JAWAHARLAL NEHRU TECHNOLOGICAL UNIVERSITY ANANTAPUR

II B.Tech II-Sem (E.C.E)	**T**	**Tu**	**C**
	3	**1**	**3**

(15A04401) ELECTRONIC CIRCUIT ANALYSIS

Course Objectives:

The aim of this course is to familiarize the student with the analysis and design of multistage amplifiers with compound connections, feedback amplifiers, oscillators, power amplifiers and tuned amplifiers. To study and analyze the frequency response of amplifier circuits.

Course Outcomes:

Upon completion of this course, student will be able to :

- Analyze the frequency response of the BJT amplifiers at low and high frequencies.
- Analyze and design multistage amplifiers with compound connections, feedback amplifiers, oscillators, power amplifiers and tuned amplifiers.

UNIT -I

Feedback Amplifiers : Feedback principle and concept, types of feedback, classification of amplifiers, feedback topologies,Characteristics of negative feedback amplifiers, Generalized analysis of feedback amplifiers, Performance comparison of feedback amplifiers, Method of Analysis of Feedback Amplifiers.

Oscillators: Oscillator principle, condition for oscillations, types of oscillators, RC-phase shift and Wein bridge oscillators with BJT and FET with the relevant analysis,Generalized analysis of LC Oscillators, Hartley and Colpitt’s oscillators with BJT and FET with relevant analysis, Crystal oscillators, Frequency and amplitude stability of oscillators.

UNIT- II

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.

UNIT – III

Multistage Amplifiers : Classification ofamplifiers, Methods of coupling**,** Cascaded 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.

UNIT- IV

Power Amplifiers: Class A large signal Amplifiers, Second harmonic Distortions, Higher order harmonic Distortion, Transformer Coupled Audio power amplifier, Efficiency, Push-pull amplifiers, Class B Amplifiers, Class AB operation, Efficiency of Class B Amplifier, Complementary Symmetry push pull amplifier, Class D amplifier, Class S amplifier, MOSFET power amplifier, Thermal stability and Heat sink.

UNIT -V

Tuned Amplifiers : Introduction, Q-Factor, Small Signal Tuned Amplifier – Capacitance single tuned amplifier, Double Tuned Amplifiers, Effect of Cascading Single tuned amplifiers on Band width, Effect of Cascading Double tuned amplifiers on Band width, Staggered tuned amplifiers, Stability of tuned amplifiers

Text Books:

1. J. Millman and C.C. Halkias, "Integrated Electronics", McGraw-Hill, 1972.
2. Donald A. Neaman, "Electronic Circuit Analysis and Design", McGraw Hill.
3. Salivahanan, N.Suressh Kumar, A. Vallavaraj, "Electronic Devices and Circuits", Tata McGraw Hill, Second Edition.

References:

1. Robert T. Paynter, "Introductory Electronic Devices and Circuits", Pearson Education, 7^{th} Edition
2. Robert L. Boylestad and Louis Nashelsky, "Electronic Devices and Circuits Theory" Pearson/Prentice Hall, 9th Edition, 2006.
3. Sedra A.S. and K.C. Smith, "Micro Electronic Circuits", Oxford University Press, 5th Edition.

UNIT-1

FEEDBACK AMPLIFIERS AND OSCILLATORS

Concepts of Feedback, Classification of Feedback Amplifiers, General Characteristics of Negative Feedback Amplifiers, Effect of Feedback on Amplifier characteristics, Voltage Series, Voltage Shunt, Current Series and Current Shunt Feedback Configurations, Illustrative design Problems. Conditions for Oscillations, RC and LC type Oscillators, RC-Phase shift and Wien-Bridge Oscillators, Generalized Analysis of LC Oscillators, Hartley and Colpitts Oscillators, Crystal Oscillators, Frequency and Amplitude Stability of Oscillators, Illustrative design problems.

Amplifier:

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

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

The above drawbacks can be minimizing if we introduce feedback

Concept of Feedback:

A sampling network samples the output voltage or current and this signal is applied to the input through a feedback two port network.

Feedback amplifiers are classified as shown below.

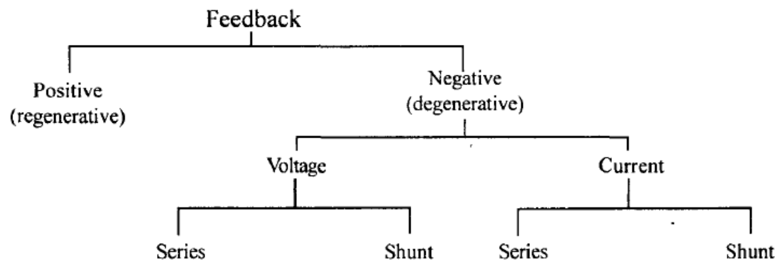


Chart 3.1: classification of feedback amplifiers

Feedback means a portion of the output of the amplifier circuit is sent back or given back or feedback at the input terminals. By this mechanism the characteristics of the amplifier circuit can be changed. Hence feedback is employed in circuits.

There are two types of feedback.

1. Positive Feedback
2. Negative Feedback

Negative feedback is also called as degenerative feedback. Because in negative feedback, the feedback signal opposes the input signal. So it is called as degenerative feedback. But there are many advantages with negative feedback.

Advantages of Negative Feedback:

1. Input impedance can be increased.
2. Output impedance can be decreased.
3. Transfer gain A_f can be stabilized against variations in It-parameter of the transistor with temperature etc. i.e. stability is improved.
4. Bandwidth is increased.
5. Linearity of operation is improved.
6. Distortion is reduced.
7. Noise reduces.

Comparison of positive and negative feedback amplifiers:

characteristic	**Positive feedback amplifier**	**Negative feedback amplifier**
Definition	Feedback signal is subtracted from original signal	Feedback signal is added from original signal
Gain	Increases	decreases
Bandwidth	Decreases	Increases
Impedances	degrades	Improves
Noise and distortion	degrades	Improves
Stability	decrease	Increases
Feedback network	Consists of L,C	Only resistive
application	As oscillator	Amplifiers

General block diagram of feedback amplifier:

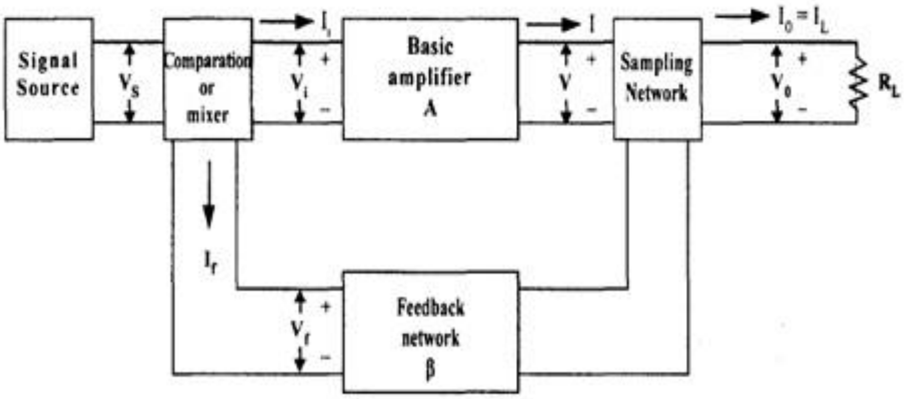


Fig.: general block diagram of feedback amplifier

Signal source:

It can be a voltage source V s or a current source I_s

Feedback network:

It is a passive two port network. It may contain resistors, capacitors or inductors. But usually a resistance is used as the feedback element. Here the output current is sampled and feedback. The feedback network is connected in series with the output. This is called as Current Sampling or Loop Sampling. A voltage feedback is distinguished in this way from current feedback. For voltage feedback, the feedback element (resistor) will be in parallel with the output. For current feedback the element will be in series.

Comparator or mixer network:

This is usually a differential amplifier. It has two inputs and gives a single output which is the difference of the two inputs.

Here A=open loop gain

β=feedback factor

Gain with feedback:

Positive feedback amplifier gain:

$V_o = A\ V_I$

$V_I = V_S + V_F$

$V_F = \beta\ V_O$

$V_I = V_S + \beta\ V_O$

$V_I = V_S + \beta A\, V_I$

$V_I(1 - \beta\, A) = V_S$

Gain with feedback $A_F = \frac{V_0}{V_S} = \frac{AV_I}{V_I(1 - A\beta)} = \frac{A}{1 - A\beta}$

Here gain is increased by factor $(1 - A\beta)$

Negative feedback amplifier gain:

$V_o = A\, V_I$

$V_I = V_S - V_F$

$V_F = \beta\, V_O$

$V_I = V_S - \beta\, V_O$

$V_I = V_S - \beta A\, V_I$

$V_I(1 + \beta\, A) = V_S$

Gain with feedback $A_F = \frac{V_0}{V_S} = \frac{AV_I}{V_I(1 + A\beta)} = \frac{A}{1 + A\beta}$

Here gain is decreased by factor $(1 + A\beta)$

Effect of negative feedback on characteristics of amplifier:

1. on stability:

$$A_F = \frac{A}{1 + A\beta} \cong \frac{1}{\beta}\left(knowingA\beta > 1\right)$$

Here β is resistive which does not depends on h-parameters thus negative feedback is more stable

$$\frac{dA_F}{A} = \frac{d}{dA}\left(\frac{A}{1 + \beta A}\right) = \frac{1}{1 + \beta A}\frac{dA}{A}$$

Gain with feedback is only fraction change in gain without feedback so stable output

2. Sensitivity of feedback:

$$S = \frac{dA_F/A}{dA/A} = \frac{1}{1 + A\beta}$$

Ideal value of sensitivity =0

Reciprocal of sensitivity =Desensitivity=∞

3. On bandwidth:

$$f_{LF} = \frac{f_l}{1 + A\beta}$$

Negative feedback reduces lower cutoff frequency by fraction (1+AB)

$$f_{hF} = f_h(1 + A\beta)$$

Negative feedback increases lower cutoff frequency by fraction (1+AB)

Finally overall BW is increased

4. Reduction in Frequency Distortion:

For a negative-feedback amplifier having B*A*>1, the gain with feedback is *Af*= 1/B It follows from this that if the feedback network is purely resistive, the gain with feedback is not dependent on frequency even though the basic amplifier gain is frequency dependent. Practically, the frequency distortion arising because of varying amplifier gain with frequency is considerably reduced in a negative-voltage feedback amplifier circuit.

5. Reduction in Noise and Nonlinear Distortion:

Signal feedback tends to hold down the amount of noise signal (such as power-supply hum) and nonlinear distortion. The factor (1+B*A*) reduces both input noise and resulting nonlinear distortion for considerable improvement. However, it should be noted that there is a reduction in overall gain (the price required for the improvement in circuit performance). If additional stages are used to bring the overall gain up to the level without feedback, it should be noted that the extra stage(s) might introduce as much noise back into the system as that reduced by the feedback amplifier. This problem can be somewhat alleviated by readjusting the gain of the feedback-amplifier circuit to obtain higher gain while also providing reduced noise signal.

Types of feedback topologies:

The four different types of feedback amplifiers are,

1. Voltage series feedback
2. Voltage shunt feedback
3. Current series feedback
4. Current shunt feedback

In the list above, voltage refers to connecting the output voltage as input to the feedback network; current refers to tapping off some output current through the feedback network. Series refers to connecting the feedback signal in series with the input signal voltage; shunt refers to connecting the feedback signal in shunt (parallel) with an input current source.

Series feedback connections tend to increase the input resistance, while shunt feedback connections tend to decrease the input resistance. Voltage feedback tends to decrease the output impedance, while current feedback tends to increase the output impedance. Typically, higher input and lower output impedances are desired for most

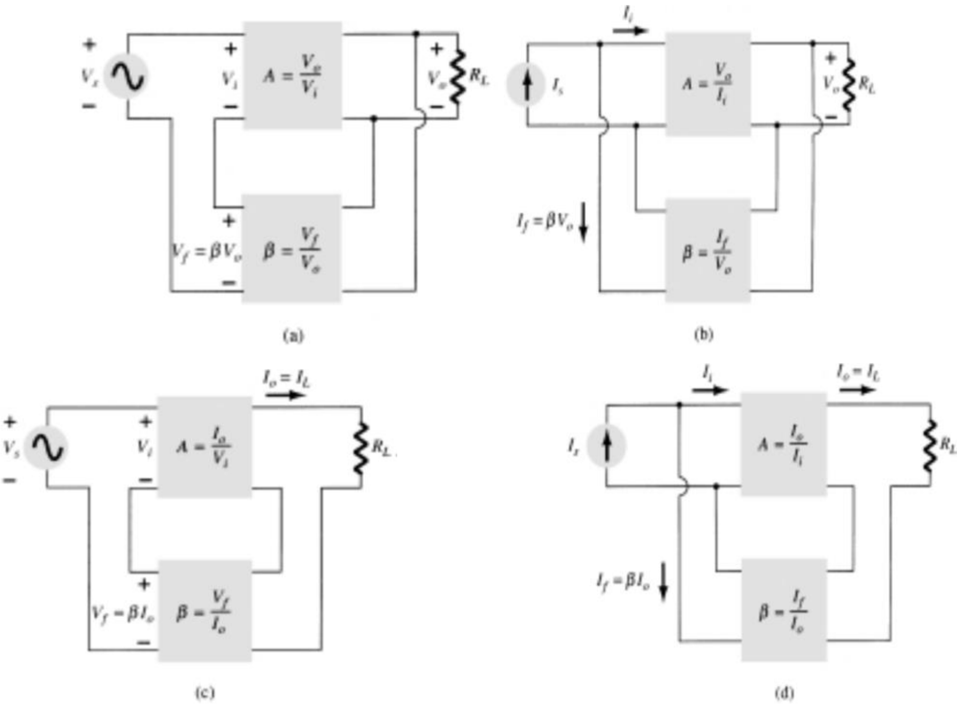


Fig.: Feedback amplifier types: (a) voltage-series feedback (b) voltage-shunt feedback (c) current-series feedback (d) current-shunt feedback

		Voltage-Series	*Voltage-Shunt*	*Current-Series*	*Current-Shunt*
Gain without feedback	A	$\frac{V_o}{V_i}$	$\frac{V_o}{I_i}$	$\frac{I_o}{V_i}$	$\frac{I_o}{I_i}$
Feedback	β	$\frac{V_f}{V_o}$	$\frac{I_f}{V_o}$	$\frac{V_f}{I_o}$	$\frac{I_f}{I_o}$
Gain with feedback	A_f	$\frac{V_o}{V_s}$	$\frac{V_o}{I_s}$	$\frac{I_o}{V_s}$	$\frac{I_o}{I_s}$

INPUT IMPEDANCE WITH FEEDBACK:

Voltage Series Feedback:

Feedback signal is taken across RL proportional to Vo. So it is voltage feedback. Vf is coming in series with VI So it is Voltage series feedback. A more detailed voltage-series feedback connection is shown in Fig. The input impedance can be determined as follows:

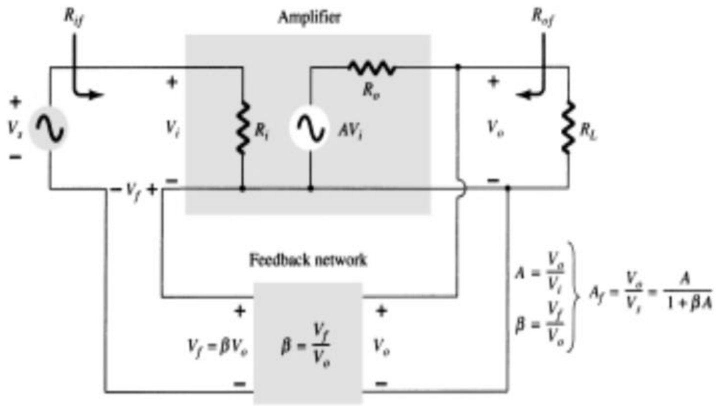


Fig.: equivalent circuit of voltage series feedback

$$I_i = \frac{V_i}{Z_i} = \frac{V_s - V_f}{Z_i} = \frac{V_s - \beta V_o}{Z_i} = \frac{V_s - \beta A V_i}{Z_i}$$

$$I_i Z_i = V_s - \beta A V_i$$

$$V_s = I_i Z_i + \beta A V_i = I_i Z_i + \beta A I_i Z_i$$

$$Z_{if} = \frac{V_s}{I_i} = Z_i + (\beta A) Z_i = Z_I(1 + \beta A)$$

VOLTAGE-SHUNT FEEDBACK:

A more detailed voltage-shunt feedback connection The input Impedance can be determined to be

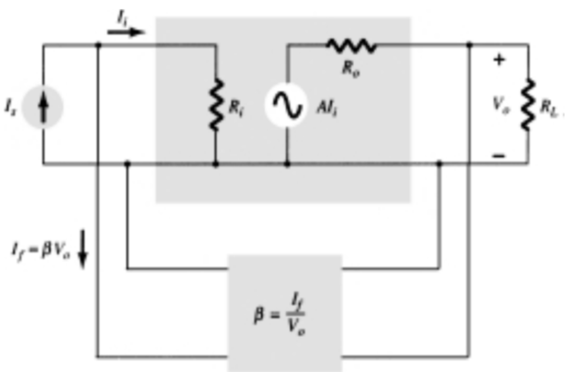


Fig.: equivalent circuit of voltage shunt feedback

$$Z_{if} = \frac{V_i}{I_s} = \frac{V_i}{I_i + I_f} = \frac{V_i}{I_i + \beta V_o}$$

$$\frac{V_i/I_i}{I_i/I_i + \beta V_o/I_i}$$

$$Z_{if} = \frac{Z_i}{1 + \beta A}$$

Output Impedance with Feedback:

The output impedance for the connections of Fig. are dependent on whether voltage or current feedback is used. For voltage feedback, the output impedance is decreased, while current feedback increases the output impedance.

Voltage-series feedback:

The voltage-series feedback circuit of Fig. provides sufficient circuit detail to determine the output impedance with feedback. The output impedance is determined by applying a voltage, *V*, resulting in a current, I, with *Vs* shorted out (*Vs* =0). The voltage *V* is then

$$Z_{Of} = \frac{Z0}{1 + \beta A}$$

Equation shows that with voltage-series feedback the output impedance is reduced from that without feedback by the factor (1 +B*A*).

Current-series feedback:

The output impedance with current-series feedback can be determined by applying a signal *V* to the output with *Vs* shorted out, resulting in a current I, the ratio of *V* to I being the output impedance. Figure shows a more detailed connection with current-series feedback. For the output part of a current-series feedback connection shown in Fig, the resulting output impedance is determined as follows. With *Vs* = 0,

Zof =V/I=Zo(1 +BA)

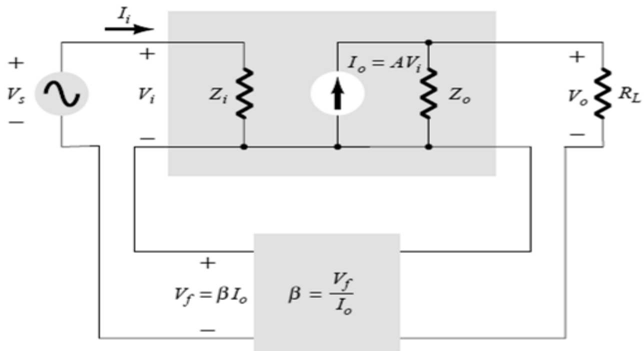


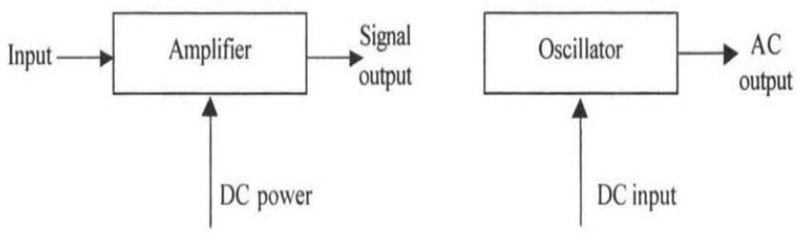
Fig.: equivalent circuit of current series feedback

Effect of Feedback Connection on Input and Output Impedance

	Voltage-Series	Current-Series	Voltage-Shunt	Current-Shunt
Z_{if}	$Z_i(1+\beta A)$ (increased)	$Z_i(1+\beta A)$ (increased)	$\frac{Z_i}{1+\beta A}$ (decreased)	$\frac{Z_i}{1+\beta A}$ (decreased)
Z_{of}	$\frac{Z_o}{1+\beta A}$ (decreased)	$Z_o(1+\beta A)$ (increased)	$\frac{Z_o}{1+\beta A}$ (decreased)	$Z_o(1+\beta A)$ (increased)

OSCILLATORS:

Oscillator is a source of AC voltage or current. We get A.C. output from the oscillator circuit. An amplifier is different from oscillator in the sense that an amplifier requires some A.C. input which will be amplified. But an oscillator doesn't need any external AC signal. This is shown in Fig.



(a) Amplifier circuit *(b) Oscillator circuit*

For an amplifier, the additional power due to amplification is derived from the DC bias supply. So an amplifier effectively converts DC to AC. But it needs AC input. Without AC input, there is no AC output. In the oscillator circuits also DC power is converted to AC. But there is no AC input signal. So the difference between amplifier and oscillator is in amplifiers circuits, the DC power conversion to AC is controlled by the AC input signal. But in oscillators, it is not so.

There are two types of oscillator circuits:

According wave form generation:

1. Harmonic Oscillators
2. Relaxation Oscillators

According fundamental mechanism;

1. Feedback oscillators

2. Negative resistance oscillators

According wave form frequency generated:

1. Audio frequency oscillators
2. Radio frequency oscillators
3. Very high oscillators
4. Ultra high oscillators
5. Micro wave oscillators

According to type of circuit used:

1. LC oscillator
2. RC oscillator

Harmonic Oscillators produce sine waves. Relaxation Oscillators produce saw tooth and square waves etc. Oscillator circuits employ both active and passive devices. Active devices convert the DC power to AC. Passive components determine the frequency of oscillators.

PERFORMANCE MEASURES OF OSCILLATOR CIRCUITS:

1. Stability:

This is determined by the passive components. R,C and L determine frequency of oscillations. If R changes with T,f changes so stability is affected. Capacitors should be of high quantity with low leakage. So silver mica and ceramic capacitors are widely used.

2. Amplitude stability:

To get large output voltage, amplification is to be done.

3. Output Power:

Class A, Band C operations can be done. Class C gives largest output power but harmonics are more. Class A gives less output power but harmonics are low.

4. Harmonics:

Undesirable frequency components are harmonics.

CONDITION FOR OSCILLATION (Bark Hausen criterion):

The circuit operates only in the linear region, and the amplifier feedback network contains reactive elements. For a sinusoidal wave form, if $X_I = X_0$, the amplitude, phase and frequency of X_I and X_0be identical. The frequency of a sinusoidal oscillator is determined by the condition that loop gain, Phase shift is zero at that frequency.

For oscillator circuits positive feedback must be there i.e., V [must be in phase with V_i to get added to V_i . When active device BJT or FET gives 180° phase shift, the feedback network must produce another 180° phase shift so that net phase shift is 0° or 360° and V [is in phase with VI to make it positive feedback.

Oscillations will not be sustained if, at the oscillator frequency the magnitude of the product of the transfer gain of the amplifier and of P are less than unity.

The conditions - AB = 1 is called Barkhausen criterion

$$\left(|A\beta| = 1\right)$$

phase of $A\beta = 0^0$ or 360^0.

Another way of seeing how the feedback circuit provides operation as an oscillator is obtained by noting the denominator in the basic feedback equation (18.2), $Af = A/(1 + A\beta)$. When $A\beta = 1$ or magnitude 1 at a phase angle of 180°, the denominator becomes 0 and the gain with feedback, *Af*, becomes infinite.

