Small Signal Amplifier

By

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Chapter-6
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AC Models

A model is the combination of circuit elements , properly chosen, the best approximates the actual behavior of a semiconductor device under specific operating conditions.

The ac equivalent of a network is

1. Setting all dc sources to zero and replacing them by a short- circuit equivalent
2. Replacing all capacitors by a short-circuit equivalent.
3. Removing all elements bypassed by the short-circuit equivalents introduced by steps 1 & 2.
4. Redrawing the network in a more convenient and logical form.

After a transistor has been biased with the Q point near the middle of load line, we can couple a small ac voltage into the base. This will produce an amplified ac collector voltage. The invention of amplifying devices was crucial to the evolution of electronics.

Base- Biased Amplifier

Good coupling occurs when the reactance of the coupling capacitor is much smaller than the resistance at the lowest frequency of the ac source. In a base-biased amplifier, the input signal is coupled into the base. This produces an ac collector voltage. The amplified and inverted ac collector voltage is than coupled to the load resistance.

Emitter Biased Amplifier

Good bypassing occurs when the reactance of the coupling capacitor is much smaller than the resistance at the lowest frequency of the ac source. The bypassed point is an ac ground. With either a VDB or a TSEB amplifier, the ac signal is coupled into the base. The amplified ac signal is then coupled to the load resistance.

Small- signal operation

The ac base voltage has a dc component and an ac component. These set up dc and ac components of emitter current. One way to avoid excessive distortion is to use small-signal operation. This means keeping the peak- to- peak ac emitter current less than $1/10^{th}$ of the dc emitter current.

AC Beta

The ac beta of a transistor is defined as the ac collector current divided by the ac base current. The values of the ac beta usually differ only slightly from the values of the dc beta. On data sheets, h_{FE} is equivalent to β_{dc} and h_{fe} is equivalent to β.

AC Resistance of the emitter diode

The base-emitter voltage of a transistor has a dc component V_{BEQ} and an ac component V_{be} . The ac base-emitter voltage sets up an ac emitter current of i_e. The ac resistance of the emitter diode is defined as v_{be} divided by i_e.

Two Transistor Models

As far as ac signal are concerned, a transistor can be replaced by either of two equivalent circuits : The π model or the T model. The π model indicates that the input impedence of the base is $\beta r'_e$.

Analyzing an amplifier

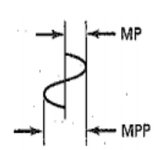
The simplest way to analyze an amplifier is to split the analysis into two parts : a dc analysis and an ac analysis. In the dc analysis, the capacitor are shorted and the dc supply points are ac grounds.

Class A & B operation

In a Class A amplifier transistor operates in the active region at all times. This implies that current in the output circuit flows at all times.

In a class B operation, the collector current flows for only half the cycle (180^0). In this operation Q point is located at cutoff.

Maximum Peak- to -Peak



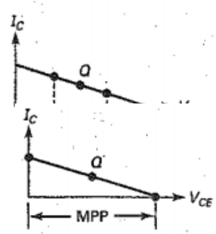
MPP= 2MP

Output Power

$P_{out} = \frac{{V_{out}}^2}{8R_L}$

Maximum power output

$P_{out(max)} = \frac{MPP^2}{8R_L}$



Effect of temperature

An increase in temperature produces an increase in the minority carrier current, but negative change in V_{BE}. These effects leads to an increase in collector current with temperature.

Heat sinks

One way to increase the power rating of a transistor is to get rid of the heat faster. This is why heat sinks are used. If we increase the surface area of the transistor case, we allow the heat to escape more easily into the surrounding air.

Thermal resistance

Thermal resistance is the ability of a material to resist flow of heat . Thermal resistivity is the reciprocal of thermal conductivity and can be expressed as

Distortion in Amplifier

When the Q point is at the centre of the dc load line, the ac signal cannot use all the ac load line without clipping. For instant, if the ac signal increases, we get distorted output i.e. cutoff clipping If a Q point is moved higher , a large signal will drive the transistor into saturation with saturation clipping or distorted output. When a distorted output derives loudspeaker sounds terrible.

Cascading of stages

To get more voltage gain , amplifier stages are cascaded i.e. output of first stage as the input to second stage & the output of second stage can be used for input to third stage.

Multistage Amplifier

The overall voltage gain equals the product of the individual voltage gains. The input impedance of second stage is the output impedance of first stage.

Frequency response

The frequency response of an amplifier is the graph of its gain versus the frequency. An ac amplifier has lower & upper cutoff frequency. Coupling & bypass capacitors produce the lower cutoff frequency. Internal transistor capacitance & stray wiring capacitances produces upper cutoff frequency.

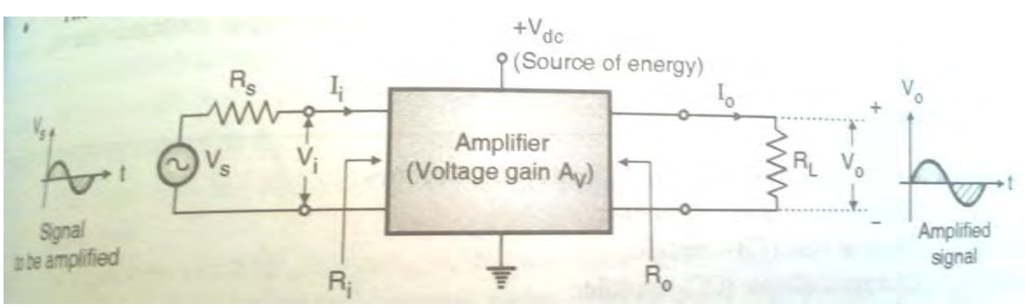
Negative & Positive feedback in transistor amplifiers

The process of returning partial part of output signal back to input circuit is called feedback. Positive feedback is also known as regenerative, as feedback part is added to input. Negative feedback also known as degenerative in which partial part of output signal feed to input is subtracted.

