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AP/ECE

SYLLABUS

Unit-I : BJT AND FET AMPLIFIERS

Biasing Methods for BJT and MOSFET - Transistor Amplification Actions – Small Signal Models and Operations of BJT and MOSFET - BJT Amplifier Configurations: CE, CC, CB - MOSFET Amplifier Configurations: CS, CD, CG.

Unit-II : IC AND DIFFERENTIAL AMPLIFIERS

IC Biasing: Current Source, Current Mirrors, Current Steering Circuits - Basic Gain Cell - Cascode Amplifiers – BJT & MOSFET Differential Amplifiers - Common Mode Rejection - DC Offset - Differential Amplifier with a Current Mirror - Frequency Response of Amplifiers.

Unit-III : FEEDBACK AND OSCILLATORS

Feedback Concept - Properties - Feedback Amplifiers - Stability Analysis - Condition for Oscillation – Sinusoidal Oscillators: Op Amp - RC Oscillators and LC Oscillators - Multivibrators.

Unit-IV : TUNED AMPLIFIERS

Principle of Tuned Amplifiers - Inductor Losses - Amplifiers with Multiple Tuned Circuits - Cascode and CC-CB Cascade Amplifiers - Synchronous Tuning and Stagger Tuning.

Unit-V : POWER AMPLIFIERS

Class A, Class B and Class AB Amplifiers - Class C Amplifier - IC Power Amplifiers: Fixed Gain IC PowerAmplifier, Bridge Amplifier - Class D Amplifier.

TEXT BOOKS:

1.” Micro Electronic Circuits” Oxford University Press, 6th Edition,2010 by Adel .S. Sedra, Kenneth C. Smith.
2. “Electronic Devices and Circuits” Oxford Higher Education Press, 5th Edition, 2010 by David A.Bell

Introduction :

- The biasing in transistor circuits is done by using two DC sources VBB and VCC. It is economical to minimize the DC source to one supply instead of two which also makes the circuit simple.

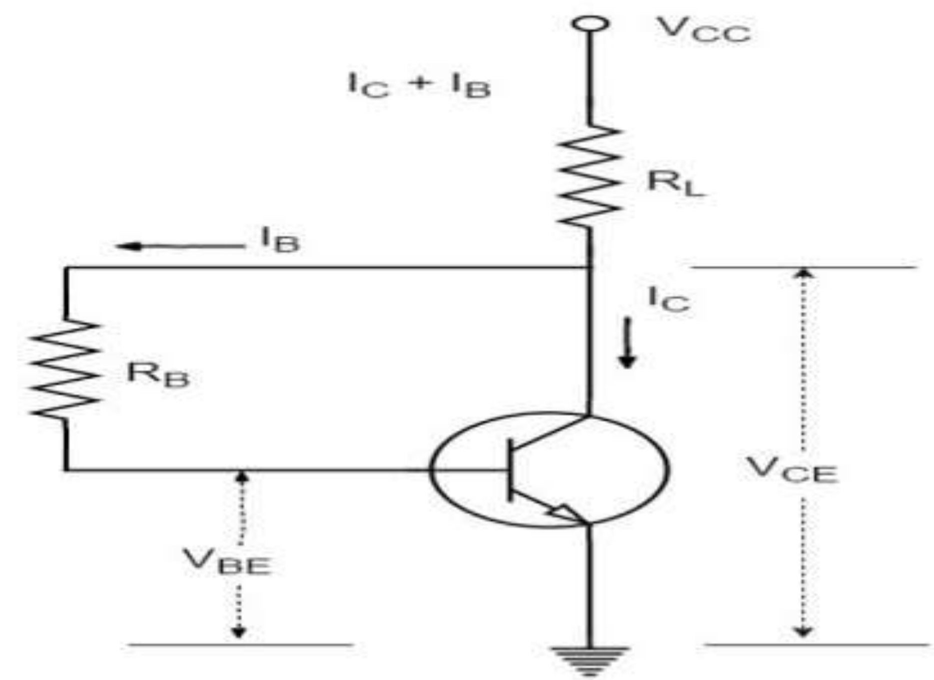
Transistor Biasing

- The biasing in transistor circuits is done by using two DC sources V_{BB} and V_{CC}. It is economical to minimize the DC source to one supply instead of two which also makes the circuit simple.

- The commonly used methods of transistor biasing are
- Base Resistor method
- Collector to Base bias
- Fixed Bias
- Voltage-divider bias
- All of these methods have the same basic principle of obtaining the required value of I_B and I_C from V_{CC} in the zero signal conditions.

- **Collector to Base Bias:**

The collector to base bias circuit is same as base bias circuit except that the base resistor R_B is returned to collector, rather than to V_{CC} supply as shown in the figure below.



Fixed Bias:

- In this method, a resistor R_B of high resistance is connected in base, as the name implies. The required zero signal base current is provided by V_{CC} which flows through R_B. The base emitter junction is forward biased, as base is positive with respect to emitter.
- The required value of zero signal base current and hence the collector current (as $I_C = \beta I_B$) can be made to flow by selecting the proper value of base resistor RB. Hence the value of R_B is to be known. The figure below shows how a base resistor method of biasing circuit looks like.

Voltage-divider bias:

Among all the methods of providing biasing and stabilization, the voltage divider bias method is the most prominent one. Here, two resistors R_1 and R_2 are employed, which are connected to V_{CC} and provide biasing. The resistor R_E employed in the emitter provides stabilization.

FET Biasing Methods:

- Unlike BJTs, thermal runaway does not occur with FETs, as already discussed in our blog. However, the wide differences in maximum and minimum transfer characteristics make I_D levels unpredictable with simple fixed-gate bias voltage.
- To obtain reasonable limits on quiescent drain currents I_D and drain-source voltage V_{DS}, source resistor and potential divider bias techniques must be used. With few exceptions, MOSFET bias circuits are similar to those used for JFETs.

Biasing MOSFET:

- MOSFET is a bit similar to the FET. An oxide layer is deposited on the substrate to which the gate terminal is connected. This oxide layer acts as an insulator (sio_2 insulates from the substrate), and hence the MOSFET has another name as IGFET. In the construction of MOSFET, a lightly doped substrate, is diffused with a heavily doped region. Depending upon the substrate used, they are called as P-type and N-type MOSFETs.

- The voltage at gate controls the operation of the MOSFET. In this case, both positive and negative voltages can be applied on the gate as it is insulated from the channel. With negative gate bias voltage, it acts as **depletion MOSFET** while with positive gate bias voltage it acts as an **Enhancement MOSFE**
- N-channel enhancement mode MOSFET circuit shows the source terminal at ground potential and is common to both the input and output sides of the circuit.
- The coupling capacitor acts as an open circuit to d.c. but it allows the signal voltage to be coupled to the gate of the MOSFET

Amplification Action

- The transistor as an amplifier The transistor is widely used as an amplifying device, and can provide voltage gain, current gain, and power gain. The basic amplifying action may be understood by considering the circuit.
- This circuit is known as the common base circuit due to the fact that the base terminal is common to both input and output circuits. The input voltage is applied between the emitter and the base, while the output voltage is developed across the load resistor RL .

The common base circuit

- There are three possible ways in which a transistor can be connected in an amplifier circuit. The circuits involved are called the common base, the common emitter, and the common collector circuits, depending on whether the base emitter or collector terminals of the transistor are common to both input and output circuits.
- The common base circuit has a high voltage gain and a high power gain, but has a current gain of slightly less than unity. It has low input impedance and a high output impedance. The circuit of a common base amplifier.

- The common collector or emitter follower circuit. In this circuit the load resistor is connected between the emitter and the common or earth terminal. The voltage gain for this circuit is slightly less than unity but it has high values of current and power gain. It has high input impedance and low output impedance. Such a circuit is often used as an impedance transformer for the matching of low impedance loads, like loudspeakers or transmission lines.
- The common emitter circuit It is the most frequently used of the three circuits mentioned. It has a high voltage gain, a high current gain, and a high power gain. The popularity of this circuit is due to the fact that its power gain is higher than for the other two circuits. The input and output impedances for this circuit are intermediate in value

Output resistance or impedance

- The total resistance looking into the amplifier at coupling capacitor C1 represents total resistance of the amplifier presented to signal source.
- Output resistance The total resistance looking into the output of the amplifier at coupling capacitor C2 represents output resistance of the amplifier. To find Zout, input source is set to 0 and test source is applied at output

Common Emitter Configuration

Characteristics of CE Configuration Input characteristics:-

1. The input characteristics of CE configuration are determined by increasing the base current I_B from zero by increasing V_{EB}, keeping V_{CE} constant. This step is repeated for various fixed values of V_{CE} .The input curve obtained are shown below

- 2. For the given value of V_{CE} and increasing the value of V_{BE}, the base current I_B increased, Input characteristics of the CE configuration is similar to CB configuration, where the Emitter base is forward biased . Hence increases in V_{BE} increases I_B.
- But when V_{CE} is increased, the width of the depletion region increases due to reverse bias which makes the effective width of the base to decreases which in turn decreases I_E. Therefore the curve shifts to the right.

