Power Amplifiers

The Power amplifiers amplify the power level of the signal. This amplification is done in the last stage in audio applications. The applications related to radio frequencies employ radio power amplifiers. But the **operating point** of a transistor, plays a very important role in determining the efficiency of the amplifier. The **main classification** is done based on this mode of operation.

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Classification Based on Mode of Operation

On the basis of the mode of operation, i.e., the portion of the input cycle during which collector current flows, the power amplifiers may be classified as follows.

- **Class A Power amplifier** − When the collector current flows at all times during the full cycle of signal, the power amplifier is known as **class A power amplifier**.
- **Class B Power amplifier** − When the collector current flows only during the positive half cycle of the input signal, the power amplifier is known as **class B power amplifier**.
- **Class C Power amplifier** − When the collector current flows for less than half cycle of the input signal, the power amplifier is known as **class C power amplifier**.

There forms another amplifier called Class AB amplifier, if we combine the class A and class B amplifiers so as to utilize the advantages of both.

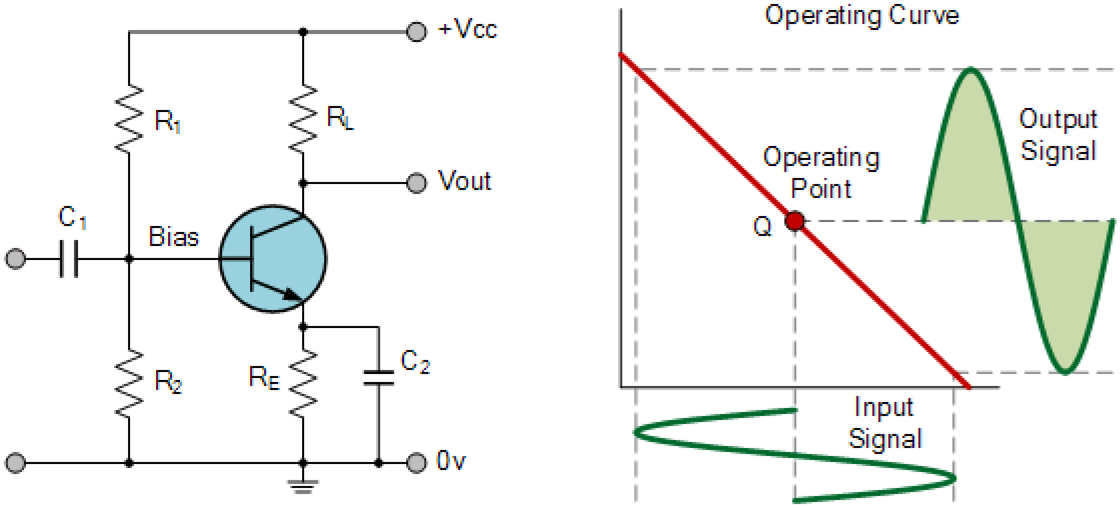
Before going into the details of these amplifiers, let us have a look at the important terms that have to be considered to determine the efficiency of an amplifier.

Class A Amplifier

Class A Amplifiers are the most common type of amplifier class due mainly to their simple design. Class A, literally means “the best class” of amplifier due mainly to their low signal distortion levels and are probably the best sounding of all the amplifier classes mentioned here. The class A amplifier has the highest linearity over the other amplifier classes and as such operates in the linear portion of the characteristics curve.

Generally class A amplifiers use the same single transistor (Bipolar, FET, IGBT, etc) connected in a common emitter configuration for both halves of the waveform with the transistor always having current flowing through it, even if it has no base signal. This means that the output stage whether using a Bipolar, MOSFET or IGBT device, is never driven fully into its cut-off or saturation regions but instead has a base biasing Q-point in the middle of its load line. Then the transistor never turns “OFF” which is one of its main disadvantages.

Class A Amplifier



To achieve high linearity and gain, the output stage of a class A amplifier is biased “ON” (conducting) all the time. Then for an amplifier to be classified as “Class A” the zero signal idle current in the output stage must be equal to or greater than the maximum load current (usually a loudspeaker) required to produce the largest output signal.

