Chapter-3

Feedback Amplifier

By

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Contents:

Objectives

- In this chapter we will address the concept of feedback. Feedback is the fundamental concept in the design of a stable amplifier and an unstable oscillator circuit.
- Beginning with the conceptual development of feedback through block diagrams, this chapter explains both negative and positive feedback, and their effects on different circuit parameters.
- Calculations of open-loop gain and closed-loop gain have been done in detail, followed by a discussion on the effects of feedback on gain, input and output impedances.
- An overview of the practical implementation of feedback topologies, and the sensitivity and bandwidth stability of the feedback amplifier has also been provided.
- The chapter ends with an examination of the effects of positive feedback with emphasis on the Nyquist and Barkhausen criteria.

INTRODUCTION

- ***Feedback*** is one of the fundamental processes in electronics. It is defined as the process whereby a portion of the output signal is fed to the input signal in order to form a part of the system-output control.
- Feedback is used to make the operating point of a transistor insensitive to both manufacturing variations in*as well as temperature.*
- There is another type of feedback called positive or regenerative feedback in which the overall gain of the amplifier is increased. Positive feedback is useful in oscillators and while establishing the two stable states of flip-flop.

Advantage of Feedback System:

- The feedback system has many advantages especially in the control of impedance levels, bandwidth improvement, and in rendering the circuit performance relatively insensitive to manufacturing as well as to environmental changes.

- These are the advantages of negative or degenerative feedback in which the signal feedback from output to input is 180 out of phase with the applied excitation. It increases bandwidth and input impedance, and lowers the output impedance.

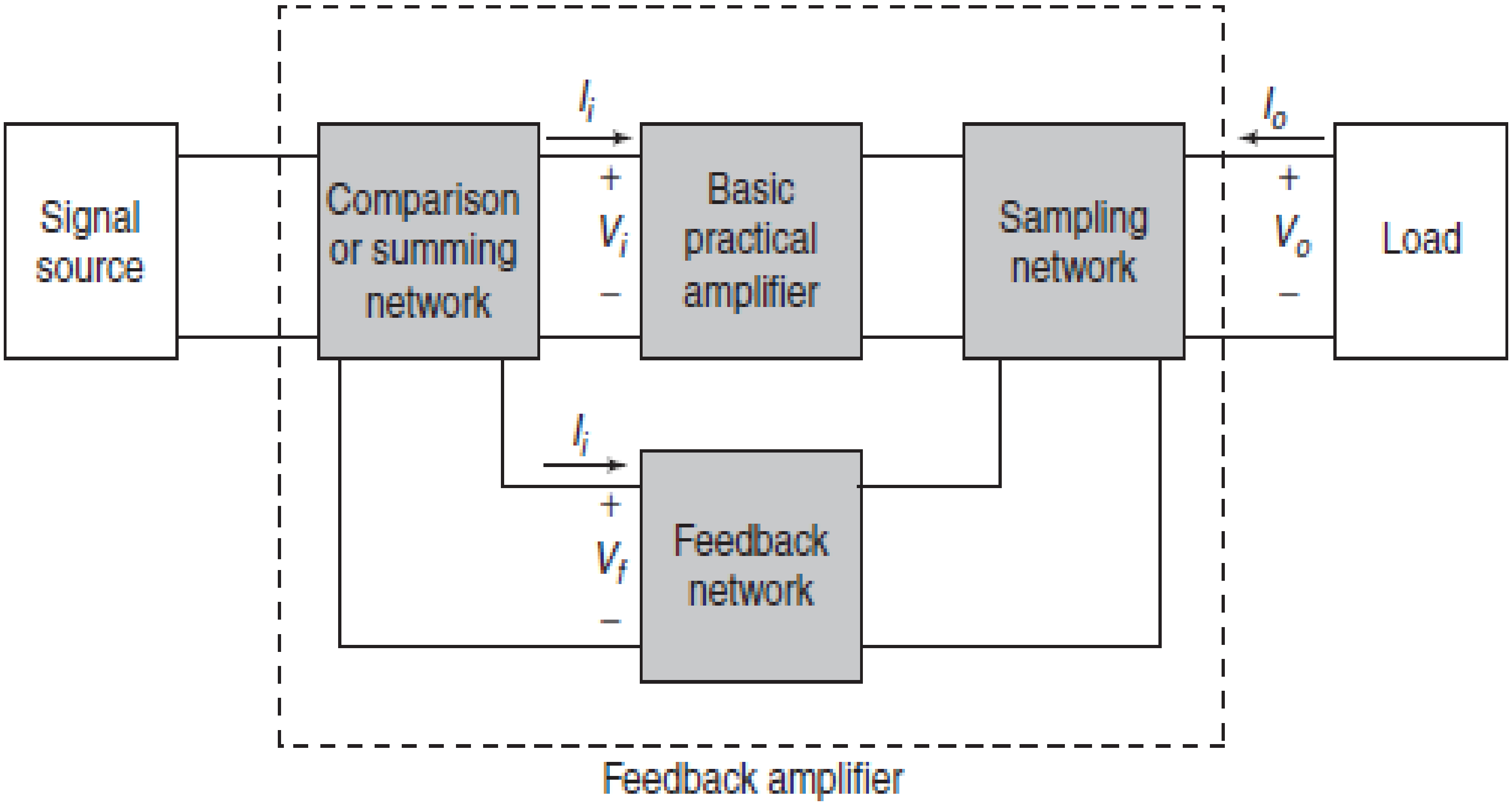
CONCEPTUAL DEVELOPMENT THROUGH BLOCK DIAGRAMS:

- The block diagram of a basic feedback amplifier consists of five basic elements.

These are:

1. Input signals
2. Output signals
3. Sampling Network
4. **Comparison or Summing Network.**
5. **Basic Amplifier**

Block diagram of a basic feedback amplifier



Block diagram of a basic feedback amplifier

Basic elements of feedback amplifier:

- **Input Signal:**

The signal source is modeled either by a voltage source Vs in series with a resistance Rs , or by a current source Is in parallel with a resistance Rs.

- **Output Signal:**

The output can either be the voltage across the load resistance or the current through it. It is the output signal that is desired to be independent of the load and insensitive to parameter variations in the basic amplifier.

- **Sampling Network:**

The function of the sampling network is to provide a measure of the output signal, i.e., a signal that is proportional to the output. This configuration is called shunt connection.

In Fig. 9-2(b) the output current is sampled and the output port of the feedback network is connected in series with the load. This is a series connection.

Measurement of the output voltage & current:

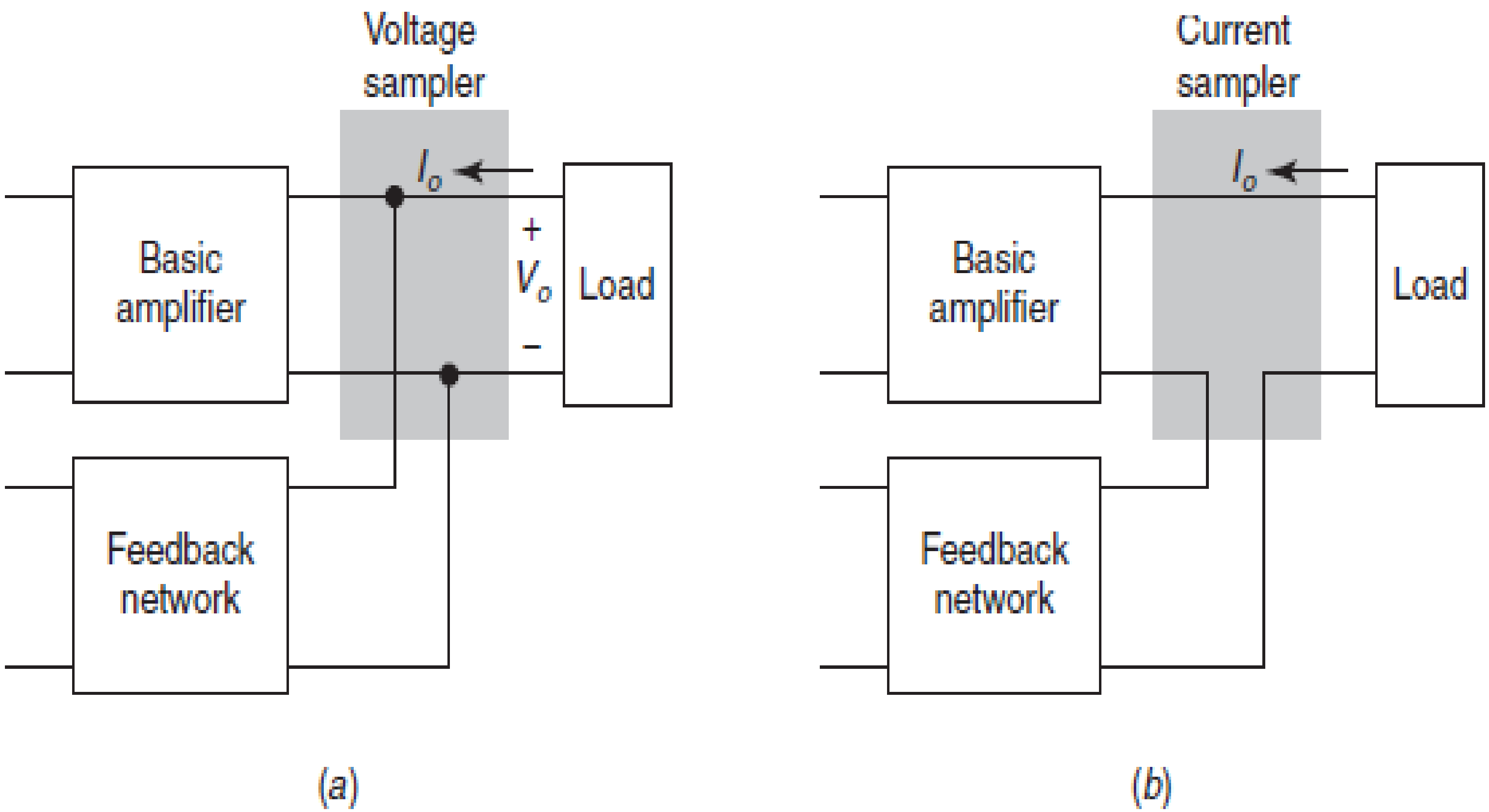


Figure 9-2 Feedback connections at the output of a basic amplifier (a) the measure of the output voltage (b) the measure of the output current

Basic elements of feedback amplifier:

- **<u>Comparison or Summing Network</u>:**

  The two very common networks used for the summing of the input and feedback signals are displayed in Fig. 9-3.

