ANALOG CIRCUITS

LECTURE NOTES

(R22A0401)

B.TECH
(II YEAR B.Tech – I SEM)
(2024-25)

Prepared by:

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MALLAREDDYCOLLEGEOFENGINEERING&TECHNOLOGY

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(AffiliatedtoJNTU,Hyderabad,ApprovedbyAICTE-AccreditedbyNBA&NAAC–'A'Grade-ISO9001:2008Certified)

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MALLA REDDY COLLEGE OF ENGINEERING AND TECHNOLOGY

II Year B.Tech. ECE- I Sem **L/T/P/C**
3/-/-/3

(R22A0401) ANALOG CIRCUITS

Course Objectives:

1. Learn the concepts of, load line analysis and biasing techniques

2. Learn the concepts of high frequency analysis of transistors.

3. To give understanding of various types of amplifier circuits

4. Learn the concepts of small signal analysis of BJT and FET amplifiers and biasing techniques

5. To familiarize the Concept of feedback in amplifiers so as to differentiate between negative and positive feedback. To design an oscillators at different frequencies.

UNIT – I

BJT Biasing: Transistor Biasing and Stabilization - Operating point, Need for biasing, DC Load line, Biasing - Fixed Bias, Self Bias, Bias Stability, Bias Compensation using Diode. Analysis of Small Signal Low Frequency BJT Amplifiers: Transistor Hybrid model, 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 Ai, Ri ,
Av ,and Ro.

UNIT –II

BJT Amplifiers-Frequency Response: Frequency response of an amplifier, Analysis at low and High Frequencies, Hybrid-pi (π) common emitter transistor model, Derive the hybrid- π model parameters, Millers theorem and it's dual. Multistage Amplifiers: Distortion in amplifiers, Analysis of cascaded BJT amplifier, Darlington pair and derive their input impedance(Ri) and current gain(Ai), coupling schemes-RC coupled amplifier, Transformer coupled amplifier, and Direct coupled Amplifier.

UNIT – III

FET-Biasing and FET Amplifiers: FET biasing: fixed bias and self bias. FET Amplifiers :Analysis of Common source (C.S), Common Drain (C.D) JFET Amplifiers, comparison of performance with BJT Amplifiers, Basic Concepts of MOSFET Amplifiers.

UNIT –IV

FEEDBACK AMPLIFIERS: Concept of Feedback and types, Effects of negative feed back on amplifiers characteristics, voltage series, current series, current shunt, and voltage shunt feedback amplifiers.

UNIT –V

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

TEXT BOOKS:

1. Jacob Millman, Christos C Halkias -Integrated Electronics, McGraw Hill Education.
2. Robert L. Boylestead, Louis Nashelsky -Electronic Devices and
Circuits theory,11th Edition,2009, Pearson

REFERENCE BOOKS:

1. David A. Bell – Electronic Devices and Circuits, 5th Edition, Oxford.2. Adel S. Sedra, Kenneth C. Smith- Microelectronic Circuits-Theory and Applications,Oxford.
3. Chinmoy Saha, Arindam Halder, Debaati Ganguly -Basic Electronics-Principles and Applications,

Course Outcomes:

Upon completing this course, the students will be able to

1. Design the amplifiers with various biasing techniques.

2. Design single stage amplifiers using BJT and FET amplifier

3. Design multistage amplifiers and understand the concepts of High Frequency
Analysis of BJT.

4. Utilize the Concepts of negative feedback to improve the stability of Amplifiers and
Positive feedback to sustained oscillations and Analysis of oscillators at different frequencies

UNIT-1

TRANSISTOR BIASING AND STABILIZATION

NEED FOR TRANSISTOR BIASING

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 biasing ckt.

Therearefourconditionstobemetbyatransistorsothatitactsasafaithfulampr:

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 signalI_c when no signal is applied should beat least equal to the max.collector current t due to signal alone.
4) Max.rating of the transistor$I_{c(max)}$,$V_{CE(max)}$ and$P_{D(max)}$ should not be exceed data any value ofi/p signal.

Consider the fig shown in fig 2.12. If operating point is selected at A,A representation 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 inthe o/psignal. It also provides linear gain and larger possible o/p voltages and currents

Henceoperatingpointforatransistoramplifierisselectedtobeinthemiddleofactiveregion.

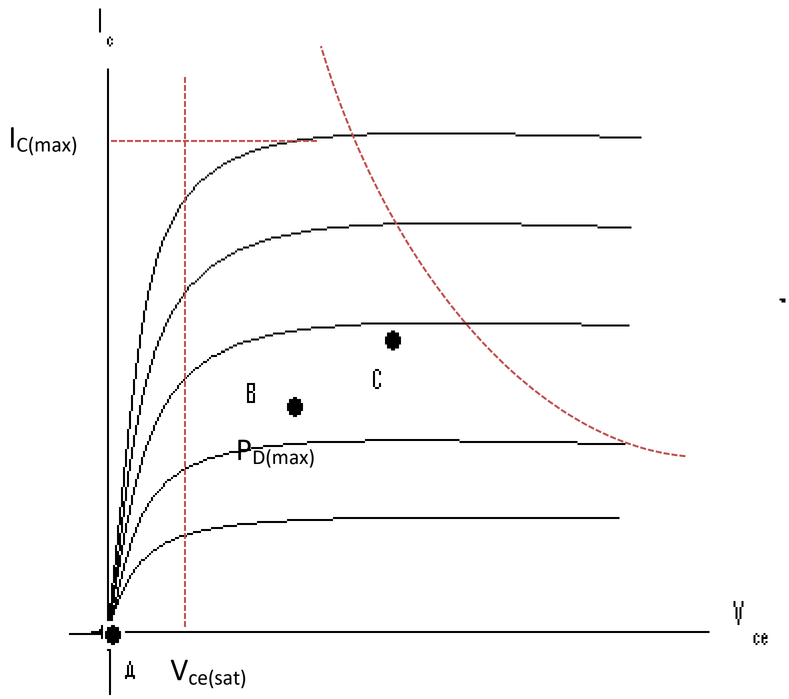


Fig2.12CEOutputCharacteristics

DCLOADLINE

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.

ApplyingKirchhoff'svoltagelawtothecollectorcircuitinfig.2.13,weget

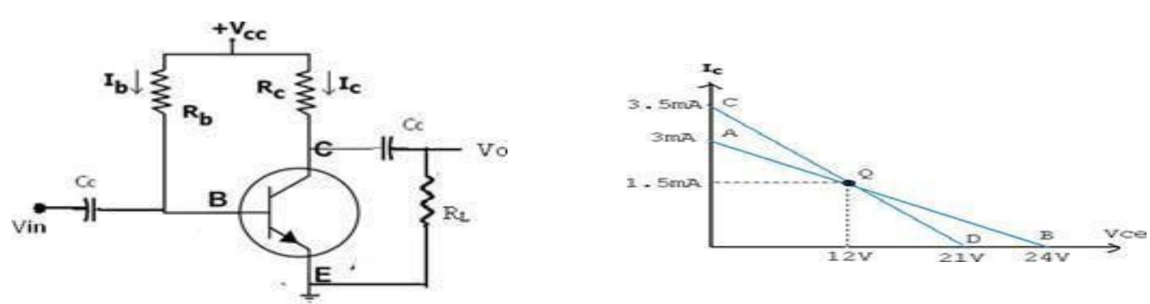


Fig2.13(a)CEAmplifie rCircuit (b)Load line

$$Vcc = IcRc + Vce$$

The straight line represented by ABinfig2.13b 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 areV_{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) Reversesaturationcurrent,Ico,whichdoublesforevery10^{o}Craiseintemperature
2) Base emitter Voltage, VBE, which decreases by 2.5mVper^{o}C
3) Transistor current gain, h_{FE} orβ which in creases with temperature.

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 ensurethat the new transistor will have identical parameters as that o fthe 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 completely unsatisfactory.

ACLOADLINE

Afterdrawing the dc load line,the operating point Q is properly located at the centerofthe 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 ofR_C paralleltoR$_L$i.e.$R_{ac} = R_L||R_C$. So the slope of the ac load line CQD will be$\left(\frac{-1}{R_{ac}}\right)$. Todraw the ac load line,two end points,I.e. $V_{CE(max)}$and $I_{C(max)}$when the signal is applied are required.

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

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

By joining point sc andD,aclo adlineCD is constructed. As $R_C>R_{ac}$,The dc loadl ineis less steepthan ac load line.

STABILITYFACTOR(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.

TheextenttowhichI$_C$isstabilizedwithvaryingI$_C$ismeasuredbyastabilityfactorS

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

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

Differentiatetheaboveequationw.r.tI$_C$,Weget

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

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

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

Sshouldbesmallto havebetterthermalstability.

StabilityfactorS'andS'':

S'isdefinedastherateofchangeofI$_C$with V_{BE},keepingI$_C$andV$_{BE}$constant.

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

S''isdefinedastherateofchangeofI$_C$withβ,keepingI$_{CO}$andV$_{BE}$constant.

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

METHODS OF TRANSISTOR BIASING

1) Fixed bias(base bias)

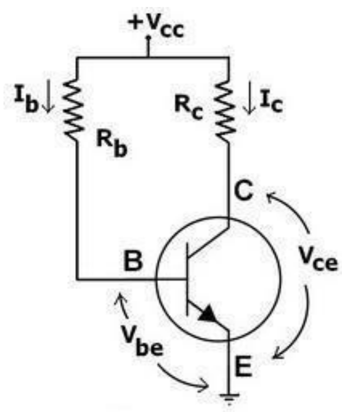


Fig2.14FixedBiasing Circuit

Thisform ofbiasingisalsocalled*basebias*.Inthe fig4.3shown,thesinglepowersource (forexample, battery) is usedfor both collectorand base of atransistor,although separate batteries can also be used.

Inthegivencircuit, V_{cc}

$= I_B R_B + V_{be}$

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

Sincetheequationis independentofcurrentI_CR,$dI_B//dI_C$R=0andthestability factor is given by the equation….. reduces to

S=1+β

Sinceβisalargequantity,thisisverypoorbiasingcircuit.Thereforeinpractice thecircuitisnotusedfo biasing.

Foragiventransistor,V_{be}doesnotvarysignificantlyduringuse.AsV_{cc}isoffixedvalue, onselectionofRthe basecurrentI_B isfixed.Thereforethistypeiscalled *fixedbias*typeofcircuit. Also for

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

Therefore, $V_{ce}=V_{cc}-I_CR_C$

Merits:

- Itissimpletoshiftthe operatingpoint anywhere intheactiveregion bymerelychanging the base resistor(R_B).
- Averysmallnumberofcomponents arerequired.

Demerits:

- Thecollectorcurrent does notremainconstantwithvariation intemperatureorpower supply voltage. Therefore the operating point isunstable.
- ChangesinV$_{be}$ willchangeI$_B$andthuscauseR$_E$to change.This inturnwillalterthe gain ofthestage.
- Whenthetransistoris replacedwithanotherone,considerablechangeinthevalueofβ 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

$V_{Rb}=V_{CC}-I_eR_e-V_{be}$.

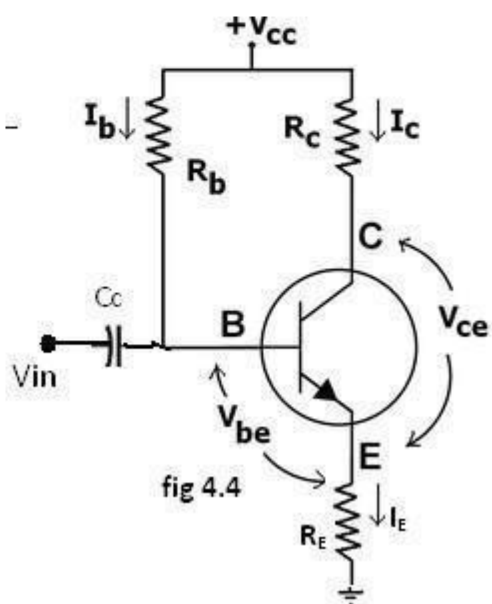


Fig2.15SelfBiasing Circuit

FromOhm'slaw,thebasecurrentis

$I_b = V_{Rb}/R_b$.

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 $V_e = I_eR_e$, which in turn reducesthe voltageV_{Rb} acrossthe baseresistor.A lower base-resistorvoltagedrop reducesthe 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, ifthetransistoris replacedbyanother,theremay bea changeinI_C (correspondingto change in β-value, for example). By similar process as above, the change is negated and operating point kept stable.

Forthegivencircuit,

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

Merits:

Thecircuithasthetendencytostabilizeoperatingpointagainstchangesintemperatureandβ-value.

Demerits:

- Inthiscircuit,tokeep$I_C$independentofβthefollowingconditionmustbemet:

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

whichisapproximatelythecaseif$(\beta+1)R_E >> R_B$.

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

- IfR_E isoflargevalue,highV_{CC} isnecessary.Thisincreasescostaswellasprecautions necessary whilehandling.
- If$R_B$is low,aseparatelowvoltagesupplyshouldbeusedinthe basecircuit.Usingtwo supplies of different voltages isimpractical.

- Inadditiontotheabove,$R_E$causesacfeedbackwhichreducesthevoltagegainof theamplifier.

3) COLLECTORTOBASEBIASORCOLLECTORFEED-BACKBIAS:

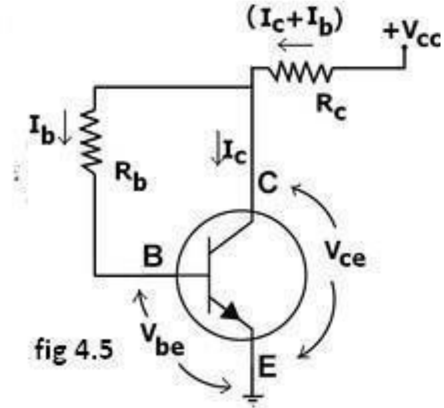


Fig2.16CollectortoBaseBiasingCircuit

This configuration shown in fig2.16 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.

FromKirchhoff'svoltagelaw,thevoltage$V_{\mathrm{R_b}}$acrossthebaseresistor$R_b$is

$$V_{\mathrm{R_b}} = V_{\mathrm{cc}} - \overbrace{(I_{\mathrm{c}} + I_{\mathrm{b}})R_{\mathrm{c}}}^{\text{Voltage drop across } R_{\mathrm{c}}} - \overbrace{V_{\mathrm{be}}}^{\text{Voltage at base}} .$$

BytheEbers–Mollmodel, I_c=βI_b,andso

$$V_{\mathrm{R_b}} = V_{\mathrm{cc}} - (\overbrace{\beta I_{\mathrm{b}}}^{I_{\mathrm{c}}} + I_{\mathrm{b}})R_{\mathrm{c}} - V_{\mathrm{be}} = V_{\mathrm{cc}} - I_{\mathrm{b}}(\beta+1)R_{\mathrm{c}} - V_{\mathrm{be}}.$$

FromOhm'slaw,thebasecurrent $I_{\mathrm{b}} = V_{\mathrm{R_b}}/R_{\mathrm{b}}$,andso

$$\overbrace{I_{\mathrm{b}}R_{\mathrm{b}}}^{V_{\mathrm{R_b}}} = V_{\mathrm{cc}} - I_{\mathrm{b}}(\beta+1)R_{\mathrm{c}} - V_{\mathrm{be}}.$$

Hence,thebasecurrent$I_b$is

$$I_{\mathrm{b}} = \frac{V_{\mathrm{cc}} - V_{\mathrm{be}}}{R_{\mathrm{b}} + (\beta+1)R_{\mathrm{c}}}$$

IfV_{be}isheldconstantandtemperatureincreases,thenthecollectorcurrent$I_c$increases. However,alarger$I_c$causesthevoltagedropacrossresistor$R_c$toincrease,whichinturnreducesthe voltage $V_{\mathrm{R_b}}$ 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 kept stable.

Merits:

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

Demerits:

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

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

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 very low.

- If R_c is large, a high V_{cc} is necessary, which increases cost as well as precautions necessary while handling.
- 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 active mode.

- The resistor R_b causes an AC feedback, reducing the voltage gain of the amplifier. This undesirable effect is a trade-off for greater Q-point stability.

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 is warranted.

4) COLLECTOR–EMITTERFEEDBACKBIAS:

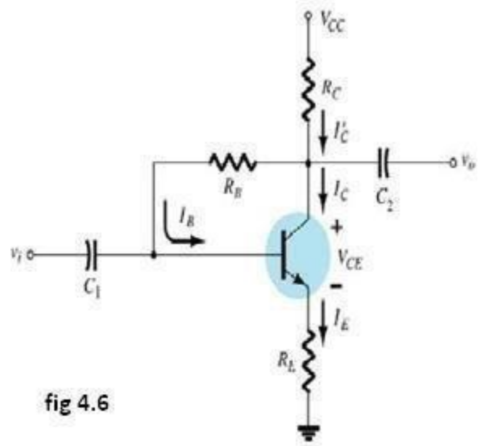


Fig2.17Collector-EmitterBiasingCircuit

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 areused tocontrol collectorcurrent and base current IB in the opposite direction to increase the stability as compared to the previous biasingcircuits.

5) VOLTAGEDIVIDERBIASORSELFBIASOREMITTERBIAS

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 pointofthetransistorcanbe made independentofβ.Inthiscircuit,thevoltagedividerholds 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.

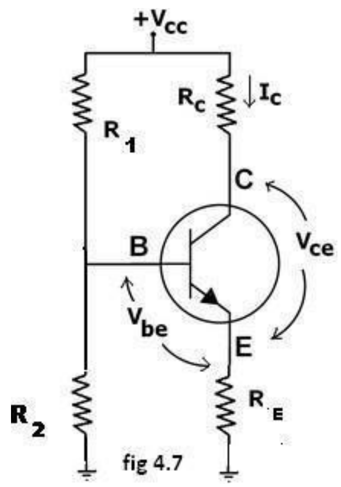


Fig2.18VoltageDividerBiasingCircuit

Inthiscircuitthebasevoltageisgivenby:

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

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

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

Forthegivencircuit,

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

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

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

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

ApplyingKVLinthecircuit,wehave

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

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

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

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

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

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 ignoredinthe above expression sothe collectorcurrent is almost independent ofthe transistor parameters thus this arrangement provides excellent stability.

AgainapplyingKVLincollectorcircuit,wehave

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

$$\because I_C \cong I_E$$

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

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

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 V2is independent of collector current. This decreases the base current, thus collector currentincreases to its formervalue.

Stabilityfactorforsuchcircuitarrangementisgivenby

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

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

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

IfReq/REisverysmallcomparedto1,itcanbe ignoredintheaboveexpression thuswehave

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

Which is excellent since it is the smallest possible value for the stability. In actual practice the value ofstability factor is around 8-10,since Req/REcannot be ignored as compared to 1.

Merits:

- Unlikeabovecircuits,onlyonedcsupplyisnecessary.
- Operatingpointisalmostindependentofβvariation.
- Operatingpointstabilizedagainstshiftintemperature.

Demerits:

- Inthiscircuit,tokeep$I_C$independentofβthefollowingconditionmustbemet:

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

whichisapproximatelythecaseif $(\beta+1)R_E >> R_1 \parallel R_2$

where$R_1||R_2$denotestheequivalentresistanceofR_1andR_2connectedinparallel.

- 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_1raises $V_B$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: Thecircuit'sstabilityandmeritsasabovemakeitwidelyusedforlinearcircuits.

BIASCOMPENSATIONUSINGDIODEANDTRANSISTOR

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.

DIODECOMPENSATION:

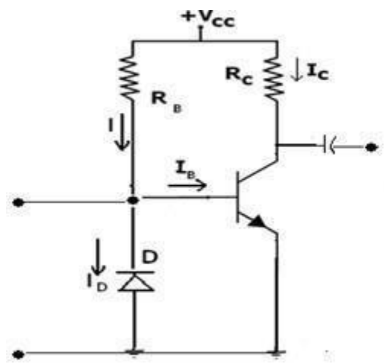


Fig2.19DiodeCompensationCircuit

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 requiredaction to keep Ic constant.

This type of biascompensation 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.

THERMISTORCOMPENSATION:

Thefollowing fig2.20 athermistorR_T, having a negativetemperature coefficient is connected in parallelwithR_2. The resistance ofthermistordecreases exponentially withincrease oftemperature. An increase of temperature will decrease the base voltage V_{BE}, reducing $I_B$and I_C.

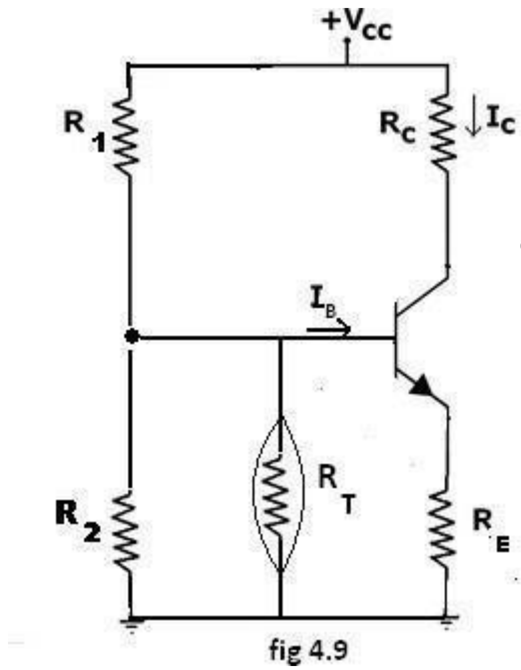


Fig2.20ThermistorCompensation

SENSISTORCOMPENSATION:

In the following fig2.21 shown a sensistor Rs having a positive temperature coefficient is connected across R_1or R_E. Rs increases with temperature. As the temperatureincreases,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.

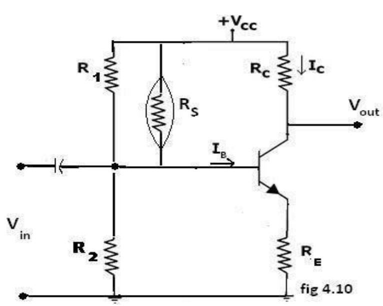


Fig2.21SensistorCompensation

BJT Hybrid Model and Transistor Amplifier

BJTHybridModelandTransistorAmplifier's-parameterrepresentationofatransistor, Conversion of h-parameters**,** Analysis of single stage transistor amplifier using H-parameters:voltagegain,currentgain,InputimpedanceandOutputimpedance. Comparison of transistor configurations in terms of A_i, R_i , A_v,and R_o ,

BJTHYBRIDMODEL

Smallsignallowfrequencytransistor Models:

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

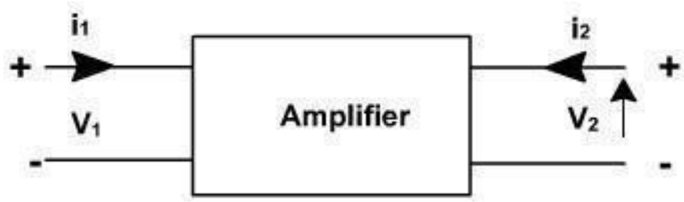


Fig.3.1:TransistorasatwoportNetwork

A two-port network is represented by fourexternalvariables: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 andtwo 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. Impedanceparameters(z-parameters)
2. Admittanceparameters(y-parameters)
3. Hybridparameters(h-parameters)

z-parameters

Atwo-port networkcanbedescribedbyz-parametersas

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

Inmatrixform,theaboveequationcanbe rewrittenas

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

Where

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

Inputimpedancewithoutputportopencircuited

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

Reversetransferimpedancewithinputportopencircuited

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

Forwardtransferimpedancewithoutputportopencircuited

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

Outputimpedancewithinputportopencircuited

Y-parameters

Atwo-portnetworkcanbedescribedbyY-parametersas

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

Inmatrixform,theaboveequationcanbe rewrittenas

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

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

Inputadmittancewithoutputportshortcircuited

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

Reversetransferadmittancewithinputportshortcircuited

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

Forwardtransferadmittancewithoutputportshortcircuited

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

Outputadmittancewithinputportshortcircuited

Hybridparameters(h-parameters)

Iftheinputcurrent I1andoutputvoltageV2aretakenasindependentvariables,thedependent variables V1 and I2 can be written as

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

Whereh$_{11}$,h$_{12}$,h$_{21}$,h$_{22}$are calledashybrid parameters.

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

Inputimpedencewitho/pportshortcircuited

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

Reversevoltagetransferratiowithi/pport opencircuited

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

Forwardvoltagetransferratiowitho/pportshortcircuited

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

outputimpedencewithi/pportopencircuited

THEHYBRID MODELFORTWOPORTNETWORK:

Basedonthe definitionofhybridparametersthe mathematicalmodelfortwopertnetworksknownas h-parameter model can be developed. The hybrid equations can be written as:

$$V_1 = h_i I_1 + h_r V_2$$

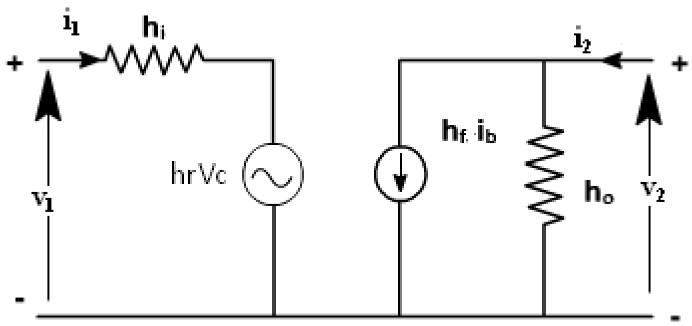
$$I_2 = h_f I_1 + h_o V_2$$

(Thefollowingconvenientalternativesubscriptnotationis recommended by the **IEEE Standards**:

***i*=11=input** ***o*=22=output**

***f*=21=forwardtransfer*r*=12=reversetransfer)**

We may now use the four h parameters to construct a mathematicalmodel 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.