As a class A amplifier operates in the linear portion of its characteristic curves, the single output device conducts through a full 360 degrees of the output waveform. Then the class A amplifier is equivalent to a current source.

Since a class A amplifier operates in the linear region, the transistors base (or gate) DC biasing voltage should by chosen properly to ensure correct operation and low distortion. However, as the output device is “ON” at all times, it is constantly carrying current, which represents a continuous loss of power in the amplifier.

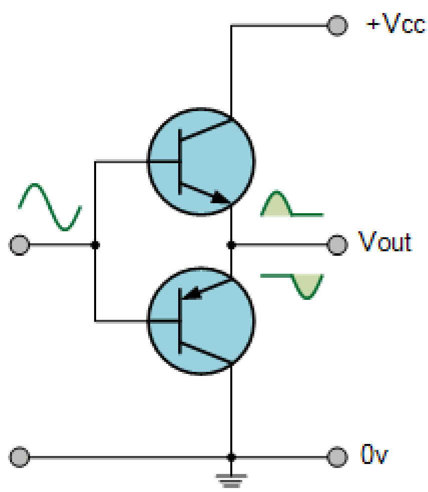
Due to this continuous loss of power class A amplifiers create tremendous amounts of heat adding to their very low efficiency at around 30%, making them impractical for high-power amplifications. Also due to the high idling current of the amplifier, the power supply must be sized accordingly and be well filtered to avoid any amplifier hum and noise. Therefore, due to the low efficiency and over heating problems of Class A amplifiers, more efficient amplifier classes have been developed.

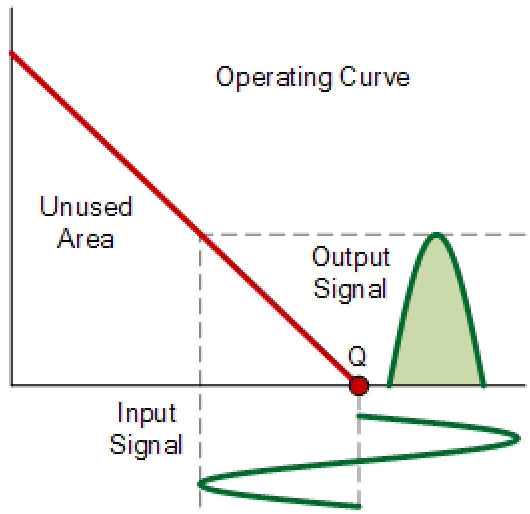
Class B Amplifier

Class B amplifiers were invented as a solution to the efficiency and heating problems associated with the previous class A amplifier. The basic class B amplifier uses two complimentary transistors either bipolar of FET for each half of the waveform with its output stage configured in a “push-pull” type arrangement, so that each transistor device amplifies only half of the output waveform.

In the class B amplifier, there is no DC base bias current as its quiescent current is zero, so that the dc power is small and therefore its efficiency is much higher than that of the class A amplifier. However, the price paid for the improvement in the efficiency is in the linearity of the switching device.

Class B Amplifier





When the input signal goes positive, the positive biased transistor conducts while the negative transistor is switched “OFF”. Likewise, when the input signal goes negative, the positive transistor switches “OFF” while the negative biased transistor turns “ON” and conducts the negative portion of the signal. Thus the transistor conducts only half of the time, either on positive or negative half cycle of the input signal.

Then we can see that each transistor device of the class B amplifier only conducts through one half or 180 degrees of the output waveform in strict time alternation, but as the output stage has devices for both halves of the signal waveform the two halves are combined together to produce the full linear output waveform.

This push-pull design of amplifier is obviously more efficient than Class A, at about 50%, but the problem with the class B amplifier design is that it can create distortion at the zero-crossing point of the waveform due to the transistors dead band of input base voltages from -0.7V to +0.7.