Thus, an infinitesimal signal (noise voltage) can provide a measurable output voltage, and the circuit acts as an oscillator even without an input signal.

RC Oscillators:

In an **RC Oscillator** circuit the input is shifted 180^o through the amplifier stage and 180^o again through a second inverting stage giving us "180^o + 180^o = 360^o" of phase shift which is effectively the same as 0^o thereby giving us the required positive feedback. In other words, the phase shift of the feedback loop should be "0". In a **Resistance-Capacitance Oscillator** or simply an **RC Oscillator**, we make use of the fact that a phase shift occurs between the input to a RC network and the output from the same network by using RC elements in the feedback branch, for example.

RC PHASE-SHIFT NETWORK:

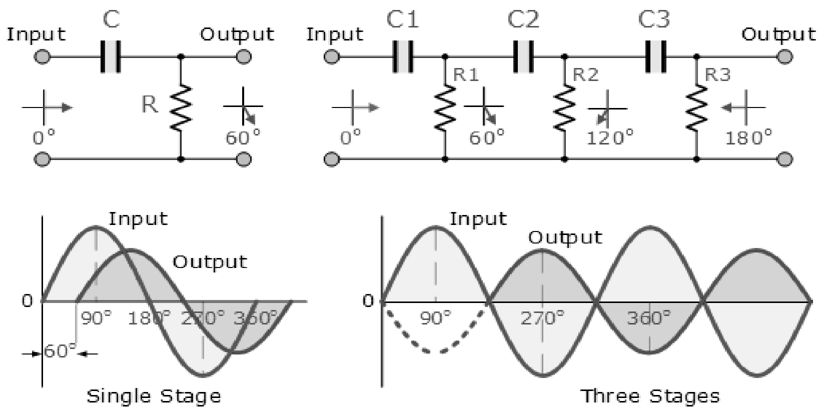


Fig: RC network basics

The circuit on the left shows a single Resistor-Capacitor Network whose output voltage "leads" the input voltage by some angle less than 90^o. An ideal single-pole RC circuit would produce a phase shift of exactly 90^o, and because 180^o of phase shift is required for oscillation, at least two single-poles must be used in an *RC oscillator* design.

In our simple example below, the values of R and C have been chosen so that at the required frequency the output voltage leads the input voltage by an angle of about 60^o. Then the phase angle between each successive RC section increases by another 60^o giving a phase difference between the input and output of 180^o (3 x 60^o) as shown by the following vector diagram. Then by connecting together three such RC networks in series we can produce a total phase shift in the circuit of 180° at the chosen frequency and this form the bases of a "phase shift oscillator" otherwise known as a **RC Oscillator** circuit.

We know that in an amplifier circuit either using a Bipolar Transistor or an Operational Amplifier, it will produce a phase-shift of 180° between its input and output. If a three-stage RC phase-shift network is connected between this input and output of the amplifier, the total phase shift necessary for regenerative feedback will become 3 x 60° + 180° = 360° as shown.

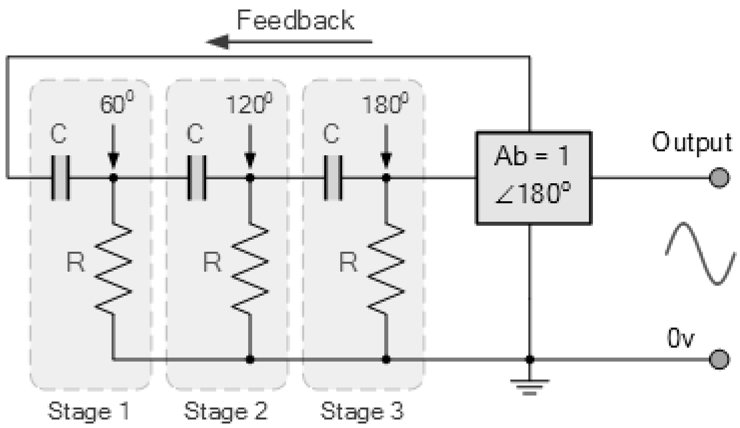


Fig: general RC phase shift oscillator

Ex: RC phase shift oscillator, wien bridge oscillator…..etc

LC OSCILLATOR:

Oscillators are also used in many pieces of test equipment producing either sinusoidal in a waves, square, saw tooth or triangular shaped waveforms or just a train of pulses of a variable or constant width. **LC Oscillators** are commonly used in radio-frequency circuits because of their good phase noise characteristics and their ease of implementation.

Oscillators work because they overcome the losses of their feedback resonator circuit either in the form of a *capacitor, inductor* or both in the same circuit by applying DC energy at the required frequency into this resonator circuit. In other words, an oscillator is an amplifier which uses positive feedback that generates an output frequency without the use of an input signal. It is self-sustaining.

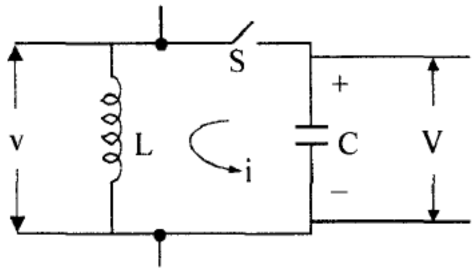


Fig: LC network

L and C are reactive elements. They can store energy. The capacitor stores energy whenever there is voltage across its plates. Inductor stores energy in its magnetic field whenever current flows. Both C and L are lossless, ideal devices. So quality factor is infinity.

Suppose at t = to' switch 'S' is closed. Then current flows. Voltage across L will be V. At t = to' the Voltage across C is V volts. When switch is closed, current flows. So the charge across Capacitor C decreases. Voltage across C decreases, as shown in the waveform. So as the energy stored in Capacitor decreases, the energy stored in inductor L increases, because current is flowing through L Thus total energy in the circuit remains the same as before. When V across C becomes 0, current through the inductor is maximum. When the energy in C is 0, energy in L is maximum. Then the current in L starts charging C in the opposite directions. So at t = t\ current in L is maximum and for t > t\, the current starts charging C in the opposite direction. So V across C becomes negative as shown in the waveform. Thus we get sinusoidal oscillations from LC circuit

Ex: colpitts oscillator, Hartley oscillator…..etc.

RC phase shift oscillator:

The basic **RC Oscillator** which is also known as a **Phase-shift Oscillator**, produces a sine wave output signal using regenerative feedback obtained from the resistor-capacitor combination.

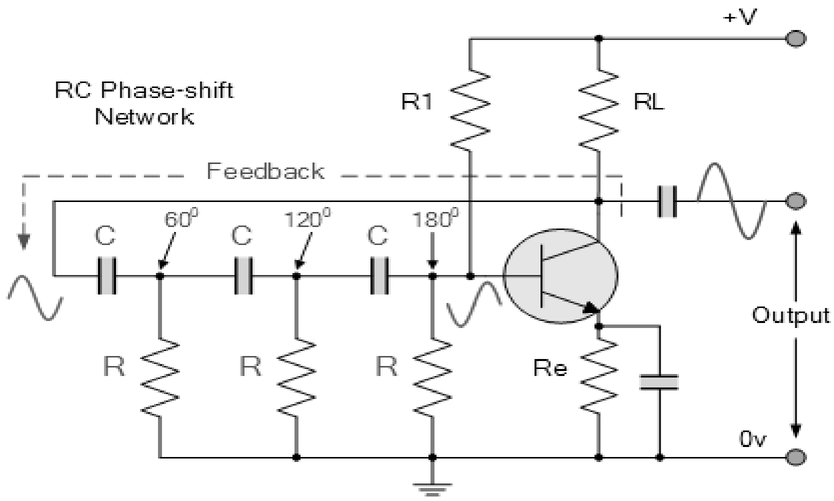


Fig: RC phase shift oscillator

This regenerative feedback from the RC network is due to the ability of the capacitor to store an electric charge, (similar to the LC tank circuit).

This resistor-capacitor feedback network can be connected as shown above to produce a leading phase shift (phase advance network) or interchanged to produce a lagging phase shift (phase retard network) the outcome is still the same as the sine wave oscillations only occur at the frequency at which the overall phase-shift is 360°.

By varying one or more of the resistors or capacitors in the phase-shift network, the frequency can be varied and generally this is done by keeping the resistors the same and using a 3-ganged variable capacitor. If all the resistors, R and the capacitors, C in the phase shift network are equal in value, then the frequency of oscillations produced by the RC oscillator is given as:

$$F_R = \frac{1}{2\pi RC\sqrt{2N}}$$

Where:

F_R is the Output Frequency in Hertz

R is the Resistance in Ohms

C is the Capacitance in Farads

N is the number of RC stages. (N = 3)

Since the resistor-capacitor combination in the **RC Oscillator** circuit also acts as an attenuator producing an attenuation of -1/29th (Vo/Vi = β) per stage, the gain of the amplifier must be sufficient to overcome the circuit losses.

Therefore, in our three stage RC network above the amplifier gain must be greater than 29.

WIEN BRIDGE OSCILLATOR:

The **Wien Bridge Oscillator** is so called because the circuit is based on a frequency-selective form of the Wheatstone bridge circuit. The Wien Bridge Oscillator is a two-stage RC coupled amplifier circuit that has good stability at its resonant frequency, low distortion and is very easy to tune making it a popular circuit as an audio frequency oscillator but the phase shift of the output signal is considerably different from the previous phase shift **RC Oscillator**.

The **Wien Bridge Oscillator** uses a feedback circuit consisting of a series RC circuit connected with a parallel RC of the same component values producing a phase delay or phase advance circuit depending upon the frequency. At the resonant frequency ƒr the phase shift is 0°. Consider the circuit below.

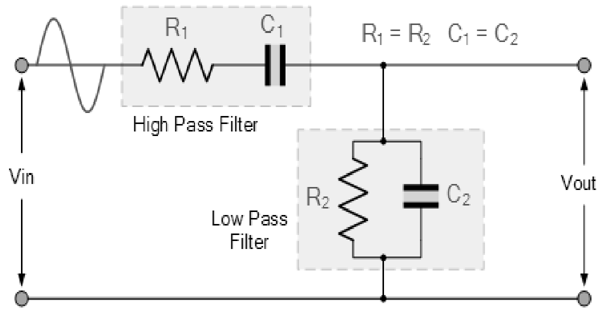


Fig: wien bridge oscillator feedback network

At low frequencies the reactance of the series capacitor (C1) is very high so acts like an open circuit and blocks any input signal at Vin. Therefore there is no output signal, Vout. At high frequencies, the reactance of the parallel capacitor, (C2) is very low so this parallel connected capacitor acts like a short circuit on the output so again there is no output signal. However, between these two extremes the output voltage reaches a maximum value with the frequency at which this happens being called the *Resonant Frequency*, (ƒr).

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

Generalized analysis of LC oscillators:

Many Oscillator Circuits fall in to the general form as shown in Fig The active device can be FET, transistor or operational amplifier, shows the equivalent circuit using an amplifier with negative gain Av and output resistance Ro. This is Voltage Series Feedback.

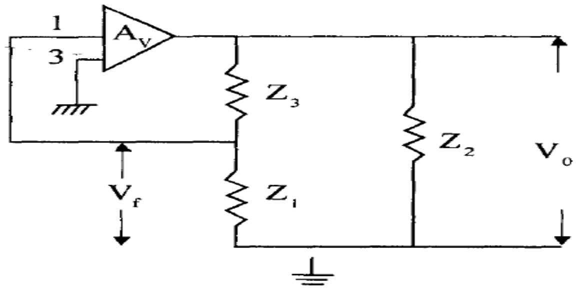


Fig: generalized LC oscillator

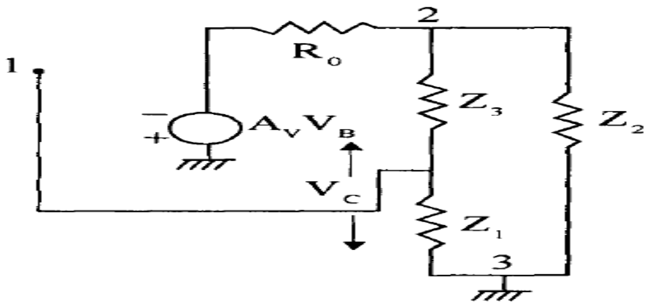


Fig: generalized LC oscillator modified circuit

$$\beta = \frac{-V_f}{V_0} = -\frac{Z_1}{Z_1 + Z_3}$$

Gain without feedback $$A = \frac{A_V Z_L}{Z_L + R_0}$$

$$-A\beta = \frac{A_V X_1 X_2}{-X_2(X_1 + X_3)} = -\frac{A_V X_1}{X_1 + X_3} = -\frac{A_V X_1}{X2} \quad \text{if } X_1+X_3=-X_2$$

So if X_1, X_2 are capacitive, X_3 is inductive

If XI and X2 are capacitors, the circuit is called Colpitts Oscillator

If XI and X2 are inductors, the circuit is called Hartely Oscillators

The Hartley Oscillator:

In the **Hartley Oscillator** the tuned LC circuit is connected between the collector and the base of a transistor amplifier. As far as the oscillatory voltage is concerned, the emitter is connected to a tapping point on the tuned circuit coil. The feedback part of the tuned LC tank circuit is taken from the centre tap of the inductor coil or even two separate coils in series which are in parallel with a variable capacitor, C as shown.

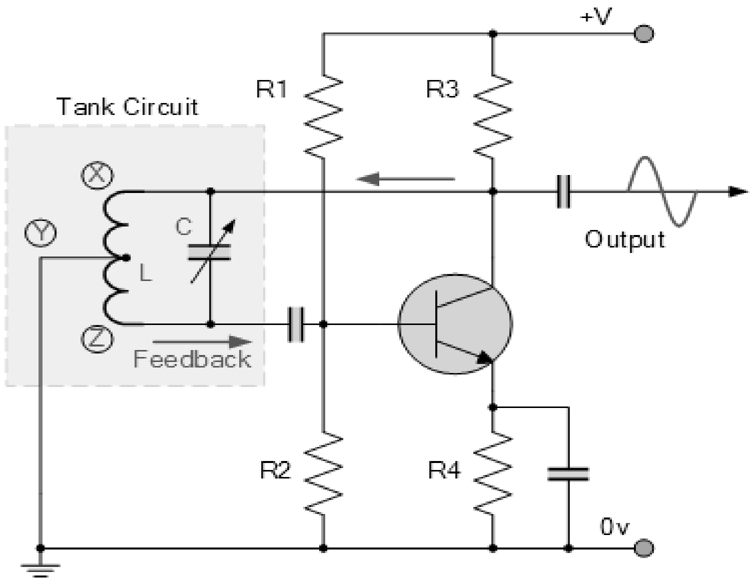


Fig: Hartley oscillator circuit

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

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

where $L_T = L_1 + L_2 + 2M$

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

COLPITTS OSCILLATOR:

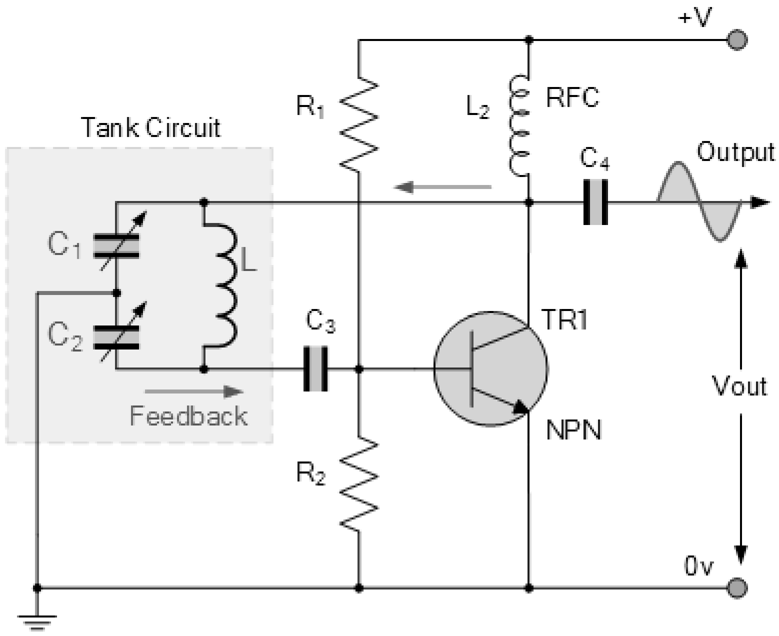


Fig: colpitts oscillator circuit

The emitter terminal of the transistor is effectively connected to the junction of the two capacitors, C1 and C2 which are connected in series and act as a simple voltage divider. When the power supply is firstly applied, capacitors C1 and C2 charge up and then discharge through the coil L. The oscillations across the capacitors are applied to the base-emitter junction and appear in the amplified at the collector output.

The frequency of oscillations for a Colpitts oscillator is determined by the resonant frequency of the LC tank circuit and is given as: $F = \frac{1}{2\pi\sqrt{LC_T}}$

Where C_T is the capacitance of C1 and C2 connected in series and is given as: $C_T = \frac{C_1 C_2}{C_1 + C_2}$

The configuration of the transistor amplifier is of a Common Emitter Amplifier with the output signal 180° out of phase with regards to the input signal. The additional 180° phase shift require for oscillation is achieved by the fact that the two capacitors are connected together in series but in parallel with the inductive coil resulting in overall phase shift of the circuit being zero or 360^o.

Crystal oscillator:

A crystal oscillator is basically a tuned-circuit oscillator using a piezoelectric crystal as a resonant tank circuit. The crystal (usually quartz) has a greater stability in holding constant at whatever frequency the crystal is originally cut to operate. Crystal oscillators are used whenever great stability is required, such as in communication transmitters and receivers.

Naturally available materials:

1. Quartz
2. Rochelle salt.

Synthetic materials:

1. Lithium sulphate
2. Ammonium-di-hydrogen phosphate, PZT(LeadZirconate Titanate), BaTi03 (Barium Titanate).

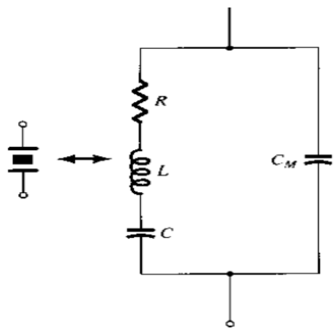


Fig: crystal equivalent circuit

A quartz crystal (one of a number of crystal types) exhibits the property that when mechanical stress is applied across the faces of the crystal, a difference of potential develops across opposite faces of the crystal. This property of a crystal is called the piezoelectric effect. Similarly, a voltage applied across one set of faces of the crystal causes mechanical distortion in the crystal shape. When alternating voltage is applied to a crystal, mechanical vibrations are set up—these vibrations having a natural resonant frequency dependent on the crystal. Although the crystal has electromechanical resonance, we can represent the crystal action by an equivalent electrical resonant circuit as shown in Fig.

Frequency and amplitude stability of oscillator:

Frequency stability is a measure of the ability of the circuit to maintain exactly the same frequency for which it is designed over a long time interval.

These factor are operating point parameters of the active device power source temperature variations output load mechanical variations

$$\text{Gain of oscillator}=\frac{V_0}{V_S}=\frac{AV_I}{V_I(1-A\beta)}=\frac{A}{1-A\beta}$$

If $A\beta=1$ the stability cannot be achieved since it produces oscillations with infinite amplitude In case of LC oscillators if inductor with zero resistance is not used then sustainable oscillations cannot be produced. Due to stray capacitance and lead inductance oscillations result, since the circuit conditions satisfy the bark hausen criterion. These oscillations are called as parasitic oscillations these result in high gain and high frequency due to the low value of L and C. These can be reduced by proper circuit layout and by isolation of components.

UNIT-2

Small Signal High Frequency Transistor Amplifier models

Logarithms, Decibels, General Frequency considerations, Frequency Response of BJT Amplifier, Analysis at Low and High Frequencies, Effect of Coupling and bypass Capacitors, The Hybrid-pi (π)-Common Emitter Transistor Model, CE short Circuit Current gain, Current gain with Resistive Load, Single Stage CE Transistor Amplifier response, Gain-Bandwidth Product, Emitter follower at higher frequencies, Illustrative design problems.

LOGARITHMS

Logarithms appear in all sorts of calculations in engineering and science, business and economics. Before the days of calculators they were used to assist in the process of multiplication by replacing the operation of multiplication by addition. Similarly, they enabled the operation of division to be replaced by subtraction. They remain important in other ways, one of which is that they provide the underlying theory of the logarithm function. This has applications in many fields, for example, the decibel scale in acoustics.

STANDARD BASES

There are two bases which are used much more commonly than any others and deserve special mention. These are base 10 and base e Logarithms to base 10, log10, are often written simply as log without explicitly writing a base down. So if you see an expression like log x you can assume the base is 10. Your calculator will be pre-programmed to evaluate logarithms to base 10. Look for the button marked log. The second common base is e. The symbol e is called the exponential constant and has a value approximately equal to 2.718. This is a number like π in the sense that it has an infinite decimal expansion. Base e is used because this constant occurs frequently in the mathematical modeling of many physical, biological and economic applications. Logarithms to base e,loge, are often written simply as ln. If you see an expression like lnx you can assume the base is e. Such logarithms are also called Naperian or natural logarithms. Your calculator will be pre-programmed to evaluate logarithms to base e. Look for the button marked ln.

DECIBELS

In many cases it is convenient to compare two powers on a logarithmic scale rather than on a linear scale. The unit of this logarithmic scale is called the decibel abbreviated as dB. Suppose P_2 is the output power and P_1 is the input power, then the power gain in decibels is

$$N = 10 \log_{10} \frac{P_2}{P_1}$$

Where N is in dbs.If N is negative, it means P_2 is less than P_1, Noise power is also expressed in decibels (dbs). It should be negative for a given device or amplifier i.e., the output noise is less than what is present in the input.

If for a given amplifier circuit, the input and output resistances are same (as R), then

$$P_1 = \frac{V_1^2}{R}, \quad P_2 = \frac{V_2^2}{R}$$

$$N = 20 \log \frac{V_2}{V_1} = 20 \log A_V$$

Where V_1 and V_2 are input and output voltages.

But even though, the input and output impedances are not equal, this convention is followed for convenience i.e., N = 20 log A_v, If A_v= 10, N = 20 log10 is 20 the decibel voltage gain of the amplifier. 20 is not the power gain because, the input resistances are not equal. Therefore 20 is the decibel voltage gain. If the output resistances are equal decibel voltage gain is equal, to power gain. Overall dB V of a multistage amplifier is equal to sum of dB V of individual stages.

GENERAL FREQUENCY CONSIDERATIONS

Amplifiers and filters are widely used electronic circuits that have the properties of amplification and filtration, hence their names. Amplifiers produce gain while filters alter the amplitude and/or phase characteristics of an electrical signal with respect to its frequency. As these amplifiers and filters use resistors, inductors, or capacitor networks (RLC) within their design, there is an important relationship between the use of these reactive components and the circuit's frequency response characteristics.

When dealing with AC Circuits it is assumed that they operate at a fixed frequency, for example either 50Hz or 60Hz. But the response of a linear AC circuit can also be examined with an AC or sinusoidal input signal of a constant magnitude but with a varying frequency such as those found in amplifier and filter circuits. This then allows such circuits to be studied using frequency response analysis.

Frequency Response of an electric or electronics circuit allows us to see exactly how the output gain (known as the *magnitude response*) and the phase (known as the *phase response*) changes at a particular single frequency, or over a whole range of different frequencies from 0Hz, (d.c.) to many thousands of mega-hertz, (MHz) depending upon the design characteristics of the circuit.

Generally, the frequency response analysis of a circuit or system is shown by plotting its gain that is the size of its output signal to its input signal, Output/Input against a frequency scale over which the circuit or system is expected to operate. Then by knowing the circuits gain, (or loss) at each frequency point helps us to understand how well (or badly) the circuit can distinguish between signals of different frequencies.

