CHAPTER 8
UNIT 4

FEEDBACK

INTRODUCTION

- In his search for methods for the design of amplifiers with stable gain for use in telephone repeaters, Harold Black, an electronics engineer with the Western Electric Company , invented the feedback amplifier in 1928.

- Feedback can be either

  negative (degenerative)

  or

  positive (regenerative).

In amplifier design, negative feedback is applied to effect one or more of the following properties:

1 . Desensitize the gain: that is, make the value of the gain less sensitive to variations in the value of circuit components, such as might be caused by changes in temperature.

2. Reduce nonlinear distortion: that is, make the output proportional to the input (in other words, make the gain constant, independent of signal level).

3. Reduce the effect of noise: that is, minimize the contribution to the output of unwanted electric signals generated, either by the circuit components themselves, or by extraneous interference.

4. Control the input and output impedances: that is, raise or lower the input and output impedances by the selection of an appropriate feedback topology.

5. Extend the bandwidth of the amplifier

THE GENERAL FEEDBACK STRUCTURE

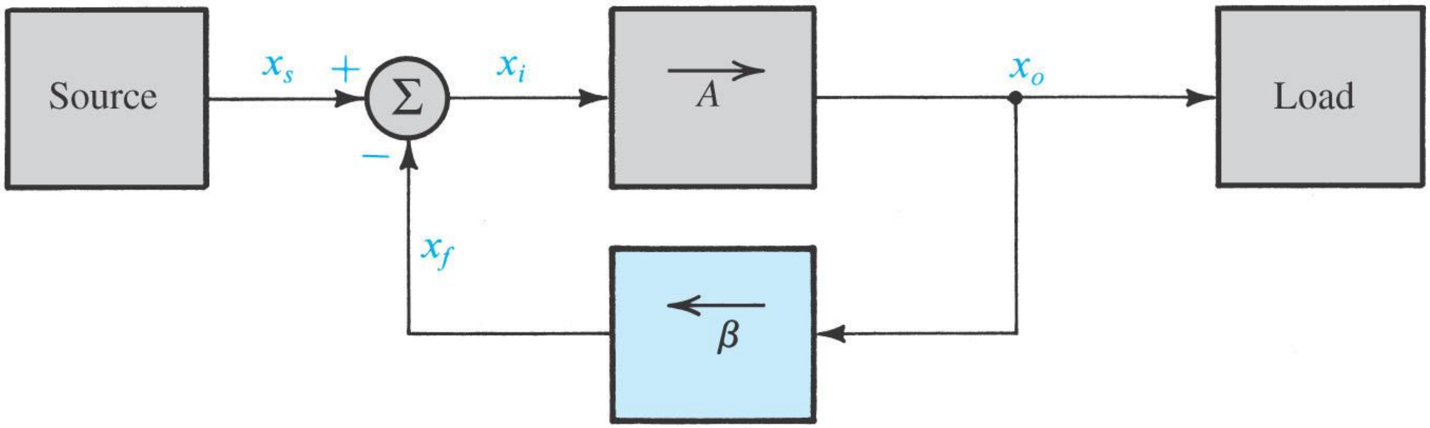


Figure 10.1 General structure of the feedback amplifier. This is a signal-flow diagram, and the quantities *x* represent either voltage or current signals.

$$x_o = Ax_i$$

$$x_f = \beta x_o$$ **feedback factor** β,

$$x_i = x_s - x_f$$

$$A_f \equiv \frac{x_o}{x_s} = \frac{A}{1 + A\beta}$$

A β is called the loop gain Eq(1)

The gain of the feedback amplifier is almost entirely determined by the feedback network. x_f

$$x_f = \frac{A\beta}{1 + A\beta} x_s$$

Thus for $A\beta \gg 1$ we see that $x_f \simeq x_s$, which implies that the signal x_i at the input of the basic amplifier is reduced to almost zero.

Thus if a large amount of negative feedback is employed, the feedback signal x_f becomes an almost identical replica of the input signal X_S'

Accordingly, the input differencing circuit is often also called a comparison circuit

$$x_i = \frac{1}{1 + A\beta} x_s$$

SOME PROPERTIES OF NEGATIVE FEEDBACK

1. Gain Desensitivity

- saw that a 20% reduction in the gain of the basic amplifier gave rise to only a 0.02% reduction in the gain of the closed-loop amplifier
- Assume that β is constant. Taking differentials of both sides of Eq (1)

$$dA_f = \frac{dA}{(1 + A\beta)^2}$$

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

•the percentage change in A_f (due to variations in some circuit parameter) is smaller than the percentage change in A by the amount of feedback

- For this reason the amount of feedback, $1 + A\beta$, is also known as the de sensitivity factor.

2 Bandwidth Extension

- Consider an amplifier whose high-frequency response is characterized by a single pole.
- Its gain at mid and high frequencies can be expressed as

$$A(s) = \frac{A_M}{1 + s/\omega_H}$$

where A_M denotes the midband gain and ω_H is the upper 3-dB frequency.

Application of negative feedback, with a frequency-independent factor , β, around this amplifier results in a closed-loop gain $A_f(s)$ given by

$$A_f(s) = \frac{A(s)}{1+\beta A(s)}$$

Substituting for $A(s)$ after a little manipulation, in

$$A_f(s) = \frac{A_M/(1+A_M\beta)}{1+s/\omega_H(1+A_M\beta)}$$

Thus the feedback amplifier will have a midband gain of $A_M/(1+A_M\beta)$ and an upper 3-dB frequency ω_{Hf} given by

$$\omega_{Hf} = \omega_H(1+A_M\beta)$$

if the open-loop gain is characterized by a dominant low frequency pole giving rise to a lower 3-dB frequency ω_L, then the feedback amplifier will

$$\omega_{Lf} = \frac{\omega_L}{1 + A_M \beta}$$

- Note that the amplifier bandwidth is increased by the same factor by which its midband gain is decreased, maintaining the gain - bandwidth product at a constant value.

3. Noise Reduction

- Negative feedback can be employed to reduce the noise or interference in an amplifier or, more precisely, to increase the ratio of signal to noise
- Consider the situation illustrated in Fig. 8.2. ,Figure 8.2(a) shows an amplifier with gain A_I an input signal V_S and noise, or interference, V_n