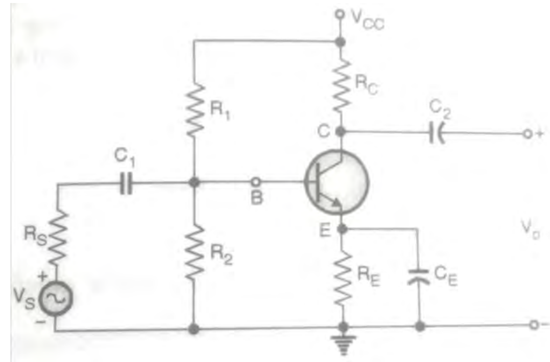
Long & Short Questions

Q.1. What is Amplifier ? Describe the principle operation of a amplifier with the help of neat block diagram. What are its types & various application of Amplifier?

Amplifier are meant to amplify the analog signals. The amplifier is supposed to multiply the input signal by a constant to produce the output. This multiplier is grater then one and called as ―gain" of the amplifier.



- In order to amplify the input signal V_S , all the amplifier needs a dc power supply i.e. $+V_{dc}$
- The amplifier should contain at least one active device such as BJT, FET or OP-AMP . If BJT used must be biased in the active region.



VDB amplifier

Types of BJT Amplifier

The types of amplifier are classified into three categories :

1. Common Emitter (CE) amplifier
2. Common Base (CB) amplifier
3. Common Collector (CC) amplifier

BJT is used

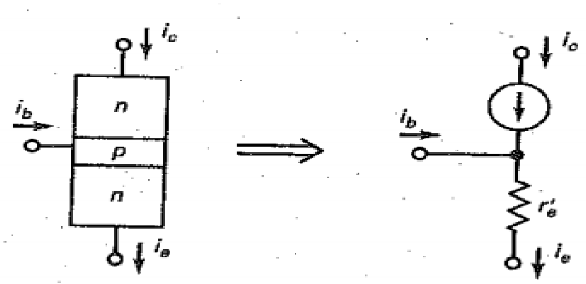
1. As buffer amplifier
2. For the impedance matching
3. As the output stage(Power amplifier)

Q.2. What are different transistor models? Analyze Amplifier using any model.

To analyze the ac operation of a transistor amplifier, we need an ac equivalent circuit for a transistor. In order words we need a model for the transistor that simulates how it behaves when an ac signal is present.

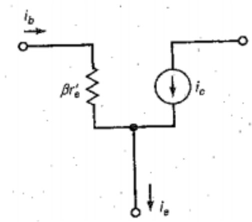
The T Model

One of the earliest models was the Ebers- Moll model as shown in fig. As far as a small ac signal is concerned, the emitter diode of a transistor acts like an ac resistance r'_e and the collector diode acts like a current source i_c. Since the Elbers- Moll model looks like a T on its side, the equivalent circuit is also called the **T model**



The п Model

Fig shows a п Model of a transistor , is easier to use then T model because the input impedence is not obvious in T model. п Model clearly shows that an input impedence of $\beta r'_e$ will load the ac voltage source driving the base.

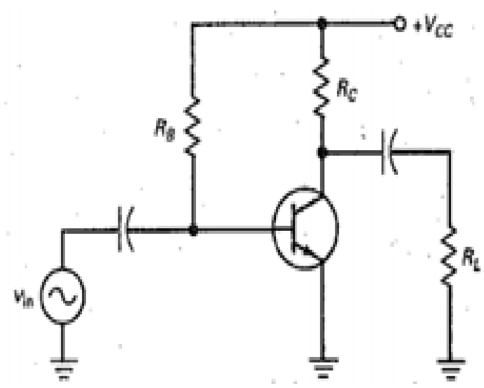


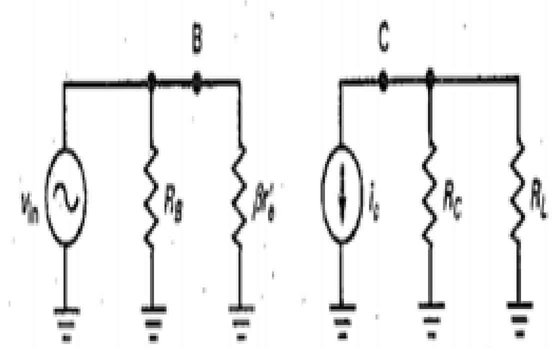
Analysig an Amplifier

Since the п & T models are ac equivalent circuits for a transistor, we can use either one when analyzing an amplifier.Amplifier action is the superposition of ac & dc effect.

The Transistor Equivalent Circuit

The equivalent circuit of amplifier is shown in figure , all the capacitors have been shorted , the dc supply point has become ac ground , and the transistor has been replaced by its п Model. In the base circuit , the ac input voltage appers across R_1 in parallel with R_2 in parallel with $\beta r'_e$ .In the collector circuit , In the collector circuit , the current source pumps an ac current of i_C through R_C in parallel with R_L .





Q.2. Explain working of two supply emitter bias amplifier with the help of neat block diagram.