The frequency response of a given frequency dependent circuit can be displayed as a graphical sketch of magnitude (gain) against frequency (f). The horizontal frequency axis is usually plotted on a logarithmic scale while the vertical axis representing the voltage output or gain, is usually drawn as a linear scale in decimal divisions. Since a systems gain can be both positive and negative, the y-axis can therefore have both positive and negative values.

Frequency Response Curve:

Then we can see that the frequency response of any given circuit is the variation in its behavior with changes in the input signal frequency as it shows the band of frequencies over which the output (and the gain) remains fairly constant. The range of frequencies either big or small betweenf_L or f_H is called the circuits bandwidth. So from this we are able to determine at a glance the voltage gain (in dB) for any sinusoidal input within a given frequency range.

As mentioned above, the Bode diagram is a logarithmic presentation of the frequency response. Most modern audio amplifiers have a flat frequency response as shown above over the whole audio range of frequencies from 20 Hz to 20 kHz. This range of frequencies, for an audio amplifier is called its Bandwidth, (BW) and is primarily determined by the frequency response of the circuit.

Frequency points f_L and f_H relate to the lower corner or cut-off frequency and the upper corner or cut-off frequency points respectively were the circuits gain falls off at high and low frequencies. These points on a frequency response curve are known commonly as the -3dB (decibel) points. So the bandwidth is simply given as:

$$\text{Bandwidth, (BW)} = f_H - f_L$$

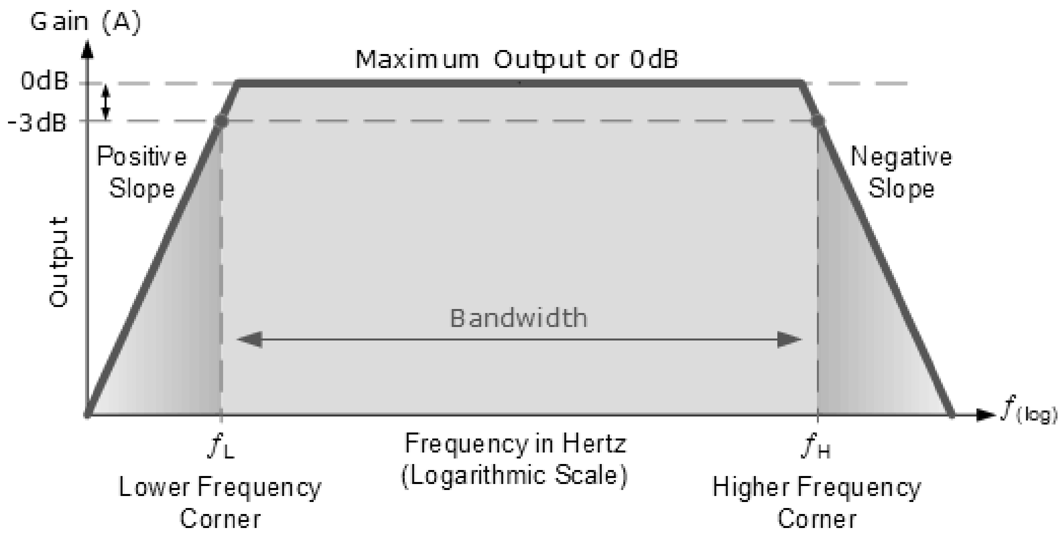
The decibel, (dB) which is 1/10th of a bel (B), is a common non-linear unit for measuring gain and is defined as $20\log_{10}(A)$ where A is the decimal gain, being plotted on the y-axis. Zero decibels, (0dB) correspond to a magnitude function of unity giving the maximum output. In other words, 0dB occurs when Vout = Vin as there is no attenuation at this frequency level and is given as:

$$\frac{V_{OUT}}{V_{IN}} = 1, \quad \therefore\ 20\log(1) = 0\text{dB}$$

We see from the Bode plot above that at the two corner or cut-off frequency points, the output drops from 0dB to -3dB and continues to fall at a fixed rate. This fall or reduction in gain is known commonly as the roll-off region of the frequency response curve. In all basic single order amplifier and filter circuits this roll-off rate is defined as 20dB/decade, which is an equivalent to a rate of 6dB/octave. These values are multiplied by the order of the circuit.

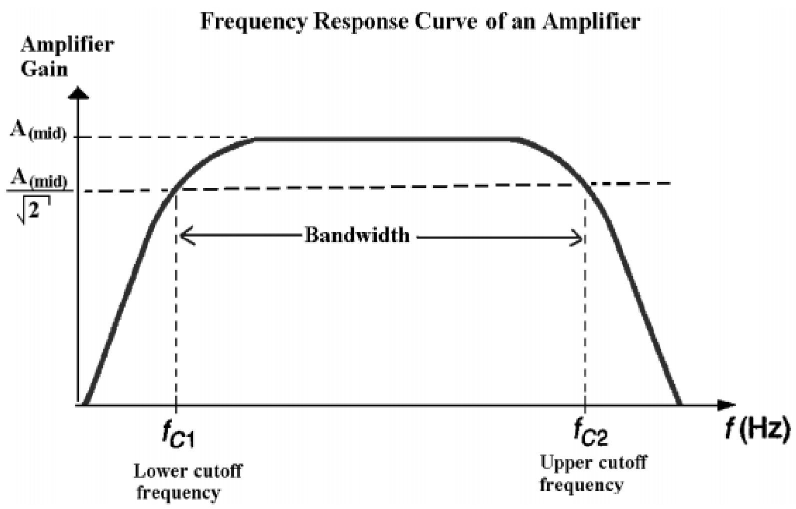
These -3dB corner frequency points define the frequency at which the output gain is reduced to 70.71% of its maximum value. Then we can correctly say that the -3dB point is also the frequency at which the systems gain has reduced to 0.707 of its maximum value.

Frequency Response -3dB Point:



FREQUENCY RESPONSE OF BJT AMPLIFIER

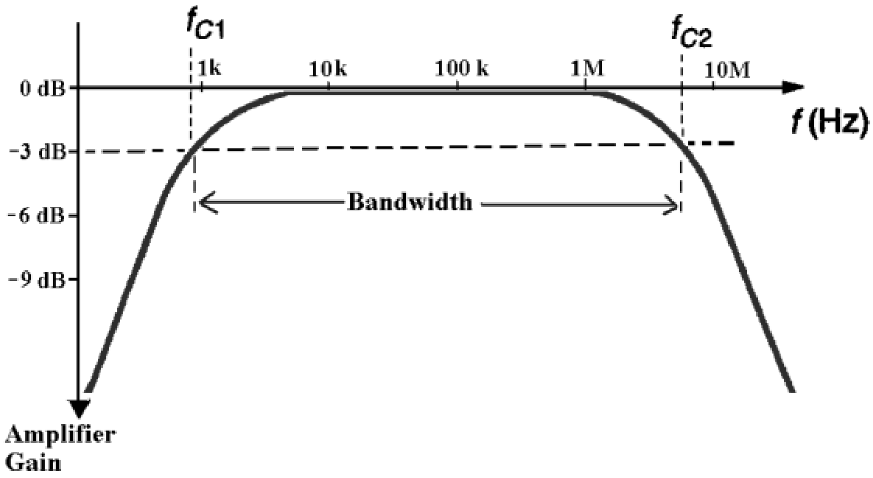
Most amplifiers have relatively constant gain over a certain range (band) of frequencies, this is called the bandwidth (BW) of the amplifier.



As the frequency response curve shows, the gain of an amplifier remains relatively constant across a band of frequencies. When the operating frequency starts to go outside this frequency range, the gain begins to drop off. Two frequencies of interest, fC1 and fC2, are identified as the lower and upper cutoff frequencies.

The Bandwidth is found as: BW = $f_{C2} - f_{C1}$ The operating frequency of an amplifier is equal to the geometric center frequency fo, fo = $\sqrt{(f_{C1}\, f_{C2})}$. Notice that the ration of fo to f_{C1} equals the ratio of f_{C2} to fo , this is: fo / f_{C1} = f_{C2} / fo Therefore we also have that: $f_{C1} = f_{o2} / f_{C2}$; $f_{C2} = f_{o2} / f_{C1}$

Frequency Response in dB



Analysis at Low Frequencies

We have

$$X_c = \frac{1}{2\pi RC} \quad \text{where } X_C \text{ ----- reactance of capacitor;}$$
$$\text{f-----frequency}$$

Since frequency is inversely proportional to the reactance, the reactance of the coupling capacitor C_C will be quite high at low frequencies.

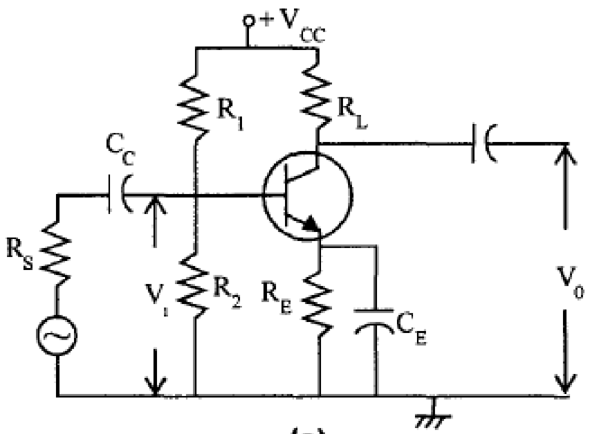
Hence very small amount of signal will pass through one stage to the next stage. Moreover C_E cannot shunt the emitter resistance R_E effectively because of its large reactance at low frequency. These two factors causes the fall of voltage gain at low frequencies.

ANALYSIS AT HIGH FREQUENCIES

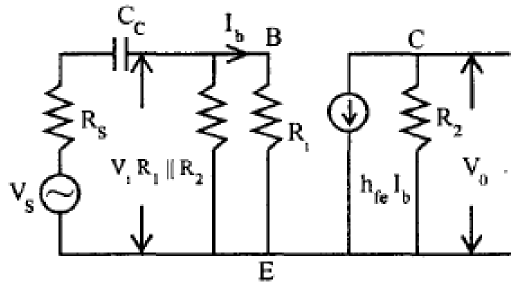
In this range of frequency, the reactance of the coupling capacitor C_C is very small and it behaves as a short circuit. This increases the loading effect of next stage (R_C will comes in parallel with R_1) and reduces the voltage gain. This reduces the current amplification there by the voltage drops at high frequencies.

EFFECT OF COUPLING CAPACITORS

Suppose that the value of CE is such that its effect on the frequency response can be neglected and the value of Xc at low frequencies is such that it is not a simple short circuit for A.C. signals, so that its effect has to be considered.



(a)



(b)

The effect of CE is, voltage drop across Cc will reduce Vi with a corresponding drop in Vo. The frequency at which the gain drops by a factor of f_i, is the lower 3 dB frequency.

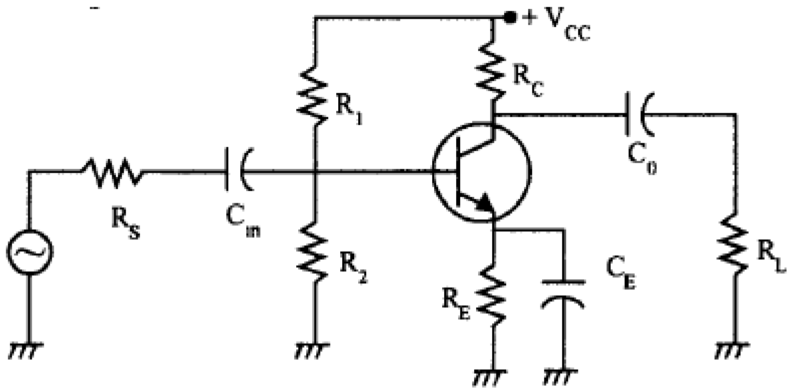
$$f_1 = \frac{1}{2\pi(R_S + R_i')C_C}$$

where $\quad R_i' = R_1 \parallel R_2 \parallel R_i$

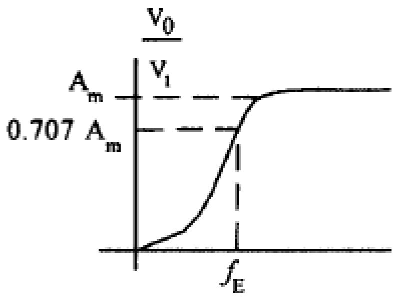
and $\quad R_i = h_{ie},$ for an ideal capacitor C_E.

These expressions are valid when emitter is bypassed. In AC equivalent circuit, emitter is assumed to be at GND potential. Therefore C_E has no effect.

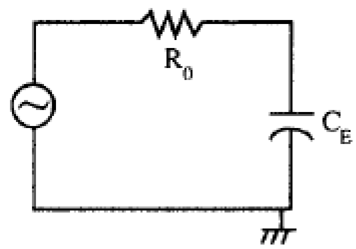
Effect of Bypass Capacitor



CE is the emitter bypass capacitor. This causes the frequency response of an amplifier to break at a cutoff frequency, designated C_e, To understand the effects of emitter bypass capacitor, suppose, C_{in} and C_o (coupling capacitor) are shorted, then the frequency response will be, as shown in above fig.



(a)



(b)

This means frequency response breaks at f_L , Thevenin's equivalent resistance driving Common Emitter, Rout is the Thevenin's resistance facing the capacitor.

$$\therefore \qquad R_{out} \simeq r_e' + \frac{R_S \| R_1 \| R_2}{\beta}$$

$$[i_e r_e' + i_e R_E - V_{in} + i_b (R_S \| R_1 \| R_2)] = 0$$

$$\because i_b = i_c / \beta, \ \cong i_e / \beta,$$

Solving for i_e, $$i_e \simeq \frac{V_{in}}{R_E + r_e' + (R_s \| R_1 \| R_2)/\beta}$$

The emitter resistor RE is driven by an AC source with an AC output resistance of

$$Z_O \text{ (emitter)} = r_e' + \frac{R_s \| R_1 \| R_2}{\beta}$$

The Hybrid-pi (π)

The **low frequency small signal model** of bipolar junction transistor crudely holds for frequencies below 1 MHz For frequencies greater than 1 MHz the response of the transistor will be limited by internal and parasitic capacitance's of the bipolar junction transistor. Hence at high frequencies the **low frequency small signal model of transistor** has to be modified to include the effects of internal and parasitic capacitance's of bipolar junction transistor.

This capacitance's limit the usage of BJT at higher frequencies. Thus in order to estimate the gain and switching on and off times of BJT at higher frequencies the **high frequency model of BJT** has to be used to get reasonably accurate estimates.

High frequency effects on BJT

- The gain decreases at high frequencies due to internal feedback capacitances. The highest frequency of operation of BJT will be limited by internal capacitances of BJT.
- The on and off switching times of BJT will be high and speed will be limited due to internal charge storage effects.

High frequency model of BJT

The high frequency parameters of BJT may vary with operating point but the variation is negligible for small signal variations around the operating point. Following is the high frequency model of a transistor.

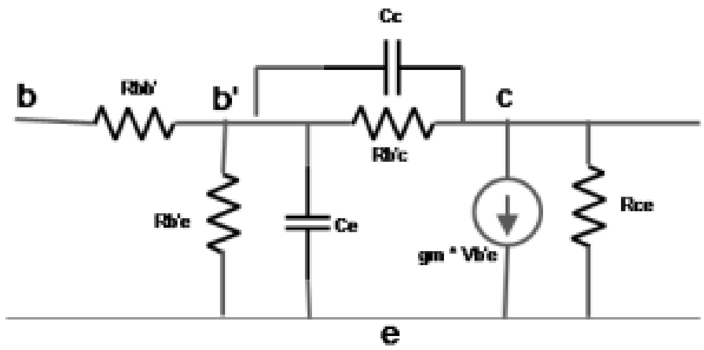


Fig. High frequency Model of BJT

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.

Physical explanation of parameters of high frequency model of BJT

$R_{bb'}$ is the base spreading resistance of BJT which represents the bulk resistance of the material between the base terminal and the physical inaccessible internal node of BJT. Typically it is of the order of 100's of ohms.

$R_{b'e}$ is the internal base node to emitter resistance. It accounts for the increase recombination base current as emitter current increases. It is in parallel with the collector circuit and hence reduces the collector current value from emitter current. This resistance will be high order of kilo ohms as the decrease in the collector current due to base recombination currents will be very less.

$R_{b'c}$ is the Feedback resistance from internal base node to collector node. It is included in the model to take in to account early effect. As collector to base reverse bias is increased (action) the effective width increases and collector current increases (feedback response).This feedback effect (early effect) is accounted for by $R_{b'c}$.

R_{ce} represents the bulk resistance of the material between collector to emitter.

C_e is the Diffusion capacitance of emitter base junction. Diffusion capacitance of emitter base junction is directly proportional to emitter bias current and forward base transit time. Forward transit time is defined as the average time the minority carrier spends in base. The Diffusion capacitance of emitter base junction accounts for the minority charge stored in base and is given as

$$C_e = \tau_F * I_E / V_T$$

Where I_E is emitter bias current

V_T is voltage equivalent of temperature = k*T/e =26 mV at 27 Deg C

τ_F is forward base transit time given as $\tau_F = W^2/(2*D_B)$

W is effective base width

D_B is diffusion constant for minority carriers in base holes in PNP transistor and electrons in NPN transistor.

C_e is a function of temperature as $D_B = V_T*\mu$ (μ varies as T^{-m}) is a function of temperature. C_e can be found theoretically from unit gain frequency and Tran conductance as follows

$$C_e = g_m/(2*pi*f_T)$$

Unity gain frequency is defined as frequency at which the current gain of transistor reduces to unity. The 3 dB higher cutoff frequency of BJT is termed as beta frequency of BJT denoted by f_β. The beta frequency and Unity gain frequency are related as

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

Where h_{fe} is current gain of BJT in CE configuration.

C_C represents the transition or space charge capacitance of base collector junction.

The transition capacitance of base collector junction is given as

$$C_j = C_o/(1+V_{CB}/V_{BV})^n$$

Where

C_o is the transition capacitance for zero collector to base bias

V_{CB} is collector to base bias

V_{BV} is the built in voltage across base collector junction

n is a constant called as grading coefficient varies from 0.25 to 0.5.

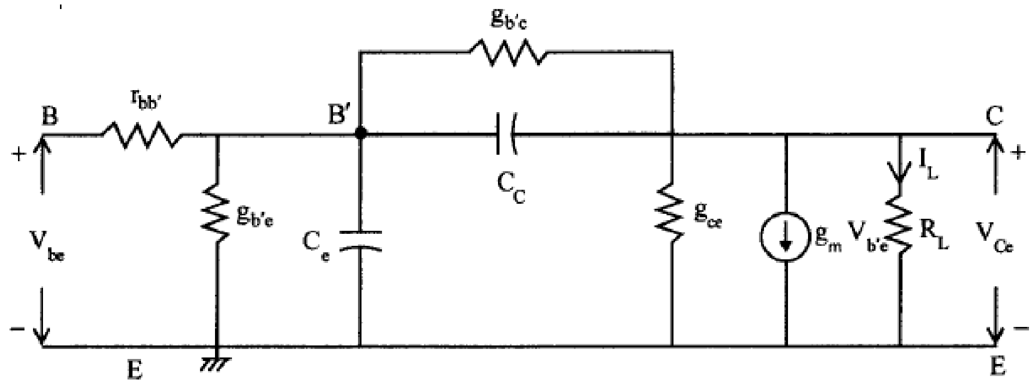
The high frequency hybrid Pi or Giacoletto model of BJT is valid for frequencies less than the unit gain frequency. High frequency model parameters of a BJT in terms of low frequency hybrid parameters

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.

CE short Circuit Current gain

Consider a single stage Common Emitter Transistor amplifier circuit. The hybrid-∏ equivalent circuit is as shown:



Current gain with Resistive Load

Single Stage CE Transistor Amplifier response

Gain-Bandwidth Product

$$A_{MF} = \frac{-h_{fe}}{h_{ie}}\left(\frac{R_C R_L}{R_C + R_L}\right)$$

$$\text{Bandwidth} = f_2 - f_1 \simeq f_2 \quad \because \quad f_1 \ll f_2$$

$$f_2 = \frac{1}{2\pi C_S \cdot \left(\frac{R_C \cdot R_L}{R_C + R_L}\right)}$$

The product of these two, (AMF and BW) is,

$$A \times f_2 = f_T = \frac{-h_{fe}}{h_{ie}} \times \frac{1}{2\pi C_S} = f_T$$

For a given value of CS, this product is constant.

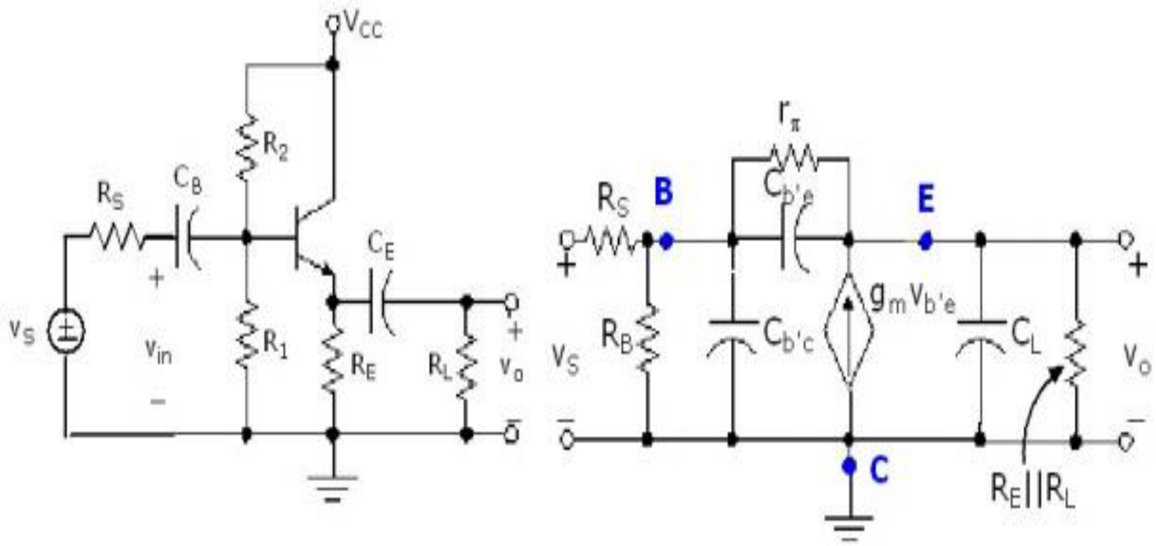
We can increase the voltage gain by increasing R_c, R_L parallel combination.

$$f_2 \propto \frac{1}{R_C \parallel R_L}$$

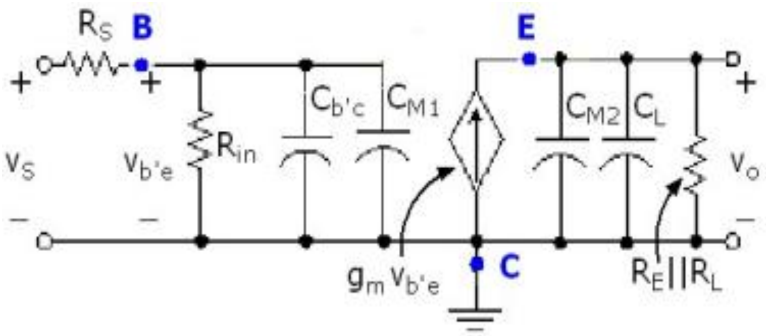
Therefore f_2 will reduce if A_{MF} is increased. *Therefore if voltage gain* RC//RL *Increases, Bandwidth decrease and vice versa.* f_1 can be increased without affecting voltage gain by reducing the value of Cs - But there is a limit to which Cs can be reduced. If higher gain is required then Bandwidth has to be sacrificed. It (B.W) will reduce. *The product of midband gain and Bandwidth* is *also known as the figure of Merit of the circuit.*

Emitter follower at higher frequencies

The generic circuit for the emitter follower (common collector) amplifier is given to the left below and the high frequency small signal circuit is shown below



The equivalent circuit using Miller's theorem is given in Figure in your text and is reproduced to the right, where



$$C_{M1} = C_{b'e}(1 - A_v)$$

$$C_{M2} = C_{b'e}\left(1 - \frac{1}{A_v}\right) \text{ and } R_{in} = R_B \,||\, [r_\pi + \beta(R_E \,||\, R_L)].$$

$$f_H = \frac{\omega_H}{2\pi} = \frac{1}{2\pi C_{b'c}(R_S \,||\, R_{in})}.$$

UNIT-3
MULTISTAGE AMPLIFIERS

Classification of Amplifiers- Distortion in amplifiers, Analysis of CE amplifier with Emitter Resistance and Emitter follower, Different Coupling Schemes used in Amplifiers- RC Coupled Amplifier, Direct and Transformer Coupled Amplifiers, Design of Single stage RC Coupled Amplifier Using BJT, Analysis of Cascaded RC Coupled BJT Amplifiers, Darlington Pair, Cascode Amplifier, Illustrative design problems.

