UNIT-III

Differential amplifier:

1. MOSFET Differential pair
2. Small signal operation
3. Frequency response of differential amplifier
4. Introduction to differential amplifier with active load

Multi-stage amplifier:

1. Direct coupled and RC coupled multistage amplifier
2. Feedback amplifiers
3. Multivibrators- Analysis and design of Bistable and monostable

Power Amplifier:

1. Power dissipation in transistors
2. Difference with voltage amplifiers
3. Amplifier classification (class A, class B, class C, Class AB, class AB push pull amplifier, collector efficiency of each, and cross over distortion

Differential amplifier:

1. MOSFET Differential pair
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3. Frequency response of differential amplifier
4. Introduction to differential amplifier with active load

Why Differential amplifier:

- Differential circuits are much less sensitive to noises
- Differential configuration enables us to bias amplifiers and connect multiple stages without using coupling or bypass capacitors
- Differential amplifiers are widely used in IC's – Excellent matching of transistors, which is critical for differential circuits

MOSFET Differential pair

1. Operation for Common mode input Signal:

$$\because Q_1 = Q_2$$

$$\therefore I_{D1} = I_{D2} = \frac{I}{2}$$

$$v_s = v_{CM} - V_{GS}$$

$$I_D = \frac{I}{2} = \frac{1}{2} k_n' \frac{W}{L} (V_{GS} - V_t)^2$$

$$v_{D1} = v_{D2} = V_{DD} - I_D R_D$$

Differential output $v_{D1} - v_{D2} = 0$

Now to get the max and min V_{CM} or range

$$\boxed{\begin{aligned} &v_{DS} > v_{GS} - V_t \\ &(V_{DD} - I_D R_D) - v_S > v_{CM} - v_s - V_t \end{aligned}}$$

The common voltages applied to both Q1 and Q2 are referred to as common mode, V_{CM} . Common mode inputs usually come from noises or interferences. Differential pair should reject V_{CM} :

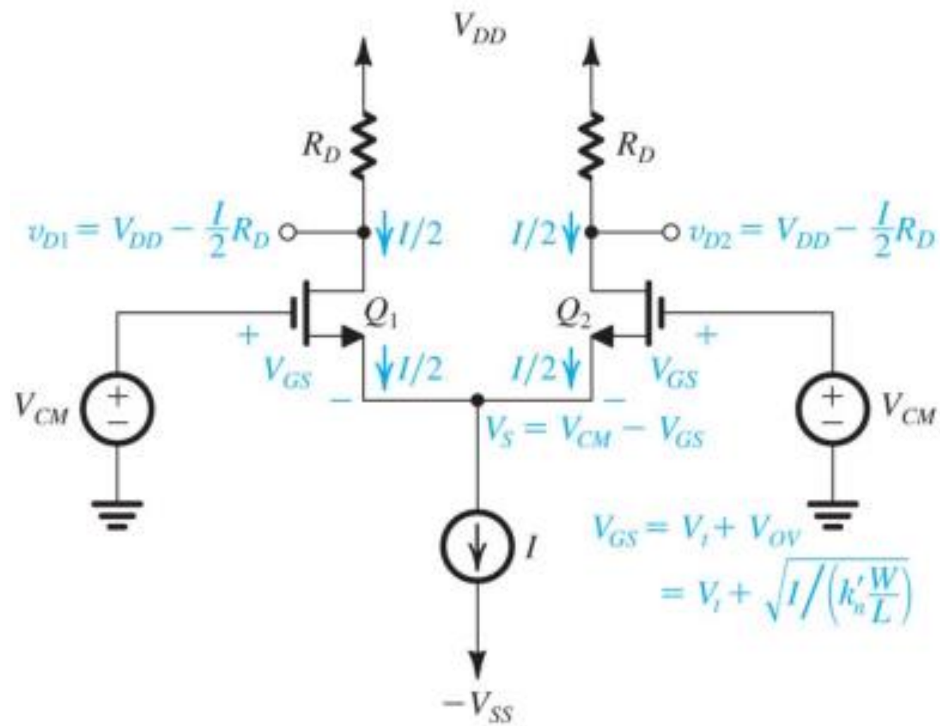


Figure 1. The MOS differential pair with a common-mode input voltage v_{CM}.

2. Large input signal operation (V_G):

Two matched MOS transistors Common current bias "Differential signals" applied to vG1 and vG2 (equal amplitude but opposite sign) "Differential outputs" are produced at vD1 and vD2

As we know the drain current as

$$i_{D1} = \frac{1}{2} k_n^{'} \frac{W}{L} (v_{GS1} - V_t)^2 \quad \ldots\ldots\textbf{(1)}$$

$$i_{D2} = \frac{1}{2} k_n^{'} \frac{W}{L} (v_{GS2} - V_t)^2$$

and

$$v_{id} = v_{GS1} - v_{GS2} = v_{G1} - v_{G2}$$

From equation (1), we get,

$$\sqrt{i_{D1}} - \sqrt{i_{D2}} = \sqrt{\frac{1}{2} k_n^{'} \frac{W}{L}} v_{id}$$

$$i_{D1} + i_{D2} = I$$

$$2\sqrt{i_{D!} i_{D2}} = I - \frac{1}{2} k_n^{'} \frac{W}{L} v_{id}^2 \quad \ldots.(2)$$

Use $(a-b)^2 = a^2 + b^2 - 2ab$

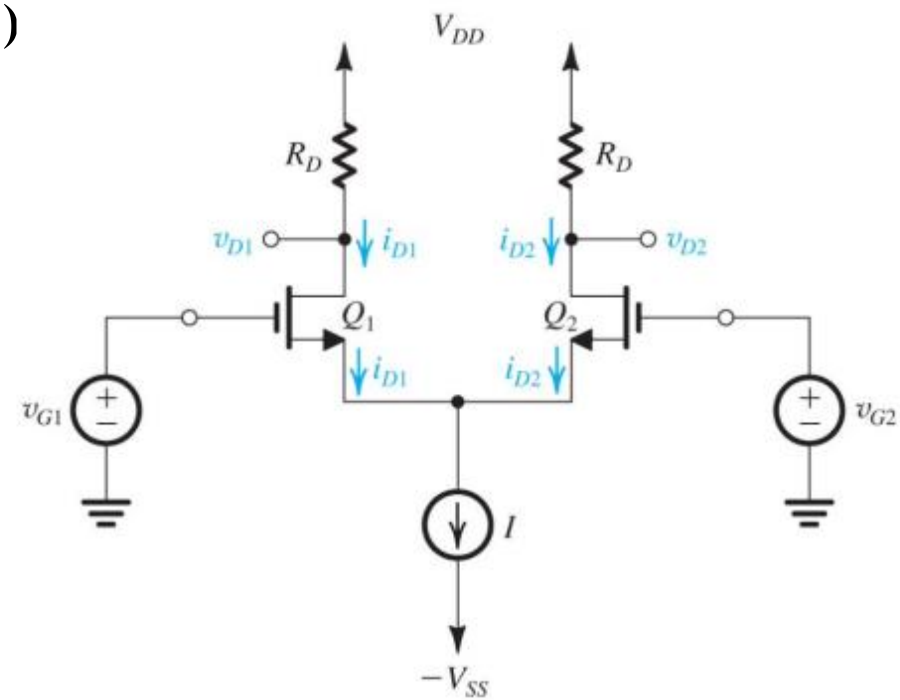


Figure 2. The MOSFET differential pair for the purpose of deriving the transfer characteristics, i_{D1} and i_{D2} versus $v_{id} = v_{G1} - v_{G2}$.

substitute $i_{D2} = I - i_{D1}$, solve quadratic equation:

$$i_{D1,2} = \frac{I}{2} \pm \sqrt{k_n I}\,\frac{v_{id}}{2}\sqrt{1 - \frac{(v_{id}/2)^2}{I/k_n}}$$

$$\frac{I}{2} = \frac{1}{2} k_n V_{OV}^2 \qquad \Rightarrow k_n = I/V_{OV}^2$$

V_{OV} is equilibrium overdrive voltage

$$\boxed{i_{D1,2} = \frac{I}{2} \pm \frac{I}{V_{OV}}\frac{v_{id}}{2}\sqrt{1 - \frac{(v_{id}/2)^2}{V_{OV}^2}}}$$

Near $v_{id} = 0$:

$$\sqrt{1 - \frac{(v_{id}/2)^2}{V_{OV}^2}} \approx 1$$ (neglect high-order tern

$$i_{D1} = \frac{I}{2} + \frac{I}{V_{OV}}\frac{v_{id}}{2}$$

$$i_{D2} = \frac{I}{2} - \frac{I}{V_{OV}}\frac{v_{id}}{2}$$

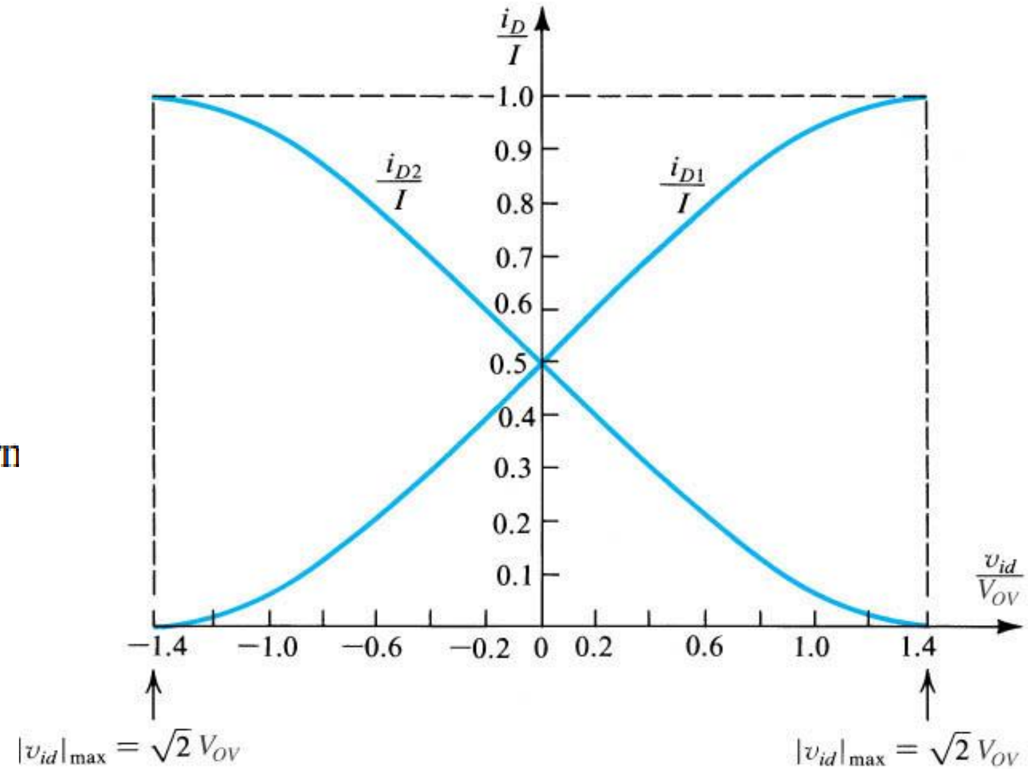


Figure 3. Normalized plots of the currents in a MOSFET differential pair. Note that V_{OV} is the overdrive voltage at which Q_1 and Q_2 operate when conducting drain currents equal to $I/2$.

Current of differential pair for various overdrive voltage

$$\boxed{i_{D1,2} = \frac{I}{2} \pm \frac{I}{V_{OV}} \frac{v_{id}}{2} \sqrt{1 - \frac{(v_{id}/2)^2}{V_{OV}^2}}}$$

The linear range of operation of the MOS differential pair can be extended by operating the transistor at a higher value of V_{OV}