Due to biasing i.e. TSEB

$V_B \approx 0V$

$V_B = -0.7V$

$V_C = 5.32$ V

$I_C = 1.3$ mA

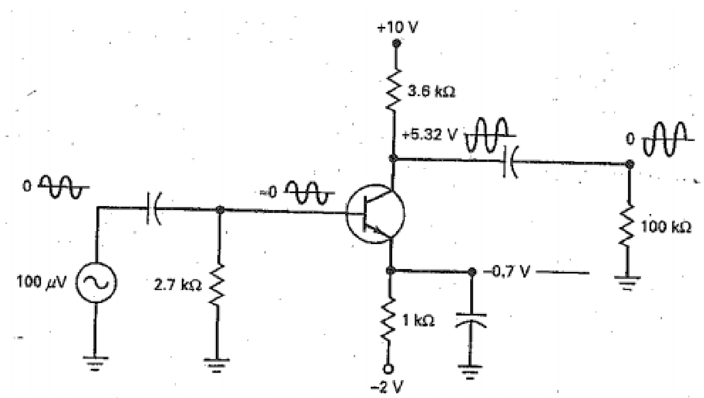


Fig. shows two coupling capacitors and an emitter bypass capacitor. The input signal is coupled into base and the signal is amplified that is coupled to the load.

Waveforms : The ac source voltage is a small sinusoidal voltage . The base voltage has a small ac component riding on the dc component of approx. 0V. The total collector voltage is an inverted sine wave riding on the dc collector voltage of +5.32V. The load voltage is the same amplified signal with no dc component.
Due to bypass capacitor there is pure dc voltage across emitter. If the bypass capacitor is open , an ac voltage appears across emitter that greatly reduces the gain of amplifier.

Q.3. Define AC resistance of Emitter diode.

The ac resistance of emitter diode is defined as the $r'_e = \frac{V_{be}}{i_e}$

With the solid state physics and calculus , it is possible to derive the formula for the ac emitter resistance. $r'_e = \frac{25mV}{I_E}$

Where I_E = DC emitter current.

Q.4. Define AC Beta & relationship between r and h parameters

The ac current gain is known as AC Beta i.e. $\beta = \frac{i_c}{i_b}$. For convenience we use capital letter & subscripts for dc and small letters for ac quantities.

Relationship

AC Beta, $\beta = h_{fe}$

AC resistance, $r'_e = \frac{h_{ie}}{h_{fe}}$

Q.5. Find the expression for voltage gain of Amplifier

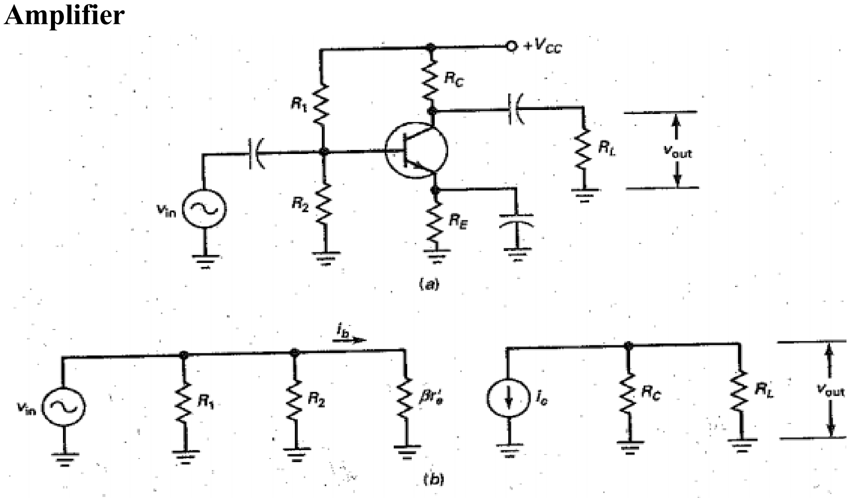


Fig. (b) shows the ac equivalent circuit of the amplifier circuit in fig. (a) ,using the π model of the transistor. The ac base current i_b flows through the **input impedance** of the base ($\beta r'_e$).

With Ohm's law, we have

$v_{in} = i_b \beta r'_e$

In the collector section , the current source pumps i_c trough the parallel connection of R_C & R_L. Therefore, the ac output voltage equals:

$v_{out} = i_c(R_C \,||\, R_L) = i_b\, \beta(R_C \,||\, R_L)$

Therefore **Voltage gain** i.e.

$A_V = \frac{v_{out}}{v_{in}} = [\, i_b\, \beta(R_C \,||\, R_L)] / i_b\, \beta r'_e$