CLASSIFICATION OF AMPLIFIERS:

Amplifier circuits are classified in different ways as indicated below:

Types of Classification

(a) Based on Frequency range

(b) Based on Type of coupling

(c) Based on Power delivered/conduction angle

(d) Based on Signal handled.

(a) Frequency Range:

AF (Audio Frequency)	: 40 Hz - 15/20 KHz
RF (Radio Frequency)	: >20 KHz
Video Frequency	: 5 -8 MHz
VLF (Very Low frequency)	:10-30 KHz
LF (Low Frequency)	:10 30 KHz
Medium Frequency	: 300 - 3000 KHz
High Frequency	: 3 -30 MHz
VHF (Very High Frequency)	:30-300 MHz
UHF (Ultra High Frequency)	:300 -3000 MHz
SHF (Super High Frequency)	:3000 - 30,000 MHz

(b) Types of Coupling:

1. Direct coupled
2. RC coupled
3. Transformer coupled
4. LC Tuned Amplifiers

5. Series fed.

(c) Output power delivered/conduction angle:

1. Low power (tens of mW or less).
2. Medium power (hundreds of mW).
3. High power (Watts).

Class A	-	360^0
Class B	-	180^0
Class AB	-	$180^0 - 360^0$
Class C	-	$< 180^0$
Class D	-	Switching type
Class S	-	Switching type.

(d) Type of signal handled:

1. Large signal
2. Small signal.

In addition to voltage amplification A_v, current amplification A_I or power amplification A_p is expected from an amplifier circuit. The amplifier circuit must also have other characteristics like High input impedance (Z_I or R_j), Low output impedance (Z_o or R_o), Large Band Width (BW), High Signal to Noise Ratio *(S/N),* and large *Figure of Merit (Gain BW product).*

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:

1. 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 the nonlinearity 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 10KHz signal. But some harmonic terms will also be present. Hence the amplitude of the signal (rms value) will be different $V_o = A_v V_i$. But it will be V_0^1.

2. Frequency distortion:

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

3. 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.

Analysis of CE amplifier:

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

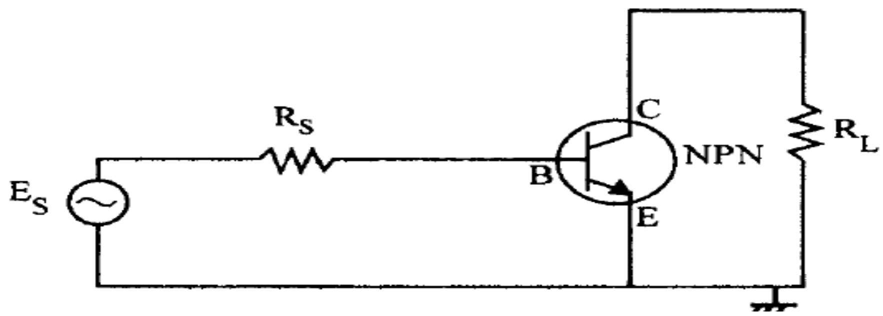


Fig. C.E. Amplifier

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

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

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

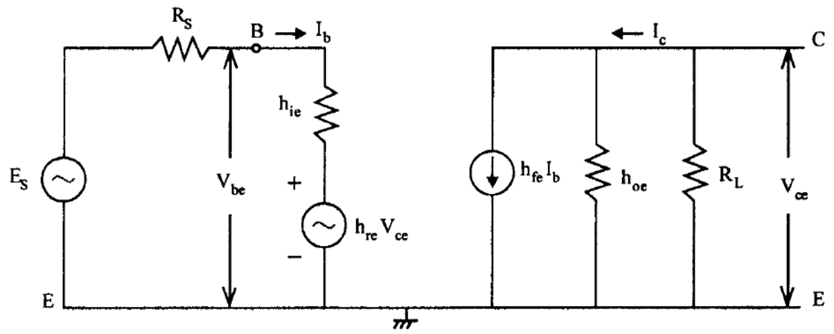


Fig. h- parameter Equivalent Circuit

Input Resistance of the Amplifier Circuit (R_i):

The general expression for RI in the case of Common Emitter Transistor Circuit is

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

R_i depends on R_L. If R_L is very small, $1/R_L$ is large, therefore the denominator in the second term is large or it can be neglected.

$$\therefore \qquad R_i \cong h_{1e}$$

If R_L increases, the second term cannot be neglected.

$$R_I = h_{ie} - \text{(finite value)}$$

Therefore, R_i decreases as R_L increases. If R_L is very large, $1/R_L$ will be negligible compared to h_{oe}.

Output Resistance of an Amplifier Circuit (R_0):

For Common Emitter Configuration,

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

Rs are the resistance of the source.

R_o depends on R_s. If R_s is very small compared to h_{ie},

$$R_o = \frac{1}{h_{oe} - \frac{h_{re}h_{fe}}{h_{ie}}} \quad \text{(independent of } R_s \text{)}$$

Current Gain (*A_I*):

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

If R_L is very small, A_i= $-h_{fe}$.So, Current Gain is large for Common Emitter Configuration.

As R_L increases, A_i drops and when R_L = infinite, A_i =0. Because, when R_L = infinite, output current I_0 or load current I_L = 0. Therefore, A_i = 0.

Voltage Gain (A_v):

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

If R_L is low, most of the output current flows through R_L. As R_L increases, output voltage increases and hence A_v increases. But if R_L>>(1/h_{oe}), then the current from the current generator in the h_{oe} *h-parameters* equivalent circuit flows through hoe and not R_L.

Power Gain (A_P):

As R_L increases, A_I decreases. As R_L increases, A_v also increases. Therefore, Power Gain which is the product of the two, A_V and A_I.

$$A_p = A_V A_I$$

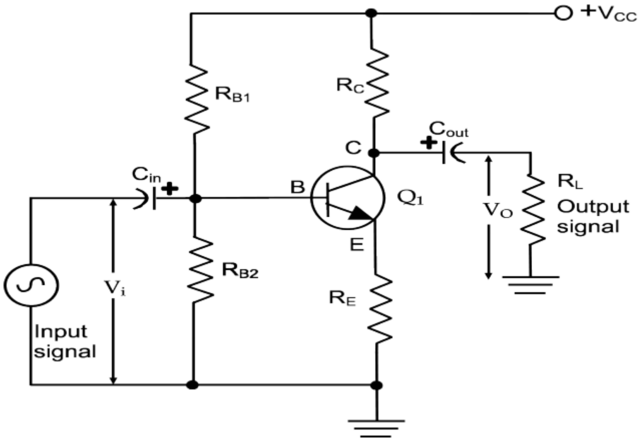
Therefore, it can be summarized as, Common Emitter Transistor Amplifier Circuit will have,

1. Low to Moderate Input Resistance.
2. Moderately High Output Resistance.
3. Large Current Amplification.
4. Large Voltage Amplification.
5. Large Power Gain.
6. 180^0 phase-shift between input and output voltages.

As the input current IB, increases, Ie increases therefore drop across Re increases and Vo = V_{cc} – (Voltage drop across Rc). Therefore, there is a phase shift of 180°.

Analysis of CE amplifier with Emitter Resistance:

The voltage gain of a CE stage depends upon h_{fe}. This transistor parameter depends upon temperature, aging and the operating point. Moreover, h_{fe} may vary widely from device to device, even for same type of transistor. To stabilize voltage gain A_V of each stage, it should be independent of h_{fe}. A simple and effective way is to connect an emitter resistor R_e as shown in. The resistor provides negative feedback and provide stabilization.



An approximate analysis of the circuit can be made using the simplified model. Subject to above approximation A_V is completely stable. The output resistance is infinite for the approximate model.

Analysis of Emitter follower

The simplified circuit diagram for AC of a transistor (BJT) in Common Collector Configuration is as shown in Fig. (without biasing resistors).

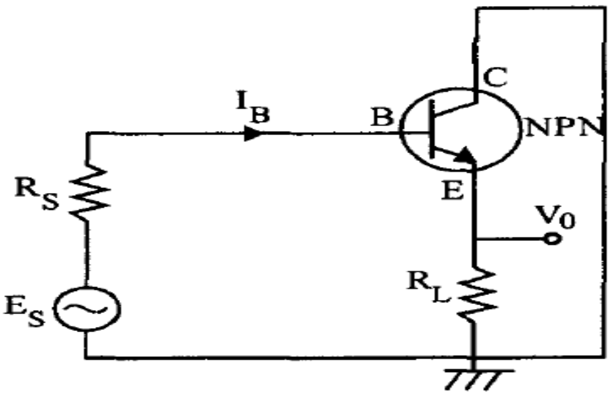


Fig. CC (emitter follower) Circuit

The *h-parameter* equivalent circuit of transistor in Common Collector Configuration is shown in below figure.

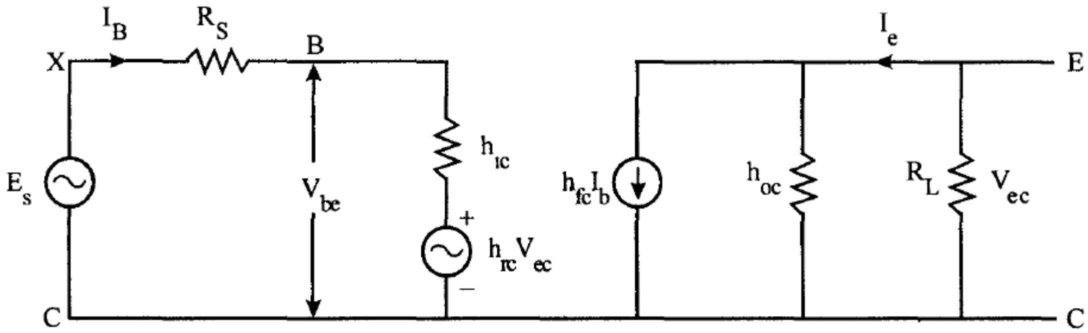


Fig. h-parameter Equivalent Circuit

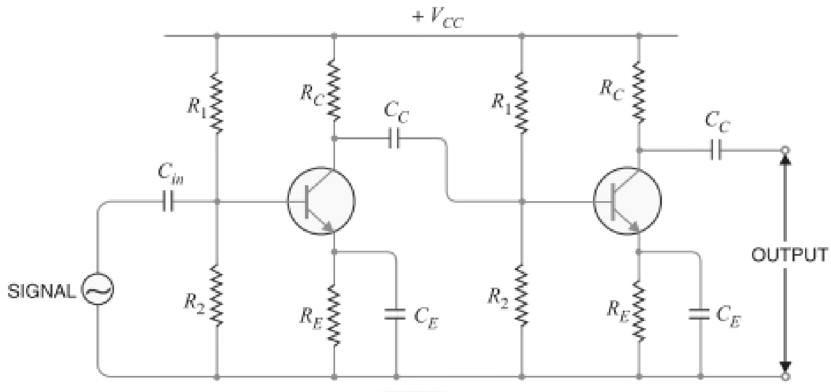
Different Coupling Schemes used in Amplifiers:

If the amplification obtained from single stage amplifiers is not sufficient, two or more such amplifiers are connected in Cascade or Series i.e., the output of the first stage will be the input to the second stage. This voltage is further amplified by the second stage and so we get large amplification or large output voltage compared to the input. In the multistage amplifiers, the output of the first stage should be coupled to the input of the second stage and so on: 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

RC Coupled Amplifier:

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 $_{RL}$ 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.



Advantages:

(i) It has excellent frequency response. The gain is constant over the audio frequency range which is the region of most importance for speech, music etc.

(ii) It has lower cost since it employs resistors and capacitors which are cheap.

(iii) The circuit is very compact as the modern resistors and capacitors are small and extremely light.

Disadvantages:

(i) The RC coupled amplifiers have low voltage and power gain. It is because the low resistance presented by the input of each stage to the preceding stage decreases the effective load resistance (RAC) and hence the gain.

(ii) They have the tendency to become noisy with age, particularly in moist climates.

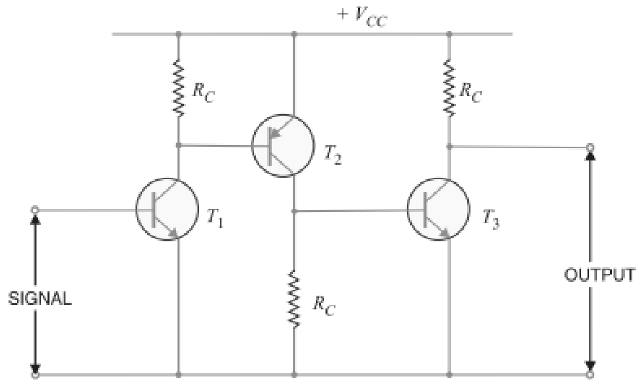
(iii) Impedance matching is poor. It is because the output impedance of RC coupled amplifier is several hundred ohms whereas the input impedance of a speaker is only a few ohms. Hence, little power will be transferred to the speaker.

Applications:

The RC coupled amplifiers have excellent audio fidelity over a wide range of frequency. Therefore, they are widely used as voltage amplifiers e.g. in the initial stages of public address system. If other type of coupling (e.g. transformer coupling) is employed in the initial stages, this results in frequency distortion which may be amplified in next stages. However, because of poor impedance matching, RC coupling is rarely used in the final stages.

Direct Coupled Amplifier:

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 can not be used for amplifications of DC or low frequency signals since X_c the capacitive reactance of the coupling capacitor will be very large or open circuit for DC.



Advantages:

(i) The circuit arrangement is simple because of minimum use of resistors.

(ii) The circuit has low cost because of the absence of expensive coupling devices.

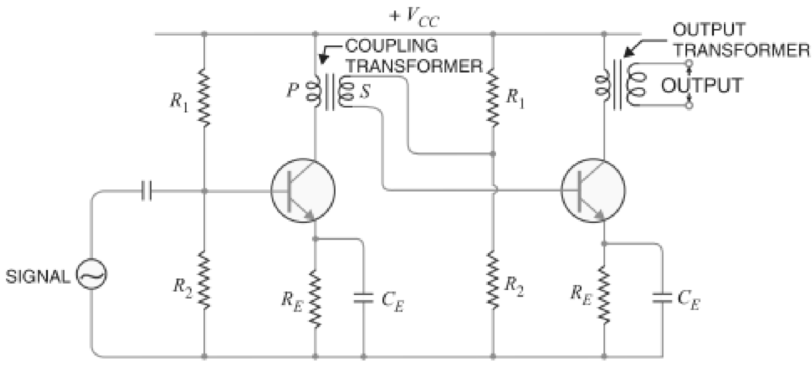
Disadvantages:

(i) It cannot be used for amplifying high frequencies.

(ii) The operating point is shifted due to temperature variations.

Transformer Coupled Amplifiers:

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 (.: $N_2/N_1= V_2/V_1$) 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.



Advantages:

(i) No signal power is lost in the collector or base resistors.

(ii) An excellent impedance matching can be achieved in a transformer coupled amplifier. It is easy to make the inductive reactance of primary equal to the output impedance of the transistor and inductive reactance of secondary equal to the input impedance of next stage.

(iii) Due to excellent impedance matching, transformer coupling provides higher gain. As a matter of fact, a single stage of properly designed transformer coupling can provide the gain of two stages of RC coupling.

Disadvantages

(i) It has a poor frequency response i.e. the gain varies considerably with frequency.

(ii) The coupling transformers are bulky and fairly expensive at audio frequencies.

(iii) Frequency distortion is higher i.e. low frequency signals are less amplified as compared to the high frequency signals.

(iv) Transformer coupling tends to introduce *hum in the output.

Applications:

Transformer coupling is mostly employed for impedance matching. In general, the last stage of a multistage amplifier is the power stage. Here, a concentrated effort is made to transfer maximum power to the output device e.g. a loudspeaker. For maximum power transfer, the impedance of power source should be equal to that of load. Usually, the impedance of an output device is a few ohms whereas the output impedance of transistor is several hundred times this value.

In order to match the impedance, a step-down transformer of proper turn ratio is used. The impedance of secondary of the transformer is made equal to the load impedance and primary impedance equal to the output impedance of transistor.

Comparison of three different coupling schemes:

S. No	Particular	*RC* coupling	Transformer coupling	Direct coupling
1.	*Frequency response*	Excellent in the audio frequency range	Poor	Best
2.	*Cost*	Less	More	Least
3.	*Space and weight*	Less	More	Least
4.	*Impedance matching*	Not good	Excellent	Good
5.	*Use*	For voltage amplification	For power amplification	For amplifiying extremely low frequencies

Darlington Pair:

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 its $A_v << 1$.

If the input impedance of the amplifier circuit is to be only 500 kohms or less the Common Collector Configuration can be used. But if still higher input impedance is required a circuit shown in below Fig. is used. This circuit is known as the *Darlington Connection* (named after Darlington) or *Darlington Pair Circuit.*

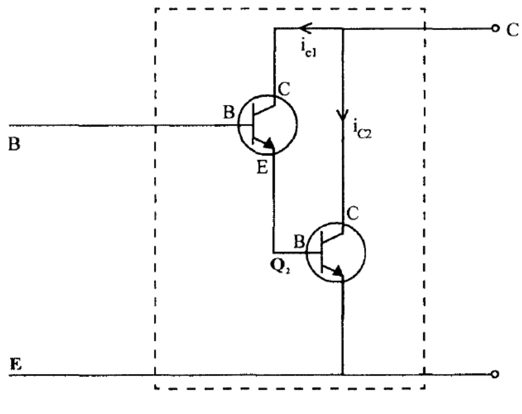


Fig. Darlington Pair Circuit

In this circuit, the two transistors are in Common Collector Configuration. The output of the first transistor Q1 (taken from the emitter of the Q1) is the input to the second transistor Q2 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.

Current Amplification for Darlington Pair:

$$I_c = I_{c1} + I_{c2}.$$
$$I_{c1} = I_{b1}\, h_{fe};$$
$$I_{c_2} = I_{b_2}\, h_{fe}. \text{ (Assuming identical transistor and } h_{fe} \text{ is same)}$$
But $$I_{b_2} = I_{e_1} \text{ (The emitter of } Q_1 \text{ is connected to the base of } Q_2\text{)}$$
$$\therefore \quad I_c = I_{b1}\, h_{fe} + I_{e1}\, h_{fe} \quad \text{.....(1)}$$
$$I_{e_1} = I_{b_1} + I_{c_1} = I_{b_1}(1 + h_{fe}) \quad \text{.....(2)}$$
$$\therefore \quad I_{c_1} = h_{fe}\, I_{b_1}$$

Substituting equation (2) in (1),

$$I_c = I_{b_1}\, h_{fe} + I_{b_1}(1 + h_{fe})h_{fe} = I_{b_1}(2h_{fe} + h_{fe}^2)$$

It means that we get very large current amplification ($A_I = I_c/I_{b1}$) in the case of Darlington Pair Circuit, it is of the order $h_{fe}{}^2$ i.e. $l00^2$ = l0,000.

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

Input Resistance (Ri):

Input resistance R_{i2} of the transistor Q_2 (which is in Common Collector Configuration) in terms of h- parameters in Common Emitter Configuration is,

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

Therefore, Darlington Circuit has very high input impedance and very large current gain Compared to Common Collector Configuration Circuit.

Voltage Gain (Av):

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

Therefore, A_v is always less than 1.

Output Resistance (R_0):

R_{02} is the output resistance of the Darlington Circuit.

$$\therefore \qquad R_{02} = \frac{R_s + h_{ie}}{(1+h_{fe})^2} + \frac{h_{ie}}{1+h_{fe}}$$

Therefore, the characteristic of Darlington Circuit are
1. Very High Input Resistance (of the order of Mega ohm).
2. Very Large Current Gain (of the order of 10,000).
3. Very Low Output Resistance (of the order of few ohms).
4. Voltage Gain, Av < 1.

Darlington Pairs are available in a single package with just three leads, like one transistor in integrated form.

Disadvantages:

We have assumed that the *h-parameters* of both the transistors are identical. But in practice it is difficult to make *h-parameters* depend upon the operating point of Q1 and Q2,Since the emitter current of transistor Q1 is the base current for transistor Q2, the value of $I_{C2} >> I_{C1}$.
1. The quiescent or operating conditions of both the transistors will be different. h_{ie} value will be small for the transistor Q1.

2. The second drawback is leakage current of the first transistor Q1 which is amplified by the Second transistor Q2.

Hence overall leakage current is more. Leakage Current is the current that flows in the circuit with no external bias voltages applied.

(a) The h-parameters for both the transistors will not be the same.

(b) Leakage Current is more.

Darlington transistor pairs are in single package available with hje as high as 30,000.

Cascode Amplifier:

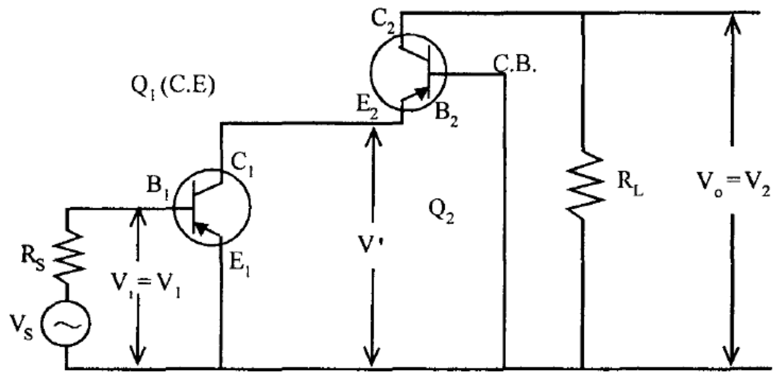


Fig. CASCODE Amplifier (C.E, C.B configuration)

The circuit is shown in Fig. 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 Q2. The transistor Q1 is in Common Emitter Configuration and transistor Q2 is in Common Base Configuration. Let us consider the input impedance (h))) etc., output admittance (h22) i.e. the *h - parameters* of the entire circuit in terms of the *Ir - parameters* of the two transistors.

Input impedance:

$$\boxed{h_i = h_{ie}}$$

Short Circuit Current Gain

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

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

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

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

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

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

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

Therefore, for a CASCODE Transistor Configuration, its input Z is equal to that of a single Common Emitter Transistor (h_{ie}), 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 h_{ie} and h_{fe} are same) with negligible internal feedback (:. h_{re} is very small) and very small output conductance, (== h_{ob}) or large output resistance (== 2MOhm equal to that of a Common Base Stage).

The above values are correct, if we make the assumption that hob RL < 0.1 or RL is < 200K. When the value of RL is < 200 K. This will not affect the values of h_i, h_r,h_o,h_f of the CASCODE Transistor, since, the value of h_r is very small.