Iftheseparametersarespecifiedforaparticularconfiguration,thensuffixes e,borcarealsoincluded, e.g.h_{fe},h_{ib}arehparametersofcommonemitterandcommoncollectoramplifiers

Usingtwoequationsthegeneralizedmodeloftheamplifiercanbedrawnasshowninfig.3.2.

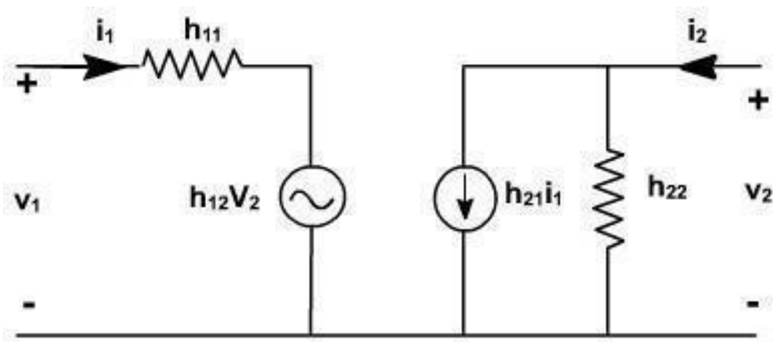


Fig.3.2:-h-parameterequivalentofTransistor

TRANSISTORHYBRIDMODEL:

Thehybridmodelforatransistoramplifiercanbederivedas follow:

LetusconsiderCEconfigurationasshowinfig.3.3.Thevariables,i_B,i_C,v_C,and$v_B$representtotal instantaneouscurrentsandvoltages$i_B$and$v_C$can betakenasindependentvariablesandv_B,$I_C$as dependent variables.

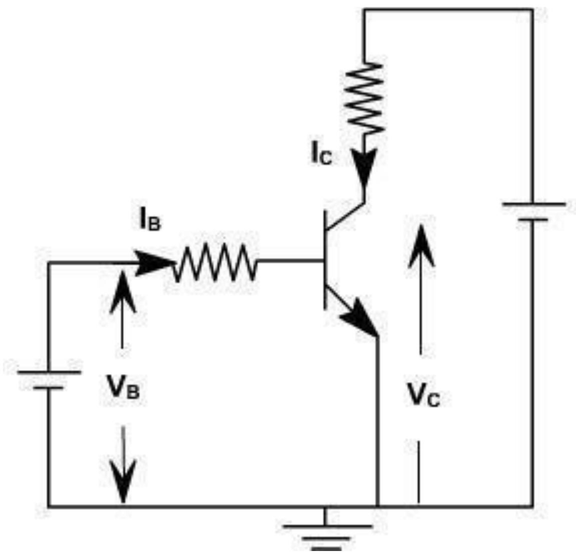


Fig.3.3CETransistorAmplifier V_B

$= f1\ (i_B, v_C)$

$I_C = f2(i_B, v_C)$.

UsingTaylor'sseriesexpression,andneglectinghigherordertermsweobtain.

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

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

Thepartial derivativesaretakenkeepingthe collectorvoltageor basecurrentconstant.The Δv_B,$\Delta\ v_C$,$\Delta\ i_B$, $\Delta\ i_C$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

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

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

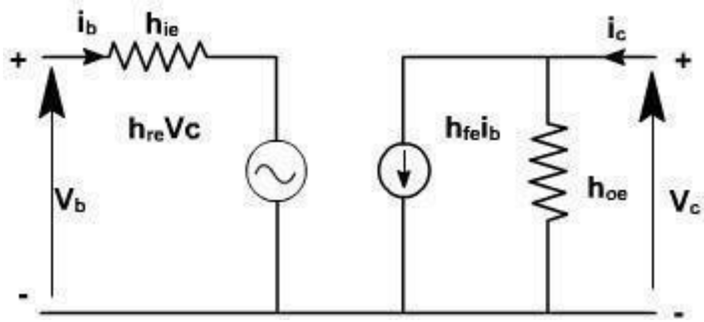


Fig.3.4:h-parametermodelofCEConfiguration

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 characteristicsofCE amplifier.

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

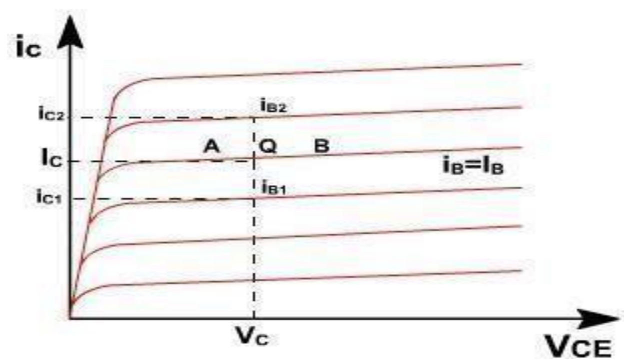


Fig.3.5TransistorCEConfigurationoutputcharacteristics

The current increments are takenaroundthe quiescent point Q whichcorresponds to$i_B = I_B$andtothe collector voltage $V_{CE} = V_C$

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

Thevalue ofh_{oe}atthe quiescentoperating pointisgivenbythe slopeofthe outputcharacteristicat 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).

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

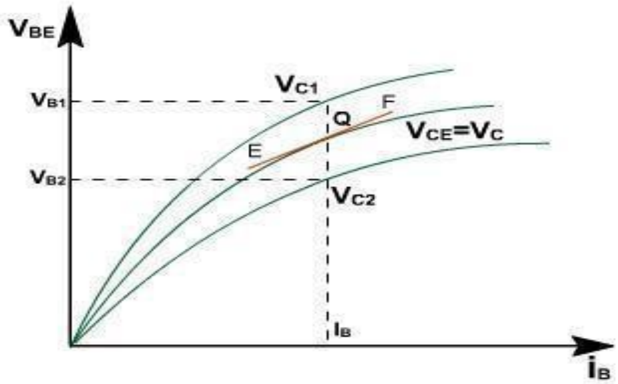


Fig.3.6 Calculation of h-parameters from output characteristics

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-parameters of transistor 2N1573 are given below:

h_{ie}= 1000ohm.
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.

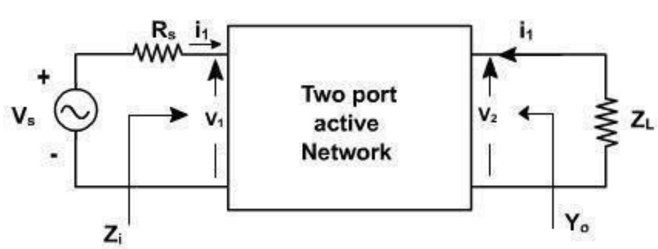


Fig.3.7Transistor two port Network

Considerthe two-port network ofCEamplifier. R_S is the source resistance andZ_L is the loadimpedence h-parameters are assumed tobe constant overthe 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.

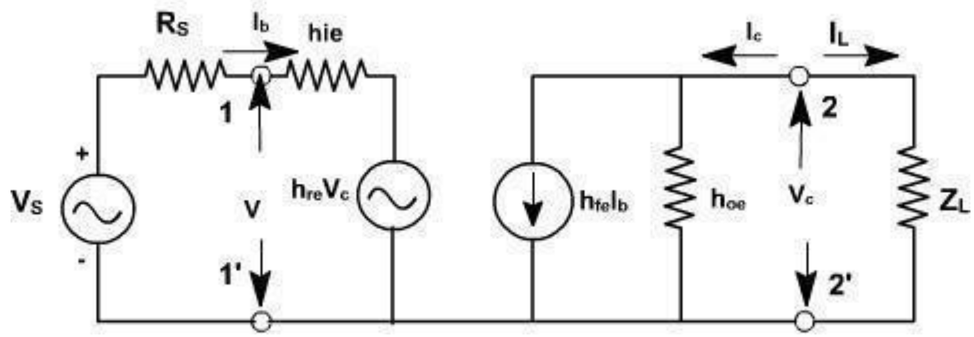


Fig3.8:hparameterequivalent ofTransistorinCE configuration

Current gain:

Forthetransistoramplifierstage,$A_i$isdefined astheratioofoutputtoinputcurrents.

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

Inputimpedence:

Theimpedence lookingintotheamplifierinputterminals(1,1')istheinputimpedanceZ_i

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

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

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

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

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

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

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

Voltagegain:

Theratioofoutputvoltagetoinputvoltagegivesthegainofthetransistors.

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

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

Output Admittance:

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

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

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

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

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

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

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

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

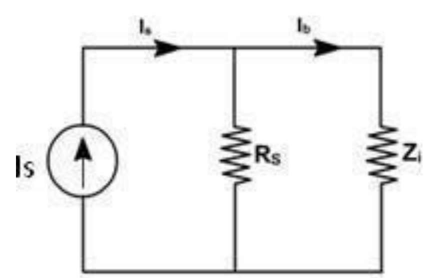
$$= A_V \cdot \frac{Z_i}{Z_i + R_s}$$

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

Itisdefinedas

$A_v$isthevoltagegainforanidealvoltagesource(R_v=0).

ConsiderinputsourcetobeacurrentsourceI$_S$inparallelwitha resistanceR$_S$asshownin<u>fig.3</u>.



Inthis case,overallcurrentgainA$_{IS}$isdefinedas

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

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

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

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

If $R_s \to \infty, \quad A_{I_s} \to A_I$

h-parameters

Toanalyzemultistageamplifiertheh-parameters ofthetransistorusedare obtainedfrommanufacture datasheet.Themanufacturedatasheetusuallyprovidesh-parameterinCEconfiguration.These parameters may be converted into CC and CB values. For example fig. 4hrc in terms of CE parameter canbeobtained as follows.

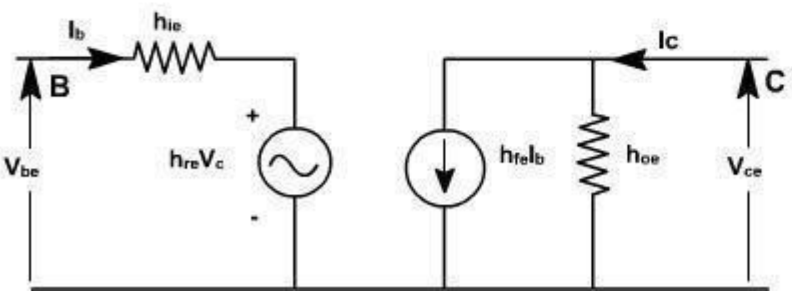


Fig.3.9CEh-parametermodel

ForCEtransistorconfiguaration Vbe

= hie Ib + hre Vce

Ic=hfeIb+hoe Vce

ThecircuitcanberedrawnlikeCCtransistorconfigurationasshownin fig.5. Vbc =

hie Ib + hrc Vec

Ic=hfeIb+hoeVec

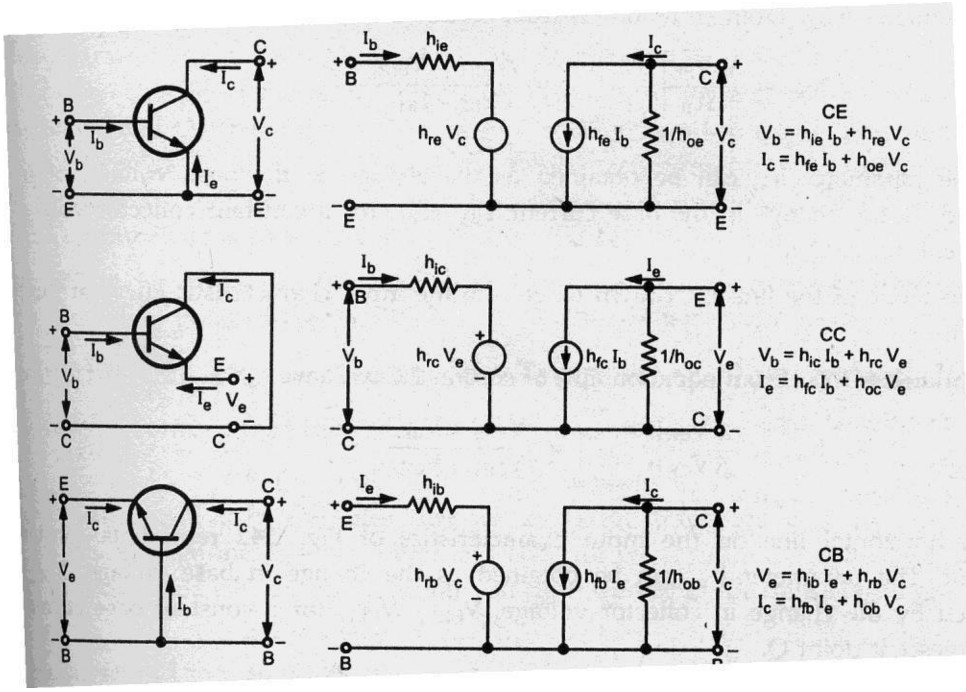


Fig3.10hybridmodelfortransistorinthreedifferentconfigurations

Typicalh-parametervaluesforatransistor

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

AnalysisofaTransistoramplifiercircuitusingh-parameters

A transistoramplifiercanbe constructed by connecting anexternal load andsignalsource and biasing the transistor properly.

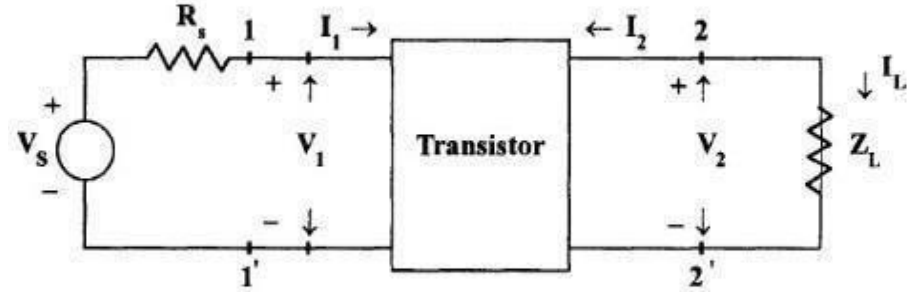


Fig.3.11BasicAmplifierCircuit

The two port network of Fig. 3.11 represents a transistor in any one of its configuration. It is assumedthath-parametersremainconstantover theoperatingrange.Theinput issinusoidalandI$_1$,V- $_1$,I$_2$ and V$_2$are phase quantities

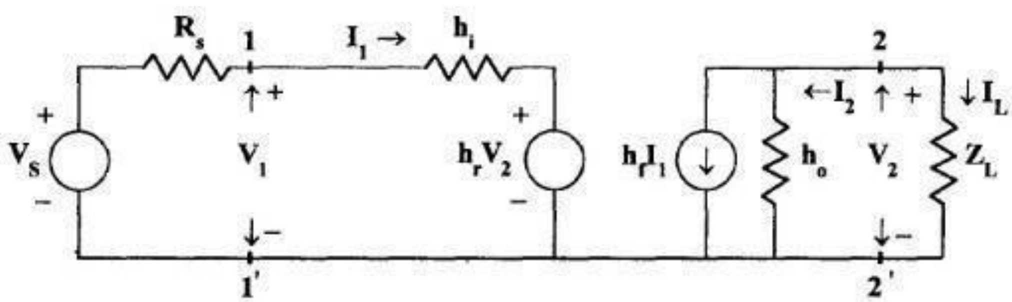


Fig.3.12TransistorreplacedbyitsHybridModel

CurrentGainorCurrentAmplification(A_i)

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

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

FromthecircuitofFig

$I_2 =$ h_f I_1 +

$h_o V_2$Substitutin

g $V_2 = I_L Z_L = -I_2 Z_L$

$I_2 = h_f I_1 - I_2 Z_L h_o$

$I_2 + I_2 Z_L h_o = h_f$

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

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

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

InputImpedence(Z_i)

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

$Z_i=V_1/ I_1$

Fromthe input circuit ofFig $V_1= h_i I_1+ h_r V_2 Z_i=$

$(h_i I_1+ h_r V_2) / I_1$

$=h_i+h_r V_2/I_1$Substituting

$V_2=-I_2 Z_L= A_1 I_1 Z_L$

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

$= h_i + h_r$

$A_1 Z_L$Substitutingf

orA_i

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

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

TakingtheLoadadmittanceas$Y_L=1/Z_L Z_i=$

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

VoltageGainorVoltageGainAmplificationFactor(A_v)

The ratio of output voltage $V_2$to input voltage V_1give the voltage gain of the transistor i.e,

$A_v = V_2 / V_1$

Substituting

$V_2=-I_2Z_L=A_1I_1Z_L$

$A_v=A_1I_1Z_L/V_1=A_iZ_L/Z_i$

OutputAdmittance(Y_o)

$Y_o$isobtainedbysetting$V_S$tozero,$Z_L$toinfinityandbydrivingtheoutputterminals fromagenerator V_2. If the current $V_2$is I_2then $Y_o= I_2/V_2$with $V_S=0$ and $R_L= \infty$.

Fromthecircuitoffig

$I_2= h_fI_1+ h_oV_2$Dividing

by V_2,

$I_2/V_2=h_fI_1/V_2+h_o$

With$V_2=0$,byKVL ininputcircuit,

$R_SI_1+ h_iI_1+ h_rV_2= 0$ (R_S

$+ h_i) I_1 + h_rV_2= 0$

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

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

$h_fh_r/(R_S+ h_i)$

Theoutputadmittance isafunctionofsourceresistance.Ifthesourceimpedence is resistivethen$Y_o$is real.

VoltageAmplificationFactor(A_{vs})takingintoaccounttheresistance(R_s)ofthesource

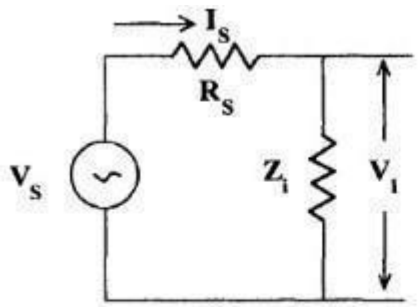


Fig.3.13 Thevenin's EquivalentInput

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

$A_{vs}=V_2/ V_S=V_2V_1/V_1V_S=A_vV_1/V_S$

FromtheequivalentinputcircuitusingThevenin's equivalentforthesourceshowninFig.5.6 $V_1 =$

$V_SZ_i/ (Z_{i+} R_S)$

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

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

Substituting $A_v = A_iZ_L/Z_i$

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

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

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

CurrentAmplification(A_{is})takingintoaccountthesourceResistance(R_S)

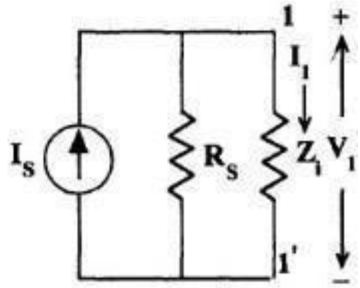


Fig.3.14Norton'sEquivalentInputCircuit

Themodifiedinputcircuit usingNorton'sequivalentcircuit forthecalculationofA_{is} isshowninFig.1.7 Overall Current Gain, $A_{is}= -I_2/ I_S= - I_2I_1/I_1I_S = A_iI_1/I_S$

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

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

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

OperatingPowerGain(A_P)

The operating power gain $A_P$of the transistor is defined as

$A_P = P_2/ P_1= -V_2I_2/ V_1I_1= A_vA_i= A_iA_iZ_L/ Z_i$

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

SmallSignalanalysisofatransistor amplifier

$A_i=-h_f/(1+Z_Lh_o)$	$A_v=A_iZ_L/Z_i$
$Z_i=h_i+h_rA_1Z_L=h_i-h_fh_r/(Y_L+h_o)$	$A_{vs}=A_vZ_i/(Z_i+R_S)=A_iZ_L/(Z_i+R_S)$ $=A_{is}Z_L/R_S$
$Y_o=h_o-h_fh_r/(R_S+h_i)=1/Z_o$	$A_{is}=A_iR_S/ (R_S+Z_i)=A_{vs}=A_{is}R_S/ Z_L$

UNIT -II BJT AMPLIFIERS FREQUIENCY RESPONCE(HYBRIDE PI MODEL)

UNIT I

Small Signal High Frequency Transistor Amplifier models

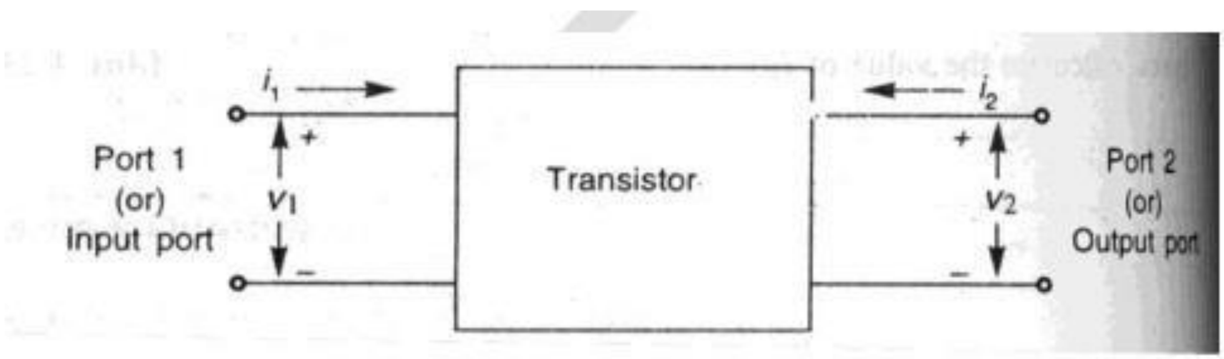
BJT: Transistor at high frequencies, Hybrid- π common emitter transistor model, Hybrid π conductances, Hybrid π capacitances, validity of hybrid π model, determination of high-frequency parameters in terms of low-frequency parameters , CE short circuit current gain, current gain with resistive load, cut-off frequencies, frequency response and gain bandwidth product. **FET:** Analysis of common Source and common drain Amplifier circuits at high frequencies.

Introduction:

Electronic circuit analysis subject teaches about the basic knowledge required to design an amplifier circuit, oscillators etc .It provides a clear and easily understandable discussion of designing of different types of amplifier circuits and their analysis using hybrid model, to find out their parameters. Fundamental concepts are illustrated by using small examples which are easy to understand. It also covers the concepts of MOS amplifiers, oscillators and large signal amplifiers.

Two port devices & Network Parameters:

A transistor can be treated as a two-part network. The terminal behavior of any two-part network can be specified by the terminal voltages V1& V2at parts 1 & 2 respectively and current i1and i2, entering parts 1 & 2, respectively, as shown in figure.



Of these four variables V1, V2, i1and i2, two can be selected as independent variables and the remaining two can be expressed in terms of these independent variables. This leads to various two part parameters out of which the following three are more important.

1. Z –Parameters (or) Impedance parameters
2. Y –Parameters (or) Admittance parameters
3. H –Parameters (or) Hybrid parameters

Hybrid parameters (or) h –parameters:

The equivalent circuit of a transistor can be dram using simple approximation by retaining its essential features. These equivalent circuits will aid in analyzing transistor circuits easily and rapidly.

If the input current i_1 and output Voltage V_2 are takes as independent variables, the input voltage V_1 and output current i_2 can be written as

$$\mathbf{V_1 = h_{11}\, i_1 + h_{12}\, V_2}$$
$$\mathbf{i_2 = h_{21}\, i_1 + h_{22}\, V_2}$$

The four hybrid parameters h11, h12, h21and h22 are defined as follows:

h11= [V1/ i1] with V2= 0 Input Impedance with output part short circuited.
h22= [i2/ V2] with i1= 0 Output admittance with input part open circuited.
h12= [V1/ V2] with i1= 0 reverse voltage transfer ratio with input part open circuited.
h21= [i2/ i1] with V2= 0 Forward current gain with output part short circuited

The dimensions of h–parameters are as follows:

h11-Ω

h22–mhos

h12, h21 –dimension less.

As the dimensions are not alike, (i.e.) they are hybrid in nature, and these parameters are called as hybrid parameters.

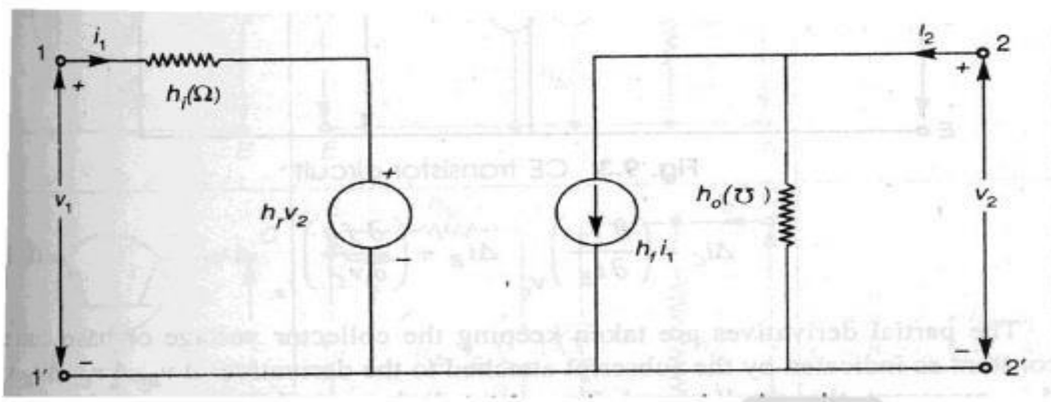
h11 = input; h 22 = output;
h21= forward transfer; h22 = Reverse transfer.

Notations used in transistor circuits:

h_{ie}= h11e= Short circuit input impedance
h_{oe}= h22e= Open circuit output admittance
h_{re} = h12e= Open circuit reverse voltage transfer ratio
h_{fe}= h21e= Short circuit forward current Gain.

