PRACTICAL FEEDBACK CIRCUITS

TABLE 18.1 Summary of Gain, Feedback, and Gain with Feedback from Fig. 18.2

		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

Fig.1 shows an FET amplifier stage with voltage-series feedback. A part of the output signal (V_o) is obtained using a feedback network of resistors $R1$ and $R2$. The feedback voltage V_f is connected in series with the source signal V_s, their difference being the input signal V_i.

Without feedback the amplifier gain is:

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

Where R_L is the parallel combination of resistors:

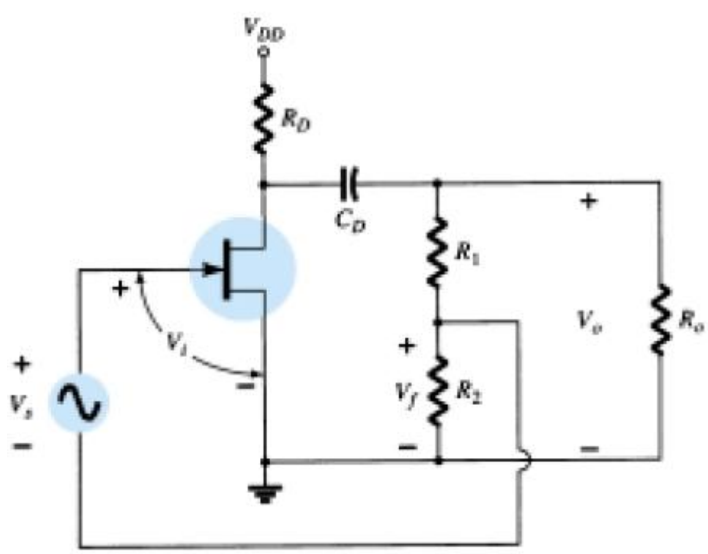

Fig.1: FET amplifier stage with voltage-series feedback.

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

The feedback network provides a feedback factor of

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

Using the values of *A* and β above in Equation

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

A_f is the gain with negative feedback

If $\beta A \gg 1$, we have

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

EXAMPLE 18.3

Calculate the gain without and with feedback for the FET amplifier circuit of Fig.1 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 100 kΩ resistance of R_1 and R_2 in series

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

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

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

Fig.2 shows a voltage-series feedback connection using an op-amp. The gain of the op-amp, *A*, without feedback, is reduced by the feedback factor

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

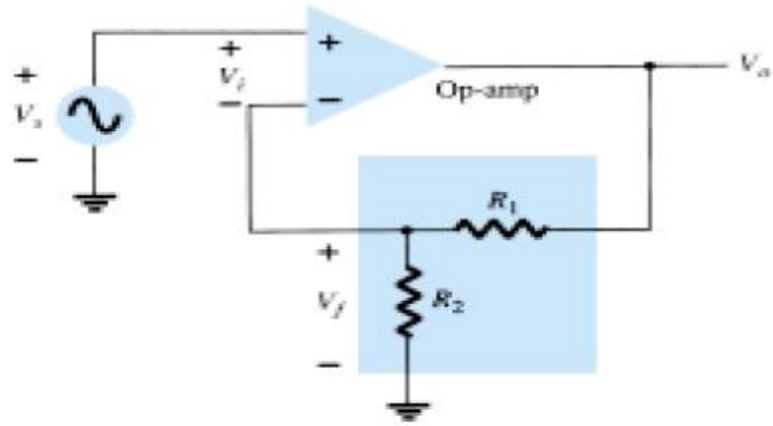

Fig.2: Voltage-series feedback in an op-amp connection.

The emitter-follower circuit of Fig.3 provides voltage-series feedback. The signal voltage, *Vs,* is the input voltage, *Vi*. The output voltage, *Vo,* is also the feedback voltage in series with the input voltage. The amplifier, as shown in Fig.3, provides the operation *with* feedback. The operation of the circuit without feedback provides *Vf* = 0, so that

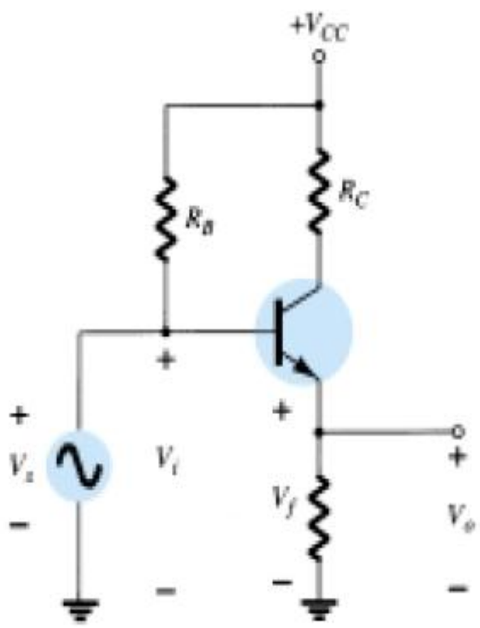

Fig.3: Voltage-series feedback circuit (emitter-follower).

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

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

Another feedback technique is to sample the output current (I_o) and return a proportional voltage in series with the input. While stabilizing the amplifier gain, the current- series feedback connection increases input resistance. Fig.4 shows a single transistor amplifier stage. Since the emitter of this stage has an unbypassed emitter, it effectively has current-series feedback. The current through resistor *RE* results in a feedback voltage that opposes the source signal applied so that the output voltage *Vo* is reduced. To remove the current-series feedback, the emitter resistor must be either removed or bypassed by a capacitor (as is usually done).