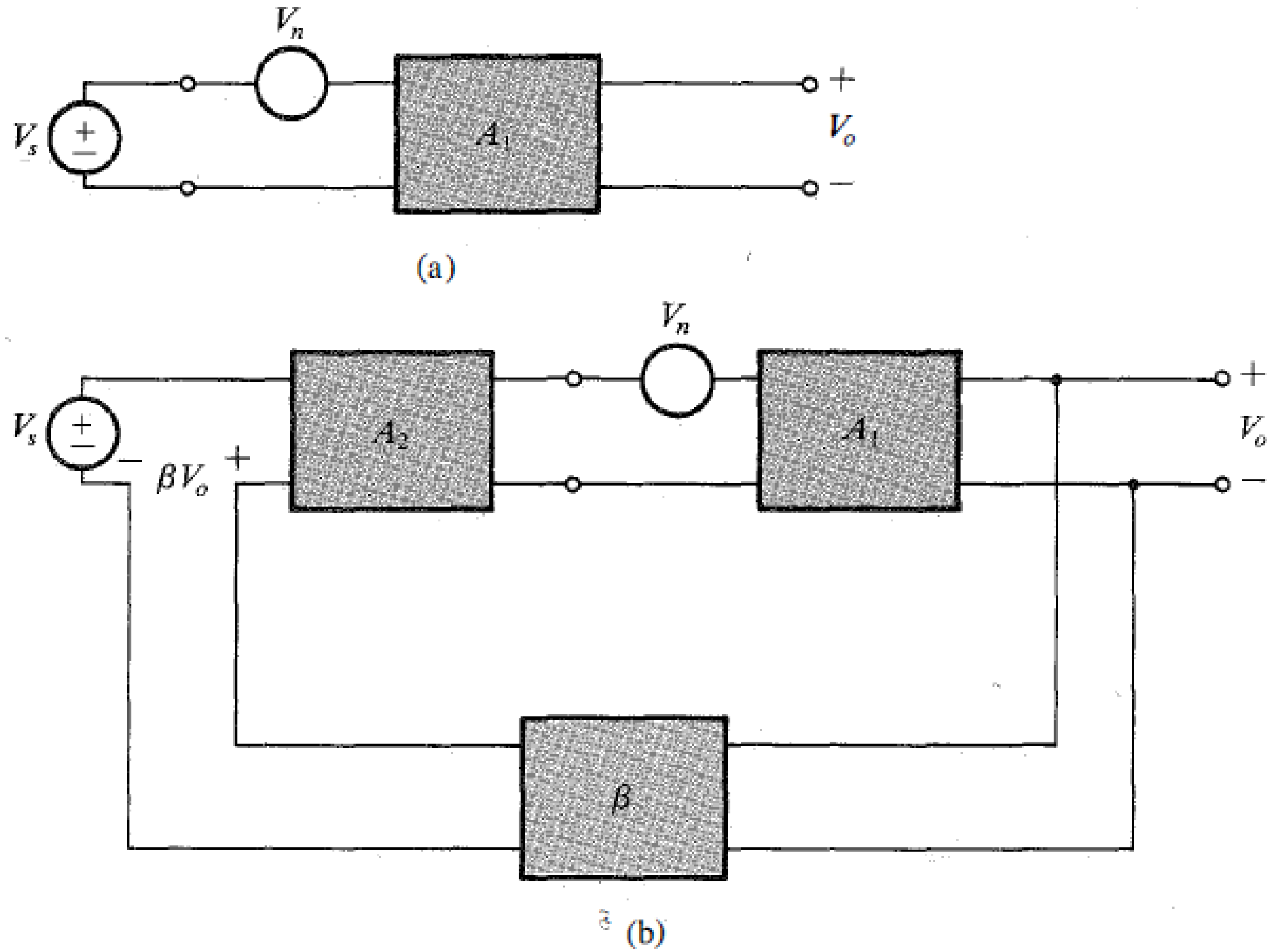


FIGURE 8.2 Illustrating the application of negative feedback to improve the signal-to-noise ratio in amplifiers.

signal-to-noise ratio for this amplifier is $S/N = V_s / V_n$

The output voltage of the circuit in Fig. 8.2(b) can be found by superposition:

$$V_o = V_s \frac{A_1 A_2}{1 + A_1 A_2 \beta} + V_n \frac{A_1}{1 + A_1 A_2 \beta}$$

Thus the signal-to-noise ratio at the output becomes

$$\frac{S}{N} = \frac{V_s}{V_n} A_2$$

which is A_2 times higher than in the original case.

We emphasize once more that the improvement in signal-to-noise ratio by the application of feedback is possible only if one can precede the noisy stage by a (relatively) noise free stage.

4. Reduction in non linear distortion

- Curve (a) in Fig. 8.3 shows the transfer characteristic of an amplifier
- the characteristic is piecewise linear, with the voltage gain changing from 1000 to 100 and then to 0.
- This nonlinear transfer characteristic will result in this amplifier generating a large amount of nonlinear distortion
- The amplifier transfer characteristic can be considerably linearized (i.e., made less nonlinear) through the application of negative feedback amplifier .
- Here the slope of the steepest segment is given by

$$A_{f1} = \frac{1000}{1 + 1000 \times 0.01} = 90.9$$

and the slope of the next segment is given by

$$A_{f2} = \frac{100}{1 + 100 \times 0.01} = 50$$

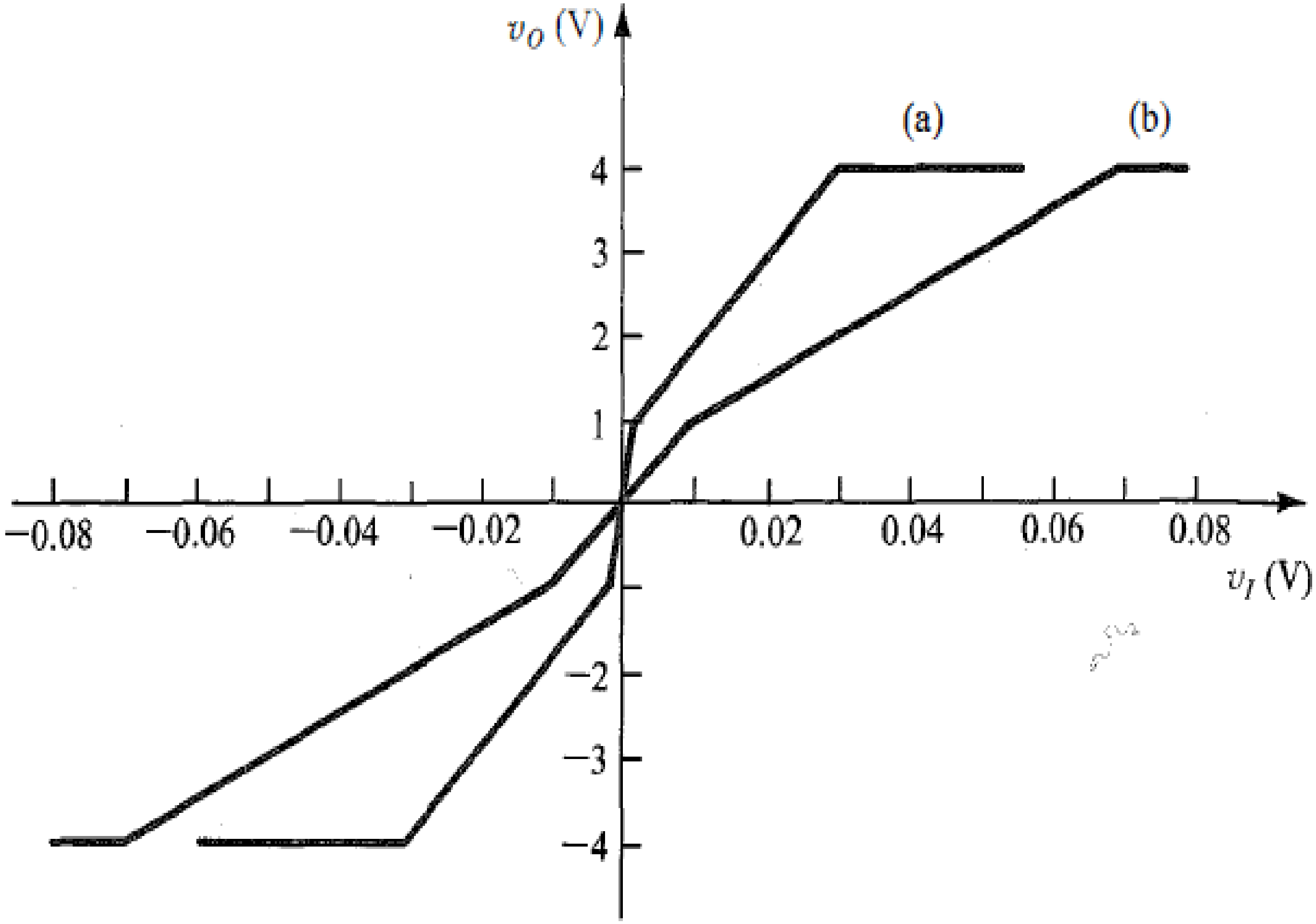


FIGURE 8.3 Illustrating the application of negative feedback to reduce the nonlinear distortion in amplifiers. Curve (a) shows the amplifier transfer characteristic without feedback. Curve (b) shows the characteristic with negative feedback ($\beta = 0.01$) applied.

The price paid, of course, is a reduction in voltage gain. Thus if the overall gain has to be restored, then a preamplifier should be added.