CASCODE Amplifier will have

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

UNIT-4
POWER AMPLIFIERS

Classification, Series fed Class A Power Amplifier, Transformer Coupled Class A Amplifier, Efficiency, Push Pull Amplifier- Complementary Symmetry Class-B Power Amplifier, Amplifier Distortion, Power Transistor Heat sinking, Class C and Class D Power amplifiers, Illustrative design problems.

CLASSIFICATION

The classification of an amplifier as either a voltage or a power amplifier is made by comparing the characteristics of the input and output signals by measuring the amount of time in relation to the input signal that the current flows in the output circuit. We saw in the Common Emitter transistor tutorial that for the transistor to operate within its "Active Region" some form of "Base Biasing" was required. This small Base Bias voltage added to the input signal allowed the transistor to reproduce the full input waveform at its output with no loss of signal. However, by altering the position of this Base bias voltage, it is possible to operate an amplifier in an amplification mode other than that for full waveform reproduction. By changing the amplifiers Base bias voltage different ranges or modes of operation can be obtained and these are categorized according to their Classification better known as Amplifier Class.

Audio power amplifiers are classified in an alphabetical order according to their circuit configurations and mode of operation. Amplifiers are designated by different classes of operation such as class "A", class "B", class "C", class "AB", etc. These different classes of operation range from a near linear output but with low efficiency to a non-linear output but with a high efficiency. No one class of operation is "better" or "worse" than any other class with the type of operation being determined by the use of the amplifying circuit. There are typical maximum efficiencies for the various types or class of amplifier, with the most commonly used being:

Class A - has low efficiency of less than 40% but good signal reproduction and linearity.

Class B - is twice as efficient as class A amplifiers with a maximum theoretical efficiency of about 70% because the amplifying device only conducts (and uses power) for half of the input signal.

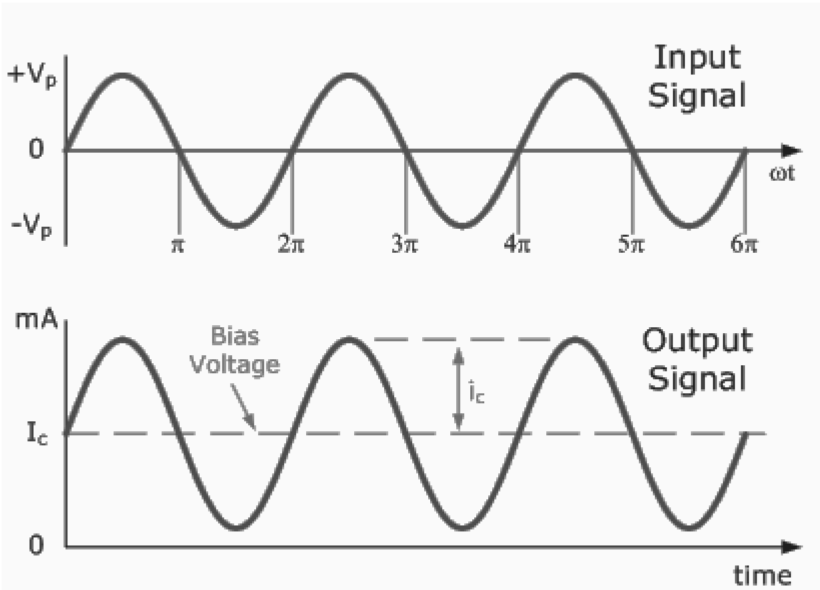
Class AB - has an efficiency rating between that of Class A and Class B but poorer signal reproduction than class A amplifiers.

Class C - is the most efficient amplifier class as only a very small portion of the input signal is amplified therefore the output signal bears very little resemblance to the input signal. Class C amplifiers have the worst signal reproduction.

Class A Operation:

Class A Amplifier operation is where the entire input signal waveform is faithfully reproduced at the amplifiers output as the transistor is perfectly biased within its active region, thereby never reaching either of its Cut-off or Saturation regions. This then results in the AC input signal being perfectly "centered" between the amplifiers upper and lower signal limits as shown below.

Class A Output Waveform



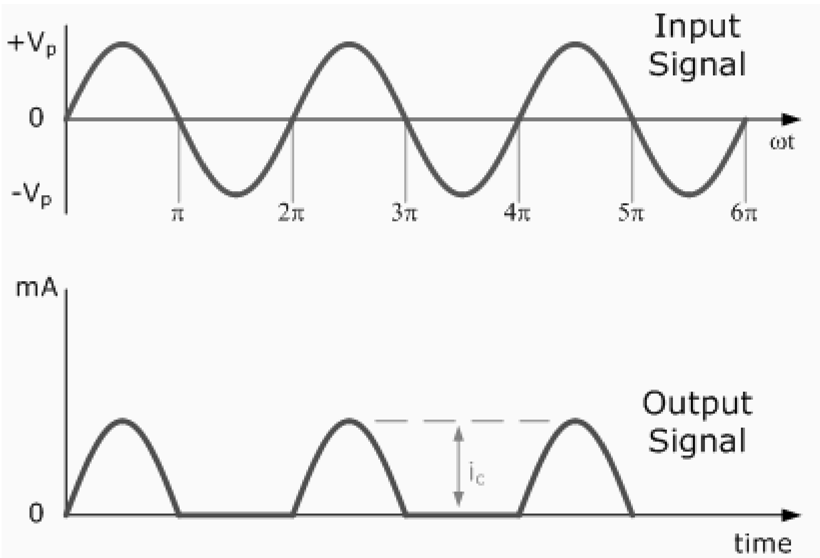
In this configuration, the Class A amplifier uses the same transistor for both halves of the output waveform and due to its biasing arrangement the output transistor always has current flowing through it, even if there is no input signal. In other words the output transistors never turns "OFF". This results in the class A type of operation being very inefficient as its conversion of the DC supply power to the AC signal power delivered to the load is usually very low. Generally, the output transistor of a Class A amplifier gets very hot even when there is no input signal present so some form of heat sinking is required. The DC current flowing through the output transistor (I_c) when there is no output signal will be equal to the current flowing through the load. then a pure Class A amplifier is very inefficient.

Class B Operation:

Unlike the Class A amplifier above that uses a single transistor for its output stage, the Class B Amplifier uses two complimentary transistors (an NPN and a PNP) for each half of the output waveform. One transistor conducts for the positive half of the waveform and another conducts for the negative half of the waveform. This means that each transistor spends half of its time in the active region and half its time in the Cut-off region thereby amplifying only 50% of the input signal.

Class B operation has no DC bias voltage instead the transistor only conducts when the input signal is greater than the base-emitter voltage and for silicon devices is about 0.7v. Therefore, at zero input there is zero output. This then results in only half the input signal being presented at the amplifiers output giving a greater efficiency as shown below.

Class B Output Waveform



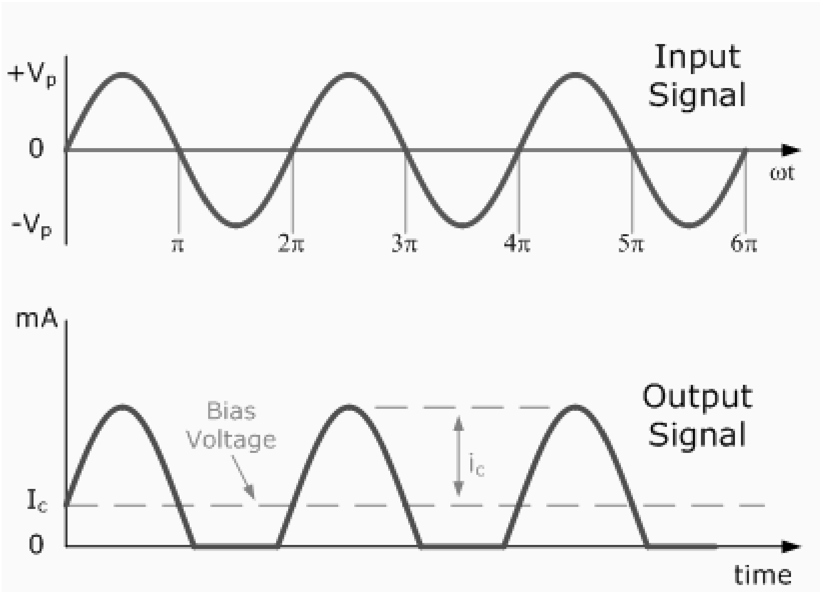
In a class B amplifier, no DC current is used to bias the transistors, so for the output transistors to start to conduct each half of the waveform, both positive and negative, they need the base-emitter voltage Vbe to be greater than the 0.7v required for a bipolar transistor to start conducting. Then the lower part of the output waveform which is below this 0.7v window will not be reproduced accurately resulting in a distorted area of the output waveform as one transistor turns "OFF" waiting for the other to turn back "ON". The result is that there is a small part of the output waveform at the zero voltage cross over point which will be distorted. This type of distortion is called Crossover Distortion and is looked at later on in this section.

Class AB Operation:

The Class AB Amplifier is a compromise between the Class A and the Class B configurations above. While Class AB operation still uses two complementary transistors in its output stage a very small biasing voltage is applied to the Base of the transistor to bias it close to the Cut-off region when no input signal is present. An input signal will cause the transistor to operate as normal in its Active region thereby eliminating any crossover distortion which is present in class B configurations.

A small Collector current will flow when there is no input signal but it is much less than that for the Class A amplifier configuration. This means then that the transistor will be "ON" for more than half a cycle of the waveform. This type of amplifier configuration improves both the efficiency and linearity of the amplifier circuit compared to a pure Class A configuration.

Class AB Output Waveform



The class of operation for an amplifier is very important and is based on the amount of transistor bias required for operation as well as the amplitude required for the input signal. Amplifier classification takes into account the portion of the input signal in which the transistor conducts as well as determining both the efficiency and the amount of power that the switching transistor both consumes and dissipates in the form of wasted heat. Then we can make a comparison between the most common types of amplifier classifications in the following table.

Power Amplifier Classes

Class	A	B	C	AB
Conduction Angle	360^o	180^o	Less than 90^o	180 to 360^o
Position of the Q-point	Centre Point of the Load Line	Exactly on the X-axis	Below the X-axis	In between the X-axis and the Centre Load Line
Overall Efficiency	Poor, 25 to 30%	Better, 70 to 80%	Higher than 80%	Better than A but less than B 50 to 70%
Signal Distortion	None if Correctly Biased	At the X-axis Crossover Point	Large Amounts	Small Amounts

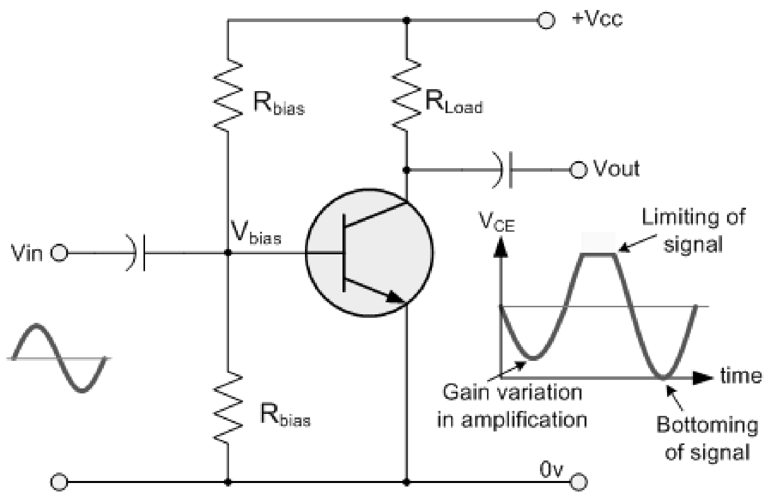
Badly designed amplifiers especially the Class "A" types may also require larger power transistors, more expensive heat sinks, cooling fans, or even an increase in the size of the power supply required to deliver the extra power required by the amplifier. Power converted into heat from transistors, resistors or any other component for that matter, makes any electronic circuit inefficient and will result in the premature failure of the device. So why use a Class A amplifier if its efficiency is less than 40% compared to a Class B amplifier that has a higher efficiency rating of over 70%. Basically, a Class A amplifier gives a much more linear output meaning that it has, Linearity over a larger frequency response even if it does consume large amounts of DC power.

AMPLIFIER DISTORTION:

From the previous tutorials we learnt that for a signal amplifier to work correctly it requires some form of DC Bias on its Base or Gate terminal so that it amplifies the input signal over its entire cycle with the bias "Q-point" set as near to the middle of the load line as possible. This then gave us a "Class-A" type amplification with the most common configuration being Common Emitter for Bipolar transistors and Common Source for unipolar transistors. We also saw that the Power, Voltage or Current Gain, (amplification) provided by the amplifier is the ratio of the peak input value to its peak output value.

However, if we incorrectly design our amplifier circuit and set the biasing Q-point at the wrong position on the load line or apply too large an input signal, the resultant output signal may not be an exact reproduction of the original input signal waveform. In other words the amplifier will suffer from distortion. Consider the common emitter amplifier circuit below.

Common Emitter Amplifier



Distortion of the signal waveform may take place because:

1. Amplification may not be taking place over the whole signal cycle due to incorrect biasing.
2. The input signal may be too large, causing the amplifier to limit.
3. The amplification may not be linear over the entire frequency range of inputs.

This means then that during the amplification process of the signal waveform, some form of Amplifier Distortion has occurred.

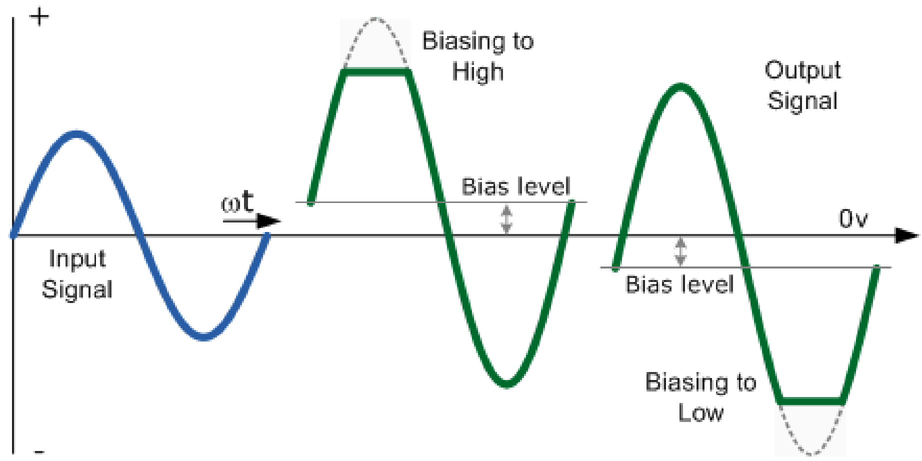
Amplifiers are basically designed to amplify small voltage input signals into much larger output signals and this means that the output signal is constantly changing by some factor or value times the input signal for all input frequencies. We saw previously that this multiplication factor is called the Beta, β value of the transistor.

Common emitter or even common source type transistor circuits work fine for small AC input signals but suffer from one major disadvantage, the bias Q-point of a bipolar amplifier depends on the same Beta value which may vary from transistors of the same type, ie. the Q-point for one transistor is not necessarily the same as the Q-point for another transistor of the same type due to the inherent manufacturing tolerances. If this occurs the amplifier may not be linear and Amplitude Distortion will result but careful choice of the transistor and biasing components can minimize the effect of amplifier distortion.

AMPLITUDE DISTORTION:

Amplitude distortion occurs when the peak values of the frequency waveform are attenuated causing distortion due to a shift in the Q-point and amplification may not take place over the whole signal cycle. This non-linearity of the output waveform is shown below.

Amplitude Distortion due to Incorrect Biasing

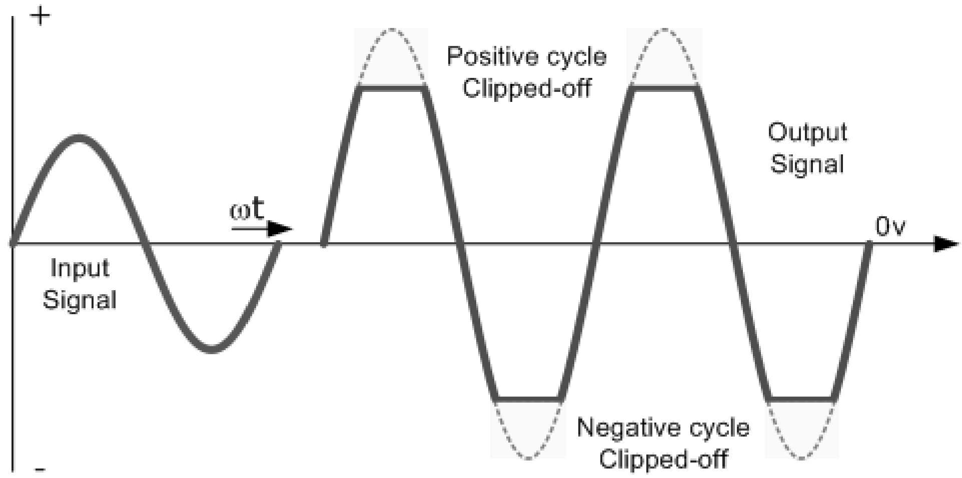


If the bias is correct the output waveform should look like that of the input waveform only bigger, (amplified). If there is insufficient bias the output waveform will look like the one on the right with the negative part of the output waveform "cut-off". If there is too much bias the output waveform will look like the one on the left with the positive part "cut-off". When the bias voltage is too small, during the negative part of the cycle the transistor does not conduct fully so the output is set by the supply voltage. When the bias is too great the positive part of the cycle saturates the transistor and the output drops almost to zero.

Even with the correct biasing voltage level set, it is still possible for the output waveform to become distorted due to a large input signal being amplified by the circuits gain. The output voltage signal becomes clipped in both the positive and negative parts of the waveform an no longer resembles a sine wave, even when the bias is correct. This type of amplitude distortion is called Clipping and is the result of "Over-driving" the input of the amplifier.

When the input amplitude becomes too large, the clipping becomes substantial and forces the output waveform signal to exceed the power supply voltage rails with the peak (+ve half) and the trough (-ve half) parts of the waveform signal becoming flattened or "Clipped-off". To avoid this the maximum value of the input signal must be limited to a level that will prevent this clipping effect as shown above.

Amplitude Distortion due to Clipping



Amplitude Distortion greatly reduces the efficiency of an amplifier circuit. These "flat tops" of the distorted output waveform either due to incorrect biasing or over driving the input do not contribute anything to the strength of the output signal at the desired frequency. Having said all that, some well known guitarist and rock bands actually prefer that their distinctive sound is highly distorted or "overdriven" by heavily clipping the output waveform to both the +ve and -ve power supply rails. Also, excessive amounts of clipping can also produce an output which resembles a "square wave" shape which can then be used in electronic or digital circuits.

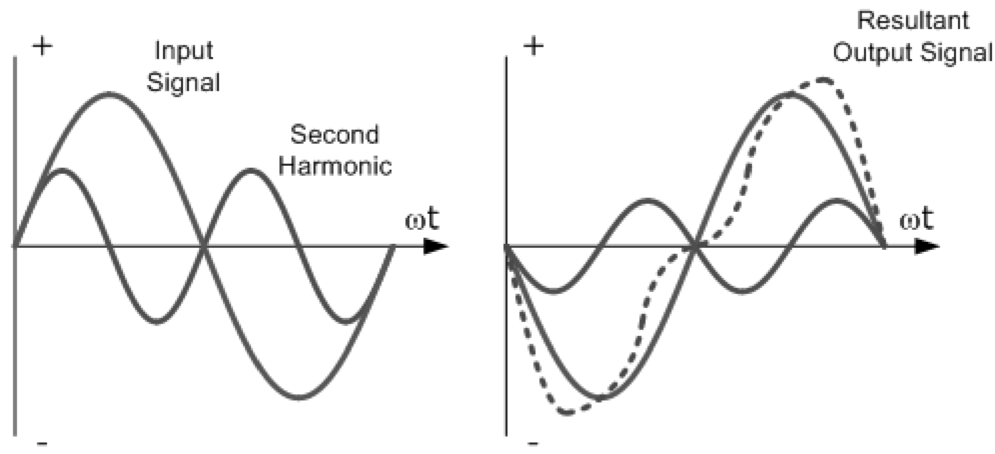
We have seen that with a DC signal the level of gain of the amplifier can vary with signal amplitude, but as well as Amplitude Distortion, other types of distortion can occur with AC signals in amplifier circuits, such as Frequency Distortion and Phase Distortion.

FREQUENCY DISTORTION:

Frequency Distortion occurs in a transistor amplifier when the level of amplification varies with frequency. Many of the input signals that a practical amplifier will amplify consist of the required signal waveform called the "Fundamental Frequency" plus a number of different frequencies called

"Harmonics" superimposed onto it. Normally, the amplitude of these harmonics are a fraction of the fundamental amplitude and therefore have very little or no effect on the output waveform. However, the output waveform can become distorted if these harmonic frequencies increase in amplitude with regards to the fundamental frequency. For example, consider the waveform below:

Frequency Distortion due to Harmonics

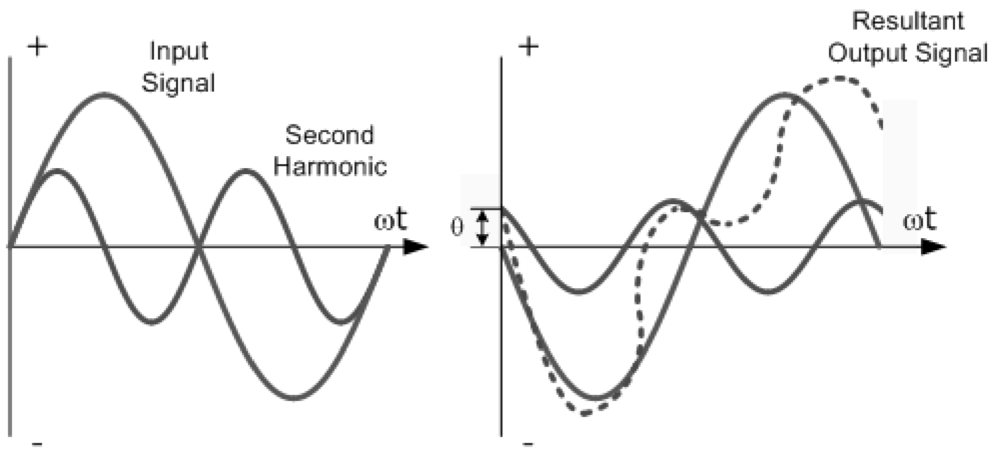


In the example above, the input waveform consists of a fundamental frequency plus a second harmonic signal. The resultant output waveform is shown on the right hand side. The frequency distortion occurs when the fundamental frequency combines with the second harmonic to distort the output signal. Harmonics are therefore multiples of the fundamental frequency and in our simple example a second harmonic was used. Therefore, the frequency of the harmonic is 2 times the fundamental, 2 x f or 2f. Then a third harmonic would be 3f, a fourth, 4f, and so on. Frequency distortion due to harmonics is always a possibility in amplifier circuits containing reactive elements such as capacitance or inductance.

PHASE DISTORTION:

Phase Distortion or Delay Distortion occurs in a non-linear transistor amplifier when there is a time delay between the input signal and its appearance at the output. If we call the phase change between the input and the output zero at the fundamental frequency, the resultant phase angle delay will be the difference between the harmonic and the fundamental. This time delay will depend on the construction of the amplifier and will increase progressively with frequency within the bandwidth of the amplifier. For example, consider the waveform below:

Phase Distortion due to Delay



Any practical amplifier will have a combination of both "Frequency" and "Phase" distortion together with amplitude distortion but in most applications such as in audio amplifiers or power amplifiers, unless the distortion is excessive or severe it will not generally affect the operation of the system.