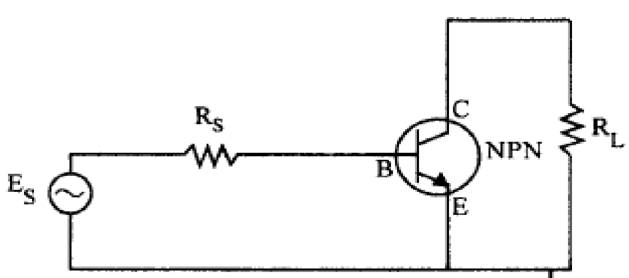
The Hybrid Model for Two-port Network:

$$V1 = h11\, i1 + h12V2$$
$$I2 = h21i1 + h22V2$$
$$V1 = h_1 i1 + h_r V2$$
$$I2 = h_f i1 + h_0 V2$$

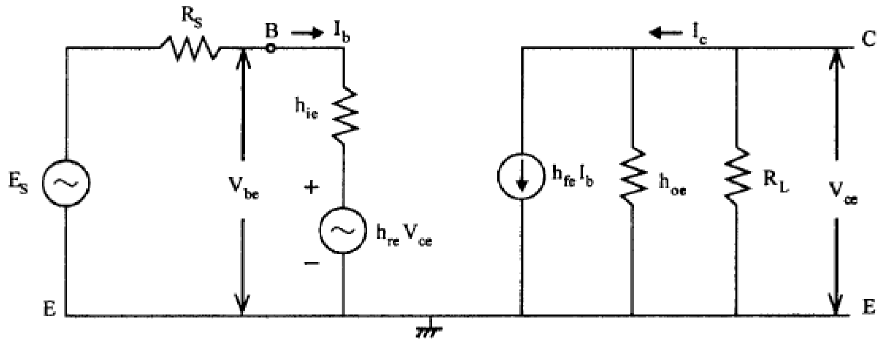


Common Emitter Amplifier

Common Emitter Circuit is as shown in the Fig. The DC supply, biasing resistors and coupling capacitors are not shown since we are performing an AC analysis.



E_S is the input signal source and R_S is its resistance. The h-parameter equivalent for the above circuit is as shown in Fig.



$$h_{ie} = \left.\frac{V_{be}}{I_b}\right|_{V_{ce}=0} \qquad h_{re} = \left.\frac{V_{be}}{V_{ce}}\right|_{I_b=0}$$

$$h_{oe} = \left.\frac{I_c}{V_{ce}}\right|_{I_b=0} \qquad h_{fe} = \left.\frac{I_c}{I_b}\right|_{V_{ce}=0}$$

The typical values of the h-parameter for a transistor in Common Emitter configuration are,

$$h_{ie} = \frac{V_{be}}{I_b}$$

$$h_{ie} = \frac{0.2V}{50\times10^{-6}} = 4K\Omega$$

$$h_{fe} = I_c/I_b \simeq 100\,.$$

$$h_{fe} >> 1 \simeq \beta$$

$$h_{re} = \frac{V_{be}}{V_{ce}}$$

$$h_{re} = 0.2 \times 10^{-3}.$$

$$h_{oe} = \frac{I_c}{V_{ce}}.$$

$$h_{oe} = 8\ \mu\mho$$

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

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

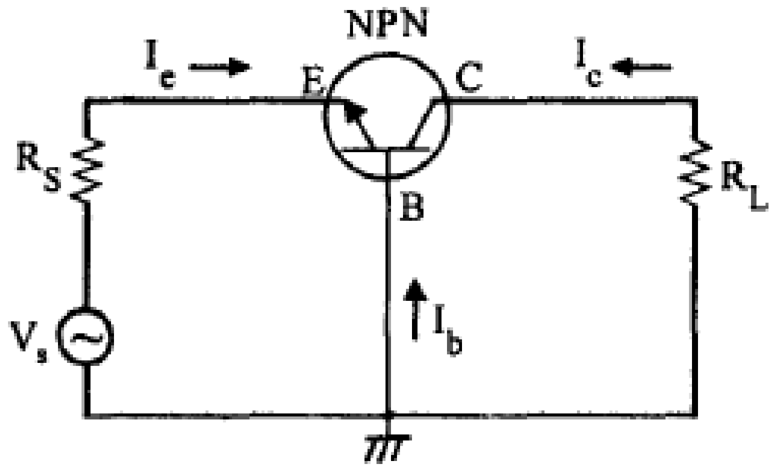
$$R_o = \frac{1}{h_{oe} - \left(\frac{h_{re}h_{fe}}{h_{ie} + R_s}\right)}$$

$$A_i = \frac{-h_{fe}}{1 + h_{oe}R_L}$$

$$A_V = \frac{-h_{fe}R_L}{h_{ie} + R_L(h_{ie}h_{oe} - h_{fe}h_{re})}$$

Common Base Amplifier

Common Base Circuit is as shown in the Fig. The DC supply, biasing resistors and coupling capacitors are not shown since we are performing an AC analysis.



$$h_{ib} = \left.\frac{V_{eb}}{I_e}\right|_{V_{cb}=0}$$

$$h_{fb} = \left.\frac{I_c}{I_e}\right|_{V_{cb}=0} = -0.99 \text{ (Typical Value)}$$

$$I_c < I_e \qquad \therefore \qquad h_{fb} < 1$$

$$h_{ob} = \left.\frac{I_c}{V_{cb}}\right|_{I_e=0} = 7.7 \times 10^{-8} \text{ mhos (Typical Value)}$$

$$h_{rb} = \left.\frac{V_{eb}}{V_{cb}}\right|_{I_e = 0} = 37 \times 10^{-6} \quad \text{(Typical Value)}$$

$$R_i = h_{ib} - \frac{h_{fb}.h_{rb}}{h_{ob} + \frac{1}{R_L}}$$

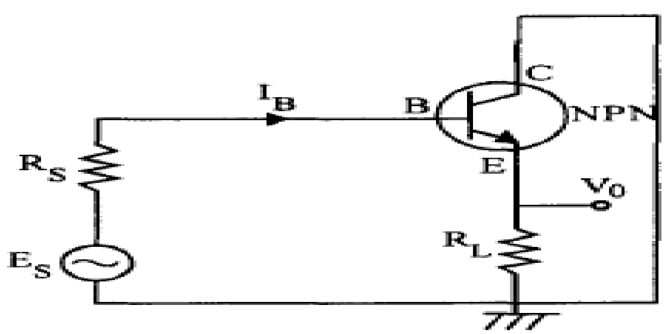
$$R_o' = \frac{1}{h_{ob} - \frac{h_{rb}h_{fb}}{h_{ib} + R_S}}$$

$$A_I = \frac{-h_{fb}}{1 + h_{ob}R_L}$$

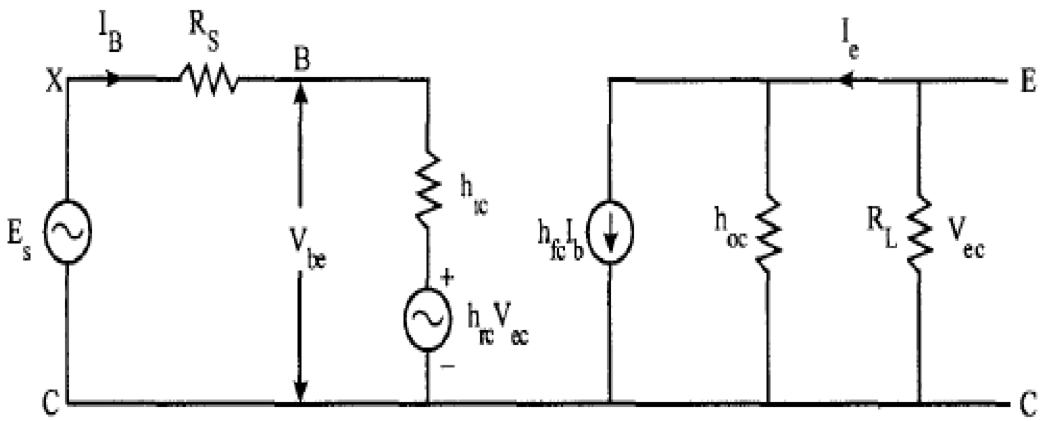
$$A_v = \frac{-h_{fb}R_L}{h_{ib} + R_L(h_{ib}h_{ob} - h_{fb}h_{rb})}$$

Common Collector Amplifier

Common Collector Circuit is as shown in the Fig. The DC supply, biasing resistors and coupling capacitors are not shown since we are performing an AC analysis



The h-parameter model is shown below



$$h_{ic} = \left.\frac{V_{bc}}{I_b}\right|_{V_{ec}=0} = 2{,}780\ \Omega \text{ (Typical Value)}$$

$$h_{oc} = \left.\frac{I_e}{V_{ec}}\right|_{I_b=0} = 7.7 \times 10^{-6} \text{ mhos (Typical Value)}$$

$$h_{fc} = -\left.\frac{I_e}{I_b}\right|_{V_{ce}=0} = 100 \text{ (Typical value)}$$

$\because\ I_e >> I_b.$

$$h_{rc} = \left.\frac{V_{bc}}{V_{ec}}\right|_{I_b=0};$$

Transistors at High Frequencies

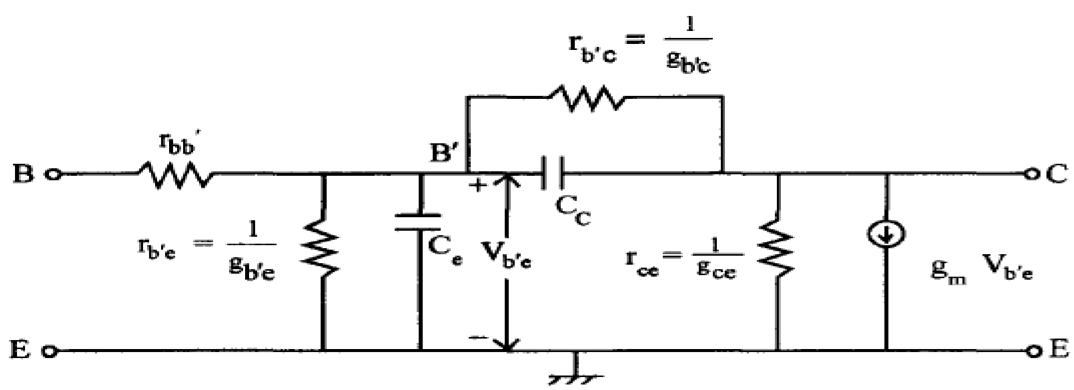
At low frequencies it is assumed that transistor responds instantaneously to changes in the input voltage or current i.e., if you give AC signal between the base and emitter of a Transistor amplifier in Common Emitter configuraii6n and if the input signal frequency is low, the output at the collector will exactly follow the change in the input (amplitude etc.,). If '1' of the input is high (MHz) and the amplitude of the input signal is changing the Transistor amplifier will not be able to respond.

It is because; the carriers from the emitter side will have to be injected into the collector side. These take definite amount of time to travel from Emitter to Base, however small it may be. But if the input signal is varying at much higher speed than the actual time taken by the carries to respond, then the Transistor amplifier will not respond instantaneously. Thus, the junction capacitances of the transistor, puts a limit to the highest frequency signal which the transistor can handle. Thus depending upon doping area of the junction etc, we have transistors which can respond in AF range and also RF range.

To study and analyze the behavior of the transistor to high frequency signals an equivalent model based upon transmission line equations will be accurate. But this model will be very complicated to analyze. So some approximations are made and the equivalent circuit is simplified. If the circuit is simplified to a great extent, it will be easy to analyze, but the results will not be accurate. If no approximations are made, the results will be accurate, but it will be difficult to analyze. The desirable features of an equivalent circuit for analysis are simplicity and accuracy. Such a circuit which is fairly simple and reasonably accurate is the Hybrid-pi or Hybrid-π model, so called because the circuit is in the form of π.

Hybrid - π Common Emitter Transconductance Model

For Transconductance amplifier circuits Common Emitter configuration is preferred. Why? Because for Common Collector (hrc< 1). For Common Collector Configuration, voltage gain Av < 1. So even by cascading you can't increase voltage gain. For Common Base, current gain is hib< 1. Overall voltage gain is less than 1. For Common Emitter, hre>>1. Therefore Voltage gain can be increased by cascading Common Emitter stage. So Common Emitter configuration is widely used. The Hybrid-x or Giacoletto Model for the Common Emitter amplifier circuit (single stage) is as shown below.



Analysis of this circuit gives satisfactory results at all frequencies not only at high frequencies but also at low frequencies. All the parameters are assumed to be independent of frequency.

Where B' = internal node in base
$r_{bb'}$ = Base spreading resistance
$r_{b'e}$ = Internal base node to emitter resistance
r_{ce} = collector to emitter resistance
C_e = Diffusion capacitance of emitter base junction
$r_{b'c}$ = Feedback resistance from internal base node to collector node
g_m = Transconductance
C_C= transition or space charge capacitance of base collector junction

Circuit Components

B' is the internal node of base of the Transconductance amplifier. It is not physically accessible. The base spreading resistance rbb is represented as a lumped parameter between base B and internal node B'. $g_{mVb'e}$ is a current generator. Vb'e is the input voltage across the emitter junction. If Vb'e increases, more carriers are injected into the base of the transistor. So the increase in the number of carriers is proportional to Vb'e. This results in small signal current since we are taking into account changes in Vb'e. This effect is represented by the current generator g_mVb'e. This represents the current that results because of the changes in Vb'e' when C is shorted to E.

When the number of carriers injected into the base increase, base recombination also increases. So this effect is taken care of by gb'e. As recombination increases, base current increases. Minority carrier storage in the base is represented by C_e the diffusion capacitance.

According to Early Effect, the change in voltage between Collector and Emitter changes the base width. Base width will be modulated according to the voltage variations between Collector and Emitter. When base width changes, the minority carrier concentration in base changes. Hence the current which is proportional to carrier concentration also changes. I_E changes and I_C changes. This feedback effect [IE on input side, I_C on output side] is taken into account by connecting gb'e between B', and C. The conductance between Collector and Base is g_{ce}.C_c represents the collector junction barrier capacitance.

Hybrid - *n* Parameter Values

Typical values of the hybrid-n parameter at I_C = 1.3 rnA are as follows:

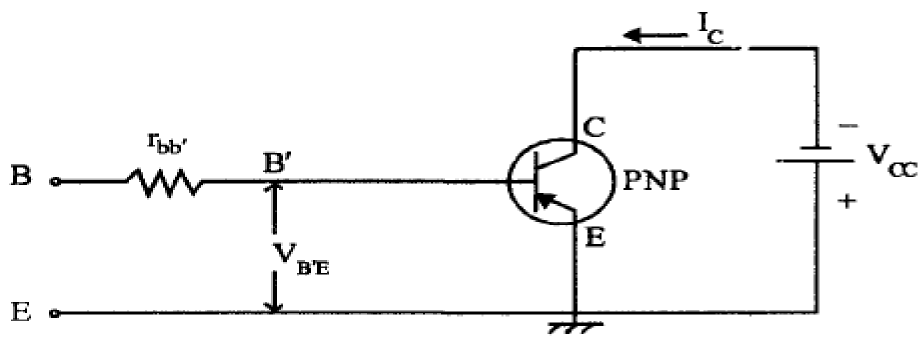
$$g_m = 50 \text{ mA/v}$$

$$rbb' = 100\ \Omega$$
$$rb'e = 1\ k\Omega$$
$$ree = 80\ k\Omega$$
$$Cc = 3\ pf$$
$$Ce = 100\ pf$$
$$rb'c = 4\ M\Omega$$

These values depend upon:
1. Temperature 2. Value of I_C

Determination of Hybrid-x Conductances

1. Trans conductance or Mutual Conductance (g_m)



The above figure shows PNP transistor amplifier in Common Emitter configuration for AC purpose, Collector is shorted to Emitter.

$$I_C = I_{C0} - \alpha_0 \cdot I_E$$

I_{CO} opposes I_E. I_E is negative. Hence $I_C = I_{CO} - \alpha_0 IE$ α_0 is the normal value of α at room temperature.

In the hybrid - π equivalent circuit, the short circuit current = $g_m Vb'e$

Here only transistor is considered, and other circuit elements like resistors, capacitors etc are not considered.

$$g_m = \left.\frac{\partial I_C}{\partial V_{b'e}}\right|_{V_{CE} = K}$$

Differentiate (l) with respect to Vb'e partially. I_{CO} is constant

$$g_m = 0 - \alpha_0 \frac{\partial I_E}{\partial V_{b'e}}$$

For a PNP transistor, Vb'e = $-V_E$ Since, for PNP transistor, base is n-type. So negative voltage is given

$$g_m = \alpha_0 \frac{\partial I_E}{\partial V_E}$$

If the emitter diode resistance is r_e then

$$r_e = \frac{\partial V_E}{\partial I_E}$$

$$g_m = \frac{\alpha_0}{r_e}$$

$$r = \frac{\eta . V_T}{I} \quad \eta = 1, \qquad I = I_E \qquad r = \frac{V_T}{I_E}$$

$$g_m = \frac{\alpha_0 . I_E}{V_T} \qquad \alpha_0 \simeq 1, \qquad I_E \simeq I_C$$

$$I_E = I_{C0} - I_C$$

$$g_m = \frac{I_{C0} - I_C}{V_T}$$

Neglect I_{C0}

$$g_m = \frac{|I_C|}{V_T}$$

g_m is directly proportional to I_C is also inversely proportional to T. For PNP transistor, I_C is negative

$$\boxed{g_m = \frac{-I_C}{V_T}}$$

At room temperature i.e. T=300^{0}K

$$g_m = \frac{|I_C|}{26}, \ I_C \text{ is in mA.}$$

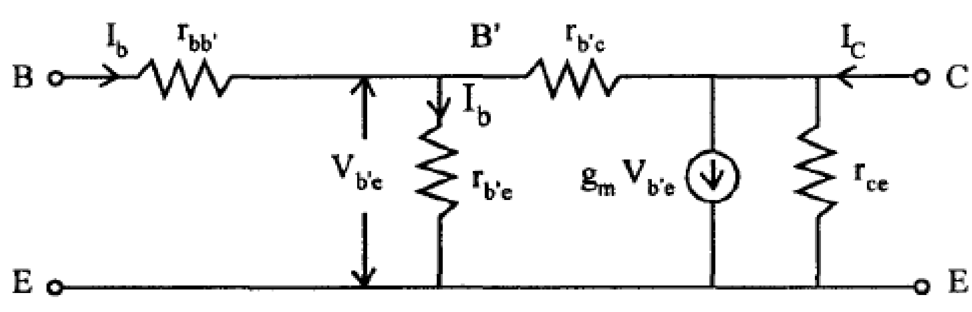
If $\quad I_C = 1.3$ mA, $g_m = 0.05$ A/V

If $\quad I_C = 10$ mA, $g_m = 400$ mA/V

Input Conductance (gb'e):

At low frequencies, capacitive reactance will be very large and can be considered as Open circuit. So in the hybrid-π equivalent circuit which is valid at low frequencies, all the capacitances can be neglected.

The equivalent circuit is as shown in Fig.



The value of rb'c» rb'e (Since Collector Base junction is Reverse Biased)So I_b flows into rb'e only. [This is lb' (IE - I_b)will go to collector junction]

$$V_{b'e} \simeq I_b \cdot r_{b'e}$$

The short circuit collector current,

$$I_C = g_m \cdot V_{b'e}; \qquad V_{b'e} = I_b \cdot r_{b'e}$$

$$I_C = g_m \cdot I_b \cdot r_{b'e}$$

$$h_{fe} = \left.\frac{I_C}{I_B}\right|_{V_{CE}} = g_m \cdot r_{b'e}$$

$$\boxed{r_{b'e} = \frac{h_{fe}}{g_m}}$$

$$g_m = \frac{|I_C|}{V_T}$$

$$r_{b'e} = \frac{h_{fe} \cdot V_T}{|I_C|}$$

$$g_{b'e} = \boxed{\frac{|I_C|}{h_{fe} V_T}} \text{ or } \boxed{\frac{g_m}{h_{fe}}}$$

Feedback Conductance ($g_{b'c}$)

hre = reverse voltage gain, with input open or $I_b = 0$
hre =Vb'e/Vce = Input voltage/Output voltage

$$h_{re} = \frac{r_{b'e}}{r_{b'e} + r_{b'c}}$$

[With input open, i.e., $I_b - 0$, V_{ce} is output. So it will get divided between $r_{b'e}$ and $r_{b'c}$ only]

or $\quad h_{re}(r_{b'e} + r_{b'c}) = r_{b'e}$

$$r_{b'e}[1 - h_{re}] = h_{re} r_{b'c}$$

But $\quad h_{re} \ll 1$

$\therefore \quad r_{b'e} = h_{re} \; r_{b'c}; \quad r_{b'c} = \dfrac{r_{b'e}}{h_{re}}$

or $\quad \boxed{g_{b'c} = h_{re} \; g_{b'e}} \quad \dfrac{1}{r_{b'c}} = g_{b'c} = \dfrac{h_{re}}{r_{b'e}}$

$$h_{re} = 10^{-4}$$

$\therefore \quad r_{b'c} \gg r_{b'e}$

Base Spreading Resistance (r bb')

The input resistance with the output shorted is hie. If output is shorted, i.e., Collector and Emitter arejoined; $r_{b'e}$ is in parallel with $r_{b'c}$.

$$h_{ie} = r_{bb'} + r_{b'e}$$

$$\boxed{r_{bb'} = h_{ie} - r_{b'e}}$$

$$h_{ie} = r_{bb'} + r_{b'e}$$

$$r_{b'e} = \frac{h_{fe}.V_T}{|I_C|}$$

$$h_{ie} = r_{bb'} + \frac{h_{fe}.V_T}{|I_C|}$$

Output Conductance (g_{ce})

This is the conductance with input open circuited. In h-parameters it is represented as hoe. For I_b= 0, we have,

$$I_C = \frac{V_{ce}}{r_{ce}} + \frac{V_{ce}}{r_{b'c} + r_{b'e}} + g_m \; V_{b'e}$$

$$h_{re} = \frac{V_{b'e}}{V_{ce}} \qquad \therefore \qquad V_{b'e} = h_{re}.\, V_{ce}$$

$$I_C = \frac{V_{ce}}{r_{ce}} + \frac{V_{ce}}{r_{b'c} + r_{b'e}} + g_m.\, h_{re}.V_{ce}$$

$$h_{oe} = \frac{1}{r_{ce}} + \frac{1}{r_{b'c}} + g_m \,.\, h_{re}$$

$$= g_{ce} + g_{b'c} + g_m\, h_{re}$$

$$g_{b'e} = \frac{g_m}{h_{fe}}$$

$$g_m = g_{b'e} \,.\, h_{fe}$$

$$h_{re} = \frac{r_{b'e}}{r_{b'e} + r_{b'c}} \approx \frac{r_{b'e}}{r_{b'c}} = \frac{g_{b'c}}{g_{b'e}}$$

$$h_{oe} = g_{ce} + g_{b'c} + g_{b'e}\, h_{fe} \,.\, \frac{g_{b'c}}{g_{b'e}}$$

$$g_{ce} = h_{oe} - (1 + h_{fe}) \,.\, g_{b'c}$$

$$h_{fe} >> 1, \quad 1 + h_{fe} \approx h_{fe}$$

$$\boxed{\mathbf{g_{ce} = h_{oe} - h_{fe} \,.\, g_{b'c}}}$$

$$g_{b'c} = h_{re} \,.\, g_{b'e}$$

$$g_{ce} = h_{oe} - h_{fe} \,.\, h_{re} \,.\, g_{b'e}$$

Hybrid - π Capacitances

In the hybrid - **π** equivalent circuit, there are two capacitances, the capacitance between the Collector Base junction is the C_c or $C_{b'e}$'. This is measured with input open i.e., $I_E = 0$, and is specified by the manufacturers as C_{Ob}. 0 indicates that input is open. Collector junction is reverse biased.

$$C_C \;\alpha\; \frac{1}{(V_{CE})^n}$$

$$n = \frac{1}{2} \quad \text{for abrupt junction}$$

$$= 1/3 \quad \text{for graded junction.}$$

C_e = Emitter diffusion capacitance C_{De} + Emitter junction capacitance C_{Te}

C_T = Transition capacitance.

C_D = Diffusion capacitance.

$C_{De} >> C_{Te}$

$C_e \simeq C_{De}$

$C_{De} \;\alpha\; I_E$ and is independent of Temperature T.

Validity of hybrid-π model

The high frequency hybrid Pi or Giacoletto model of BJT is valid for frequencies less than the unit gain frequency.

High frequency model parameters of a BJT in terms of low frequency hybrid parameters

The main advantage of high frequency model is that this model can be simplified to obtain low frequency model of BJT. This is done by eliminating capacitance's from the high frequency model so that the BJT responds without any significant delay (instantaneously) to the input signal. In practice there will be some delay between the input signal and output signal of BJT which will be very small compared to signal period (1/frequency of input signal) and hence can be neglected. The high frequency model of BJT is simplified at low frequencies and redrawn as shown in the figure below along with the small signal low frequency hybrid model of BJT.