$= (R_C \,||\, R_L) / r'_e$

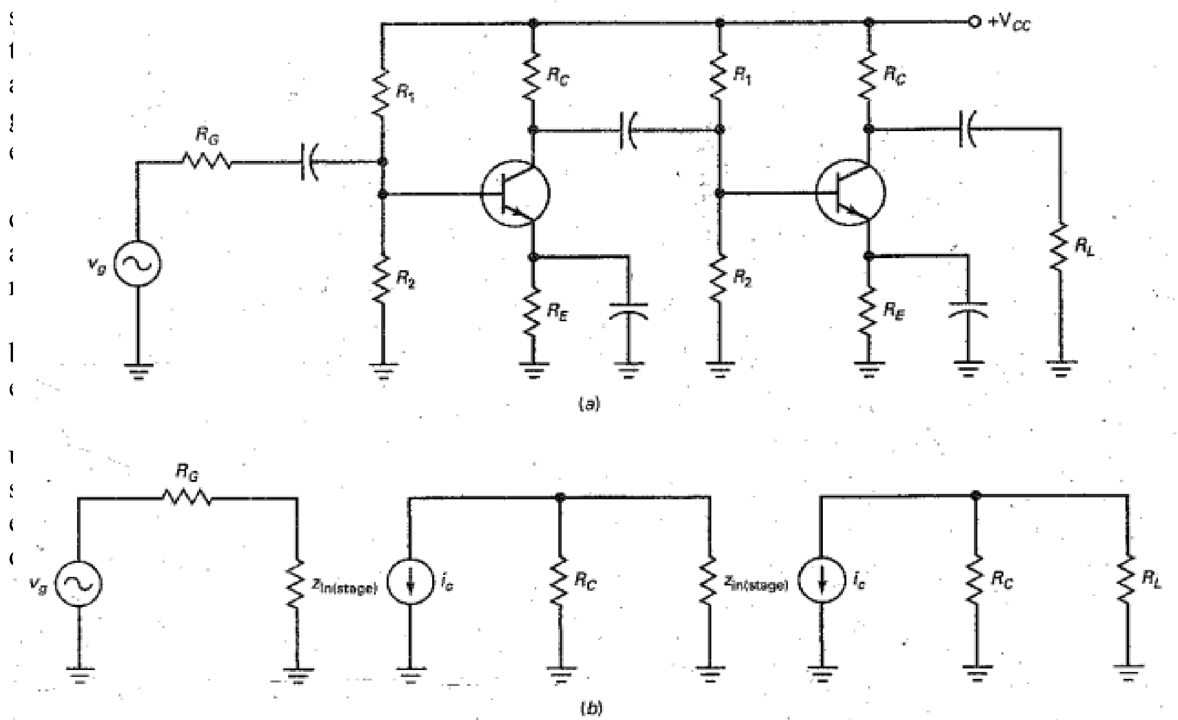
If $r_c = (R_C \,||\, R_L)$, the $A_V = r_c / r'_e$

The **input impedance** is $z_{in} = R_1 \,||\, R_2 \,||\, \beta r'_e$

If the input source has internal resistance of R_G , then $v_{in} = \frac{z_{in}}{R_G + z_{in}} v_S$

Q.6. What are multistage amplifier ? Find the expression for voltage gain.

To get more voltage gain, we can create multistage amplifier by cascading two or more amplifier stages**.** This means using the output of the first stage as the input to a second stage The output of the second



as the input to the third stage and so on.

Voltage Gain of first stage

With the equivalent circuit shown in fig. b . The ac collector resistance of the first stage is

First stage : $r_c = R_C \parallel z_{in(stage)}$

The voltage gain of the first stage is :

$$A_{v_1} = R_C \parallel z_{in(stage)} / r'_e$$

Voltage Gain of second stage

The ac collector resistance of the second stage is:

Second stage : $r_c = R_C \parallel R_L$

& the voltage gain is :

$$A_{v_2} = [R_C \parallel R_L] / r'_e$$

Total voltage gain

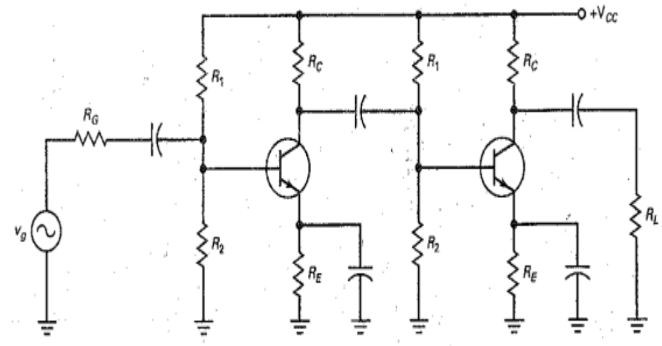
The total voltage gain of the amplifier is given by the product of the individual gains :

$$A_v = A_{v_1} . A_{v_2}$$

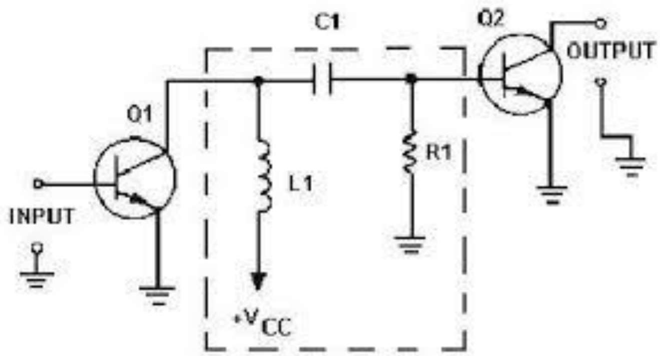
Q.7. What do you mean by amplifier coupling?

The process of transferring signals from one stage to other via a medium without any loss know as coupling. Some of the famous coupling are

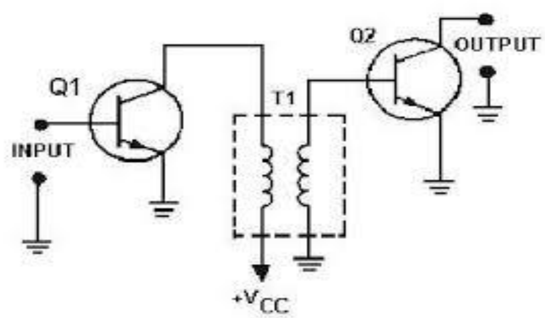
1. RC coupling



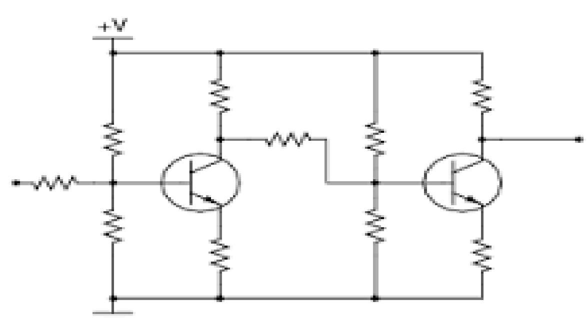
2. Impedance Coupling



3. Transformer coupling



4. Direct coupling (DC)



Q.8. Explain the working of a RC coupled amplifier in common emitter configuration . Draw its frequency response curve

Or

Draw circuit of a two-stage RC coupled CE amplifier. Explain with reasons what factors affect the gain of the amplifier at low and high frequencies?