We remember from the **Transistor** tutorial that it takes a base-emitter voltage of about 0.7 volts to get a bipolar transistor to start conducting. Then in a class B amplifier, the output transistor is not “biased” to an “ON” state of operation until this voltage is exceeded.

This means that the the part of the waveform which falls within this 0.7 volt window will not be reproduced accurately making the class B amplifier unsuitable for precision audio amplifier applications.

To overcome this zero-crossing distortion (also known as Crossover Distortion) class AB amplifiers were developed.

Class AB Amplifier

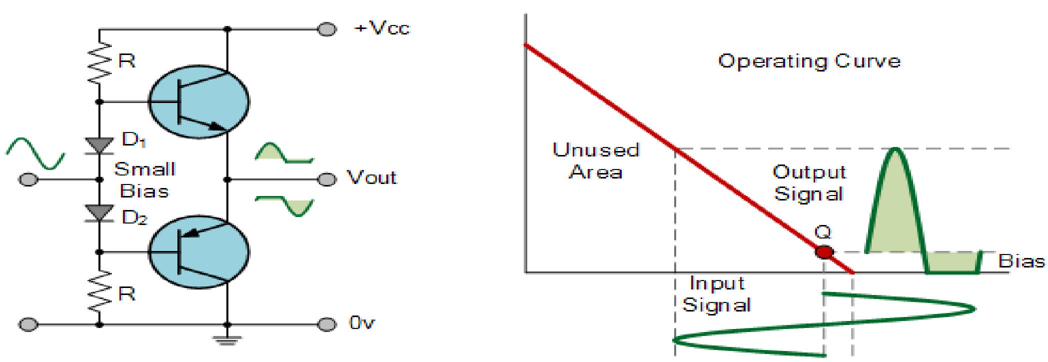
As its name suggests, the **Class AB Amplifier** is a combination of the “Class A” and the “Class B” type amplifiers we have looked at above. The AB classification of amplifier is currently one of the most common used types of audio power amplifier design. The class AB amplifier is a variation of a class B amplifier as described above, except that both devices are allowed to conduct at the same time around the waveforms crossover point eliminating the crossover distortion problems of the previous class B amplifier.

The two transistors have a very small bias voltage, typically at 5 to 10% of the quiescent current to bias the transistors just above its cut-off point. Then the conducting device, either bipolar of FET, will be “ON” for more than one half cycle, but much less than one full cycle of the input signal. Therefore, in a class AB amplifier design each of the push-pull transistors is conducting for slightly more than the half cycle of conduction in class B, but much less than the full cycle of conduction of class A.

In other words, the conduction angle of a class AB amplifier is somewhere between 180^{o}and 360^{o} depending upon the chosen bias point as shown.

The advantage of this small bias voltage, provided by series diodes or resistors, is that the crossover distortion created by the class B amplifier characteristics is overcome, without the inefficiencies of the class A amplifier design. So the class AB amplifier is a good compromise between class A and class B in terms of efficiency and linearity, with conversion efficiencies reaching about 50% to 60%.