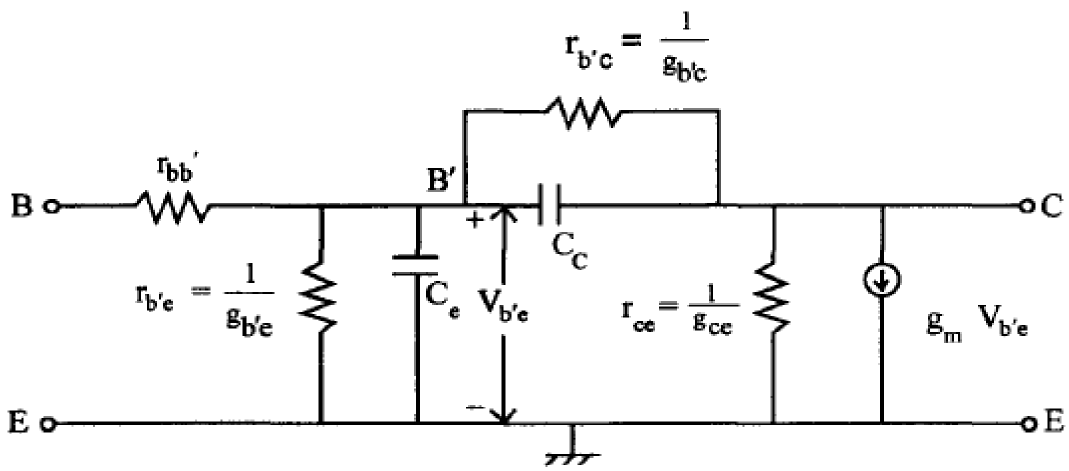


Fig. high frequency model of BJT at low frequencies

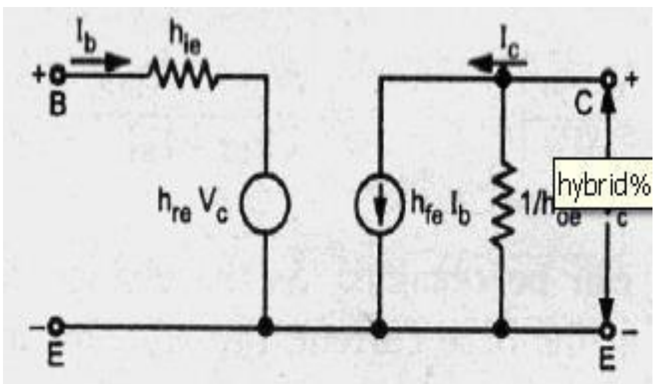


Fig hybrid model of BJT at low frequencies

The High frequency model parameters of a BJT in terms of low frequency hybrid parameters are given below:

Transconductance $g_m = I_c/V_t$
Internal Base node to emitter resistance $r_{b'e} = h_{fe}/ g_m = (h_{fe}* V_t)/ I_c$
Internal Base node to collector resistance $r_{b'e} = (h_{re}* r_{b'c}) / (1- h_{re})$ assuming $h_{re} << 1$ it reduces to $r_{b'e} = (h_{re}* r_{b'c})$
Base spreading resistance $r_{bb'} = h_{ie} – r_{b'e} = h_{ie} – (h_{fe}* V_t)/ I_c$
Collector to emitter resistance $r_{ce} = 1 / (h_{oe} – (1+ h_{fe})/r_{b'c})$

Collector Emitter Short Circuit Current Gain

Consider a single stage Common Emitter transistor amplifier circuit. The hybrid-1t equivalent circuit is as shown:

$$I_L = -g_m V_{b'e}$$

$$V_{b'e} = \frac{I_i}{g_{b'e} + j\omega(C_e + C_c)}$$

A_i under short circuit condition is,

$$A_i = \frac{I_L}{I_i} = \frac{-g_m}{g_{b'e} + j\omega(C_e + C_c)}$$

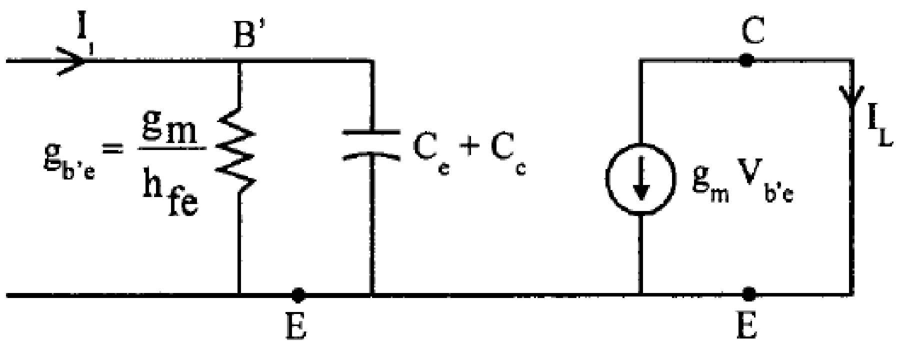
But $$g_{b'e} = \frac{g_m}{h_{fe}}, \quad C_e + C_c \simeq C_e$$

$$C_e = \frac{g_m}{2\pi f_T}$$

$$= \frac{-g_m}{\dfrac{g_m}{h_{fe}} + \dfrac{j\,2\pi . g_m . f}{2\pi f_T}}$$

$\therefore$ $$A_i = \frac{-1}{\dfrac{1}{h_{fe}} + j\left(\dfrac{f}{f_T}\right)}$$

If the output is shorted i.e. $R_L = 0$, what will be the flow response of this circuit? When $R_L = 0$, $V_o = 0$. Hence $A_v = 0$. So the gain that we consider here is the current gain I_L/Ic. The simplified equivalent circuit with output shorted is,



A current source gives sinusoidal current Ic. Output current or load current is IL· $g_{b'c}$ isneglected since $g_{b'c} \ll g_{b'e}$, g_{ce} is in shunt with short circuit R = 0. Therefore g_{ce} disappears. The current is delivered to the output directly through Ce and $g_{b'c}$ is also neglected since this will be very small.

$$I_L = -g_m V_{b'e}$$

$$V_{b'e} = \frac{I_i}{g_{b'e} + j\omega(C_e + C_c)}$$

A_I under short circuit condition is,

$$A_I = \frac{I_L}{I_i} = \frac{-g_m}{g_{b'e} + j\omega(C_e + C_c)}$$

But $\quad g_{b'e} = \frac{g_m}{h_{fe}}, \quad C_e + C_c \simeq C_e$

$$C_e = \frac{g_m}{2\pi f_T}$$

$$= \frac{-g_m}{\frac{g_m}{h_{fe}} + \frac{j\,2\pi.g_m.f}{2\pi f_T}}$$

$$\therefore \quad A_I = \frac{-1}{\frac{1}{h_{fe}} + j\left(\frac{f}{f_T}\right)}$$

$$= \frac{-h_{fe}}{1 + j\, h_{fe}\left(\frac{f}{f_T}\right)}$$

$$A_i = \frac{-h_{fe}}{1 + j\left(\frac{f}{f_\beta}\right)}$$

$$\frac{f_T}{h_{fe}} = f_\beta$$

$$|A_i| = \frac{h_{fe}}{\sqrt{1 + \left(\frac{f}{f_\beta}\right)^2}}$$

Where $$f_\beta = \frac{g_{b'e}}{2\pi(C_e + C_C)}$$

$$g_{b'e} = \frac{g_m}{h_{fe}}$$

$\therefore$ $$f_\beta = \frac{g_m}{h_{fe}\, 2\pi(Ce + C_c)}$$

At $f = f_\beta$, $A_i = \frac{1}{\sqrt{2}}$ $= 0.707$ of h_{fe}.

Current Gain with Resistance Load:

$$f_T = f_\beta \, . \, h_{fe} = \frac{g_m}{2\pi(C_e + C_c)}$$

Considering the load resistance R_L

$V_{b'e}$ is the input voltage and is equal to V_1

V_{ce} is the output voltage and is equal to V_2

$$K_2 = \frac{V_{ce}}{V_{b'e}}$$

This circuit is still complicated for analysis. Because, there are two time constants associated with the input and the other associated with the output. The output time constant will be much smaller than the input time constant. So it can be neglected.

K = Voltage gain. It will be >> 1

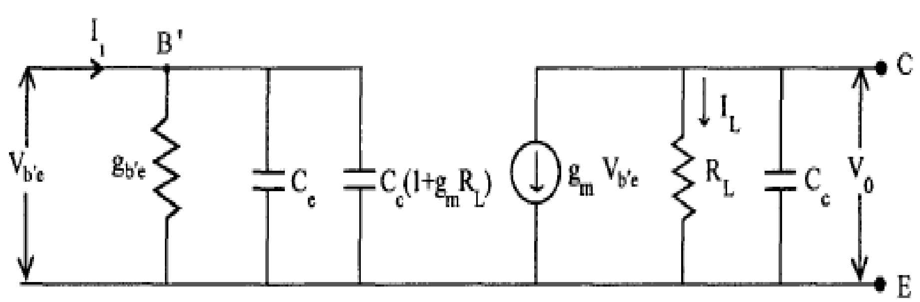
$$g_{b'c}\left(\frac{K-1}{K}\right) \simeq g_{b'c}$$

$$g_{b'c} < g_{ce} \quad \because \quad r_{b'c} \simeq 4\ M\Omega, \qquad r_{ce} = 80\ K \ \text{(typical values)}$$

So $g_{b'c}$ can be neglected in the equivalent circuit. In a wide band amplifier RL will not exceed 2KΩ. If R_L is small f_H is large.

$$f_H = \frac{1}{2\pi C_S (R_C \| R_L)}$$

Therefore g_{ce} can be neglected compared with R_L. Therefore the output circuit consists of current generator gm $V_{b'e}$ feeding the load R_L so the Circuit simplifies as shown in Fig.



$$K = \frac{V_{ce}}{V_{b'e}} = -g_m R_L; \quad g_m = 50 \text{ mA\V}, \quad R_L = 2K\Omega \text{ (typical values)}$$

$$K = -100$$

Miller's Theorem

It states that if an impedance Z is connected between the input and output terminals, of a network, between which there is voltage gain, K, the same effect can be had by removing Z and connecting an impedance Z_i at the input =Z/(1-K) and Zo across the output = ZK/(K-1)

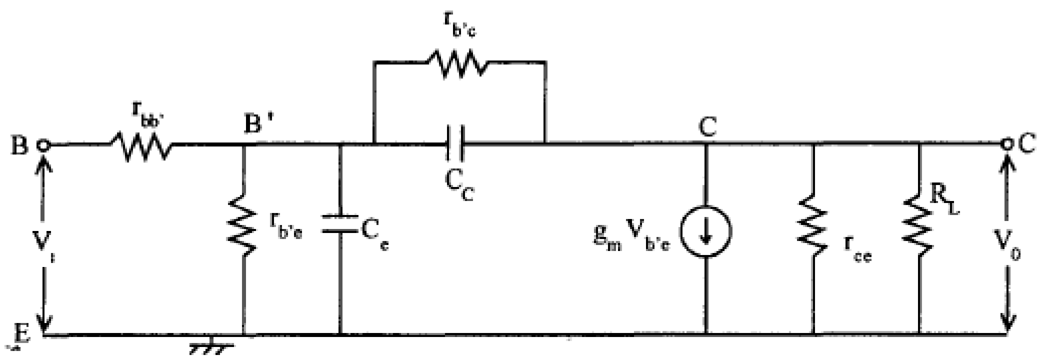


Fig. High frequency equivalent circuit with resistive load R_L

Therefore high frequency equivalent circuit using Miller's theorem reduces to

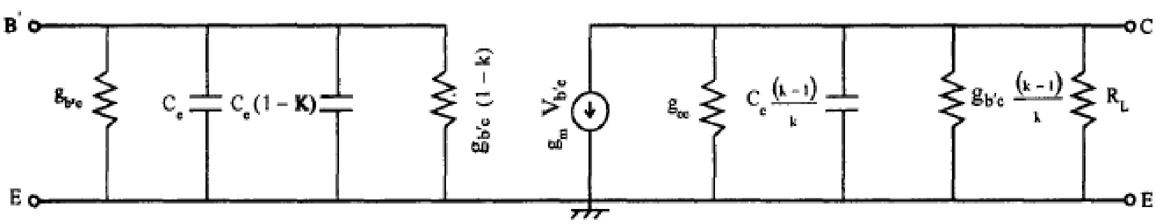


Fig. Circuit after applying Millers' Theorem

$$K = \frac{V_{ce}}{V_{b'e}}$$

$$V_{ce} = -I_c \cdot R_L$$

$$K = \frac{-I_C . R_L}{V_{b'e}}$$

$$\frac{I_C}{V_{b'e}} = g_m$$

$$K = -g_m . R_L$$

The Parameters f_T

f_T is the frequency at which the short circuit Common Emitter current gain becomes unity.

The Parameters f_β

$$A_i = 1, \quad \text{or} \quad \frac{h_{fe}}{\sqrt{1+\left(\frac{f_T}{f_\beta}\right)^2}} = 1$$

$$f = f_T, \quad A_i = 1$$

$$h_{fe} = \sqrt{1+\left(\frac{f_T}{f_\beta}\right)^2}$$

$$(h_{fe})^2 = 1 + \left(\frac{f_T}{f_\beta}\right)^2 \cong \left(\frac{f_T}{f_\beta}\right)^2$$

$$h_{fe} \simeq \frac{f_T}{f_\beta} \text{ when } Ai = 1$$

$$\boxed{f_T \simeq h_{fe} \cdot f_\beta}$$

$$f_\beta = \frac{g_m}{h_{fe}\{C_e + C_c\}}$$

$$f_T = f_\beta \cdot h_{fe} = \frac{g_m}{2\pi(C_e + C_c)}$$

$$C_e >> C_c$$

$$\boxed{f_T \simeq \frac{g_m}{2\pi C_e}}$$

$$A_i = \frac{-g_m}{g_{b'e} + j\omega(C_e + C_c)}$$

Dividing by $g_{b'e}$, Numerator and Denominator,

$$A_i = \frac{-g_m / g_{b'e}}{1 + \frac{j2\pi f (C_e + C_c)}{g_{b'e}}}$$

we know that $g_{b'e} = \frac{g_m}{h_{fe}}$

$\therefore$ $\frac{g_m}{g_{b'e}} = h_{fe}$

$$A_i = \frac{-h_{fe}}{1 + jf\left[\frac{2\pi(C_e + C_C)}{g_{b'e}}\right]}$$

But we know that $A_i = \frac{-h_{fe}}{1 + j\frac{f}{f_\beta}}$

Comparing, $f_\beta = \frac{g_{b'e}}{2\pi(C_e + C_c)} = \frac{g_m}{h_{fe}.2\pi(C_e + C_c)}$ $\because$ $g_{b'e} = \frac{g_m}{h_{fe}}$

$\therefore$ $\boxed{f_\beta = \frac{g_m}{h_{fe}.2\pi(C_e + C_c)}}$

$$\boxed{f_T = \frac{g_m}{2\pi(C_e + C_c)}}$$

Gain - Bandwidth (B.W) Product

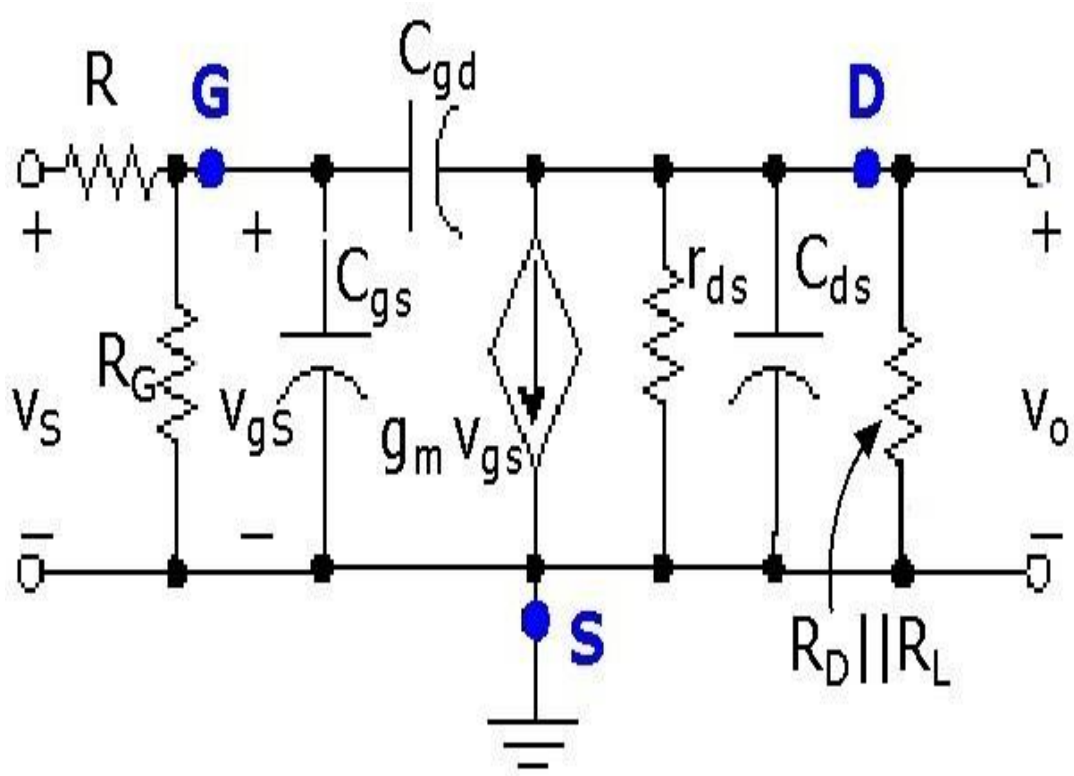
This is a measure to denote the performance of an amplifier circuit. Gain - B. W product is also referred as Figure of Merit of an amplifier. Any amplifier circuit must have large gain and large bandwidth. For certain amplifier circuits, the mid band gain Am maybe large, but not Band width or Vice - Versa. Different amplifier circuits can be compared with thus parameter.

FET: Analysis of common Source and common drain Amplifier circuits at high frequencies.

Just like for the BJT, we could use the original small signal model for low frequency analysis–the only difference was that external capacitances had to be kept in the circuit. Also just like the BJT, for high frequency operation, the internal capacitances between each of the device's terminals can no longer be ignored and the small signal model must be modified. Recall that for high frequency operation, we're stating that external capacitances are so large (in relation to the internal capacitances) that they may be considered short circuits.

High frequency response of Common source amplifier

The JFET implementation of the common-source amplifier is given to the left below, and the small signal circuit in corporating the high frequency FET model is given to the right below. As stated above, the external coupling and bypass capacitors are large enough that we can model them as short circuits for high frequencies.



We may simplify the small signal circuit by making the following approximations and observations:

1. R_{ds} is usually larger than $R_D||R_L$, so that the parallel combination is dominated by $R_D||R_L$ and r_{ds} may be neglected. If this is not the case, a single equivalent resistance, $r_{ds}||R_D||R_L$ may be defined.

2. The Miller effect transforms C_{gd} into separate capacitances seen in the input and output circuits as

$$C_{M1} = C_{gd}(1 - A_v) \quad (input\ circuit)$$
$$C_{M2} = C_{gd}\left(1 - \frac{1}{A_v}\right)(output\ circuit).$$

3. C_{ds} is very small, so the impedance contribution of this capacitance may be considered to be an open circuit and may be ignored.

$$C_{in} = C_{gs} + C_{M1} = C_{gs} + C_{gd}(1 - A_v).$$

4. The parallel capacitances in the input circuit, C_{gs} and C_{M1}, may be combined to a single equivalent capacitance of value

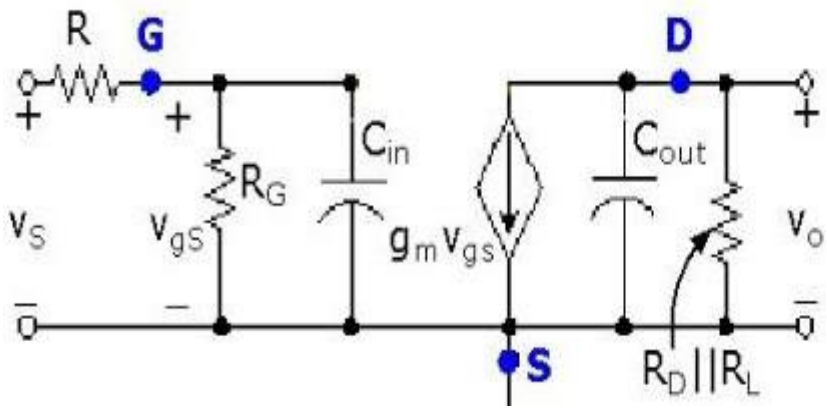
$$C_{in} = C_{gs} + C_{M1} = C_{gs} + C_{gd}(1 - A_v).$$

5. Similarly, the parallel capacitances in the output circuit, C_{ds} and C_{M2}, may be combined to a single equivalent capacitance of value

$$C_{out} = C_{ds} + C_{M2} = C_{ds} + C_{gd}\left(1 - \frac{1}{A_v}\right),$$

Where $A_v = -g_m(R_D||R_L)$ for a common-source amplifier.

Setting the input source, v_S, equal to zero allows us to define the equivalent resistances seen by C_{in} and C_{out}(the Method of Open Circuit Time Constants).Note that, with v_S=0, the dependent current source also goes to zero (opens) and the input and output circuits are separated.



$$R_{Cin} = R \,||\, R_G \,.$$

$$R_{Cout} = R_D \,||\, R_L \,.$$

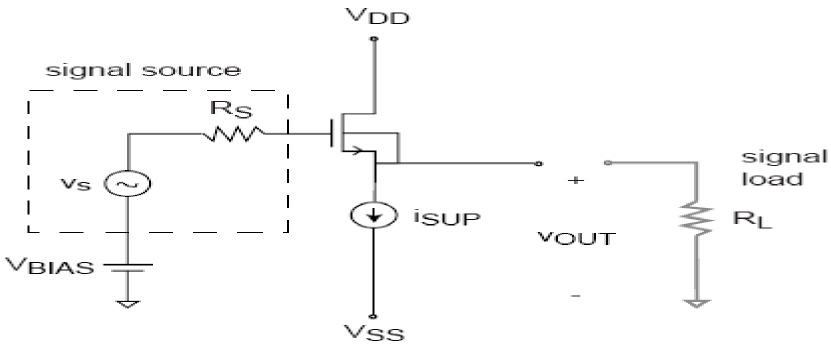
$$\tau_{Cin} = C_{in} R_{Cin} \,; \qquad \tau_{Cout} = C_{out} R_{Cout} \,,$$

$$\omega_H = \frac{1}{\frac{1}{\omega_{Cin}} + \frac{1}{\omega_{Cout}}} = \frac{1}{\tau_{Cin} + \tau_{Cout}} = \frac{1}{C_{in} R_{Cin} + C_{out} R_{Cout}} = \frac{1}{C_{in}(R \,||\, R_G) + C_{out}(R_D \,||\, R_L)}$$

Generally, the input is going to provide the dominant pole, so the high frequency cut off is given by

$$\omega_H = \frac{1}{C_{in}(R \,||\, R_G)} \,; \qquad f_H = \frac{\omega_H}{2\pi} = \frac{1}{2\pi C_{in}(R \,||\, R_G)} \,.$$

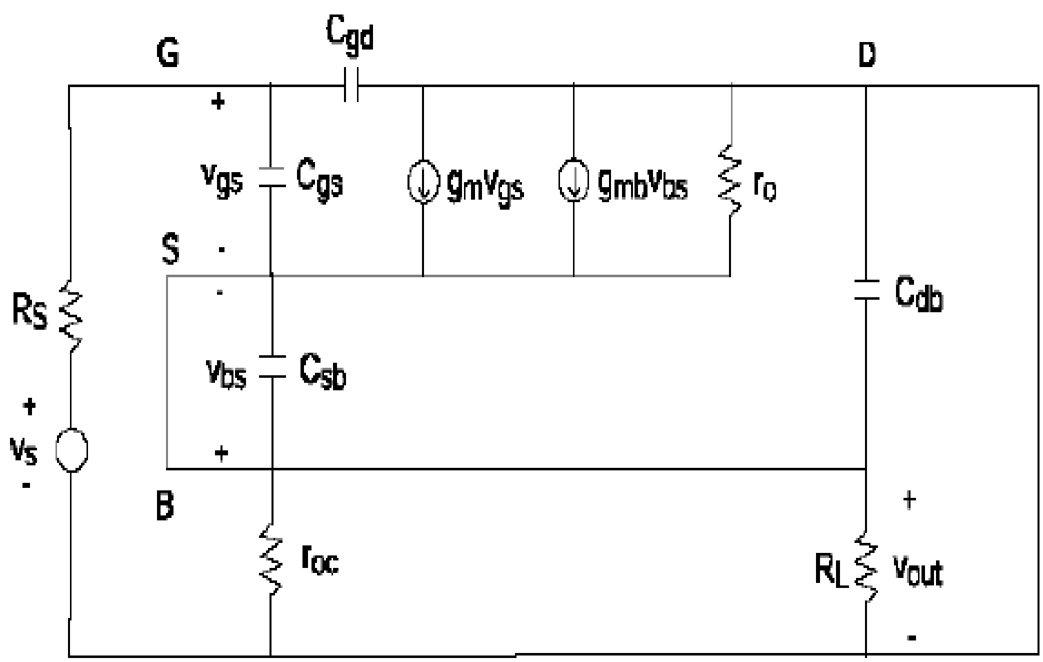
High frequency response of Common source amplifier

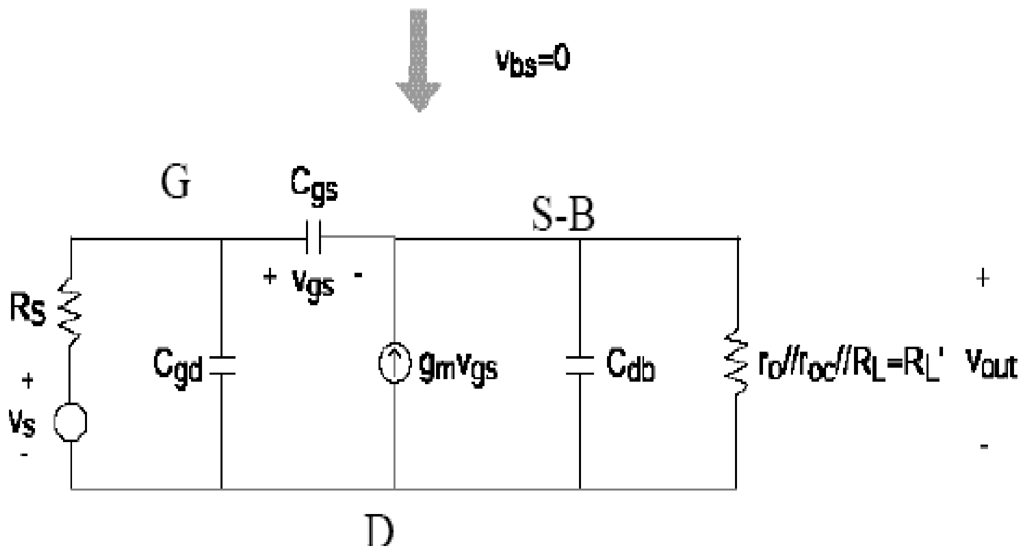


Characteristics ofCDAmplifier:

- Voltagegain ≈1
- Highinputresistance
- Lowoutputresistance
- Goodvoltage buffer

High frequency small signal model





$$A_{vC_{gs}} = \frac{R_L}{R_{out} + R_L} = \frac{g_m R_L}{1 + g_m R_L}$$

$$C_M = C_{gs}\left(1 - A_{vC_{gs}}\right) = C_{gs}\left(1 - \frac{g_m R_L}{1 + g_m R_L}\right) = \frac{C_{gs}}{1 + g_m R_L}$$

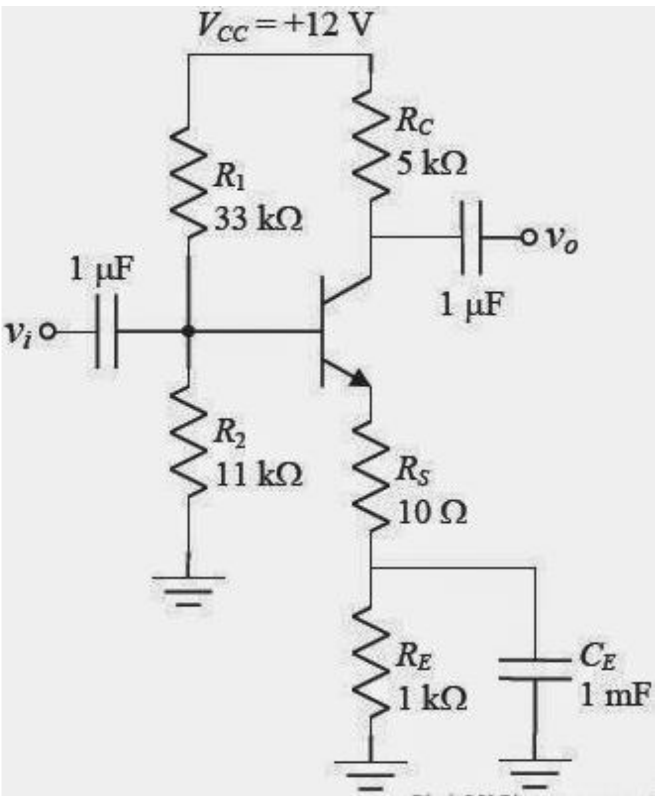
$$C_T = C_{gs}\left(1 - \frac{g_m R_L}{1 + g_m R_L}\right) + C_{gd}$$

$$R_T = R_S \parallel R_{in} = R_S$$

$$R_{C_{db}} = R_{out} \parallel R_L = \frac{R_{out} R_L}{R_{out} + R_L} = \frac{R_L}{1 + g_m R_L}$$

$$\omega_{3dB} \approx \frac{1}{R_S\left(\frac{C_{gs}}{1+g_m R_L} + C_{gd}\right) + C_{db}\frac{R_L}{1+g_m R_L}}$$

If R_S is not too high, bandwidth can be rather high and approach ω_T



UNIT-II

Multistage Amplifiers : Classification of amplifiers, methods of coupling**, c**ascaded transistor amplifier and its analysis, analysis of two stage RC coupled amplifier, high input resistance transistor amplifier circuits and their analysis-Darlington pair amplifier, Cascode amplifier, Boot-strap emitter follower, Analysis of multi stage amplifiers using FET, Differential amplifier using BJT.

