

- Once triggered, the emitter current *IE* of the UJT increases regeneratively till it reaches a limiting value determined by the externalpower supply. Because of this particular behavior , UJT is used in a variety of circuit applications.

- Some of which are :

i. phase control

ii. sine wave generator

iii. switching

iv. Pulse generator

v. sawtooth generator

vi. timing and trigger circuits,

Voltage or current regulated supplies

Code No:

R20

MALLA REDDY COLLEGE OF ENGINEERING & TECHNOLOGY

(Autonomous Institution – UGC, Govt. of India)

II B. Tech I Semester Regular Examinations

Electronic Devices Circuits

(ECE)

Roll No										

Time: 3 hours **Max. Marks: 70**

Note: This question paper Consists of 5 Sections. Answer **FIVE** Questions, Choosing ONE Question from each SECTION and each Question carries 14 marks.

SECTION-I

1. Draw and explain the circuit diagram of full-wave rectifier with inductor filter. Derive the Ripple factor equation. [14]

(OR)

2. Derive expressions for ripple factor ,regulation and rectification efficiency of a Center tapped Transformer Fullwave rectifier. [14]

SECTION-II

3. What are the compensation techniques used for V_{BE} and I_{CO}? Explain with the help of suitable circuits[14]

(OR)

4. Designacollectortobasebiascircuitusingsilicontransistortoachieveastabilityfactorof 20, with the following specifications: V_{CC} =16V,V_{BE} = 0.7V,V_{CEQ} = 8V,I_{CQ} = 4mA &β= 50 [7]

(b) Derive condition for thermal stability? [7]

SECTION-III

5.(a) Draw the h-parameter model of BJT [7]

(b) Covert CB h-parameters into CE h-parameters [7]

(OR)

6) Draw the circuit diagram of Common Emitter amplifier using accurate h-parameter model. Derive expressions for Ai,Av,Ri&Ro. [14]

SECTION-IV

7a. Draw and the block schematic of amplifier with negative feedback. [5]

b. Draw the circuit diagram of voltage series feedback amplifier and derive expressions for input and output resistances. [9]

(OR)

8a. Explain Barkhausen criterion for oscillation in feedback oscillator. [5]

b. Derive an expression for frequency oscillation of Hartley oscillator using transistor. [9]

SECTION-V

9. Explain Common Source amplifier [14]

(OR)

10. Explain the constructional and principal operations of PHOTO diode. [14]

R20

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SECTION-I

1. (a)A Full wave single phase rectifier makes use of 2 diodes, the internal forward resistanceof each is considered to be constant and equal to 30Ω. The load resistance is 1KΩ. Thetransformersecondaryvoltageis200-0-200V(rms).Calculate V_{DC},I_{DC},Ripple factor [7]

(b) A Zener voltage regulator circuit is to maintain constant voltage at 60 V, over a current range from 5 to 50 mA. The input supply voltage is 200 V. Determine the value ofresistance R to be connected in the circuit, for voltage regulation from load current I_L = 0mAto$I_L$max,the maximum possible value of I_L.What is the value $I_L$max?[7]

(OR)

2. Derive expression for FWR Rectifier D C load curren tii)DC output voltage iii)Peak Inverse Voltage of each diode IV)Efficiency v)Ripple factor [14]

SECTION-II

3. Draw a Fixed bias circuit& explain it so operation Calculate the Stability factors S'. [14]

(OR)

4. DefinestabilityfactorsforaBJTwithSelfbiasingmethod.Suggesthowthismethodtoeffectsonoperatingpointofa BJTcircuit [14]

SECTION-III

5. Determine the hybrid –π parameters of a Transistor operating at Collector Current I_C(Q)=2mA,V_{CE}(Q)=20V and I_B(Q)=20μA.Transistor specifications are β=100,unity gain frequency f_T=50MHz,C_O=3pF,h_{ie}=1.4KΩ,h_{re}=2.5*10-4,h_{oe}=25μmhos.Assume that the Operating temperature is 3000K [14]

(OR)

6. Draw the circuit diagram of Common Emitter amplifier using accurate h-parameter model. Derive expressions for Ai, Av ,Ri &Ro . [14]