- Finally, it should be noted that negative feedback can do nothing at all about amplifier saturation, since in saturation the gain is very small (almost zero) and hence the amount of feedback is also very small

THE FOUR BASIC FEEDBACK TOPOLOGIES

Based on the

- quantity to be amplified (voltage or current)
- the desired form of output (voltage or current)

Amplifiers are classified into 4 basic categories

i. Voltage Amplifiers –series-shunt feedback

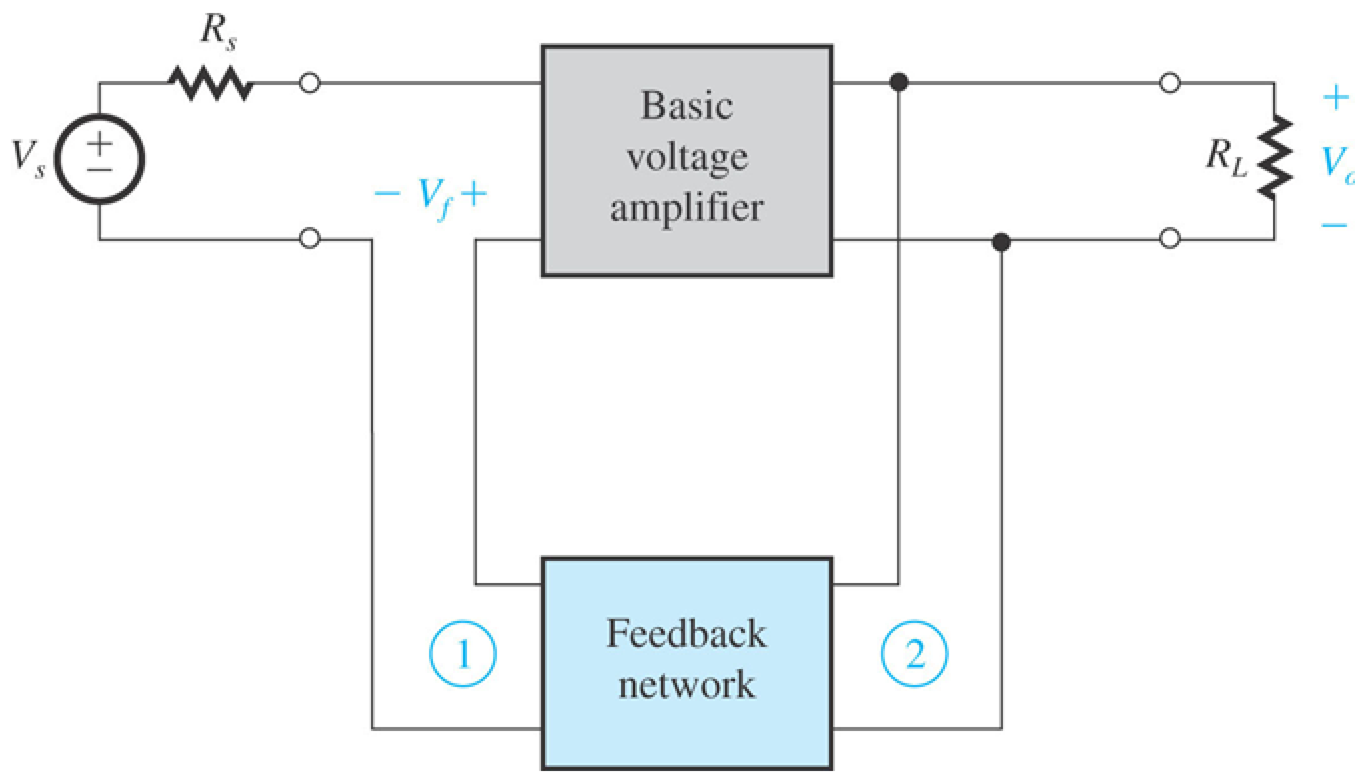


Figure 10.6 Block diagram of a feedback voltage amplifier. Here the appropriate feedback topology is series–shunt.

•In a voltage amplifier the output quantity of interest is the output voltage. It follows that the feedback network should sample the output voltage.

•Also, because of the Thevenin representation of the source, the feedback signal x_f should be a voltage that can be mixed with the source voltage in series.

- this topology not only stabilizes the voltage gain but also results in a higher input resistance (intuitively, a result of the series connection at the input) and a lower output resistance (intuitively, a result of the parallel connection at the output), which are desirable properties for a voltage amplifier

ii Current Amplifiers- shunt-series feedback

- The feedback topology suitable for a current amplifier is the current-mixing current-sampling
- this topology not only stabilizes the current gain but also results in a lower input resistance, and a higher output resistance, both desirable properties for a current amplifier.

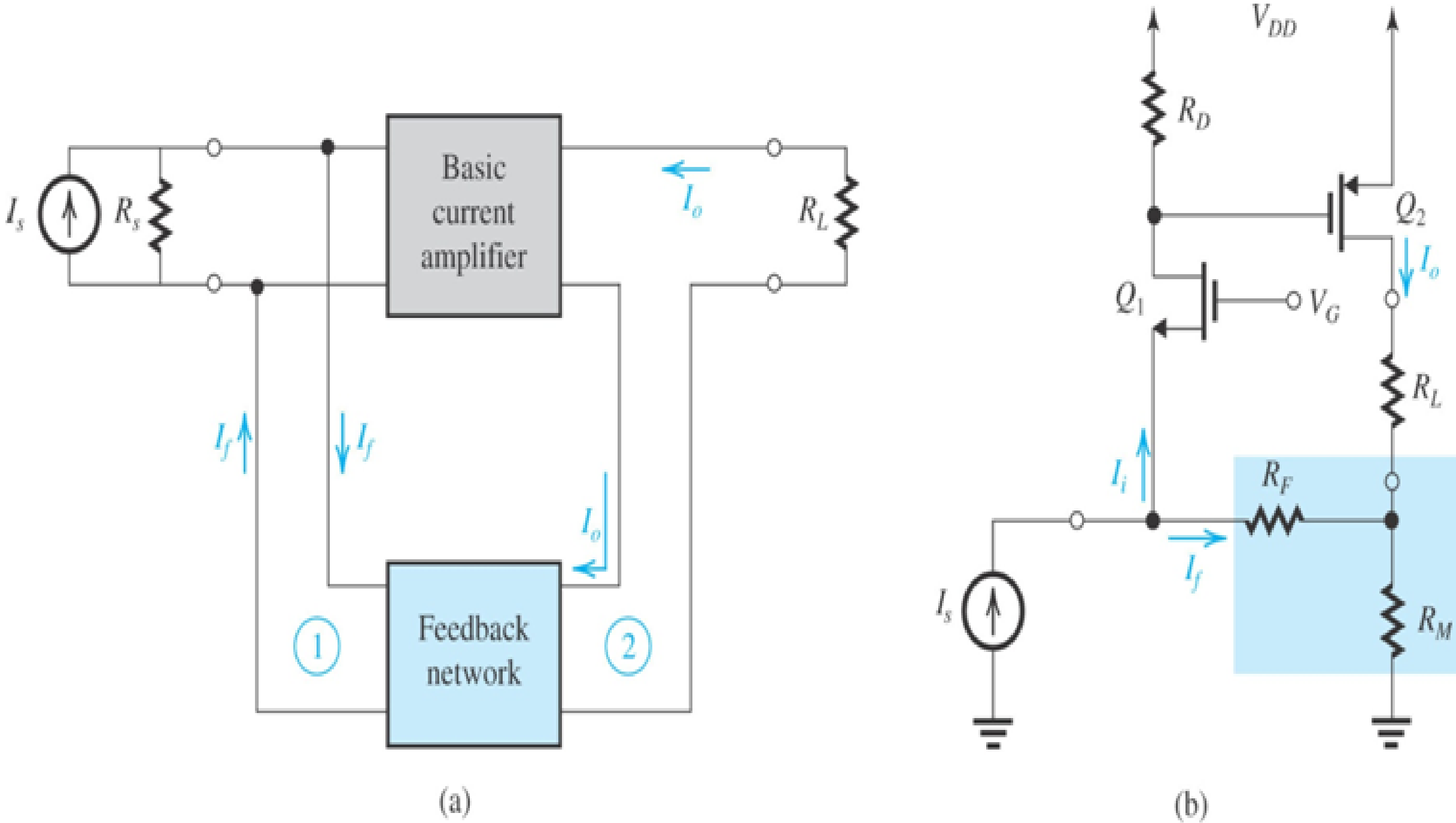


Figure 10.8 (**a**) Block diagram of a feedback current amplifier. Here, the appropriate feedback topology is the shunt–series. (**b**) Example of a feedback current amplifier.