Classification of amplifiers

Depending upon the type of coupling, the multistage amplifiers are classified as :

1. Resistance and Capacitance Coupled Amplifiers (RC Coupled)
2. Transformer Coupled Amplifiers
3. Direct Coupled DC Amplifiers
4. Tuned Circuit Amplifiers.

Based upon the B. W. of the amplifiers, they can be classified as :

1. Narrow hand amplifiers
2. Untuned amplifiers

Narrow hand amplifiers: Amplification is restricted to a narrow band of frequencies around a centre frequency. There are essentially tuned amplifiers.

Untuned amplifiers: These will have large bandwidth. Amplification is desired over a considerable range of frequency spectrum.

Untuned amplifiers are further classified w.r.t bandwidth.

I. DC amplifiers (Direct Coupled) DC to few KHz	
2. Audio frequency amplifiers (AF)	20 Hz to 20 KHz
3. Broad band amplifier	DC to few MHz
4. Video amplifier	100 Hz to few MHz

The gain provided by an amplifier circuit is not the same for all frequencies because the reactance of the elements connected in the circuit and the device reactance value depend upon the frequency. Bandwidth of an amplifier is the frequency range over which the amplifier stage gain is reasonably constant within ± 3 db, or O. 707 of A_V Max Value.

Resistance and Capacitance Coupled Amplifiers (RC Coupled)

This type of amplifier is very widely used. It is least expensive and has good frequency response. In the multistage resistive capacitor coupled amplifiers, the output of the first stage is coupled to the next through coupling capacitor and R_L. In two stages Resistor Capacitor coupled amplifiers, there is no separate R_L between collector and ground, but Reo the resistance between collector and V cc (R_C) itself acts as R_L in the AC equivalent circuit.

Transformer Coupled Amplifiers
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Here the output of the amplifier is coupled to the next stage or to the load through a transformer. With this overall circuit gain will be increased and also impedance matching can be achieved. But such transformer coupled amplifiers will not have broad frequency response i.e., (f_2-f_1) is small since inductance of the transformer windings will be large. So Transformer coupling is done for power amplifier circuits, where impedance matching is critical criterion for maximum power to be delivered to the load.

Direct Coupled (DC) Amplifiers

Here DC stands for direct coupled and not (direct current). In this type, there is no reactive element. L or C used to couple the output of one stage to the other. The AC output from the collector of one stage is directly given to the base of the second stage transistor directly. So type of amplifiers is used for large amplification of DC and using low frequency signals. Resistor Capacitor coupled amplifiers cannot be used for amplifications of DC or low frequency signals since Xc the capacitive reactance of the coupling capacitor will be very large or open circuit for DC

Tuned Circuit Amplifiers

In this type there will be one RC or LC tuned circuit between collector and V_{CC} in the place of Re. These amplifiers will amplify signals of only fixed frequency.fo which is equal to the resonance frequency of the tuned circuit LC. These are also used to amplify signals of a narrow band of frequencies centered on the tuned frequency f_0.

Distortion in Amplifiers

If the input signal is a sine wave the output should also be a true sine wave. But in all the cases it may not be so, which we characterize as distortion. Distortion can be due to the nonlinear characteristic of the device, due to operating point not being chosen properly, due to large signal swing of the input from the operating point or due to the reactive elements Land C in the circuit. Distortion is classified as:

(a) **Amplitude distortion**:

This is also called non linear distortion or harmonic distortion. This type of distortion occurs in large signal amplifiers or power amplifiers. It is due to then on linearity of the characteristic of the device. This is due to the presence of new frequency signals which are not present in the input. If the input signal is of 10 KHz the output signal should also be 10 KHz signal. But some harmonic terms will also be present. Hence the amplitude of the signal (rms value) will be different Vo = Ay Vi.

(b) **Frequency distortion**:

The amplification will not be the same for all frequencies. This is due to reactive component in the circuit.

(c) **Phase - shift delay distortion**:

There will be phase shift between the input and the output and this phase shift will not be the same for all frequency signals. It also varies with the frequency of the input signal. In the output signal, all these distortions may be present or anyone may be present because of which the amplifier response will not be good.

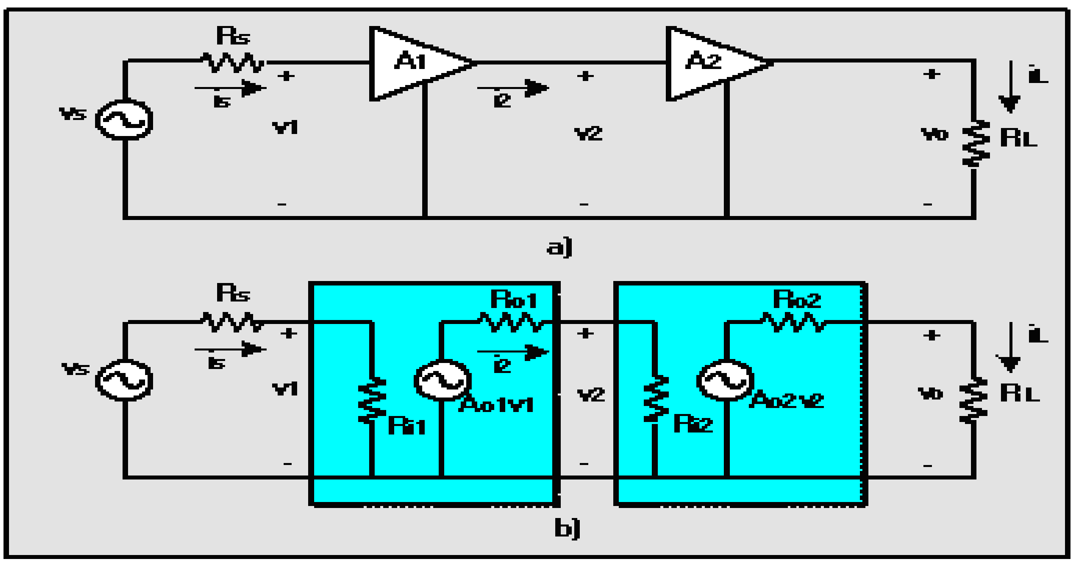
The performance obtainable from a single stage amplifier is often insufficient for many applications; hence several stages may be combined forming a multistage amplifier. These stages may be combined forming a multistage amplifier. These stages are connected in cascade, i.e. output of the first stage is connected to form input of second stage, whose output becomes input of third stage, and so on. The overall gain of a multistage amplifier is the product of the gains of the individual stage (ignoring potential loading effects):

Gain (A) = A1 * A2 * A3 * A4 * …… *An.

Alternately, if the gain of each amplifier stage is expressed in decibels (dB), the total gain is the sum of the gains of the individual stages

Gain in dB (A) = A1 + A2 + A3 + A4 + …… + An.

When we want to achieve higher amplification than a single stage amplifier can offer, it is a common practice to cascade various stages of amplifiers, as it is shown in Fig.1.a. In such a structure the input performance of the resulted multistage amplifier is the input performance of the first amplifier while the output performance is that of the last amplifier. It is understood that combining amplifiers of various types we can create those characteristics that are necessary to fulfill the specifications of a specific application. In addition, using feedback techniques in properly chosen multistage amplifiers can further increase this freedom of the design.



According to the small signal equivalent circuit of a two stage amplifier shown in Fig., we can calculate the ac performance of the circuit.

Voltage amplification

$$A_v = \frac{V_o}{V_1} = \frac{V_o}{V_2} \cdot \frac{V_o}{V_1} = A_{v2} \cdot A_{v1}$$

Current amplification

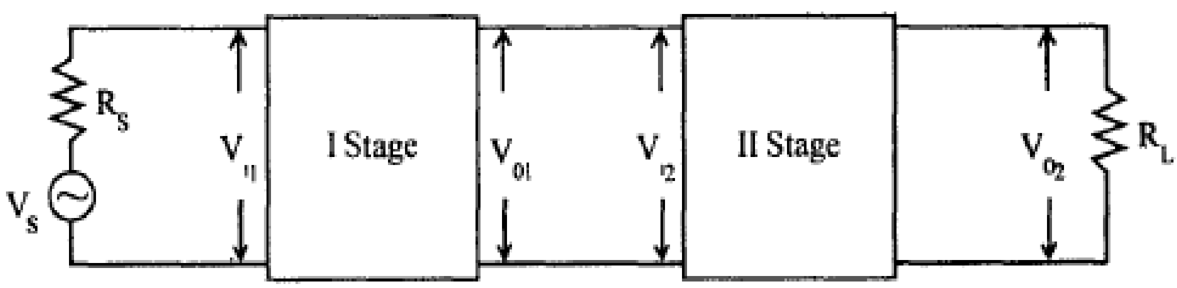
$$A_i = \frac{i_L}{i_s} = \frac{i_L}{i_2} \cdot \frac{i_2}{i_s} = A_{i2} \cdot A_{i1}$$

Power amplification

$$A_p = A_v \cdot A_i = (A_{v2} \cdot A_{i2}) \cdot (A_{v1} \cdot A_{i1}) = A_{p2} \cdot A_{p1}$$

Cascading Transistor Amplifiers

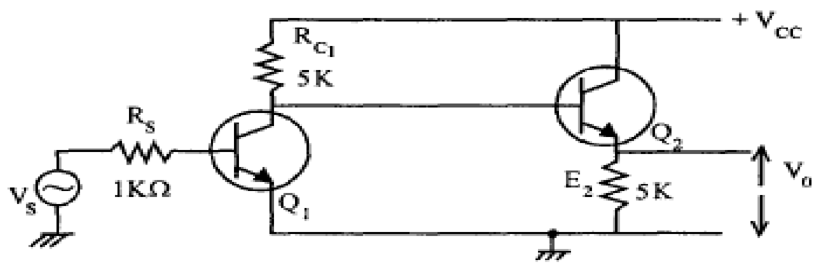
When the amplification of a single transistor is not sufficient for a particular purpose (say to deliver output to the speaker or to drive a transducer etc) or when the input or output impedance is not of the correct magnitude for the desired application, two or more stages may be connected in cascade. Cascade means in series i.e. the output of first stage is connected to the input of the next stage.



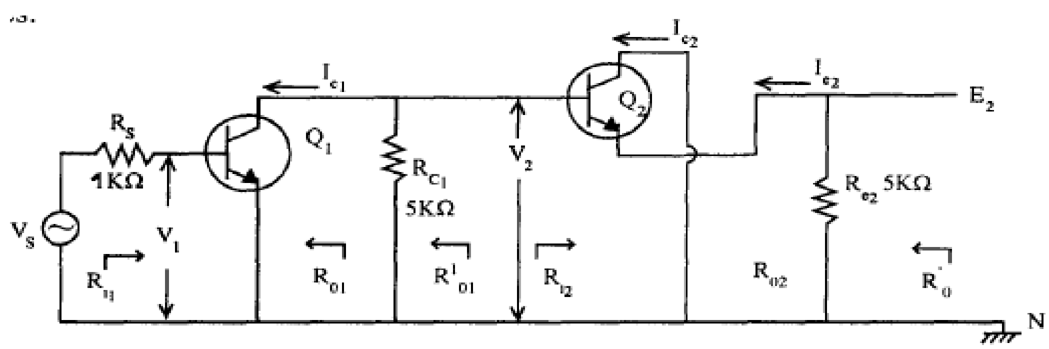
Let us consider two stage cascaded amplifier. Let the first stage is in common emitter configuration. Current gain is high and let the II stage is in common collector configuration to provide high input impedance and low output impedance. So what are the expressions for the total current gain A_I of the entire circuit (i.e. the two stages), Z_i, A_v and Y_o? To get these expressions, we must take the h-par ammeters of these transistors in that particular configuration. Generally manufactures specify the h-parameters for a given transistor in common emitter configuration. It is widely used circuit and also A_I is high. To get the transistor h-parameters in other configurations, converts ion formulae are used.

The Two Stage Cascaded Amplifier Circuit

The Transistor Q_1 is in Common Emitter configuration. The second Transistor Q_2 is in Common Collector (CC) configuration. Output is taken across 5K, the emitter resistance. Collector is at ground potential in the A.C. equivalent circuit. Biasing resistors are not shown since their purpose in only to provide the proper operating point and they do not affect the response of the amplifier. In the low frequency equivalent circuit, since the capacitors have large value, and so is X_c low, and can be neglected. So the capacitive reactance is not considered, and capacitive reactance X_c is low when C is large and taken as short circuit.



The small signal Common Emitter configuration circuit reduces as shown in Fig. In this circuit Q2 collector is at ground potential, in AC equivalent circuit. It is in Common Collector configuration and the output is taken between emitter point E2 and ground. So the circuit is redrawn as shown in Figure indicating voltages at different stages and input and output resistances.



Choice of Transistor in a Cascaded Amplifier Configuration

By connecting transistor in cascade, voltage gain gets multiplied. But what type of configuration should be used? Common Collector(CC) or Common Base(CB) or Common

Emitter(CE)? To get voltage amplification and current amplification, only Common Emitter (CE) configuration is used. Since it is Common Collector amplifier, the voltage gain is less than one for each stage. So the overall amplification is less than 1.

Common Base Configuration is also not used since A_I is less than 1.

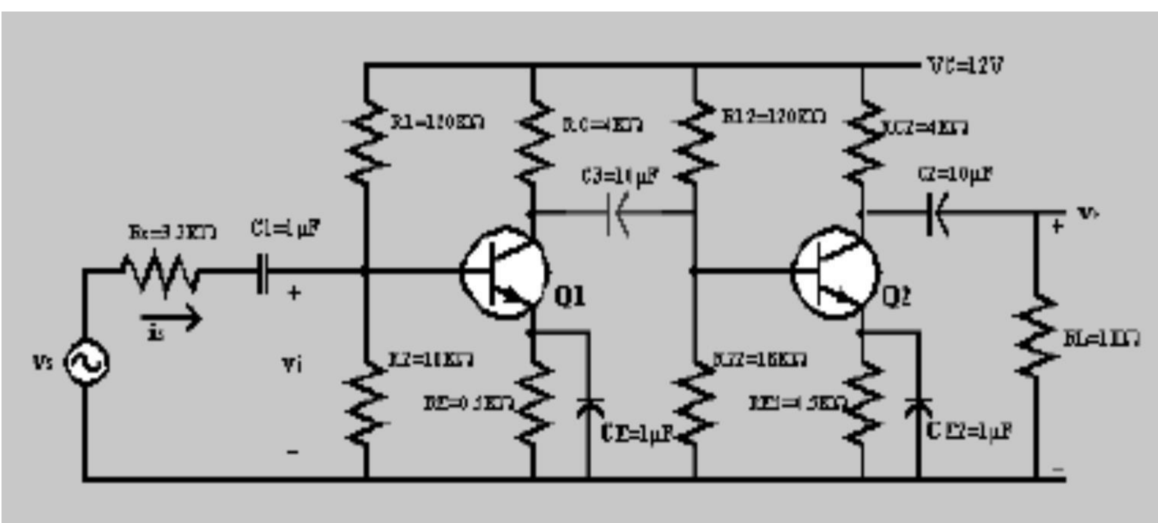
$$A_V = A_I \times \frac{R_L}{R_i}$$

Effective load resistance R_L is parallel combination of R_c and R_i of the following stage, (next stage) (since in multi stage connection, the output of one stage is the input to the other stage). This parallel combination is less than R_i. Therefore $R_L/R_i < 1$.

The current gain A_I in common base configurations is hib< 1 or =1.Therefore overall voltage gain = 1. Therefore Common Base configuration is not used for cascading. So only Common Emitter configuration is used (hfe>> I).Therefore overall voltage gain and current gains are> 1 in Common Emitter configuration.

Two stage RC coupled amplifier

One way to connect various stages of a multistage amplifier is via capacitors, as indicated in the two-stage amplifier in Figure. Where two stages of common emitter amplifier are coupled to each other by the capacitor C_3.



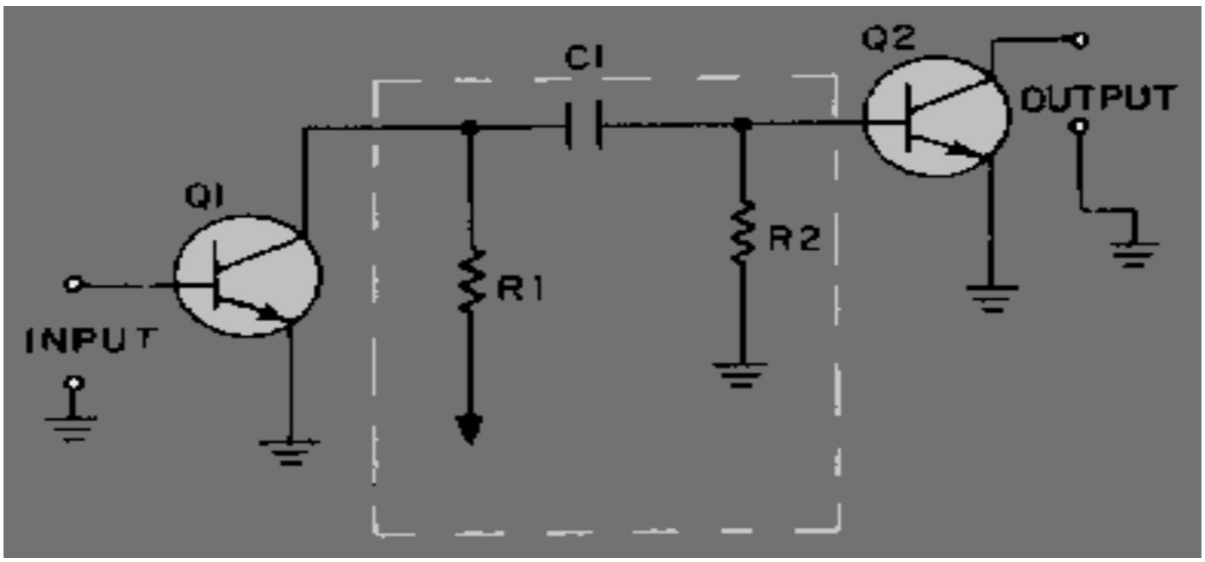
In RC-coupled amplifiers:

1. The various stages are DC isolated. This feature facilitates the biasing of individual stages.

2. The various stages can be similar. Hence the design of the amplifier is simplified.

3. The coupling capacitors influence the responses of the amplifier.

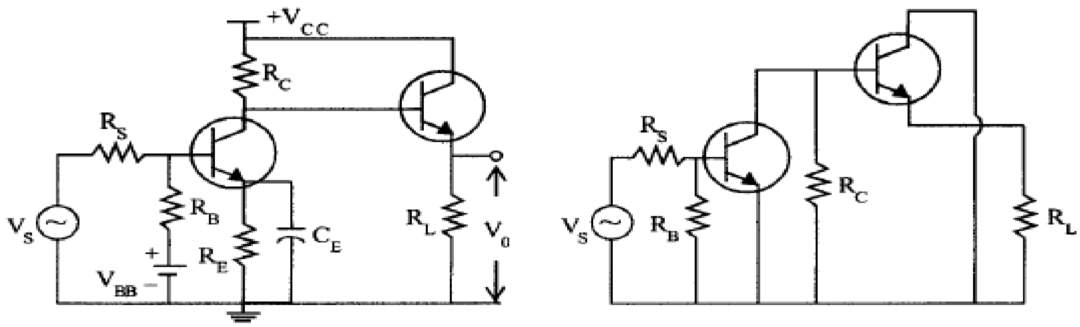
4. A great number of biasing resistors is necessary.



The most commonly used coupling in amplifiers is RC coupling. An RC-coupling network is shown in the illustration above. The network of R1, R2, and C1 enclosed in the dashed lines of the figure is the coupling network. You may notice that the circuitry for Q1 and Q2 is incomplete. That is intentional so that you can concentrate on the coupling network. R1 acts as a load resistor for Q1 (the first stage) and develops the output signal of that stage. Do you remember how a capacitor reacts to ac and dc? The capacitor, C1, "blocks" the dc of Q1's collector, but "passes" the ac output signal. R2 develops this passed, or coupled, signal as the input signal to Q2 (the second stage). This arrangement allows the coupling of the signal while it isolates the biasing of each stage. This solves many of the problems associated with direct coupling.

CE - CC Amplifiers

This is another type of two-stage BJT amplifier. The first stage in Common Emitter (CE) configuration provides voltage and current gains. The second stage in Common-Collector (CC) configuration provides impedance matching. This circuit is used in audio frequency amplifiers. The circuit is shown in Fig.



$$R_{L_2} \simeq R_L$$
$$h_{oc} \; R_{L_1} \leq 0.1$$
$$A_{I2} = A_{I'2} = (1 + h_{fe})$$
$$R_{i_2} = (1 + h_{fe})\, R_{L_2}$$
$$A_{V2} = A_{V2'} = \frac{A_{I_2} . R_{L_2}}{R_{i_2}}$$
$$= \frac{(1 + h_{fe}\; R_{L_2})}{h_{ie} + (1 + h_{fe}) R_{L_2}}$$
$$= 1 - \frac{h_{ie}}{R_{i_2}} \; ;$$
$$A_{V_2} < 1$$
$$A_{I_1} = A_{I_1}' = -h_{fe}$$
$$R_{i_1} = R_{i_1}' = h_{ie}$$
$$A_{V_1} = A_{V_1}' = (A_{I_1} \, . \, R_{L_1} / R_i)$$

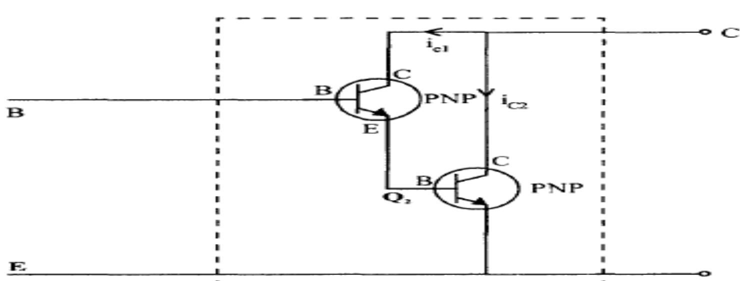
$$A_V = A_{V_1} \cdot A'_{V_2}$$
$$R_i = R_{i_1}$$
$$R_o = R_{o_1}$$
$$A_I = \frac{A_V . R_{i_1}}{R_{L_2}}$$

High Input Resistance Transistor Circuits

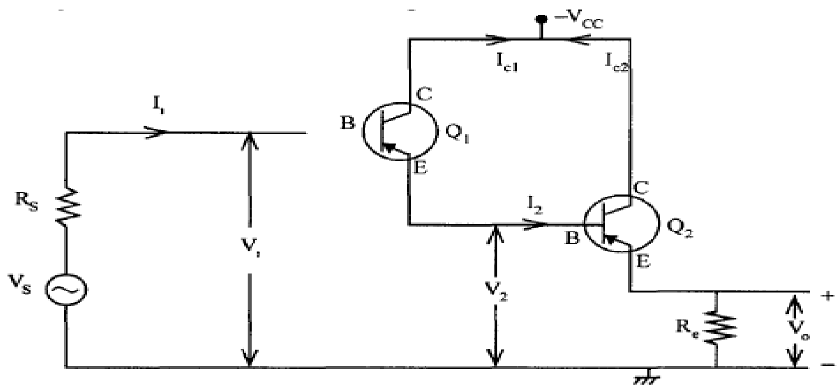
In some applications the amplifier circuit will have to have very high input impedance. Common Collector Amplifier circuit has high input impedance and low output impedance. But it's A_v<1.If the input impedance of the amplifier circuit is to be only 500 KO or less the Common Collector Configuration can be used. But if still higher input impedance is required a circuit. This circuit is known as the Darlington Connection (named after Darlington) or Darlington Pair Circuit.