- The circuit shown in Fig. 9-3(a) is a series connection and it is used to compare the signal voltage *Vs and feedback* signal *Vf .*

- *The amplifier input signal Vi is proportional to the voltage difference Vs -Vf that results from the* comparison. A differential amplifier is used for comparison as its output voltage is proportional to the difference between the signals at the two inputs.

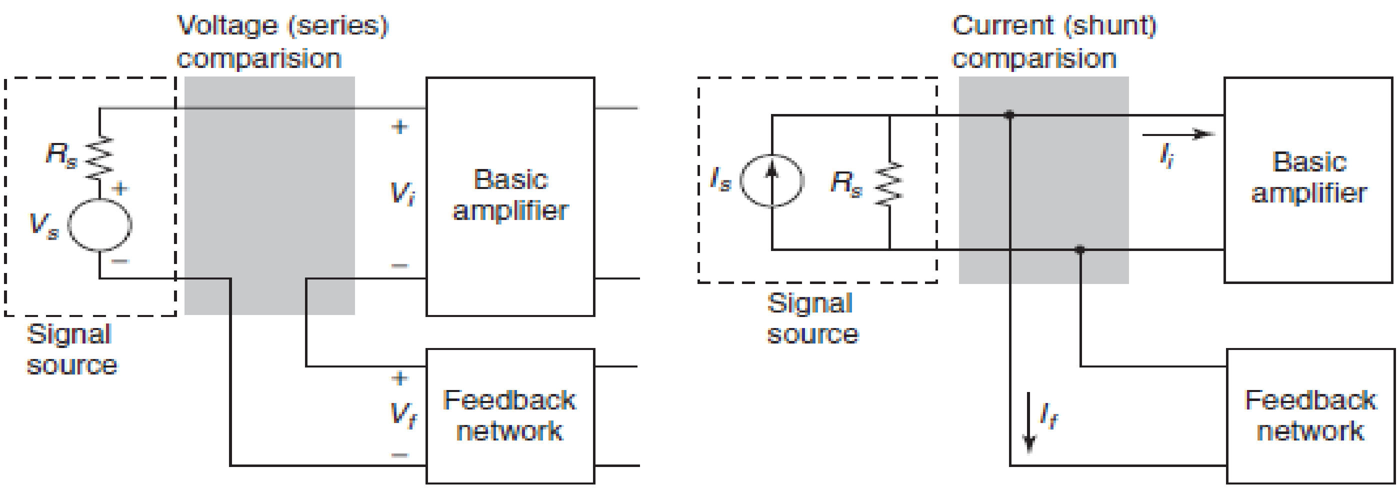
- A shunt connection is shown in Fig. 9-3(b) in which the source current *Is* and feedback current *If are compared. The amplifier input current Ii is proportional to the difference Is If .*

Basic elements of feedback amplifier:

- ***Basic Amplifier:***

The basic amplifier is one of the important parts of the feedback amplifier.

- The circuit amplifies the difference signal that results from comparison and this process is responsible for de-sensitivity and control of the output in a feedback system.



Feedback connections at the input of a basic amplifier (a) voltage summing (series comparison) (b) current summing (shunt comparison)

PROPERTIES OF NEGATIVE FEEDBACK:

- A comparative study of the advantages and disadvantages of negative feedback illustrates the basic properties of negative feedback.

- Negative feedback has the following advantages:

(i) Negative feedback increases the input impedance of the voltage amplifier.

(ii) The output impedance of the voltage amplifier can be further lowered by negative feedback.

(iii) The transfer gain *Af of the amplifier with a feedback can be stabilized against the variations of h or* hybrid parameters of the transistors, or the parameters of the other active devices used in the amplifier.

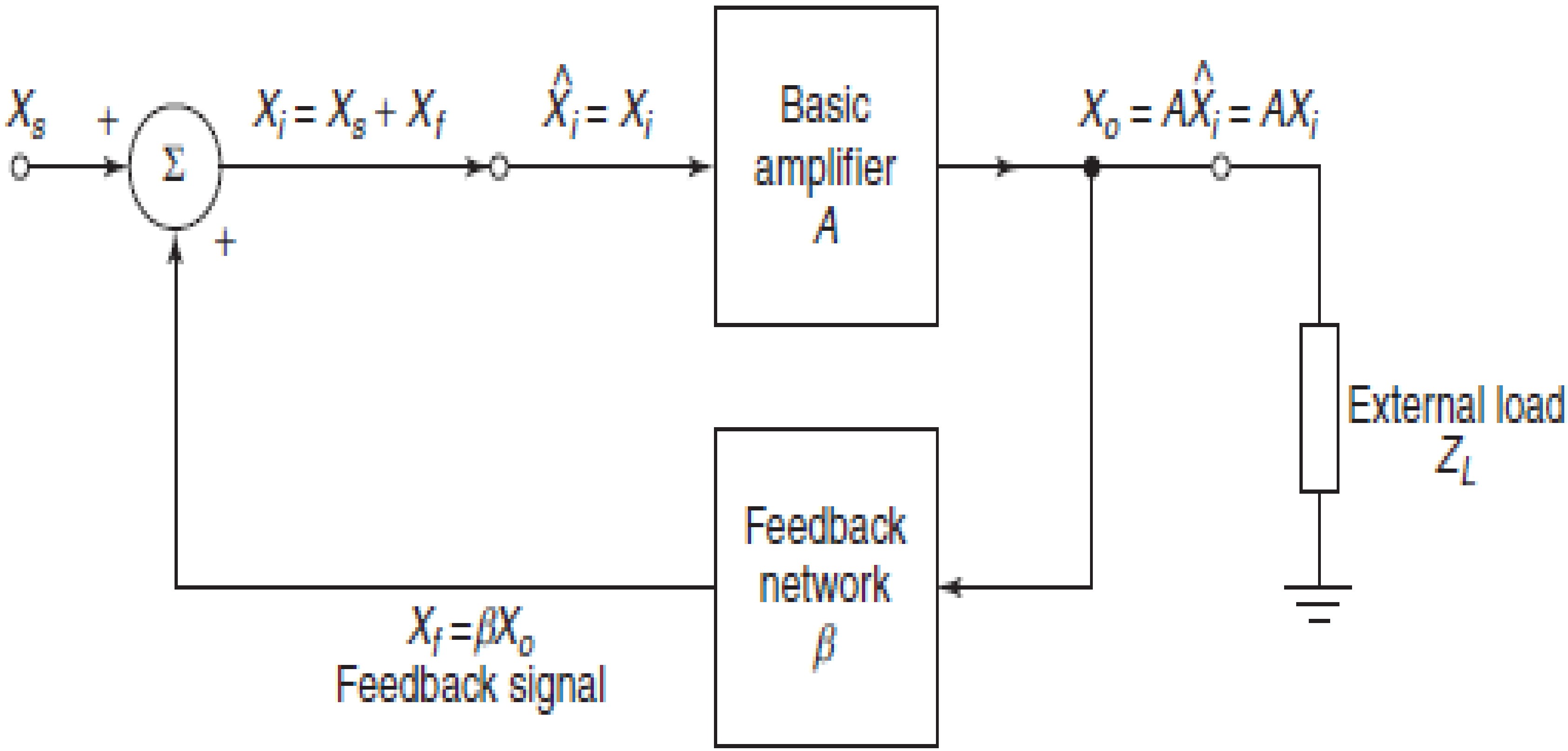
(iv) Negative feedback increases the frequency response and the bandwidth of the amplifier.

(v) Negative feedback increases the linear range of operation of the amplifier.

(vi) Negative feedback causes reduction in noise.

(vii) Phase distortion is reduced.

Block diagram of ideal feedback amplifier:



Block diagram of ideal feedback amplifier

Table of Signals and transfer ratios in feedback amplifiers:

Table 9-1 Signals and transfer ratios in feedback amplifiers

	Feedback Topology			
Signals	*Series-Shunt (Voltage-Series)*	*Series-Series (Current-Series)*	*Shunt-Series (Current-Shunt)*	*Shunt-Shunt (Voltage-Shunt)*
X_o	Voltage	Current	Current	Voltage
X_s, X_i, X_f	Voltage	Voltage	Current	Current
Ratio or Gain				
A	V_o/V_i	I_o/V_i	I_o/I_i	V_o/I_i
β	V_f/V_o	V_f/I_o	I_f/I_o	I_f/V_o
A_f	V_o/V_s	I_o/V_s	I_o/I_s	V_o/I_s

CALCULATIONS OF OPEN-LOOP GAIN, CLOSED-LOOP GAIN & FEEDBACK FACTORS:

The input signal *Xs , the output signal Xo , the feedback signal Xf and the difference signal Xi each represent* either a voltage or a current.

- The symbol indicated by the circle with the summation sign enclosed within (see Fig. 9-4), represents the summing network whose output is the algebraic sum of inputs.
- Thus, for a positive feedback, we get:

  $$Xi = Xs + Xf \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (9\text{-}1)$$

- The signal *Xi , representing the output of the summing network is the amplifier input Xi . If the feedback* signal *Xf is 180 out of phase with the input Xs—as is true in negative feedback systems—then Xi is a difference*

  signal. Therefore, *Xi decreases as | Xf | increases.*

  The reverse transmission of the feedback network is defined by:

  $$\beta = Xf \;/\; Xa \qquad \ldots\ldots\ldots\ldots\ldots (9\text{-}2)$$

CALCULATIONS OF OPEN-LOOP GAIN, CLOSED-LOOP GAIN & FEEDBACK FACTORS:

- The transfer function *is a real number, but in general it is a function of frequency. The gain of the basic* amplifier*A is defined as:*

  $A = Xo / Xi$ ………….. (9-3)
- Now, from Eq. (9-1), we get: $Xi = Xs / Xf$
- Substituting the value of *Xf from Eq. (9-2) as Xf Xo in Eq. (9-1), we get:*

  $Xi = Xs + Xf = Xs + \beta Xo$ ………….(9-3a)
- From Eq. (9-3) we get:: $Xo = A{*}Xi$ …………….(9-3b)
- Substituting the value of *Xi from Eq. (9-3a), we get:*

  $Xo = A{*}Xi = A(Xs + Xo) = AXs + A\beta Xo$

  or, $Xo(1 - A\beta) = AXs$

  Or, $Xo / X s = A/(1 - A\beta)$ ……………. (9-3c)
- The feedback gain *Af is obtained from Eq. (9-3c) as:*

  $Af = Xo / Xs = A/(1 - A\beta)$ ………………. (9-4)
- we can represent the feedback gain as:

$$A_f = \frac{A}{1 \pm A\beta}$$

Loop Gain or Return Ratio:

