FEEDBACK AMPLIFIER, ITS OPERATION, EFFECT IMPORTANCE AND CONNECTING TYPES: A REVIEW

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FEEDBACK AMPLIFIER, ITS OPERATION, EFFECT IMPORTANCE AND CONNECTING TYPES: A REVIEW

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ABSTRACT

Feedback is the process of taking a proportion of an amplifier´s output signal and feeding it back into the input. Feedback can be arranged to increase or decrease the input signal. When feedback is used to increase the input signal, it is called Positive Feedback and when the effect of the feedback reduces the input signal it is called Negative Feedback. In positive feedback, the feedback signal adds to the input signal. For this reason, it is also called a regenerative feedback. Positive feedback is used in oscillators. If the signal feedback is of possible polarity or out of phase by 180^0 with respect to input signal the feedback is called as degenerative feedback or negative feedback. Negative feedback is used in amplifiers.
Keywords: Feedback, Amplifier, Oscillator, Negative feedback.

INTRODUCTION

This topic is an essential theory in electronics. Feedback is covered also in courses on control theory but the complexity of circuit topologies require to develop a specific approach in order to fully analyze a real circuit within the framework of feedback theory. New concepts and terminology need to be developed (open and closed-loop parameters, loop gain, ideal gain, direct feed-through, etc.) (Castoldi, 2012). It must be stressed that feedback is virtually present in all analog circuits, therefore it is important that students develop a good understanding of feedback concepts in circuits and learn a sound analysis method. However, the research in feedback amplifier should focus on:

a. To study the various feedback amplifiers, their qualities and differences.

b. Understand the working operation, characteristics and how feedback amplifier functions.

c. To understand feedback amplifier with other electrical components on a circuit.

d. To understand the general expression of a basic amplifier circuit.

e. How to solve the problem of negative feedback transistor amplifier using h-parameter.

f. Characteristics of negative feedback amplifier.

FEEDBACK AMPLIFIER AND TYPES

Positive feedback

When the feedback energy (voltage or current) is in phase with the input signal and thus aids it, it is called positive feedback. Both amplifier and feedback network introduce a phase shift of 180°, figure 1. The result is a 360° phase shift around the loop, causing the feedback voltage V_f to be in phase with the input signal V_{in} (Amplifiers with Negative Feedback - Talking Electronics, 2017).

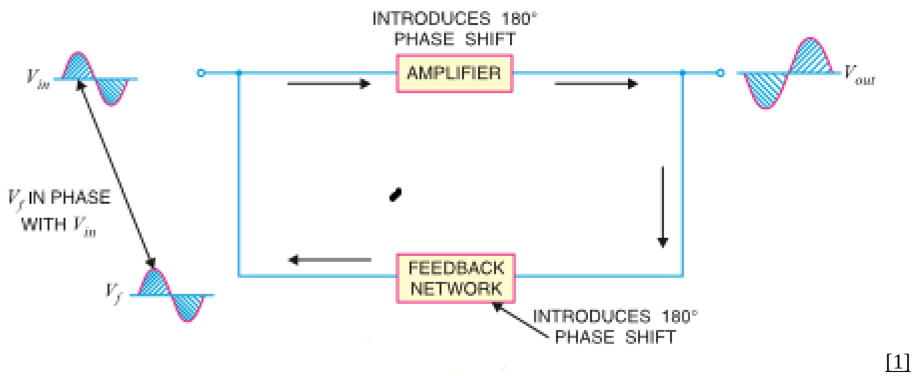
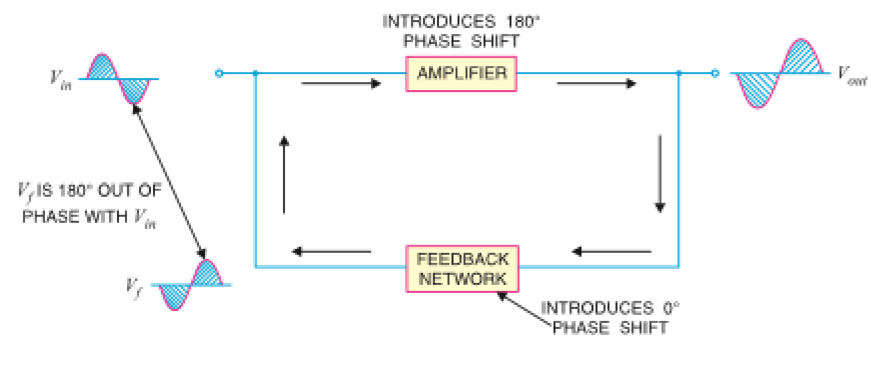