Class AB Amplifier



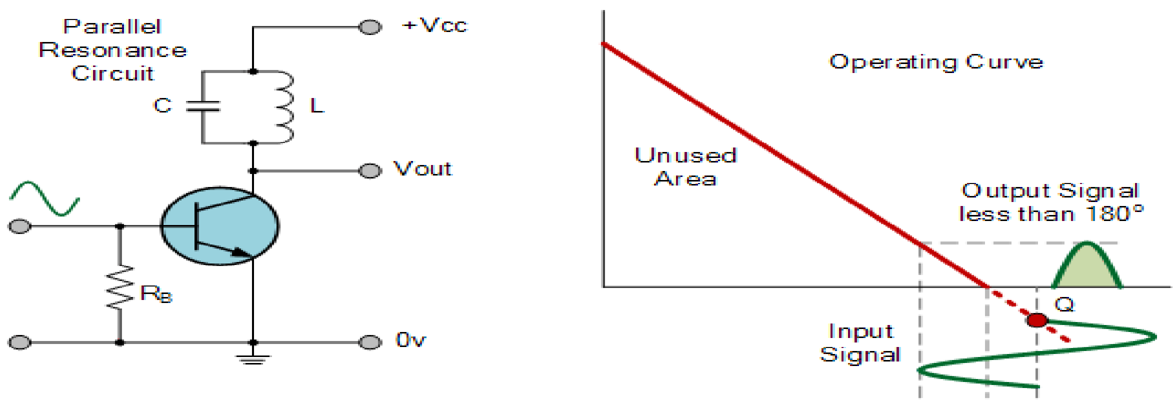
Class C Amplifier

The **Class C Amplifier** design has the greatest efficiency but the poorest linearity of the classes of amplifiers mentioned here. The previous classes, A, B and AB are considered linear amplifiers, as the output signals amplitude and phase are linearly related to the input signals amplitude and phase.

However, the class C amplifier is heavily biased so that the output current is zero for more than one half of an input sinusoidal signal cycle with the transistor idling at its cut-off point. In other words, the conduction angle for the transistor is significantly less than 180 degrees, and is generally around the 90 degrees area.

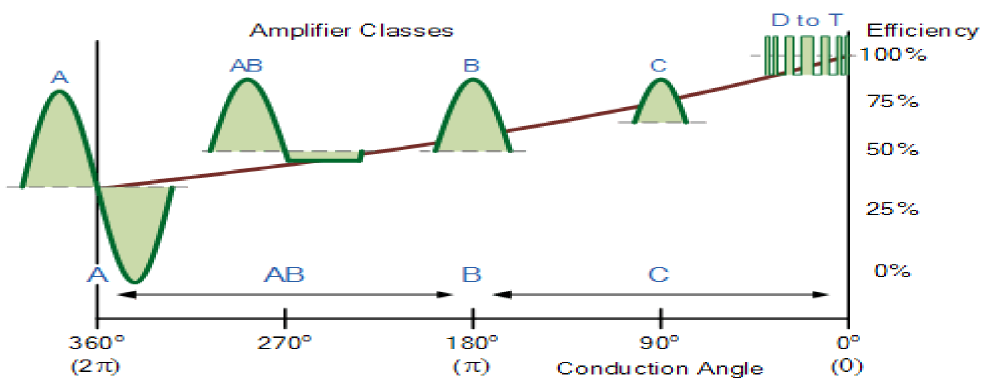
While this form of transistor biasing gives a much improved efficiency of around 80% to the amplifier, it introduces a very heavy distortion of the output signal. Therefore, class C amplifiers are not suitable for use as audio amplifiers.

Class C Amplifier



Due to its heavy audio distortion, class C amplifiers are commonly used in high frequency sine wave oscillators and certain types of radio frequency amplifiers, where the pulses of current produced at the amplifiers output can be converted to complete sine waves of a particular frequency by the use of LC resonant circuits in its collector circuit.

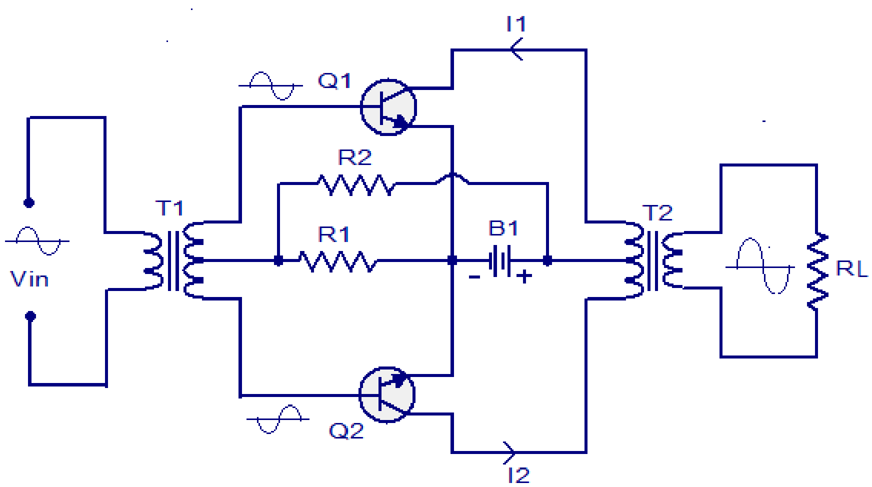
Amplifier Classes and Efficiency



[Push pull amplifier]