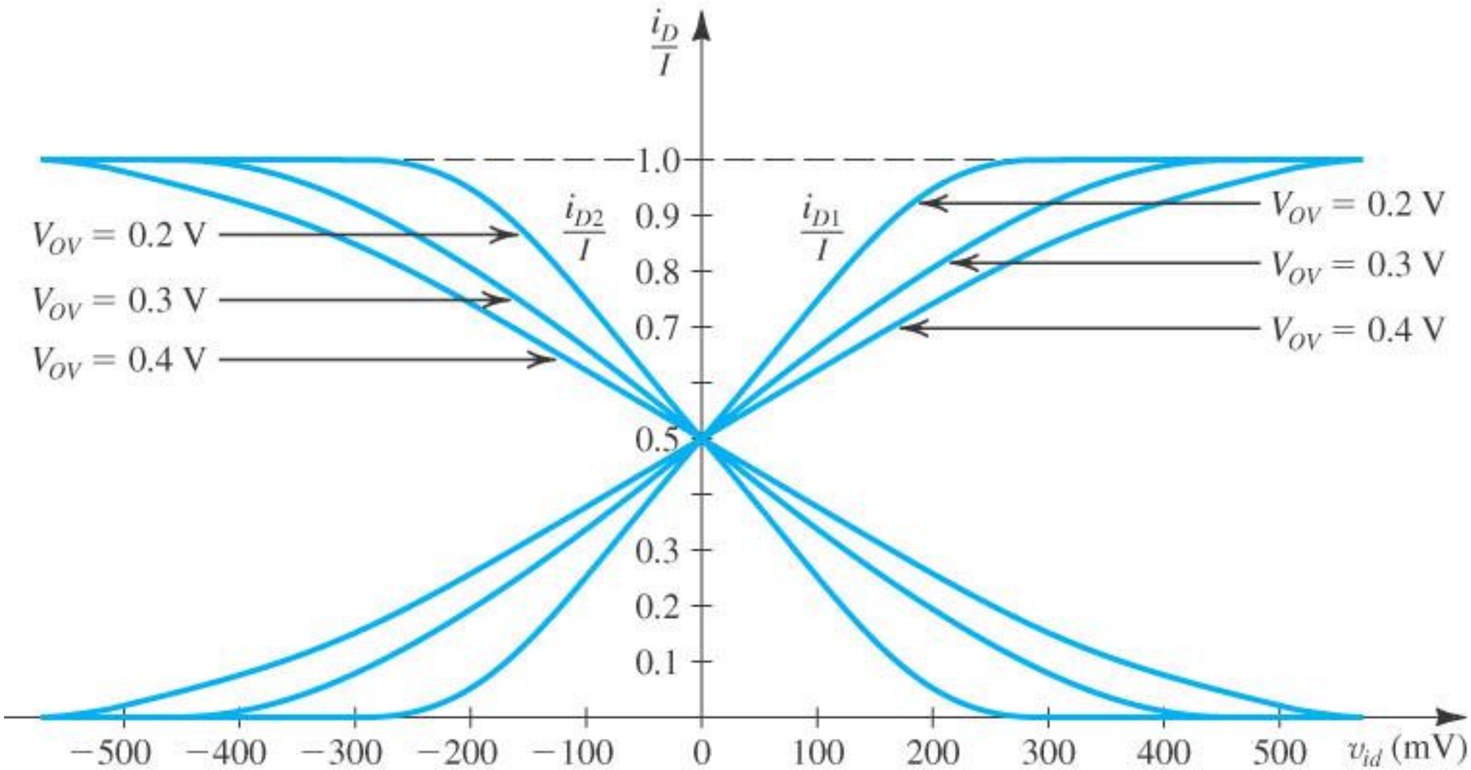


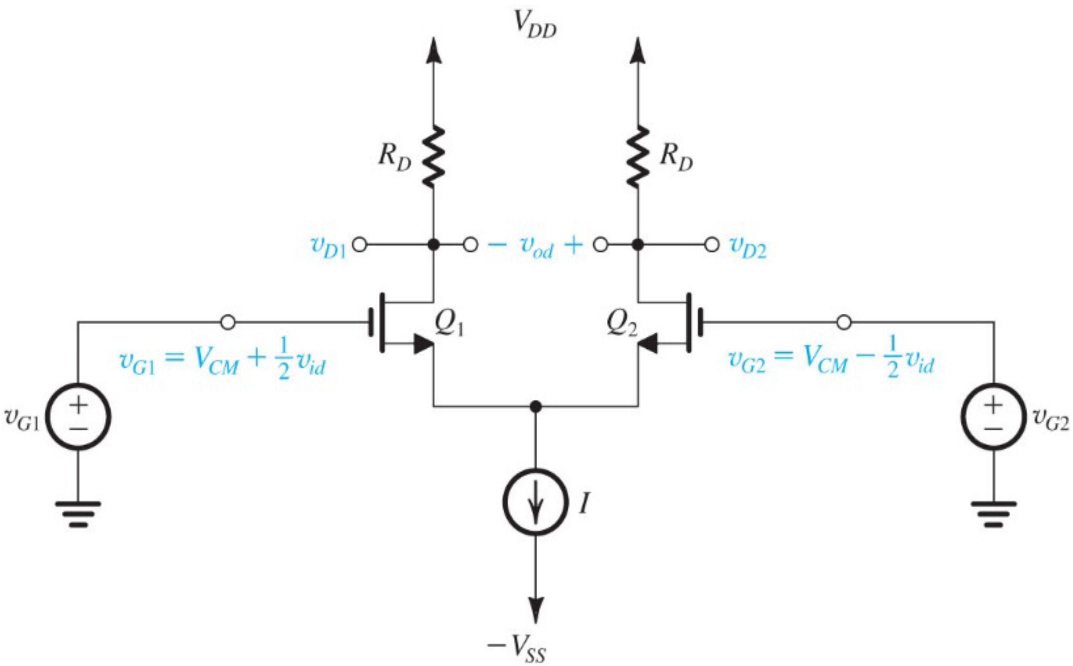
Figure 4. Plots of the currents in a MOSFET differential pair.

3.Small Signal Operation:

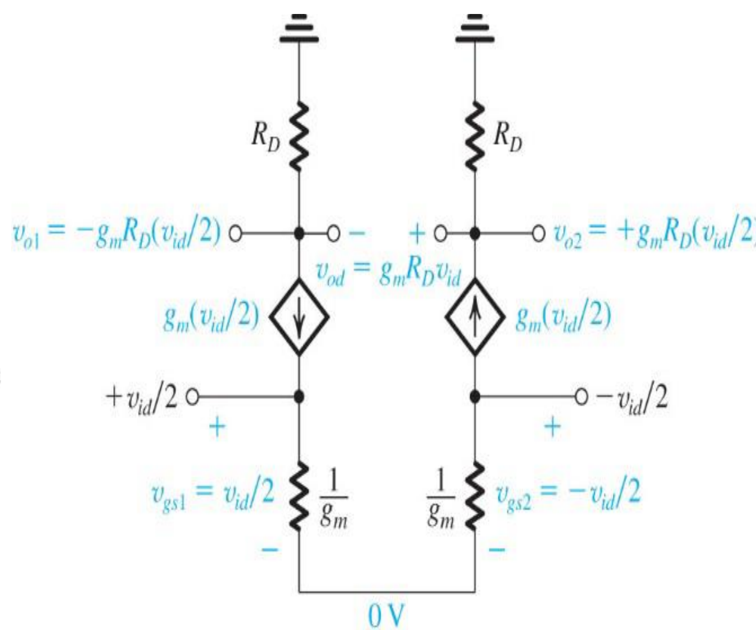
Objective:

To analyze small signal operation

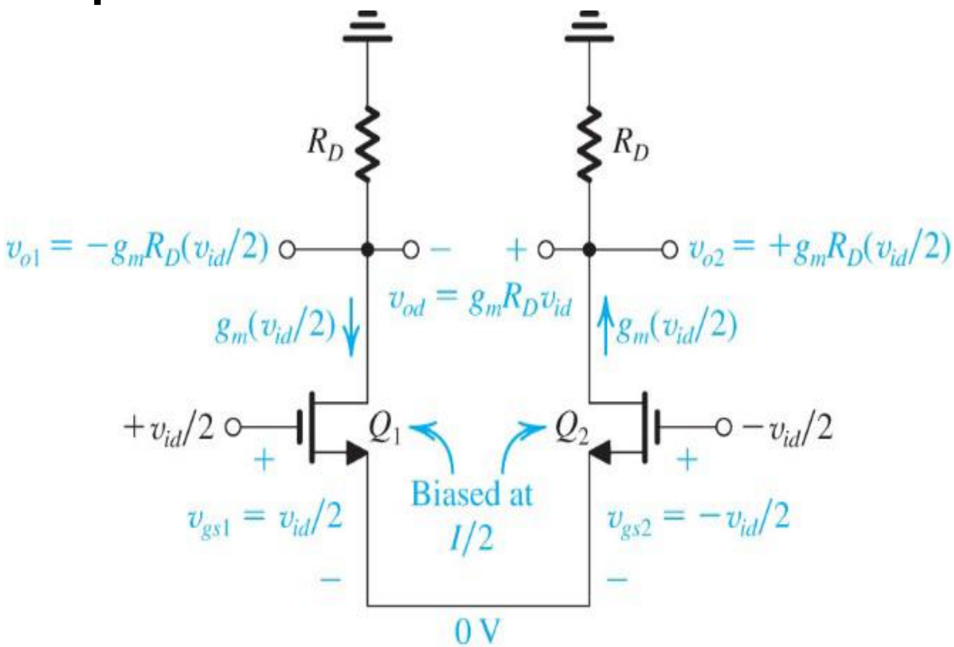
Determine voltage gain in response to differential input signal



T-model equivalent circuit



AC equivalent circuit



- Power supplies are grounded, bias current source is open circuited and v_{CM} eliminated
- Gate-to-source voltage at Q_1 is $v_{gs1} = v_{id}/2$
- Gate-to-source voltage at Q_2 is $v_{gs2} = -v_{id}/2$
- Source voltage is zero acting as virtual ground

- Drain voltages

$$v_{o1} = -i_{d1} R_D$$
$$v_{o2} = -i_{d2} R_D$$

- Drain current

$$i_{d1} = g_m v_{gs1} = g_m v_{id}/2$$
$$i_{d2} = g_m v_{gs2} = -g_m v_{id}/2$$

- If output is taken single-ended,

$$v_{o1} = -g_m \frac{v_{id}}{2} R_D$$
$$v_{o2} = g_m \frac{v_{id}}{2} R_D$$

- Single-ended gain

$$\frac{v_{o1}}{v_{id}} = -g_m \frac{1}{2} R_D$$
$$\frac{v_{o2}}{v_{id}} = g_m \frac{1}{2} R_D$$

- Differential gain

$$A_d \equiv \frac{v_{o2} - v_{o1}}{v_{id}} = g_m R_D$$

For differential AC small signal, the differential pair is "anti-symmetric". The potential at the mid point (Source) is zero. This is called **"Virtual Ground"**

This is the differential amplifier Gain which is same as common source gain

Amplifier Type	R_{in}	R_{out}	A_v	A_i
Common-source/emitter	High	High	High	High
Common-gate/base	Low	High	High	· 1
Common-drain/collector	High	Low	< 1	High

Multistage amplifier:

We can cascade different types of amplifiers to get desired overall characteristics. Often want:

- High input impedance
- High gain
- Low output impedance

- Mix and match cascades of different types of amplifiers to get desired result

Content:

1. **Multi-stage amplifier:** RC coupled multistage amplifier and Direct coupled amplifier
2. **Feedback amplifiers**
3. **Multivibrators**- Analysis and design of Bistable and monostable

Multi-stage amplifier

What is multistage amplifier?

- The output from a single stage amplifier is usually insufficient to drive a output device.
- The gain of single stage amplifier is not enough for practical purpose. So, more then one stage of amplification is required.
- To active the output, one stage is coupled with input of next stage.
  The resulting system is referred as multi-stage amplifier.
- Example, for a radio receiver the number of amplification stage is six or more.
- Transistor circuit containing more than one stage of amplification is known as multi-stage transistor amplification. In a multi stage amplifier a number of single stage amplifier are connected in cascade arrangement.
  i.e., the output of one stage is connected to input of next stage.

Figure1. Cascading of one or more stages

The objective of coupling device (e.g. a capacitor, transformer etc.):
(i) to transfer A.C. output of one stage to the input of the next stage and
(ii) to isolate the D.C. conditions of one stage from the next stage.

Coupling Methods

1. RC coupling
2. Direct coupling
3. Transformer coupling
4. RL coupling

Thus, the multistage amplifiers are RC coupled amplifier, Direct coupled amplifier, Transformer coupled amplifier and RL coupled amplifier

1. RC Coupled Amplifier:- (*Resistance - Capacitance coupled amplifiers*)

Circuit diagram:

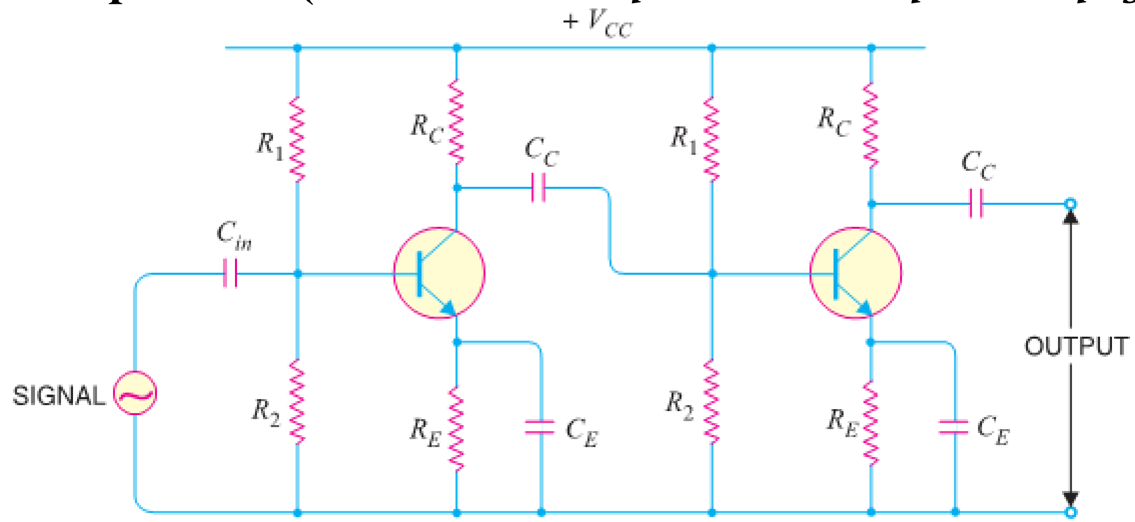


Figure 2. RC coupled amplifier

- This is the most popular type of coupling because it is cheap and provides excellent audio fidelity over a wide range of frequency. It is usually used for **voltage amplification**.
- Fig. 2 shows two stages of RC coupled amplifier. A coupling capacitor C_C is used to connect the output of first stage to the base (i.e. input) of the second stage and so on.
- As the coupling from one stage to next is achieved by a coupling capacitor followed by shunt resistors, therefore such amplifiers are called **RC Coupled Amplifier.**
- The resistances R_1, R_2, R_C and R_E form the self biasing and stabilization of transistor.
- The emitter bypass capacitor C_E offers *low reactance path* to the signal. Without it, the voltage gain of each stage would be lost.
- The coupling capacitor C_C transmits A.C. signal but blocks D.C. This prevents D.C. interference between various stages and the shifting of operating point. It is also called as **blocking capacitor**.

Working:

- When A.C. signal is applied to the base of the first transistor, it appears in the amplified form across its collector load R_C.
- The amplified signal developed across R_C is given to base of next stage through coupling capacitor C_C. The second stage does further amplification of the signal.
- In this way, the cascaded stages amplify the signal and the overall gain is considerably increased.

Frequency response:

Frequency response is the variation of gain with frequency of the signal.

Fig 3. shows the frequency response of a typical RC coupled amplifier. It is clear that voltage gain drops off at low (< 50 Hz) and high (> 20 kHz) frequencies whereas it is uniform over mid-frequency range (50 Hz to 20 kHz).

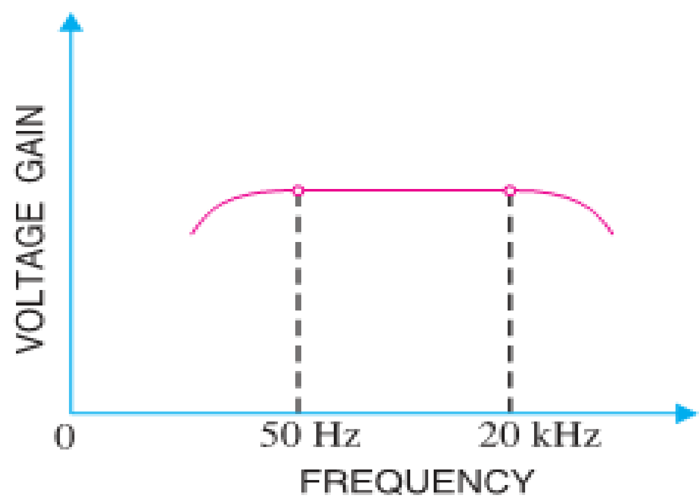


Figure 3. Frequency Response of RC coupled Amplifier

(i) At low frequencies (< 50 Hz):- At this stage the reactance of coupling capacitor C_C is quite high and hence very small part of signal will pass from one stage to the next stage. Moreover, C_E cannot shunt the emitter resistance R_E effectively because of its large reactance at low frequencies.
These two factors cause a falling of voltage gain at low frequencies.

(ii) At high frequencies (> 20 kHz):-At this stage the reactance of C_C is very small and it behaves as a short circuit. These increases the loading effect of next stage and serves to reduce the voltage gain. Moreover, at high frequency , capacitive reactance of base emitter junction is low which increases the base current. This reduces the current amplification factor β. Due to these two reasons, the voltage gain drops off at high frequency.

(iii) At mid-frequencies (50 Hz to 20 kHz):- At this stage the voltage gain of the amplifier is constant. The effect of coupling capacitor in this frequency range is such so as to maintain a uniform voltage gain. Thus, as the frequency increases in this range, reactance of C_C decreases which tends to increase the gain. However, at the same time, lower reactance means higher loading of first stage and hence lower gain. These two factors almost cancel each other, resulting in a uniform gain at mid frequency.