Fig.1. Positive feedback with a phase shift of 180°

The positive feedback increases the gain of the amplifier. However, it has the disadvantages of increased distortion and instability. Therefore, positive feedback is seldom employed in amplifiers. One important use of positive feedback is in oscillators. As we shall see in the next chapter, if positive feedback is sufficiently large, it leads to oscillations. As a matter of fact, an oscillator is a device that converts D.C power into A.C power of any desired frequency [2].

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 shown below, 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 V_f (figure 2) is 180° out of phase with the input signal V_{in} (Amplifiers with Negative Feedback - Talking Electronics, 2017).



[2]

Fig.2. Negative feedback with a phase shift of 180°

Negative feedback reduces the gain of the amplifier. However, the advantages of negative feedback are: reduction in distortion, stability in gain, increased bandwidth and improved input and output impedances. It is due to these advantages that negative feedback is frequently employed in amplifiers [3].

Table 1. Advantages of feed feedback amplifiers

Negative feedback	Positive feedback
In negative feedback the input signal and feedback are out of phase by 180°	In positive feedback the input signal and feedback signal are in phase (0° or 360°)
Voltage gain of negative feedback amplifier is given by $Avf = \frac{Av}{1+ \beta Av}$ where Avf = gain with feedback Av = open loop gain of amplifier. β = feedback factor.	Voltage gain of positive feedback amplifier is given by $Avf = \frac{Av}{1- \beta Av}$ where Avf = gain with feedback Av = open loop gain of amplifier. β = feedback factor.
Negative feedback increases stability of the amplifier	Stability of amplifier decreases.
Reduces distortion	Increases distortion.
Bandwidth increased.	Bandwidth decreases.
Used in amplifiers.	Used in oscillators.

It is due to these advantages (see table 1), negative feedback is frequently employed in amplifiers while positive feedback is used for oscillators.

A Basic Feedback Amplifier

The block diagram of a basic feedback amplifier is shown below in figure 3 and 4 [2].

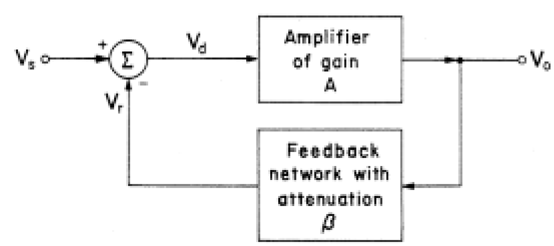


Fig. 3. Feedback system block diagram

Vs= Source voltage

V_d = voltage at input terminals

A = Amplifier of gain

V_o = Output voltage

V_r = return voltage

β = feedback network with attenuation

General Expression for Stage Gain of a Basic Feedback Amplifier

$$A_{vf} = \frac{A_v}{1 + \beta A_v}$$

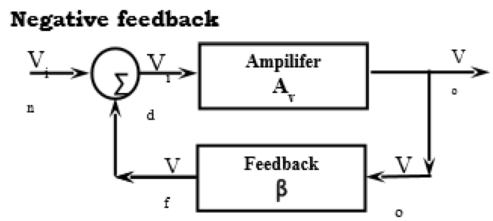


Fig. 4. Feedback amplifier

$V_{id} = V_{in} - V_f$

Where V_{in} = input voltage

V_f = feedback voltage

V = difference input voltage

The circuit amplifies the difference input voltage V_{id}. This difference is equal to the input voltage V_{in} minus feedback voltage V_f. In the other words the feedback voltage always opposes the input voltage (or is out of phase by 180^o with respect to the input voltage) hence, the feedback is said to be negative.