iii Transconductance Amplifier series-series feedback

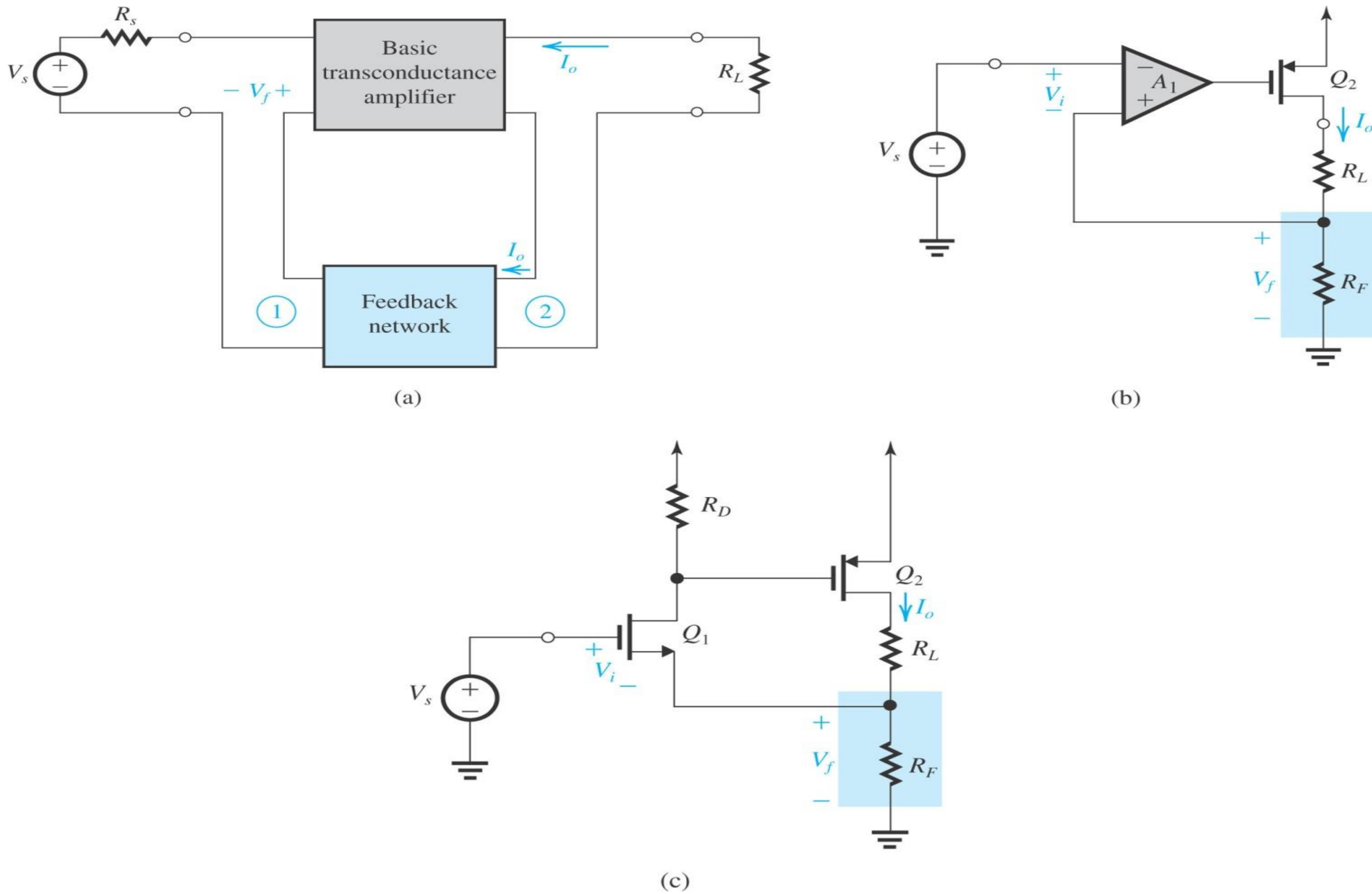
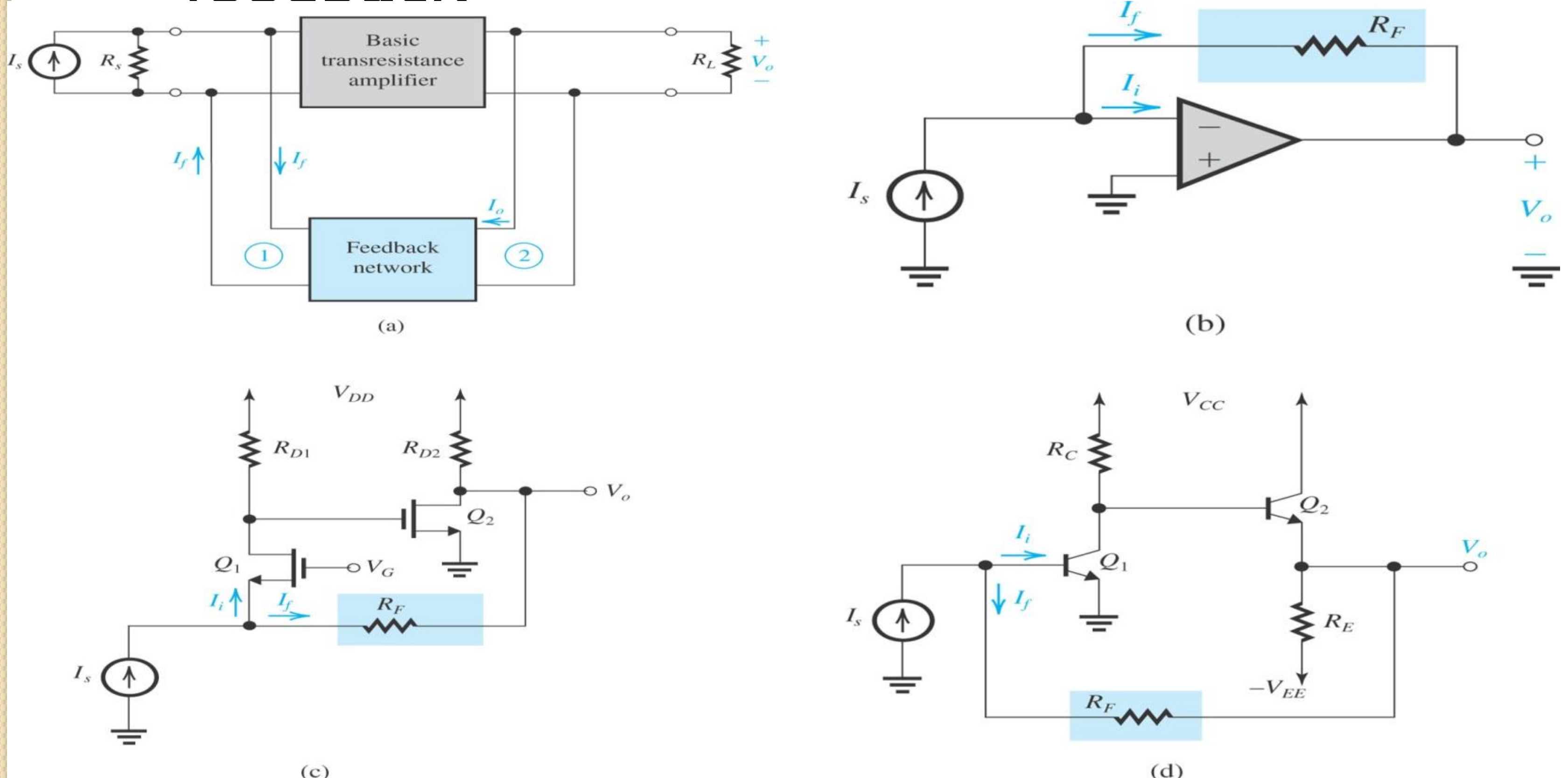


Figure 10.10 (a) Block diagram of a feedback transconductance amplifier. Here, the appropriate feedback topology is series–series. **(b)** Example of a feedback transconductance amplifier. **(c)** Another example.