Output characteristics:

The output characteristics of the CE configuration is determined by increasing the collector current I_C by increasing V_{CE}, keeping I_B constant at a suitable value by adjusting V_{CB}. This step is repeated for various fixed values of I_B. The curves obtained are shown below.

- The output characteristics have three regions namely
- **(i) Active region:**
- In this region, curves are uniform in spacing increases in the collector voltage increases I_C here for large value of I_B, I_C is larger than I_B. Thus current gain is greater than unity makes the transistor to be uses as an amplifier.
- **(ii) Saturation region:**
- For low values of V_{CE}, the transistor operates in this region. Increase in the base current I_B does not cause a corresponding change in I_C.
- **(iii)Cutoff Region:**
- In this region, the collector current becomes almost zero and small amount of collector current flows even when I_B=0. This is called $I_{CEO.}$

- **Common Base Configuration**
- For the common base configuration to operate as an amplifier, the input signal is applied to the emitter terminal and the output is taken from the collector terminal. Thus the emitter current is also the input current, and the collector current is also the output current, but as the transistor is a three layer, two pn-junction device, it must be correctly biased for it to work as a common base amplifier. That is the base-emitter junction is forward-biased.

- The basic common base configuration that the input variables relate to the emitter current IE and the base-emitter voltage, VBE, while the output variables relate to the collector current IC and the collector-base voltage, VCB.
- Since the emitter current, IE is also the input current, any changes to the input current will create a corresponding change in the collector current, IC. For a common base amplifier configuration, current gain, Ai is given as i_{OUT}/i_{IN} which itself is determined by the formula I_C/I_E. The current gain for a CB configuration is called Alpha, (α).

- In a BJT amplifier the emitter current is always greater than the collector current as $I_E = I_B + I_C$, the current gain (α) of the amplifier must therefore be less than one (unity) as I_C is always less than IE by the value of IB. Thus the CB amplifier attenuates the current, with typical values of alpha ranging from between 0.980 to 0.995.

Common Base Amplifier Voltage Gain

Since the common base amplifier can not operate as a current amplifier (Ai ≅ 1), it must therefore have the ability to operate as a voltage amplifier. The voltage gain for the common base amplifier is the ratio of V_{OUT}/V_{IN}, that is the collector voltage V_C to the emitter voltage V_E. In other words, $V_{OUT} = V_C$ and $V_{IN} = V_E$.as the output voltage V_{OUT} is developed across the collector resistance, R_C, the output voltage must therefore be a function of I_C as from Ohms Law, $V_{RC} = I_C{*}R_C$. So any change in I_E will have a corresponding change in I_C.

- For AC input signals the emitter diode junction has an effective small-signal resistance given by: r'e = 25mV/IE, where the 25mV is the thermal voltage of the pn-junction and IE is the emitter current. So as the current flowing through the emitter increases, the emitter resistance will decrease by a proportional amount.

- Some of the input current flows through this internal base-emitter junction resistance to the base as well as through the externally connected emitter resistor, RE. For small-signal analysis these two resistances are connected in parallel with each other.

- Since the value of r’e is very small, and R_E is generally much larger, usually in the kilohms (kΩ) range, the magnitude of the amplifiers voltage gain changes dynamically with different levels of emitter current.

Common Source:

- The SR amplifier circuit is shown ,the ac input is applied at CG and the ac output is taken at CD. The CS amplifier circuit is exactly the same with the addition of CS, which is connected to the dc voltage source or ground.The ac small signal model for the source resistor configuration is shown.

- The device output resistance, rO, in this circuit for the sake of completeness. However, as we found for the BJT (and your author assumes), this output resistance is usually much larger than the resistances it is in parallel with and may be neglected.
- In the source follower (SF) configuration, the ac input is applied at CG, the ac output is taken at CS and the drain is either connected to a dc voltage supply (with or without CD). This is also called the common drain (CD) and is analogous to the common collector (a.k.a. emitter follower) configuration for the BJT.

- In the common gate (CG) configuration, the ac input is applied at CS, the ac output is taken at CD and CG is connected to a dc voltage course or ground. Sometimes in the CG configuration, CG is omitted and the gate is connected directly to a dc voltage source.
- The ac small signal model for the CG amplifier is shown .To derive the output resistance, we follow the same procedure.For the CG amplifier:

IC AND DIFFERENTIAL AMPLIFIERS

- Biasing in integrated circuit (IC) design is based on the use of transistors configured to act as constant current sources. On a multistage amplifier IC chip, a constant dc current source is generated at one location and is then reproduced at different locations for biasing the various amplification stages. The major advantages to this approach include: (i) The requirement for resistors, coupling capacitors and bypass capacitors is removed; (ii) The biasing of the multiple stages track each other in case of parameter changes, such as voltage supply or temperature fluctuations.

- Using the transistors geometries $(W/L)_1$ and $(W/L)_2$as design parameters, we want to create a DC current Io, as long as transistor Q_2 is in Saturation Mode The Drain of transistor Q_2 is connected to a load circuit, not necessarily a resistor. The load circuit typically involves one or more additional MOSFET transistors. Depending on the load, transistor Q_2 may be in any of three modes: Saturation, Triode or Cutoff. Of course, only when it is in Saturation it will work as originally planned (DC current source) The current Io always goes away from the load circuit and into Q_2. Such a DC current source is said to be a sink.

- **Current Mirror**

A current mirror is a circuit designed to copy a current through one active device by controlling the current in another active device of a circuit, keeping the output current constant regardless of loading.

BJT Current Mirror:

- If a voltage is applied to the BJT base-emitter junction as an input quantity and the collector current is taken as an output quantity, the transistor will act as an exponential voltage-to-current converter. By applying a negative feedback (simply joining the base and collector) the transistor can be "reversed" and it will begin acting as the opposite logarithmic current-to-voltage converter; now it will adjust the "output" base-emitter voltage so as to pass the applied "input" collector current.

- The simplest bipolar current mirror (shown in Figure) implements this idea. It consists of two cascaded transistor stages acting accordingly as a reversed and direct voltage-to-current converters. The emitter of transistor Q_1 is connected to ground. Its collector-base voltage is zero as shown. Consequently, the voltage drop across Q_1 is V_{BE}, that is, this voltage is set by the diode law and Q_1 is said to be diode connected.
- It is important to have Q_1 in the circuit instead of a simple diode, because Q_1 sets V_{BE} for transistor Q_2. If Q_1 and Q_2 are matched, that is, have substantially the same device properties, and if the mirror output voltage is chosen so the collector-base voltage of Q_2 is also zero, then the V_{BE}-value set by Q_1 results in an emitter current in the matched Q_2 that is the same as the emitter current in Q_1. Because Q_1 and Q_2 are matched, their β_0-values also agree, making the mirror output current the same as the collector current of Q_1.

Wilson Current Mirror

- that accepts an input current at the input terminal and provides a "mirrored" current source or sink output at the output terminal. The mirrored current is a precise copy of the input current. It may be used as a Wilson current source by applying a constant bias current to the input.

Current Steering : constant dc current (reference current) at one location & replicated current source at various other locations utilizes a precision resistor external to the chip bias currents track each other under changes in power-supply voltage or in temperature circuit building block for bias design & load element of IC amplifiers.

Two types of basic gain cells on IC

- Both are loaded with constant-current source
- Resistor-on-chip is difficult to fabricate (tolerance and area)
- Current source provides higher output resistance than discrete resistor and will increase the gain
- These circuits are referred to as current-source loaded or active-loaded

Cascode Amplifier:

- The gain of the basic gain cell can be increased by cascading CG (CB) stage on top of the CS (CE) stage called Cascoding ,increases gain , Increase output resistance
- The cascode is a two-stage amplifier that consists of a common-emitter stage feeding into a common-base stage.

BJT Differential Amplifiers

- Differential Amplifier is a device that is used to amplify the difference in voltage of the two input signals. Differential Amplifier is an important building block in integrated circuits of analog system.