Or

Draw a circuit diagram of a two-stage RC coupled amplifier in common emitter configuration and explain its working .

Refer to Q. 6

Effects of gain of the amplifier at low and high frequencies

The frequency response of an amplifier is the graph of its gain versus the frequency. An ac amplifier has lower & upper cutoff frequency. Coupling & bypass (fig. b)capacitors produce the lower cutoff frequency. Internal transistor capacitance & stray wiring capacitances (fig. b) produces upper cutoff frequency.

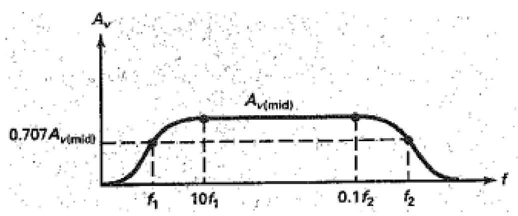


fig. (a)

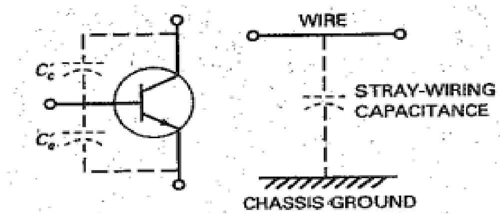


fig. (b)

Fig. (a) shows the frequency response of an amplifier. In the middle range of frequencies, the voltage gain is maximum. At low frequencies, the voltage gain decreases because the coupling and bypass capacitor no longer act like short circuits. Instead, their capacitive reactances are large enough to drop some of the ac signal voltage.

The approximation for calculating gain $A_v = \frac{A_{v(mid)}}{\sqrt{1+(\frac{f1}{f})^2} \cdot \sqrt{1+(\frac{f}{f2})^2}}$.

Loading effects of input impedance

Loading effects occurs when amplifiers are cascaded. Due to cascading of amplifier , the output resistance of previous stage decreases due to which , gain of amplifier decreases.

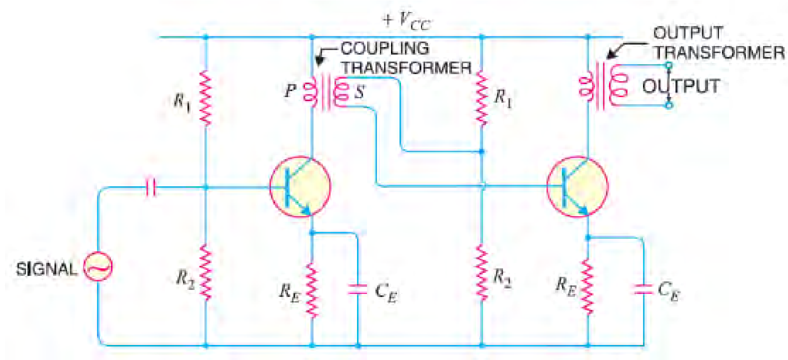
Q.9. Draw the circuit diagram of a transformer coupled transistor. Derive the expression for voltage gain at low, mid and high frequency .

Transformer Coupled Transistor Amplifier

In case of a RC coupled transistor amplifier the voltage and power gain are low since, the effective load resistance of each stage is decreased due to the low resistance presented by the input of each stage to the next stage. If the effective load resistance of each stage could be increased, the voltage and power gain could also be increased. This can be achieved by **transformer coupling.**

- By using the impedance matching properties of transformer, the low resistance of one stage or load can be reflected as a high load resistance to the previous stage.
- Transformer coupling is normally used when the load is small. It is mostly used for power amplification.

Working of Transformer Coupled Transistor Amplifier



As shown in the above fig. a coupling transformer is used to feed the output of one stage to the input of the next stage. The primary P of this transformer is made the collector load and its secondary S supplies input to the next stage.
When an a.c. signal is applied to the base of first transistor, it appears in the amplified form across the primary P of the coupling transformer.
Now the voltage developed across P is transferred to the input of the next stage by the transformer secondary S.
The second stage now performs the amplification in an exactly same manner.

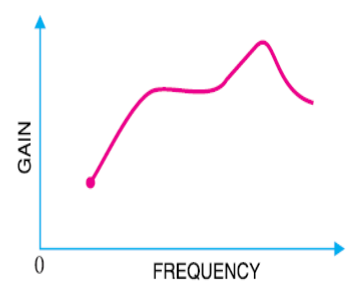
Voltage gain

$A_{v_1} = \frac{r_{0.1}}{r_{e.1}}$, $where\ , r_{0.1} = a^2\, r_{i.2}$

Where a= N_1/ N_2 for T_1 $r_{i.2} = R_1 \,||\, R_2 \,||\, \beta_2 r_{e.2}$ {R_1, R_2 of 2nd stage}

Similarly , $A_{v_2} = \frac{r_{0.2}}{r_{e.2}}$ $where\ , r_{0.2} = a^2\, r_{i.1}$

Frequency Response of Transformer Coupled Transistor Amplifier



- The frequency response of a transformer coupled amplifier is shown in the figure. It is clear from the above fig. that its frequency response is poor than the RC coupled amplifier. The gain is constant only over a small range of frequency.
- Since, the output voltage is equal to the collector current multiplied by reactance of primary, hence at low frequencies, as the reactance of primary begins to fall , the output voltage also decrease and hence the gain.
- At high frequencies, the capacitance between turns of windings acts as a bypass condenser to reduce the output voltage and hence the gain.
- Due to these two factors, there is disproportionate amplification of frequencies in a complete signal such as music, speech etc. Hence, transformer coupled amplifier introduces frequency distortion.