•The presence of the series connection at both the input and the output gives this feedback topology the alternative name series-series feedback.

iv Transresistance Amplifier-shunt-shunt feedback



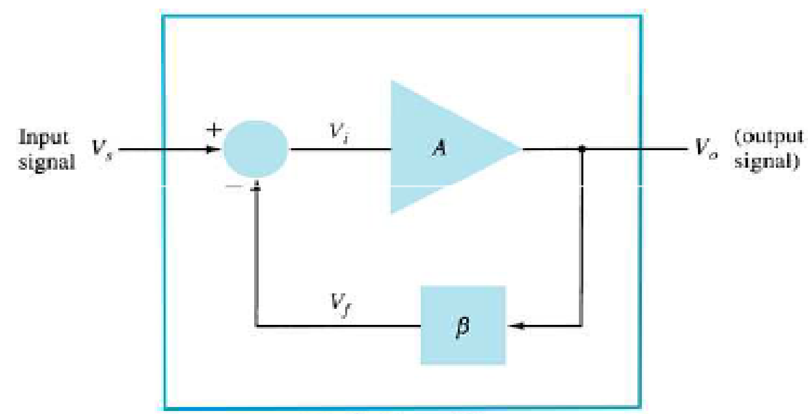
•In trans resistance amplifiers the input signal is current and the output signal is voltage. It follows that the appropriate feedback topology is of the current-mixing voltage-sampling

Feedback Concepts

The effects of negative feedback on an amplifier:

Disadvantage
- **Lower gain**

Advantages
- **Higher input impedance**
- **More stable gain**
- **Improved frequency response**
- **Lower output impedance**
- **Reduced noise**
- **More linear operation**



Feedback amplifier

Feedback Connection Types

- **Voltage-series feedback(14.2a)**
- **Voltage-shunt feedback(14.2b)**
- **Current-series feedback(14.2c)**
- **Current-shunt feedback(14.2d)**

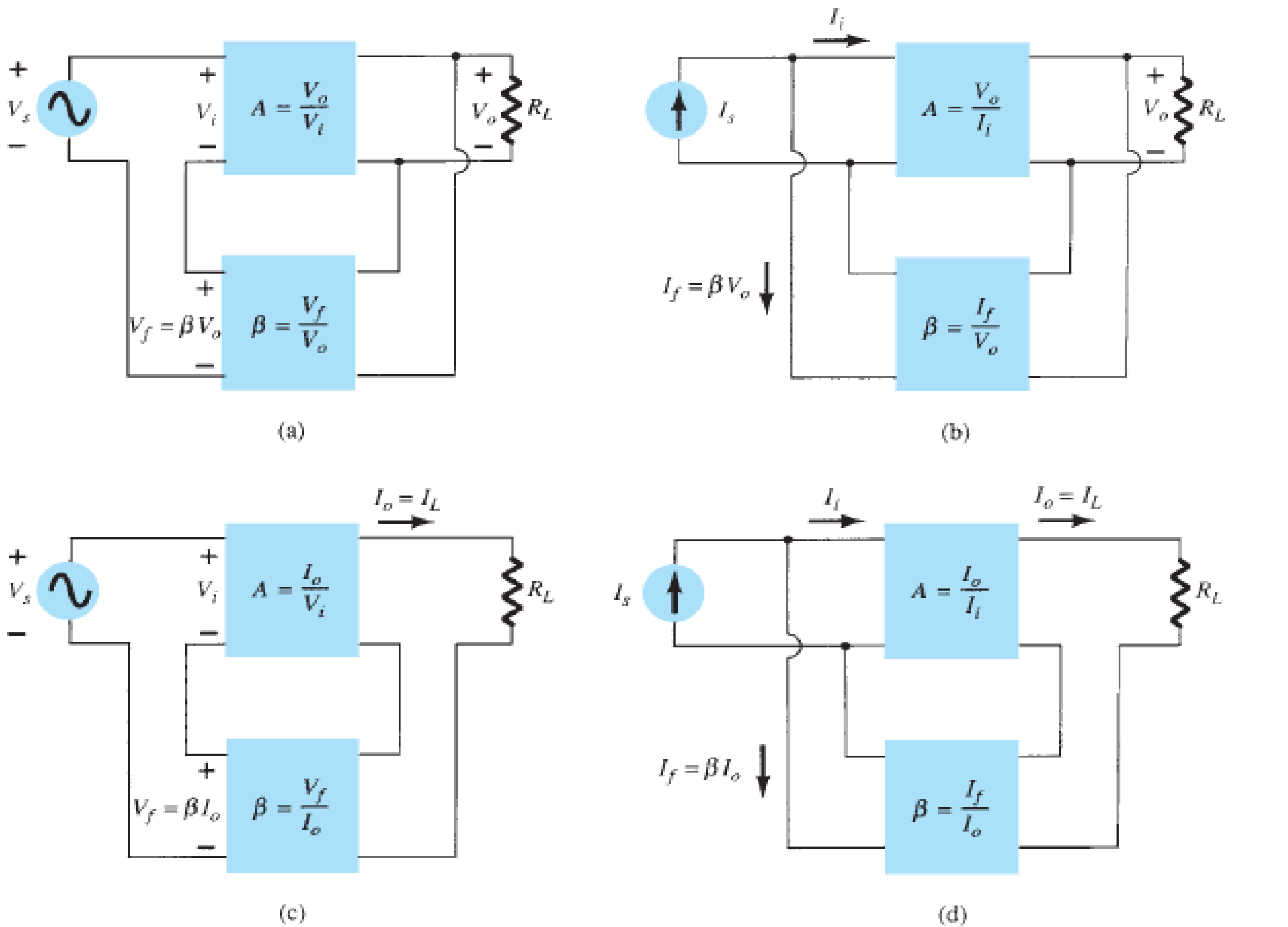


FIG. 14.2

Feedback amplifier types: (a) voltage-series feedback, $A_f = V_o/V_s$; (b) voltage-shunt feedback, $A_f = V_o/I_s$; (c) current-series feedback, $A_f = I_o/V_s$; (d) current-shunt feedback, $A_f = I_o/I_s$.

Gain with Feedback

TABLE 14.1

Summary of Gain, Feedback, and Gain with Feedback from Fig. 14.2

		Voltage-Series	Voltage-Shunt	Current-Series	Current-Shunt
Gain without feedback	A	$\dfrac{V_o}{V_i}$	$\dfrac{V_o}{I_i}$	$\dfrac{I_o}{V_i}$	$\dfrac{I_o}{I_i}$
Feedback	β	$\dfrac{V_f}{V_o}$	$\dfrac{I_f}{V_o}$	$\dfrac{V_f}{I_o}$	$\dfrac{I_f}{I_o}$
Gain with feedback	A_f	$\dfrac{V_o}{V_s}$	$\dfrac{V_o}{I_s}$	$\dfrac{I_o}{V_s}$	$\dfrac{I_o}{I_s}$

Voltage series feedback(as shown in Fig 14.2a)

$$A = \frac{V_o}{V_s} = \frac{V_o}{V_i} \tag{14.1}$$

If a feedback signal V_f is connected in series with the input, then

$$V_i = V_s - V_f$$

Since $\quad V_o = AV_i = A(V_s - V_f) = AV_s - AV_f = AV_s - A(\beta V_o)$

then $\quad (1 + \beta A)V_o = AV_s$

so that the overall voltage gain *with* feedback is

$$\boxed{A_f = \frac{V_o}{V_s} = \frac{A}{1 + \beta A}} \tag{14.2}$$

Voltage shunt feedback

$$A_f = \frac{V_o}{I_s} = \frac{A\,I_i}{I_i + I_f} = \frac{A\,I_i}{I_i + \beta V_o} = \frac{A\,I_i}{I_i + \beta A\,I_i}$$