- The signal $\hat{X}_i$ *in Fig. 9-4 is multiplied by gain A when passing through the amplifier and by in transmission* through the feedback network. Such a path takes us from the amplifier input around the loop consisting of the amplifier and the feedback network. The product *A, is called the loop gain or return ratio T.*
- Equation (9-4) can be written in terms of *AOL and T as:*

$$A_F = \frac{A}{1 - A\beta} = \frac{A_{OL}}{1 + T}$$

- For negative feedback, *−A β= T > 0,* We can give a physical interpretation for the return ratio by considering the input signal *Xs = 0, and keeping*

the path between *Xi and X^i open. If a signal X^i is now applied to the amplifier input, then Xi =Xf = Aβ.*

$$T = -A\beta = -\left.\frac{X_i}{\hat{X}_i}\right|_{X_s = 0}$$

- The return ratio is then the negative of the ratio of the feedback signal to the amplifier input. Often the quantity *F= 1+Aβ= 1+T is referred to as the return difference. If negative feedback is considered then both F and T are greater than zero.*

TOPOLOGIES OF THE FEEDBACK AMPLIFIER:

 There are four basic amplifier types. Each of these is being approximated by the characteristics of an ideal controlled source. The four feedback topologies are as follows:

1. Series-shunt feedback
2. Series-series feedback
3. Shunt-series feedback
4. Shunt-shunt feedback

 The alternative nomenclature used is as follows:

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

Voltage amplifiers with voltage-series feedback:

- The input voltage *Vi of the basic amplifier is the algebraic sum of input signal Vs and the feedback signal Vo , where Vo is the output voltage.*

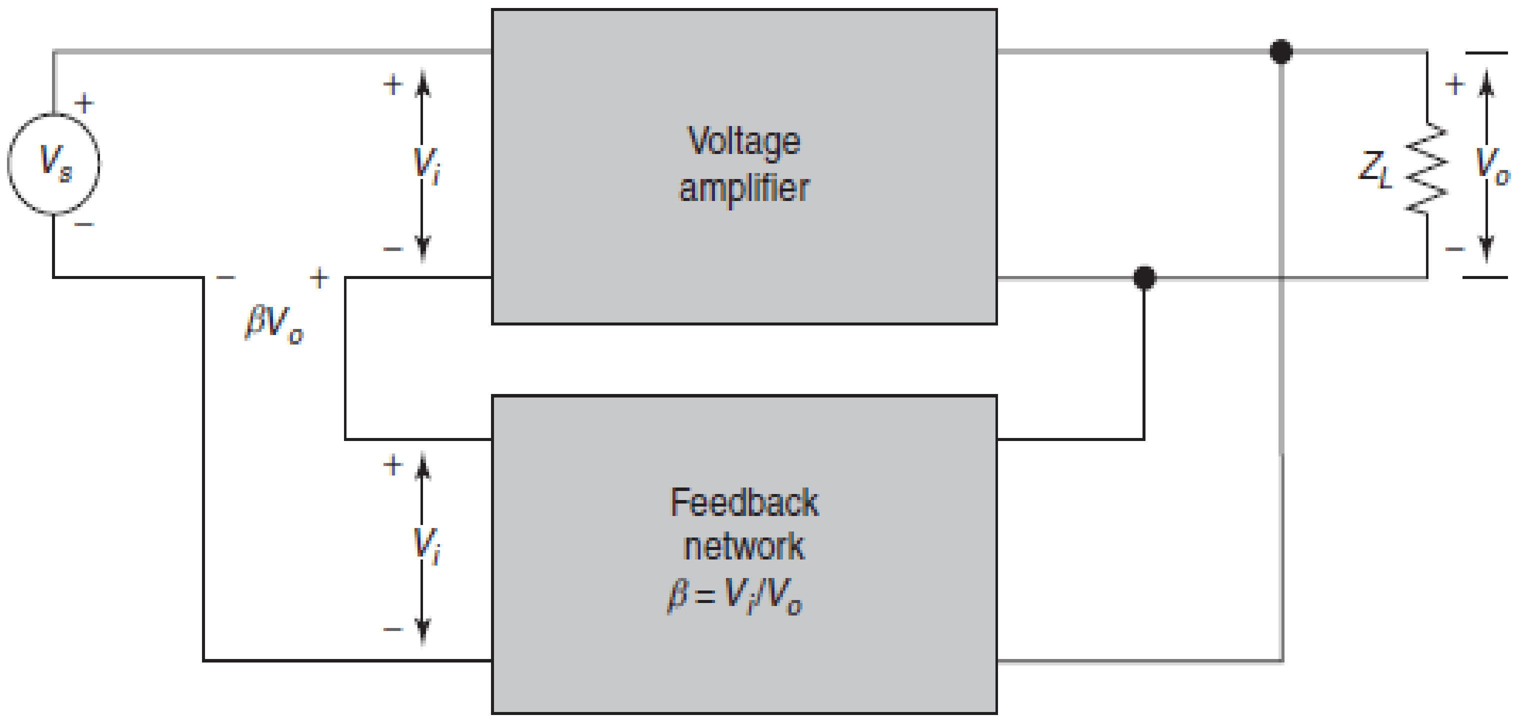
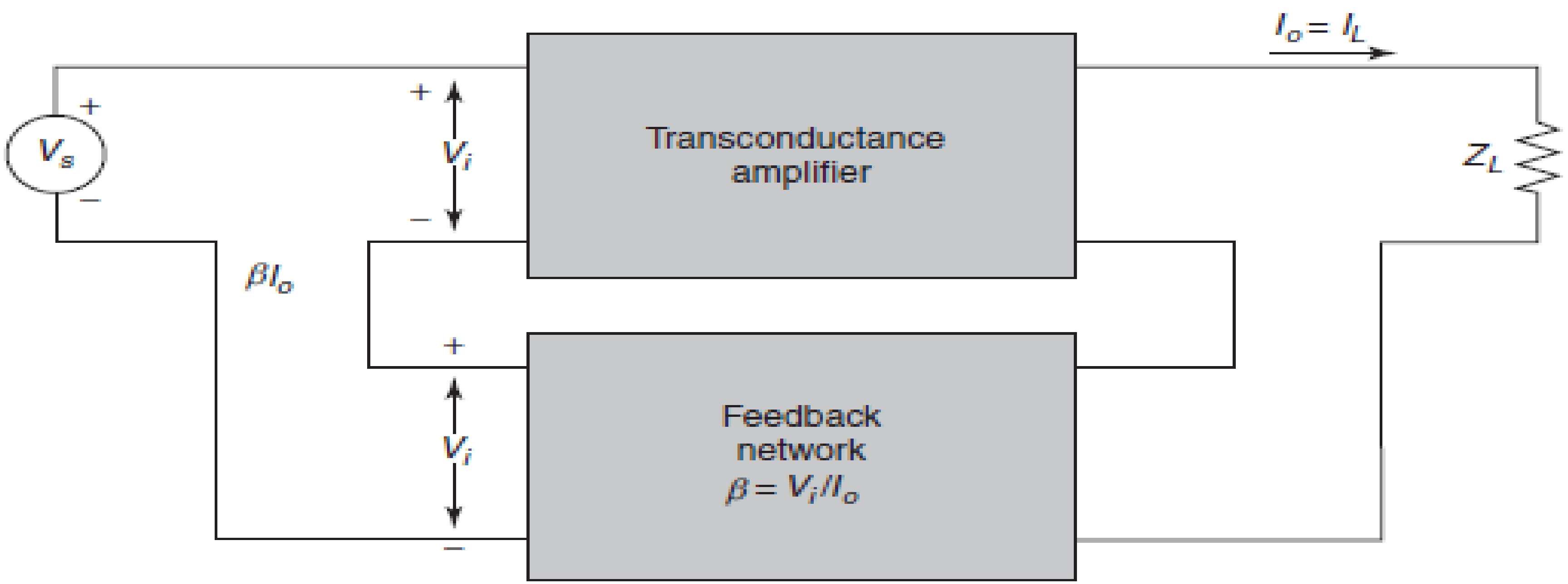


Figure 9-5 Voltage amplifiers with voltage-series feedback

Current-Series or Series-Series Feedback:

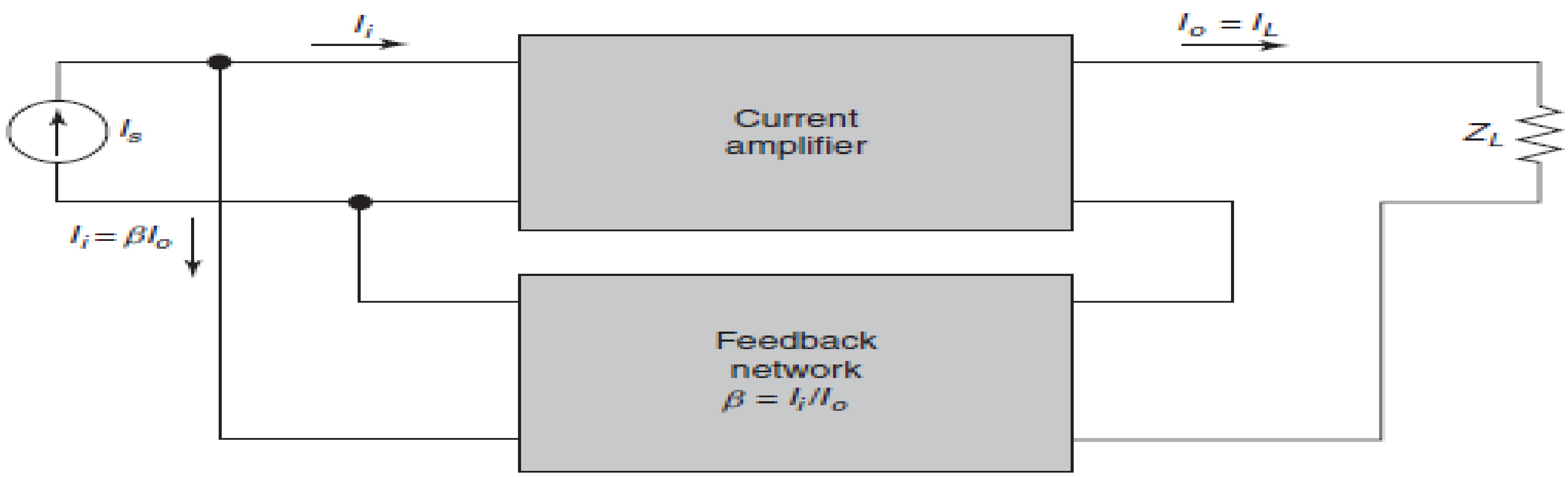
- Trans-conductance feedback amplifier provides an output current *Io which* is proportional to the input voltage *Vs . The feedback signal is the voltage Vf , which is added to Vs at the input* of the basic amplifier.