Advantages of Transformer Coupled Transistor Amplifier

1. There is no loss of signal power in the collector or base resistors.
2. An excellent impedance matching can be achieved in a transformer coupled amplifier.

3. Due to excellent impedance matching, transformer coupling provides higher gain. A properly designed single stage transformer coupling can provide the gain of two stages of RC coupling.

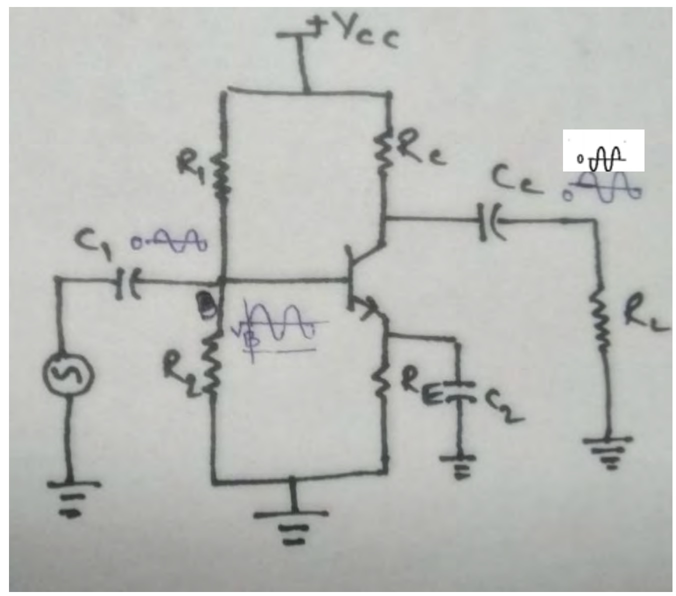
Disadvantages of Transformer Coupled Transistor Amplifier

1. It has a poor frequency response.
2. The coupling transformers are bulky and expensive at audio frequencies.
3. Frequency distortion is higher i.e. low frequency signals are less amplified as compared to the high frequency signals.
4. Transformer coupling introduces hum in the output.

Q.10. Show that the output voltage of a single stage common emitter transistor amplifier is 180^0 out of phase with input voltage .

Or

What is single stage transistor amplifier ?



When only one transistor is used in amplifier to amplify the signal is known as single stage amplifier as shown in figure.

In fig. the voltage beyond B point is AC type due to the capacitor C_1.

Due to voltage divider biasing ,the ac input voltage superimpose on dc voltage V_B , keeping base-emitter terminal always forward bias.

$v_{out} = V_{cc} - i_c R_C$

$= V_{cc} - \beta i_b R_C$ { since , $i_c = \beta i_b$}

Now when i_b will be at maximum, i_c will be at maximum i.e. magnitude of $i_c R_C$ will be maximum . It means maximum subtraction from V_{CC} and therefore minimum v_{out} .

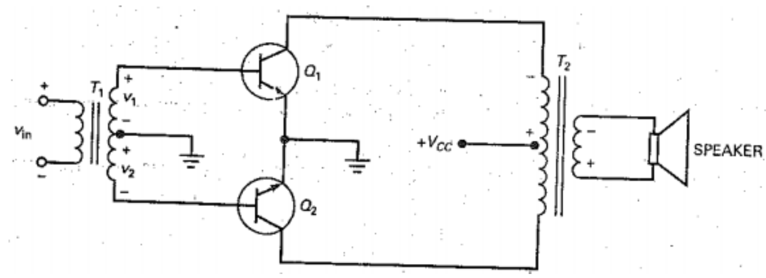
when i_b will be at minimum i_c will be at minimum i.e. magnitude of $i_c R_C$ will be minimum . It means minimum subtraction from V_{CC} and therefore maximum v_{out} . This happens sinusoidally & this practice is periodic in nature.
Therefore the output voltage is 180^0 out of phase w.r.t. input as shown in above fig.

Q. 11. Draw the circuit of push-pull class B audio "Power amplifier". Derive an expression for the efficiency of the amplifier. What are the advantages of push- pull amplifier?

Class A is the Common way to run a transistor in linear circuits because it leads to the simplest and most stable biasing circuits. But Class A is not most efficient way to operate a transistor .This need introduces class B operation of power amplifier.

Push –Pull Circuit

Fig. shows a basic class B amplifier. When the transistor operates as class B, it clips off half a cycle (there is no any biasing circuit), To avoid the resulting distortion , two transistors are used in a push-pull arrangement. Push –Pull means that one transistor conducts for half a cycle while the other is off and vice versa.



Operation

- On positive half cycle of input voltage , the secondary winding of T_1 has voltage v_1 & v_2 as shown.
- Therefore the upper transistor conducts and the lower one cuts off. The collector current through Q_1 flows through the upper half of the output primary winding.
- This produces an amplified and inverted voltage, which is transformer-coupled to the loudspeaker.
- On the next half cycle of input voltage , the polarities reversed . Now , the lower transistor turn on and the upper transistor turns off . The lower transistor amplifies the signal, and the alternate half cycle appears across the loudspeaker.
- Since each transistor amplifies one-half of the input cycle, the load-speaker recives a complete cycle of the amplified signal

For derivation refer to Q.9.