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 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**.
- 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.

2. Direct Coupled amplifier:

Circuit diagram:

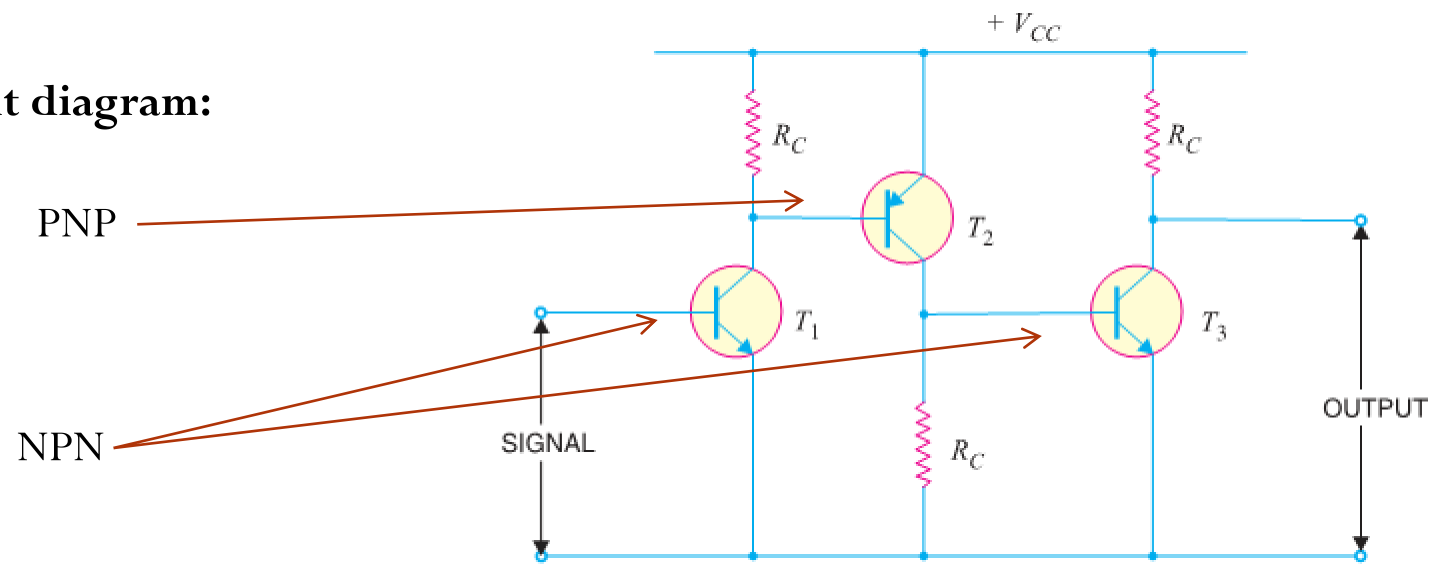


Figure 4. Direct coupled amplifier

- The other type of coupling is Direct coupled amplifier.it is especially used to amplify lower frequency.
- The output of first transistor T1 is connected to the input of the second stage T2.
- The variation of one transistor tends to cancel the variation in other
- The raise in the collector current and β of the transistor is cancelled by other transistor.

Working:

Signal is applied to the base of T1, the amplified signal is appeared at the collector of T1, which is further applied as input to the base of T2 which is further amplified .

Advantages:

- The circuit is simple because of minimum use of resistor
- Cost effective because of minimum number of component use and no use of transformer.

Disadvantages:

- It cannot be used for high frequency
- The operating point is shifted due to temperature

Applications:

- Low frequency application
- Low current application

Table 1. Comparison table for the coupling amplifiers

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

Feedback amplifiers

Feedback:

- The process of injecting a fraction of output energy of some device back to input is known as feedback.
- Depending upon whether the feedback energy aids or opposes the input signal, there are two basic types of feedback in amplifiers (i) **Positive Feedback** (ii) **Negative Feedback**
- The noise in the output of an amplifier is undesirable and must be kept to as small a level as possible. The noise level in amplifiers can be reduced considerably by the use of negative feedback i.e. by injecting a fraction of output in phase opposition to the input signal.

(i) Positive Feedback :

- When the feedback energy (voltage or current) is in phase with the input signal it is called *positive feedback*.
- Both amplifier and feedback network introduce a phase shift of 180°. The result is a 360° phase shift around the loop, causing the feedback voltage V_f to be in phase with the input signal Vin.
- The positive feedback increases the gain of the amplifier.

Disadvantages:

Increased distortion and instability. Therefore, positive feedback is not often employed in amplifiers.

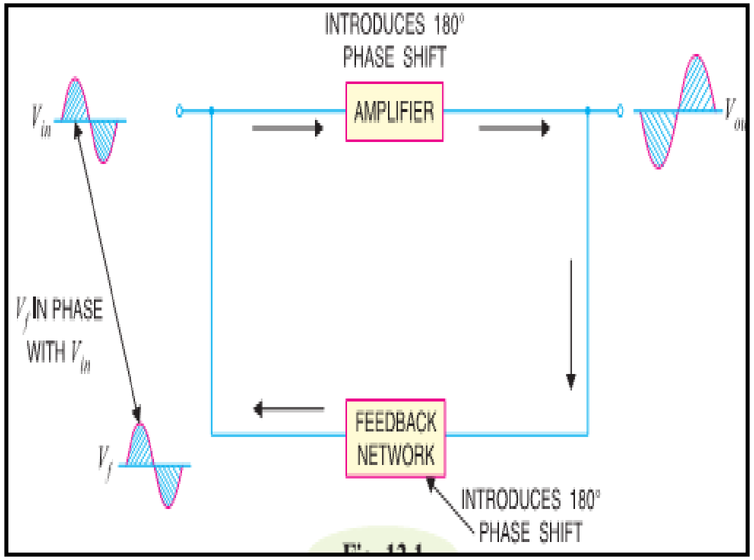


Figure 5. Positive feedback

ii) Negative Feedback:

- When the feedback energy (voltage or current) is out of phase with the input signal and thus opposes it, it is called *negative feedback*.
- As you can see, the amplifier introduces a phase shift of 180° into the circuit while the feedback network is so designed that it introduces no phase shift (i.e., 0° phase shift). The result is that the feedback voltage Vf is 180° out of phase with the input signal Vin.
- Negative feedback reduces the gain of the amplifier.

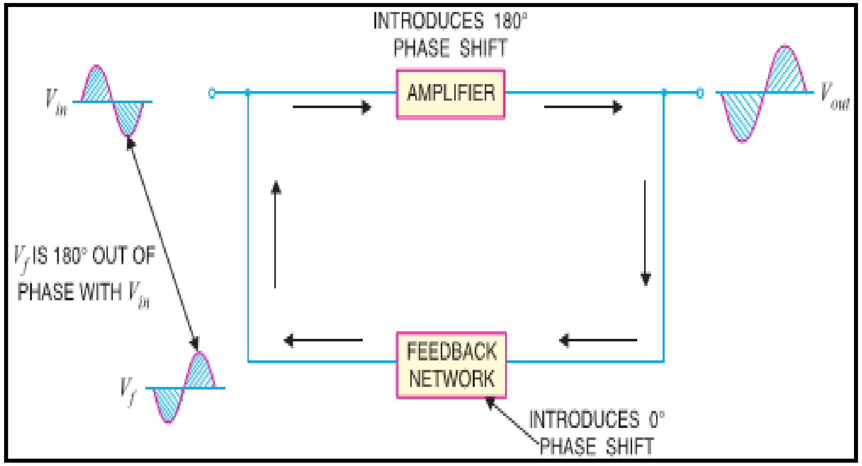


Figure 6. Negative feedback

Advantages of negative feedback are:
Reduction in distortion, stability in gain, increased bandwidth & improved input and output impedance impedances.
Therefore the negative feedback is frequently employed in amplifiers

Principle of feedback in amplifier:

Consider an ordinary amplifier i.e., **without feedback**. Let Vo and Vi be the output and input voltages respectively.
Thus,
Gain is defined as A =Vo/Vin (open loop gain)

Let us now consider an amplifier with feedback.
In such case the circuit has two part (i) Amplifier (ii) feedback part.
Where,
Vo = output voltage with feedback
β = feedback ratio
Vi ± βVo = input voltage
Now

- **Gain for positive feedback is**:
  A (Vi + βVo)= Vo
  A = Vo/Vin = A/1-A β

i.e., with positive feedback gain is increased

- **Gain for negative feedback is**:
  A (Vi - βVo)= Vo
  A = Vo/Vin = A/1+A β

i.e., with negative feedback gain is decreased

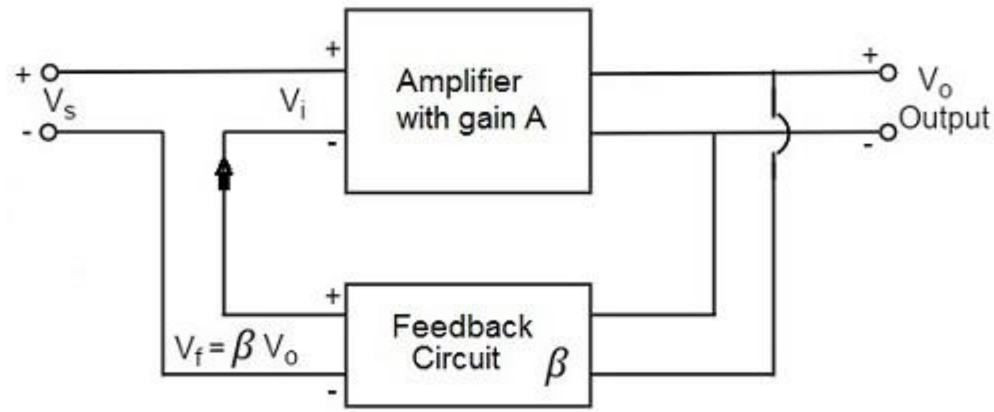


Figure 7. Feedback circuit

A β is the feedback factor

Advantages of negative feedback:

(i) Gain stability
(ii) Reduces non linear distortion
(iii) Increases the bandwidth
(iv) Increases the circuit stability
(v) Increases the input impedance and reduces the output impedances
(vi) Decreases the noise

Multivibrators

An electronic circuit that generates square waves (or other non-sinusoidals such as rectangular, saw-tooth waves) is know as a **multivibrator**.

Or

Multi means many, vibrator means oscillator. i.e., A circuit which can oscillate at a number of frequencies is called a **multivibrator**.

- It is a switching circuit which depends for operation on positive feedback.
- It is basically a two-stage amplifier with output of one **feedback** to the input of the other as in fig. 8
- It operates in two operating regions i.e., **saturation** and **cut-off** region. (not in active region because we want to generate the signal not the amplification of signal)

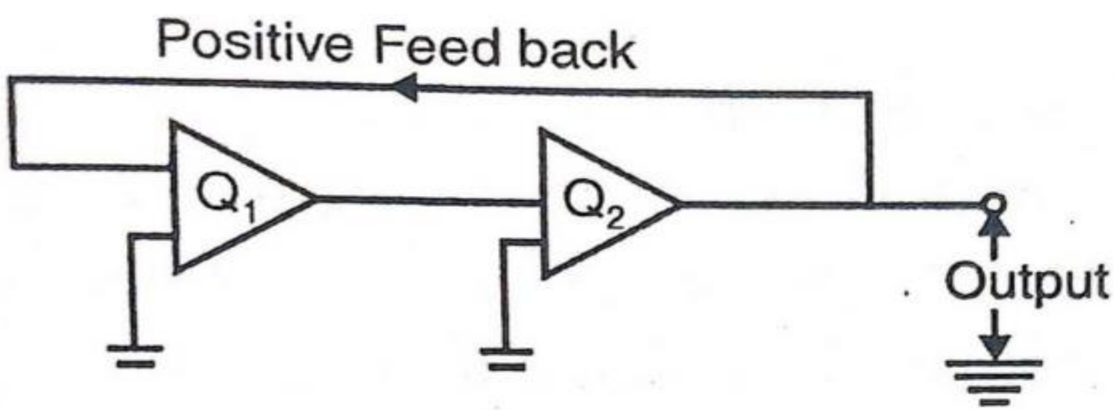


Figure 8. Feedback in multivibrator

A multivibrator circuit can be constructed using the electronic devices as Op-Amp, Transistor and 555 timer IC.

Types of Multivibrators:

The two possible states of a multivibrator are

	ON	**OFF**
First state	Q1	Q2
Second sate	Q2	Q1

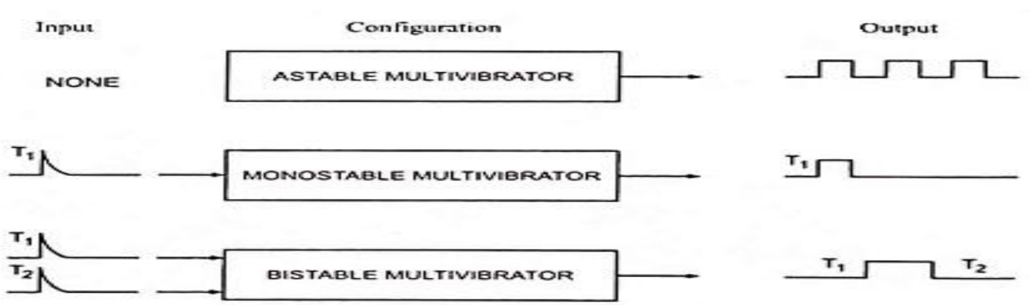
i.e., one transistor is ON and the other is OFF. After a certain time depending upon the circuit components (resistor and capacitor) , the stages reverse their conditions, the conducting stage suddenly cuts off and the non-conducting stage starts to conduct.

Depending on the operating mode **multivibrator** is classified as,

1. Astable or free running multivibrator

2. Monostable or one-shot multivibrator

3. Bi-stable or flip-flop multivibrator



1. **Astable** or free running multivibrator:

- A multivibrator which generates square waves of its own i.e., without any external input triggering pulse is know as an astable or free running multivibrator.
- It has no stable state. It switches back and forth from one state to the other.
- Its output oscillates between ON and OFF freely. So it know as free running multivibrator.