The Darlington Pair

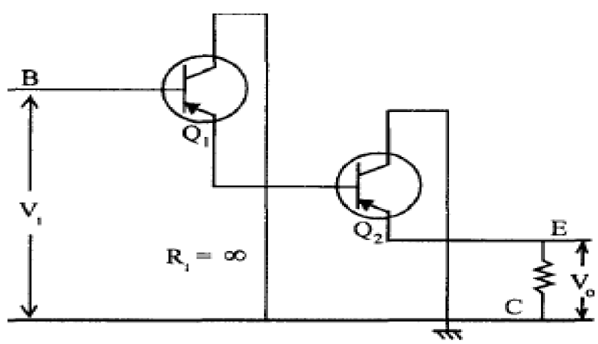
This is two transistors connected together so that the amplified current from the first is amplified further by the second transistor. This gives the Darlington pair a very high current gain such as 10000. Darlington pairs are sold as complete packages containing the two transistors. They have three leads (B, C and E) which are equivalent to the leads of a standard individual transistor.



In this circuit, the two transistors are in Common Collector Configuration. The output of the first transistor Q_1 (taken from the emitter of the Q_1) is the input to the second transistor Q_2 at the base. The input resistance of the second transistor constitutes the emitter load of the first transistor. So, Darlington Circuit is nothing but two transistors in Common Collector Configuration connected in series. The same circuit can be redrawn as AC equivalent circuit. So, DC is taken as ground shown in below Fig. Hence 'C' at ground potential, Collectors of transistors $Q_1$and Q_2 is at ground potential.



There is no resistor connected between the emitter of Q_1 and ground i.e., Collector Point. So, we can assume that infinite resistance is connected between emitter and collector.



The overall current gain is equal to the two individual gains multiplied together:

Darlington pair current gain, $h_{FE} = h_{FE1} \times h_{FE2}$

Here h_{FE1} and h_{FE2} are the gains of the individual transistors

If both the transistors are identical then

Current gain

$$A_I = \frac{I_c}{I_{b_1}} \cong (h_{fe})^2$$

Input resistance

$$R_i \simeq \frac{(1+h_{fe})^2 R_e}{1+h_{oe}h_{fe}R_e}$$

Voltage gain

$$A_v \cong \left(1 - \frac{h_{ie}}{Ri_2}\right)$$

Output resistance

$$R_{o2} = \frac{R_s + h_{ie}}{(1+h_{fe})^2} + \frac{h_{ie}}{1+h_{fe}}$$

Therefore, the characteristic of Darlington Circuit are

1. Very High Input Resistance
2. Very Large Current Gain
3. Very Low Output Resistance
4. Voltage Gain, $A_V < 1$.

This gives the Darlington pair a very high current gain, such as 10000, so that only a tiny base current is required to make the pair switch on.

A Darlington pair behaves like a single transistor with a very high current gain. It has three leads (B, C and E) which are equivalent to the leads of a standard individual transistor. To turn on there must be 0.7V across both the base-emitter junctions which are connected in series inside the Darlington pair, therefore it requires 1.4V to turn on.

Darlington pairs are available as complete packages but you can make up your own from two transistors; TR1 can be a low power type, but normally TR2 will need to be high power. The maximum collector current Ic(max) for the pair is the same as Ic(max) for TR2.

A Darlington pair is sufficiently sensitive to respond to the small current passed by your skin and it can be used to make a touch-switch as shown in the diagram. For this circuit which just lights an LED the two transistors can be any general purpose low power transistors. The 100k resistor protects the transistors if the contacts are linked with a piece of wire. Two transistors may be combined to form a configuration known as the Darlington pair which behaves like a single transistor with a current gain equivalent to the product of the current gain of the two transistors. This is especially useful where very high currents need to be controlled as in a power amplifier or power-regulator circuit. Darlington transistors are available whereby two transistors are combined in one single package. The base-emitter volt-drop is twice that of a small transistor.

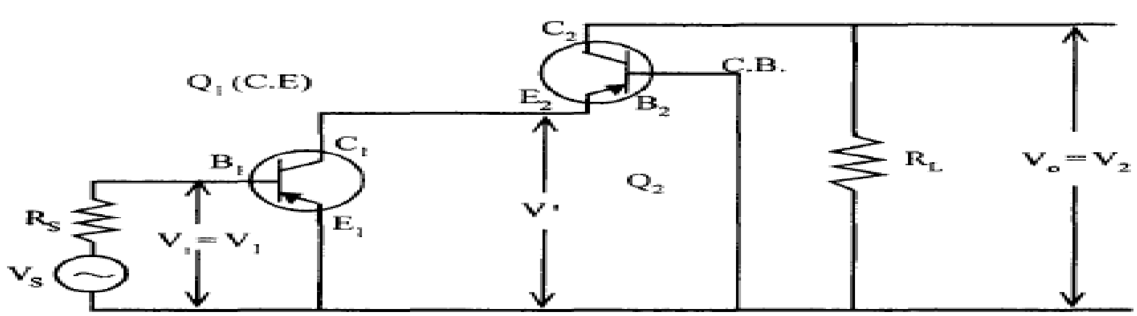
Disadvantages

1. The h-parameters for both the transistors will not be the same.
2. Leakage Current is more

The CASCODE Transistor Configuration

The circuit is shown in Figure. This transistor configuration consists of a Common Emitter Stage in cascade with a Common Base Stage. The collector current of transistor Q) equals the emitter current of Q_2.

The transistor Q_1 is in Common Emitter Configuration and transistor Q_2 is in Common Base Configuration. Let us consider the input impedance (h_{11}) etc., output admittance (h22) i.e. the h - parameters of the entire circuit in terms of the h- parameters of the two transistors



Input impedance

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

$$h_{11} \cong h_{ie}$$

Short circuit current gain

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

$$h_{21} = \frac{I_2}{I_1} = \frac{I}{I_1} \times \left.\frac{I_2}{I_0}\right|_{V_2 = 0}$$

$$\frac{I'}{I_1} = h_{fe} \qquad \text{since, } I = I_{C_1}.\ I_1 = I_{B_1}$$

$$\frac{I_2}{I'} = -h_{fb} \qquad \text{since, } I = I_{E_2}.\ I_2 = I_{C_2}.$$

$$h_{21} = -h_{fe}.\ h_{fb}.$$

$$h_{fe} >> 1\ .\ -h_{fb} \simeq 1, \qquad \text{since } h_{fb} = \frac{I_C}{I_E}$$

$$\boxed{h_{21} \cong h_{fe}}$$

Output conductance

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

Reverse voltage gain

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

$$= \left.\frac{V_1}{V'} \times \frac{V^1}{V_2}\right|_{I_1 = 0}$$

$$\left.\frac{V_1}{V_0'}\right|_{I_i = 0} = h_{re}. \left.\frac{V'}{V_2}\right| = h_{rb}$$

$h_{12} \cong h_{re}\, h_{rb}.$

$h_{re} \cong 10^{-4}$ $\quad h_{rb} = 10^{-4}.$ $\because$ h_{12} is very small

$h_i = h_{11} \cong h_{ie}.$ $\quad$ Typical value = 1.1KΩ

$h_f = h_{21} \cong h_{fe}.$ $\quad$ Typical value = 50

$h_o = h_{22} \cong h_{ob}.$ $\quad$ Typical value = 0.49 μ A/V

$h_r = h_{12} \cong h_{re}\, h_{rb}.$ $\quad$ Typical value = 7×10^{-8}.

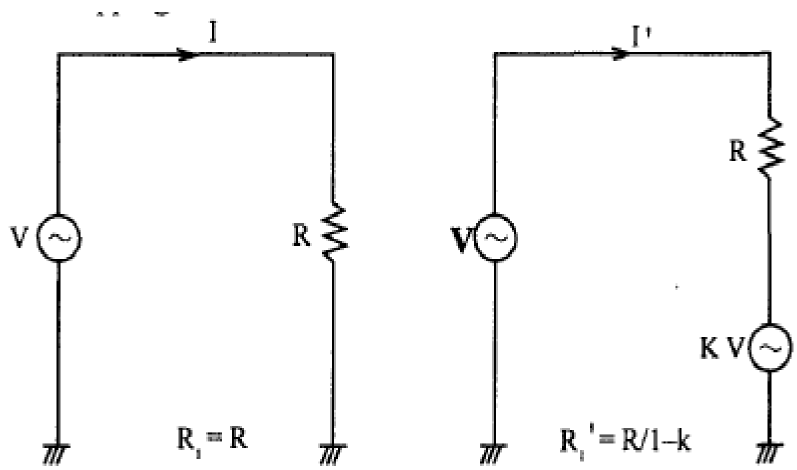
Therefore, for a CASCODE Transistor Configuration, its input Z is equal to that of a single Common Emitter Transistor (hie)' Its Current Gain is equal to that of a single Common Base Transistor (h_{fe}). Its output resistance is equal to that of a single Common Base Transistor (hob)' the reverse voltage gain is very small, i.e., there is no link between V_1 (input voltage) and V_2 (output voltage). In other words, there is negligible internal feedback in the case of, a CASCODE Transistor Circuit, acts like a single stage C.E. Transistor (Since hie and hfe are same) with negligible internal feedback (:.hre is very small) and very small output conductance, (= hob) or large output resistance (=2MΩ equal to that of a Common Base Stage). The above values are correct, if we make the assumption that hob R_L< 0.1 or RL is <200K.

CASCODE Amplifier will have

1. Very Large Voltage Gain.
2. Large Current Gain
3. Very High Output Resistance.

Boot-strap emitter follower

The maximum input resistance of a practical Darlington Circuit is only 2 MΩ. Higher input resistance cannot be achieved because of the biasing resistors R_1, R_2 etc. They come in parallel with R_i of the transistors and thus reduce the value of Ri. The maximum value of Ri is only 1/hob since, hob is resistance between base and collector. The input resistance can be increased greatly by boot strapping, the Darlington Circuit through the addition of Co between the first collector C_1 and emitter B_2.

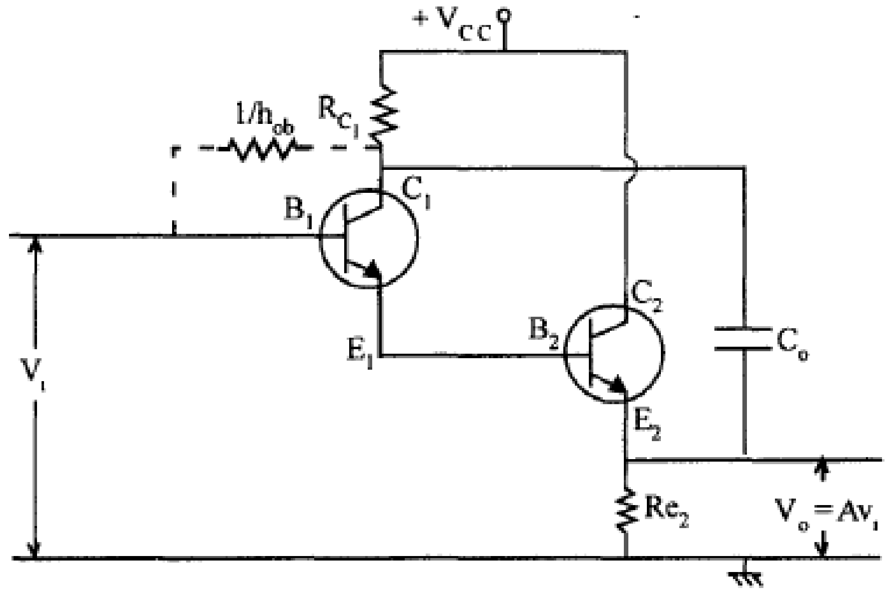


Boot strapping

In Fig, V is an AC signal generator, supplying current I to R. Therefore, the input resistance of V seen by the generator is $R_1 = V/I= R$ itself. Now suppose, the bottom end of R is not at ground potential but at higher potential i.e. another voltage source of KV (K < I) is connected between the bottom end of R and ground. Now the input resistance of the circuit is

$$R_i' = \frac{V}{I'} \qquad\qquad I' = \frac{(V - KV)}{R}$$

$$R_i' = \frac{VR}{V(1-K)} = \frac{R}{1-K}$$

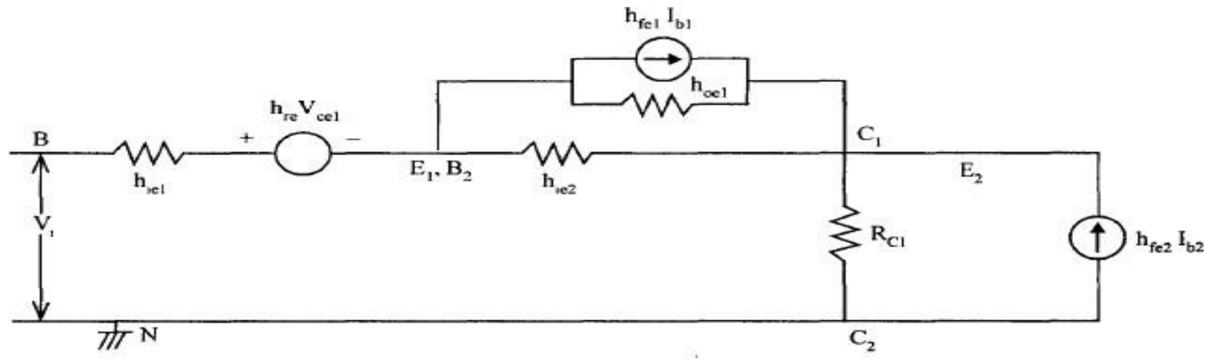


I' can be increased by increasing V. When V increases KV also increases. K is constant.Therefore the potential at the two ends of R will increase by the same amount, K is less than 1, therefore R_i> R. Now if K = 1, there is no current flowing through R (So V = KV there is nopotential difference). So the input resistance R\ = 00. Both the top and bottom of the resistorterminals are at the same potential. This is called as the Boots Strapping method which increases theinput resistance of a circuit. If the potential at one end of the resistance changes, the other end of Ralso moves through the same potential difference. It is as if R is pulling itself up by its boot straps.For CC amplifiers A_v< 1 = 0.095. So R_i can be made very large by this technique. K = Av = 1.Ifwe pull the boot with both the edges of the strap (wire) the boot lifts up. Here also, if the potentialat one end ofR is changed, the voltage at the other end also changes or the potential level ofR_3 rises,as if it is being pulled up from both the ends.

$$R_i = \frac{h_{ie}}{1 - A_V}; \quad A_V \cong 1.$$

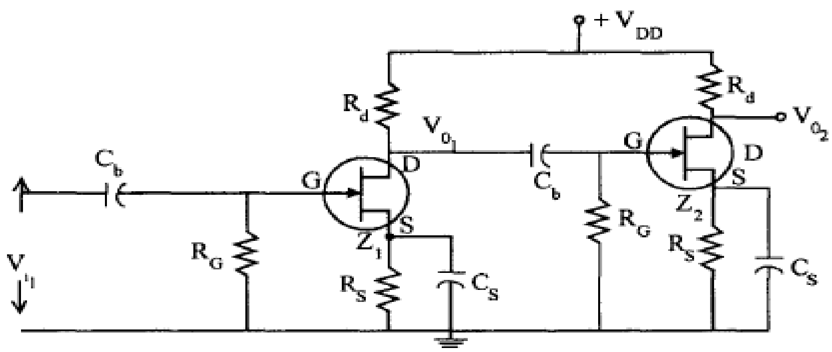
$$R_i = \frac{R}{1 - K}$$

AC Equivalent circuit



Two Stage RC Coupled JFET amplifier (in Common Source (CS) configuration)

The circuit for two stages of RC coupled amplifier in CS configuration is as shown in fig.



The output Vo of I Stage is coupled to the input Vi of II Stage through a blocking capacitor C_b. It blocks the DC components present in the output or I Stage from reaching the input of the I stage which will alter the biasing already fixed for the active device. Resistor Rg is connected between gate and ground resistor Ro is connected between drain and V_{DD} supply. C_S is the bypass capacitor used to prevent loss of gain due to negative feedback. The active device is assumed to operate in the linear region. So the small signal model of the device is valid. Frequency Roll-off is the term used for the decrease in gain with frequency in the uppercut-off region. It is expressed as db/octave on db/decade.

The purpose of multistage amplifiers is to get large .gain. So with BJTs, Common Emitter Configuration is used. If JFETs are employed, common source configuration is used.

UNIT III
FET Biasing AND FET Amplifiers

FET-Biasing and FET Amplifiers: FET biasing: fixed bias and self bias. FET Amplifiers: Analysis of Common source (C.S), Common Drain (C.D) JFET Amplifiers, comparison of performance with BJT Amplifiers,

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

Thiscanbeachievedbysuitablyselectingthegateto sourcevoltageVGSand draincurrentID which is referred to as biasing

JFET biasing circuits are very similar to BJT biasing circuits The main difference betweenJFETcircuitsandBJTcircuitsistheoperationoftheactivecomponentsthemselves

TherearemainlytwotypesofBiasingcircuits

1) Selfbias
2) Voltagedivider-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 theself biasarrangementasshowninFig.ThegateresistorRG doesn'taffectthe biasbecauseithasessentially 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 sourcejunction reverse biased.

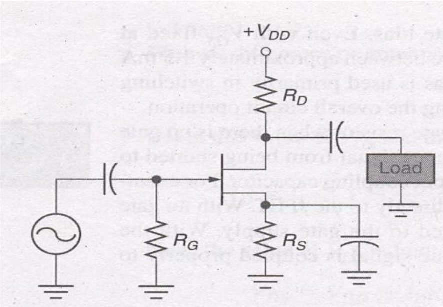


FIGURE 12.19 Self-bias.

Forthedcanalysiscouplingcapacitorsareopencircuits. 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 throughthe device tothe draincircuit .This is due tothe fact that there is no significant gate current.

Wecan definesourcecurrentasIS=ID

(VG=0becausethere isnogatecurrentflowing inRGSoVGacrossRGiszero) VG =0

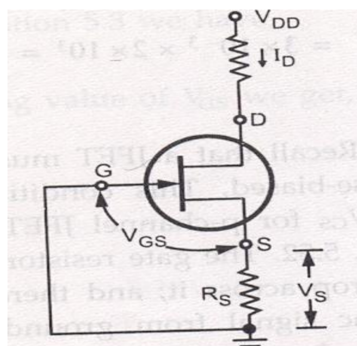
then VS= ISRS =ID RS

VGS=VG-VS=0-IDRS=-IDRS

DCanalysis ofselfBias:-

InthefollowingDCanalysis,theNchannelJFETshowninthefig.isusedforillustration.

ForDCanalysiswecanreplacecoupling capacitorsbyopencircuitsandwecanalsoreplacethe resistor RG by a short circuit equivalent.:. IG = 0.The relationbetweenID and VGS is givenby



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

VGSforNchannel JFET is=-idRs

Substutingthisvalueintheaboveequation

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

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

FortheN-chanelFETintheabovefigure

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 andVg=0 then

Vs=Is Rs =IdRs

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

Drawingtheselfbiasline:-

TypicaltransfercharacteristicsforaselfbiasedJFETareshowninthefig.

Themaximum draincurrent is5mAandthegatesource cutoffvoltageis -3V.Thismeansthegate voltage has to be between 0 and -3V.

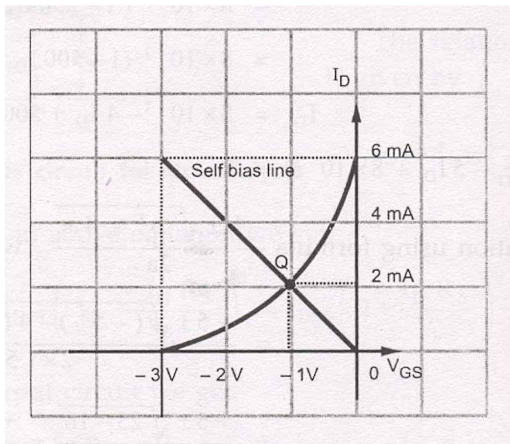


Fig. 5.55 Transfer characteristics

Now using theequation VGS = -IDRS and assuming RSofany suitable value we can draw the selfbias line.

Letusassume RS=500Ω

WiththisRs,wecanplottwopointscorrespondingtoID=0andId=IDSS for ID =0

VGS=-IDRS

VGS=0X(500.Ω)=0V

Sothefirstpointis(0,0)

(I_d,VGS)

ForID= IDSS=5mA

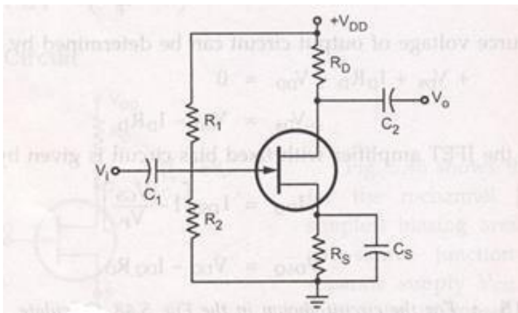
VGS=(-5mA)(500Ω) =-3V

Sothe2ndPointwillbe (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 > than2mA and VGS is slightly > -1V. The Q point forthe 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.

VOLTAGEDIVIDERBIAS:-



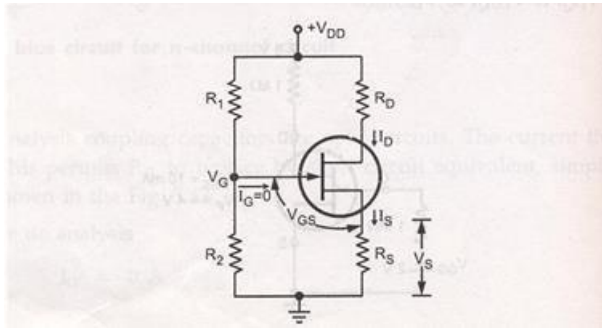
The fig. shows N channel JFET with voltage divider bias. The voltage at the source of JFET must be more positive than the voltage at the gate in order to keep the gate to source junction reverse biased. The source voltage is

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

Fordcanalysis



ApplyingKVLtotheinputcircuit

VG-VGS-VS =0

::VGS=VG-Vs=VG-ISRS

VGS=VG-IDRS ::IS=ID

ApplyingKVLtotheinputcircuitweget

VDS+IDRD+VS-VDD =0

::VDS=VDD-IDRD-IDRS

VDS = VDD-ID (RD +RS)

TheQpoint ofaJFETamplifier,usingthevoltagedividerbias is IDQ =

IDSS[1-VGS/VP]2

VDSQ=VDD-ID(RD+RS)

COMPARISONOFMOSFETWITHJFET

a. Inenhancementand depletion types ofMOSFET, thetransverse electricfield induced across an insulating layer deposited on the semiconductor material controls the conductivity of thechannel.

b. IntheJFETthetransverseelectricfieldacrossthereversebiasedPNjunctioncontrols the conductivity of thechannel.

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

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

e. JFETsareoperatedonly inthedepletionmode.ThedepletiontypeMOSFETmaybe operated in both depletion and enhancementmode.

f. ComparingtoJFET,MOSFETsareeasiertofabricate.

g. SpecialdigitalCMOScircuitsareavailablewhichinvolvenearzeropowerdissipationand very low voltage and current requirements. This makes them suitable for portable systems.

FETAMPLIFIERS

INTRODUCTION

Field Effect Transistor (FET) amplifiers provide an excellent voltage gain and high input impedence.Becauseofhighinput impedenceandothercharacteristics ofJFETsthey arepreferred over BJTs for certain types of applications.

Thereare3basicFETcircuitconfigurations:

i) CommonSource

ii) CommonDrain

iii) CommonGain

SimilartoBJTCE,CCandCBcircuits,only differenceisinBJTlargeoutputcollectorcurrentis controlledbysmallinputbasecurrentwhereasFETcontrolsoutputcurrentbymeansofsmallinputvoltage. In both the cases output current is controlledvariable.

FETamplifiercircuitsusevoltagecontrollednatureoftheJFET.InPinchoffregion,$I_D$depends only on V_{GS}.