Amplifier rejects the common-mode signal relative to the differential signal is the common-mode rejection ratio (CMRR). By definition, the CMRR is ratio of the gain for the differential signal to the gain for common-mode signal.

BJT Differential Amplifiers – DC Offset

Causes of dc voltage and current offset • Modeling dc offset • RC mismatch • I_s mismatch • β mismatch • dc offsets in differential amplifiers due to component mismatch can be modeled as differential phenomena.

MOSFET Differential Amplifiers - Common Mode Rejection

The MOSFET is by far the most widely used transistor in both digital and analog circuits, and it is the backbone of modern electronics. One of the most common uses of the MOSFET in analog circuits is the construction of differential amplifiers. The latter are used as input stages in op-amps, video amplifiers, high-speed comparators, and many other analog-based circuits. MOSFET differential amplifiers are used in integrated circuits, such as operational amplifiers, they provide a high input impedance for the input terminals

- Differential amplifiers apply gain not to one input signal but to the *difference* between two input signals. This means that a differential amplifier naturally eliminates noise or interference that is present in both input signals.
- Differential amplification also suppresses common-mode signals—in other words, a DC offset that is present in both input signals will be removed, and the gain will be applied only to the signal of interest (assuming, of course, that the signal of interest is not present in both inputs). This is particularly advantageous in the context of IC design because it eliminates the need for bulky DC-blocking capacitors.
- The subtraction that occurs in a differential pair makes it easy to incorporate the circuit into a negative-feedback amplifier.

- Any mismatch of the transistor pair gives rise to VO, the output DC offset voltage. Then one can define an equivalent input offset voltage, for the matched case, VOS, that gives rise to the output offset voltage

Differential Amplifier with a Current Mirror.

Differential amplifiers with differential outputs have three distinct advantages:

1. It reduces the common-mode gain and increases the common-mode rejection ratio (CMRR).
2. It reduces the input offset voltage since inherent cancelation exists in the design.
3. 3. It increases the differential gain by a factor of 2 when the output is taken across two transistors.

Frequency Response of Amplifiers – BJT

Frequency Response of an electric or electronics circuit allows us 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.

General shape of frequency response of amplifiers:

- To plot this curve, input voltage to the amplifier is kept constant and frequency of input signal is continuously varied.
- The output voltage at each frequency of input signal is noted and the gain of the amplifier is calculated.
- Bandwidth of the amplifier is defined as the difference between f2 & f1.
- Bandwidth of the amplifier = f2 - f1
- The frequency f2 lies in high frequency region while frequency f1 lies in low frequency region.

- These two frequencies are also called as half-power frequencies since gain or output voltage drops to 70.7% of maximum value and this represents a power level of one half the power at the reference frequency in mid-frequency region.

Low Frequency Analysis of BJT:

- The schematic of a typical common-emitter amplifier is shown in figure.
- Capacitors C_B and C_C are used to block the amplifier DC bias point from the input and output (AC coupling).
- Capacitor C_E is an AC bypass capacitor used to establish a low frequency AC ground at the emitter of Q_1. Miller capacitor C_F is a small capacitance that will be used to control the high frequency 3-dB response of the amplifier.

Feedback concept- Properties:

The purpose of an amplifier is to amplify the input signal without changing its characteristics except its amplitude. The amplifier that works on the principle of feedback is called feedback amplifier.

The input signal Vin is applied to a mixer network, in which it is combined with a feedback signal Vf. The difference of these signals Vi is the input to the amplifier. A portion of the amplifier output is connected to the input through a feedback network.

- If the input signal and the feedback signal are in same phase, the signals get added up and the resultant output increases. This is called positive feedback. Positive feedback is also known as regenerative or direct feedback.
- Positive feedback causes distortion and instability in amplifiers and hence it is not used for amplifiers; whereas positive feedback increases the gain and overall power of input signal and hence used in oscillator circuits.

Properties of Negative Feedback Amplifier

- The various properties of a negative feedback amplifier are:
- Desensitize the gain: It brings stability to amplifier by making gain less sensitive to all kind of variations.
- Reduce non-linear distortion: The negative feedback makes the output proportional to the input, i.e. reduces non-linear distortion.
- Reduce the effect of noise: It minimizes the contribution of unwanted electric signals. This noise may be generated by circuit components or by extraneous interference.
- Control the input and output impedances: It increases or decreases the input and output impedances. This is done by choosing appropriate feedback topology.
- Extend the bandwidth of the amplifier: By incorporating negative feedback, the bandwidth can be increased.

Advantages of Negative Feedback Amplifier

- In a negative feedback amplifier, the gain of the amplifier reduces. However, it is still used in almost every amplifier due to its various advantages. Some of the advantages are given below:
- Gain desensitivity
- Significant extension of bandwidth
- Very less distortions
- Decreased output resistance
- Stable operating point
- Reduces noise and other interference in amplifier

Gain Desensitivity

- Feedback can be used to desensitize the closed-loop gain to variations in the basic amplifier.

Bandwidth Extension

- It is mentioned several times in the past that we can trade gain for bandwidth.
- Finally, we see how to do so with feedback.

Types of Feedback:

- Voltage series feedback
- Voltage shunt feedback
- Current series feedback
- Current shunt feedback

- Depending on the input signal (voltage or current) to be amplified and form of the output (voltage or current), amplifiers can be classified into four categories. Depending on the amplifier category, one of four types of feedback structures should be used (series-shunt, series-series, shunt-shunt, or shunt-series)
- 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 cascade amplifiers. Both of these are provided using the voltage series feedback connection.

Voltage amplifier – voltage-controlled voltage source

- Requires high input impedance, low output impedance
- Use series-shunt feedback (voltage-voltage feedback)

Current amplifier – current-controlled current source

- Use shunt-series feedback (current-current feedback)

Series-Shunt Feedback Amplifier (Voltage-Voltage Feedback) :

- Samples the output voltage and returns a feedback voltage signal. Ideal feedback network has infinite input impedance and zero output resistance
- Find the closed-loop gain and input resistance

Transconductance amplifier – voltage-controlled current source

- Use series-series feedback (current-voltage feedback)

Transimpedance amplifier – current-controlled voltage source

- Use shunt-shunt feedback (voltage-current feedback)
- **Shunt-Shunt Feedback Amplifier (Voltage-Current FB)**
- When voltage-current FB is applied to a transimpedance amplifier, output voltage is sensed and current is subtracted from the input
- The gain stage has some resistance

Shunt-Series Feedback Amplifier (Current-Current FB)

- A current-current FB circuit is used for current amplifiers
- For the β circuit – input resistance should be low and output resistance be high.
- RS and RF constitute the FB circuit
- RS should be small and RF large
- The same steps can be taken to solve for A, Aβ, Af, Rif, and Rof
- Remember that both *A* and β circuits are
- current controlled current sources

Condition for oscillation:

The oscillators that produce an output having a sine waveform are called sinusoidal or harmonic oscillators. Such oscillators can provide output at frequencies ranging from 20 Hz to 1 GHz.

Sinusoidal Oscillators

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

- The use of positive feedback results in a feedback amplifier having closed-loop gain greater than the open-loop gain. It results in instability and operates as an oscillatory circuit. An oscillatory circuit provides a constantly varying amplified output signal of any desired frequency.
- An Oscillator circuit is a complete set of all the parts of circuit which helps to produce the oscillations. These oscillations should sustain and should be Undamped as just discussed before. Let us try to analyze a practical Oscillator circuit to have a better understanding on how an Oscillator circuit works.

Frequency Stability of an Oscillator

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

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

- Operating point of the active device such as BJT or FET used should lie in the linear region of the amplifier. Its deviation will affect the oscillator frequency.
- The temperature dependency of the performance of circuit components affect the oscillator frequency.

- The changes in d.c. supply voltage applied to the active device, shift the oscillator frequency. This can be avoided if a regulated power supply is used.
- A change in output load may cause a change in the Q-factor of the tank circuit, thereby causing a change in oscillator output frequency.
- The presence of inter element capacitances and stray capacitances affect the oscillator output frequency and thus frequency stability.
- The **Barkhausen Criterion** With the knowledge we have till now, we understood that a practical oscillator circuit consists of a tank circuit, a transistor amplifier circuit and a feedback circuit. so, let us now try to brush up the concept of feedback amplifiers, to derive the gain of the feedback amplifiers.

Principle of Feedback Amplifier

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

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

- If $A\beta = 1$, $A_f = \infty$. Thus the gain becomes infinity, i.e., there is output without any input. In another words, the amplifier works as an Oscillator.
- The condition $A\beta = 1$ is called as Barkhausen Criterion of oscillations. This is a very important factor to be always kept in mind, in the concept of Oscillators.