Circuit Diagram:

- The collector loads of two stages is equal i.e., R1=R4 and base resistor are also equal i.e., R2=R4. But R1,R4 << R2,R3. Also C1=C2.
- The output of transistor Q1 is coupled to the input of Q2 through C1 while the output of Q2 is fed to the input of Q1through C2.
- The square wave output can be taken from Q1and Q2.
- Both the coupling elements are capacitor (ac coupling)

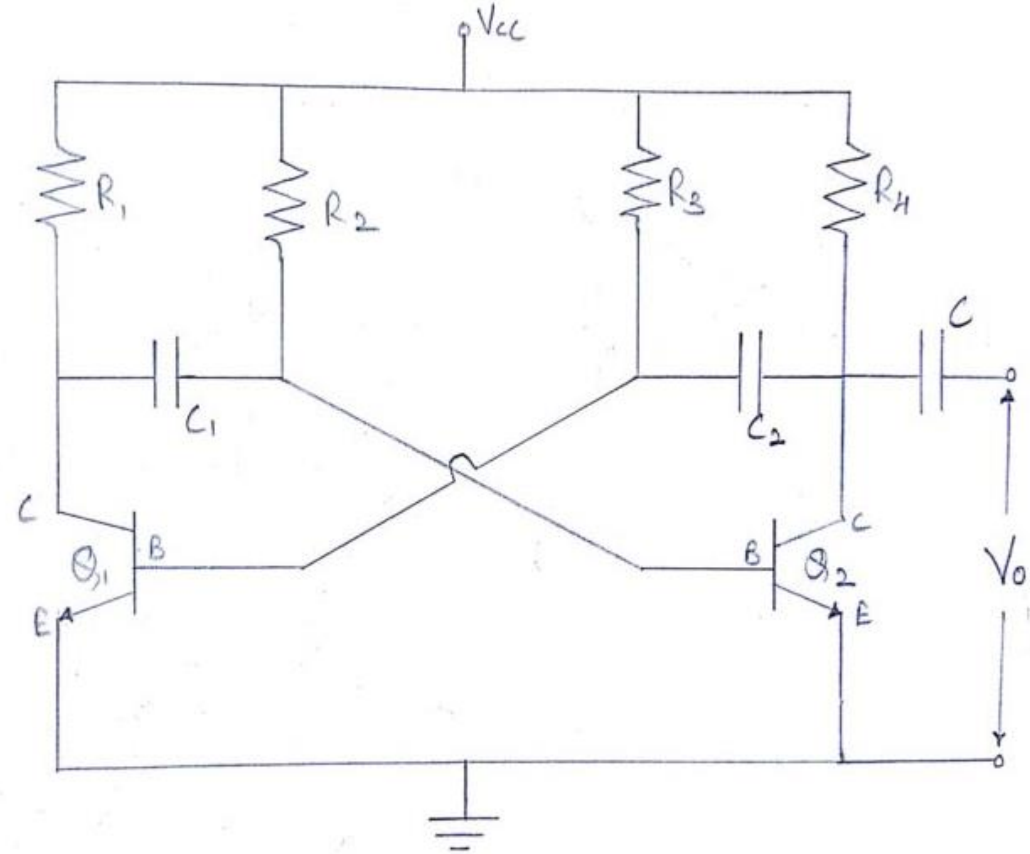


Figure 9. Astable Multivibrator circuit Diagram

Working:

When Vcc is applied, the collector current of the transistors increase. As the collector current depends upon the base current, **$I_c = \beta I_B$.**
As no transistor characteristics are alike, one of the two transistors say Q1 has its collector current increase and thus conducts. The collector of Q1 is applied to the base of Q2 through C1. This connection lets the increased negative voltage at the collector of Q1 to get applied at the base of Q2 and its collector current decreases. This continuous action makes the collector current of Q2 to decrease further. This current when applied to the base of Q1 makes it more negative and with the cumulative actions Q1 gets into saturation and Q2 to cut off. Thus the output voltage of Q1 will be V_{CE} (sat) and Q2 will be equal to V_{CC}.
The capacitor C1 charges through R1 and when the voltage across C1 reaches 0.7v, this is enough to turn the transistor Q2 to saturation. As this voltage is applied to the base of Q2, it gets into saturation, decreasing its collector current. This reduction of voltage at point B is applied to the base of transistor Q1 through C2 which makes the Q1 reverse bias. A series of these actions turn the transistor Q1 to cut off and transistor Q2 to saturation. Now point A has the potential V_{CC}. The capacitor C2 charges through R2. The voltage across this capacitor C2 when gets to 0.7v, turns on the transistor Q1 to saturation.
Hence the output voltage and the output waveform are formed by the alternate switching of the transistors Q1 and Q2. The time period of these ON/OFF states depends upon the values of biasing resistors and capacitors used, i.e., on the RC values used. As both the transistors are operated alternately, the output is a square waveform, with the peak amplitude of V_{CC}.

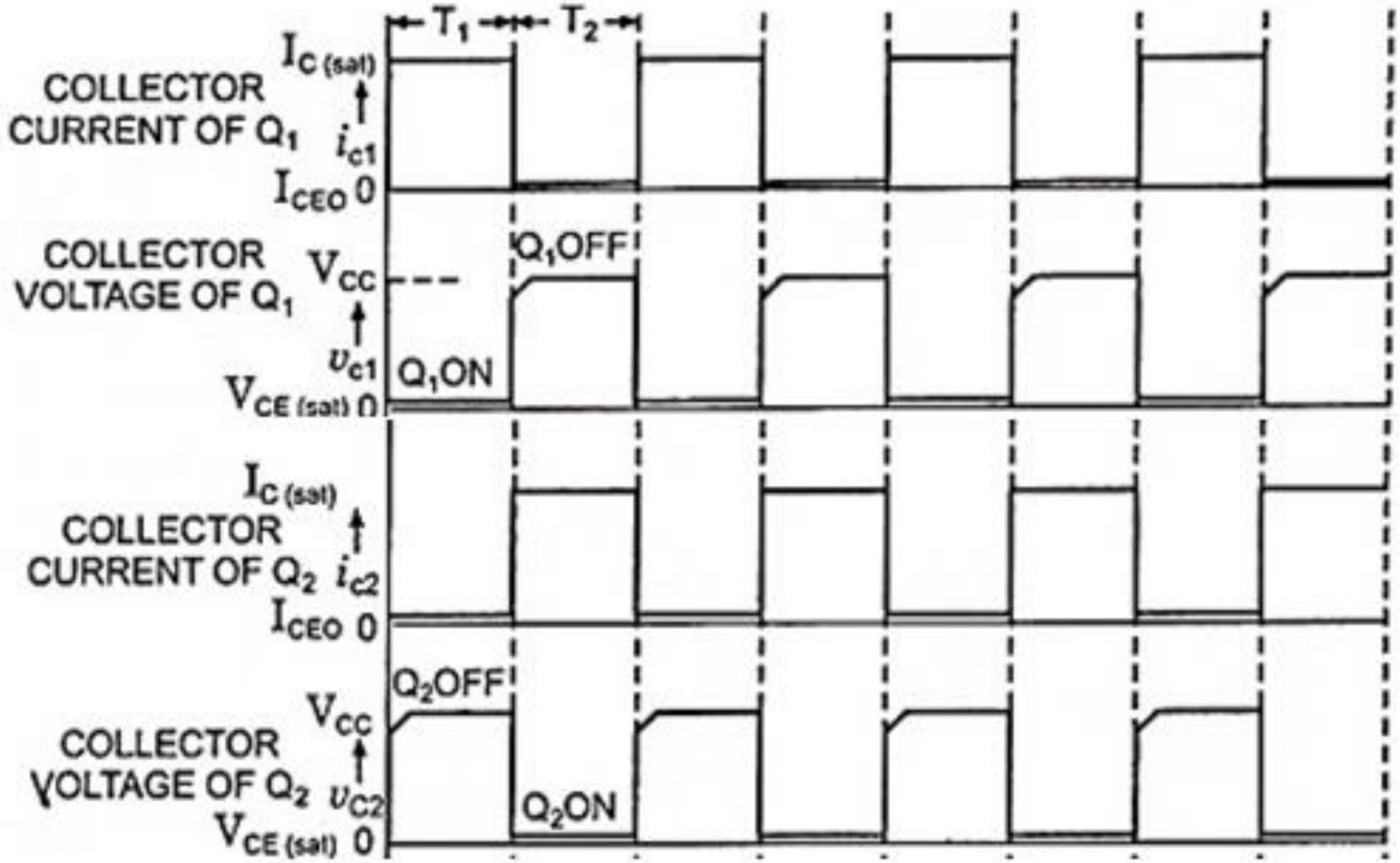
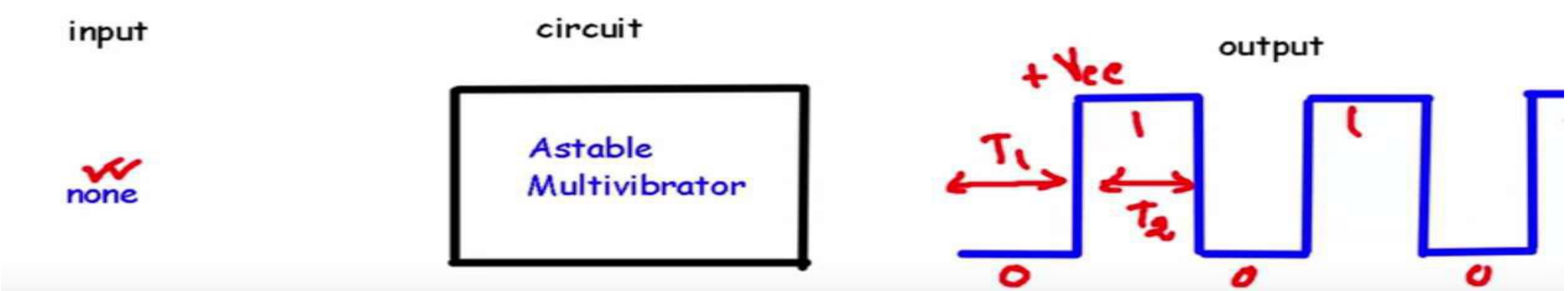


Figure 10. Wave form for Astable Multivibrator



Frequency of Oscillations

The ON time of transistor Q1 or the OFF time of transistor Q2 is given by

$$t1 = 0.69R1C1$$

Similarly, the OFF time of transistor Q1 or ON time of transistor Q2 is given by

$$t2 = 0.69R2C2$$

Hence, total time period of square wave

$$t = t1 + t2 = 0.69(R1C1 + R2C2)$$

As R1 = R2 = R and C1 = C2 = C, the frequency of square wave will be

$$\boxed{F = 1/t = 1.38RC}$$

Advantages

No external triggering required.

Circuit design is simple

Inexpensive

Can function continuously

Disadvantages

Energy absorption is more within the circuit.

Applications

Astable Multivibrators are used in many applications such as radio equipment, Morse code generators, timer circuits, analog circuits, and TV system

2. Monostable Multivibrator:

- A multivibrator in which one transistor is always conducting (i.e. in the ON state) and the other is non-conducting (i.e. in the OFF state) is called a **monostable multivibrator.**
- if one transistor is conducting and the other is non-conducting, the circuit will remain in this position. It is only with the application of external pulse that the circuit will interchange the states. However, after a certain time, the circuit will automatically switch back to the original stable state and remains there until another pulse is applied. Thus a monostable multivibrator cannot generate square waves of its own like an astable multivibrator. Only external pulse will cause it to generate the square wave

Circuit diagram:.

- It consists of two similar transistors Q 1 and Q 2 with R1 = R4 .
- The values of V_{BB} and R5 are such as to reverse bias Q1 and keep it at cut off.
- The collector supply V_{CC} and R2 forward bias Q 2 and keep it at saturation.
- The input pulse is given through C2 to obtain the square wave. Again output can be taken from Q 1 or Q 2 .
- The coupling elements are resistor and capacitor

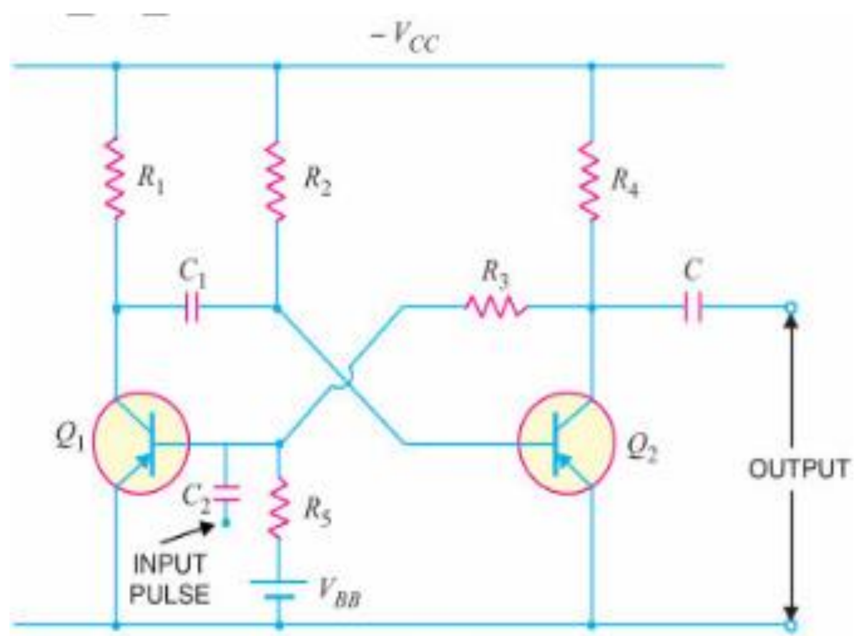


Figure 11. Monostable Multivibrator

Working:

- With the circuit arrangement shown, Q1 is at cut off and Q2 is at saturation. This is the stable state for the circuit and it will continue to stay in this state until a triggering pulse is applied at C2 .
- When a negative pulse of short duration and sufficient magnitude is applied to the base of Q1 through C2 , the transistor Q1 starts conducting and positive potential is established at its collector. The positive potential at the collector of Q1 is coupled to the base of Q2 through capacitor C1 . This decreases the forward bias on Q2 and its collector current decreases. The increasing negative potential on the collector of Q2 is applied to the base of Q1 through R3 . This further increases the forward bias on Q1 and hence its collector current. With this set of actions taking place, Q1 is quickly driven to saturation and Q2 to cut off.
- With Q1 at saturation and Q2 at cut off, the circuit will come back to the original stage (i.e. Q 2 at saturation and Q 1 at cut off) after some time.

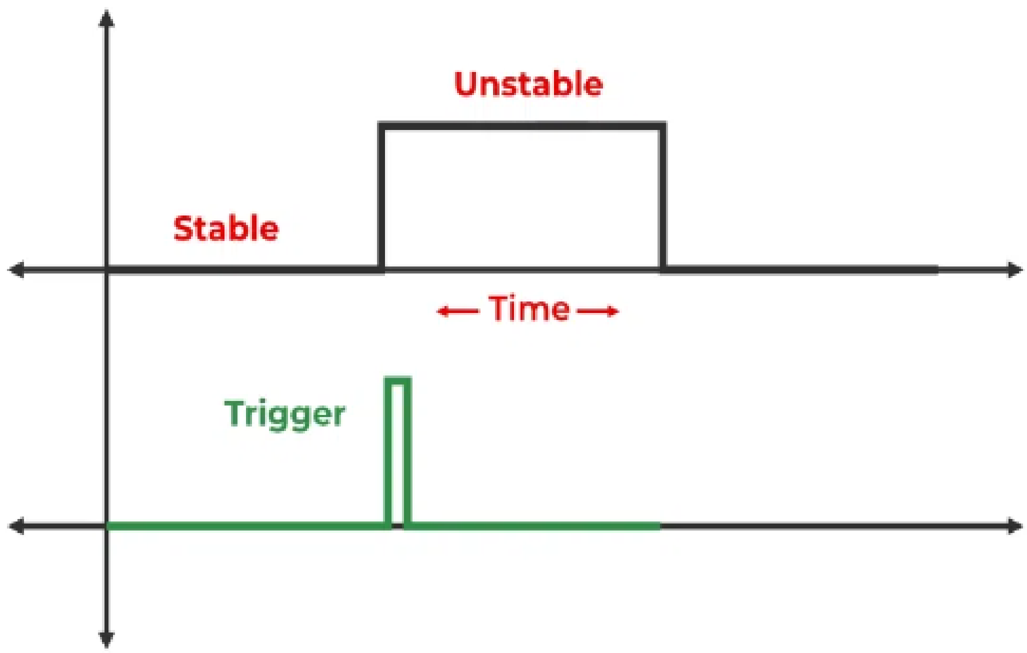


Figure 12. Wave form for mono-stable Multivibrator

3. Bistable Multivibrator

- A multivibrator which has both the states stable is called a bistable multivibrator.
- suppose at any particular instant, transistor Q 1 is conducting and transistor Q 2 is at cut off. If left to itself, the bistable multivibrator will stay in this position forever. However, if an external pulse is applied to the circuit in such a way that Q 1 is cut off and Q 2 is turned on, the circuit will stay in the new position. Another trigger pulse is then required to switch the circuit back to its original state.