$$V_o = A_v V_{in} - A_v V_f$$

$$\beta = \frac{V_f}{V_o}$$

$$= A_v V_{in} - A_v \beta V_o$$

$V_o + A_v \beta V_o = A_v V_{in}$

$V_o (1+A_v\beta) = A_v V_{in}$

$$A_v = \frac{V_o}{V_{id}}$$

$\frac{V_o}{V_{in}} = \frac{A_v}{(1+A_v\beta)}$, $\quad A_{vf} = \frac{V_o}{V_{in}}$

$$A_{vf} = \frac{A_v}{(1 + A_v\beta)}$$

Gain with feedback with feedback is reduced by factor 1+ $A_v\beta$. Equation shows that feedback (-ve) reduces gain of amplifier.

$$A_{vf} = \frac{A_v}{(1 + A_v\beta)}$$

Negative Feedback Connection Types and Effects

Series Current Feedback Amplifier

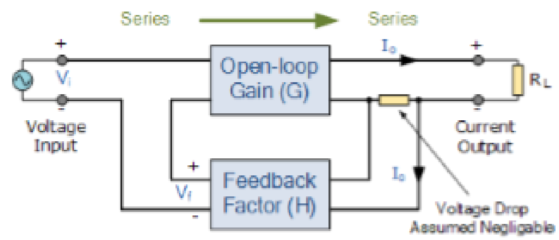


Fig. 5. Series Current Feedback Amplifier

Series-Series Feedback Systems (figure 5), also known as series current feedback, operates as a voltage-current controlled feedback system. In the series current configuration the feedback error signal is in series with the input and is proportional to the load current, I_{out}. Actually, this type of feedback converts the current signal into a voltage which is actually fed back and it is this voltage which is subtracted from the input (Amplifiers with Negative Feedback - Talking Electronics, 2017). For the series-series connection, the configuration is defined as the output current to the input voltage. Because the output current, Io of the series connection is fed back as a voltage, this increases both the input and output impedances of the system. Therefore, the circuit works best as a transconductance amplifier with the ideal input resistance, R_{in} being very large, and the ideal output resistance, Rout is also very large. Then the "series-series feedback configuration" functions as transconductance type amplifier system as the input signal is a voltage and the output signal is a current. Then for a series-series feedback circuit the transfer gain is given as: $G_m = V_{out} \div I_{in}$.

Series Voltage Feedback Amplifier

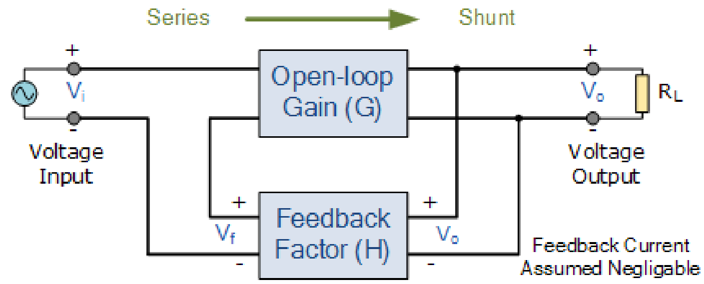


Fig. 6. Series Voltage Feedback Amplifier (Tutorials)

Series-Shunt Feedback, also known as *series voltage feedback (figure 6)*, operates as a voltage-voltage controlled feedback system. The error voltage fed back from the feedback network is in *series* with the input. The voltage which is fed back from the output being proportional to the output voltage, V_o as it is parallel, or shunt connected. For the series-shunt connection, the configuration is defined as the output voltage to the input voltage. Most inverting and non-inverting operational amplifier circuits operate with series-shunt feedback producing what is known as a "voltage amplifier" (Tutorials). As a voltage amplifier the ideal input resistance, R_{in} is very large, and the ideal output resistance, R_{out} is very small. Then the "series-shunt feedback configuration" works as a true voltage amplifier as the input signal is a voltage and the output signal is a voltage, so the transfer gain is given as: $Av = V_{out} \div V_{in}$.

Parallel Current

Shunt-Series Feedback, also known as shunt current feedback, operates as a current-current controlled feedback system. The feedback signal is proportional to the output current, Io flowing in the load. The feedback signal is fed back in parallel or shunt with the input as shown.