CommonSource(CS)Amplifier

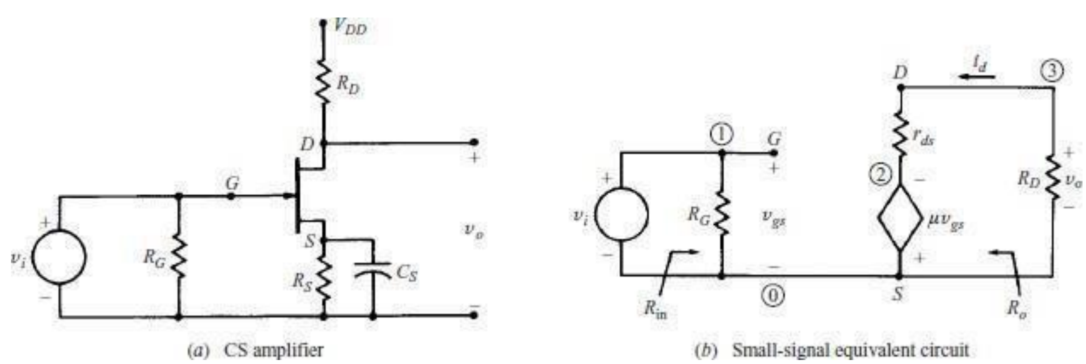


Fig.5.1(a)CSAmplifier(b)Small-signalequivalentcircuit

Asimple CommonSourceamplifier isshown inFig.5.1(a)and associatedsmall signalequivalent circuit using voltage-source model of FET is shown in Fig. 5.1(b)

VoltageGain

Source resistance(R_S)isusedtosettheQ-PointbutisbypassedbyC$_S$formid-frequency operation.

Fromthesmallsignalequivalentcircuit,theoutputvoltage V_O = -

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

Where V_{gs}=V_i,the inputvoltage, Hence,

the voltage gain,

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

InputImpedence

FromFig.5.1(b)InputImpedenceis Z_i =

R_G

ForvoltagedividerbiasasinCEAmplifiersof 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

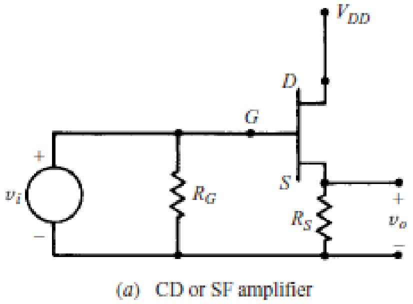
$\mu V_{gs}=0$

TheequivalentcircuitforcalculatingoutputimpedenceisgiveninFig.5.2. Output impedence $Z_o = r_d \| R_D$

Normallyr$_d$will befargreaterthanR_D.Hence$Z_o \approx R_D$

Common Drain Amplifier

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 moreeasily determined than V_{gs},the voltage source in the output circuit is expressed in termsof$V_{gs}$and Thevenin's theorem.



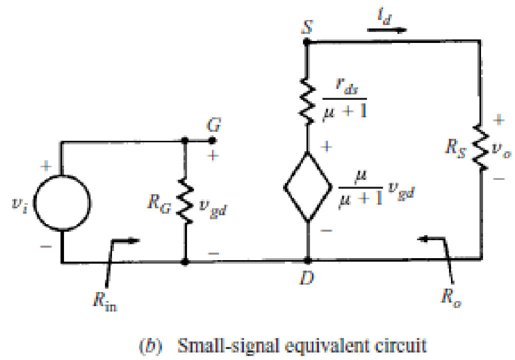


Fig.5.2(a)CDAmplifier(b)Small-signalequivalentcircuit

VoltageGain

Theoutputvoltage,

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

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

Hence, the voltage gain,

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

InputImpedence

FromFig.5.2(b),InputImpedence $Z_i = R_G$

Output Impedence

FromFig.5.2(b),Output impedence measuredattheoutputterminalswithinputvoltage$V_i=0$canbe 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$\mu \gg 1$

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

BIASINGFET

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 achievedby suitablyselecting thegatetosource voltageVGSand draincurrentID whichis referred to as biasing

JFETbiasingcircuitsareverysimilartoBJTbiasing circuitsThemaindifferencebetweenJFET circuits and BJT circuits is the operation of the active components themselves

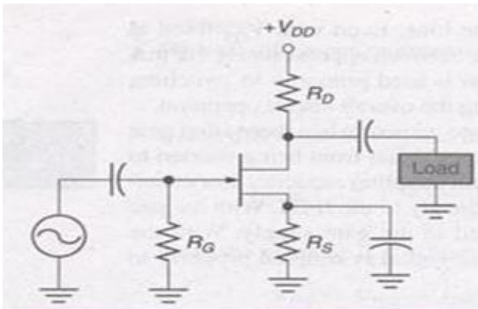
Therearemainlytwotypesof Biasingcircuits

1. Selfbias
2. Voltagedividerbias.

5.13.1.SELFBIAS:-

SelfbiasisaJFETbiasingcircuitthatusesasourceresistortohelpreversebiastheJFETgate.

Aselfbiascircuitisshowninthefig5.3



SelfbiasisthemostcommontypeofJFETbias.
ThisJFETmustbe operatedsuchthatgatesourcejunctionisalwaysreversebiased.
ThisconditionrequiresanegativeVGSforanNchannelJFETandapositiveVGSforPchannelJFET. This can be achieved using the self bias arrangement as shown in Fig 5.3.
ThegateresistorRGdoesn'taffectthebiasbecause ithasessentiallynovoltagedropacrossit,and: thegateremainsat0V.RGisnecessaryonlytoisolate anacsignalfromgroundinamplifierapplications. The voltage drop across resistor RS makes gate source junction reverse biased.

DC analysis of self Bias:-

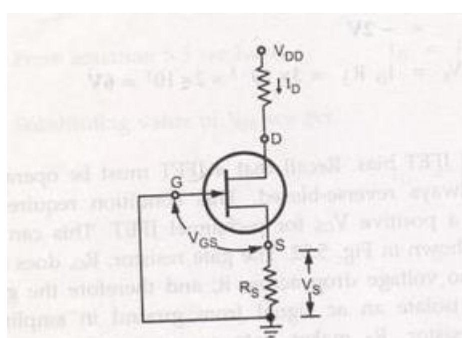
InthefollowingDCanalysis,theNchannelJFETshowninthefig5.4.isusedforillustration.

ForDCanalysiswecanreplacecouplingcapacitorsbyopencircuitsand we canalsoreplace the resistor RG by a short circuitequivalent.

:.IG= 0

TherelationbetweenIDandVGSisgivenby

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



VGS for N channel JFET is =-id Rs

Substutingthisvalueintheaboveequation

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

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

FortheN-chanelFETintheabovefigure

IsproducesavoltagedropacrossRsandmakesthesourcepositivew.r.tground

inanyJFETcircuitallthe source currentpassesthroughthedevicetodraincircuitthisisduetothe fact that there is no significant gate current

thereforewecandefinesourcecurrentasIs=IdandVg=0then Vs= Is

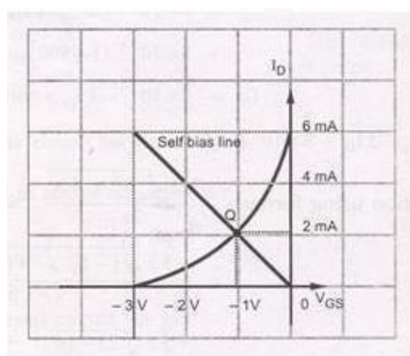
Rs =IdRs

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

Drawingtheselfbiasline:-

TypicaltransfercharacteristicsforaselfbiasedJFETareshowninthefigure5.5below:

Themaximum draincurrent is6mAandthegatesource cutoffvoltageis -3V.Thismeansthegate voltage has to be between 0 and -3V.



Now using theequation VGS = -IDRS and assuming RSofany suitable value we can draw theselfbias line.

LetusassumeRS=500Ω

Withthis Rs , wecan plot twopoints corresponding toID =0 and Id=IDSS for

ID =0

VGS=-IDRS

VGS=0X(500.Ω)=0V

Sothefirstpointis(0,0)

(I_d,VGS)

ForID= IDSS=6mA

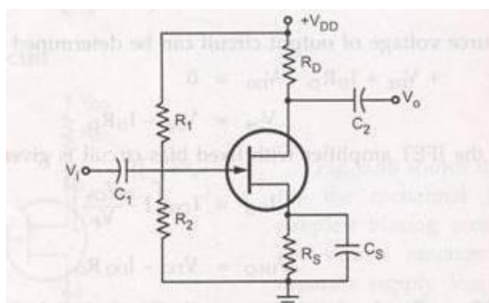
VGS=(-6mA)(500Ω)=-3V

Sothe2[nd]Pointwillbe (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 forthe selfbias 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 farup onthe curve ,ID is large.

5.13.2VOLTAGEDIVIDERBIAS:-



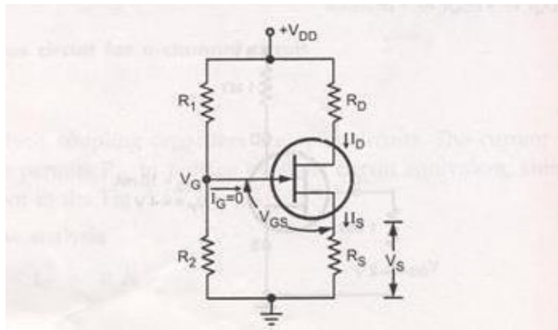
The fig5.6 shows N channel JFET with voltage divider bias. The voltage at the source of JFET mustbemore positive than thevoltageatthe gatein order to keep thegateto sourcejunction reverse biased. The source voltage is

VS=IDRS

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

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

Fordcanalysisfig5.5



ApplyingKVLtotheinputcircuit

VG-VGS-VS =0

::VGS=VG-Vs=VG-ISRS

VGS=VG-IDRS ::IS=ID

ApplyingKVLtotheinputcircuitweget

VDS+IDRD+VS-VDD =0

::VDS=VDD-IDRD-IDRS

VDS = VDD-ID (RD +RS)

TheQpoint ofaJFETamplifier,usingthevoltagedividerbias is IDQ = IDSS[1-VGS/VP]2

VDSQ=VDD-ID(RD+RS)

UNITIV
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.

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 tosudden 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 amplifiershould reproduce the input signal,with change in magnitude and withorwithoutchangeinphase.Butsomeofthe shortcomingsoftheamplifiercircuitare

1. Changeinthevalueofthegainduetovariation insupplyingvoltage,temperature or due tocomponents.
2. Distortioninwave-formduetononlinearitiesintheoperatingcharacters of the Amplifying device.
3. Theamplifiermayintroducenoise(undesiredsignals)

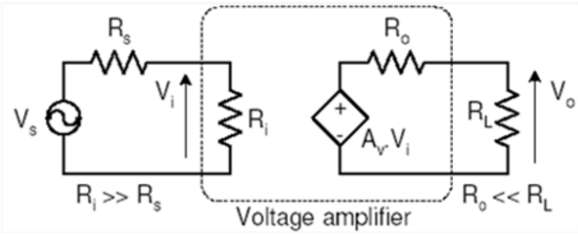
Theabovedrawbackscanbeminimizingifweintroducefeedback.

CLASSIFICATIONOFAMPLIFIERS

Amplifierscanbeclassifiedbroadlyas:

1. Voltage amplifiers.
2. Currentamplifiers.
3. Tranconductanceamplifiers.
4. Tranresistanceamplifiers.

1.1 Voltage amplifier



if $R_i >> R_s$

then $V_i \approx V_s$

and if $R_o << R_L$

then

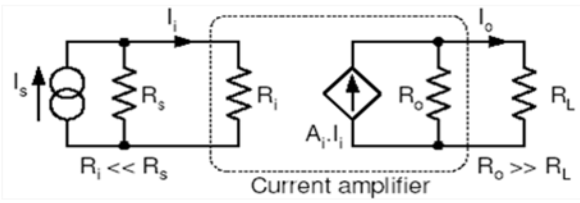
$$V_o \approx A_v V_i \approx A_v V_s$$

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

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

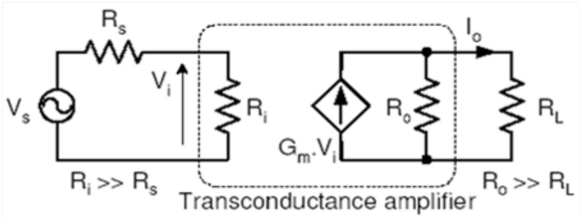
$$I_o \approx A_i I_i \approx A_i I_s$$

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

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

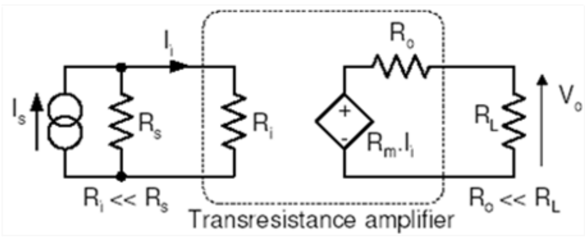
$$I_o \approx G_m V_i \approx G_m V_s$$

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.

ConceptofFeedback

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 withinformation. This noiseorsomedisturbance is introduced inthe amplifiers becauseoftheir 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 afractionofoutput in phase opposition tothe input signal.

PrincipleofFeedbackAmplifier

Afeedbackamplifiergenerallyconsistsoftwoparts.Theyaretheamplifier andthe 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 extractsavoltage $V_f = \beta V_o$ from the output V_o of theamplifier.

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

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

Thequantity$\beta = V_f / V_o$iscalledasfeedbackratioorfeedbackfraction.

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,

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

LetA$_f$betheoverallgain(gainwiththefeedback) oftheamplifier. This isdefinedastheratio of output voltage $V_o$to the applied signal voltage V_s,i.e.,

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

Theequationofgainofthefeedbackamplifier,withpositivefeedbackisgivenby

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

Thesearethestandardequationstocalculatethegainoffeedbackamplifiers.

TypesofFeedbacks

The process of injecting a fraction of output energy of some device back to the input is knownas Feedback. It has beenfoundthat feedback is very usefulinreducing noise andmaking the amplifier operation stable.

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

PositiveFeedback

Thefeedbackinwhichthefeedback energyi.e.,eithervoltageorcurrentis inphasewith the input signal and thus aids it is called asPositive feedback.

Boththeinputsignalandfeedbacksignalintroducesaphaseshiftof180^othusmakinga 360^oresultant phaseshift aroundthe loop,tobe finally inphase with the inputsignal.

Thoughthepositivefeedbackincreasesthegainoftheamplifier,ithasthe disadvantages such as

- Increasing distortion
- Instability

It is because of these disadvantages the positive feedback is not recommended for the amplifiers.Ifthe positivefeedback issufficiently large,it leadstooscillations,by whichoscillator circuits are formed.

NegativeFeedback

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

In negative feedback, the amplifier introduces aphase shift of 180^o into the circuit while thefeedback network issodesignedthat it producesnophaseshiftorzerophaseshift. Thusthe resultant feedback voltage $V_f$is 180^o out ofphase withthe input signalV_{in}.

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

- Stabilityofgainisimproved
- Reductionindistortion
- Reductioninnoise
- Increaseininputimpedance
- Decreaseinoutputimpedance
- Increaseintherangeofuniformapplication

Itisbecauseoftheseadvantagesnegativefeedbackisfrequentlyemployedinamplifiers.

Negative feedback in an amplifier is the method of feeding a portion ofthe amplified outputtothe inputbut inoppositephase.The phaseoppositionoccursasthe amplifierprovides 180^{o}phase shift whereas the feedback network doesn’t.

While the output energy is being applied tothe input,forthe voltage energy tobe 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.

Therearetwomaintypesofnegativefeedbackcircuits.Theyare−

- NegativeVoltageFeedback
- NegativeCurrentFeedback

NegativeVoltageFeedback

Inthismethod,thevoltagefeedbacktotheinput ofamplifierisproportionaltothe output voltage. This is further classified into twotypes −

- Voltage-seriesfeedback
- Voltage-shuntfeedback

NegativeCurrentFeedback

Inthismethod,thevoltagefeedbacktotheinput ofamplifierisproportionaltothe output current. This is further classified into two types.

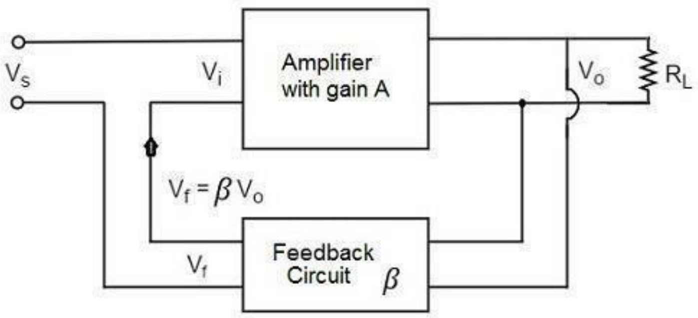
- Current-seriesfeedback
- Current-shunt feedback

Letushaveabriefideaonallofthem.

Voltage-Series Feedback

Inthevoltageseriesfeedbackcircuit,afractionoftheoutputvoltageisappliedinseries withtheinputvoltagethroughthefeedbackcircuit.Thisisalsoknownasshunt-drivenseries- fed feedback, i.e., a parallel-series circuit.

The following figure shows the block diagram of voltage series feedback, by which it is evidentthatthefeedbackcircuit isplacedinshuntwiththeoutputbut inseries withtheinput.

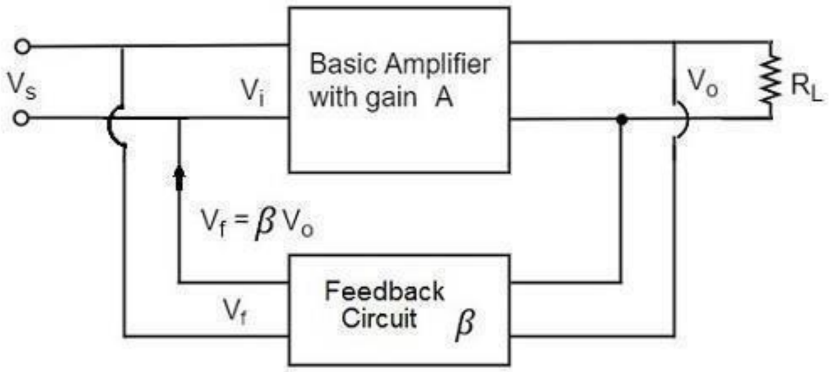


As the feedback circuit is connected in shunt with the output, the output impedance is decreasedandduetotheseriesconnectionwiththeinput,the inputimpedanceisincreased.

Voltage-ShuntFeedback

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 feedbacki.e., a parallel-parallel proto type.

The below figure shows the block diagram ofvoltage shunt feedback,by whichit is evident that the feedback circuit is placed in shunt withthe output andalso with the input.

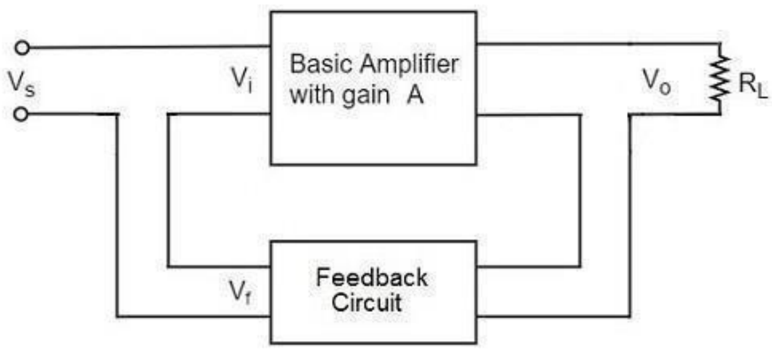


As the feedback circuit is connected in shunt with the output and the input as well,both the output impedance and the input impedance are decreased.

Current-SeriesFeedback

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 knownas series-driven series- fed feedbacki.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 inseries withthe output andalsowiththe input.



Asthefeedbackcircuitisconnectedinserieswiththeoutputandthe inputaswell,both the output impedance and the input impedance are increased.

UNIT –V

OSCILLATORS:

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

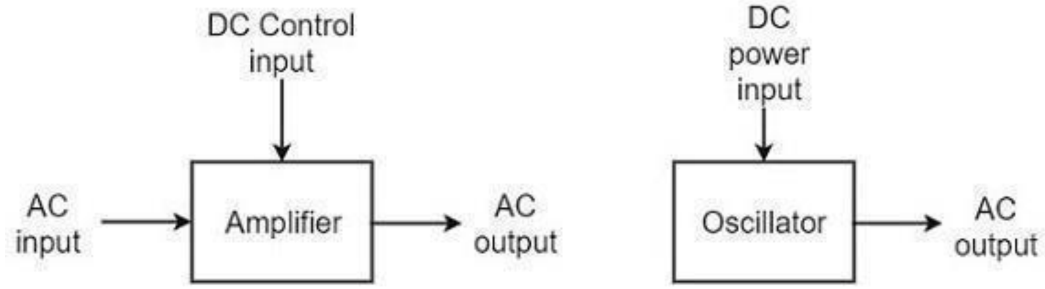
Oscillators:

An **oscillator** generates output without any ac input signal. An electronicoscillator 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.

Amplifiervs.Oscillator

An**amplifier**increasesthesignalstrengthoftheinputsignalapplied,whereas an**oscillator**generatesa signalwithoutthat input signal,but it requiresdcforitsoperation. This is the main difference between an amplifier and anoscillator.

Take a look at the following illustration. It clearly shows how an amplifier takesenergyfrom 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 thecomponents inthecircuit itself, whichmeans noexternalcontrolling voltageis required.

Alternatorvs.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. Theoutput frequency depends onthe number of poles andthe speed of rotation of thearmature.

Thefollowingpointshighlightthedifferencesbetweenanalternatorandanoscillator−

- Analternatorconvertsmechanicalenergytoa.c.energy,whereastheoscillator converts d.c. energy into a.c. energy.
- AnoscillatorcanproducehigherfrequenciesofseveralMHzwhereasanalternator cannot.
- Analternatorhasrotatingparts,whereasanelectronicoscillatordoesn’t.
- Itiseasytochangethefrequencyofoscillationsinanoscillatorthaninan alternator.

Oscillatorscanalsobeconsideredasoppositetorectifiersthatconverta.c.tod.c.asthese convert d.c. to a.c.

ClassificationofOscillators

Electronicoscillatorsareclassifiedmainlyintothefollowingtwocategories−

- **Sinusoidal Oscillators** − The oscillators that produce an output having a sine waveformarecalled **sinusoidal**or**harmonicoscillators**. Suchoscillators canprovide output at frequencies ranging from 20 Hz to 1 GHz.
- **Non-sinusoidalOscillators** − 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 20MHz.

SinusoidalOscillators

Sinusoidaloscillatorscanbeclassifiedinthefollowingcategories−

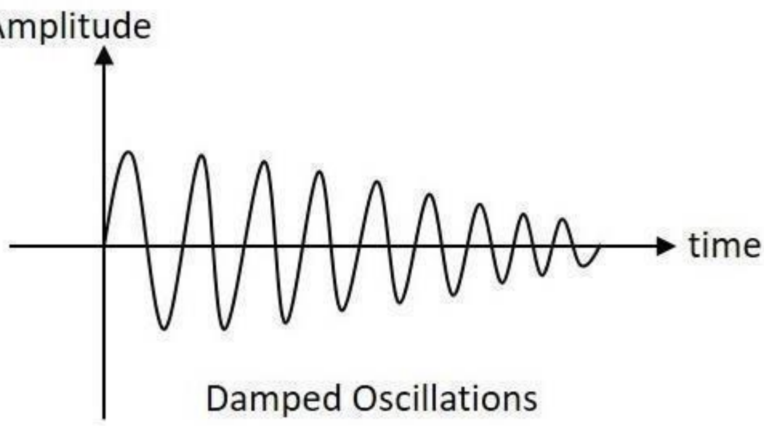
- **Tuned Circuit Oscillators** − These oscillators use a tuned-circuit consisting of inductors (L) and capacitors (C) and are used to generate high-frequency signals. Thus they are also known as radio frequency R.F. oscillators. Such oscillators are Hartley, Colpitts, Clapp-oscillators etc.
- **RC Oscillators** − 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 signalwith frequencies upto 10MHz. 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.

NatureofSinusoidalOscillations

Thenatureofoscillationsinasinusoidalwaveisgenerallyoftwotypes.Theyare **damped**and**undampedoscillations**.

DampedOscillations

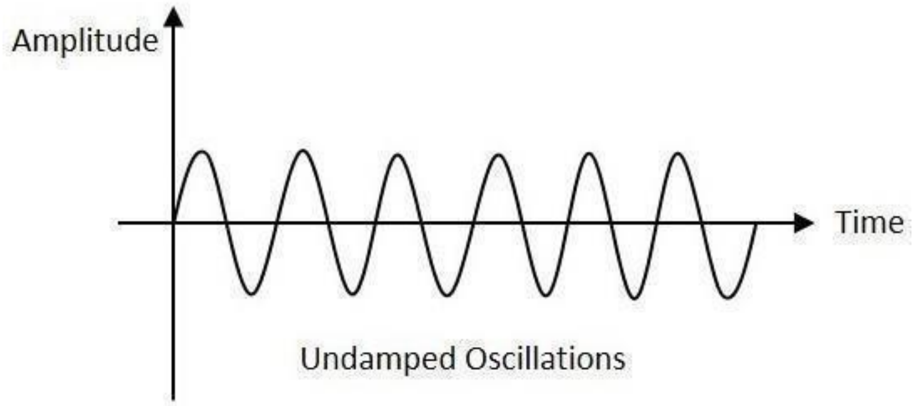
Theelectricaloscillationswhoseamplitudegoesondecreasingwithtimearecalled as **Damped Oscillations**. The frequency of the damped oscillations may remain constant depending upon the circuit parameters.



Dampedoscillationsaregenerallyproducedbytheoscillatorycircuitsthatproducepower losses and doesn’t compensate if required.

