INTEGRATED TECHNICAL EDUCATION CLUSTER
AT ALAMEERIA

J-601-1448
Electronic Principals

Lecture #11
Feedback Circuits

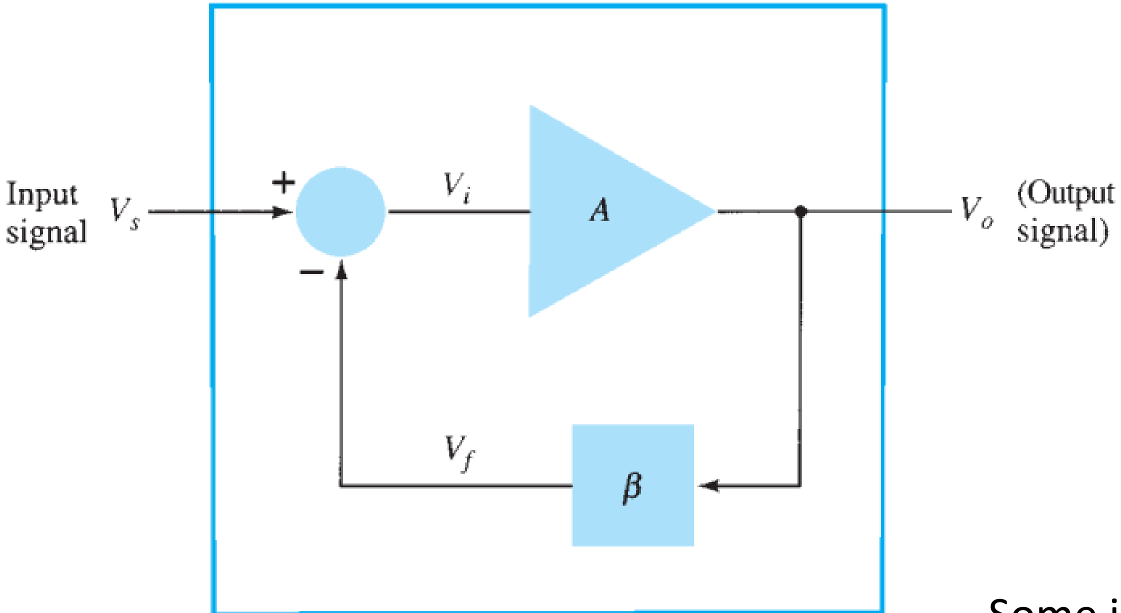
Instructor:
Dr. Ahmad El-Banna

DECEMBER 2014

Agenda

- Feedback Concepts
- Feedback Connection Types
- Practical Feedback Circuits

Simple block diagram of feedback amplifier



Feedback amplifier

Some improvements are :

1. Higher input impedance.
2. Better stabilized voltage gain.
3. Improved frequency response.
4. Lower output impedance.
5. Reduced noise.
6. More linear operation.

FEEDBACK CONNECTION TYPES

1. Voltage-series feedback (Fig. 14.2a).
2. Voltage-shunt feedback (Fig. 14.2b).
3. Current-series feedback (Fig. 14.2c).
4. Current-shunt feedback (Fig. 14.2d).