Circuit diagram:.

- The feedback is coupled through resistors (R2 , R3) by capacitors C1 and C2 . The main purpose of capacitors C1 and C2 is to improve the switching characteristics of the circuit by passing the high frequency components of the square wave.
- The output can be taken across either transistor.

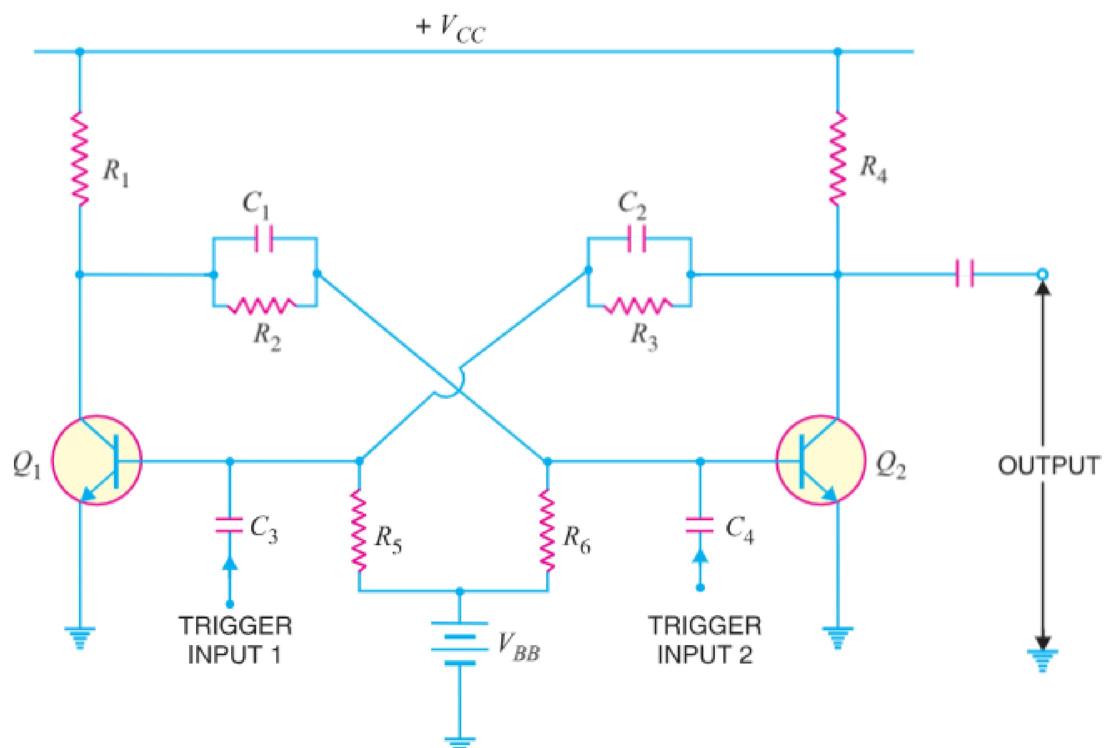
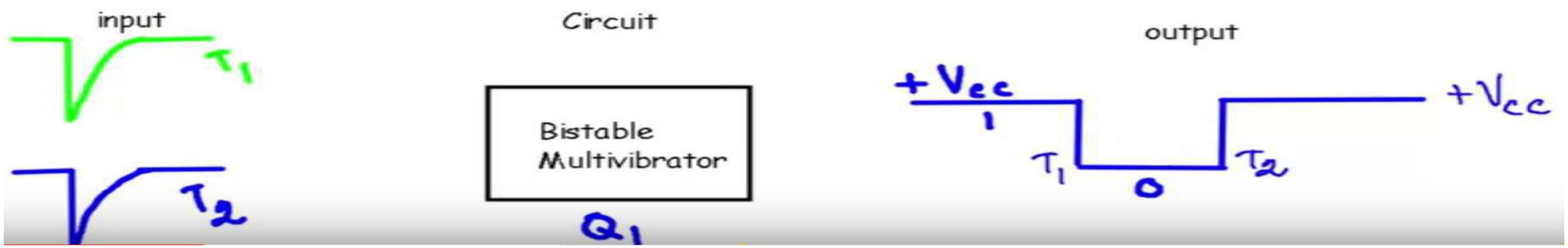


Figure 13. Bistable Multivibrator

Working:

When V_{CC} is applied, one transistor will start conducting slightly ahead of the other due to some differences in the characteristics of the transistors. This will drive one transistor to saturation and the other to cut off in a manner described for the astable multivibrator. Assume that $Q1$ is turned ON and $Q2$ is cut OFF. If left to itself, the circuit will stay in this condition. In order to switch the multivibrator to its other state, a trigger pulse must be applied. A negative pulse applied to the base of $Q1$ through $C3$ will cut it off or a positive pulse applied to the base of $Q2$ through $C4$ will cause it to conduct. Suppose a negative pulse of sufficient magnitude is applied to the base of $Q1$ through $C3$. This will reduce the forward bias on $Q1$ and cause a decrease in its collector current and an increase in collector voltage. The rising collector voltage is coupled to the base of $Q2$ where it forward biases the base-emitter junction of $Q2$. This will cause an increase in its collector current and decrease in collector voltage. The decreasing collector voltage is applied to the base of $Q1$ where it further reverse biases the base-emitter junction of $Q1$ to decrease its collector current. With this set of actions taking place, $Q2$ is quickly driven to saturation and $Q1$ to cut off. The circuit will now remain stable in this state until a negative trigger pulse at $Q2$ (or a positive trigger pulse at $Q1$) changes this state.



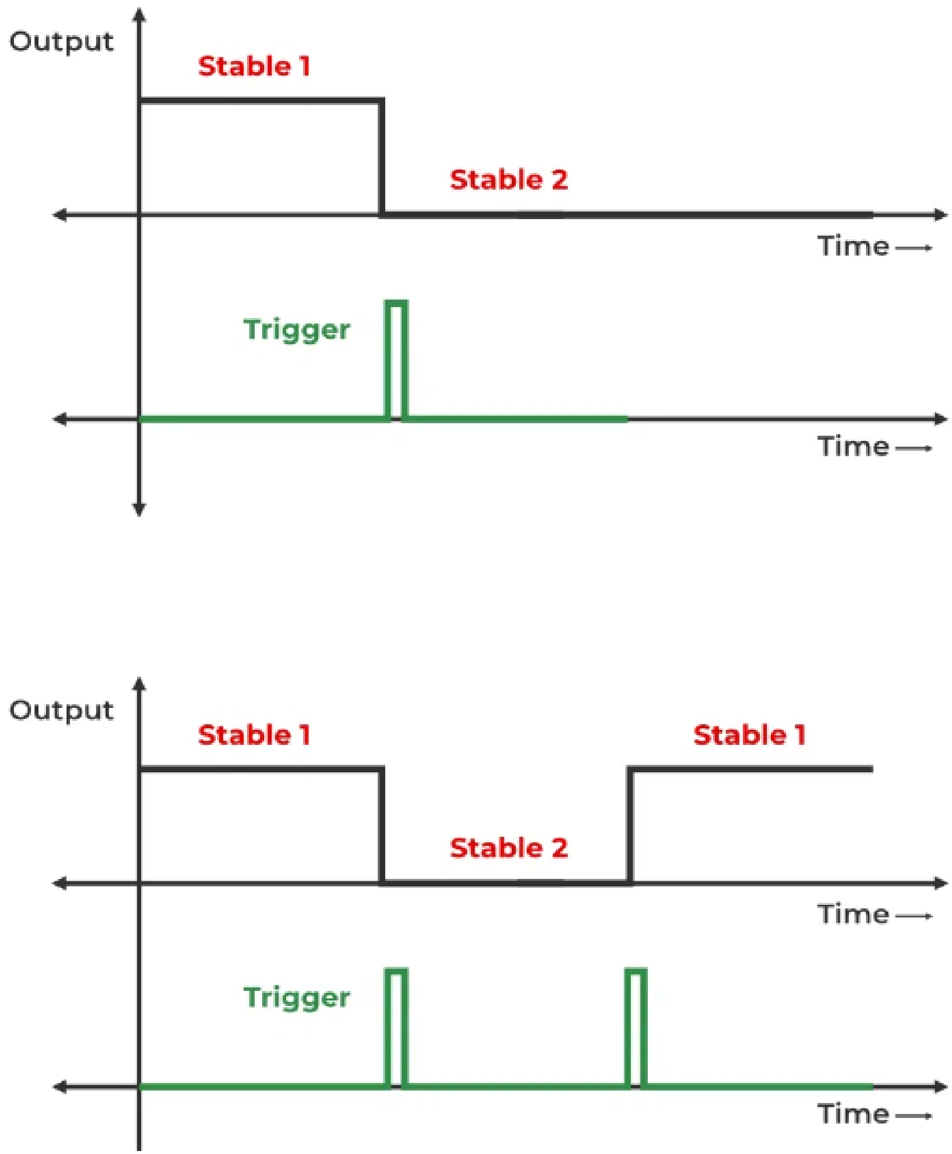


Figure 14. Wave form for Bi-stable Multivibrator

Power Amplifier:

1. Difference between voltage amplifiers and power amplifier
2. Amplifier classification (class A, class B, class C, Class AB, class AB push pull amplifier, collector efficiency of each and power dissipation
3. Cross over distortion

Classification of amplifier:

Transistor amplifier may be classified on the basis of their circuit, uses, frequency capabilities, coupling methods and mode of operations.

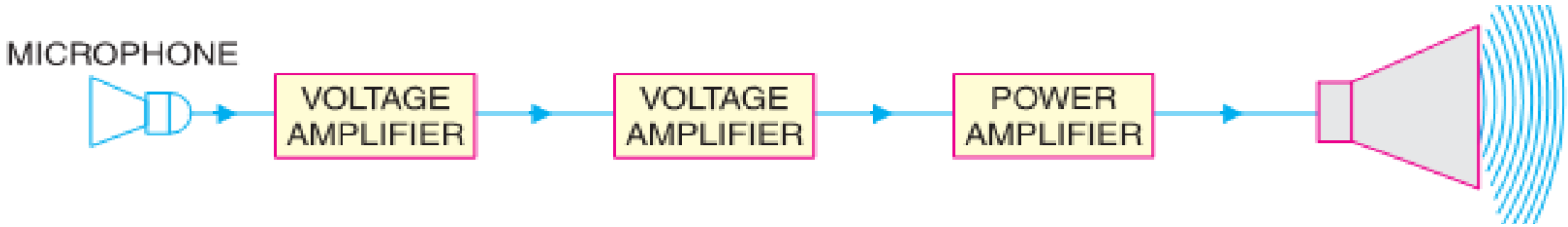
Amplifier

1.According uses	2.According to frequency capabilities	3. According to coupling method	4. According to mode of operation
• Voltage Amplifier (increases the voltage level) • Power Amplifier (increases the power level	• Audio amplifier (amplifies the signal in the 20Hz to 20 KHz) • Radiofrequency amplifier (amplifies the signal in higher frequency)	• RC coupling • Direct coupling • RL coupling • Transformer coupling	• **Class A (**entire input is amplified at the output) • **Class B** (collector current flows for half cycle of the input signal) • **Class C** (collector current flows for less than half cycle of the input signal)

5. According circuit: Single stage amplifier and cascade amplifier

Amplifier:

- A practical amplifier always consists of a number of stages that amplify a weak signal until sufficient power is available to operate a loudspeaker or other output device.
- The first few stages in this multistage amplifier have the function of only voltage amplification. However, last stage is designed to provide maximum power. This final stage is known as power stage.



Transistor Audio Power Amplifier: -

- A transistor amplifier which raises the power level of signals having audio frequency range is known as transistor **Audio Power Amplifier**. Generally last stage of a multistage amplifier is the power stage.
- The power amplifier differs from all the previous stages in that here a concentrated effort is made to obtain maximum output power.
- A transistor that is suitable for power amplification is generally called a ***power transistor***.

Difference between voltage and power amplifiers:

- The difference between the two types is really one of degree; it is a question of how much voltage and how much power.
- A voltage amplifier is designed to achieve maximum voltage amplification. It is, however, not important to raise the power level.
- On the other hand, a power amplifier is designed to obtain maximum output power

1) <u>Voltage Amplifier:</u>

The voltage gain of an amplifier is given by :

$$Av = \beta \times Rc/Rin$$

In order to achieve high voltage amplification, the following features are incorporated :

- The transistor with high β(>100) is used in the circuit. i.e. Transistors are employed having thin base.
- The input resistance Rin of transistor is sought to be quite low as compared to the collector load Rc.
- A relatively high load Rc is used in the collector. To permit this condition, voltage amplifiers are always operated at low collector currents (≈ mA). If the collector current is small, we can use large Rc in the collector circuit

2) Power Amplifier:

A power amplifier is required to deliver a large amount of power and as such it has to handle large current. In order to achieve high power amplification, the following features are incorporated in such amplifiers:

- The size of power transistor is made considerably larger in order to dissipate the heat produced in the transistor during operation.
- The base is made thicker to handle large currents. In other words, transistors with comparatively smaller β are used.
- Transformer coupling is used for impedance matching

Table: The comparison between voltage and power amplifiers

S. No.	Particular	Voltage amplifier	Power amplifier
1.	β	High (> 100)	low (5 to 20)
2.	R_C	High (4 – 10 kΩ)	low (5 to 20 Ω)
3.	*Coupling*	usually *R* – *C* coupling	Invariably transformer coupling
4.	*Input voltage*	low (a few mV)	High (2 – 4 V)
5.	*Collector current*	low (≃ 1 mA)	High (> 100 mA)
6.	*Power output*	low	high
7.	*Output impedance*	High (≃ 12 kΩ)	low (200 Ω)

Performance quantities of power amplifiers:

The prime objective for a power amplifier is to obtain maximum output power. Since a transistor, like any other electronic device has voltage, current and power dissipation limits, therefore, the criteria for a power amplifier are : **Collector Efficiency, Distortion & Power Dissipation Capability**

1. **Collector efficiency η:**

- The main criterion for a power amplifier is not the power gain rather it is the maximum ac power output. Now, an amplifier converts dc power from supply into ac power output.
- Therefore, the ability of a power amplifier to convert dc power from supply into ac output power is a measure of its effectiveness. This is known as *collector efficiency* .
- The ratio of ac output power to the zero signal power (i.e. dc power) supplied by the battery of a power amplifier is known as **collector efficiency**.

$$\boxed{\text{Collector efficiency } (\eta) = \text{ac output power/dc input power}}$$

2. **Distortion:**

The change of output wave shape from input wave shape of amplifier is called **Distortion**.