A push pull amplifier is an amplifier which has an output stage that can drive a current in either direction through through the load. The output stage of a typical push pull amplifier consists of of two identical BJTs or MOSFETs one sourcing current through the load while the other one sinking the current from the load. Push pull amplifiers are superior over single ended amplifiers (using a single transistor at the output for driving the load) in terms of distortion and performance. A single ended amplifier, how well it may be designed will surely introduce some distortion due to the non linearity of its dynamic transfer characteristics. Push pull amplifiers are commonly used in situations where low distortion, high efficiency and high output power are required. The basic operation of a push pull amplifier is as follows: The signal to be amplified is first split into two identical signals 180° out of phase. Generally this splitting is done using an input coupling transformer. The input coupling transformer is so arranged that one signal in applied to the input of one transistor and the other signal is applied to the input of the other transistor. Advantages of push pull amplifier are low distortion, absence of magnetic saturation in the coupling transformer core, and cancellation of power supply ripples which results in the absence of hum while the disadvantages are the need of two identical transistors and the requirement of bulky and costly coupling transformers.

Class A push pull amplifier.

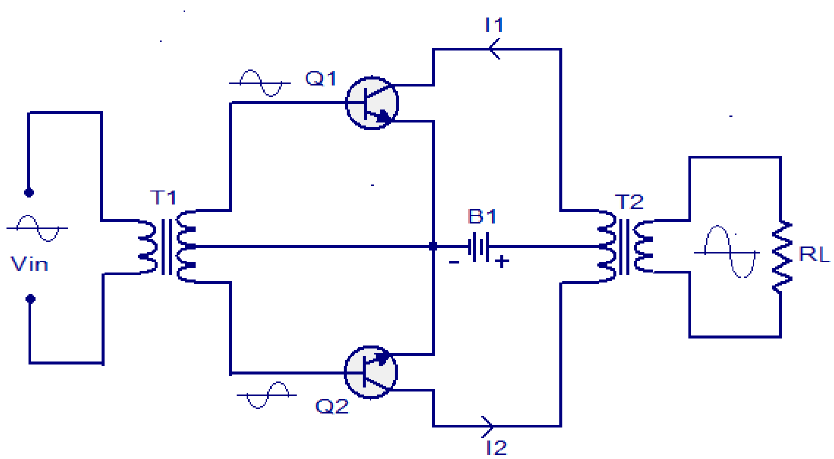


Class A push pull amplifier

A push pull amplifier can be made in Class A, Class B, Class AB or Class C configurations. The circuit diagram of a typical Class A push pull amplifier is shown above. Q1 and Q2 are two identical transistor and their emitter terminals are connected together. R1 and R2 are meant for biasing the transistors. Collector terminals of the two transistor are connected to the respective ends of the primary of the output transformer T2. Power supply is connected between the center tap of the T2 primary and the emitter junction of the Q1 and Q2. Base terminal of each transistor is connected to the respective ends of the secondary of the input coupling transformer T1. Input signal is applied to the primary of T1 and output load RL is connected across the secondary of T2.Quiescent current of Q2 and Q1 flows in opposite directions through the corresponding halves of the primary of T2 and as a result there will be no magnetic saturation. From the figure you can see the phase splited signals being applied to the base of each transistors. When Q1 is driven positive using the first half of its input signal, the collector current of Q1 increases. At the same time Q2 is driven negative using the first half of its input signal and so the collector current of Q2 decreases. From the figure you can understand that the collector currents of Q1 and Q2 ie; I1 and I2 flows in the same direction trough the corresponding halves of the T2 primary. As a result an amplified version of the original input signal is induced in the T2 secondary. It is clear that the current through the T2 secondary is the difference between the two collector currents. Harmonics will be much less in the output due to cancellation and this is results in low distortion.