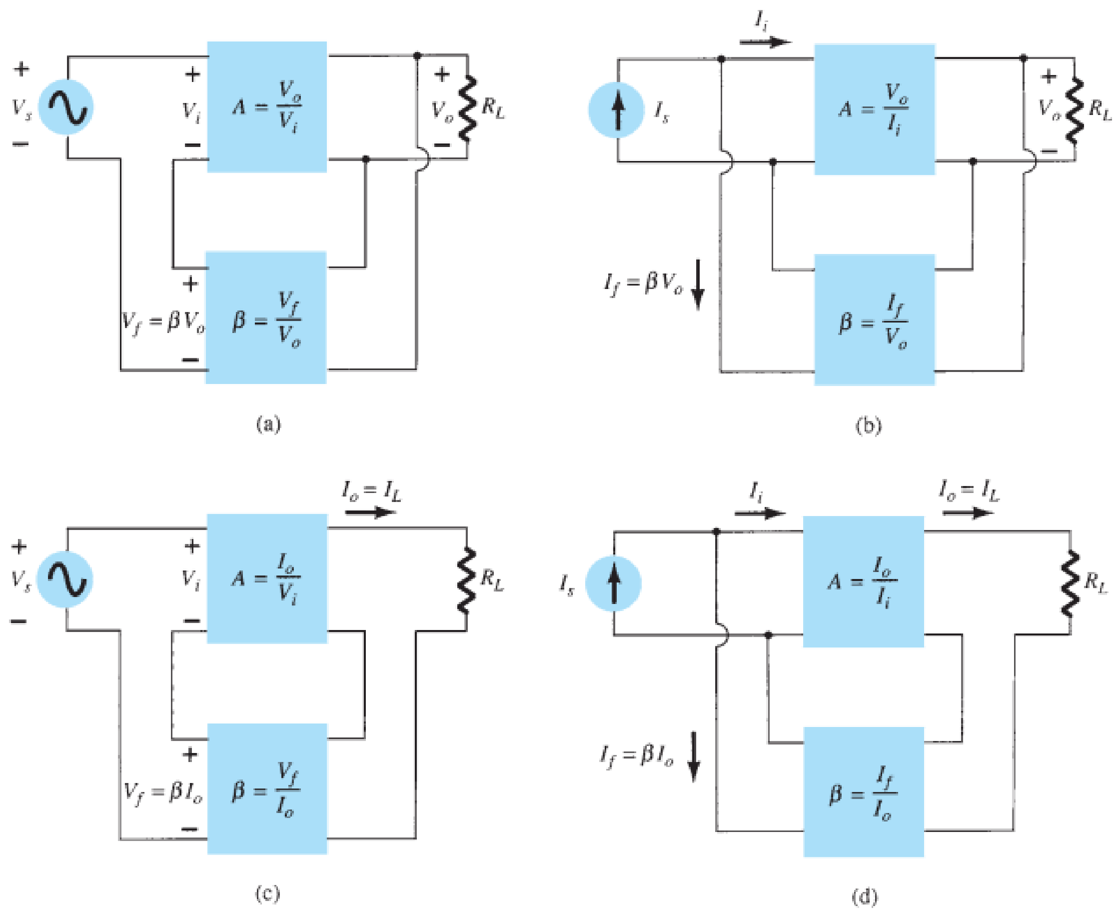


FIG. 14.2

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, $A_f = I_o/I_s$.

- Series feedback connections tend to increase the input resistance, whereas shunt feed-back connections tend to decrease the input resistance.
- Voltage feedback tends to decrease the output impedance, whereas current feedback tends to increase the output impedance.

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	$\frac{V_o}{V_i}$	$\frac{V_o}{I_i}$	$\frac{I_o}{V_i}$	$\frac{I_o}{I_i}$
Feedback	β	$\frac{V_f}{V_o}$	$\frac{I_f}{V_o}$	$\frac{V_f}{I_o}$	$\frac{I_f}{I_o}$
Gain with feedback	A_f	$\frac{V_o}{V_s}$	$\frac{V_o}{I_s}$	$\frac{I_o}{V_s}$	$\frac{I_o}{I_s}$