In the next tutorial about Amplifiers we will look at the Class A Amplifier. Class A amplifiers are the most common type of amplifier output stage making them ideal for use in audio power amplifiers.

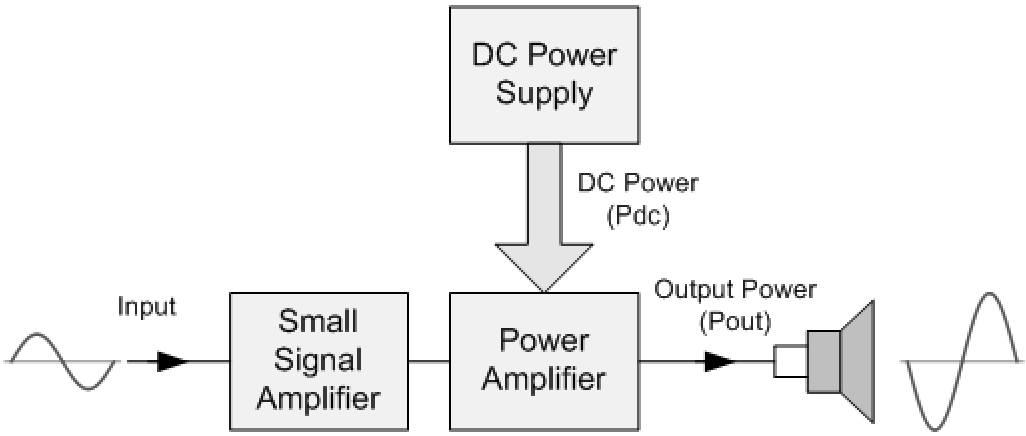
Class A Amplifier:

Common emitter amplifiers are the most commonly used type of amplifier as they have a large voltage gain. They are designed to produce a large output voltage swing from a relatively small input signal voltage of only a few milli volt's and are used mainly as "small signal amplifiers" as we saw in the previous tutorials. However, sometimes an amplifier is required to drive large resistive loads such as a loudspeaker or to drive a motor in a robot and for these types of applications where high switching currents are needed Power Amplifiers are required.

The main function of the power amplifier, which are also known as a "large signal amplifier" is to deliver power, which is the product of voltage and current to the load. Basically a power amplifier is also a voltage amplifier the difference being that the load resistance connected to the output is relatively low, for example a loudspeaker of 4 or 8Ωs resulting in high currents flowing through the collector of the transistor. Because of these high load currents the output transistor(s) used for power amplifier output stages such as the 2N3055 need to have higher voltage and power ratings than the general ones used for small signal amplifiers such as the BC107.

Since we are interested in delivering maximum AC power to the load, while consuming the minimum DC power possible from the supply we are mostly concerned with the "conversion efficiency" of the amplifier. However, one of the main disadvantage of power amplifiers and especially the Class A amplifier is that their overall conversion efficiency is very low as large currents mean that a considerable amount of power is lost in the form of heat. Percentage efficiency in amplifiers is defined as the r.m.s. output power dissipated in the load divided by the total DC power taken from the supply source as shown below.

Power Amplifier Efficiency:



$$\eta\,\% = \frac{P_{OUT}}{P_{DC}}\,x100$$

Where:

η% - is the efficiency of the amplifier.

P_{out} - is the amplifiers output power delivered to the load.

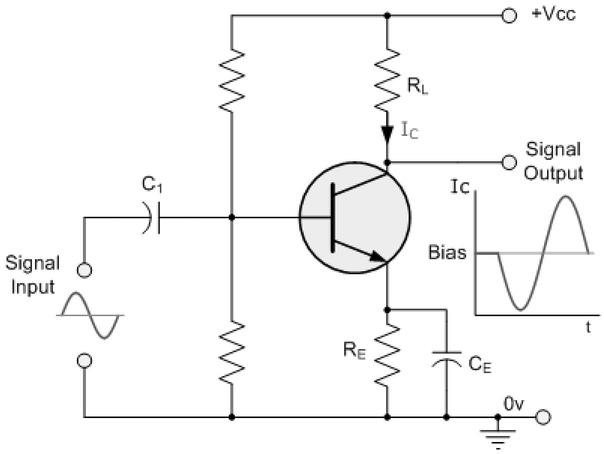
P_{dc} - is the DC power taken from the supply.

For a power amplifier it is very important that the amplifiers power supply is well designed to provide the maximum available continuous power to the output signal.

CLASS A AMPLIFIER:

The most commonly used type of power amplifier configuration is the Class A Amplifier. The Class A amplifier is the most common and simplest form of power amplifier that uses the switching transistor in the standard common emitter circuit configuration as seen previously. The transistor is always biased "ON" so that it conducts during one complete cycle of the input signal waveform producing minimum distortion and maximum amplitude to the output. This means then that the Class A Amplifier configuration is the ideal operating mode, because there can be no crossover or switch-off distortion to the output waveform even during the negative half of the cycle. Class A power amplifier output stages may use a single power transistor or pairs of transistors connected together to share the high load current. Consider the Class A amplifier circuit below.

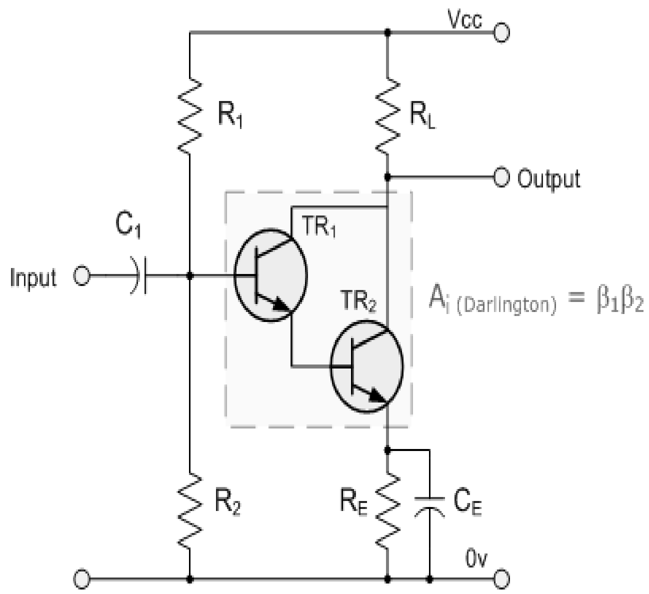
Single Stage Amplifier Circuit:



This is the simplest type of Class A power amplifier circuit. It uses a single-ended transistor for its output stage with the resistive load connected directly to the Collector terminal. When the transistor switches "ON" it sinks the output current through the Collector resulting in an inevitable voltage drop across the Emitter resistance thereby limiting the negative output capability. The efficiency of this type of circuit is very low (less than 30%) and delivers small power outputs for a large drain on the DC power supply. A Class A amplifier stage passes the same load current even when no input signal is applied so large heat sinks are needed for the output transistors.

However, another simple way to increase the current handling capacity of the circuit while at the same time obtain a greater power gain is to replace the single output transistor with a Darlington Transistor. These types of devices are basically two transistors within a single package, one small "pilot" transistor and another larger "switching" transistor. The big advantage of these devices are that the input impedance is suitably large while the output impedance is relatively low, thereby reducing the power loss and therefore the heat within the switching device.

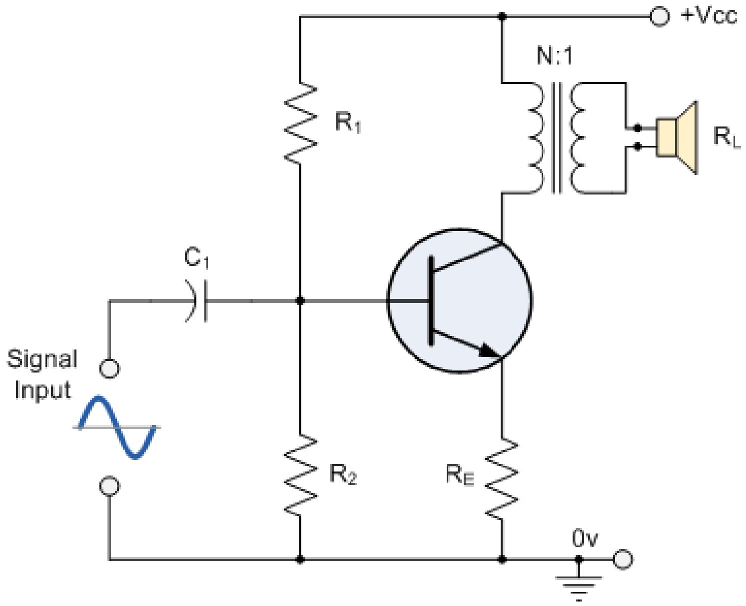
Darlington Transistor Configurations



The overall current gain Beta (β) or h_{fe} value of a Darlington device is the product of the two individual gains of the transistors multiplied together and very high β values along with high Collector currents are possible compared to a single transistor circuit.

To improve the full power efficiency of the Class A amplifier it is possible to design the circuit with a transformer connected directly in the Collector circuit to form a circuit called a Transformer Coupled Amplifier. This improves the efficiency of the amplifier by matching the impedance of the load with that of the amplifiers output using the turns ratio (N) of the transformer and an example is given below.

TRANSFORMER-COUPLED AMPLIFIER CIRCUIT:



As the Collector current, Ic is reduced to below the quiescent Q-point set up by the base bias voltage, due to variations in the base current, the magnetic flux in the transformer core collapses causing an induced emf in the transformer primary windings. This causes an instantaneous collector voltage to rise to a value of twice the supply voltage 2Vcc giving a maximum collector current of twice Ic when the Collector voltage is at its minimum.

Then the efficiency of this type of Class A amplifier configuration can be calculated as follows.

The r.m.s. Collector voltage is given as:

$$V_{CE} = \frac{V_{C(max)} - V_{C(min)}}{2\sqrt{2}} = \frac{2V_{CC} - 0}{2\sqrt{2}}$$

The r.m.s. Collector current is given as:

$$I_{CE} = \frac{I_{C(max)} - I_{C(min)}}{2\sqrt{2}} = \frac{2I_C - 0}{2\sqrt{2}}$$

The r.m.s. Power delivered to the load (Pac) is therefore given as:

$$P_{ac} = V_{CE} \times I_{CE} = \frac{2V_{CC}}{2\sqrt{2}} \times \frac{2I_C}{2\sqrt{2}} = \frac{2V_{CC}\,2I_C}{8}$$

The average power drawn from the supply (P_{dc}) is given by:

$$P_{dc} = V_{CC} \times I_C$$

and therefore the efficiency of a Transformer-coupled Class A amplifier is given as:

$$\eta_{(max)} = \frac{P_{ac}}{P_{dc}} = \frac{2V_{CC}\,2I_C}{8V_{CC}I_C} \times 100\%$$

This improves the efficiency of the amplifier by matching the impedance of the load with that of the amplifier using the turns ratio of the transformer and efficiencies reaching 40% are possible with most commercially available Class-A type power amplifiers of this type of configuration, but the use of inductive components is best avoided. Also one big disadvantage of this type of circuit is the additional cost and size of the audio transformer required.

The type of "Class" or classification that an amplifier is given really depends upon the conduction angle, the portion of the 360° of the input waveform cycle, in which the transistor is conducting. In the Class A amplifier the conduction angle is a full 360° or 100% of the input signal while in other amplifier classes the transistor conducts during a lesser conduction angle.

It is possible to obtain greater power output and efficiency than that of the Class A amplifier by using two complementary transistors in the output stage with one transistor being an NPN or N-channel type while the other transistor is a PNP or P-channel (the complement) type connected in a "push-pull" configuration. This type of configuration is generally called a Class B Amplifier.

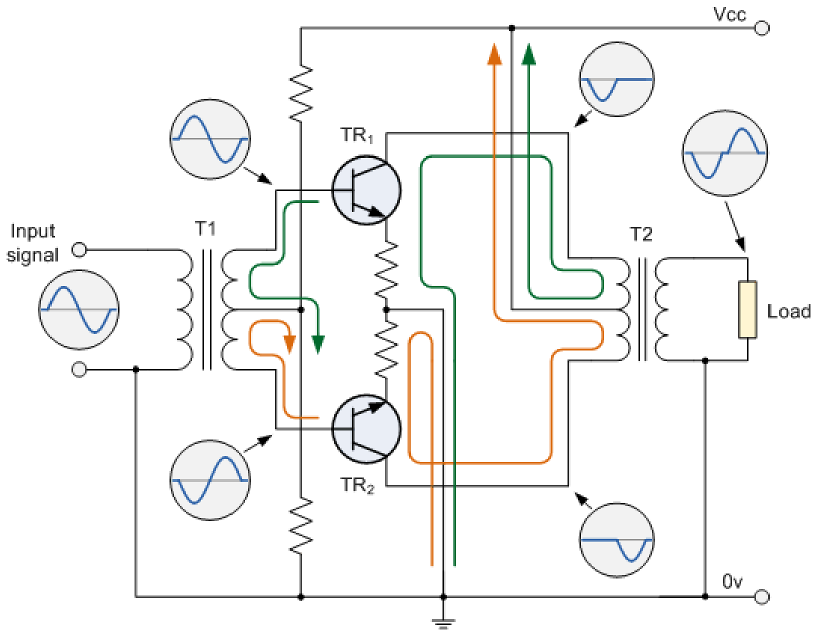
The Class B Amplifier:

To improve the full power efficiency of the previous Class A amplifier by reducing the wasted power in the form of heat, it is possible to design the power amplifier circuit with two transistors in its output stage producing what is commonly termed as a "push-pull" type amplifier configuration.

Push-pull amplifiers use two "complementary" or matching transistors, one being an NPN-type and the other being a PNP-type with both power transistors receiving the same input signal together that is equal in magnitude, but in opposite phase to each other. This results in one transistor only amplifying one half or 180° of the input waveform cycle while the other transistor amplifies the other half or remaining 180^o of the input waveform cycle with the resulting "two-halves" being put back together again at the output terminal.

Then the conduction angle for this type of amplifier circuit is only 180^o or 50% of the input signal. This pushing and pulling effect of the alternating half cycles by the transistors gives this type of circuit its amusing name, but these types of audio amplifier circuit are more generally known as the Class B Amplifier as shown below.

Class B Push-pull Transformer Amplifier Circuit



The circuit above shows a standard Class B Amplifier circuit that uses a balanced centre-tapped input transformer, which splits the incoming waveform signal into two equal halves and which are 180° out of phase with each other. Another centre-tapped transformer on the output is used to recombined the two signals providing the increased power to the load. The transistors used for this type of transformer push-pull amplifier circuit are both NPN transistors with their emitter terminals connected together.

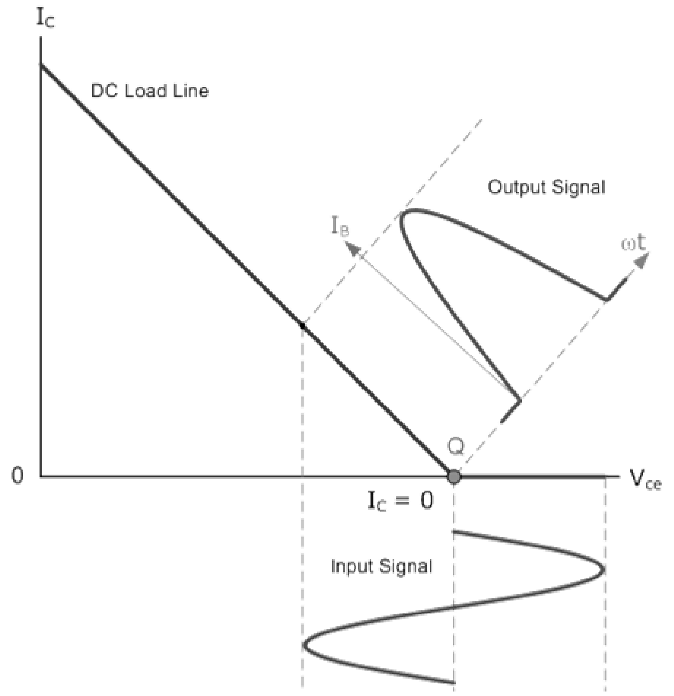
Here, the load current is shared between the two power transistor devices as it decreases in one device and increases in the other throughout the signal cycle reducing the output voltage and current to zero. The result is that both halves of the output waveform now swings from zero to twice the quiescent current thereby reducing dissipation. This has the effect of almost doubling the efficiency of the amplifier to around 70%.

Assuming that no input signal is present, then each transistor carries the normal quiescent collector current, the value of which is determined by the base bias which is at the cut-off point. If the transformer is accurately centre tapped, then the two collector currents will flow in opposite directions (ideal condition) and there will be no magnetization of the transformer core, thus minimizing the possibility of distortion. When a signal is present across the secondary of the driver transformer T1, the transistor base inputs are in "anti-phase" to each other as shown, thus if TR1 base goes positive driving the transistor into heavy conduction, its collector current will increase but at the same time the base current of TR2 will go negative further into cut-off and the collector current of this transistor decreases by an equal amount and vice versa.

Hence negative halves are amplified by one transistor and positive halves by the other transistor giving this push-pull effect. Unlike the DC condition, these AC currents are ADDITIVE resulting in the two output half-cycles being combined to reform the sine-wave in the output transformers primary winding which then appears across the load.

Class B Amplifier operation has zero DC bias as the transistors are biased at the cut-off, so each transistor only conducts when the input signal is greater than the base-emitter voltage. Therefore, at zero input there is zero output and no power is being consumed. This then means that the actual Q-point of a Class B amplifier is on the V_{ce} part of the load line as shown below.

Class B Output Characteristics Curves

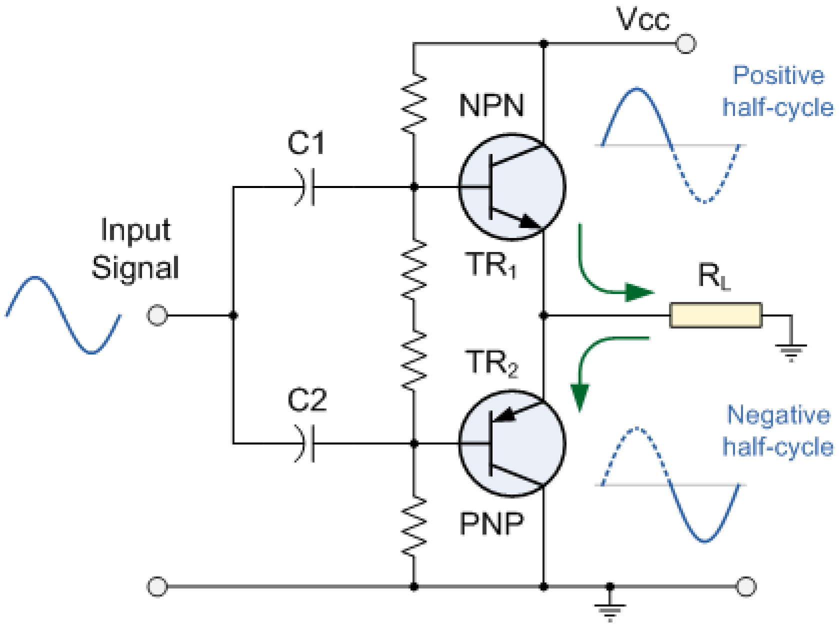


The Class B Amplifier has the big advantage over their Class A amplifier cousins in that no current flows through the transistors when they are in their quiescent state (i.e., with no input signal), therefore no power is dissipated in the output transistors or transformer when there is no signal present unlike Class A amplifier stages that require significant base bias thereby dissipating lots of heat - even with no input signal present. So the overall conversion efficiency (η) of the amplifier is greater than that of the equivalent Class A with efficiencies reaching as high as 70% possible resulting in nearly all modern types of push-pull amplifiers operated in this Class B mode.

TRANSFORMER LESS CLASS B PUSH-PULL AMPLIFIER:

One of the main disadvantages of the Class B amplifier circuit above is that it uses balanced centre-tapped transformers in its design, making it expensive to construct. However, there is another type of Class B amplifier called a Complementary-Symmetry Class B Amplifier that does not use transformers in its design therefore, it is transformer less using instead complementary or matching pairs of power transistors. As transformers are not needed this makes the amplifier circuit much smaller for the same amount of output, also there are no stray magnetic effects or transformer distortion to effect the quality of the output signal. An example of a "transformer less" Class B amplifier circuit is given below.

Class B Transformer less Output Stage



The Class B amplifier circuit above uses complimentary transistors for each half of the waveform and while Class B amplifiers have a much high gain than the Class A types, one of the main disadvantages of class B type push-pull amplifiers is that they suffer from an effect known commonly **as Crossover Distortion.**

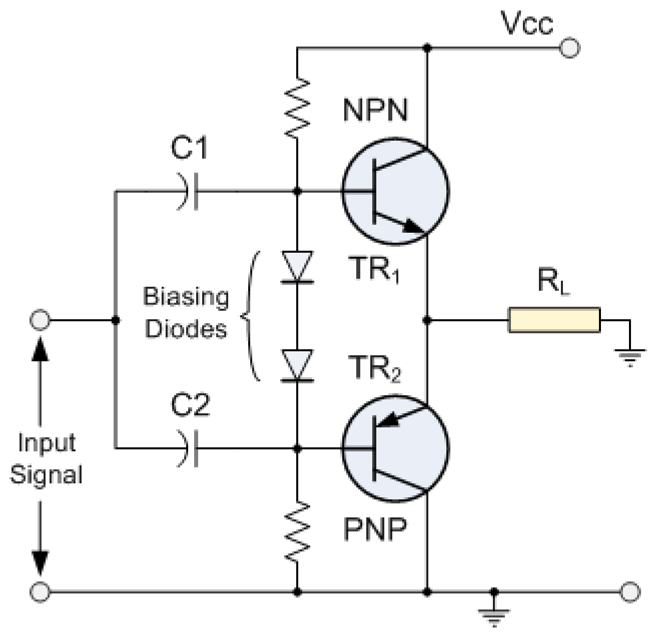
We remember from our tutorials about Transistors that it takes approximately 0.7 volts (measured from base to emitter) to get a bipolar transistor to start conducting. In a pure class B amplifier, the output transistors are not "pre-biased" to an "ON" state of operation. This means that the part of the output waveform which falls below this 0.7 volt window will not be reproduced accurately as the transition between the two transistors (when they are switching over from one to the other), the transistors do not stop or start conducting exactly at the zero crossover point even if they are specially matched pairs. The output transistors for each half of the waveform (positive and negative) will each have a 0.7 volt area in which they will not be conducting resulting in both transistors being "OFF" at the same time.

A simple way to eliminate crossover distortion in a Class B amplifier is to add two small voltage sources to the circuit to bias both the transistors at a point slightly above their cut-off point. This then would give us what is commonly called an Class AB Amplifier circuit. However, it is impractical to add additional voltage sources to the amplifier circuit so pn-junctions are used to provide the additional bias in the form of silicon diodes.

The Class AB Amplifier

We know that we need the base-emitter voltage to be greater than 0.7v for a silicon bipolar transistor to start conducting, so if we were to replace the two voltage divider biasing resistors connected to the base terminals of the transistors with two silicon Diodes, the biasing voltage applied to the transistors would now be equal to the forward voltage drop of the diode. These two diodes are generally called Biasing Diodes or Compensating Diodes and are chosen to match the characteristics of the matching transistors. The circuit below shows diode biasing.

Class AB Amplifier:



The Class AB Amplifier circuit is a compromise between the Class A and the Class B configurations. This very small diode biasing voltage causes both transistors to slightly conduct even when no input signal is present. An input signal waveform will cause the transistors to operate as normal in their active region thereby eliminating any crossover distortion present in pure Class B amplifier designs.

A small collector current will flow when there is no input signal but it is much less than that for the Class A amplifier configuration. This means then that the transistor will be "ON" for more than half a cycle of the waveform but much less than a full cycle giving a conduction angle of between 180 to 360^{o} or 50 to 100% of the input signal depending upon the amount of additional biasing used. The amount of diode biasing voltage present at the base terminal of the transistor can be increased in multiples by adding additional diodes in series.