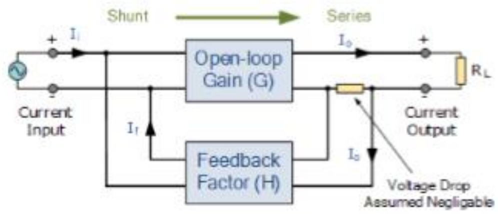
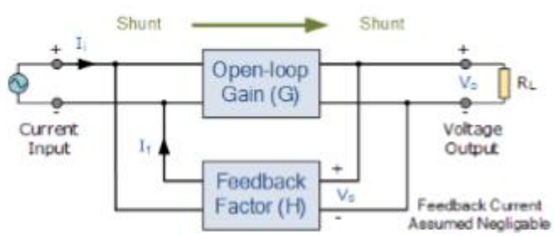


Fig. 7. Shunt-series configuration

For the shunt-series connection, the configuration is defined as the output current to the input current. In the shunt-series feedback configuration (figure 7) the signal fed back is in parallel with the input signal and as such it's the currents, not the voltages that add (Tutorials). This parallel shunt feedback connection will not normally affect the voltage gain of the system, since for a voltage output a voltage input is required. Also, the series connection at the output increases output resistance, Rout while the shunt connection at the input decreases the input resistance, R_{in}. Then the "shunt-series feedback configuration" works as a true current amplifier as the input signal is a current and the output signal is a current, so the transfer gain is given as: $A_i = I_{out} \div I_{in}$. [7]

Parallel (Shunt) Voltage



[7]

Fig. 8. Shunt-Shunt Feedback Systems

Shunt-Shunt Feedback Systems, also known as shunt voltage feedback, operates as a current-voltage controlled feedback system, figure 8. In the shunt-shunt feedback configuration the signal fed back is in parallel with the input signal. The output voltage is sensed and the current is subtracted from the input current in shunt, and as such it's the currents, not the voltages that subtract. For the shunt-shunt connection, the configuration is defined as the output voltage to the input current. As the output voltage is fed back as a current to a current-driven input port, the shunt connections at both the input and output terminals reduce the input and output impedance. Therefore the system works best as a transresistance system with the ideal input resistance, R_{in} being very small, and the ideal output resistance, Rout also being very small. Then the shunt voltage configuration works as transresistance type voltage amplifier as the input signal is a current and the output signal is a voltage, so the transfer gain is given as: $Rm = I_{out} \div V_{in}$. [7]

EFFECT OF APPLYING NEGATIVE FEEDBACK TO AN AMPLIFIER

The effect of negative feedback on an amplifier is considered in relation to gain, gain stability, distortion, noise, input/output impedance and bandwidth and gain-bandwidth product.

Gain

The gain of an amplifier is a measure of the "Amplification" of an amplifier, i.e. how much it inc reases the amplitude of signal. More precisely it is the ratio of the output signal amplitude to the i nput signal amplitude, and is given the symbol "A". it can be calculated for voltage (Av), Current (Ai), or power (Ap), when the subscript letter after the A is in lower case this refer to small signal conditions, and when the subscript is in capital letters, it refers to DC conditions (Amplifiers - Learn About Electronics). The gain or amplification for the three (3) types of amplifier can be described using the appropriate formula:

Voltage gain Av = Amplitude of output voltage ÷ Amplitude of input voltage.

$$A_v = \frac{V_{out}}{V_{in}}$$

Current gain *Ai* = Amplitude of output current ÷ Amplitude of input current.

$$A_i = \frac{I_{out}}{I_{in}}$$

Power gain *Ap* = Signal power out ÷ Signal power in.

$$A_P = \frac{P_{out}}{P_{in}}$$

The gain of an amplifier is governed, not only by the components (transistors etc.) used, but also by the way they are interconnected within the amplifier circuit.

Gain Stability

An important advantage of negative voltage feedback is that the resultant gain of the amplifier can be made independent of transistor parameters or the supply voltage variations (Advantages of Negative Voltage Feedback, 2017).

$$A_{vf} = \frac{A_v}{1 + A_v m_v}$$

For negative voltage feedback in an amplifier to be effective, the designer deliberately makes the product Av mv much greater than unity. Therefore, in the above relation, ‘1’ can be neglected as compared to Av mv and the expression becomes (Advantages of Negative Voltage Feedback, 2017):

$$A_{vf} = \frac{A_v}{1+A_v m_v} = \frac{1}{m_v}$$

It may be seen that the gain now depends only upon feedback fraction, m_v i.e., on the characteristics of feedback circuit. As feedback circuit is usually a voltage divider (a resistive network), therefore, it is unaffected by changes in temperature, variations in transistor parameters and frequency. Hence, the gain of the amplifier is extremely stable. [1]

Distortion

A large signal stage has non-linear distortion because its voltage gain changes at various points in the cycle. The negative voltage feedback reduces the nonlinear distortion in large signal amplifiers. It can be proved mathematically that:

$$D_{vf} = \frac{D}{1 + A_v m_v}$$

Where D = distortion in amplifier without feedback

D_{vf} = distortion in amplifier with negative feedback

It is clear that by applying negative voltage feedback to an amplifier (Advantages of Negative Voltage Feedback, 2017), distortion is reduced by a factor $1 + A_v m_v$.