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

Input Impedance with Feedback

Voltage-Series Feedback

$$I_i = \frac{V_i}{Z_i} = \frac{V_s - V_f}{Z_i} = \frac{V_s - \beta V_o}{Z_i} = \frac{V_s - \beta A V_i}{Z_i}$$

$$I_i Z_i = V_s - \beta A V_i$$

$$V_s = I_i Z_i + \beta A V_i = I_i Z_i + \beta A I_i Z_i$$

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

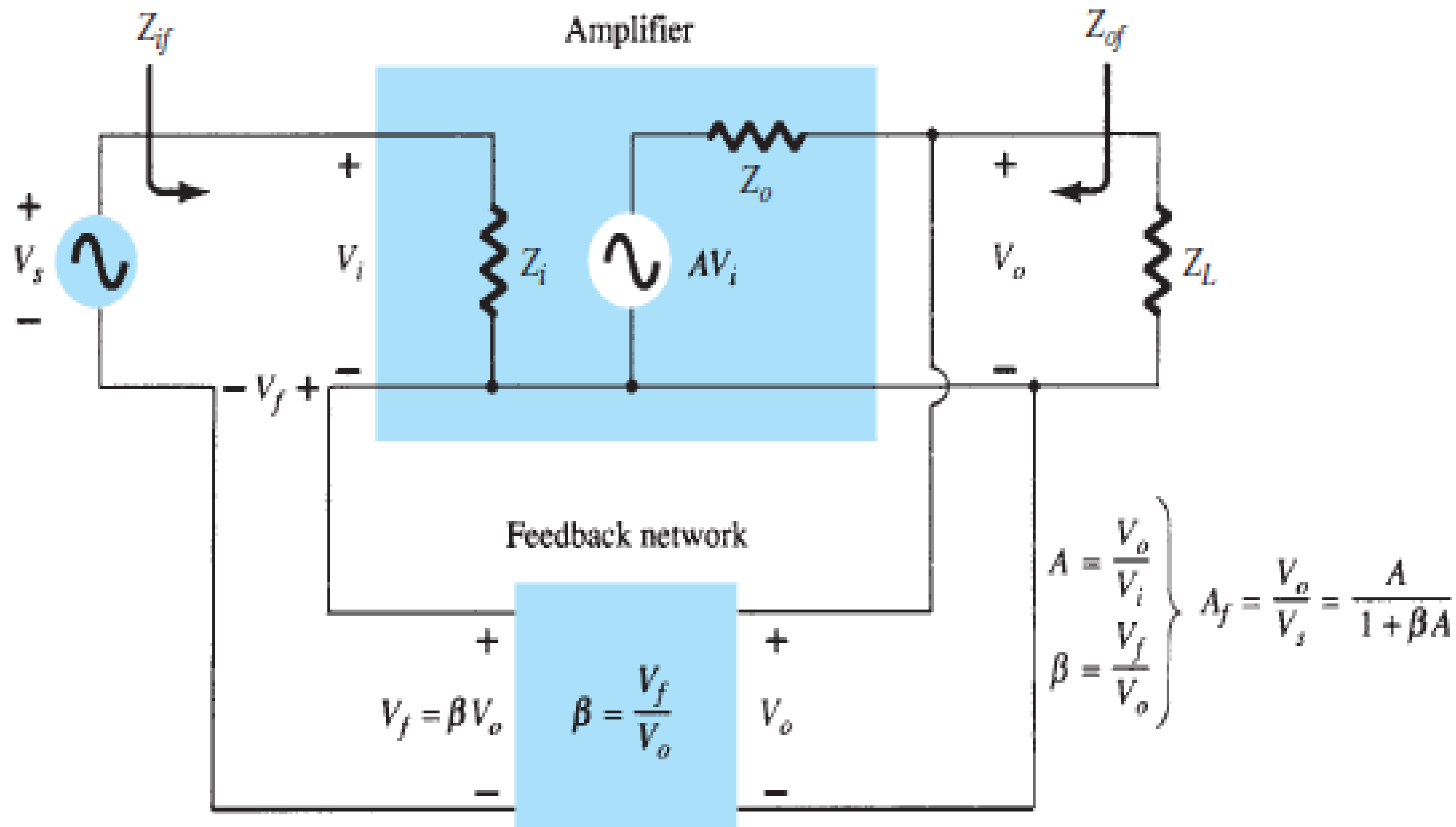


FIG. 14.3

Voltage-series feedback connection.

Voltage-Shunt Feedback

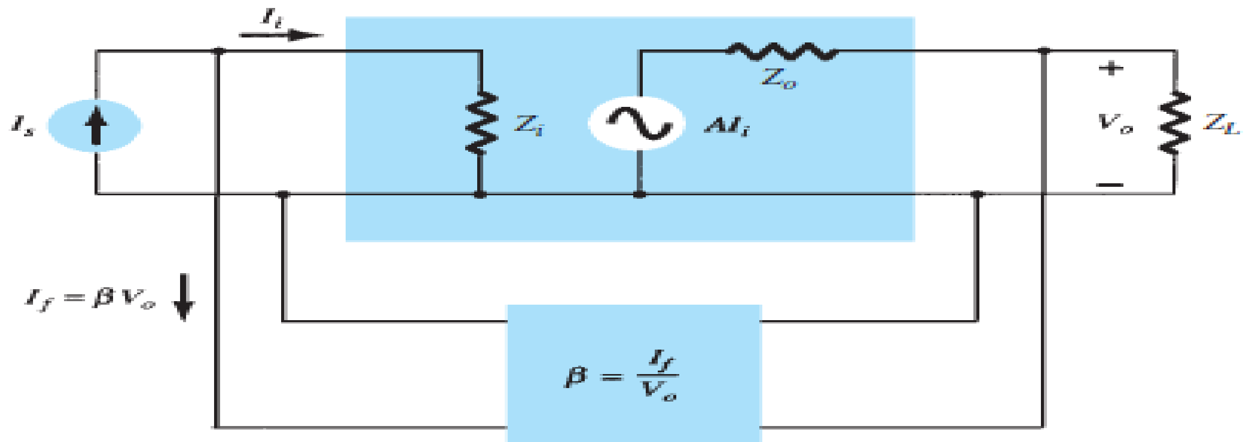


FIG. 14.4
Voltage-shunt feedback connection.

$$Z_{if} = \frac{V_i}{I_s} = \frac{V_i}{I_i + I_f} = \frac{V_i}{I_i + \beta V_o}$$

$$= \frac{V_i/I_i}{I_i/I_i + \beta V_o/I_i}$$

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

Output Impedance with Feedback

Voltage-Series Feedback

$$V = IZ_o + AV_i$$

For $V_s = 0$, $\quad V_i = -V_f$

so that $\quad V = IZ_o - AV_f = IZ_o - A(\beta V)$

Rewriting the equation as

$$V + \beta AV = IZ_o$$

allows solving for the output impedance with feedback:

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

Current-Series Feedback

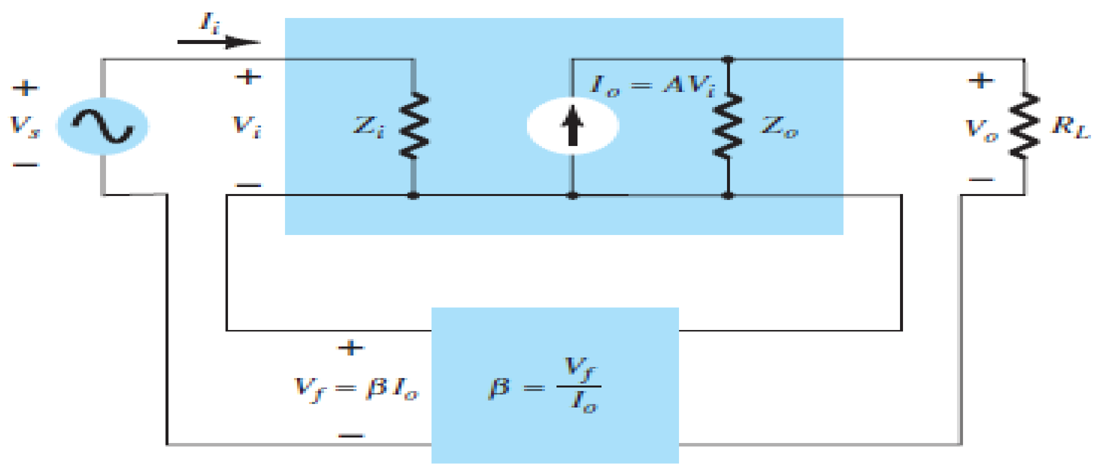


FIG. 14.5
Current-series feedback connection.