SECTION-IV

7. a. Show that the bandwidth increases in negative feedback amplifiers. [7]

b. What are the different types of feedback amplifiers? Give their equivalent circuits.[7]

(OR)

8. a. Draw the circuit diagram of RC-phase shift oscillator using BJT and derive the expression for frequency of oscillations. [10]

b. Compare positive feedback and negative feedback. [4]

SECTION-V

9 Explain the principle of CS FET amplifier with the help of circuit diagram. Derive the expressions for A_V,input impedance and output impedance[14]

(OR)

10) Explain the working of Tunnel diode with help of energy band diagrams and Draw V-I Characteristics

UNIT WISE QUESTION BANK

UNIT-I

1. Study thoroughly the following terms of a half wave rectifier with resistive load.
   i. Ripple factor.
   ii. Peak inverse voltage.
   iii. Rectification efficiency.
2. Define the terms as referred to Full wave rectifier circuit.
   i. PIV
   ii. Average d.c. voltage
   iii. RMS current
   iv. Ripple factor.
3. Discuss full wave rectifier with Π filter.
4. Draw the circuit diagram of a bridge rectifier circuit with Π - section followed by L-section filter and explains its operation.
5. Compare the performance of inductive, L-section and Π section filters.
6. Compare half wave, Full wave and Bridge rectifier.
7. Compare the performance of series inductor, L-Section and p - Section filters.
8. Derive the following expression for
   (a) Ripple in a - section filter when used with a half wave rectifier.
   (b) The ripple factor of half wave rectifier and full wave rectifier.
   (c) Ripple factor in a full wave rectifier using an inductor filter.
   (d) D.C. or average value of current, R.M.S. value of current and Average voltage across the load for a half wave rectifier.

UNIT-II

1. Explain thermistor and sensistor compensation
2. Study thoroughly the concept of thermal runaway
3. Write down the need for bias stabilization.
4. Write down the requirements of a biasing circuit?
5. Explain briefly about the simplest biasing circuit.
6. Explain thermal instability.
7. What are the factors affecting the stability factor.
8. Write down the types of biasing and compare them.
9. Draw a BJT fixed bias circuit and derives the expression for the stability factor's'.

UNIT-III

1. With the help of necessary equations, discuss the variation of A_I, A_V, R_i, and R_o with R_S and R_L in Common Emitter simplified configuration.
2. With the help of necessary equations, discuss the variation of A_I, A_V, R_i, and R_o with R_S and R_L in Common Base simplified configuration.
3. With the help of necessary equations, discuss the variation of A_I, A_V, R_i, and R_o with R_S and R_L in Common Collector simplified configuration.

UNIT-IV

1. With a neat sketch explain a negative feedback amplifier and derive the expression for closed loop gain, higher cut-off frequency, lower cut-off frequency, stability.
2. Draw the circuit diagram of voltage series feedback amplifier and derive expressions for input and output resistances.
3. Draw the circuit diagram of current shunt feedback amplifier and derive expressions for input and output resistances.
4. Explain Barkhausen criterion for oscillation in feedback oscillator.
5. Draw the circuit diagram of RC-phase shift oscillator using BJT and derive the expression for frequency of oscillations
6. Draw the circuit diagram of wein bridge oscillator using BJT and derive the expression for frequency of oscillations
7. Draw the circuit of Hartley oscillator and explain its working. Derive the expressions for frequency of oscillation.
8. Draw the circuit of Colpitt's oscillator and explain its working. Derive the expressions for frequency of oscillation.

UNIT-V

1. Sketch the circuit of a CS amplifier.
2. For CS amplifier derive the expression for the voltage gain at low frequencies.
3. Sketch the circuit of a CD amplifier.
4. Sketch the circuit of a generalized FET amplifier
5. Explain the principle of operation of tunnel diode.
6. Compare PN junction diode with tunnel diode.
7. Draw the Energy band diagram of the Tunnel diode .
8. Compare energy band diagram of PN junction diode with tunnel diode.
9. In what way varactor diode is different from normal PN diode
10. Explain the principle of operation of the ujt and characteristics
11. Explain the structure of photo diode and characteristics