Noise

There are numbers of sources of noise in an amplifier depending upon whether a tube or transistor is used. The noise N can be reduced by the factor $1/ (1+\beta A_v)$, in a similar manner to non-linear distortion, so that the noise with feedback is given by $N_f = \frac{N}{(1+\beta A_v)}$. However, if it is necessary to increase the gain to its original level by the addition of another stage, it is quite possible that the overall system will be noisier that it was at the start. If the increase gain can be accomplished by the adjustment of circuit parameters, a definite reduction in noise will result from the use of negative feedback.

Input / Output Impedance

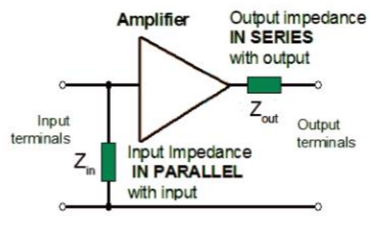


Fig. 9. Input/Output Impedance Schematic

The negative voltage feedback increases the input impedance and decreases the output impedance of amplifier. Such a change is profitable in practice as the amplifier can then serve the purpose of impedance matching (Sadasiva).

Bandwidth and Gain-bandwidth Product

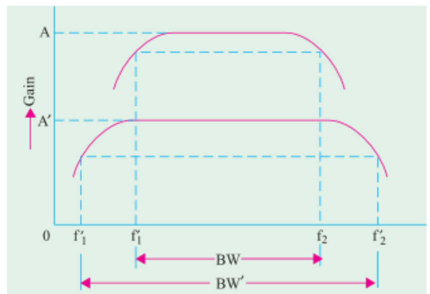


Fig. 10. Bandwidth and Gain-bandwidth Product

An important piece of information that can be obtained from a frequency response curve is the bandwidth (see figure 10) of the amplifier. This refers to the ‘band’ of frequencies for which the amplifier has a useful gain. Outside this useful band, the gain of the amplifier is considered to be insufficient compared with the gain at the center of the bandwidth (Eric, 2017). The bandwidth specified for the voltage amplifiers is the range of frequencies for which the amplifiers gain is greater than 0.707 of the maximum gain alternatively, decibels are used to indicate gain, the ratio of output to input voltage. The useful bandwidth would be described as extending to those frequencies at which the gain is -3db down compared to the gain at the mid-band frequency. Several ways of describing the bandwidth can be used, firstly it would be said that “the bandwidth is from 10Hz to 20kHz.” Alternatively, it could be said that the bandwidth is 9kHz, centered on 774kHz” or even that it is “774 kHz plus or minus 4.5 kHz” (Module 1.1, 2017).

FEEDBACK PRINCIPLE TO PRACTICAL TRANSISTOR CIRCUITS

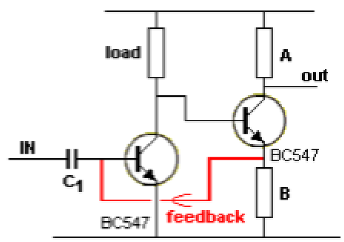
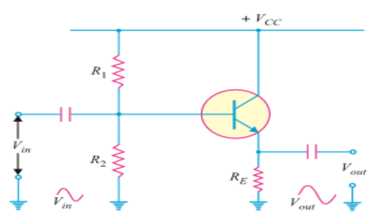


Fig. 11. Feedback principle to practical transistor circuits

Figure 11 shows biasing of the first transistor has been taken from the emitter of the second transistor. This does not save any components but introduces a new term: Feedback (actually Negative Feedback). Negative feedback provides stability to a circuit. Transistors have a very wide range of values (called parameters) such as gain and when two transistors are placed in a circuit, the gain of each transistor can produce an enormous final result when the two values are multiplied together. To control this we can directly couple two transistors and take the output of the second to the input of the first (The Transistor Amplifier - Talking Electronics).