Advantages

- No bias circuit is needed
- Improved efficiency , the maximum efficiency is 78.5 %, so class B push-pull amplifier is more commonly used for an output stage then a class A power amplifier

Disadvantages

The main disadvantage of amplifier is the use of transformer , making it bulky & expensive

Q. 12. Explain the principle of a feedback amplifier. What are positive and negative feedbacks?

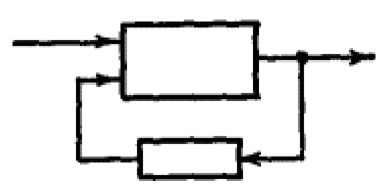
Or

What is the principle of feedback? Establish the relation between voltage gains of a common amplifier and a feedback amplifier.

Or

What is meant by feedback in amplifier? Define negative & positive feedback . Explain how negative feedback in an amplifier helps in improving gain stability and reducing the distortion.

Suppose a small voltage is fed back from the output of an amplifier to its input as in fig.



If this voltage is in the same phase (crest for crest, trough for trough) as the input or signal voltage, the feedback is said to be positive or *regenerative* and the circuit will likely go into oscillation.

If the voltage is in reverse phase (crest for trough of the wave-form), the feedback is negative or *degenerative.*

Let the amount of the feedback voltage be a fraction *(F)* of the output voltage *E*. Then the actual input will be *FE* plus the original signal e. The output voltage is equal to the actual input voltage multiplied by the voltage amplification *A.*

Thus $E = A(e + FE)$. Solving this equation for the effective amplification or gain of a feedback amplifier, we find

$$G = E/e = \frac{A}{1-FA} = -\frac{1}{F}\left(\frac{1}{1-\frac{1}{FA}}\right)$$

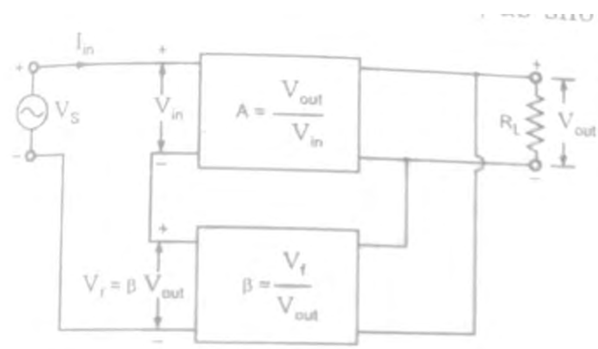
When *F* is positive, the circuit is regenerative, and vice versa. When the " feedback factor " *FA* is very large, the gain becomes (— *1/F),* and the effective amplification is independent of the gain *A* of the amplifier alone. This means that, with degenerative feedback, the amplifier will have *great stability,* retaining its overall voltage gain at a constant value for long periods of time despite appreciable changes in battery voltages, temperature, and mechanical vibration.

Degenerative feedback *reduces harmonic distortion* arising in the amplifier. This is because the distortion is fed back and is itself degenerated.

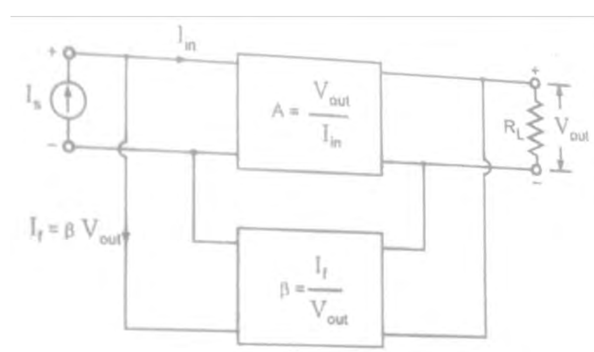
Basic negative feedbacks.

Negative feedback are generally of four types

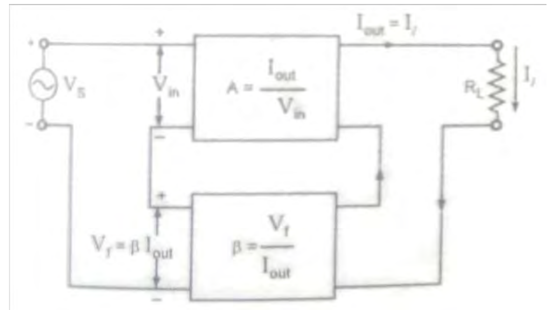
Voltage series feedback



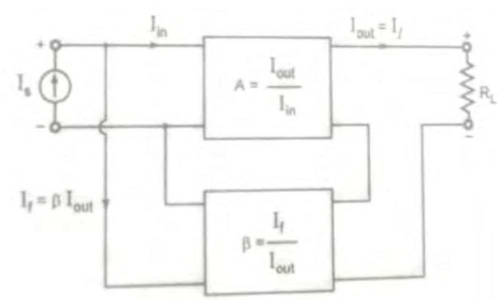
Voltage shunt feedback



Current series feedback

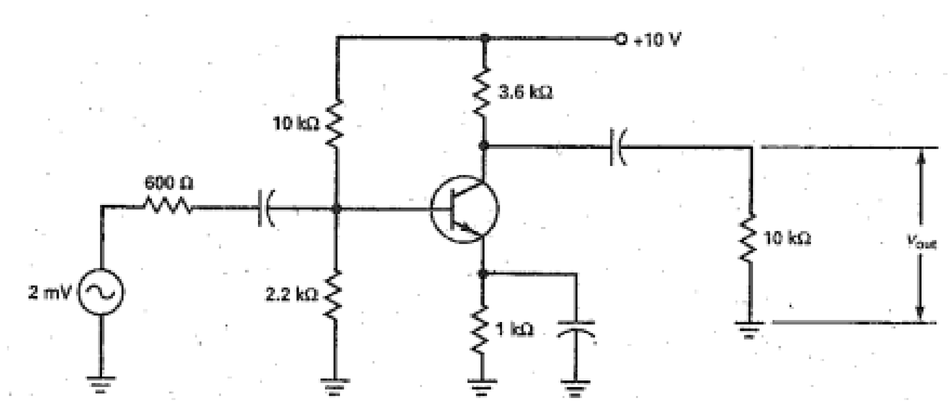


Current shunt feedback



Numerical

Q.1. Calculate amplifier gain , if β= 300 ?