Voltage-Series Feedback

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

$$V_i = V_s - V_f$$

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

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

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

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

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

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

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

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

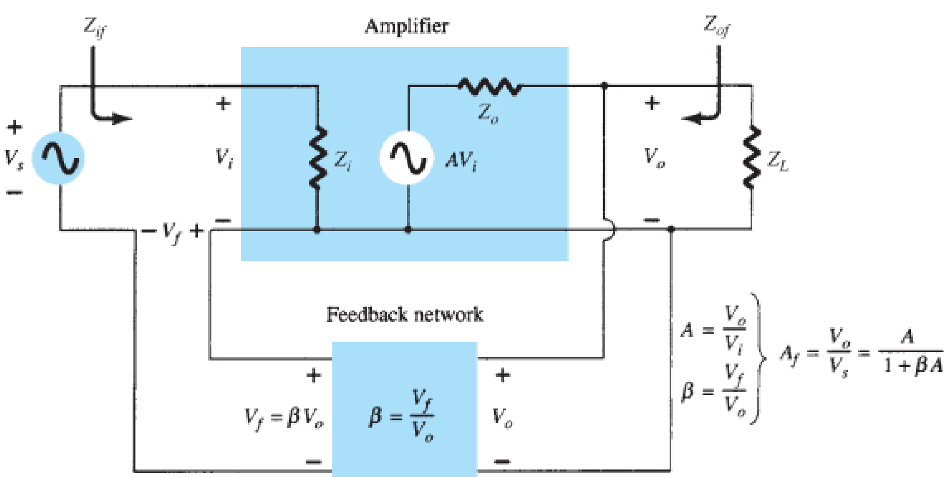


FIG. 14.3
Voltage-series feedback connection.

Voltage-Shunt Feedback

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

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

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

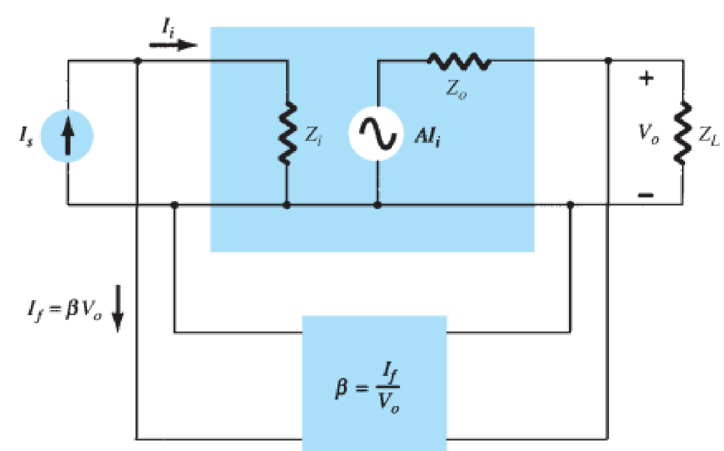


FIG. 14.4
Voltage-shunt feedback connection.

Output Impedance with Feedback

Voltage-Series Feedback

$$V = IZ_o + AV_i$$
$$V_i = -V_f$$
$$V = IZ_o - AV_f = IZ_o - A(\beta V)$$

$$V + \beta AV = IZ_o$$

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

Current-Series Feedback

$$V_i = V_f$$
$$I = \frac{V}{Z_o} - AV_i = \frac{V}{Z_o} - AV_f = \frac{V}{Z_o} - A\beta I$$
$$Z_o(1 + \beta A)I = V$$

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

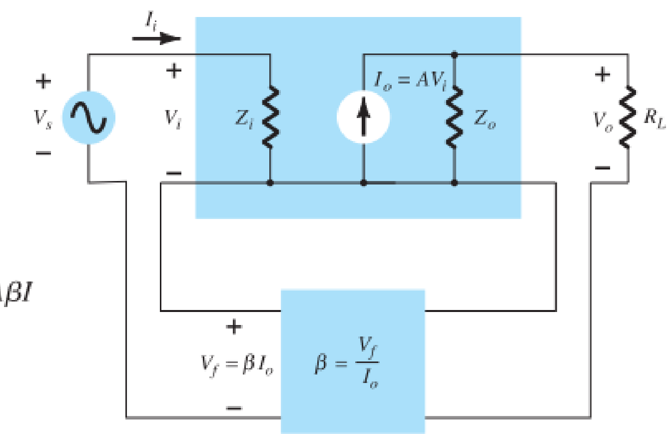


FIG. 14.5
Current-series feedback connection.