Sinusoidal oscillator-RC phase shift oscillator.

- A Phase Shift Oscillator is an electronic oscillator circuit which produces sine wave output. It can either be designed by using transistor or by using an Op-amp as inverting amplifier.
- Generally, these phase shift oscillators are used as audio oscillators. In RC phase shift oscillator, 180 degree phase shift is generated by the RC network and another 180 degree is generated by the Op-amp, so the resulting wave is inverted by 360 degree.

- The disadvantage of RC phase shift oscillator using op-amp is that it can't be used for high frequency applications. Because whenever the frequency is too high the capacitor's reactance is very low and it act as a short circuit.
- Apart from generating the sine wave output they are also used to provide significant control over the phase shifting process.

Other usages of phase shift oscillators are:

- In audio oscillators
- Sine Wave Inverter
- Voice Synthesis
- GPS units
- Musical Instruments.

Wien Bridge Oscillator Using Op-amp

- One of the simplest sine wave oscillators which uses a RC network in place of the conventional LC tuned tank circuit to produce a sinusoidal output waveform, is called a 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 fr the phase shift is 0°.

- Wien-Bridge networks are low frequency oscillators which are used to generate audio and sub-audio frequencies ranging between 20 Hz to 20 KHz. Further, they provide stabilized, low distorted sinusoidal output over a wide range of frequency which can be selected using decade resistance boxes.
- In addition, the oscillation frequency in this kind of circuit can be varied quite easily as it just needs variation of the capacitors C_1 and C_2. However these oscillators require large number of circuit components and can be operated upto a certain maximum frequency only.

Hartley Oscillator using Op-Amp

- The Hartley oscillator is one of the classical LC feedback circuits and used to generate high frequency waveforms or signals. As we discussed in the LC oscillators article that if the reactance elements X1 and X2 are chosen as inductors and X3 as capacitor in the feedback network, then the oscillator is called as Hartley oscillator.
- These can be implemented by using different circuit configurations. The major parts of the Hartley oscillators are the amplifier section and the tank section. The tank section consists of two inductors and one capacitor. Each section produces a phase shift of 180 degrees of the AC signal voltage and hence it produces a sine wave voltage.

Hartley Oscillator using Op-Amp

- The circuit diagram of a Hartley oscillator is shown in figure below. An NPN transistor connected in common emitter configuration serves as active device in amplifier stage. R1 and R2 are biasing resistors and RFC is the radio frequency choke which provides the isolation between AC and DC operation.
- At high frequencies, the reactance value of this choke is very high; hence it can be treated as open circuit. The reactance is zero for DC condition hence causes no problem for DC capacitors. CE is the emitter bypass capacitor and RE is also a biasing resistor. Capacitors CC1 and CC2 are the coupling capacitors.

Hartley Oscillator using Op-Amp

- 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.
- Thus 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.
- The amount of feedback depends upon the position of the "tapping point" of the inductor. If this is moved nearer to the collector the amount of feedback is increased, but the output taken between the Collector and earth is reduced and vice versa. Resistors, R1 and R2 provide the usual stabilizing DC bias for the transistor in the normal manner while the capacitors act as DC-blocking capacitors.

Colpitts Oscillator using transistor

- The basic configuration of the **Colpitts Oscillator** resembles that of the *Hartley Oscillator* but the difference this time is that the centre tapping of the tank sub-circuit is now made at the junction of a "capacitive voltage divider" network instead of a tapped autotransformer type inductor as in the Hartley oscillator.
- The Colpitts oscillator uses a capacitive voltage divider network as its feedback source. The two capacitors, C1 and C2 are placed across a single common inductor, L as shown. Then C1, C2 and L form the tuned tank circuit with the condition for oscillations being: $X_{C1} + X_{C2} = X_L$, the same as for the Hartley oscillator circuit.

Colpitts Oscillator using transistor

- 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°.
- Then the amount of feedback developed by the Colpitts oscillator is based on the capacitance ratio of C1 and C2 and is what governs the excitation of the oscillator. This ratio is called the "feedback fraction"

Multivibrators

- A multivibrator circuit oscillates between a “HIGH” state and a “LOW” state producing a continuous output. Astable multivibrators generally have an even 50% duty cycle, that is that 50% of the cycle time the output is “HIGH” and the remaining 50% of the cycle time the output is “OFF”. In other words, the duty cycle for an astable timing pulse is 1:1.
- There are basically three types of clock pulse generation circuits:
- Astable – A free-running multivibrator that has NO stable states but switches continuously between two states this action produces a train of square wave pulses at a fixed frequency.
- Monostable – A one-shot multivibrator that has only ONE stable state and is triggered externally with it returning back to its first stable state.
- Bistable – A flip-flop that has TWO stable states that produces a single pulse either positive or negative in value.

Astable Multivibrators

- The astable multivibrator is also called as a free running multivibrator. It has two quasi-stable states i.e. no stable state such. No external signal is required to produce the changes in state. The component values used to decide the time for which circuit remains in each state. Usually, as the astable multivibrator oscillates between two states, is used to produce a square wave.
- The basic transistor circuit for an Astable Multivibrator produces a square wave output from a pair of grounded emitter cross-coupled transistors. Both transistors either NPN or PNP, in the multivibrator are biased for linear operation and are operated as Common Emitter Amplifiers with 100% positive feedback.

- Regenerative switching circuits such as **Astable Multivibrators** are the most commonly used type of relaxation oscillator because not only are they simple, reliable and ease of construction they also produce a constant square wave output waveform.
- So **Astable Multivibrators** can produce TWO very short square wave output waveforms from each transistor or a much longer rectangular shaped output either symmetrical or non-symmetrical depending upon the time constant of the RC network.

Monostable multivibrator

- In this multivibrator one state is permanent stable state while the other state is temporary state. The permanent stable state is either HIGH or LOW. Assume the permanent state is HIGH. Apply a triggering pulse to change output state to LOW. But this state is a temporary state.
- So it will remain in LOW state for some time and after some time without applying any triggering pulse output goes back to permanent stable state i.e. HIGH.
- Thus only one triggering pulse is required to come back to the permanent stable state so frequency of output is equal to frequency of input triggering pulse. Thus called as single shot or mono-shot multivibrator.

- Multivibrators produce an output wave shape resembling that of a symmetrical or asymmetrical square wave and as such are the most commonly used of all the square wave generators. Multivibrators belong to a family of oscillators commonly called “Relaxation Oscillators“.
- Monostable Multivibrators have only ONE stable state (hence their name: “Mono”), and produce a single output pulse when it is triggered externally. Monostable Multivibrators only return back to their first original and stable state after a period of time determined by the time constant of the RC coupled circuit.

Bistable multivibrator

- Bistable is an electronic circuit also referred to as a flip-flop or latch. It is a circuit that has two stable states and can be used to store state information.
- A flip-flop is a bistable multivibrator and it can be made to change state by signals applied to one or more control inputs and will have one or two outputs. The bistable has two stable states - hence the name bistable. It can be flipped from one state to another by incoming pulses.
- Flip-flops and latches are a fundamental building block of digital electronics systems. One of their chief applications is in storing data and as such they are widely used in computers and processor systems of all sorts.

Bistable multivibrator

- The **Bistable Multivibrator** is another type of two state device similar to the Monostable Multivibrator we looked at in the previous tutorial but the difference this time is that BOTH states are stable.
- The discrete **Bistable Multivibrator** is a two state non-regenerative device constructed from two cross-coupled transistors operating as "ON-OFF" transistor switches.
- To change the bistable over from one state to the other, the bistable circuit requires a suitable trigger pulse and to go through a full cycle, two triggering pulses, one for each stage are required.

Bistable multivibrator

- Its more common name or term of "flip-flop" relates to the actual operation of the device, as it "flips" into one logic state, remains there and then changes or "flops" back into its first original state.
- The **Bistable Multivibrator** circuit above is stable in both states, either with one transistor "OFF" and the other "ON" or with the first transistor "ON" and the second "OFF".
- Switching between the two states is achieved by applying a single trigger pulse which in turn will cause the "ON" transistor to turn "OFF" and the "OFF" transistor to turn "ON" on the negative half of the trigger pulse. The circuit will switch sequentially by applying a pulse to each base in turn and this is achieved from a single input trigger pulse using a biased diodes as a steering circuit.