Transconductance amplifier with current-series feedback

Current amplifi ers with current-shunt feedback

- The current-shunt feedback amplifier, supplies an output current *I_o which* is proportional to the input current *I_i. This makes it a current amplifier.*
- The feedback signal is the current *I_f the input current of the basic amplifier is $I_i = I_s + I_f$ and the output* current is *$I_o = I_L$.*



Current amplifiers with current-shunt feedback

Voltage-Shunt or Shunt-Shunt Feedback

- The voltage-shunt or shunt-shunt feedback amplifier provides an output voltage *Vo in proportion to the input current Is. The input current Ii of the basic* amplifier is the algebraic sum of *Is and the feedback current If .*

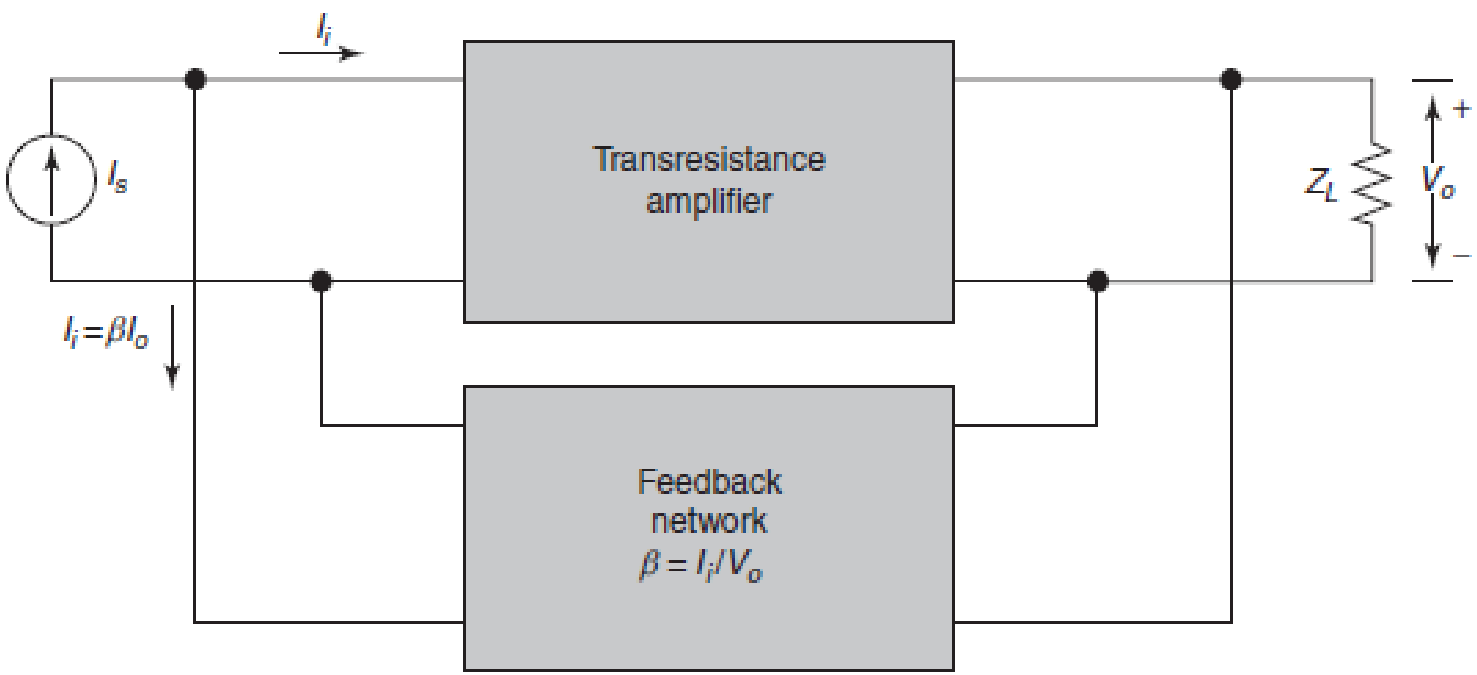
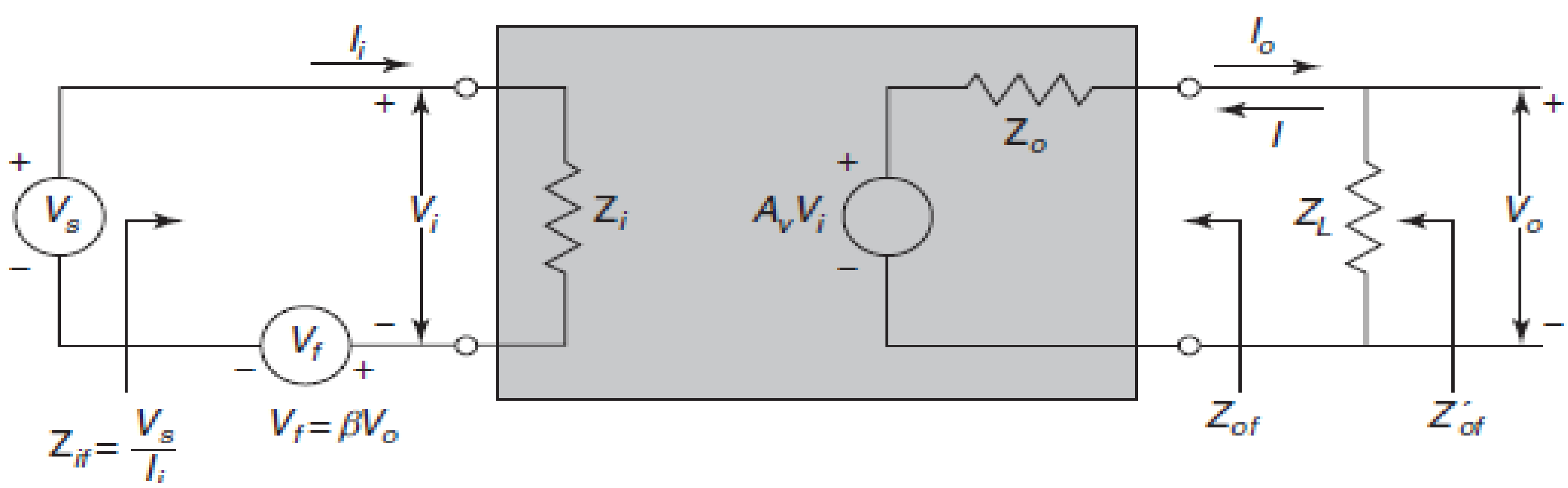


Figure 9-8 Transresistance amplifier with voltage-shunt feedback

EFFECT OF FEEDBACK ON GAIN, INPUT AND OUTPUT IMPEDANCES:

- Feedback is applied with the objective of improving the performance of an amplifier. The operation of an amplifier is regulated by controlling the gain and impedance.
- The effect of feedback on gain and impedance for the different topologies—voltage-series, current-series, current-shunt, voltage-shunt—are discussed in the following sections.



Voltage-series feedback circuit used to calculate input and output resistance

Effect of Feedback on Input Impedance

- ***Voltage-series feedback:***
- Input Impedance with the feedback is:

Z [illegible]

and V [illegible]

- Using voltage divider rule, we get:

$Vo = A$ [illegible]

- Where, $Ii = V$ [illegible]

Now, $Vo = A$ [illegible]

- Or A [illegible]
- The input impedance without feedback is:

$Zi = Vi / Ii.$

Effect of Feedback on Input Impedance

- ***<u>Current-series feedback</u>*:**
- In a similar manner as for voltage series, for current series feedback we obtain:

  Z [illegible]
- where, Y [illegible]
- Y [illegible]
- Y [illegible]
- where, Y [illegible]
- From Eq. (9-11a) it is clear that for series mixing
- *Z if >Z i.*

Current-shunt feedback circuit:

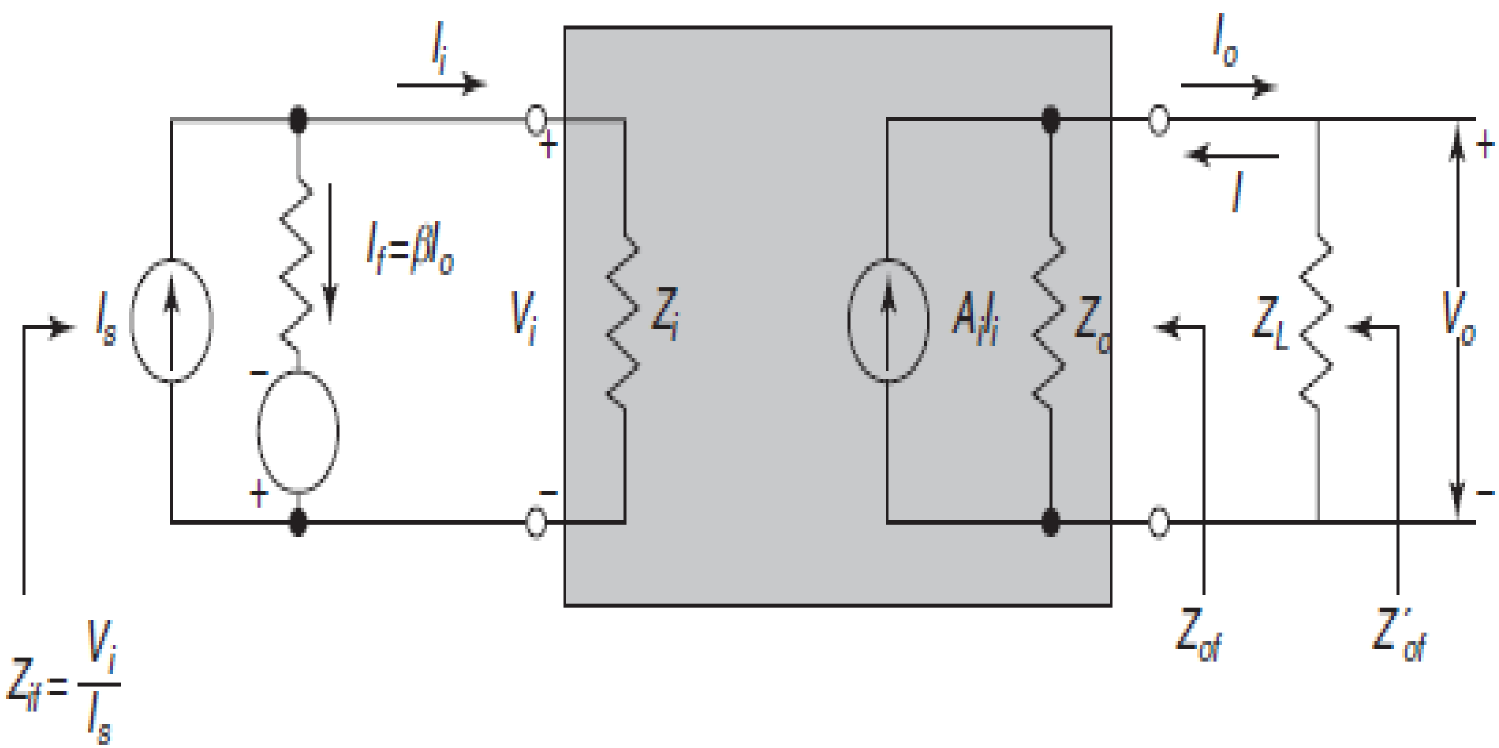


Figure 9-10 Current-shunt feedback circuit used to calculate input and output resistance