Class B amplifiers are greatly preferred over Class A designs for high-power applications such as audio power amplifiers and PA systems. Like the Class A Amplifier circuit, one way to greatly boost the current gain (A_i) of a Class B push-pull amplifier is to use Darlington transistors pairs instead of single transistors in its output circuitry.

In the next tutorial about Amplifiers we will look more closely at the effects of Crossover Distortion in Class B amplifier circuits and ways to reduce its effect.

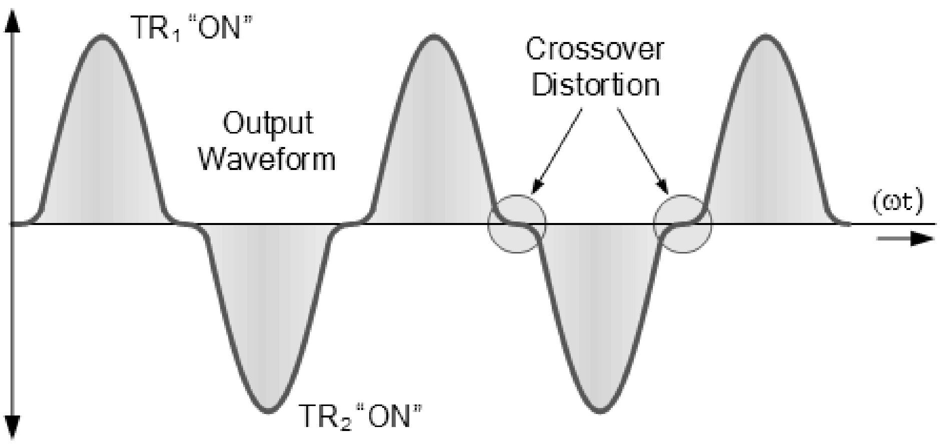
Crossover Distortion:

We have seen that one of the main disadvantages of a Class A Amplifier is its low full power efficiency rating. But we also know that we can improve the amplifier and almost double its efficiency simply by changing the output stage of the amplifier to a Class B push-pull type configuration. However, this is great from an efficiency point of view, but most modern Class B amplifiers are transformer less or complementary types with two transistors in their output stage.

This results in one main fundamental problem with push-pull amplifiers in that the two transistors do not combine together fully at the output both halves of the waveform due to their unique zero cut-off biasing arrangement. As this problem occurs when the signal changes or "crosses-over" from one transistor to the other at the zero voltage point it produces an amount of "distortion" to the output wave shape. This results in a condition that is commonly called Crossover Distortion.

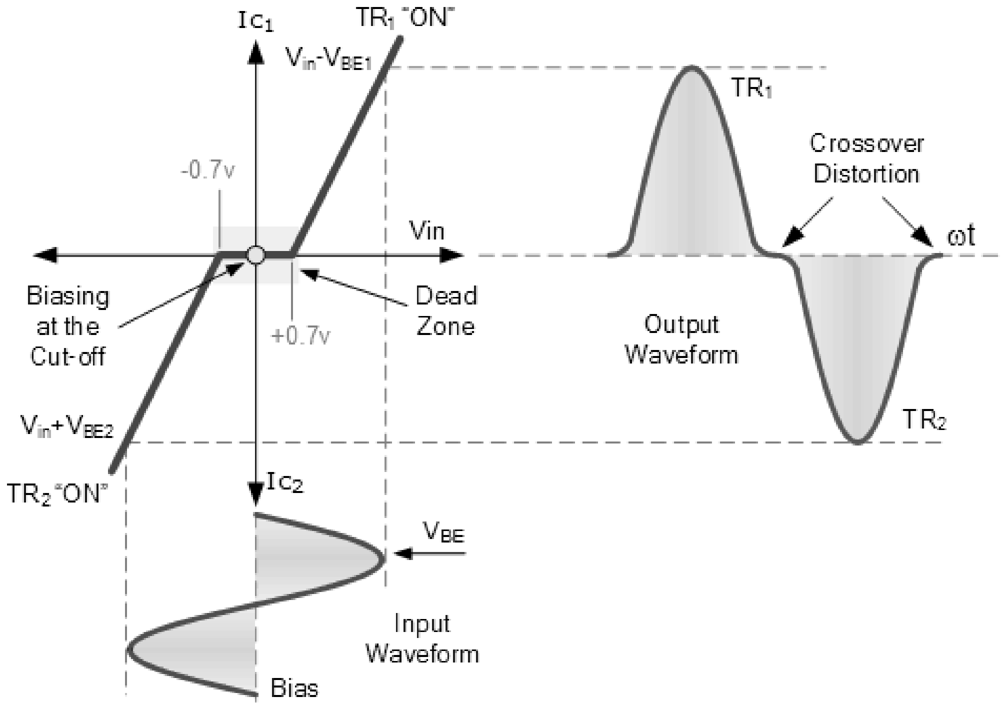
Crossover Distortion produces a zero voltage "flat spot" or "dead band" on the output wave shape as it crosses over from one half of the waveform to the other. The reason for this is that the transition period when the transistors are switching over from one to the other, does not stop or start exactly at the zero crossover point thus causing a small delay between the first transistor turning "OFF" and the second transistor turning "ON". This delay results in both transistors being switched "OFF" at the same instant in time producing an output wave shape as shown below.

Crossover Distortion Waveform



In order that there should be no distortion of the output waveform we must assume that each transistor starts conducting when its base to emitter voltage rises just above zero, but we know that this is not true because for silicon bipolar transistors the base voltage must reach at least 0.7v before the transistor starts to conduct thereby producing this flat spot. This crossover distortion effect also reduces the overall peak to peak value of the output waveform causing the maximum power output to be reduced as shown below.

Non-Linear Transfer Characteristics

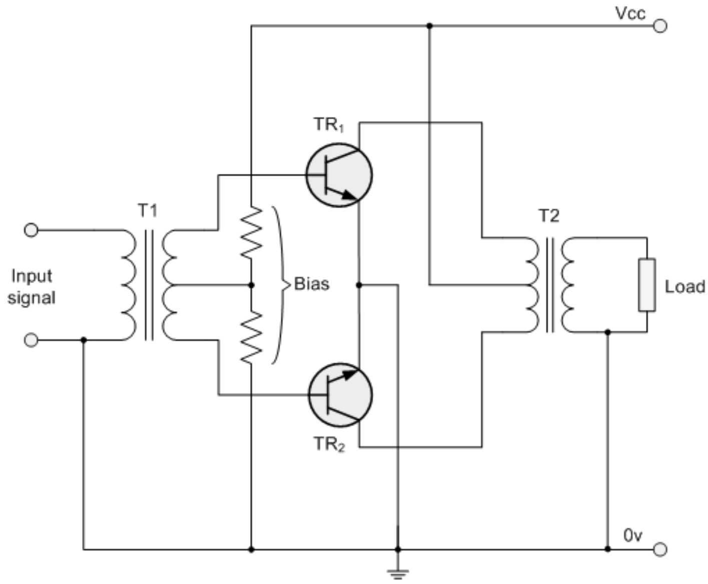


This effect is less pronounced for large input signals as the input voltage is usually quite large but for smaller input signals it can be more severe causing audio distortion to the amplifier.

Pre-biasing the Output

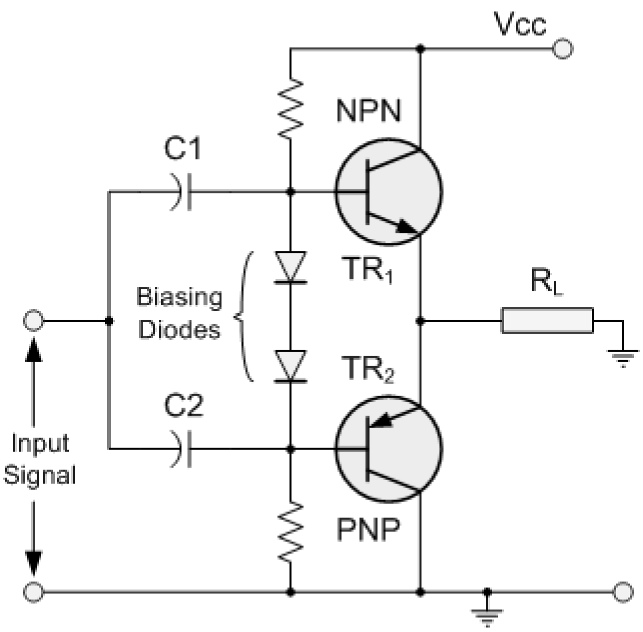
The problem of Crossover Distortion can be reduced considerably by applying a slight forward base bias voltage (same idea as seen in the Transistor tutorial) to the bases of the two transistors via the centre-tap of the input transformer, thus the transistors are no longer biased at the zero cut-off point but instead are "Pre-biased" at a level determined by this new biasing voltage.

Push-pull Amplifier with Pre-biasing



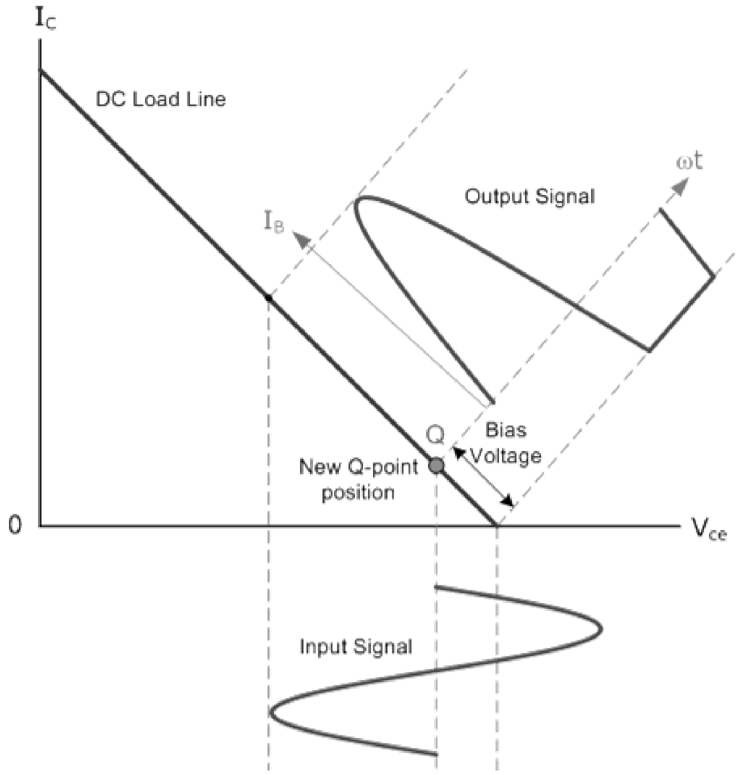
This type of resistor pre-biasing causes one transistor to turn "ON" exactly at the same time as the other transistor turns "OFF" as both transistors are now biased slightly above their original cut-off point. However, to achieve this the bias voltage must be at least twice that of the normal base to emitter voltage to turn "ON" the transistors. This pre-biasing can also be implemented in transformer less amplifiers that use complementary transistors by simply replacing the two potential divider resistors with Biasing Diodes as shown below.

Pre-biasing with Diodes



This pre-biasing voltage either for a transformer or transformer less amplifier circuit, has the effect of moving the amplifiers Q-point past the original cut-off point thus allowing each transistor to operate within its active region for slightly more than half or 180° of each half cycle. In other words 180° + Bias. The amount of diode biasing voltage present at the base terminal of the transistor can be increased in multiples by adding additional diodes in series. This then produces an amplifier circuit commonly called a Class AB Amplifier and its biasing arrangement is given below.

Class AB Output Characteristics



Crossover Distortion Summary

Then to summaries, Crossover Distortion occurs in Class B amplifiers because the amplifier is biased at its cut-off point. This then results in BOTH transistors being switched "OFF" at the same instant in time as the waveform crosses the zero axis. By applying a small base bias voltage either by using a resistive potential divider circuit or diode biasing this crossover distortion can be greatly reduced or even eliminated completely by bringing the transistors to the point of being just switched "ON". The application of a biasing voltage produces another type or class of amplifier circuit commonly called a Class AB Amplifier.

Then the difference between a pure Class B amplifier and an improved Class AB amplifier is in the biasing level applied to the output transistors. One major advantage of using diodes over resistors is that the pn-junctions compensate for variations in the temperature of the transistors.

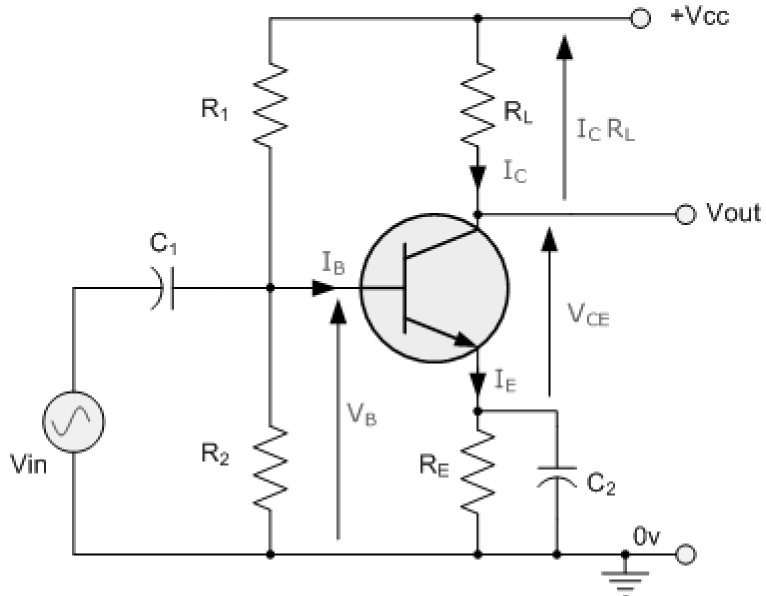
Therefore, we can say that Class AB amplifier is a Class B amplifier with "Bias" and we can summaries as:

Class A Amplifiers have no Crossover Distortion as they are biased in the centre of the load line.

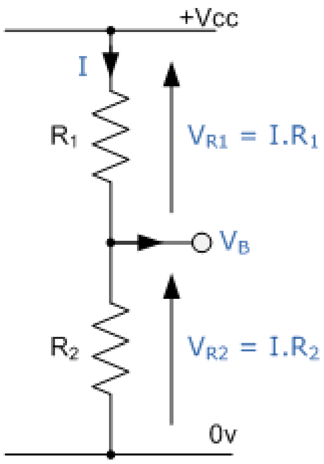
Class B Amplifiers have large amounts of Crossover Distortion due to biasing at the cut-off point.

Class AB Amplifiers may have some Crossover Distortion if the biasing level is too low.

The Common Emitter Amplifier Circuit



The single stage common emitter amplifier circuit shown above uses what is commonly called "Voltage Divider Biasing". This type of biasing arrangement uses two resistors as a potential divider network and is commonly used in the design of bipolar transistor amplifier circuits. This method of biasing the transistor greatly reduces the effects of varying Beta, (β) by holding the Base bias at a constant steady voltage level allowing for best stability. The quiescent Base voltage (Vb) is determined by the potential divider network formed by the two resistors, R1, R2 and the power supply voltage Vcc as shown with the current flowing through both resistors. Then the total resistance RT will be equal to R1 + R2 giving the current as i = Vcc/RT. The voltage level generated at the junction of resistors R1 and R2 holds the Base voltage (Vb) constant at a value below the supply voltage. Then the potential divider network used in the common emitter amplifier circuit divides the input signal in proportion to the resistance. This bias reference voltage can be easily calculated using the simple voltage divider formula below:



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

The same supply voltage, (Vcc) also determines the maximum Collector current, Ic when the transistor is switched fully "ON" (saturation), Vce = 0. The Base current Ib for the transistor is found from the Collector current, Ic and the DC current gain Beta, β of the transistor.

$$\beta = \frac{\Delta I_C}{\Delta I_B}$$

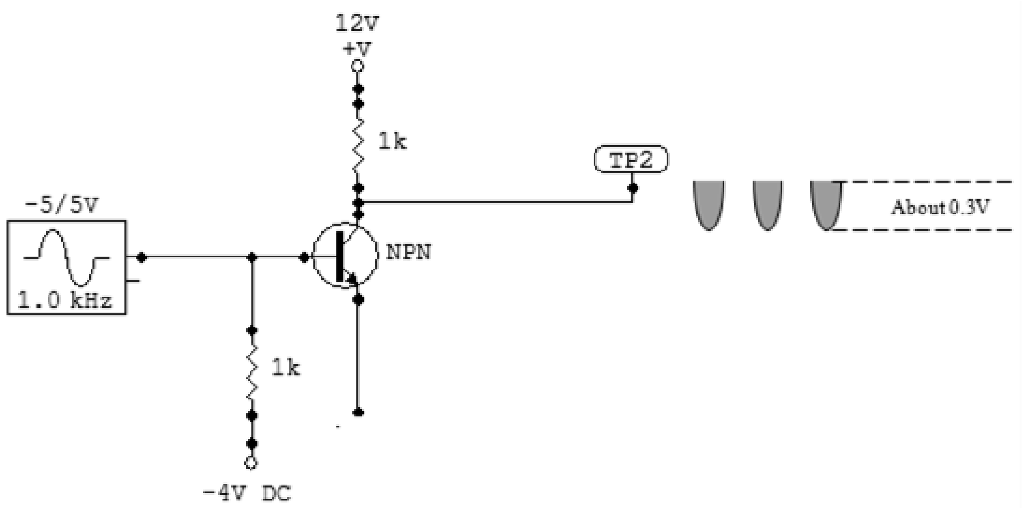
Beta is sometimes referred to as h_{FE} which is the transistors forward current gain in the common emitter configuration. Beta has no units as it is a fixed ratio of the two currents, Ic and Ib so a small change in the Base current will cause a large change in the Collector current. One final point about Beta. Transistors of the same type and part number will have large variations in their Beta value for example, the BC107 NPN Bipolar transistor has a DC current gain

Beta value of between 110 and 450 (data sheet value) this is because Beta is a characteristic of their construction and not their operation.

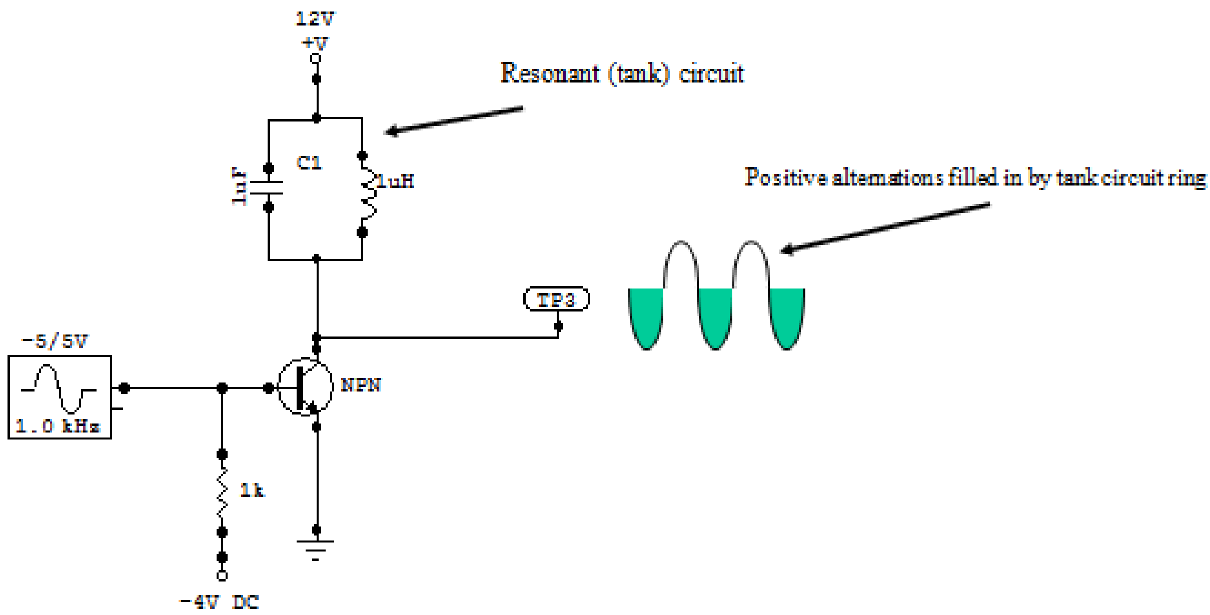
As the Base/Emitter junction is forward-biased, the Emitter voltage, Ve will be one junction voltage drop different to the Base voltage. If the voltage across the Emitter resistor is known then the Emitter current, Ie can be easily calculated using Ohm's Law. The Collector current, Ic can be approximated, since it is almost the same value as the Emitter current.

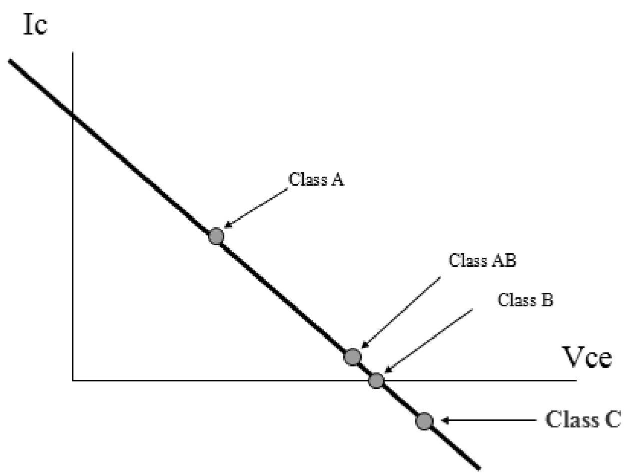
Class C Amplifier:

The Class C amplifier has a negative voltage at the base, and zero volts at the emitter. The Base-Emitter junction is reverse biased.The transistor will turn on at a signal voltage of 4.7V. The transistor will only conduct a small pulse through to the collector output. Amplifier is very efficient but has very little usefulness…. Unless….



Collector resonant circuit responds to an impulse by 'ringing' at its resonant frequency. This is like pushing someone on a swing. A sharp short push each trip allows the swing to oscillate back and forth at its resonant frequency Collector impulses occur by design at the resonant frequency of the tank circuit. Resonant circuit continues to ring and restores the sine wave at the output. Class C Amplifier is used in radio/RF applications and is also called a 'tuned' amplifier


12V
+V
Resonant (tank) circuit
C1
1nF
1uH
Positive alternations filled in by tank circuit ring
TP3
-5/5V
1.0 kHz
NPN
1k
-4V DC


Ic
Class A
Class AB
Class B
Vce
Class C

UNIT-5
TUNED AMPLIFIERS

Introduction, Q-Factor, Small Signal Tuned Amplifiers, Effect of Cascading Single Tuned Amplifiers on Bandwidth, Effect of Cascading Double Tuned Amplifiers on Bandwidth, Stagger Tuned Amplifiers, Stability of Tuned Amplifiers, Illustrative design problems.

INTRODUCTION:

When a radio or television set is turned on, many events take place within the "receiver" before we hear the sound or see the picture being sent by the transmitting station. Many different signals reach the antenna of a radio receiver at the same time. To select a station, the listener adjusts the tuning dial on the radio receiver until the desired station is heard. Within the radio or TV receiver, the actual "selecting" of the desired signal and the rejecting of the unwanted signals are accomplished by means of a tuned circuit.

A tuned circuit consists of a coil and a capacitor connected in series or parallel. Whenever the characteristics of inductance and capacitance are found in a tuned circuit, the phenomenon as RESONANCE takes place.