3. Power Dissipation Capability:

The ability of a power transistor to dissipate heat is known as power dissipation capability.

Classification of amplifier according to mode of operation :

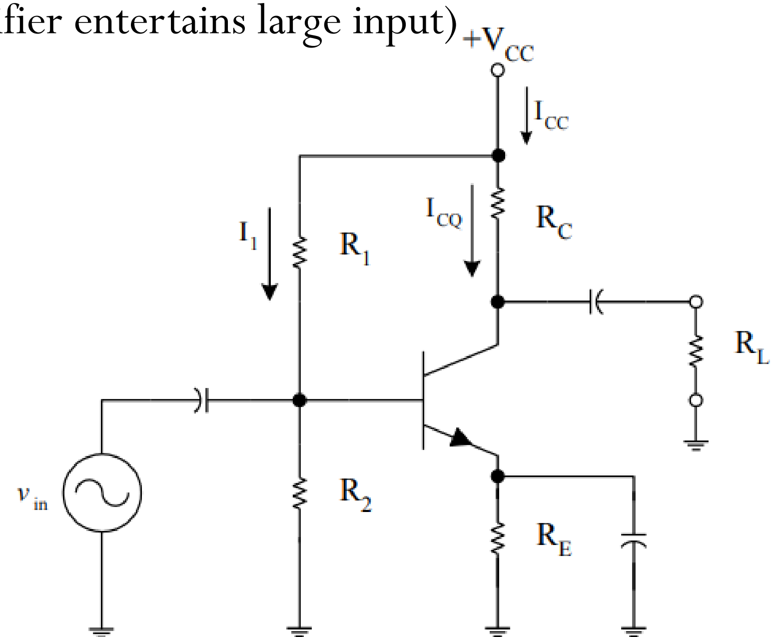
- Transistor power amplifiers handle large signals. Many of them are driven by the input large signal that collector current is either cut-off or is in the saturation region during a large portion of the input cycle.
- Therefore, such amplifiers are generally classified according to their mode of operation i.e. the portion of the input cycle during which the collector current is expected to flow. On this basis, they are classified as

(i) Class A power amplifier
(ii) Class B power amplifier
(iii) Class C power amplifier
(iv) Class AB power amplifier.

(i). Class A Power amplifier:

- If the collector current flows at all times during the full cycle of the signal, the power amplifier is known as ***class A power amplifier***.
- In this case the transistor is so biased that the output current flows for the full cycle of input. The base-emitter junction remains forward for the complete.
- Q-point is in the center of load line.
- Amplification in active region or linear region.
- Vin is in order of volts (large voltage as power amplifier entertains large input)

Circuit diagram & operation:



Case I: (Positive cycle)

Let's consider Vin as +ve cycle of input signal,
That means the base current $\mathbf{I_B}$ **increases**, which in turn **increases collector current** $\mathbf{I_C}$ as

$$I_C = \beta\, I_B$$

as we know,

$$V_{CE} = V_{CC} - I_C R_C \quad \ldots\ldots..(1)$$

so increasing I_C makes equation 1 negative i.e., the output voltage V_{CE} decreases.
Thus, increase in input voltage results in decrease output voltage.

Case II: (Negative cycle)

Let's consider Vin as -ve cycle of input signal,

That means the base current I_B **decreases**, which in turn **decreases the collector current I_C** as

$$I_C = \beta\, I_B$$

Now from eq. 1 we can seen that decrease in I_C makes equation 1 positive i.e., the output voltage V_{CE} increases.

Thus, decease in input voltage results in increase output voltage.

there is phase shift of 180°

For max values of V_{CE} and I_C again consider eq.1

$$V_{CE}(max) = V_{CC} \quad \text{at } I_C = 0$$

$$I_{C(max)} = V_{CC}/R_C \quad \text{at } V_{CE} = 0$$

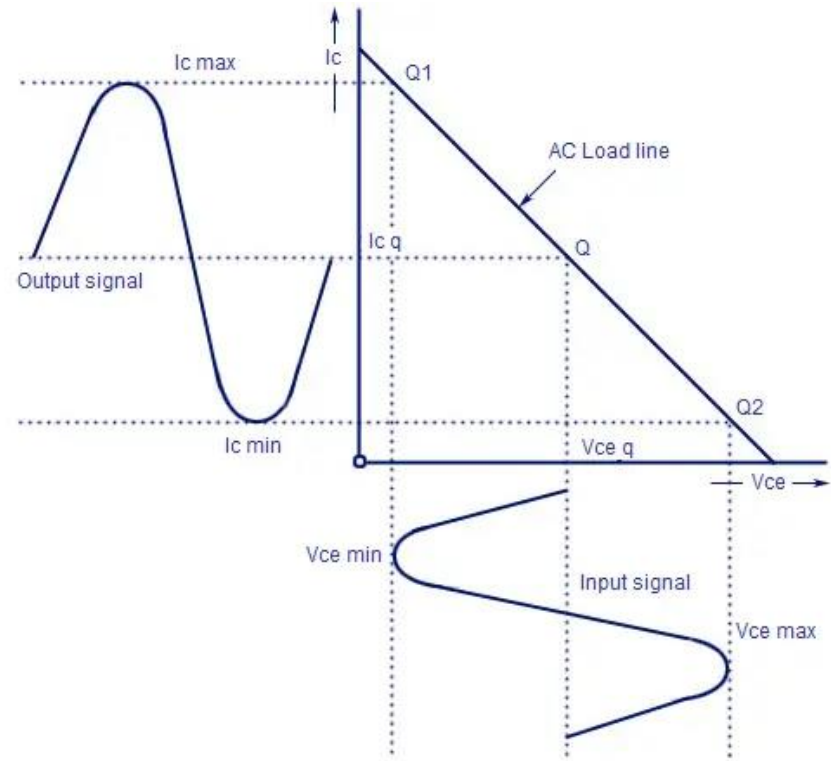


Fig 2. Class A power amplifier output characteristics

Case III: Vin=0

i.e., due to DC biasing collector current is I_{CQ}

And $V_{CE} = V_{CEQ}$

So in such case power dissipation $= I_{CQ} * V_{CEQ}$

Means there is heat generation in absence of Vin , this is the biggest disadvantage of this Class A amplifier.

Collector Efficiency (η) :

It is defined as

$$\textbf{Collector efficiency } (\eta) = \textbf{ac output power/dc input power} \quad \textbf{...... (2)}$$

- Input power (dc) (P_{in}):

$$P_{in} = V_{CC} * I_{CQ} \quad .... (3)$$

from the figure 2, we see

$$I_{CQ} = V_{CC}/2R_C ...... (4)$$

Substituting eq. 4 in eq. 3, we get

$$\mathbf{P_{in} = V_{CC}^2/2R_C} \quad \textbf{....(5)}$$

- Output power (ac) P_{out}:

$$P_{out} = V_{CErms} * Icrms ......(6)$$

From figure 2, we see

$$V_{CE(p\text{-}p)=} V_{CC}$$
$$V_{CE(p)} = V_{CC}/2$$
$$V_{CErms} = V_{CE(p)}/\sqrt{2}$$

which implies,

$$V_{CErms} = V_{cc}/2\sqrt{2} ....(7)$$

Similarly,

$$I_{C(p\text{-}p)} = V_{CC}/R_C$$
$$I_{C(p)} = V_{CC}/2R_C$$

$$Icrms = V_{cc}/2R_C\sqrt{2} \; ....(8)$$

Substituting eq.7 and 8 in eq. 6, we get

$$P_{out} = (V_{cc}/2\sqrt{2})*(V_{cc}/2R_C\sqrt{2})$$

$$\mathbf{P_{out} = V_{CC}^2/8R_C \;.......(9)}$$

Substituting eq. 5 and eq. 9 in eq. 2, we get

$$\eta = (V_{CC}^2/8R_C)/(V_{CC}^2/2R_C)$$

$$\eta\ (\%) = (1/4)*100$$

$$\boxed{\eta\ (\%) = 25\%}$$

Thus, the collector efficiency of class A power amplifier is 25%.
Example: That means if input power is 10Watt then we get only 25% of this at the collector i.e., 2.5 Watt, rest 7.5% of 10 Watt is dissipated .

Power Dissipated by a transistor is given by :

$$P_{dis} = P_{dc} - P_{ac}$$

where P_{dc} = available dc power
P_{ac} = available ac power

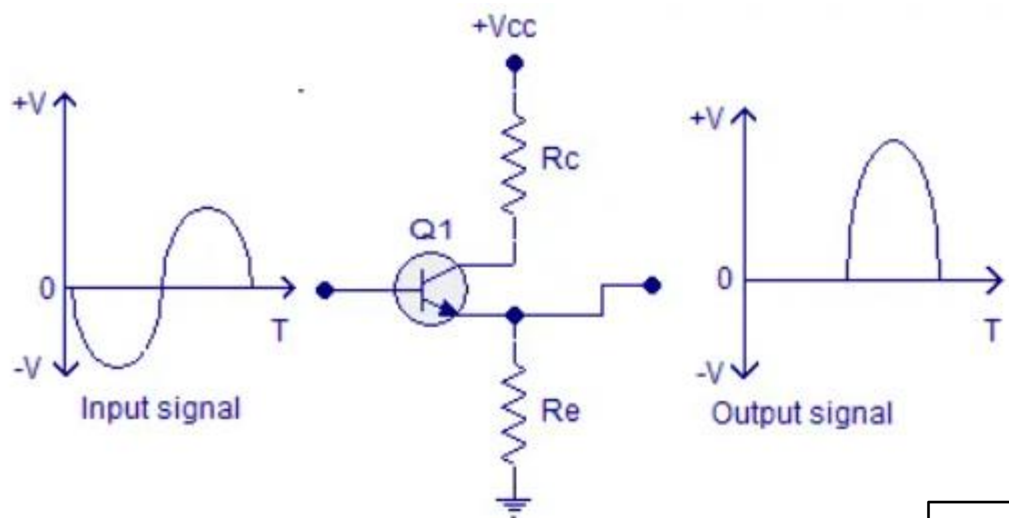
- In class *A* operation, the transistor must dissipate less heat when signal is applied and therefore runs cooler.
- When no signal is applied to a class *A* power amplifier, $Pac = 0$.

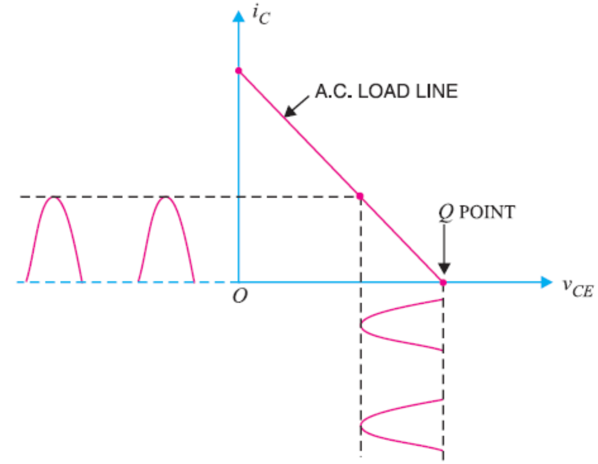
$$\therefore\ P_{dis} = P_{dc}$$

Thus in class *A* operation, maximum power dissipation in the transistor occurs under zero signal conditions.

(i). Class B Power amplifier:

- If the collector current flows only during the positive half-cycle of the input signal, it is called a *class B power amplifier*.
- In class B operation, the transistor bias is so adjusted that zero signal collector current is zero i.e. **no biasing** circuit is needed at all.
- During the positive half-cycle of the signal, the input circuit is forward biased and hence collector current flows. However, during the negative half-cycle of the signal, the input circuit is reverse biased and no collector current flows. Fig. shows the class B operation in terms of ac load line.
- The **operating point Q** shall be located at collector cut off voltage.
- The output from a class B amplifier is amplified half-wave rectification.
- In a class B amplifier, the negative half-cycle of the signal is cut off and hence a **severe distortion** occurs.
- However, class B amplifiers provide higher power output and collector efficiency (50 − 60%). Such amplifiers are mostly used for power amplification in push-pull arrangement.
- In such an arrangement, 2 transistors are used in class B operation. One transistor amplifies the positive half cycle of the signal while the other amplifies the negative half-cycle.





Class B power amplifier output characteristics

Case 1: Positive cycle

When positive cycle is applied to the transistor Q1, the Emitter junction remains in forward bias (FB) and the collector junction in reverse bias (RB). That means when the signal is positive cycle I_B increases , which increases the output collector current IC.

$$V_O = V_{CC} - I_C R_C \quad \ldots\ldots..(1)$$

i.e., increase is I_C decreases V_O

Input junction FB and output junction RB (Transistor is in active region and further increase in IB it goes to **saturation region)**

Case 1: Negative cycle

here negative cycle to the input junction makes it RB and the output RB. Thus the transistor operates in **cutoff region.**

Therefore, to amplify the entire cycle it is necessary to add a second class B amplifier that operates on the negative half.
i.e., push pull amplifier

Push-Pull class B amplifier:

- The push-pull amplifier is a power amplifier and is frequently employed in the output stages of electronic circuits. It is used whenever **high output power at high efficiency** is required. Fig. shows the circuit of a push-pull amplifier.
- Two transistors Tr1 and Tr2 placed back to back are employed. Both transistors are operated in class B operation i.e. collector current is nearly zero in the absence of the signal.
- The centre tapped secondary of driver transformer T1 supplies equal and opposite voltages to the base circuits of two transistors. The output transformer T2 has the centre-tapped primary winding. The supply voltage VCC is connected between the bases and this centre tap.
- The loudspeaker is connected across the secondary of this transformer.