Tuned Amplifiers

- Tuned amplifiers are the amplifiers that are employed for the purpose of tuning. Tuning means selecting. Among a set of frequencies available, if there occurs a need to select a particular frequency, while rejecting all other frequencies, such a process is called Selection. This selection is done by using a circuit called as Tuned circuit.
- When an amplifier circuit has its load replaced by a tuned circuit, such an amplifier can be called as a Tuned amplifier circuit.

Tuned Amplifiers

- The tuner circuit is nothing but a LC circuit which is also called as resonant or tank circuit. It selects the frequency. A tuned circuit is capable of amplifying a signal over a narrow band of frequencies that are centered at resonant frequency.
- When the reactance of the inductor balances the reactance of the capacitor, in the tuned circuit at some frequency, such a frequency can be called as resonant frequency. It is denoted by f_r.

Types of Tuned Circuits

- A tuned circuit can be Series tuned circuit (Series resonant circuit) or Parallel tuned circuit (parallel resonant circuit) according to the type of its connection to the main circuit.

Series Tuned Circuit:

- The inductor and capacitor connected in series make a series tuned circuit, as shown in the following circuit diagram.
- At resonant frequency, a series resonant circuit offers low impedance which allows high current through it. A series resonant circuit offers increasingly high impedance to the frequencies far from the resonant frequency.

Characteristics of a Parallel Tuned Circuit

- The frequency at which parallel resonance occurs (i.e. reactive component of circuit current becomes zero) is called the resonant frequency $\mathbf{f_r}$. The main characteristics of a tuned circuit are as follows.

Impedance

- The ratio of supply voltage to the line current is the impedance of the tuned circuit. Impedance offered by LC circuit is given by
- At resonance, the line current increases while the impedance decreases.
- The below figure represents the impedance curve of a parallel resonance circuit.

Detailed content of the Lecture:

- **Circuit Current**
- At parallel resonance, the circuit or line current I is given by the applied voltage divided by the circuit impedance Z_r i.e.,
- Because Z_r is very high, the line current I will be very small.

Quality Factor

- For a parallel resonance circuit, the sharpness of the resonance curve determines the selectivity. The smaller the resistance of the coil, the sharper the resonant curve will be. Hence the inductive reactance and resistance of the coil determine the quality of the tuned circuit.
- The ratio of inductive reactance of the coil at resonance to its resistance is known as Quality factor. It is denoted by Q.

Frequency Response of Tuned Amplifier

- For an amplifier to be efficient, its gain should be high. This voltage gain depends upon β, input impedance and collector load. The collector load in a tuned amplifier is a tuned circuit.
- The voltage gain of such an amplifier is given by
- Where Z_C = effective collector load and Z_{in} = input impedance of the amplifier.
- The value of Z_C depends upon the frequency of the tuned amplifier. As Z_C is maximum at resonant frequency, the gain of the amplifier is maximum at this resonant frequency.

Bandwidth

- The range of frequencies at which the voltage gain of the tuned amplifier falls to 70.7% of the maximum gain is called its **Bandwidth**.
- The range of frequencies between f_1 and f_2 is called as bandwidth of the tuned amplifier. The bandwidth of a tuned amplifier depends upon the Q of the LC circuit i.e., upon the sharpness of the frequency response. The value of Q and the bandwidth are inversely proportional.

Relation between Q and Bandwidth

- The quality factor Q of the bandwidth is defined as the ratio of resonant frequency to bandwidth, i.e.,
- In general, a practical circuit has its Q value greater than 10.
- Under this condition, the resonant frequency at parallel resonance is given by

Advantages of tuned amplifiers

- The usage of reactive components like L and C, minimizes the power loss, which makes the tuned amplifiers efficient.
- The selectivity and amplification of desired frequency is high, by providing higher impedance at resonant frequency.
- A smaller collector supply VCC would do, because of its little resistance in parallel tuned circuit.
- It is important to remember that these advantages are not applicable when there is a high resistive collector load.

Inductor Losses

- Various components of coil losses are (1) Copper loss,(2) Eddy current loss and (3) Hysteresis loss
- Quality factor is kept as high as possible in tuned circuits at 1. When Q is high, bandwidth is low and we get better selectivity. 2. When Q is high inductor losses are less.

Single tuned amplifiers

- It use one parallel resonant circuit as the load impedance in each stage and all the tuned circuits are tuned to the same frequency.

Double Tuned Amplifier

- The double-tuned amplifier is one of the types of tuned amplifiers. The designing of this circuit can be done using two tuned circuits which are coupled inductively. The primary tuned circuit includes L1, C1 whereas the secondary circuit includes L2 C2. Here L1C1 and L2C2 are inductors and capacitors.
- The double tuned circuit can provide a bandwidth of several percent of the resonant frequency and gives steep sides to the response curve.
- Tuned amplifiers are the amplifiers that are employed for the purpose of tuning. Tuning means selecting. Among a set of frequencies available, if there occurs a need to select a particular frequency, while rejecting all other frequencies, such a process is called Selection. This selection is done by using a circuit called as Tuned circuit.

Double Tuned Amplifier

- The tuner circuit is nothing but a LC circuit which is also called as resonant or tank circuit. It selects the frequency. A tuned circuit is capable of amplifying a signal over a narrow band of frequencies that are centered at resonant frequency.When the reactance of the inductor balances the reactance of the capacitor, in the tuned circuit at some frequency, such a frequency can be called as resonant frequency.

Cascode Amplifier:

The cascode is a two-stage amplifier that consists of a common-emitter stage feeding into a common-base stage.. In modern circuits, the cascode is often constructed from two transistors (BJTs or FETs), with one operating as a common emitter or common source and the other as a common base or common gate.

- The characteristics due to the cascoding of amplifiers are:
- The impedances at input and output are high.
- The signals amplification undergoes under high bandwidths possessed by the system.
- The isolation amid input and the output is high.
- The load in the amplifier stacked vertically and it is referred to as cascode connection.
- The first stage configuration is connected in parallel to the second stage configuration of the transistor. To isolate and avoid direct feedback from the output to the input. This type of connection is known as cascode.

- A cascade amplifier is a two-port network designed with amplifiers which are connected in series when every amplifier transmits its o/p to the second amplifiers input in a daisy chain. The problem in measuring the gain of the cascaded stage is the non-perfect coupling among two stages because of loading.
- To avoid saturation the collector voltage of each stage must be greater than the base voltage, enough greater to allow for the collector voltage signal swing. However since the base voltage of the second stage is taken from the collector of the first stage it is inherently larger that the first stage base voltage, and the second stage collector voltage is still higher.

- But this decreases the available amplitude for the amplified signal. Adding a third stage would even further aggravate this situation.
- If a PNP second stage is used a base voltage close to the positive power supply accommodates a desirable higher first stage NPN collector voltage.
- Moreover a third NPN stage can be cascaded at the PNP stage output without the severe voltage offset problem of a cascade of similar stages.

Applications:

- Used in tuned RF amplifiers within television circuits.
- Used as a wideband amplifier.
- The isolation offered among input & output with these amplifiers is extremely high.

Stagger Tuning:

- Staggered tuned amplifier is an amplifier that is used to improve the total frequency response of the tuned amplifier. Usually, these amplifiers are designed to exhibit an overall response for maximal flatness in the region of the center frequency.
- To overcome the design complexity of the double-tuned amplifiers, cascading process is applied to single tuned amplifiers. This cascaded version is known as a stagger tuned amplifier.
- At a certain range of bandwidth, two single tuned amplifiers are taken. It must be tuned such that both possess the same resonating frequencies.
- The frequency responses of both the single tuned amplifiers together give a large flat bandwidth in this type of amplifier

- The amplifier using stagger tuning has greater BW, faster passband and number of stages used. The flatter will be the passband. The circuit is called stagger because the tuned circuit's resonance frequencies are displaced.
- As these frequencies are staggered and called as stagger tuned amplifiers. The characteristics of these amplifiers are shown below.
- The following image shows the main relationship between individual stages amplification characteristics within a stagger tuned amplifier.
- The stagger tuned amplifier's total frequency response is contrasted with the equivalent and separate single tuned stages.
- These stages include similar resonant circuits. In the following characteristics, the staggering decrease in the total amplification of the middle frequency to 0.5 of the crest amplification of the separation stage.

Synchronous tuning

- Synchronous Tuning where each amplifier stage is tuned identically. This scheme maximises the amplifier gain but has narrower bandwidth than staggered tuning.
- The amplitude of N equally tuned stages rolls off approaching an asymptote of -N×20dB/decade.The stronger the bending of the corresponding curve, the smaller becomes the bandwidth
- Tuned amplifiers serve the best for two purposes:
- a) Selection of desired frequency.
- b) Amplifying the signal to a desired level.