Current-shunt feedback to calculate input and output resistance:

- ***<u>Current-shunt feedback</u>*:**
- Figure 9-10 shows the current-shunt feedback in which the amplifier is replaced by its Norton equivalent circuit. If *Ai is the short-circuit current gain then from Fig. 9-10:*
- $Is = Ii + If = Ii + \beta I0$ …………………(9-12)
- And $Io = AiIi / Z$ [illegible]
- Where, $Ai = Io / I$ [illegible]
- From Eqs. (9-12) and (9-13) we have: $IS = Ii(1 + \beta AI)$ ………….. (9-15)
- Z [illegible]
- and $Zi = Vi / I i$
- Using Eq. (9-15) we obtain:
- Z [illegible]
- where, *Ai represents the short-circuit current gain.*

Voltage-shunt feedback to calculate input and output resistance:

- ***Voltage-shunt feedback*:**
- For voltage-shunt feedback, proceeding in a similar way as we have done in the previous sections, we obtain:
- *Zif =Zi /(1+βZ* [illegible]
- where,*Z* [illegible]
- (9-17b)
- where,*Z* [illegible]
- From Eq. (9-17 b) it is clear that for shunt comparison*Z* [illegible]

Effects of Feedback on Output Impedance:

Voltage-series feedback

To find the output resistance with feedback Z_{of}—looking into output terminals with Z_L disconnected—external signals must be removed ($V_s = 0$ or $I_s = 0$). Let $Z_L = \infty$ impress a voltage V across the output terminals which delivers current I.

Therefore:

$$Z_{of} = \frac{V}{L} \tag{9-18}$$

Replacing V_0 by V in Fig. 9-10 we get:

$$I = \frac{V - A_V V_i}{Z_o} = \frac{V + \beta A_V V}{Z_o} \tag{9-19}$$

with $\quad V_s = 0,\ V_i = -V_f = -\beta V$

Hence: $$Z_{of} = \frac{V}{I} = \frac{Z_o}{1 + \beta A_V} \tag{9-20}$$

The output resistance with feedback Z'_{of}, which includes Z_L, is given by Z_{of} in parallel with Z_L. So:

Effects of Feedback on Output Impedance:

$$Z'_{of} = \frac{Z_{of} Z_L}{Z_{of} + Z_L} = \frac{Z_o Z_L}{1 + \beta A_V} \frac{1}{Z_o |(1 + \beta A_V) + Z_L}$$

$$= \frac{Z_o Z_L}{Z_o + Z_L + \beta A_V Z_L} = \frac{Z_o Z_L / Z_o + Z_L}{1 + \beta A_V Z_L / (Z_o + Z_L)} \qquad (9\text{-}21)$$

It should be noted that $Z'_o = Z_0 \| Z_L$ is the output resistance without feedback.

Using Eq. (9-9) in Eq. (9-21) we obtain:

$$Z'_{of} = \frac{Z'_o}{1 + \beta A_V} \qquad (9\text{-}22)$$

Effects of Feedback on Output Impedance:

Voltage-shunt feedback

Proceeding in the similar manner, we have:

$$Z_{of} = \frac{Z_o}{1 + \beta Z_m} \quad (9\text{-}23)$$

and

$$Z'_f = \frac{Z'_0}{1 + \beta Z_M} \quad (9\text{-}24)$$

For voltage sampling it is clear that $Z_{of} < Z_o$.

Effects of Feedback on Output Impedance:

Current-shunt feedback

In Fig. 9-10, replacing V_0 by V, we have:

$$I = \frac{V}{Z_o} - A_i I_i \tag{9-25}$$

with $$I_s = 0, I_i = -I_f = -\beta I_0 = \beta I.$$

Hence: $$I = \frac{V}{Z_o} - \beta A_i I_i$$

or, $$I(1 + \beta A_i) = \frac{V}{Z_o} \tag{9-26}$$

$$Z_{of} = \frac{V}{I} = Z_o(1 + \beta A_i) \tag{9-27}$$

Effects of Feedback on Output Impedance:

Eq. (9-27) is the expression for the output impedance with feedback, and without load resistance R_L. To find R'_{of}:

$$Z'_{of} = \frac{Z_{of}Z_L}{Z_{of} + Z_L} = \frac{Z_o(1 + \beta A_i)Z_L}{Z_o(1 + \beta A_i) + Z_L}$$

$$= \frac{Z_oZ_L}{Z_o + Z_L} \frac{1 + \beta A_i}{1 + \beta A_i Z_o/(Z_o + Z_L)} \tag{9-28}$$

Using Eq. (9-27), and with $Z'_o = Z_o \| Z_L$, we have:

$$Z'_{of} = Z'_o \frac{1 + \beta A_i}{1 + \beta A_i} \tag{9-29}$$

Effects of Feedback on Output Impedance:

Current-series feedback

Proceeding in the similar manner we have:

$$Z_{of} = Z_o(1 + \beta Y_m) \quad (9\text{-}30a)$$

and

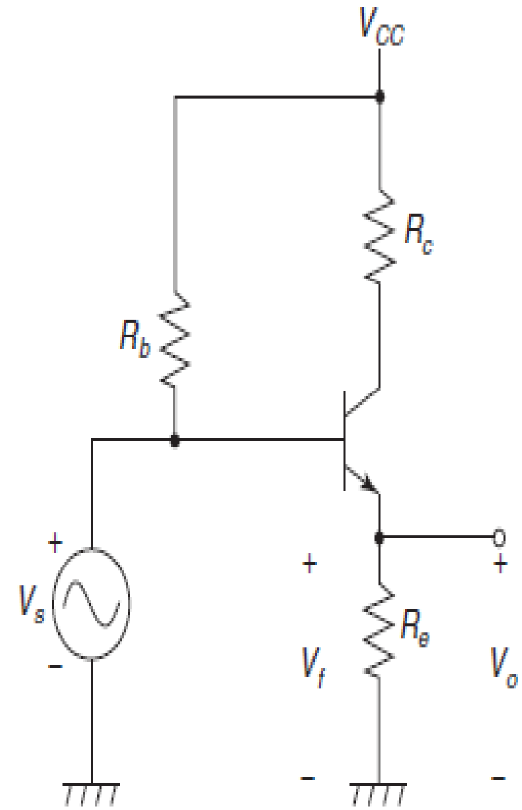
$$Z'_{of} = Z'_o \frac{1 + \beta Y_m}{1 + \beta Y_m} \quad (9\text{-}30b)$$

From Eqs. (9-30a) and (9-30b) we see that for current sampling $Z_{of} > Z_0$.

PRACTICAL IMPLEMENTATIONS OF THE FEEDBACK TOPOLOGIES:

- 1) **Voltage-series Feedback Using Transistor**:
- The emitter-follower circuit, as shown in Fig. 9-11 is an example of voltage-series feedback. The feedback signal *Vf and the output signal Vo are both voltage*

$$A_v = \frac{V_o}{V_s} = \frac{h_{fe} I_b Z_e}{V_s} = \frac{h_{fe} Z_e}{h_{ie}}$$



Voltage-series feedback circuit

practical voltage-series feedback amplifier:

- To determine the gain of the basic amplifier without feedback we should consider *Vo = 0 for the input loop and Ib = 0 for the output loop so that we obtain the approximate hybrid* equivalent circuit, as given in Fig. 9-12.

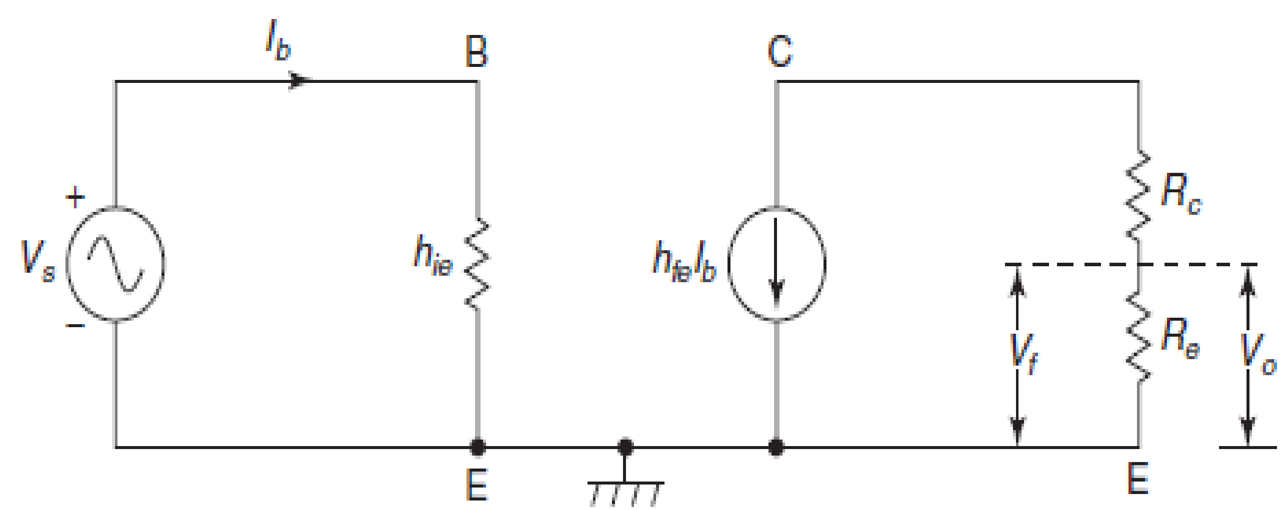


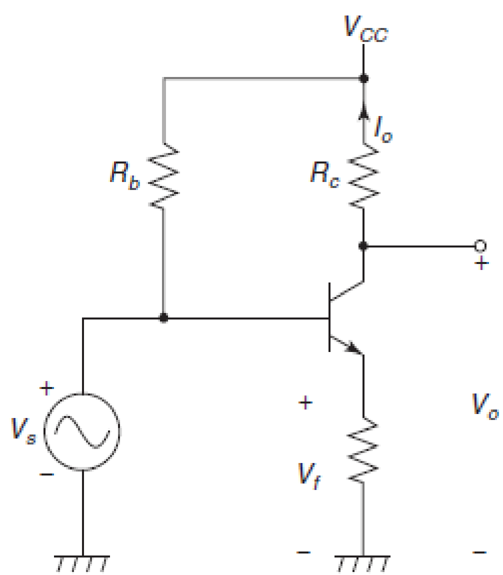
Figure 9-12 Approximate hybrid equivalent circuit of practical voltage-series feedback amplifier