UndampedOscillations

Theelectricaloscillationswhoseamplituderemainsconstantwithtimearecalledas **UndampedOscillations**.Thefrequencyoftheundampedoscillationsremainsconstant.



Undamped oscillations are generally produced by the oscillatory circuits that produce nopower losses andfollow 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.

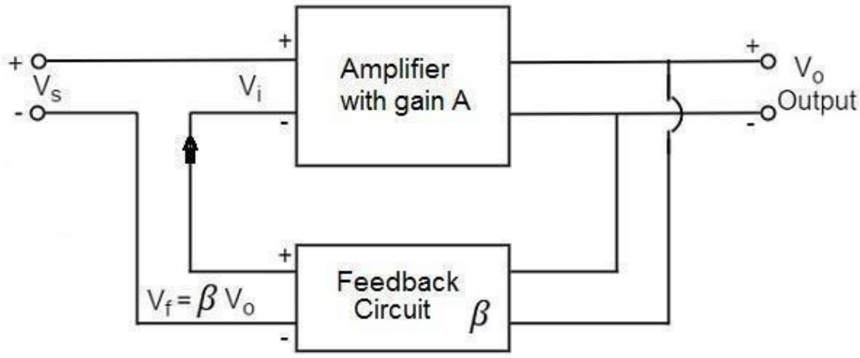
The use of positive feedback results in a feedback amplifier having closed-loop gain greater than the open-loop gain. It results in **instability** and operates as an oscillatory circuit. An oscillatorycircuit provides aconstantlyvarying amplified outputsignalofany desired frequency.

TheBarkhausenCriterion

With the knowledge we have till now, we understood that a practical oscillator circuit consistsof atank circuit,atransistor amplifier circuitanda feedbackcircuit.so,let usnow try to brushupthe concept of feedback amplifiers,to derive the gainofthe feedback amplifiers.

PrincipleofFeedbackAmplifier

A feedback amplifier generally consists oftwoparts.Theyarethe**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 ofoutput voltage Vo tothe input voltage V_i. The feedback network extracts avoltage $V_f = \beta V_o$ 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,forapositivefeedback,

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

Thequantity$\beta=V_f/V_o$iscalledasfeedbackratioorfeedbackfraction.

TheoutputV$_o$mustbeequaltothe inputvoltage($V_s+\beta V_o$)multipliedbythegainAofthe amplifier.

Hence,

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

Or

$AVs+A\beta Vo=Vo$

Or

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

Therefore

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

LetA$_f$betheoverallgain(gainwiththefeedback) oftheamplifier. This isdefinedastheratio of output voltage $V_o$to the applied signal voltage V_s,i.e.,

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

fromtheabovetwoequations,wecanunderstandthat,theequationofgainofthefeedback amplifier with positive feedback is given by

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

Where**Aβ**isthe**feedbackfactor**orthe**loopgain**.

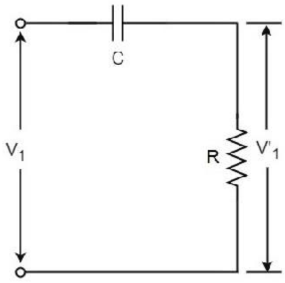
If$A\beta=1$,$A_f=\infty$.Thusthegainbecomes infinity,i.e.,thereisoutputwithoutany input.In another words, the amplifier works as an Oscillator.

Thecondition$A\beta=1$iscalledas**BarkhausenCriterionofoscillations**.Thisisavery important factor to be always kept inmind, in the concept of Oscillators

RC-Phase–shiftOscillators

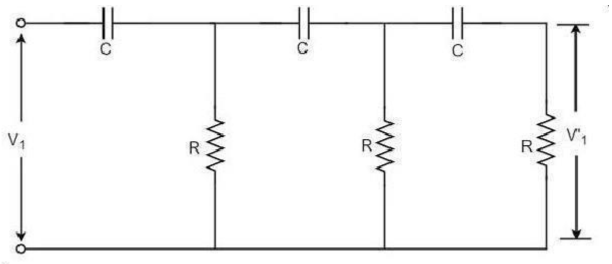
PrincipleofPhase-shiftoscillators

We know that the output voltage of an RC circuit for a sinewave input leads the input voltage.ThephaseanglebywhichitleadsisdeterminedbythevalueofRCcomponentsusedin the circuit. The following circuit diagram shows asingle 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 Rwere reduced to zero, V_1'will lead the V_1 by 90^o i.e.,$\phi^o=90^o$.

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^o. The following circuit diagram shows the three sections ofthe RC network.



Eachsectionproducesaphaseshiftof60^o.Consequently,atotalphaseshiftof$180^o$is produced, i.e., voltage V_2 leads the voltage V_1 by 180^o.

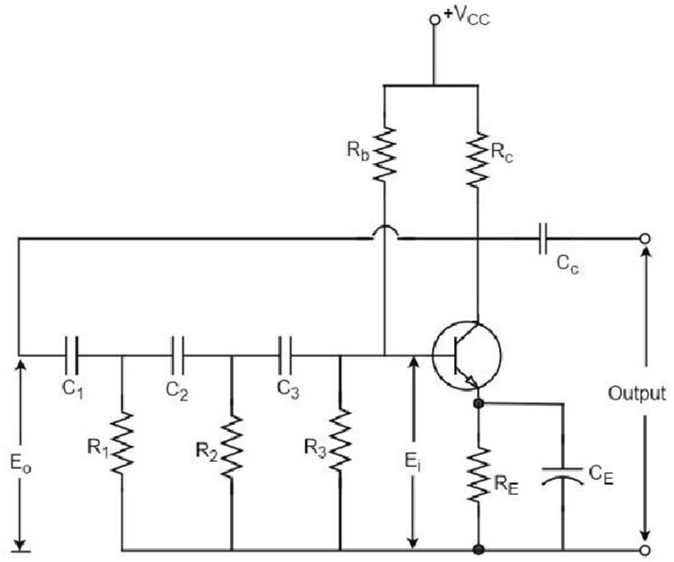
Phase-shiftOscillatorCircuit

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.

ThefollowingcircuitdiagramshowsthearrangementofanRCphase-shift oscillator.



Thefrequencyofoscillationsisgivenby

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

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 toRC feedback network. This network produces a phase shift of 180°anda voltage E_i appears at its output. This voltage is applied tothe transistor amplifier.

Thefeedbackappliedwillbe

m=Ei/Eo

The feedback is in correct phase, whereas the transistor amplifier, which is in CE configuration,producesa180°phaseshift.Thephaseshiftproducedbynetworkandthe transistoradd toform a phase shift around the entire loop which is 360°.

Advantages

TheadvantagesofRCphaseshiftoscillatorareasfollows−

- Itdoesnotrequiretransformersorinductors.
- Itcanbeusedtoproduceverylowfrequencies.
- Thecircuitprovidesgoodfrequencystability.

Disadvantages

ThedisadvantagesofRCphaseshiftoscillatorareasfollows−

- Startingtheoscillationsisdifficultasthefeedbackissmall.
- Theoutputproducedissmall.

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**.

Themain advantageofthisoscillatoristhatthefrequencycanbevariedin therangeof 10Hz toabout 1MHz whereas in RC oscillators, the frequency is not varied.

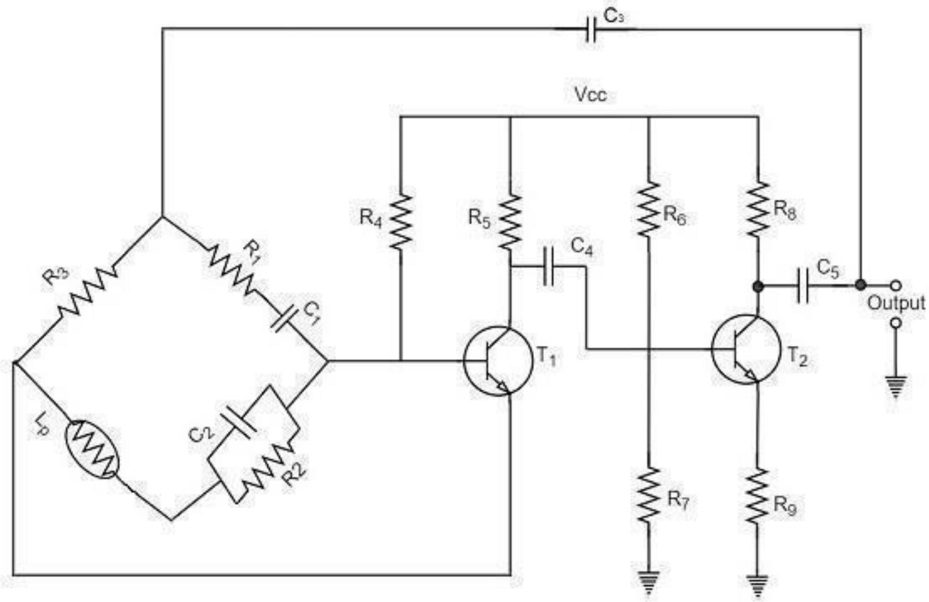
Wienbridge

oscillator

Construction

The circuit construction of Wien bridge oscillator can be explained as below. It is a two-stageamplifierwithRCbridgecircuit.ThebridgecircuithasthearmsR$_1$C$_1$,R$_3$,R$_2$C$_2$andthe tungstenlampL$_p$.ResistanceR$_3$andthelampL$_p$ areusedtostabilizetheamplitudeofthe output.

Thefollowingcircuitdiagramshowsthearrangementofa Wienbridgeoscillator.



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 circuitprovides 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 determinedby the series element R_1C_1 andparallelelement R_2C_2 of the bridge.

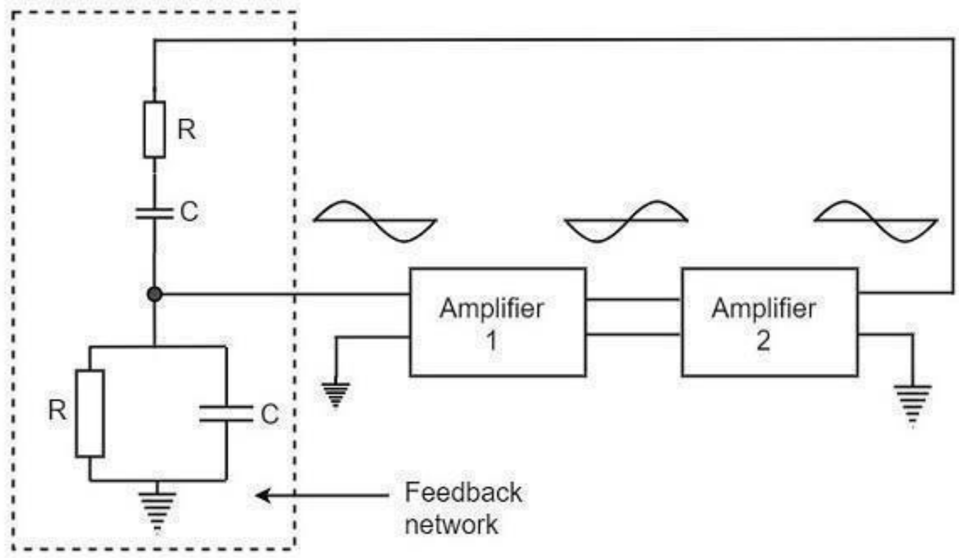
$$f = \frac{1}{2\pi\sqrt{R_1C_1R_2C_2}}$$

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

Then,

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

Now,wecansimplifytheabovecircuitasfollows−



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 inpoorfrequency stability. By adding Wienbridgefeedbacknetwork,theoscillatorbecomessensitivetoaparticularfrequency 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 achievedby temperature sensitive tungstenlamp 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 originalvalue. Whereas, if the output tends to decrease, reverse action would take place.

Advantages

TheadvantagesofWienbridgeoscillatorareasfollows−

- Thecircuitprovidesgoodfrequencystability.

- Itprovidesconstantoutput.
- Theoperationofcircuitisquiteeasy.
- Theoverallgainishighbecause oftwotransistors.
- Thefrequencyofoscillationscanbechangedeasily.
- Theamplitudestabilityoftheoutputvoltagecanbemaintainedmoreaccurately,by replacing R_2 with a thermistor.

Disadvantages

ThedisadvantagesofWienbridgeoscillatorareas follows−

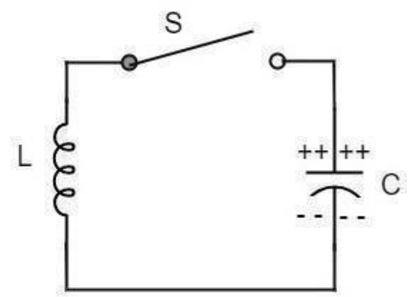
- Thecircuitcannotgenerateveryhighfrequencies.
- Twotransistorsandnumberofcomponentsarerequiredforthecircuitconstruction.

LCOscillators

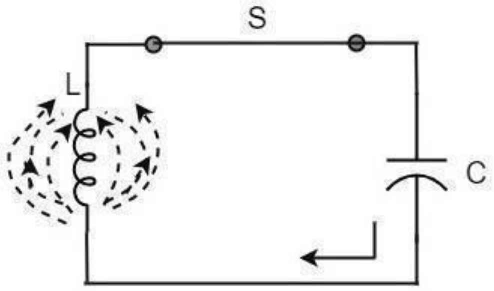
An oscillatory circuit produces electrical oscillations of a desired frequency. They are also known as **tank circuits**.

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

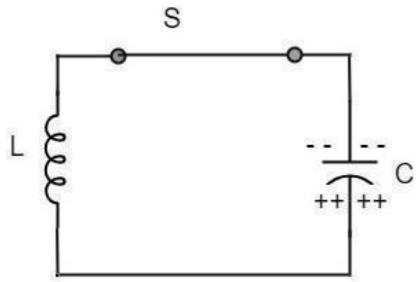
To understand the concept of oscillatory circuit, let us consider the following circuit. The capacitor in this circuit is already charged using a dc source. In this situation, the upper plate of the capacitor has excess of electrons whereas the lower plate has deficit of electrons. The capacitor holds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



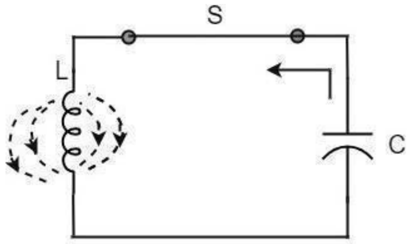
Whenthe switch **S** is closed, the capacitor discharges andthe current flows through the inductor.Duetotheinductiveeffect,thecurrentbuildsupslowlytowardsamaximum value.Oncethecapacitor dischargescompletely,themagneticfieldaroundthecoilis maximum.



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 lowerplate.



Oncethecapacitorisfullycharged,itstartstodischargetobuildupamagneticfieldaroundth e 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.

FrequencyofOscillations

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 **resonantfrequency** (ornatural frequency) of the tank circuit which is givenby

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

Capacitanceofthecapacitor

The frequency of oscillation f_o is inversely proportional to the square rootofthe 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 ofthecoil

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,thefrequency,

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

Combiningboththeaboveequations,

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

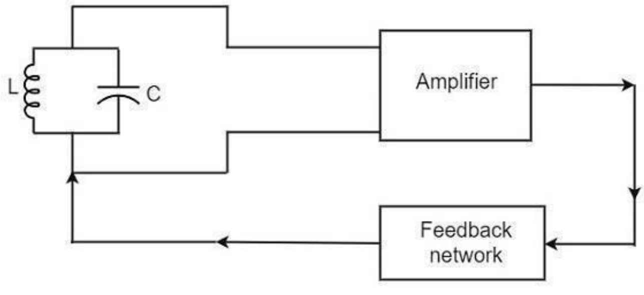
$$f_o = \frac{1}{2\pi\sqrt{LC}}$$

The above equation, though indicates the output frequency, matchesthe**naturalfrequency** 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 shouldsustainand shouldbe Undampedas just discussedbefore. Let us try to analyze a practical Oscillator circuit to have a better understanding on how an Oscillator circuit works.

PracticalOscillatorCircuit

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



Letusnowdiscussthepartsofthispracticaloscillatorcircuit.

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 ofthe 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 amplifiedhere. Hence the output of these oscillations are increasedby theamplifier.
- **FeedbackCircuit**− Thefunction of feedbackcircuitistotransfer apartofthe output energy to LC circuit in proper phase. This feedback is positive in oscillators while negative inamplifiers.

FrequencyStabilityofanOscillator

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 havea drift from the previously setvalue either by increasing orby decreasing.

Thechangeinoscillatorfrequencymayariseduetothefollowingfactors−

- OperatingpointoftheactivedevicesuchasBJTorFETusedshouldlieinthelinear region ofthe amplifier. Its deviation willaffect the oscillatorfrequency.
- Thetemperaturedependencyoftheperformanceofcircuitcomponentsaffectthe oscillator frequency.
- Thechangesind.c.supplyvoltageappliedtotheactivedevice,shifttheoscillator frequency. This can be avoided ifa regulated powersupply isused.
- Achangeinoutput loadmaycauseachangeintheQ-factorofthetank circuit, thereby causing a change in oscillator output frequency.
- Thepresenceofinterelementcapacitancesandstraycapacitancesaffectthe 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 amplifierwithtunedcircuit oscillators. WithanamplifierandanLC tank circuit,we canfeedback a signalwith right amplitude and phase to maintain oscillations.

TypesofTunedCircuitOscillators

Most ofthe oscillators used in radio transmitters andreceivers are of LC oscillators type. Depending upon the way the feedback is used in the circuit,the LC oscillators are dividedas the following types.

- **HartleyOscillator**−Itusesinductivefeedback.
- **ColpittsOscillator**−Itusescapacitivefeedback.
- **ClappOscillator**−Itusescapacitivefeedback.

HartleyOscillator

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 areas discussed below.

Construction

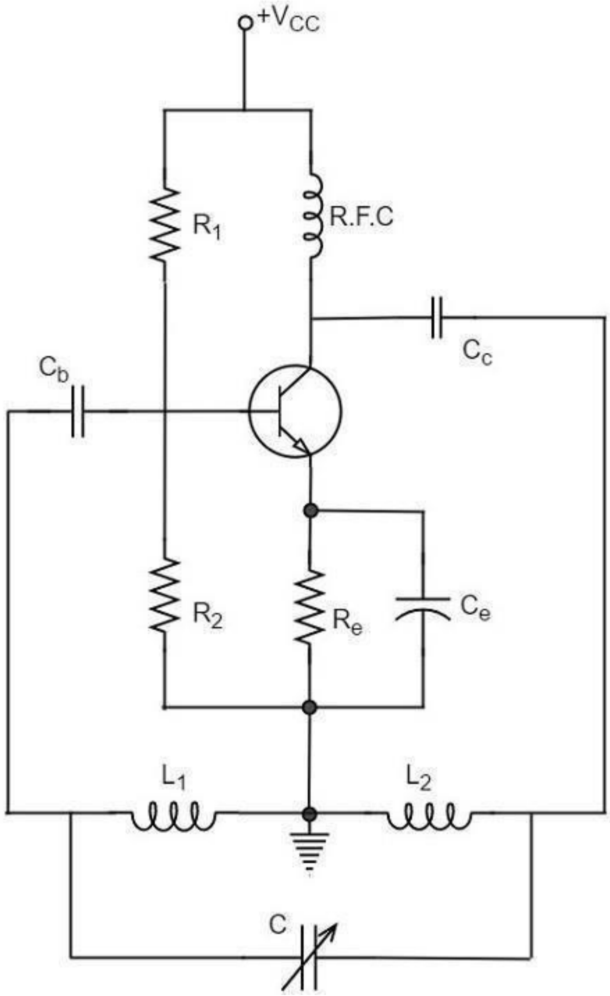
In the circuit diagram of a Hartley oscillator shown below,the resistors R_1,R_2 and R_e provide necessary bias condition for the circuit. The capacitor C_e provides a.c. ground thereby providing any signal degeneration. This also provides temperature stabilization.

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

TankCircuit

The frequency determining network is a parallel resonant circuit which consists of the inductors L_1andL_2along withavariable capacitor C. Thejunction ofL_1 andL_2 areearthed. ThecoilL_1has itsoneend connectedtobasevia$C_c$andtheothertoemitterviaC_e.So,L_2 is in the output circuit. Both the coils$L_1$and L_2 are inductivelycoupled and together form an**Auto-transformer**.

Thefollowingcircuitdiagramshowsthearrangementofa Hartleyoscillator.Thetank circuit is **shuntfed** in this circuit. It canalso be a **series-fed**.



Operation

Whenthecollectorsupply is given,atransient current is produced intheoscillatory ortank 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.AstheCEconfiguredtransistorprovides180^{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 theamplifier is greater than one**,oscillations are sustained in the circuit.

Frequency

Theequationfor**frequencyofHartleyoscillator**isgivenas

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

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

Here,**L_T**isthetotalcumulativelycoupledinductance;**L1**and**L2**representinductancesof $1^{st}$and 2^{nd}coils; and **M** represents mutual inductance.

Mutualinductanceiscalculatedwhentwowindingsareconsidered.

Advantages

TheadvantagesofHartleyoscillatorare

- Insteadofusinga largetransformer,asinglecoilcanbeusedasanauto-transformer.
- Frequencycanbevariedbyemployingeitheravariablecapacitororavariable inductor.
- Lessnumberofcomponentsaresufficient.
- Theamplitudeoftheoutputremainsconstantoverafixedfrequencyrange.

Disadvantages

ThedisadvantagesofHartleyoscillatorare

- Itcannotbea lowfrequencyoscillator.
- Harmonicdistortionsarepresent.

Applications

TheapplicationsofHartleyoscillatorare

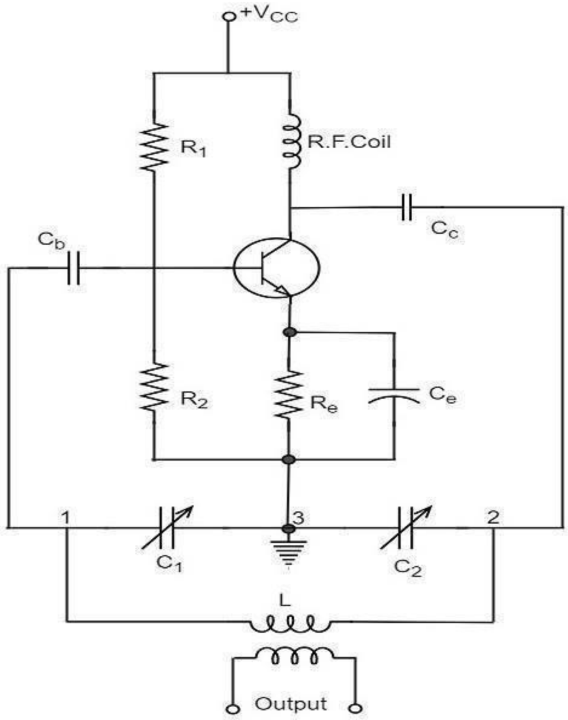
- Itisusedtoproduceasinewaveofdesiredfrequency.
- Mostlyusedasalocaloscillatorinradioreceivers.
- ItisalsousedasR.F.Oscillator.

Colpittsoscillator

AColpitts oscillatorlooks just liketheHartley oscillatorbut theinductors andcapacitors are replaced with each other in the tank circuit. The constructional details and operation of a colpitts oscillator are as discussed below.

Construction

Letusfirsttakealookatthecircuitdiagramofa Colpittsoscillator.



The resistors R_1, R_2 and R_e providenecessary 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 fora.c. Hence it provides d.c. load forcollector andkeeps a.c. currents out of d.c. supply source.

TankCircuit

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 developedacross C_1 provides the regenerative feedback required forthe sustainedoscillations.

Operation

Whenthecollectorsupplyisgiven,atransientcurrentisproducedintheoscillatory ortank circuit. The oscillatory current inthe tank circuit produces a.c. voltage across C_1 whichare appliedtothe baseemitterjunctionandappear inthe amplified form inthe collectorcircuit 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^o.

AstheCEconfiguredtransistorprovides 180^ophaseshift,itmakes360^ophaseshift 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

Theequationfor**frequencyofColpittsoscillator**isgivenas

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

$C_T$isthetotalcapacitance ofC_1andC_2connectedinseries.

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

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

Advantages

TheadvantagesofColpittsoscillatorareasfollows−

- Colpittsoscillatorcangeneratesinusoidalsignalsofveryhighfrequencies.
- Itcanwithstandhighandlowtemperatures.
- Thefrequencystabilityishigh.
- Frequencycanbevariedbyusingboththevariablecapacitors.
- Lessnumberofcomponentsaresufficient.
- Theamplitudeoftheoutputremainsconstantoverafixedfrequencyrange.

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.

TheoperationofClapposcillatorcircuitis inthesamewayasthatofColpittsoscillator.Thefrequency 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 ismuchsmallerthan C_1 andC_2.Asa result ofthis, **C** isapproximatelyequal to C_3. Therefore, the frequency of oscillation,

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

It is understood that the Clapp oscillator is similar to the Colpitts oscillator, however they differinthe way the inductances andcapacitances 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 constructinga variable frequency oscillator. The Clapp oscillators are used in receiver tuning circuits as a frequency oscillator.

One ofthe important features ofan oscillator is that the feedback energy appliedshouldbe in correct phase to the tank circuit. The oscillator circuits discussed so farhasemployed inductor(L)and capacitor (C) combination,in the tank circuit orfrequency determiningcircuit.

We have observed that the LC combination in oscillators provide 180° phase shift and transistor in CE configuration provide180°phase shift to make a total of 360° phase shift sothat it would make a zero difference in phase.

DrawbacksofLCcircuits

Thoughtheyhavefewapplications,the**LC**circuitshavefew**drawbacks**suchas

- Frequencyinstability
- Waveformispoor
- Cannotbeusedforlowfrequencies
- Inductorsarebulkyandexpensive

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 oscillatorare

- Powersupplyvariations
- Changesintemperature
- Changesinloadoroutputresistance

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.