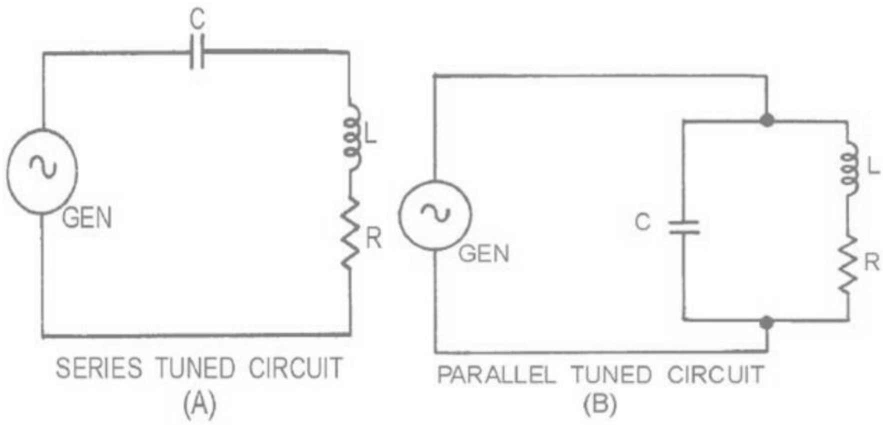
Resonance circuits

The frequency applied to an LCR circuit causes X_L and X_C to be equal, and the circuit is RESONANT. If X_L and X_C are equal ONLY at one frequency (the resonant frequency). This fact is the principle that enables tuned circuits in the radio receiver to select one particular frequency and reject all others.

This is the reason why so much emphasis is placed on X_L and X_C. figure 1-1 Shows that a basic tuned circuit consists of a coil and a capacitor, connected either in series, view (A), or in parallel, view (B). The resistance (R) in the circuit is usually limited to the inherent resistance of the components (particularly the resistance of the coil).

Tuned amplifier

- Communication circuit widely uses tuned amplifier and they are used in MW & SW radio frequency 550 KHz – 16 MHz, 54 – 88 MHz, FM 88 – 108 MHz, cell phones 470 - 990 MHz
- Band width is 3 dB frequency interval of pass band and –30 dB frequency interval
- Tuned amplifiers are also classified as A, B, C similar to power amplifiers based on conduction angle of devices.



SERIES RESONANT CIRCUIT

Series resonant features minimum impedance (RS) at resonant.

- f_r = ½√LC; Q = L/Rs at resonance L=1/c, BW=f_r/Q
- It behaves as purely resistance at resonance, capacitive below and inductive above resonance

PARALLEL RESONANT CIRCUIT

- Parallel resonance features maximum impedance at resonance = L/RsC
- At resonance Fr=1/2√1/(LC-Rs2/L2); if Rs=0, fr=1/2√(LC)
- At resonance it exhibits pure resistance and below fr parallel circuit exhibits inductive and above capacitive impedance

NEED FOR TUNED CIRCUITS:

To understand tuned circuits, we first have to understand the phenomenon of self-induction. And to understand this, we need to know about induction. The first discovery about the interaction between electric current and magnetism was the realization that an electric current created a magnetic field around the conductor. It was then discovered that this effect could be enhanced greatly by winding the conductor into a coil. The effect proved to be two-way: If a conductor, maybe in the form of a coil was placed in a changing magnetic field, a current could be made to flow in it; this is called induction.

So imagine a coil, and imagine that we apply a voltage to it. As current starts to flow, a magnetic field is created. But this means that our coil is in a changing magnetic field, and this induces a current in the coil. The induced current runs contrary to the applied current, effectively diminishing it. We have discovered self-induction. What happens is that the self-induction delays the build-up of current in the coil, but eventually the current will reach its maximum and stabilize at a value only determined by the ohmic resistance in the coil and the voltage applied. We now have a steady current and a steady magnetic field.

During the buildup of the field, energy was supplied to the coil, where did that energy go? It went into the magnetic field, and as long as the magnetic field exists, it will be stored there. Now imagine that we remove the current source. Without a steady current to uphold it, the magnetic field starts to disappear, but this means our coil is again in a variable field which induces a current into it. This time the current is in the direction of the applied current, delaying the decay of the current and the magnetic field till the stored energy is spent. This can give a funny effect: Since the coil must get rid of the stored energy, the voltage over it rises indefinitely until a current can run somewhere! This means you can get a surprising amount of sparks and arching when coils are involved. If the coil is large enough, you can actually get an electric shock from a low-voltage source like an ohmmeter.

APPLICATIONS OF TUNED AMPLIFIER

A tuned amplifier is a type of electronic device designed to amplify specific ranges of electrical signals while ignoring or blocking others. It finds common use in devices that work with radio frequency signals such as radios, televisions, and other types of communication equipment; however, it also can be useful in many other applications. Tuned amplifiers can be found in aircraft autopilot systems, audio systems, scientific instruments, spacecraft, or anywhere else there is a need to select and amplify specific electronic signals while ignoring others.

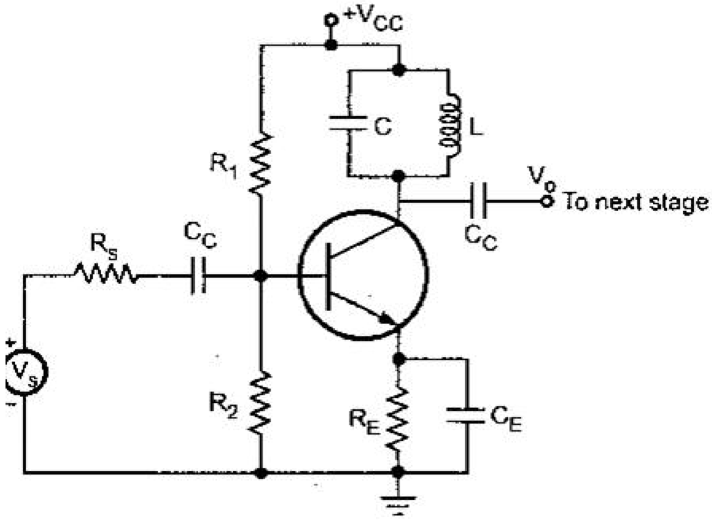
The most common tuned amplifiers an average person interacts with can be found in home or portable entertainment equipment, such as FM stereo receivers. An FM radio has a tuned amplifier that allows listening to only one radio station at a time. When the knob is turned to change the station, it adjusts a variable capacitor, inductor, or similar device inside the radio, which alters the inductive load of the tuned amplifier circuit. This retunes the amplifier to allow a different specific radio frequency to be amplified so a different radio station can be heard.

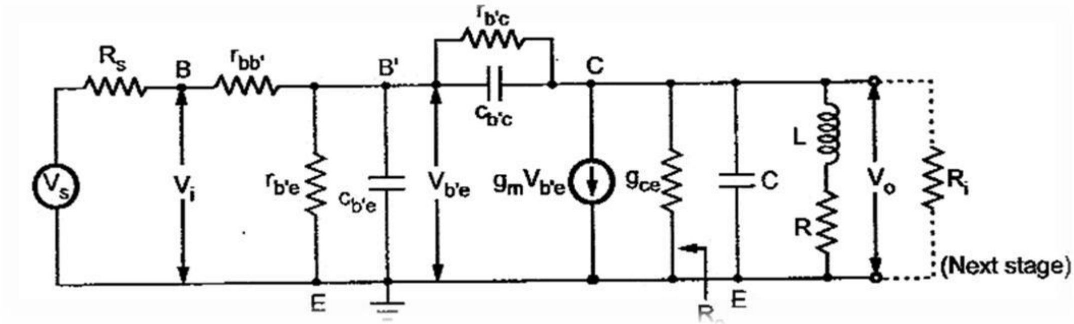
CLASSIFICATION:

1. Single tuned amplifier
2. Double tuned amplifier
3. Stagger tuned amplifier

SINGLE TUNED AMPLIFIER

Single Tuned Amplifiers consist of only one Tank Circuit and the amplifying frequency range is determined by it. By giving signal to its input terminal of various Frequency Ranges. The Tank Circuit on its collector delivers High Impedance on resonant Frequency, Thus the amplified signal is Completely Available on the output Terminal. And for input signals other than Resonant Frequency, the tank circuit provides lower impedance, hence most of the signals get attenuated at collector Terminal.



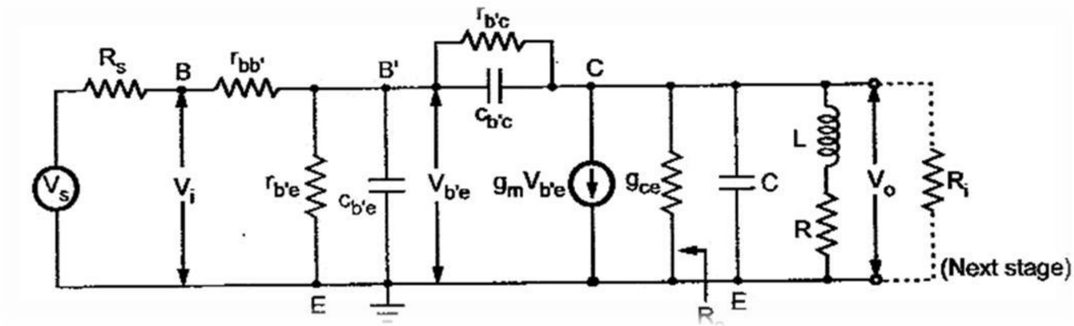


Ri- input resistance of the next stage

R0-output resistance of the generator gmVb'e

Cc & CE are negligible small

The equivalent circuit is simplified by



SIMPLIFIED EQUIVALENT CIRCUIT

$$C_i = C_{b'_e} + C_{b'_c}(1 - A)$$

$$C_{eq} = C_{b'_c}\left(\frac{A-1}{A}\right) + C$$

Where,

A-Voltage gain of the amplifier

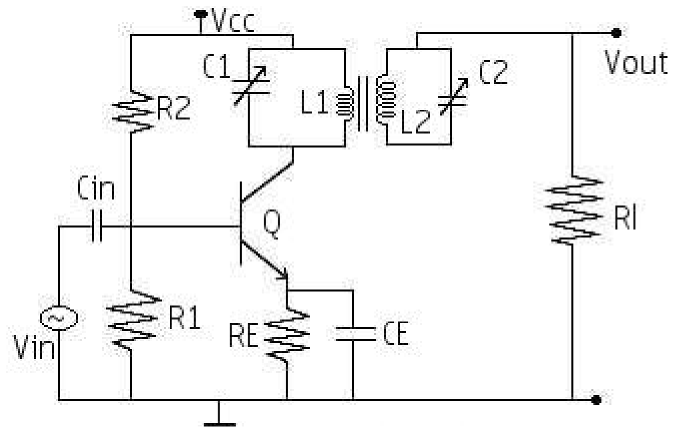
C-tuned circuit capacitance

DOUBLE TUNED AMPLIFIER

An amplifier that uses a pair of mutually inductively coupled coils where both primary and secondary are tuned, such a circuit is known as "double tuned amplifier". Its response will provide substantial rejection of frequencies near the pass band as well as relative flat pass band response. The disadvantage of POTENTIAL INSTABILITY in single tuned amplifiers can be overcome in Double tuned amplifiers.

A double tuned amplifier consists of inductively coupled two tuned circuits. One L1, C1 and the other L2, C2 in the Collector terminals. A change in the coupling of the two tuned circuits results in change in the shape of the Frequency response curve.

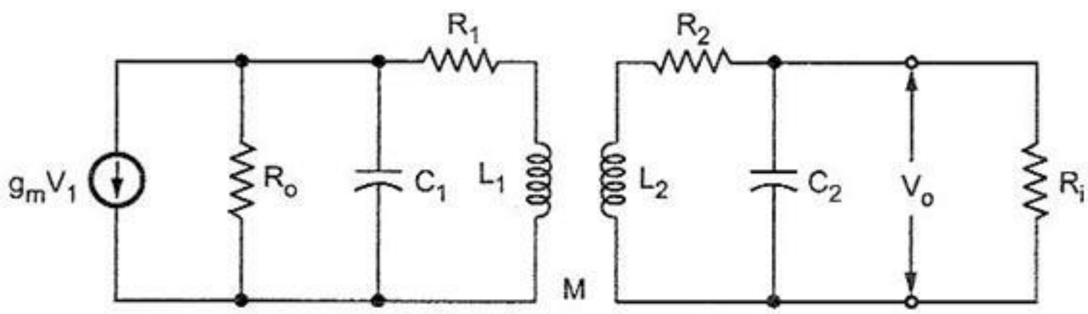
By proper adjustment of the coupling between the two coils of the two tuned circuits, the required results (High selectivity, high Voltage gain and required bandwidth) may be obtained.

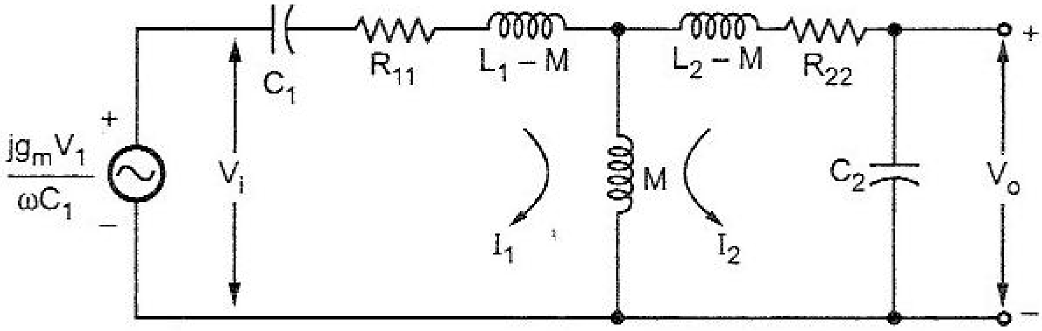


OPERATION:

The high Frequency signal to be amplified is applied to the input terminal of the amplifier. The resonant Frequency of TUNED CIRCUIT connected in the Collector circuit is made equal to signal Frequency by varying the value of C1. Now the tuned circuit L1, C1 offers very high Impedance to input signal Frequency and therefore, large output is developed across it. The output from the tuned circuit L1,C1 is transferred to the second tuned circuit L2, C2 through Mutual Induction. Hence the Frequency response in Double Tuned amplifier depends on the Magnetic Coupling of L1 and L2

Equivalent circuit of double tuned amplifier:





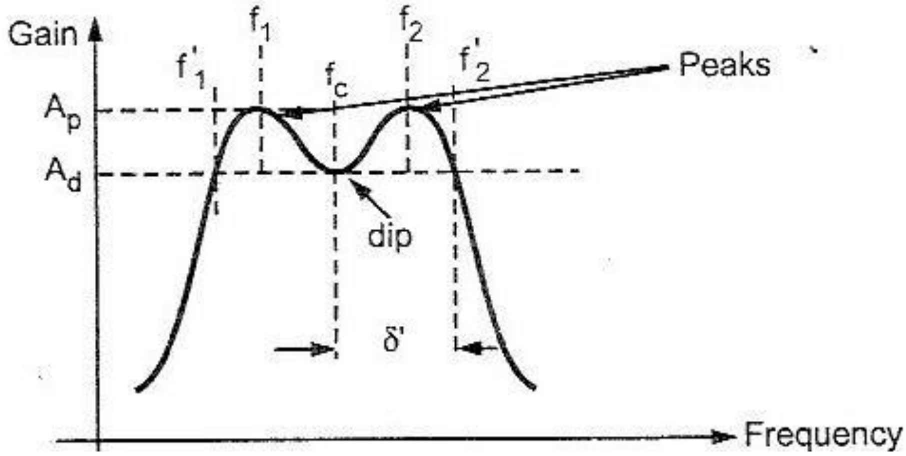
$$\dot{Y}_T = \frac{kQ^2}{\omega_r \sqrt{L_1 L_2}\left[4Q\delta - j(1 + k^2Q^2 - 4Q^2\delta^2)\right]}$$

$$|A_v| = g_m \omega_r \sqrt{L_1 L_2}\, Q \frac{kQ}{\sqrt{1 + k^2Q^2 - 4Q^2\delta^2 + 16Q^2\delta^2}}$$

Two gain peaks in frequencies f1 and f2

$$f_1 = f_r\left(1 - \frac{1}{2Q}\sqrt{k^2Q^2 - 1}\right) \text{ and}$$

$$f_2 = f_r\left(1 + \frac{1}{2Q}\sqrt{k^2Q^2 - 1}\right)$$



At

$$k^2Q^2 = 1, \text{ i.e. } k = \frac{1}{Q}, f_1 = f_2 = f_r.$$

This condition is known as critical coupling.

For the values of k<1/Q the peak gain is less than the maximum gain and the coupling is poor. For the values k> , the circuit is overcoupled and the response shows double peak. This double peak is useful when more bandwidth is required.

The gain magnitude at peak is given as,

$$|A_p| = \frac{g_m \omega_o \sqrt{L_1 L_2}\, kQ}{2}$$

And gain at the dip at $\delta = 0$ is given as,

$$|A_d| = |A_p| \frac{2\, kQ}{1 + k^2 Q^2}$$

The ratio of peak and dip gain is denoted as γ and it represents the magnitude of the ripple in the gain curve.

$$\gamma = \left|\frac{A_p}{A_d}\right| = \frac{1 + k^2 Q^2}{2\, kQ}$$

Using quadratic simplification and positive sign

$$kQ = \gamma + \sqrt{\gamma^2 - 1}$$

Bandwidth:

$$BW = 2\,\delta' = \sqrt{2}\,(f_2 - f_1)$$

At 3dB Bandwidth

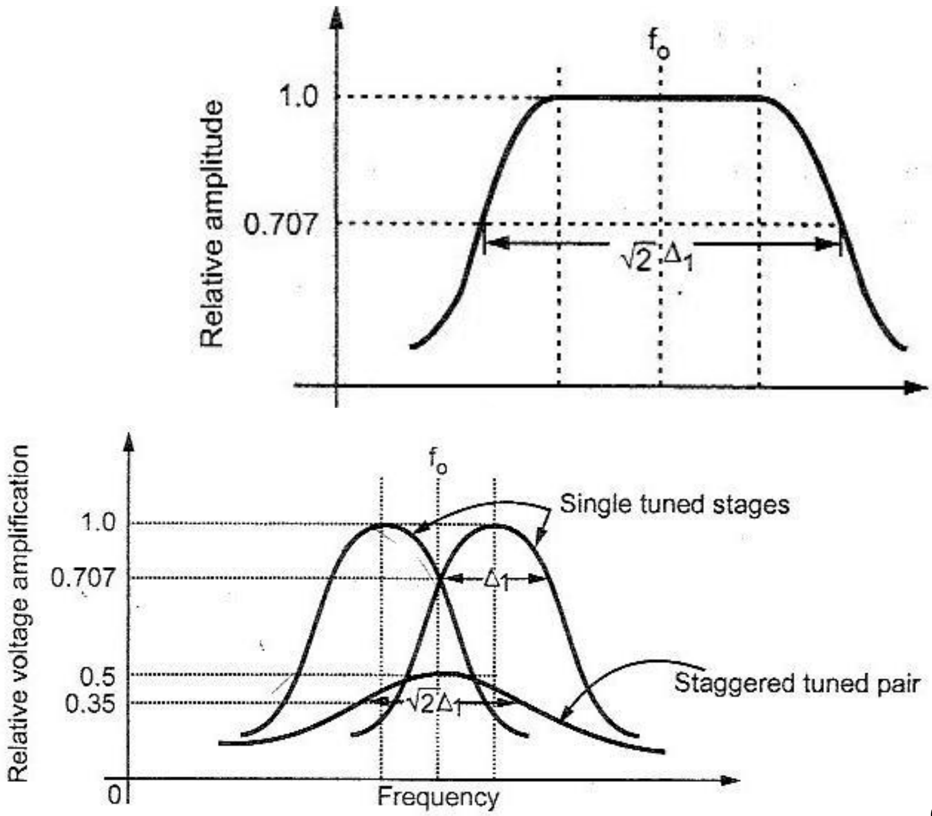
$$3\text{ dB BW} = \frac{3.1\, f_r}{Q}$$

STAGGERED TUNED AMPLIFIER

Double tuned amplifier gives greater 3 dB bandwidth having steeper sides and flat top. But alignment of double tuned amplifier is difficult.

To overcome this problem two single tuned cascaded amplifiers having certain bandwidth are taken and their resonant frequencies are so adjusted that they are separated by an amount equal to the bandwidth of each stage. Since the resonant frequencies are displaced or staggered, they are known as staggered tuned amplifiers. If it is desired to build a wide band high gain amplifier, one procedure is to use either single tuned or double tuned circuits which have been heavily loaded so as to increase the bandwidth.

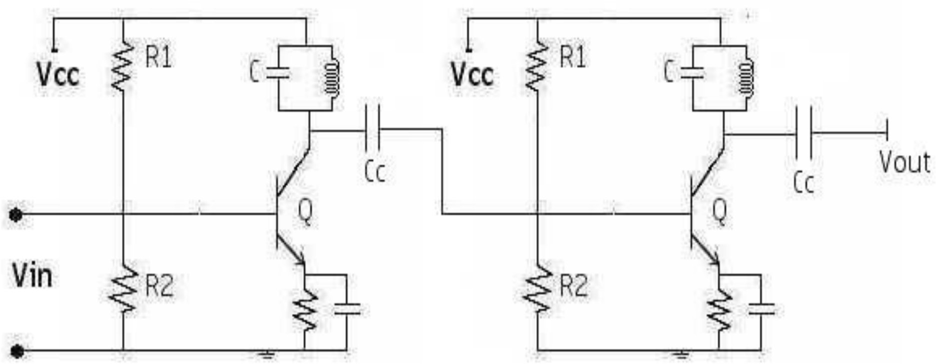
The gain per stage is correspondingly reduced, by virtue of the constant gain-bandwidth product. The use of a cascaded chain of stages will provide for the desired gain. Generally, for a specified gain and bandwidth the double tuned cascaded amplifier is preferred, since fewer tubes are often possible, and also since the pass-band characteristics of the double tuned cascaded chain are more favorable, falling more sensitive to variations in tube capacitance and coil inductance than the single tuned circuits.



Comparison of single and synchronously tuned amplifier

Response of individual stages

Circuit diagram:



Stagger Tuned Amplifiers are used to improve the overall frequency response of tuned Amplifiers. Stagger tuned Amplifiers are usually designed so that the overall response exhibits maximal flatness around the centre frequency. It needs a number of tuned circuits operating in union. The overall frequency response of a Stagger tuned amplifier is obtained by adding the individual response together. Overall response of synchronous amplifier Comparison of single and synchronously tuned amplifier

Since the resonant Frequencies of different tuned circuits are displaced or staggered, they are referred as STAGGER TUNED AMPLIFIER. The main advantage of stagger tuned amplifier is increased bandwidth. Its Drawback is Reduced Selectivity and critical tuning of many tank circuits. They are used in RF amplifier stage in Radio Receivers.

Analysis:

Gain of the single tuned amplifier:

$$\frac{A_v}{A_v \text{ (at resonance)}_1} = \frac{1}{1+j(X+1)}$$

$$\frac{A_v}{A_v \text{ (at resonance)}_2} = \frac{1}{1+j(X-1)}$$

$$\text{where } X = 2\, Q_{eff}\, \delta$$

Gain of the cascaded amplifier:

$$\frac{A_v}{A_v \text{ (at resonance)}_{cascaded}} = \frac{A_v}{A_v \text{ (at resonance)}_1} \times \frac{A_v}{A_v \text{ (at resonance)}_2}$$

$$\left|\frac{A_v}{A_v \text{ (at resonance)}}\right|_{cascaded} = \frac{1}{\sqrt{4+(2Q_{eff}\delta)^4}} = \frac{1}{\sqrt{4+16\,Q_{eff}^4\,\delta^4}}$$

$$= \frac{1}{2\sqrt{1+4Q_{eff}^4\,\delta^4}}$$