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)	$\frac{Z_i}{1 + \beta A}$ (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)

Example

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

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

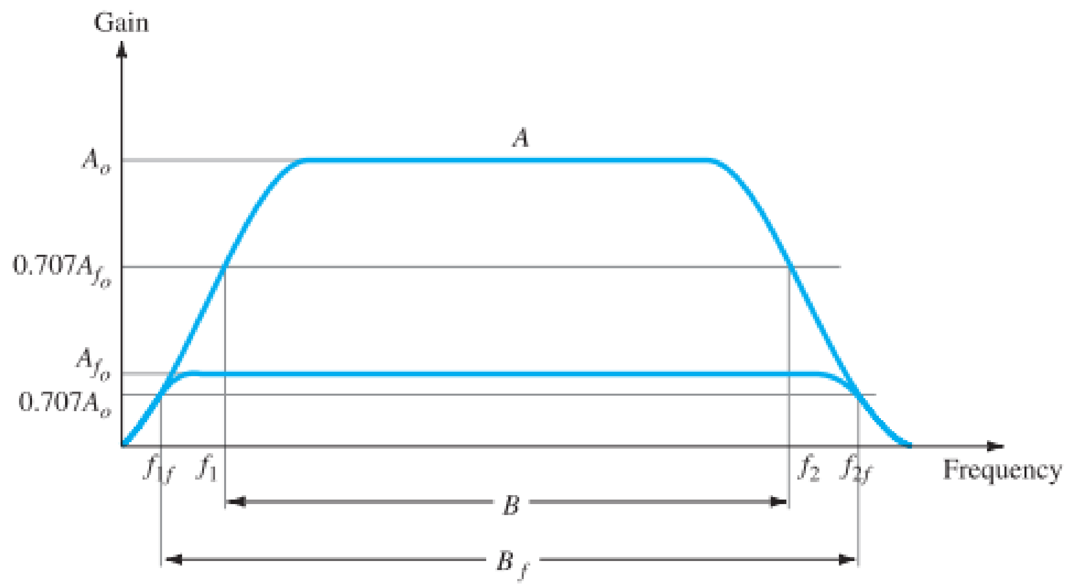
$$Z_{of} = \frac{Z_o}{1 + \beta A} = \frac{20 \times 10^3}{51} = \mathbf{392.16\,\Omega}$$

Effects of feedback on Gain and Bandwidth

Reduction in Frequency Distortion

Reduction in Noise and Nonlinear Distortion

$$A_f = \frac{A}{1+\beta A} \cong \frac{A}{\beta A} = \frac{1}{\beta} \qquad \text{for } \beta A \gg 1$$



Gain Stability with Feedback

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

$$\left|\frac{dA_f}{A_f}\right| \cong \left|\frac{1}{\beta A}\right|\left|\frac{dA}{A}\right| \qquad \text{for } \beta A \gg 1$$

Practical Feedback Circuits

Voltage-Series Feedback

$$A = \frac{V_o}{V_i} = -g_m R_L$$

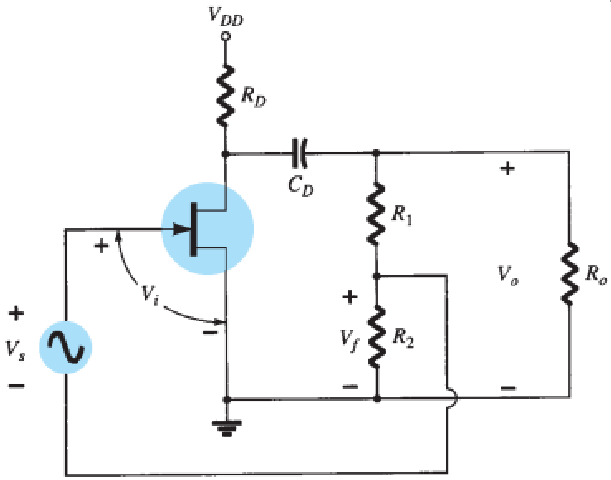


FIG. 14.7
FET amplifier stage with voltage-series feedback.