With $V_s = 0$,

$$V_i = V_f$$

$$I = \frac{V}{Z_o} - AV_i = \frac{V}{Z_o} - AV_f = \frac{V}{Z_o} - A\beta I$$

$$Z_o(1 + \beta A)I = V$$

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

TABLE 14.2

Effect of Feedback Connection on Input and Output Impedance

	Voltage-Series	Current-Series	Voltage-Shunt	Current-Shunt
Z_{if}	$Z_i(1+\beta A)$ (increased)	$Z_i(1+\beta A)$ (increased)	$\dfrac{Z_i}{1+\beta A}$ (decreased)	$\dfrac{Z_i}{1+\beta A}$ (decreased)
Z_{of}	$\dfrac{Z_o}{1+\beta A}$ (decreased)	$Z_o(1+\beta A)$ (increased)	$\dfrac{Z_o}{1+\beta A}$ (decreased)	$Z_o(1+\beta A)$ (increased)

EXAMPLE 14.1 Determine the voltage gain, input, and output impedance with feedback for voltage-series feedback having $A = -100$, $R_i = 10\,\text{k}\Omega$, and $R_o = 20\,\text{k}\Omega$ for feedback of (a) $\beta = -0.1$ and (b) $\beta = -0.5$.

Solution: Using Eqs. (14.2), (14.4), and (14.6), we obtain

a. $$A_f = \frac{A}{1+\beta A} = \frac{-100}{1+(-0.1)(-100)} = \frac{-100}{11} = \mathbf{-9.09}$$

$$Z_{if} = Z_i(1+\beta A) = 10\,\text{k}\Omega\,(11) = \mathbf{110\,k\Omega}$$

$$Z_{of} = \frac{Z_o}{1+\beta A} = \frac{20\times 10^3}{11} = \mathbf{1.82\,k\Omega}$$

b. $$A_f = \frac{A}{1+\beta A} = \frac{-100}{1+(-0.5)(-100)} = \frac{-100}{51} = \mathbf{-1.96}$$

$$Z_{if} = Z_i(1+\beta A) = 10\,\text{k}\Omega\,(51) = \mathbf{510\,k\Omega}$$

$$Z_{of} = \frac{Z_o}{1+\beta A} = \frac{20\times 10^3}{51} = \mathbf{392.16\,\Omega}$$

EXAMPLE 14.2 If an amplifier with gain of -1000 and feedback of $\beta = -0.1$ has a gain change of 20% due to temperature, calculate the change in gain of the feedback amplifier.

Solution: Using Eq. (14.9), we get

$$\left|\frac{dA_f}{A_f}\right| \cong \left|\frac{1}{\beta A}\right|\left|\frac{dA}{A}\right| = \left|\frac{1}{-0.1(-1000)}(20\%)\right| = 0.2\%$$

The improvement is 100 times. Thus, whereas the amplifier gain changes from $|A| = 1000$ by 20%, the gain with feedback changes from $|A_f| = 100$ by only 0.2%.

Summary of Feedback Effects

Summary of Gain, Feedback, and Gain with Feedback					
		Voltage-Series	*Voltage-Shunt*	*Current-Series*	*Current Shunt*
Gain without feedback	A	$\frac{V_o}{V_i}$	$\frac{V_o}{I_i}$	$\frac{I_o}{V_i}$	$\frac{I_o}{I_i}$
Feedback	b	$\frac{V_f}{V_o}$	$\frac{I_f}{V_o}$	$\frac{V_f}{I_o}$	$\frac{I_f}{I_o}$
	A_f	$\frac{V_o}{V_s}$	$\frac{V_o}{I_s}$	$\frac{I_o}{V_s}$	$\frac{I_o}{I_s}$

Effect of Feedback Connection on Input and Output Impedance				
	Voltage-Series	*Current-Series*	*Voltage-Shunt*	*Current-Shunt*
Z_{if}	$Z_i(1+\beta A)$ (increased)	$Z_i(1+\beta A)$ (increased)	$\frac{Z_i}{1+\beta A}$ (decreased)	$\frac{Z_i}{1+\beta A}$ (decreased)
Z_{of}	$\frac{Z_o}{1+\beta A}$ (decreased)	$Z_o(1+\beta A)$ (increased)	$\frac{Z_o}{1+\beta A}$ (decreased)	$Z_o(1+\beta A)$ (increased)

PRACTICAL FEEDBACK CIRCUITS
voltage series feedback

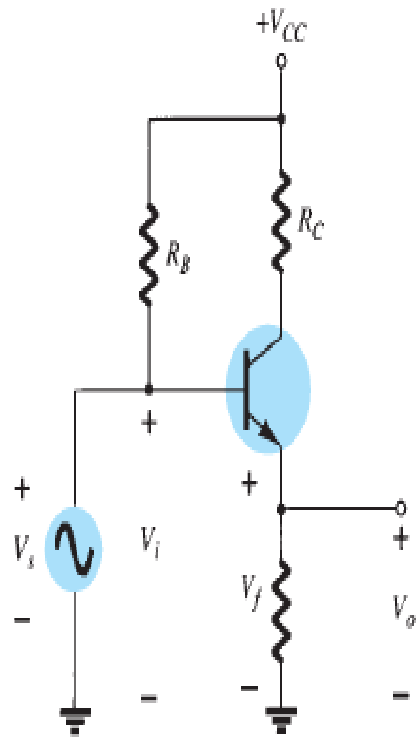


FIG. 14.9
Voltage-series feedback circuit (emitter-follower).

The emitter-follower circuit of Fig. 14.9 provides voltage-series feedback. The signal voltage V_s is the input voltage V_i. The output voltage V_o is also the feedback voltage in series with the input voltage. The amplifier, as shown in Fig. 14.9, provides the operation *with* feedback. The operation of the circuit without feedback provides $V_f = 0$, so that

$$A = \frac{V_o}{V_s} = \frac{h_{fe} I_b R_E}{V_s} = \frac{h_{fe} R_E (V_s/h_{ie})}{V_s} = \frac{h_{fe} R_E}{h_{ie}}$$

and

$$\beta = \frac{V_f}{V_o} = 1$$

The operation with feedback then provides that

$$A_f = \frac{V_o}{V_s} = \frac{A}{1+\beta A} = \frac{h_{fe} R_E/h_{ie}}{1+(1)(h_{fe} R_E/h_{ie})}$$

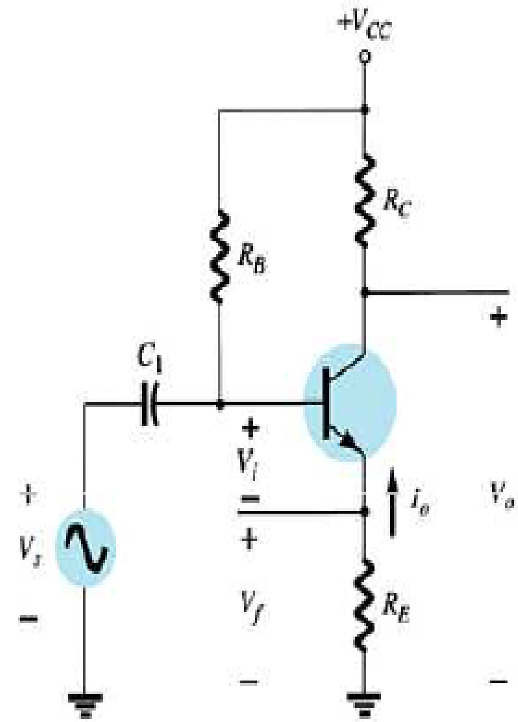
$$= \frac{h_{fe} R_E}{h_{ie} + h_{fe} R_E}$$

For $h_{fe} R_E \gg h_{ie}$,

$$A_f \cong 1$$

Current-Series Feedback

For a current-series feedback amplifier, a portion of the output current is fed back in series with the input.



To determine the feedback gain:

$$A_f = \frac{I_o}{V_s} = \frac{A}{1+\beta A} = \frac{-h_{fe}/h_{ie}}{1+(-R_E)\left(\dfrac{-h_{fe}}{h_{ie}+R_E}\right)} \cong \frac{-h_{fe}}{h_{ie}+h_{fe}R_E}$$

EXAMPLE 14.5 Calculate the voltage gain of the circuit of Fig. 14.11.