Class B push pull amplifier.

The Class B push pull amplifier is almost similar to the Class A push pull amplifier and the only difference is that there is no biasing resistors for a Class B push pull amplifier. This means that the two transistors are biased at the cut off point.The Class B configuration can provide better power output and has higher efficiency(up to 78.5%). Since the transistor are biased at the cutoff point, they consumes no power during idle condition and this adds to the efficiency. The advantages of Class B push pull amplifiers are, ability to work in limited power supply conditions (due to the higher efficiency), absence of even harmonics in the output, simple circuitry when compared to the Class A configuration etc. The disadvantages are higher percentage of harmonic distortion when compared to the Class A, cancellation of power supply ripples is not as efficient as in Class A push pull amplifier and which results in the need of a well regulated power supply.The circuit diagram of a classic Class B push pull amplifier is shown in the diagram below.



Class B push pull amplifier

The circuit arrangement of the Class B push pull amplifier is similar to the Class A push pull amplifier except for the absence of the biasing resistors. T1 is the input coupling capacitor and the input signal is applied to its primary. Q1 and Q2 are two identical transistors and their emitter terminals are connected together. Center tap of the input coupling transformer and the negative end of the voltage source is connected to the junction point of the emitter terminals. Positive end of the voltage source is connected to the center tap of the output coupling transformer. Collector terminals of each transistor are connected to the respective ends of the primary of the output coupling transformer T2. Load RL is connected across the secondary of T2.The input signal is converted into two similar but phase opposite signals by the input transformer T1. One out of these two signals is applied to the base of the upper transistor while the other one is applied to the base of the other transistor. You can understand this from the circuit diagram. When transistor Q1 is driven to the positive side using the positive half of its input signal, the reverse happens in the transistor Q2. That means when the collector current of Q1 is going in the increasing direction, the collector current of Q2 goes in the decreasing direction. Anyway the current flow through the respective halves of the primary of the T2 will be in same direction. Have a look at the figure for better understanding. This current flow through the T2 primary results in a wave form induced across its secondary. The wave form induced across the secondary is similar to the original input signal but amplified in terms of magnitude.

Cross over distortion.

Cross over distortion is a type of distortion commonly seen in Class B amplifier configurations. As we said earlier ,the transistor are biased at cut off point in the Class B amplifier. We all know a Silicon transistor requires 0.7V and a Germanium diode requires 0.2V of voltage across its base emitter junction before entering in to conducting mode and this base emitter voltage is called cut in voltage. Germanium diodes are out of scope in amplifiers and we can talk about a Class B push pull amplifier based on Silicon transistors. Since the transistors are biased to cut off, the voltage across their base emitter junction remains zero during the zero input condition. The only source for the transistors to get the necessary cut in voltage is the input signal itself and the required cut in voltage will be looted from the input signal itself. As a result portions of the input wave form that are below 0.7V (cut in voltage) will be cancelled and so the corresponding portions will be absent in the output wave form too. Have a look at the figure below for better understanding.

Class AB push pull amplifier.