$$R_L = R_D R_o (R_1 + R_2)$$

$$\beta = \frac{V_f}{V_o} = \frac{-R_2}{R_1 + R_2}$$

$$A_f = \frac{A}{1 + \beta A} = \frac{-g_m R_L}{1 + [R_2 R_L/(R_1 + R_2)]g_m}$$

$$A_f \cong \frac{1}{\beta} = -\frac{R_1 + R_2}{R_2}$$

EXAMPLE 14.3 Calculate the gain without and with feedback for the FET amplifier circuit of Fig. 14.7 and the following circuit values: $R_1 = 80\ \text{k}\Omega$, $R_2 = 20\ \text{k}\Omega$, $R_o = 10\ \text{k}\Omega$, $R_D = 10\ \text{k}\Omega$, and $g_m = 4000\ \mu\text{S}$.

Solution:

$$R_L \cong \frac{R_o R_D}{R_o + R_D} = \frac{10\ \text{k}\Omega(10\ \text{k}\Omega)}{10\ \text{k}\Omega + 10\ \text{k}\Omega} = 5\ \text{k}\Omega$$

Neglecting the 100-kΩ resistance of R_1 and R_2 in series gives

$$A = -g_m R_L = -(4000 \times 10^{-6}\ \mu\text{S})(5\ \text{k}\Omega) = \mathbf{-20}$$

The feedback factor is

$$\beta = \frac{-R_2}{R_1 + R_2} = \frac{-20\ \text{k}\Omega}{80\ \text{k}\Omega + 20\ \text{k}\Omega} = -0.2$$

The gain with feedback is

$$A_f = \frac{A}{1 + \beta A} = \frac{-20}{1 + (-0.2)(-20)} = \frac{-20}{5} = \mathbf{-4}$$

Using OP-Amp & Emitter follower

$$\beta = \frac{R_2}{R_1 + R_2}$$

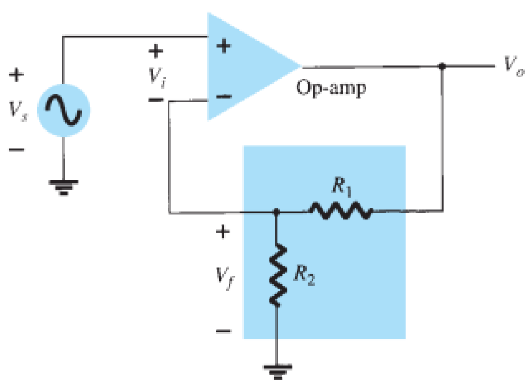


FIG. 14.8
Voltage-series feedback in an op-amp connection.

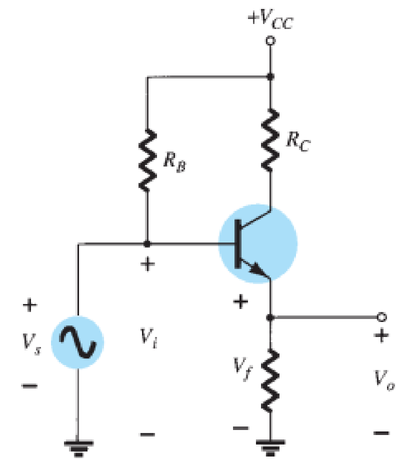


FIG. 14.9
Voltage-series feedback circuit (emitter-follower).