Current-Series Feedback using transistor:

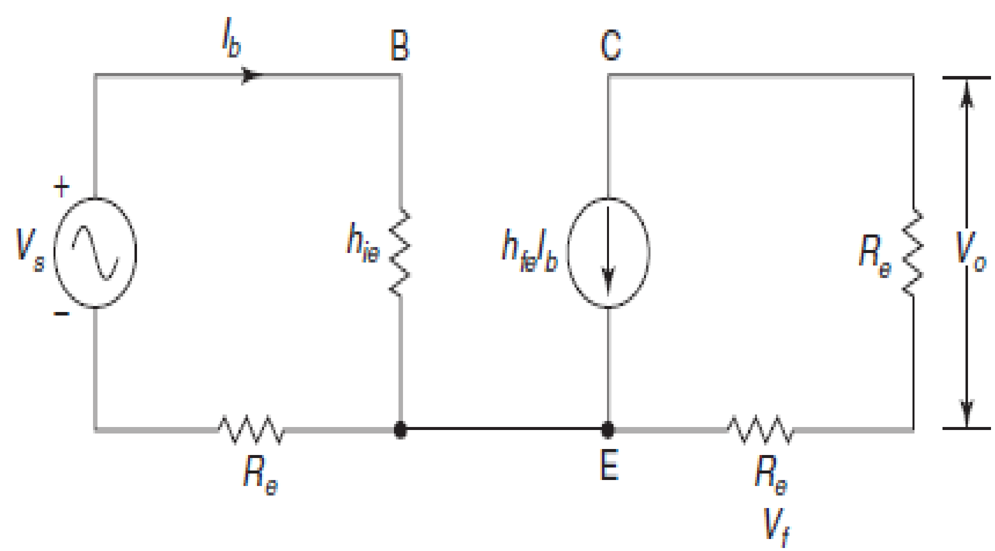
transfer gain of the basic amplifier is:

$$Y_m = \frac{I_o}{V_s} = \frac{-I_b h_{fe}}{I_b(h_{ie} + R_e)} = \frac{-h_{fe}}{h_{ie} + R_e}$$

$$\beta = \frac{V_f}{I_o} = \frac{-I_o R_e}{I_o}$$



Current-series feedback circuit using transistor



Simplified *h*-parameter circuit of the current-series feedback amplifier

Voltage-Shunt Feedback Using Transistor:

- In the circuit given in Fig. 9-15, the input current is proportional to the output voltage *Vo.*

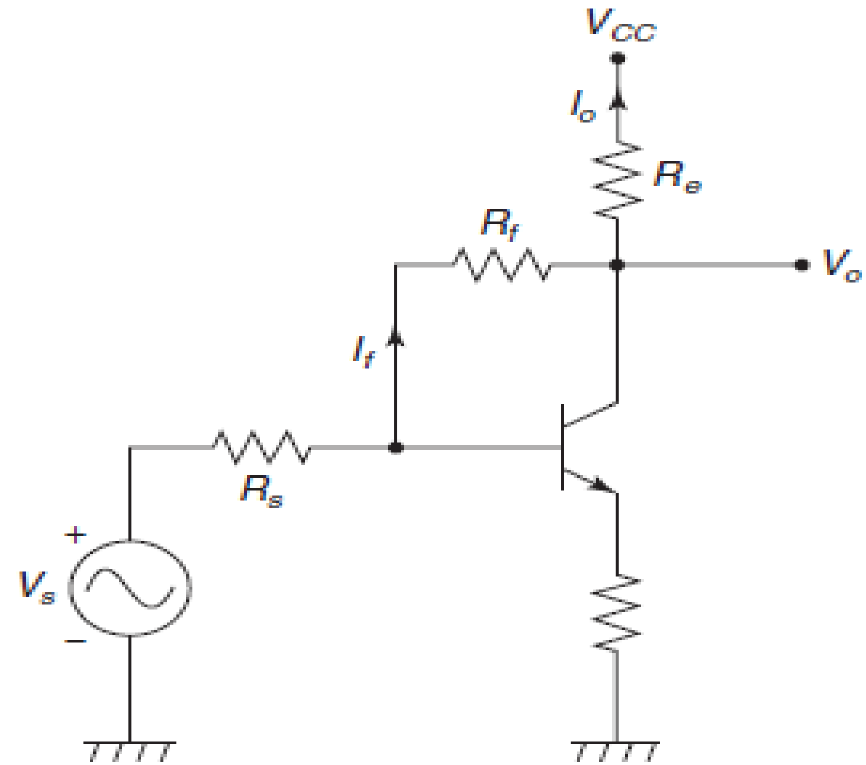


Figure 9-15 Implementation of voltage-shunt feedback

Voltage-Shunt Feedback Using Transistor:

- *To determine* the gain of the basic amplifier we consider that *Rf is open-circuited and we can draw the approximate h-parameter equivalent circuit as shown in Fig. 9-16.*

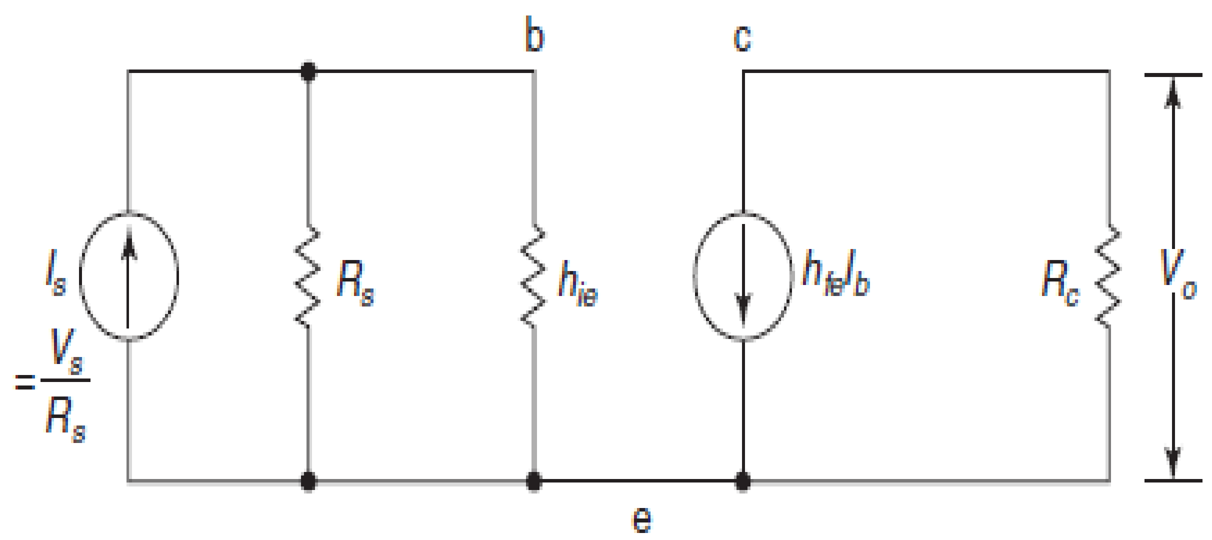


Figure 9-16 Approximate *h*-parameter equivalent circuit for voltage-shunt feedback circuit

Voltage-Shunt Feedback Using Transistor:

Considering the resistance R_f in Fig. 9-16 we obtain:

$$I_f = \frac{h_{fe} I_b R_c}{h_{ie} + R_c + R_f} \qquad (9\text{-}31f)$$

From Eq. (9-31f)

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

$$\beta = \frac{h_{fe} I_b R_c}{h_{ie} + R_c + R_f} \times \frac{-1}{h_{fe} I_b R_c} = \frac{-1}{h_{ie} + R_c + R_f} \qquad (9\text{-}31g)$$

From Eqs. (9-31e) and (9-31g), and using Eqs. 9-17(a), 9-17(b) and 9-24, we can obtain Z_M, Z_{if}, Z'_{of}.

Current-Shunt Feedback Using Transistor:

A simple current-shunt feedback amplifier is shown in Fig. 9-17.

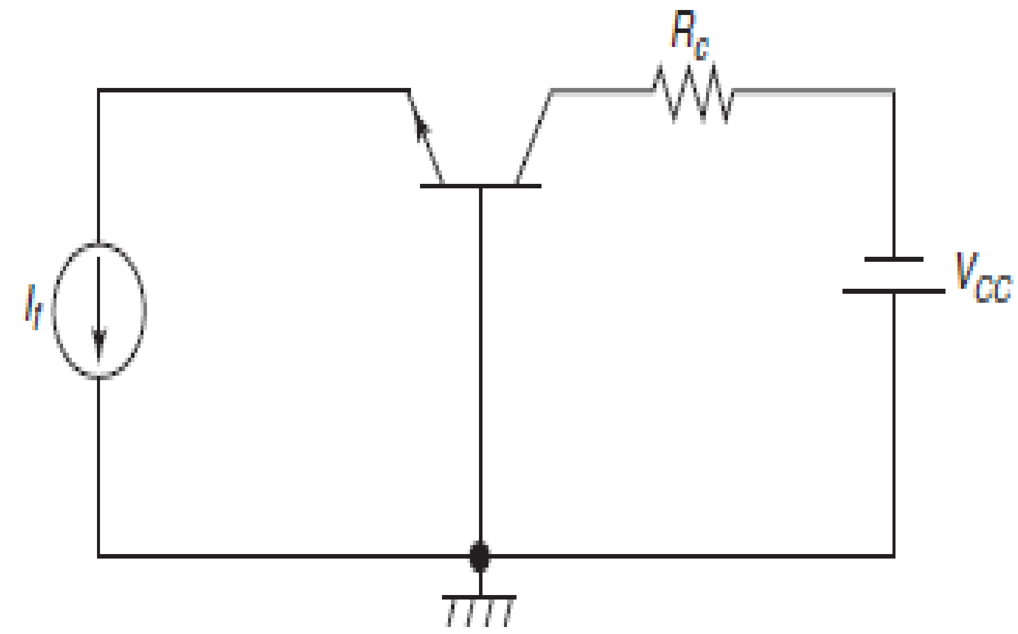


Figure 9-17 Current-shunt feedback circuit

Current-Shunt Feedback Using Transistor:

Without feedback $I_s = I_e$, we can draw the approximate h-parameter circuit as shown in Fig. 9-18. From Fig. 9-18 we have:

$$I_s = -(h_{fe} + 1)I_b \tag{9-31h}$$

and

$$I_o = -h_{fe} i_b \tag{9-31i}$$

Substituting the values of I_s and I_o from Eqs. (9-31h) and (9-31i) in Eq. 9-14, we get:

$$A_I = \frac{I_o}{I_s} = \frac{h_{fe}}{1 + h_{fe}} = \frac{A_i Z_0}{Z_0 + Z_L} \tag{9-31j}$$

Hence, we can write $A_i = h_{fe}$ and $\beta = 1$. The values of Z_{if} and Z'_{if} of can be determined from Eqs. (9-16) and (9-29) using the value of A_i and β.