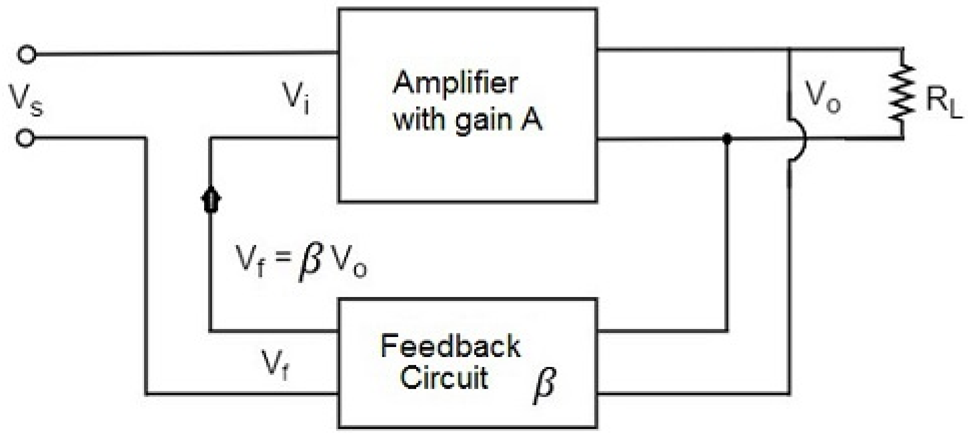
Class AB is another type of push pull amplifier which is almost similar to that of a Class A push pull amplifier and the only difference is that the value of biasing resistors R1 and R2 are so selected that the transistors are biased just at the cut in voltage (0.7V). This reduces the time for which both transistors are simultaneously OFF (the time for which input signal is between (-0.7V and +0.7V) and so the cross over distortion gets reduced. Of the above said classes Class A has least distortion, then Class AB and then Class B. Any way Class AB configuration has reduced efficiency and wastes a reasonable amount of power during zero input condition. Class B has the highest efficiency (78.5%), then Class B (between 78.5 to 50%) and then Class A (50%) .

Type of Negative Feedback

Voltage-Series Feedback

In the voltage series feedback circuit, a fraction of the output voltage is applied in series with the input voltage through the feedback circuit. This is also known as **shunt-driven series-fed** feedback, i.e., a parallel-series circuit.

The following figure shows the block diagram of voltage series feedback, by which it is evident that the feedback circuit is placed in shunt with the output but in series with the input.

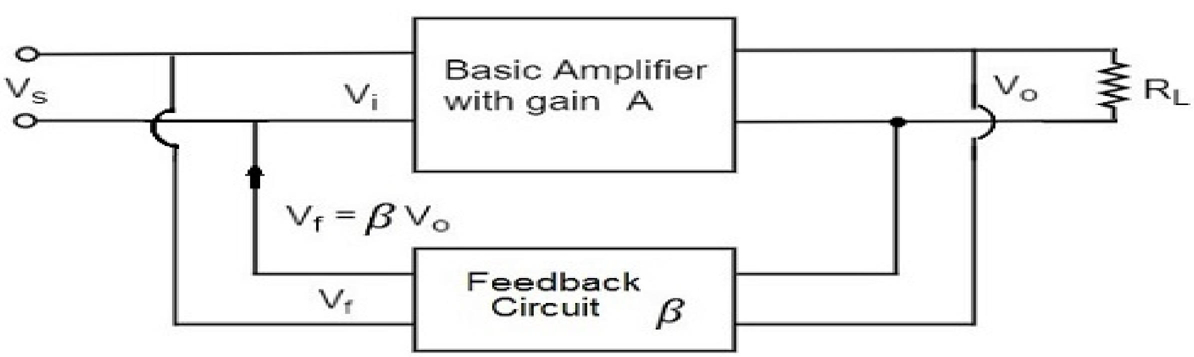


As the feedback circuit is connected in shunt with the output, the output impedance is decreased and due to the series connection with the input, the input impedance is increased.

Voltage-Shunt Feedback

In the voltage shunt feedback circuit, a fraction of the output voltage is applied in parallel with the input voltage through the feedback network. This is also known as **shunt-driven shunt-fed** feedback i.e., a parallel-parallel proto type.

The below figure shows the block diagram of voltage shunt feedback, by which it is evident that the feedback circuit is placed in shunt with the output and also with the input.