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

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

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

For $h_{fe} R_E \gg h_{ie}$, $\quad A_f \cong 1$

Check EXAMPLE 14.4

Current Series Feedback

Current-Series Feedback

Without Feedback

$$A = \frac{I_o}{V_i} = \frac{-I_b h_{fe}}{I_b h_{ie} + R_E} = \frac{-h_{fe}}{h_{ie} + R_E}$$

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

$$Z_i = R_B \| (h_{ie} + R_E) \cong h_{ie} + R_E$$

$$Z_o = R_C$$

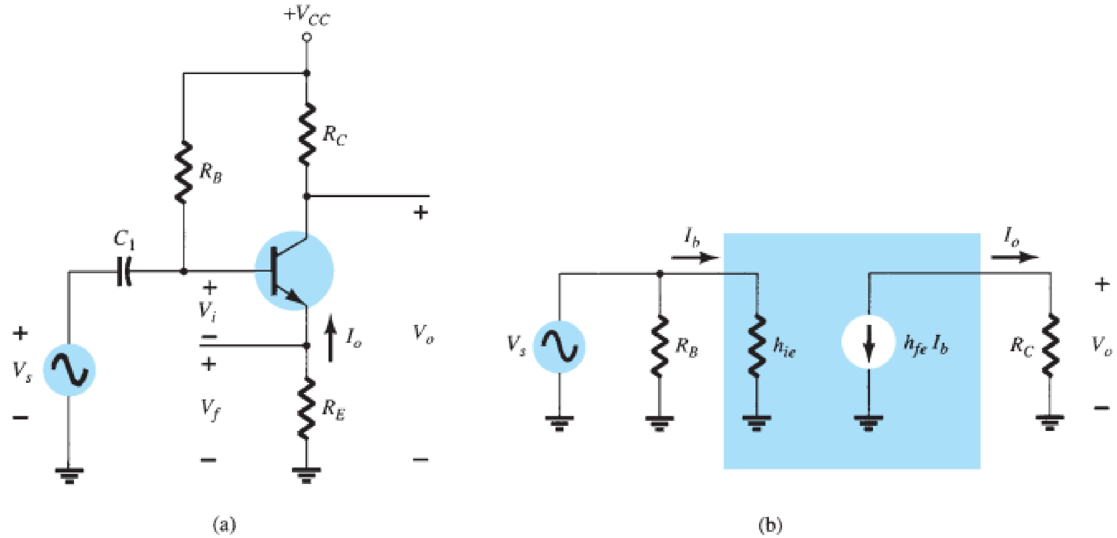


FIG. 14.10
Transistor amplifier with unbypassed emitter resistor (R_E) for current-series feedback: (a) amplifier circuit; (b) ac equivalent circuit without feedback.

With Feedback

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

$$Z_{if} = Z_i(1 + \beta A) \cong h_{ie}\left(1 + \frac{h_{fe} R_E}{h_{ie}}\right) = h_{ie} + h_{fe} R_E$$

$$Z_{of} = Z_o(1 + \beta A) = R_C\left(1 + \frac{h_{fe} R_E}{h_{ie}}\right)$$

$$A_{vf} = \frac{V_o}{V_s} = \frac{I_o R_C}{V_s} = \left(\frac{I_o}{V_s}\right) R_C = A_f R_C \cong \frac{-h_{fe} R_C}{h_{ie} + h_{fe} R_E}$$

Voltage Shunt Feedback

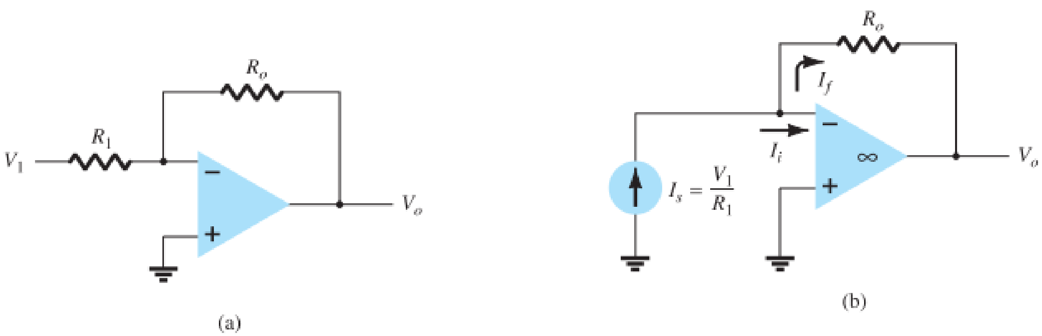


FIG. 14.12
Voltage-shunt negative feedback amplifier: (a) constant-gain circuit; (b) equivalent circuit.