Frequency Response of Single Tuned Amplifier:

- 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.
- 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.

Frequency Response of Double Tuned Amplifier:

- The double tuned amplifier has the special feature of **coupling** which is important in determining the frequency response of the amplifier. The amount of mutual inductance between the two tuned circuits states the degree of coupling, which determines the frequency response of the circuit.
- In order to have an idea on the mutual inductance property, let us go through the basic principle.
- The construction of double tuned amplifier is understood by having a look at the following figure.
- This circuit consists of two tuned circuits L1C1 and L2C2 in the collector section of the amplifier.
- The signal at the output of the tuned circuit L1C1 is coupled to the other tuned circuit L2C2 through mutual coupling method.

Mutual Inductance

- As the current carrying coil produces some magnetic field around it, if another coil is brought near this coil, such that it is in the magnetic flux region of the primary, then the varying magnetic flux induces an EMF in the second coil. If this first coil is called as **Primary** coil, the second one can be called as a Secondary coil.
- When the EMF is induced in the secondary coil due to the varying magnetic field of the primary coil, then such phenomenon is called as the Mutual Inductance.

Power Amplifiers:

An amplifier is an electronic device used to increase the magnitude of voltage/current/power of an input signal. It takes in a weak electrical signal/waveform and reproduces a similar stronger waveform at the output by using an external power source.

- Class A
- Class B
- Class AB Amplifiers
- Class C Amplifier
- A power amplifier is an electronic amplifier designed to increase the magnitude of power of a given input signal. The power of the input signal is increased to a level high enough to drive loads of output devices like speakers, headphones, RF transmitters etc.

Power Amplifiers:

- Unlike voltage/current amplifiers, a power amplifier is designed to drive loads directly and is used as a final block in an amplifier chain.
- The input signal to a power amplifier needs to be above a certain threshold. So instead of directly passing the raw audio/RF signal to the power amplifier, it is first pre-amplified using current/voltage amplifiers and is sent as input to the power amp after making necessary modifications.
- They are broadly classified into two categories. Power amplifiers designed to amplify analog signals come under A, B, AB or C category. Power amplifiers designed to amplify Pulse Width Modulated(PWM) digital signals come under D, E, F etc.

Class A Amplifier

- The most commonly used type of power amplifier configuration is the Class A Amplifier. The Class A amplifier is the simplest form of power amplifier that uses a single switching transistor in the standard common emitter circuit configuration as seen previously to produce an inverted output.
- 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 of the output signal.
- 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 Amplifier

- 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.
- 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.

Class A Amplifier

- 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.
- 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.
- The transformer 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.

Class B Amplifier

- 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.
- 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 (ie, 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.

Class B Amplifier

- Transformer less Class B Push-Pull Amplifier
- One of the main disadvantages of the Class B amplifier circuit above is that it uses balanced center-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.

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.
- 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 transistor 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 are not conducting. The result is that both transistors are turned "OFF" at exactly the same time.

Class AB Amplifier

- 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 these diodes. 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.
- 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 180o to 360o 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 C Amplifier

- The most common application of the Class C amplifier is the RF (radio frequency) circuits like RF oscillator, RF amplifier etc where there are additional tuned circuits for retrieving the original input signal from the pulsed output of the Class C amplifier and so the distortion caused by the amplifier has little effect on the final output. Input and output waveforms of a typical Class C power amplifier.
- Biasing resistor Rb pulls the base of Q1 further downwards and the Q-point will be set some way below the cut-off point in the DC load line. As a result the transistor will start conducting only after the input signal amplitude has risen above the base emitter voltage (Vbe~0.7V) plus the downward bias voltage caused by Rb. That is the reason why the major portion of the input signal is absent in the output signal.

Class C Amplifier

- Inductor L1 and capacitor C1 forms a tank circuit which aids in the extraction of the required signal from the pulsed output of the transistor.
- Actual job of the active element (transistor) here is to produce a series of current pulses according to the input and make it flow through the resonant circuit. Values of L1 and C1 are so selected that the resonant circuit oscillates in the frequency of the input signal.
- Since the resonant circuit oscillates in one frequency (generally the carrier frequency) all other frequencies are attenuated and the required frequency can be squeezed out using a suitably tuned load.

Classes of Amplifiers:

- Amplifier Classes represent the amount of the output signal which varies within the amplifier circuit over one cycle of operation when excited by a sinusoidal input signal.
- The classification of amplifiers range from entirely linear operation (for use in high-fidelity signal amplification) with very low efficiency, to entirely non-linear (where a faithful signal reproduction is not so important) operation but with a much higher efficiency, while others are a compromise between the two.
- Amplifier classes are mainly lumped into two basic groups. The first are the classically controlled conduction angle amplifiers forming the more common amplifier classes of A, B, AB and C, which are defined by the length of their conduction state over some portion of the output waveform, such that the output stage transistor operation lies somewhere between being "fully-ON" and "fully-OFF".

Classes of Amplifiers:

Class	A	B	C	AB
Conduction Angle	360^0	180^0	Less than 90^0	180 to 360^0
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

Classes of Amplifiers:

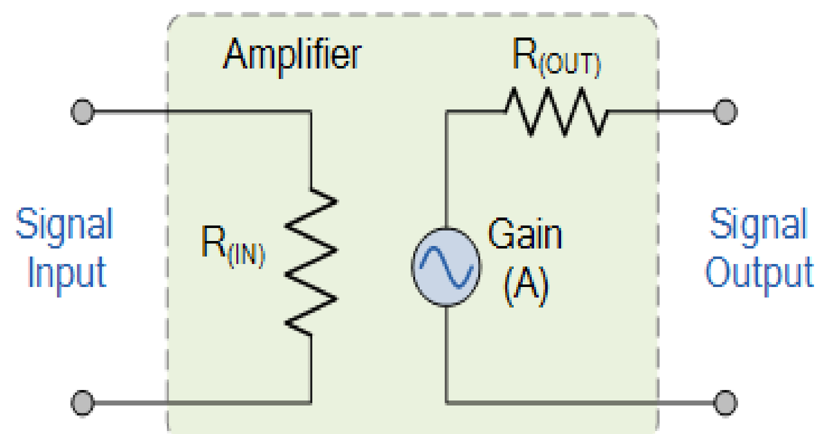
- The second set of amplifiers are the newer so-called “switching” amplifier classes of D, E, F, G, S, T etc, which use digital circuits and pulse width modulation (PWM) to constantly switch the signal between “fully-ON” and “fully-OFF” driving the output hard into the transistors saturation and cut-off regions.
- **Amplifier** is the generic term used to describe a circuit which produces and increased version of its input signal. However, not all amplifier circuits are the same as they are classified according to their circuit configurations and modes of operation.
- In “Electronics”, small signal amplifiers are commonly used devices as they have the ability to amplify a relatively small input signal, for example from a *Sensor* such as a photo-device, into a much larger output signal to drive a relay, lamp or loudspeaker for example.

Classes of Amplifiers:

- There are many forms of electronic circuits classed as amplifiers, from Operational Amplifiers and Small Signal Amplifiers up to Large Signal and Power Amplifiers.
- The classification Amplifiers can be thought of as a simple box or block containing the amplifying device, such as a Bipolar Transistor, Field Effect Transistor or Operational Amplifier, which has two input terminals and two output terminals (ground being common) with the output signal being much greater than that of the input signal as it has been "Amplified".
- of an amplifier depends upon the size of the signal, large or small, its physical configuration and how it processes the input signal, that is the relationship between input signal and current flowing in the load.