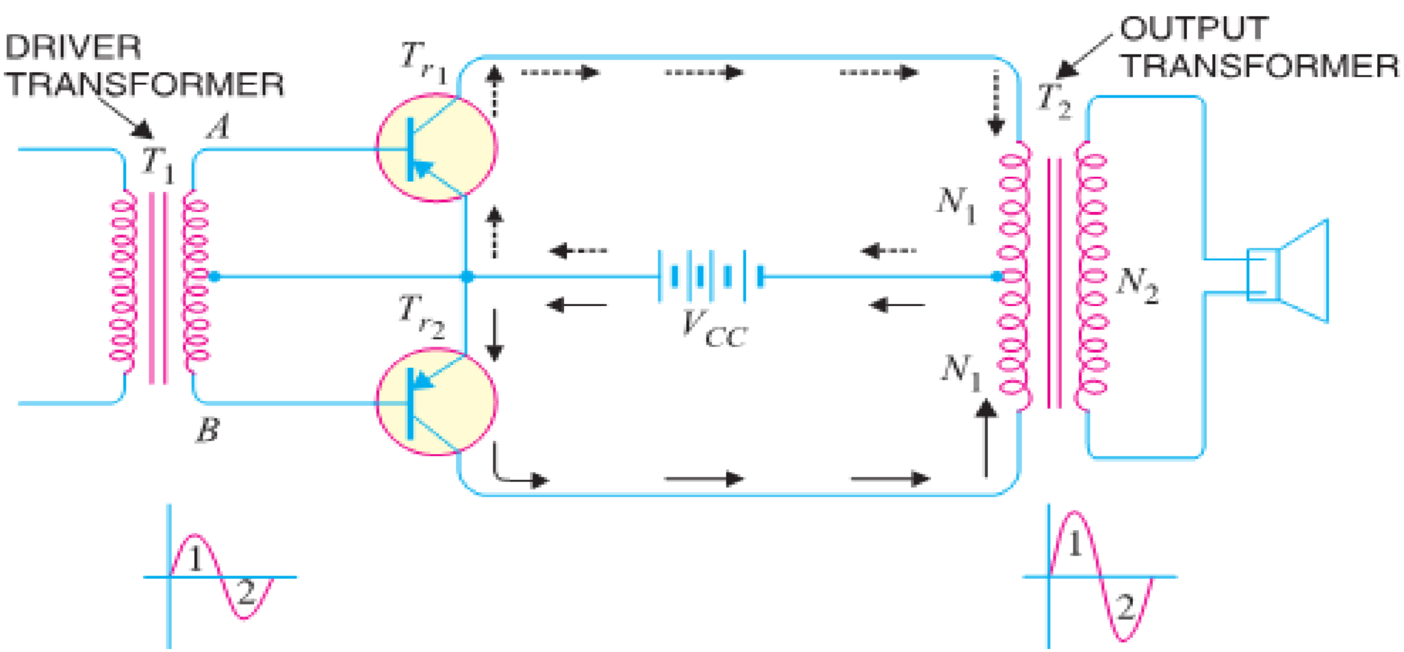
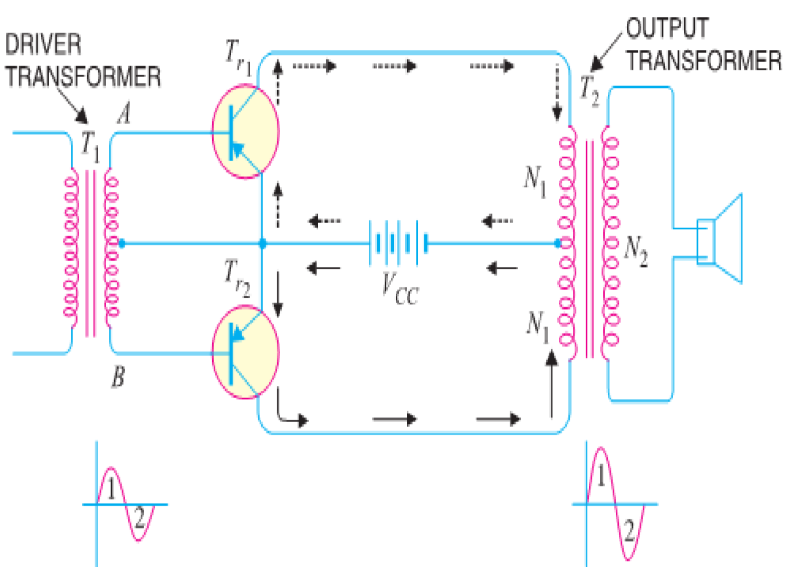
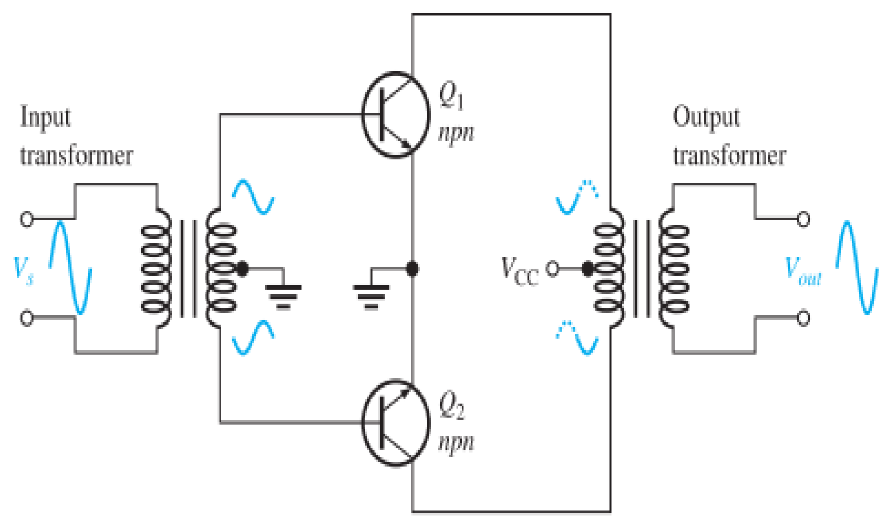


Figure. Class B Push-Pull Power Amplifier

Circuit operation:

- The input signal appears across the secondary AB of driver transformer. Suppose during the first half cycle (marked 1) of the signal, end A becomes positive and end B negative.
- This will make the base-emitter junction of Tr1 forward biased and that of Tr2 reversed biased. The circuit will conduct current due to Tr1 only and is shown by dotted arrows.
- Therefore, this half-cycle of the signal is amplified by Tr1 and appears in the upper half of the primary of output transformer. In the next half cycle of the signal, Tr2 is forward biased whereas Tr1 is reverse biased. Therefore, Tr2 conducts and is shown by solid arrows.
- Consequently, this half-cycle of the signal is amplified by Tr2 and appears in the lower half of the output transformer primary. The centre-tapped primary of the output transformer combines two collector currents to form a sine wave output in the secondary.





Collector Efficiency (η) :

It is defined as

Collector efficiency (η) = ac output power/dc input power

$$\therefore \quad \text{Peak a.c. output voltage} = V_{CE}$$

$$\text{Peak a.c. output current} = I_{C\,(sat)} = \frac{V_{CE}}{R_L} = \frac{V_{CC}}{2\,R_L} \qquad \left(\because V_{CE} = \frac{V_{CC}}{2}\right)$$

Maximum average a.c. output power $P_{o\,(max)}$ is

$$P_{o\,(max)} = \text{Product of r.m.s. values of a.c. output voltage and a.c. output current}$$

$$= \frac{V_{CE}}{\sqrt{2}} \times \frac{I_{C\,(sat)}}{\sqrt{2}} = \frac{V_{CE}\,I_{C\,(sat)}}{2}$$

$$= \frac{V_{CC}}{2} \times \frac{I_{C\,(sat)}}{2} = \frac{V_{CE}\,I_{C\,(sat)}}{4} \qquad \left(\because V_{CE} = \frac{V_{CC}}{2}\right)$$

$$\therefore \quad P_{o\,(max)} = 0.25\,V_{CC}\,I_{C\,(sat)}$$

The input d.c. power from the supply V_{CC} is

$$P_{dc} = V_{CC}\,I_{dc}$$

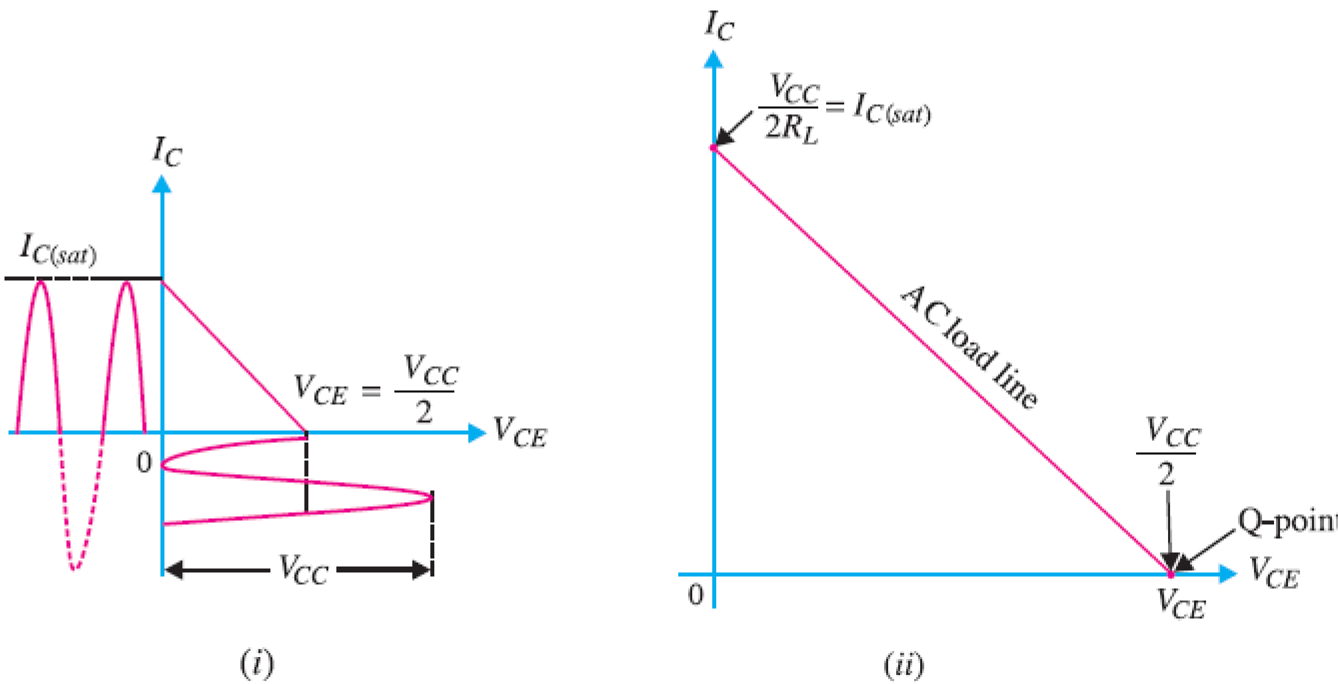


Fig. 12.15

where I_{dc} is the average current drawn from the supply V_{CC}. Since the transistor is on for alternating half-cycles, it effectively acts as a half-wave rectifier.

$$\therefore \quad I_{dc} = \frac{I_{C\,(sat)}}{\pi}$$

$$\therefore \quad P_{dc} = \frac{V_{CC}\, I_{C\,(sat)}}{\pi}$$

$$\therefore \quad \text{Max. collector } \eta = \frac{P_{o\,(max)}}{P_{dc}} = \frac{0.25\, V_{CC}\ \ I_{C\,(sat)}}{\left(V_{CC}\, I_{C\,(sat)}\right)/\pi} \times 100 = 0.25\pi \times 100 = 78.5\%$$

Thus the maximum collector efficiency of class *B* power amplifier is 78.5%.

Power dissipated by transistors (P):

The power dissipated (as heat) by the transistors in class *B* amplifier is the difference between the input power delivered by V_{CC} and the output power delivered to the load *i.e.*

$$P_{2T} = Pdc - Pac$$

where P_{2T} = power dissipated by the two transistors

∴ Power dissipated by each transistor is

$$P_T = \mathrm{P}_{\mathrm{T2}}/2$$

$$\boxed{P_T = (Pdc - Pac)/2}$$

This is the power dissipated (as heat) by the transistors in class *B* amplifier (Push pull)

Numerical:

Example 1. A power transistor working in class A operation has zero signal power dissipation of 10 watts. If the ac output power is 4 watts, find the collector efficiency .

Example 2. For a class B amplifier using a supply of V_{CC} = 12V and driving a load of 8Ω, determine:
(i) Maximum load power **(ii)** dc input power **(iii)** collector efficiency (η)

Example 3. A class B push-pull amplifier with transformer coupled load uses two transistors rated 10 W each. What is the maximum power output one can obtain at the load from the circuit? **Hint:** $P_{dc} = Po\ (max) + P_{2T}$

Cross over distortion:

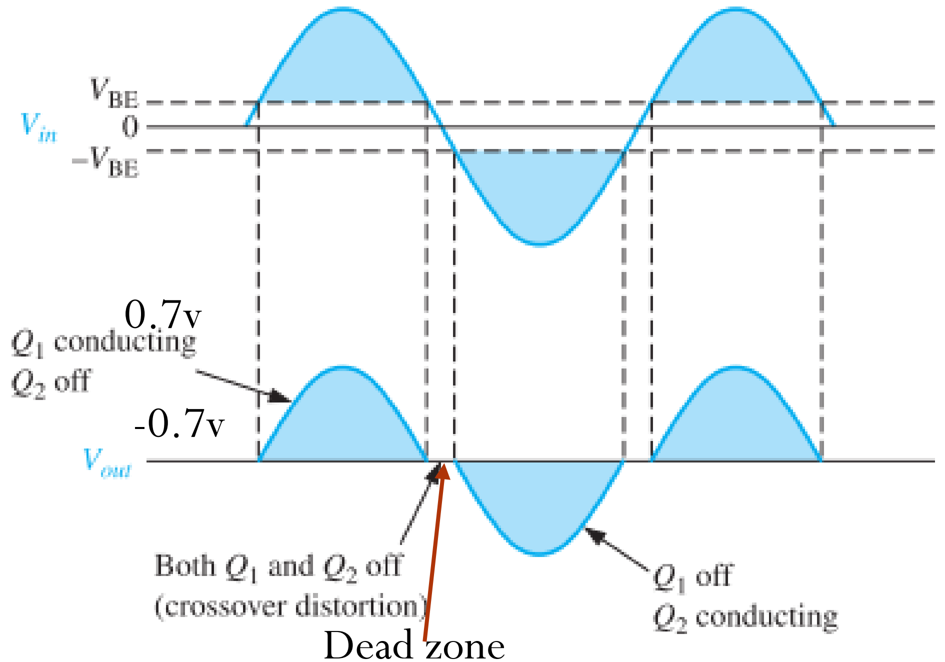
- **When the dc base voltage is zero**, both transistors are off and the input signal voltage must exceed V_{BE} before a transistor conducts.
- Because of this, there is a time interval between the positive and negative alternations of the input when neither transistor is conducting, as shown in Figure.
- The resulting distortion in the output waveform is called **crossover distortion**

❖ If **-0.7 v <Vin <0.7 v**

Then EB junction is reversed biased and CB junction is in revere bias, in such case the output is Zero, means there is no output.

Dead zone : the range of input voltage for which output is zero is know as dead zone.

This kind of distortion is mainly observed in **Class B power** amplifier.