$$A = \frac{V_o}{I_i} = \infty$$

$$\beta = \frac{I_f}{V_o} = \frac{-1}{R_o}$$

$$A_f = \frac{V_o}{I_s} = \frac{V_o}{I_i} = \frac{A}{1 + \beta A} = \frac{1}{\beta} = -R_o$$

$$A_{vf} = \frac{V_o}{I_s}\frac{I_s}{V_1} = (-R_o)\frac{1}{R_1} = \frac{-R_o}{R_1}$$

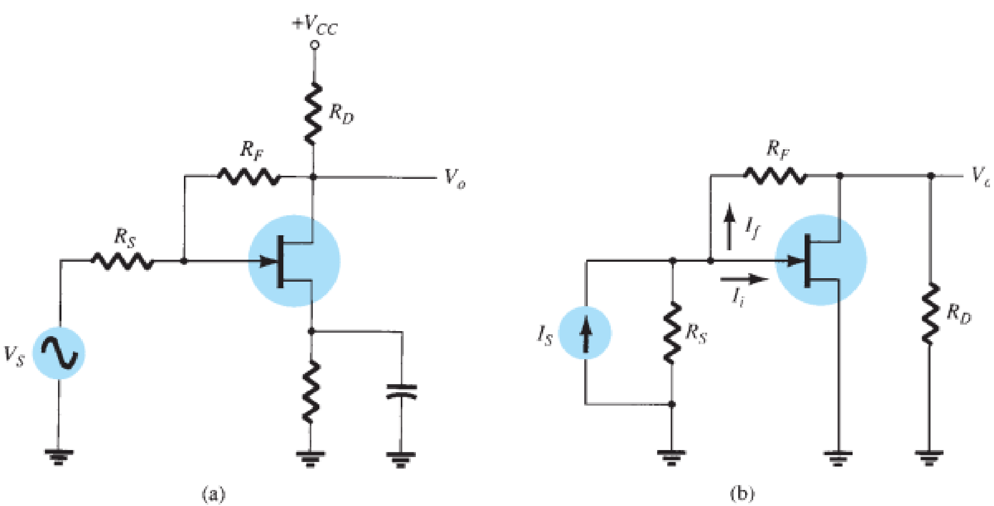


FIG. 14.13
Voltage-shunt feedback amplifier using an FET: (a) circuit; (b) equivalent circuit.

$$A = \frac{V_o}{I_i} \cong -g_m R_D R_S$$

$$\beta = \frac{I_f}{V_o} = \frac{-1}{R_F}$$

$$A_f = \frac{V_o}{I_s} = \frac{A}{1 + \beta A} = \frac{-g_m R_D R_S}{1 + (-1/R_F)(-g_m R_D R_S)} = \frac{-g_m R_D R_S R_F}{R_F + g_m R_D R_S}$$

$$A_{vf} = \frac{V_o}{I_s}\frac{I_s}{V_s} = \frac{-g_m R_D R_S R_F}{R_F + g_m R_D R_S}\left(\frac{1}{R_S}\right) = \frac{-g_m R_D R_F}{R_F + g_m R_D R_S} = (-g_m R_D)\frac{R_F}{R_F + g_m R_D R_S}$$

- For more details, refer to:
  - Chapter 14, Electronic Devices and Circuits, Boylestad.
- The lecture is available online at:
  - https://speakerdeck.com/ahmad_elbanna
- For inquires, send to:
  - ahmad.elbanna@feng.bu.edu.eg