Ideal Amplifier Model

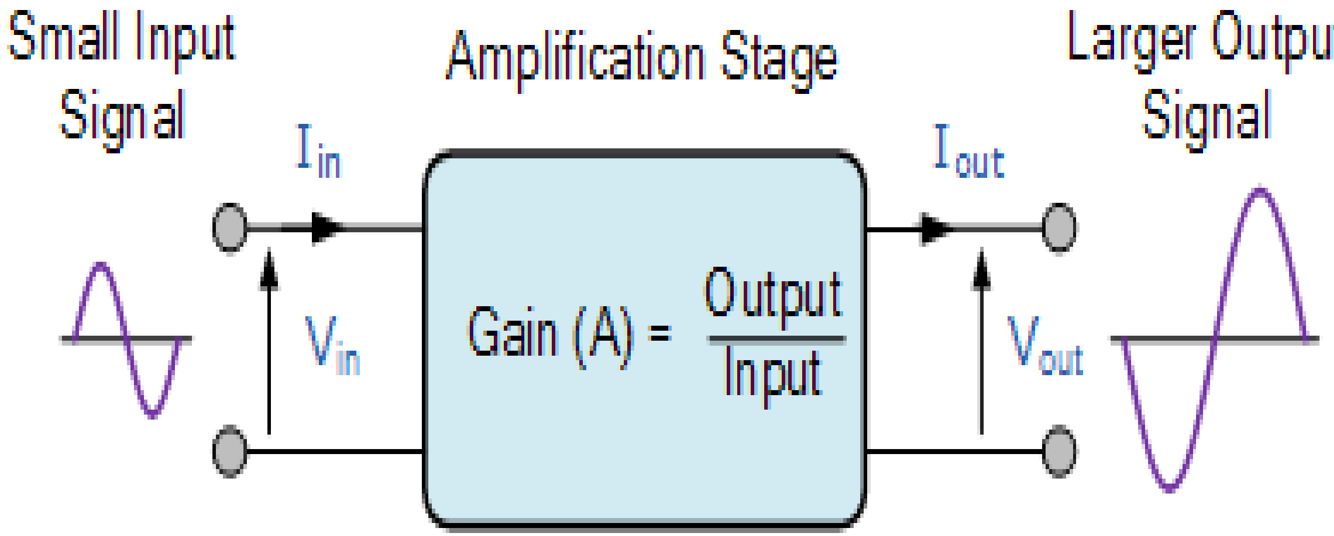
- The amplified difference between the input and output signals is known as the Gain of the amplifier. Gain is basically a measure of how much an amplifier "amplifies" the input signal. The amplified difference between the input and output signals is known as the Gain of the amplifier. Gain is basically a measure of how much an amplifier "amplifies" the input signal.



- Amplifier gain is simply the ratio of the output divided-by the input. Gain has no units as its a ratio, but in Electronics it is commonly given the symbol “A”, for Amplification. Then the gain of an amplifier is simply calculated as the “output signal divided by the input signal”.

Amplifier Gain

- The introduction to the amplifier gain can be said to be the relationship that exists between the signal measured at the output with the signal measured at the input. There are three different kinds of amplifier gain which can be measured and these are: *Voltage Gain* (Av), *Current Gain* (Ai) and *Power Gain* (Ap)


Small Input Signal
Amplification Stage
Larger Output Signal
I_{in}
I_{out}
V_{in}
V_{out}
Gain (A) = Output / Input

Power Amplifier Gain:

- The Power Gain you can also divide the power obtained at the output with the power obtained at the input. Also when calculating the gain of an amplifier, the subscripts v, i and p are used to denote the type of signal gain being used.
- The power gain (Ap) or power level of the amplifier can also be expressed in Decibels, (dB).

$$Power\,Gain\,(A_p) = A_v \; x \; A_i$$

$$Efficiency\ (\eta) = \frac{Power\ delivered\ to\ the\ Load}{Power\ taken\ from\ the\ Supply} = \frac{P_{OUT}}{P_{IN}}$$

Power Amplifier Gain:

- Voltage Gain in dB: $a_v = 20*\log(Av)$
- Current Gain in dB: $a_i = 20*\log(Ai)$
- Power Gain in dB: $a_p = 10*\log(Ap)$
- DC power gain of an amplifier is equal to ten times the common log of the output to input ratio, where as voltage and current gains are 20 times the common log of the ratio. That 20dB is not twice as much power as 10dB because of the log scale.
- Also, a positive value of dB represents a Gain and a negative value of dB represents a Loss within the amplifier. For example, an amplifier gain of +3dB indicates that the amplifiers output signal has "doubled", (x2) while an amplifier gain of -3dB indicates that the signal has "halved", (x0.5) or in other words a loss.

Power Amplifier Gain:

- The -3dB point of an amplifier is called the **half-power point** which is -3dB down from maximum, taking 0dB as the maximum output value.
- Generally, amplifiers can be sub-divided into two distinct types depending upon their power or voltage gain. One type is called the Small Signal Amplifier which include pre-amplifiers, instrumentation amplifiers etc. Small signal amplifies are designed to amplify very small signal voltage levels of only a few micro-volts (μV) from sensors or audio signals.
- The other type are called Large Signal Amplifiers such as audio power amplifiers or power switching amplifiers. Large signal amplifiers are designed to amplify large input voltage signals or switch heavy load currents as you would find driving loudspeakers.

Efficiency of IC power amplifiers:

- The **Small Signal Amplifier** is generally referred to as a "Voltage" amplifier because they usually convert a small input voltage into a much larger output voltage.
- Sometimes an amplifier circuit is required to drive a motor or feed a loudspeaker and for these types of applications where high switching currents are needed Power Amplifiers are required.
- The power amplifier works on the basic principle of converting the DC power drawn from the power supply into an AC voltage signal delivered to the load.
- Although the amplification is high the efficiency of the conversion from the DC power supply input to the AC voltage signal output is usually poor.

Efficiency of IC power amplifiers:

- The perfect or ideal amplifier would give us an efficiency rating of 100% or at least the power “IN” would be equal to the power “OUT”. However, in reality this can never happen as some of the power is lost in the form of heat and also, the amplifier itself consumes power during the amplification process.

Ideal Amplifier

- The amplifiers gain, (A) should remain constant for varying values of input signal.
- Gain is not be affected by frequency. Signals of all frequencies must be amplified by exactly the same amount.
- The amplifiers gain must not add noise to the output signal. It should remove any noise that is already exists in the input signal.
- The amplifiers gain should not be affected by changes in temperature giving good temperature stability.
- The gain of the amplifier must remain stable over long periods of time.

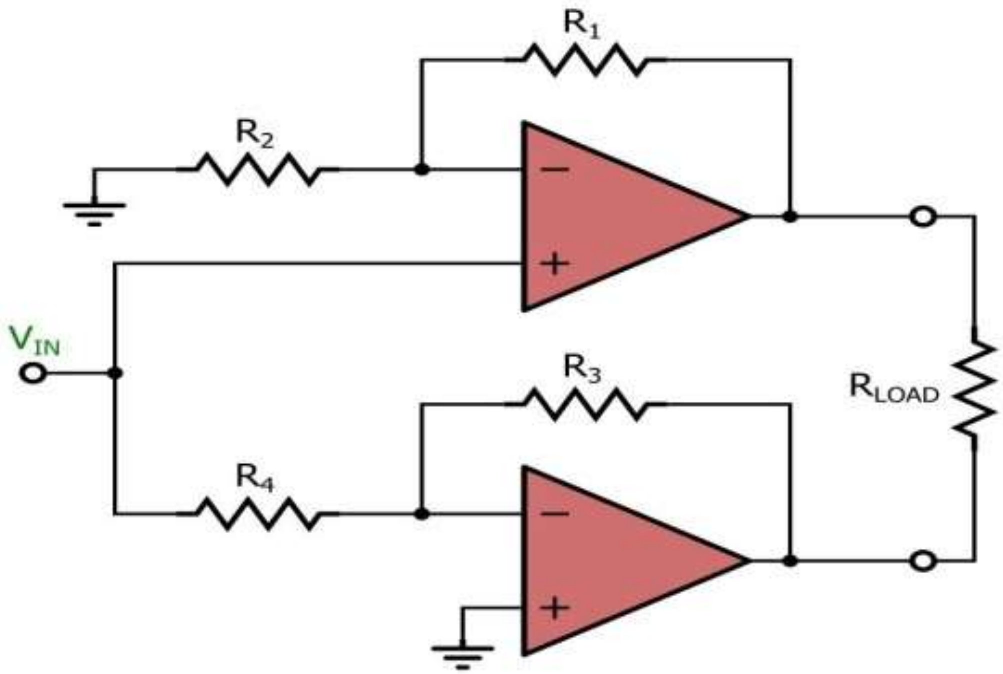
Bridge amplifiers

- A two channel amp can be bridged to one channel, and a four channel amp into two channels. Bridging the channels increases the power output. An amplifier is usually bridged to combine two channels to power one subwoofer, or to combine four channels into powering two subwoofers.
- There are a few different terms used to refer to a system in which the designer has access to positive and negative voltage rails: bipolar, symmetrical, dual-supply, split-supply.
- The dual-supply system is usually a persona non grata in the world of modern electronics. The reason for this is simple enough: generating a negative voltage supply requires additional circuitry, which means more design time, higher cost, and a larger PCB; thus, if system requirements can somehow be met without recourse to a negative supply rail, all the better.