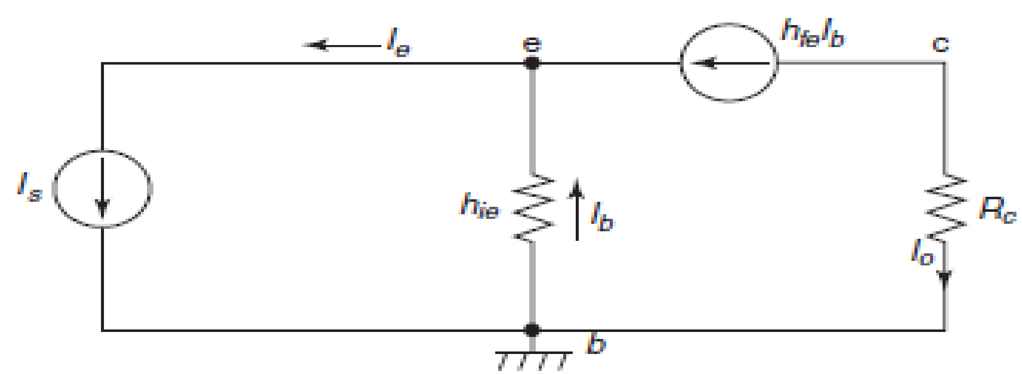


Figure 9-18 Approximate h-parameter circuit of current-shunt feedback circuit

SENSITIVITY:

- The sensitivity of transfer gain of the feedback amplifier *AF with respect to the variations in the internal* amplifier gain *A is defined as the ratio of the fractional change in gain with the feedback to the fractional* change in gain without the feedback.

- The gain sensitivity *S of the feedback amplifier is given by:*

$$S = \frac{\frac{dA_f}{A_f}}{\frac{dA}{A}}$$

where, *dAf /Af = fractional change in gain with the feedback; dA/A = fractional change in gain without the* feedback.

SENSITIVITY & DESENSITIVITY:

From Eq. (9-4a) we have:

$$A_f = \frac{A}{1 + A\beta}$$

Differentiating with respect to A:

$$\frac{dA_f}{A_f} = \frac{1}{1 + A\beta} \frac{dA}{A}$$

Therefore:

$$S = \frac{\frac{dA_f}{A_f}}{\frac{dA}{A}} = \frac{1}{1 + A\beta}$$

The inverse or reciprocal of sensitivity is called **De-Sensitivity**.

De-Sensitivity *(D)* *indicates the fraction by which the voltage gain has been* reduced due to feedback.

$$S = \frac{1}{1 + A\beta} = \frac{1}{D}$$

$$A_f = \frac{A}{1 + A\beta} = \frac{A}{D}$$

$$D = \frac{A}{A_f}$$

BANDWIDTH STABILITY:

The transfer gain of an amplifier having the feedback is given by:

$$A_f = \frac{A}{1+\beta A}$$

If $|\beta A| >> 1$, then:

$$A_f \approx \frac{A}{\beta A} = \frac{1}{\beta} \qquad (9\text{-}37)$$

From Eq. (9-37) we can directly conclude that the transfer gain can be made dependent entirely on the feedback network . *The gain A is not* constant and depends on the frequency. This means that at certain high or low frequencies *|A| will be much* larger than unity. The gain *A of* single-pole transfer function is given by:

$$A = \frac{A_0}{1 + j(f/f_H)} \qquad (9\text{-}38)$$

A0 is the mid-band gain without the feedback and fH is the high frequency (where A0 is decreased by 3 dB).

BANDWIDTH STABILITY:

The gain *A of the single pole amplifier with the feedback is obtained from Eq. (9-4) and (9-38) as:*

$$A_f = \frac{A_0/[1 + j(f/f_H)]}{1 + \beta A_0/[1 + j(f/f_H)]} = \frac{A_0}{1 + \beta A_0 + j(f/f_H)} \qquad (9\text{-}39)$$

By dividing the numerator and denominator by $1 + \beta A_0$, Eq. (9-39) can be written as:

$$A_f = \frac{A_{0f}}{1 + j(f/f_{Hf})} \qquad (9\text{-}40)$$

where,

$$A_{0f} \equiv \frac{A_0}{1 + \beta A_0} \qquad (9\text{-}41)$$

and

$$f_{Hf} \equiv f_H(1 + \beta A_0) \qquad (9\text{-}42)$$

It should be noted that A_{0f} is the mid-band gain with the feedback, and f_{Hf} is the high 3 dB frequency with the feedback.
From Eq. (9-41), we have:

$$A_{0f} f_{Hf} = A_0 f_H \qquad (9\text{-}43)$$

Similarly, it can be shown that the low 3 dB frequency with the feedback is given by:

$$f_{Lf} = \frac{f_L}{1 + \beta A_0} \qquad (9\text{-}44)$$

where, f_L is the low 3 dB frequency without the feedback.

BANDWIDTH STABILITY:

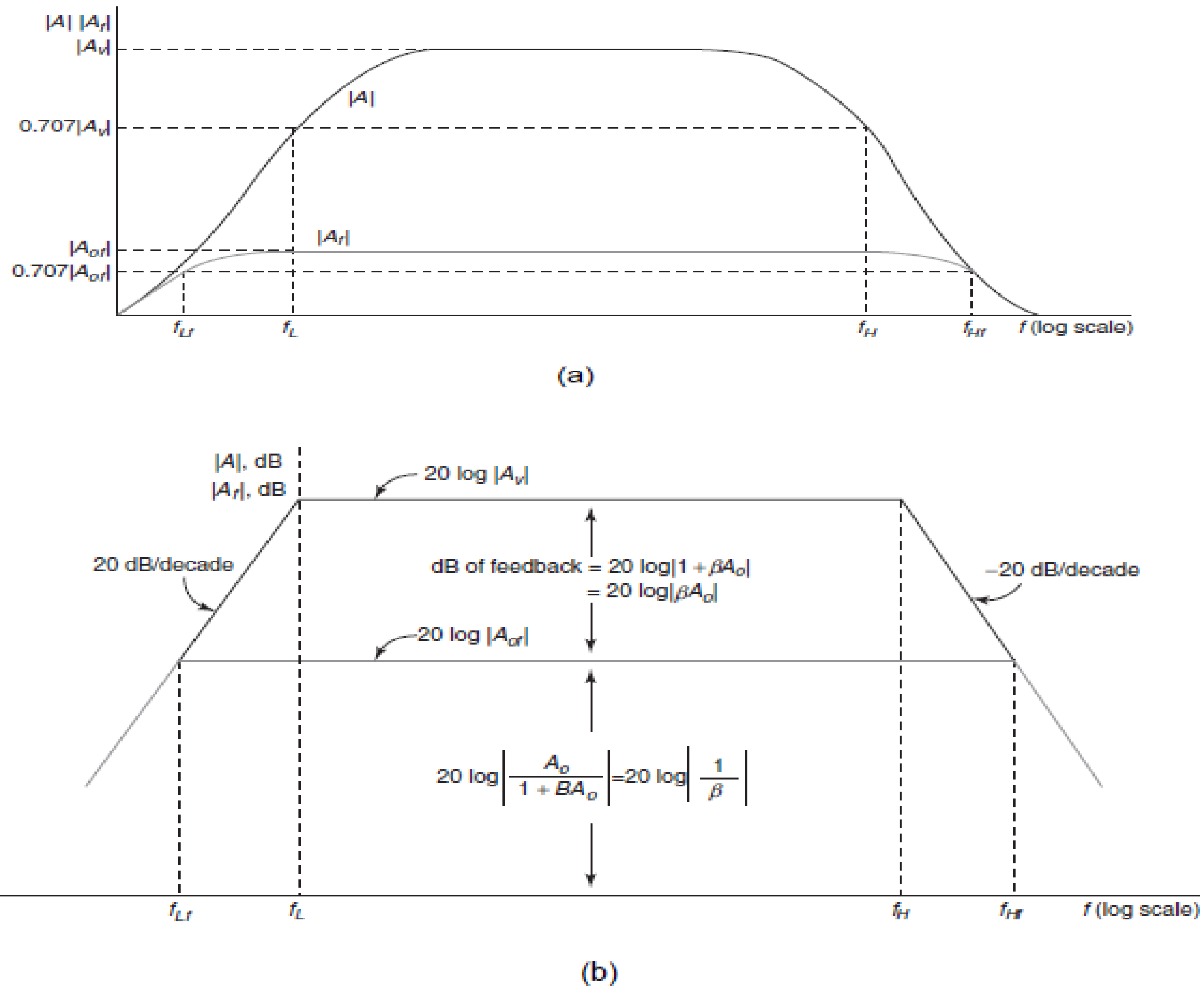


Figure 9-19 (a) Transfer gain is decreased and bandwidth is increased for an amplifier using negative feedback. (b) Idealized bode plot

EFFECT OF POSITIVE FEEDBACK:

If $|1 + \beta A| > 1$, it is considered to be negative feedback, and if $|1 + \beta A| < 1$, it is considered to be positive feedback. In second case, the resultant transfer gain A_f will be greater than A—the nominal gain without feedback—since $|A_f| = |A|/|1 + \beta A| > |A|$. Positive feedback increases the amplification but at the cost of reduced stability.