Principle of Operation and Characteristics of Amplifier Circuits



[2]

Fig. 12. Diagram of an emitter follower

Operation:

For the emitter follower, figure 12, the input voltage is applied between base and emitter and the resulting A.C. emitter current produces an output voltage (I_eR_E) across the emitter resistance. This voltage opposes the input voltage, thus providing negative feedback. Clearly, it is a negative current feedback circuit since the voltage feedback is proportional to the emitter current i.e., output current. It is called emitter follower because the output voltage follows the input voltage.

Characteristics:

The major characteristics of the emitter follower are (Rohit, 2008):

(i) No voltage gain. In fact, the voltage gain of an emitter follower is close to 1.

(ii) Relatively high current gain and power gain.

(iii) High input impedance and low output impedance.

(iv) Input and output ac voltages are in phase.

For Cathode Follower, figure 13, any impedance connected between grid and cathode is effectively multiplied by the feedback factor. The output source impedance is effectively divided by the feedback factor. Table 2 shows source follower FET amplifier characteristics. Characteristics of more amplifier circuits' topologies are illustrated in table 3 and table 4.

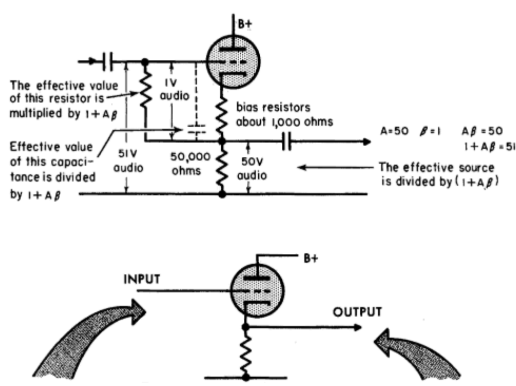


Fig. 13. Cathode Follower

Table 2. Source follower FET amplifier characteristics

Parameter	**Amplifier Characteristics**
Voltage gain	Zero
Current gain	High
Power gain	Medium
Input / output phase relationship	0°
Input resistance	Very High
Output resistance	Low

Table 3. Amplifier Feedback Circuits comparison

Circuit	*β*	*Gain*	*Input Impedance*	*Output impedance*
Voltage-series feedback amplifier (VCVS)	$\frac{V_f}{V_O}$	$A = A_V = \frac{V_O}{V_i} = 1 + (\frac{R_1}{R_2})$	$Z_{in}(1+\beta A)$	$\frac{Z_{out}}{(1+\beta A)}$
Voltage shunt feedback amplifier (CCVS)	$\frac{R_S}{R_S + R}$	$A = R_m = \frac{V_O}{I_i} = R$	$\frac{R}{1+A}$	$\frac{Z_{out}}{(1+\beta A)}$
Voltage series feedback amplifier (VCCS)	$\frac{R}{R_L + R}$	$A = G_m = \frac{I_O}{V_i} = \frac{1}{R}$	$Z_{in}(1+\beta A)$	AR
Voltage shunt feedback amplifier (CCCS)	$\frac{I_f}{I_O}$	$A = A_i = \frac{I_O}{I_i} = 1 + (\frac{R_1}{R_2})$	$\frac{Z_{in}}{1+\beta A}$	$Z_{out}(1+\beta A)$

Table 4. Characteristic of Feedback toppologies

Characteristics	**Type of Feedback**			
	Voltage series	Voltage shunt	Current series	Current shunt
Voltage gain	Decreases	Decreases	Decreases	Decreases
Bandwidth	Increases	Increases	Increases	Increases
Harmonic Distortion	Decreases	Decreases	Decreases	Decreases
Noise	Decreases	Decreases	Decreases	Decreases
Input Resistance	Increases	Decreases	Increases	Decreases
Output Resistance	Decreases	Decreases	Increases	Increases

CONCLUSION

A practical amplifier has a gain of nearly one million i.e. its output is one million times the input. This shows the power of an amplifier and it is imperative to understand its working which we have been able to dissect between positive and negative feedback amplifier. With respect to the stated breakdowns, we have been able to simplify the importance of an amplifier and its value to us.

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