Exp: $V_E = 2.2\ k\Omega \times 10V / (2.2\ k\Omega + 10\ k\Omega) - 0.7V = 1.103V$

$I_E = V_E / R_E = 1.103V / 1\ k\Omega = 1.103mA$

$\therefore r_e = 25mV / I_E = 25mV/1.103mA = 22.66\ \Omega$

$\because r_c = R_C \mid\mid R_L$

$\therefore r_c = 3.6\ k\Omega \mid\mid 10k\ \Omega = 2.65\ k\Omega$

$\because A_V = r_c / r'_e$

$\therefore A_V = 2.65\ k\ \Omega / 22.66\ \Omega = 116.94$ Ans

Q.2. The ac generator has an internal resistance of 600Ω for the amplifier in Q.1. What is the output voltage , if β= 300 ?

Exp: As calculated above r_e =22.66 Ω , A_V = 116.94

When β= 300 , the input impedance is z_{in}

$\mathbf{z_{in}} = R_1 \mid\mid R_2 \mid\mid \beta r'_e$

$\therefore \mathbf{z_{in}} = 10k\ \Omega \mid\mid 2.2\ k\Omega \mid\mid 300 \times 22.66\ \Omega$

$= 10k\ \Omega \mid\mid 2.2\ k\Omega \mid\mid 6.798k\ \Omega = 1.42k\ \Omega$

$\because \mathbf{v_{in}} = \frac{z_{in}}{R_G + z_{in}} v_s$

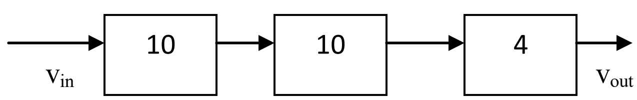
$\therefore \mathbf{v_{in}} = 1.42\ k\ \Omega \times 2mV / (600\ \Omega + 1.42\ k\ \Omega) = 1.41mV$

$\because v_{out} = A_V\ v_{in}$

$\therefore v_{out} = 116.94\ k\ \Omega / 1.41mV = 165mV$ Ans

Q.3. The value of r.ms. voltage of the input signal of atree stage RC coupled amplifier is 0.1volt. If the voltage gains of the three stage are 10,10 and 4 resp., what will be the output voltage ?

Exp:



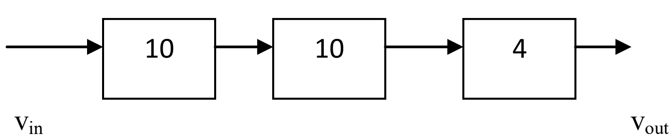
Since , gain of three RC coupled amplifier are 10,10 & 4 respectively

therefore, gain of three cascade system= 10*10*4=400

v_{out}= 0.1*400= 40v

Q.4. A two stage common emitter RC coupling. The voltage gain of each stage is 50 & R_C = 5k Ω for each stage . If input impedance of each stage is 2k Ω , then find the overall voltage gain.

Exp:



Since , gain of three RC coupled amplifier are 50,50 & 50 respectively

therefore, gain of three cascade system= 50*50*50=125000 Ans

Q.6. An ac amplifier with a midband voltage gain of 200. If the cutoff frequencies are f_1= 20Hz and f_2 = 20kHz, what does the frequency response look like ? What is the voltage gain if the input frequency response look like ? What is the voltage gain if the input frequency is 5Hz ? If it is 200kHz ?

Exp: In the midband , the voltage gain is 200 . At either cutoff frequency , it equals

A_V= 0.707 (200) = 141

Voltage gain for the an input frequency of 5Hz

$$A_V = \frac{A_{v(mid)}}{\sqrt{1+(\frac{f_1}{f})^2}}$$

$$\therefore A_V = \frac{200}{\sqrt{1+(\frac{20}{5})^2}} = \frac{200}{\sqrt{1+(4)^2}} = \frac{200}{\sqrt{17}} = 48.5$$

Voltage gain for the an input frequency of 200kHz

$$\therefore A_V = \frac{200}{\sqrt{1+(\frac{200}{20})^2}} = 19.9$$

Q.5. A two stage common emitter R-C coupled amplifier uses transistor of the type BC149B, whose hybrid parameter are : h_{fe} =330, h_{ie}= 4.5 kΩ & load resistance R_L= 5.5 kΩ . Find the required value of the coupling capacitor C so that the lower half power frequency is 30Hz.

Exp: Given : h_{fe} =330, h_{ie}= 4.5 kΩ, R_L= 5.5 kΩ and f_L= 5.5 kΩ

Since, for two stage RC coupled amplifier the half power frequency , f_L is given by

$$f_L = 1/ [2\pi C_C(h_{ie} + R_L)]$$

$$\therefore C_C = 1/ [2\pi f_L (h_{ie} + R_L)]$$

$$\therefore C_C = 1/ (2 \times 3.14 \times 30 (4.5 + 5.5) \times 10^3) = 0.53 \times 10^{-6} = 0.53\mu F$$ Ans