Wave form of cross over distortion

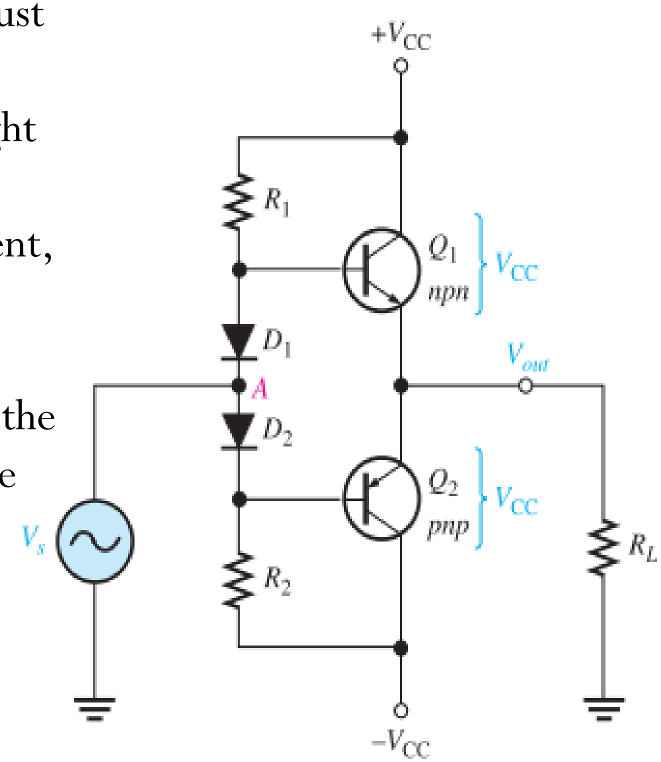
Note:

Class A: Efficiency (Low) Power dissipation (high), Distortion (low)

Class B: Efficiency (high), PD (low), Distortion (high)

Class AB Push pull amplifier:

- To overcome crossover distortion, the biasing is adjusted to just overcome the V_{BE} of the transistors
- In class AB operation, the push-pull stages are biased into slight conduction, **even when no input signal is present**.
- This can be done with a voltage-divider and diode arrangement, as shown in figure.
- When the diode characteristics of D1 and D2 are closely matched to the characteristics of the transistor BE junctions, the current in the diodes and the current in the transistors are the same; **(i.e., current mirror.)**



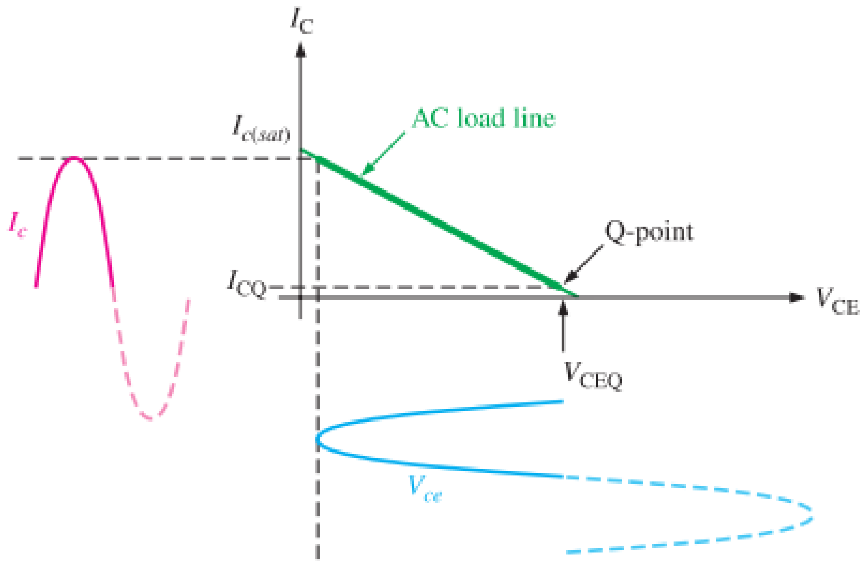
The diode current will be the same as I_{CQ}

$$I_{CQ} = \frac{V_{CC} - 0.7\text{ V}}{R_1}$$

- The Q-point is slightly above cutoff. (In a true class B amplifier, the Q-point is at cutoff.)
- The ac cutoff voltage is at V_{CC}
- The ac saturation current is:

$$I_{c(sat)} = \frac{V_{CC}}{R_L}$$

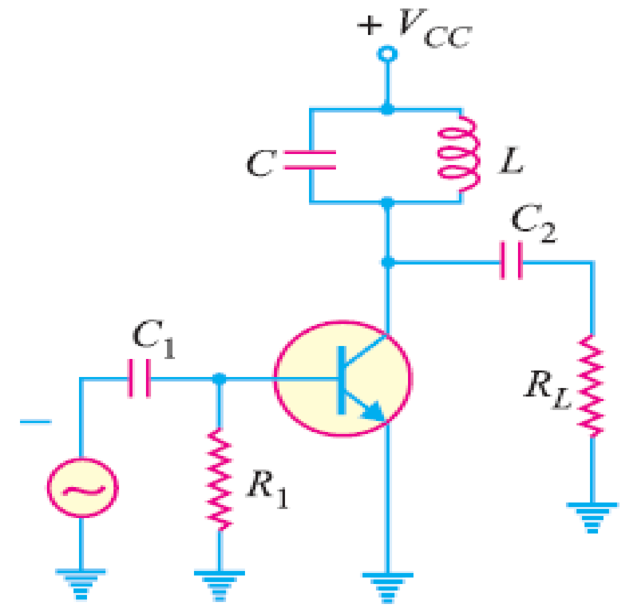
- ✓ In class A , the Q-point is near the middle and there is significant current in the transistors even with no signal.
- ✓ In class B , when there is no signal, the transistors have only a very small current and therefore dissipate very little power.
- ✓ Thus, the efficiency of a class B amplifier can be much higher than a class A amplifier.



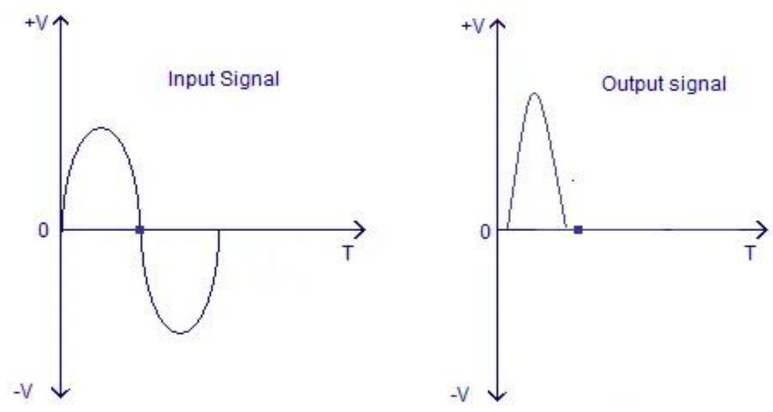
(a) AC load line for Q_1

Class C power amplifier:

- If the collector current flows for less than half-cycle of the input signal, it is called **Class C power amplifier.**
- In class *C* amplifier, the base is given some negative bias so that collector current does not flow just when the positive half-cycle of the signal starts. Such amplifiers are never used for power amplification. However, they are used as tuned amplifiers *i.e.* to amplify a narrow band of frequencies near the resonant frequency.
- Class C power amplifier is a type of amplifier where the active element (transistor) conduct for less than one half cycle of the input signal. **Less than one half cycle means the conduction angle is less than 180° and its typical value is 80° to 120°**. The reduced conduction angle improves the efficiency to a great extend but causes a lot of distortion
- **Operating point below cut off region**
- **High distortions**
- **High efficiency**



Circuit Diagram Class C power amplifier



Circuit operation:

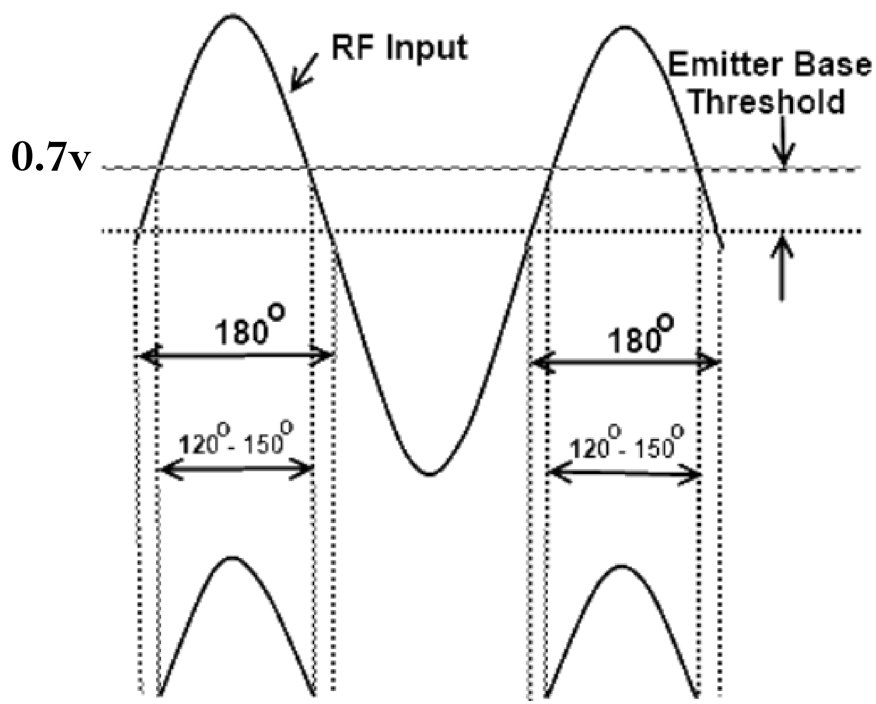
Case 1: Positive cycle

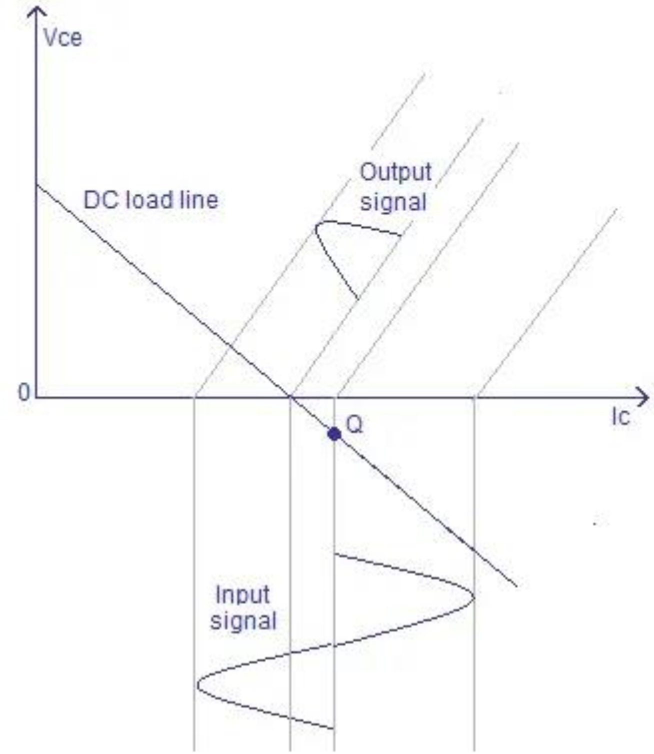
Vin < 0.7v i.e., V_B= Vin <0.7, transistor Q1 does not conduct

If **Vin > 0.7v,** transistor Q1 conducts.

Case 2: Negative cycle:

Vin negative i.e., V_B negative, which makes the base-emitter RB. So transistor Q1 operates in cutoff region, Thus Q1 if off.





Class C power amplifier output characteristics

Collector Efficiency (η) :

It is defined as

Collector efficiency (η) = ac output power/dc input power

i.e., when no signal is applied, the collector-emitter voltage is V_{CC}

$$V_{CE} = V_{CC}$$

The maximum output power (ac) is :

$$P_{o(max)} = \frac{V_{r.m.s.}^2}{R_{AC}} = \frac{\left(V_{CC}/\sqrt{2}\right)^2}{R_{AC}} = \frac{V_{CC}^2}{2\,R_{AC}}$$

where R_{AC} = a.c. load

Maximum efficiency. The d.c. input power (P_{dc}) from the supply is :

$$P_{dc} = P_{o(max)} + P_D$$

where P_D = power dissipation of the transistor

As, P_D =Pdc -Pac

$$\therefore \quad \text{Max. collector } \eta = \frac{P_{o(max)}}{P_{o(max)} + P_D}$$

As P_D is very small in Class C , so P_D may be neglected compared to $P_{o(max)}$ so maximum efficiency is becomes,

$$\therefore \quad \text{Maximum } \eta \simeq \frac{P_{o(max)}}{P_{o(max)}} \simeq 100\ \%$$

It is worthwhile to give a passing reference about the maximum efficiencies of class *A*, class *B* and class *C* amplifiers. *A* class *A* amplifier (transformer-coupled) has a maximum efficiency of 50%, class *B* of 78.5% and class *C* nearly 100%. It is emphasised here that class *C* operation is suitable only for *resonant *RF* applications.

Advantage:

- High efficiency
- Radio frequency application
- High power output with small size

Disadvantages:

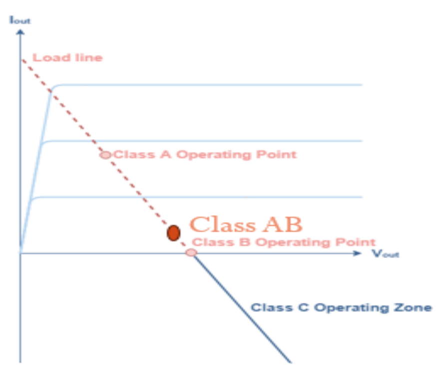
- Distortion

Applications:

- RF amplifier
- RF oscillator
- Tuned amplifier

Summary of class amplifier:

Differences	Q-point	Cycles/ conduction angle	Signal distortion	Efficiency	Applications
Class A	Centre point of load line	Provides complete 360-degree rotations.	None if correctly biased	Poor (25% - 30%)	Used in low powered devices such as radio and outdoor sound systems
Class B	Exactly on X-axis	provides half cycles. 180°	At the x-axis cross over point	Better (70-80%)	Great for battery-powered devices
Class AB	In between x-axis and the centre load line	more than half the cycle. (180° to 360°)	Small amount	Better than A but less than B (50-70%	Used in a high-fidelity audio amplifier.
Class C	Below the x-axis	Less than half the cycle. (<90°)	Large amount	Higher than 80%	Unsuitable for audio applications because the current pulse is making it useful in RF oscillators.



Operating point (Q-point)

Questions:

Question1. A class B amplifier has an efficiency of 60% and each transistor has a rating of 2.5W. Find the ac output power and dc input power.

Question 2. Explain the difference between a voltage and a power amplifier.

Question 3. What do you understand by class A, class B and class C power amplifiers ?

Question 4. Define and explain the following terms as applied to power amplifiers :

(i) collector efficiency

(ii) distortion

(iii) power dissipation capability

Question 5. Show that maximum collector efficiency of class A transformer coupled power amplifier

Question 6. For a class B amplifier with $V_{CC} = 25V$ driving an 8Ω load, determine :

(i) maximum input power

(ii) maximum output power

(iii) maximum circuit efficiency