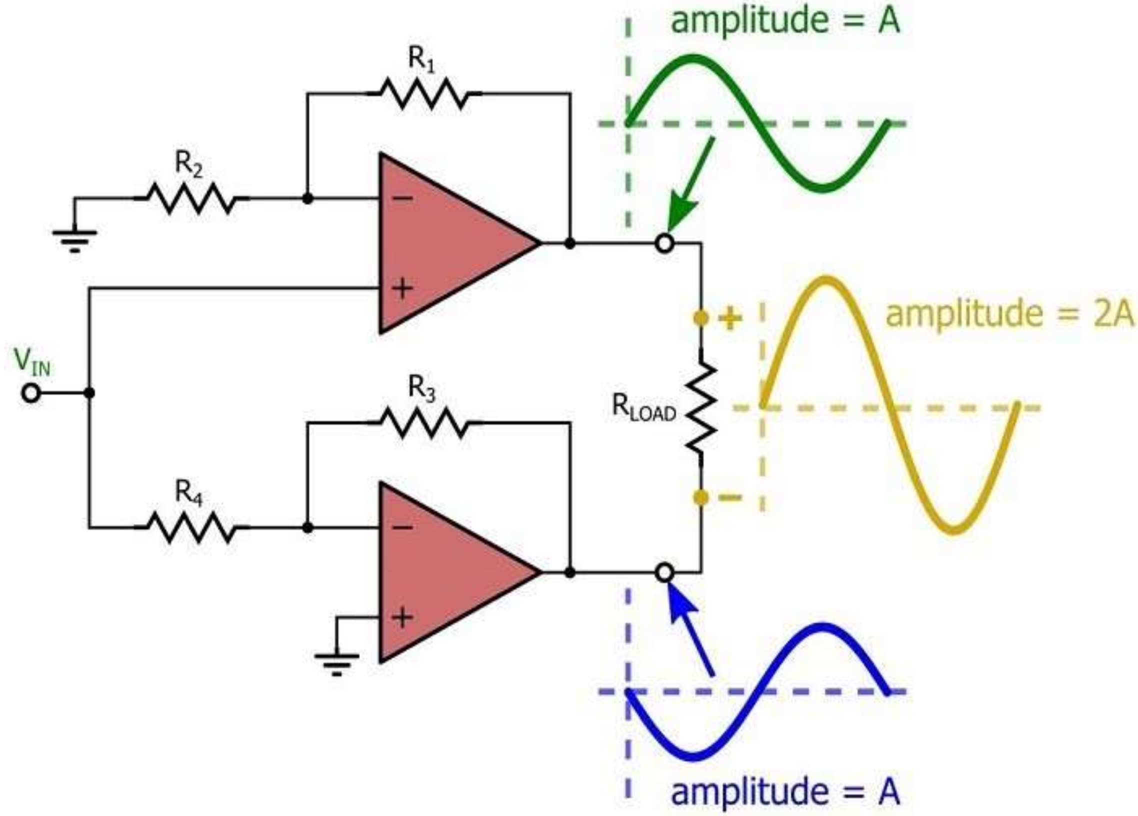
Bridge amplifiers

- The input signal is fed to two op-amp circuits, one noninverting, the other inverting; the resistors are chosen so that both amplifiers have the same gain magnitude. The load is connected between the outputs of the two amplifiers; note that the load is "floating," i.e., it has no direct connection to the ground node. As you have probably figured out by now, the bridge amplifier results in a factor-of-two increase in the voltage across the load.
- The bridge amplifier may prove quite useful when you need to deliver Significant power of AC Supply from a low-voltage or single-supply system.
- One thing that can be difficult in a single-supply environment is generating high-power AC output signals.

Bridge amplifiers



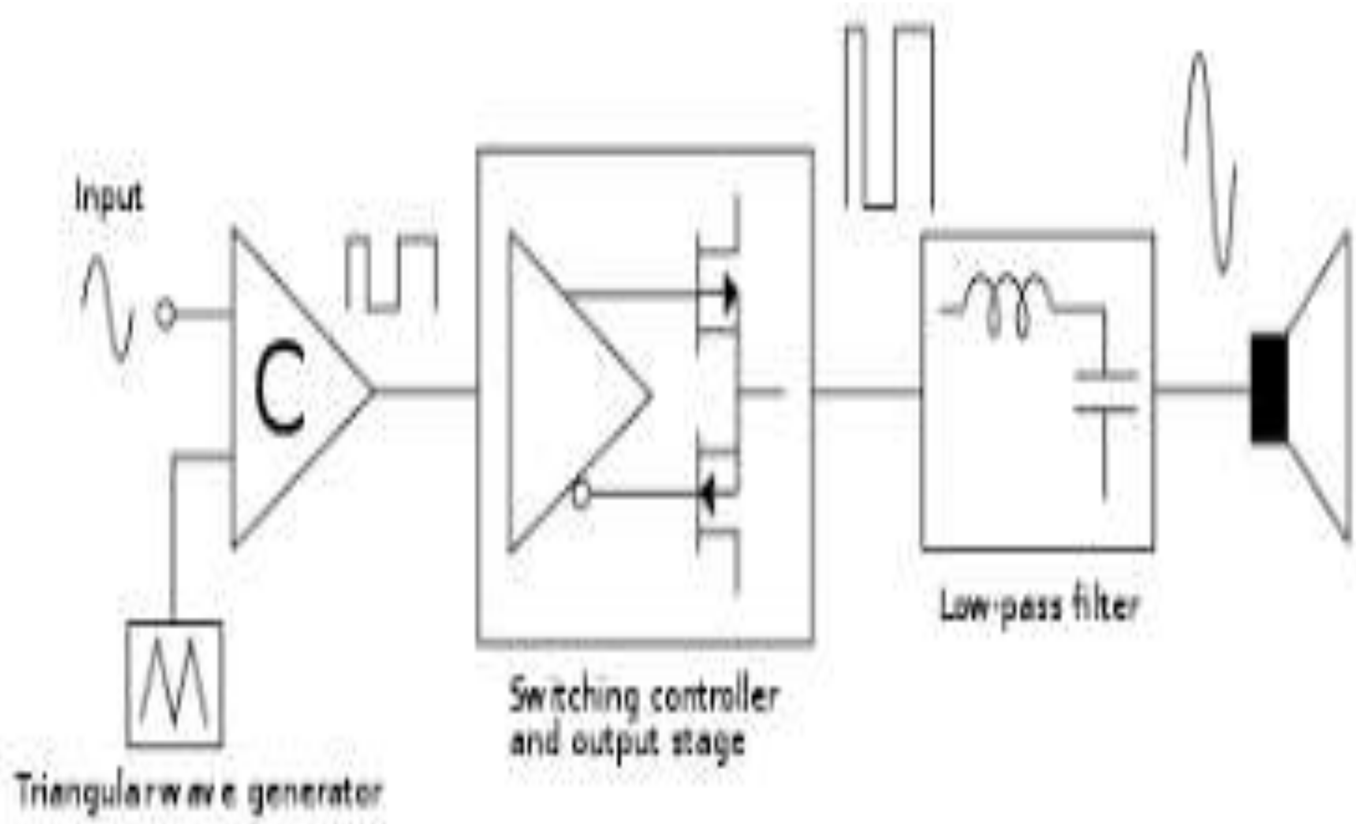
Bridge amplifiers



Class D amplifier

- A Class D audio amplifier is basically a switching amplifier or PWM amplifier. This class of amplifier is obviously more efficient than Class A, at about 50%, but has some issue with linearity at the crossover point, due to the time it takes to turn one device off and turn the other device on.
- The goal of audio amplifiers is to reproduce input audio signals at sound-producing output elements, with desired volume and power levels—faithfully, efficiently, and at low distortion.
- Power capabilities vary widely depending on the application, from milliwatts in headphones, to a few watts in TV or PC audio, to tens of watts for “mini” home stereos and automotive audio, to hundreds of watts and beyond for more powerful home and commercial sound systems—and to fill theaters or auditoriums with sound.

Class D amplifier



Class D amplifier

- In a conventional transistor amplifier, the *output stage* contains transistors that supply the instantaneous continuous output current. The many possible implementations for audio systems include Classes A, AB, and B.
- Compared with *Class D* designs, the output-stage power dissipation is large in even the most efficient *linear* output stages. This difference gives Class D significant advantages in many applications because the lower power dissipation produces less heat, saves circuit board space and cost, and extends battery life in portable systems.
- Audio frequencies range from about 20 Hz to 20 kHz, so the amplifier must have good frequency response over this range.