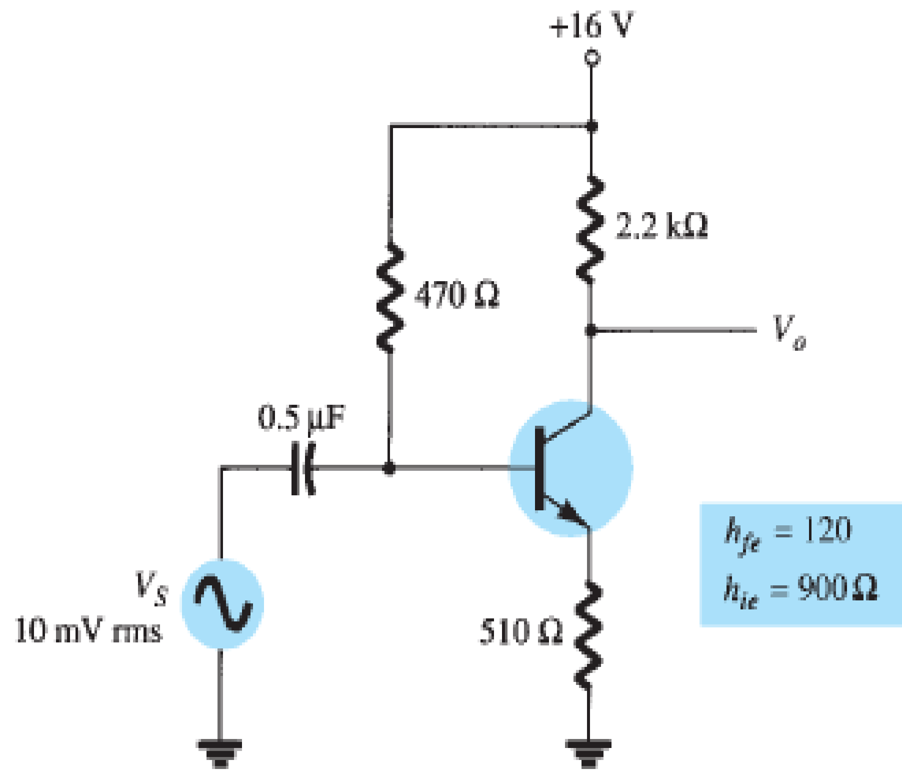


FIG. 14.11
BJT amplifier with current-series feedback for Example 14.5.

Solution: Without feedback,

$$A = \frac{I_o}{V_i} = \frac{-h_{fe}}{h_{ie} + R_E} = \frac{-120}{900 + 510} = -0.085$$

$$\beta = \frac{V_f}{I_o} = -R_E = -510$$

The factor $(1 + \beta A)$ is then

$$1 + \beta A = 1 + (-0.085)(-510) = 44.35$$

The gain with feedback is then

$$A_f = \frac{I_o}{V_s} = \frac{A}{1 + \beta A} = \frac{-0.085}{44.35} = -1.92 \times 10^{-3}$$

and the voltage gain with feedback A_{vf} is

$$A_{vf} = \frac{V_o}{V_s} = A_f R_C = (-1.92 \times 10^{-3})(2.2 \times 10^3) = \mathbf{-4.2}$$

Without feedback ($R_E = 0$), the voltage gain is

$$A_v = \frac{-R_C}{r_e} = \frac{-2.2 \times 10^3}{7.5} = \mathbf{-293.3}$$

An amplifier without feedback has a transfer gain of -2000. The transfer gain changes by 20% due to temperature. if negative feedback with β = -0.1 is given, calculate the change in gain of the feedback amplifier

$$A = -2000 \quad \beta = -0.1$$

$$\% \left| \frac{dA}{A} \right| = 20\%$$

$$1 + \beta A = 1 + (-0.1)(-2000)$$

$$= 201$$

$$\% \left| \frac{dA_f}{A_f} \right| = \frac{\% \left| \frac{dA}{A} \right|}{1 + \beta A}$$

$$= \frac{20\%}{201} = 0.099\,\%$$

For the current series feedback amplifier shown below, calculate the following

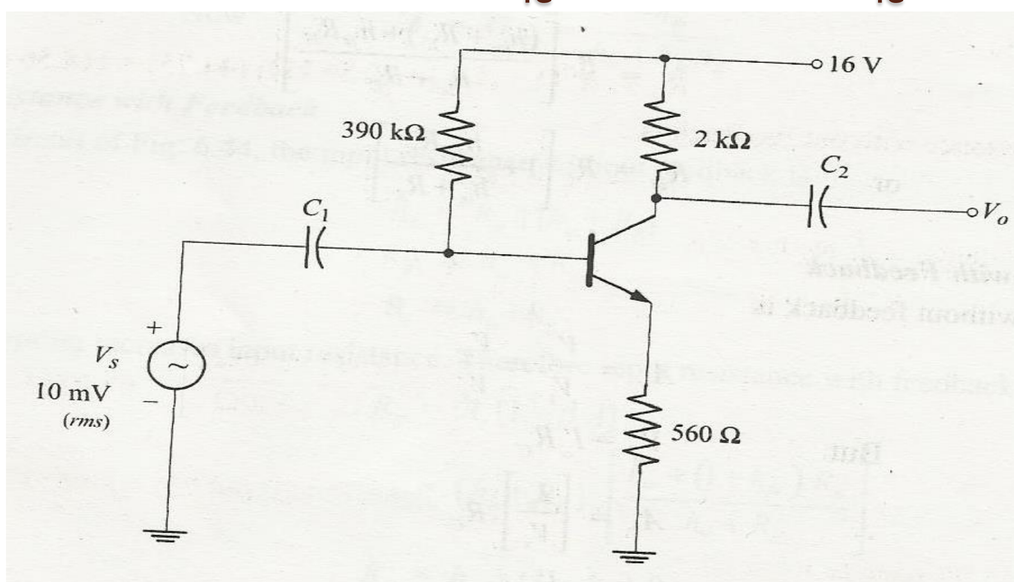
a) Desensitvity factor b) Transfer gain with feedback

c) voltage gain with and without feeback

d) input resistance with and without feedback

e) output resistance with and without feedback

For the transistor used $h_{fe} = 200$ and $h_{ie} = 2k\Omega$



(a) Desentisivity factor is

$$D = 1 + \beta A$$

$$\beta = -R_E = -560\ \Omega$$

$$A = G_M = \frac{-h_{fe}}{h_{ie} + R_E}$$

$$= \frac{-200}{2000\ \Omega + 560\ \Omega} = -\ 0.078125\ \mho$$

$$D = 1 + [-560\ \Omega]\ [-\ 0.078125\ \mho] = 44.75$$

(b) Transfer gain with feedback is

$$A_f = G_{Mf} = \frac{A}{D} = \frac{-\ 0.078125}{44.75} = -\ 1.745\ \text{m}\mho$$

(c) Voltage gain without feedback is

$$A_V = A\,R_C = [-\ 0.078125\ \mho\ ]\ [2\ \text{k}\Omega] = -\ 156.25$$

Voltage gain with feedback is

$$A_{Vf} = A_f\,R_C = (-\ 1.745\ \text{m}\mho)\ (2\ \text{k}\Omega) = -\ 3.49$$

(d) Input resistance without feedback is

$$R_i = h_{ie} + R_E = 2\,\text{k}\Omega + 560\,\Omega = 2.56\,\text{k}\Omega$$

Input resistance with feedback is

$$R_{if} = h_{ie} + h_{fe} R_E = 2\,\text{k}\Omega + (200)(560\,\Omega) = 114\,\text{k}\Omega$$

Alternatively

$$R_{if} = R_i\,[1 + \beta A] = (2.56\,\text{k}\Omega)(44.75) = 114.56\,\text{k}\Omega$$

(e) Output resistance with out feedback is

$$R_o = R_C = 2\,\text{k}\Omega$$

Output resistance with feedback is

$$R_{of} = R_C \left[1 + \frac{h_{fe} R_E}{h_{ie} + R_E}\right]$$

$$= (2\,\text{k}\Omega)\left[1 + \frac{(200)\,(560\Omega)}{2\text{k}\Omega + 560\Omega}\right] = 89.5\,\text{k}\Omega$$

Alternatively

$$R_{of} = R_o\,[1 + \beta A] = (2\,\text{k}\Omega)(44.75) = 89.5\,\text{k}\Omega$$