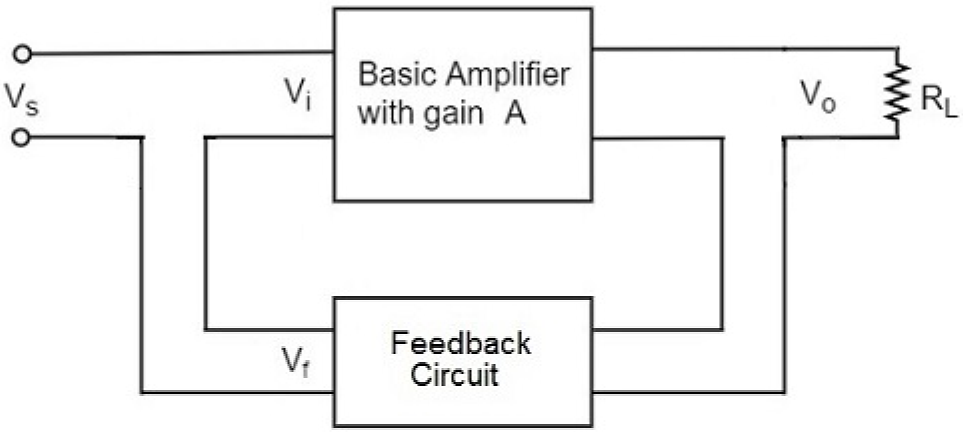


As the feedback circuit is connected in shunt with the output and the input as well, both the output impedance and the input impedance are decreased.

Current-Series Feedback

In the current series feedback circuit, a fraction of the output voltage is applied in series with the input voltage through the feedback circuit. This is also known as **series-driven series-fed** feedback i.e., a series-series circuit.

The following figure shows the block diagram of current series feedback, by which it is evident that the feedback circuit is placed in series with the output and also with the input.

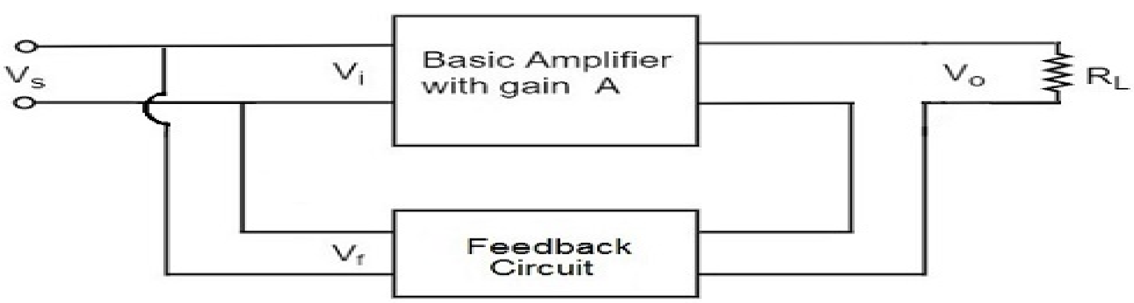


As the feedback circuit is connected in series with the output and the input as well, both the output impedance and the input impedance are increased.

Current-Shunt Feedback

In the current shunt feedback circuit, a fraction of the output voltage is applied in series with the input voltage through the feedback circuit. This is also known as **series-driven shunt-fed** feedback i.e., a series-parallel circuit.

The below figure shows the block diagram of current shunt feedback, by which it is evident that the feedback circuit is placed in series with the output but in parallel with the input.



As the feedback circuit is connected in series with the output, the output impedance is increased and due to the parallel connection with the input, the input impedance is decreased.

Let us now tabulate the amplifier characteristics that get affected by different types of negative feedbacks.

Characteristics	Types of Feedback			
	Voltage-Series	**Voltage-Shunt**	**Current-Series**	**Current-Shunt**
Voltage Gain	Decreases	Decreases	Decreases	Decreases
Bandwidth	Increases	Increases	Increases	Increases
Input resistance	Increases	Decreases	Increases	Decreases
Output resistance	Decreases	Decreases	Increases	Increases
Harmonic distortion	Decreases	Decreases	Decreases	Decreases
Noise	Decreases	Decreases	Decreases	Decreases