A portion of this signal $-\beta X_0$ will be the feedback to the input circuit, and will appear in the output as an increased signal $-A\beta X_0$. If this term just equals X_0, then the spurious output has regenerated itself. In other words, if $-A\beta X_0 = X_0 \Rightarrow -A\beta = 1$, the amplifier will oscillate. If an attempt is made to obtain a large gain by making $|\beta A|$ almost equal to unity, there is a possibility that the amplifier may break into spontaneous oscillation. This situation may be created by the processes like variation in supply voltages, ageing of transistors, etc.

Instability and Oscillation:

- If an amplifier is designed to have negative feedback in a particular frequency range but breaks into oscillation at some high or low frequency, it is useless as an amplifier.
- While designing the amplifier, it must be ensured that the circuit is stable at all frequencies and not merely over the frequency range of interest.

- The stability of a circuit lies in the pole of the transfer function of the circuit, which also determines the transient response of the circuit .
- A pole existing with a positive real part will result in a signal disturbance increasing with time.
- So the condition to be satisfied, if a system is to be stable, is that the poles of the transfer function must all lie in the left-hand half of the complex-frequency plane.

Nyquist Criterion:

The criterion for positive or negative feedback is represented in the complex plane. Figure 9-20 shows that $|1 + A\beta| = 1$ represents a circle with radius equal to unity and centre at the point $-1 + j0$. For any frequency, $A\beta$ extends outside this circle and the feedback is negative; therefore $|1 + A\beta| > 1$. If the feedback is positive and the $A\beta$ value falls within the circle, then $|1 + A\beta| < 1$. Also, when the feedback is positive the system will not oscillate unless the Nyquist criterion is satisfied.

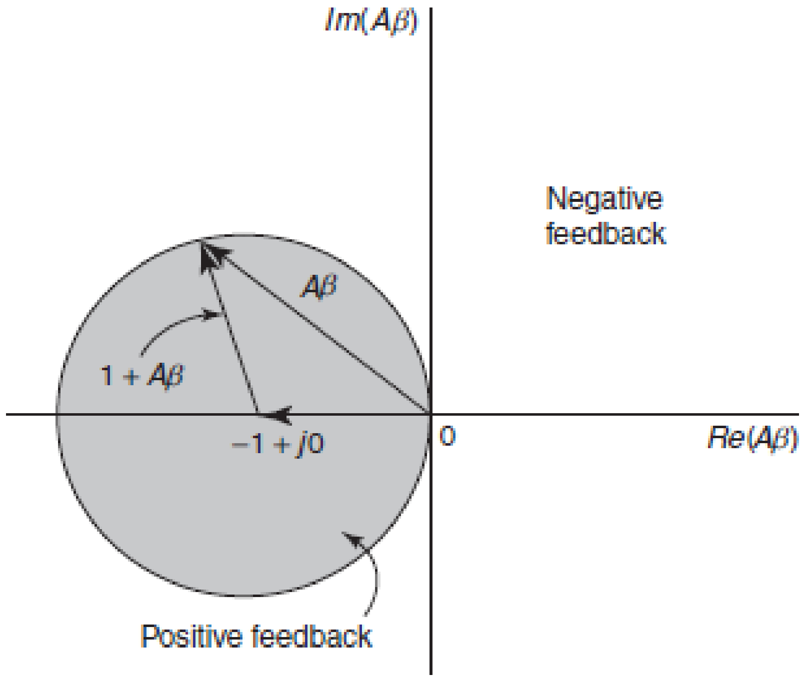


Figure 9-20 The locus of $|1 + A\beta| = 1$ is a circle of unit radius with centre at $-1 + j0$ (when the vector $A\beta$ ends in the shaded region, the feedback is positive)

Condition of Oscillation:

To investigate the oscillation of the circuit consider Fig. 9-21. It shows an amplifier, a feedback network and an input mixing circuit *not connected to form a closed loop*. The amplifier provides an output signal x_0 as a consequence of the signal x_i applied directly to the amplifier input terminal. The output of feedback network is $x_f = \beta x_0 = A\beta x_i$ and the output of the mixing circuit is:

$$x'_f = -x_f = -A\beta x_i$$

From Fig. 9-21, loop gain can be written as:

$$\frac{x'_f}{x_i} = \frac{-x_f}{x_i} = -A\beta \qquad (9\text{-}45)$$

The statement, $x'_f = -x_i$, means that the instantaneous values of x'_f and x_i are exactly equal at all times. The condition $x'_f = x_i$ is equivalent to $-A\beta = 1$ or, the loop gain must be unity. This is the condition of oscillation.

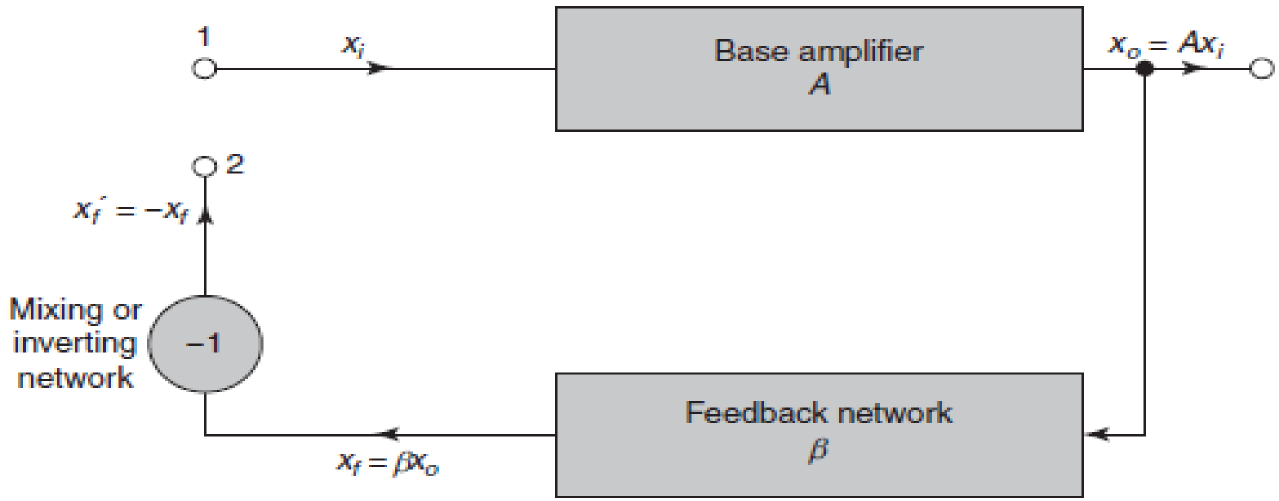


Figure 9-21 An amplifier with feedback gain A and feedback network β not yet connected to the network

Barkhausen Criterion:

Let us consider that the entire circuit operates linearly and that the feedback or the amplifier network or both contain reactive elements. In such a case the only periodic waveform which will maintain its form is the sinusoidal waveform.

For a sinusoidal waveform the condition $x_i = x'_f$ is equivalent to the condition that the amplitude, phase and frequency of x_i and x'_f are identical. As the phase shift is introduced, any signal that is transmitted through a reactive network is always a function of the frequency. Hence we have the following important principle:

The frequency at which a sinusoidal oscillator will operate is the frequency for which the total shift introduced, as a signal proceeds from the input terminals, through the amplifier and feedback network, and back again to the input, is precisely zero or an integral multiple of 2π. Stated more simply, the frequency of a sinusoidal oscillator is determined by the condition that the loop gain phase shift is zero.

Barkhausen Criterion:

The condition given here determines the frequency, provided that the circuit will oscillate at all. Another condition, which must clearly be met, is that the magnitude of x_i and x'_f must be identical. This condition is then embodied in the following principle:

> *Oscillations will not be sustained if, at the oscillator frequency, the magnitude of the product of the transfer gain of the amplifier and the magnitude of the feedback factor of the feedback network (the magnitude of the loop gain) are less than unity.*

The condition of unity loop gain $A\beta = 1$ is called the Barkhausen criterion. This condition implies, of course, that $|A\beta| = 1$, and that the phase of $-A\beta$ is zero. The two principles stated previously are consistent with the feedback formula $A_f = A/(1 + \beta A)$. If $-\beta A = 1$ then $A_f \rightarrow \infty$, which may be interpreted to mean that there exists an output voltage even in the absence of an externally applied signal voltage. Therefore, the conditions for Barkhausen criteria for oscillation are as follows:

1. Positive feedback
2. Loop gain is unity, $A\beta = 1$; therefore, the feedback gain is infinite, $A_f = \infty$
3. Phase variation is zero or integral multiple of 360°

POINTS TO REMEMBER:

1. Feedback is defined as the process by which a portion of the output is returned to the input to form part of the system excitation.
2. The four feedback topologies are:
   (a) Shunt-shunt
   (b) Shunt-series
   (c) Series-shunt
   (d) Series-series
3. The main advantage of negative feedback is stability. Its main application is in the design of a stable amplifier.
4. Positive feedback produces instability in the system. Its main application is in the design of an oscillator.
5. Conditions for Barkhausen criteria:
   (a) Positive feedback
   (b) Loop gain is unity, i.e., $A\beta = 1$; therefore, feedback gain is infinite ($A_f = \infty$).
   (c) Phase variation is zero or integral multiple of 360.
6. The frequency of a sinusoidal oscillator is determined by the condition that the loop gain phase shift is zero.

IMPORTANT FORMULAE:

1. Gain with feedback:

$$A_f = \frac{A}{1 + A\beta}$$

2. dB of feedback:

$$N = 20\log_{10}\left|\frac{A_f}{A}\right| = 20\log_{10}\left(\frac{1}{1 + \beta A}\right)$$

3. Sensitivity:

$$S = \frac{\frac{dA_f}{A_f}}{\frac{dA}{A}} = \frac{1}{1 + A\beta}$$

4. Voltage-series feedback:

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

$$Z_{of} = \frac{V}{I} = \frac{Z_o}{1 + \beta A_v}$$

5. Current-series feedback:

$$Z_{if} = Z_i\,(1 + \beta Y_M)$$

$$Z_{of} = Z_o\,(1 + \beta Y_m)$$

6. Current-shunt feedback:

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

$$Z_{of} = \frac{V}{I} = Z_o\,(1 + \beta A)$$

7. Voltage-shunt feedback:

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

$$Z_{of} = \frac{Z_o}{1 + \beta Z_m}$$

8. Distortion with feedback:

$$D' = \frac{D}{1 + A_v\beta}$$