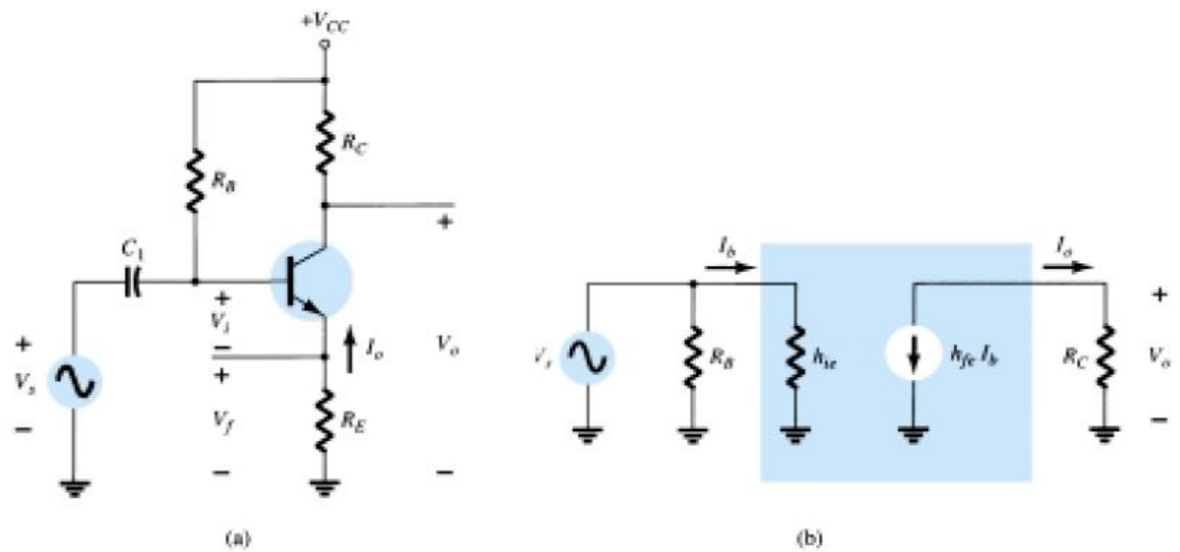

Fig.4: Transistor amplifier with unbypassed emitter resistor (R_E) for current- series feedback: (a) amplifier circuit; (b) ac equivalent circuit without feedback.

WITHOUT FEEDBACK

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

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

The input and output impedances are

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

$$Z_o = R_C$$

WITH FEEDBACK

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

The input and output impedance is calculated as specified in Table 18.2.

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

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

The voltage gain (A) with feedback is

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

EXAMPLE 18.5 Calculate the voltage gain of the circuit of Fig. 5 .

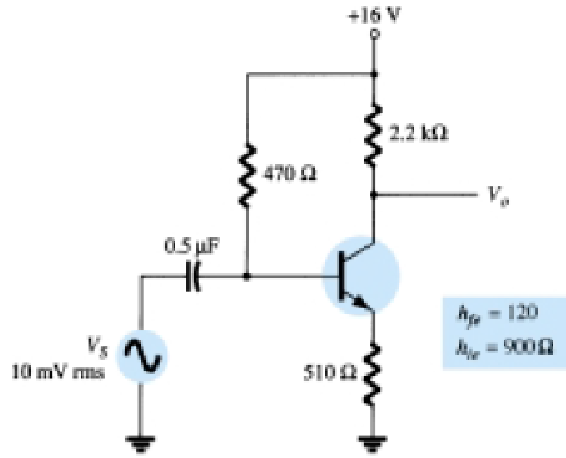

Fig.5 BJT amplifier with current-series feedback for Example 18.5.

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

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

§ 18.2 Feedback Connection Types

1. Calculate the gain of a negative-feedback amplifier having $A = -2000$ and $\beta = -1/10$.
2. If the gain of an amplifier changes from a value of -1000 by 10%, calculate the gain change if the amplifier is used in a feedback circuit having $\beta = -1/20$.
3. Calculate the gain, input, and output impedances of a voltage-series feedback amplifier having $A = -300$, $R_i = 1.5\ \text{k}\Omega$, $R_o = 50\ \text{k}\Omega$, and $\beta = -1/15$.

§ 18.3 Practical Feedback Circuits

* 4. Calculate the gain with and without feedback for an FET amplifier as in Fig. 1 for circuit values $R_1 = 800\ \text{k}\Omega$, $R_2 = 200\ \Omega$, $R_o = 40\ \text{k}\Omega$, $R_D = 8\ \text{k}\Omega$, and $g_m = 5000\ \mu\text{S}$.

5. For a circuit as in Fig. 5 and the following circuit values, calculate the circuit gain and the input and output impedances with and without feedback: $R_B = 600\ \text{k}\Omega$, $R_E = 1.2\ \text{k}\Omega$, $R_C = 4.7\ \text{k}\Omega$, and $\beta = 75$. Use $V_{CC} = 16$ V.

1. $$A_f = \frac{A}{1+\beta A} = \frac{-2000}{1+(-\frac{1}{10})(-2000)} = \frac{-2000}{201} = \underline{-9.95}$$

3. $$A_f = \frac{A}{1+\beta A} = \frac{-300}{1+(-\frac{1}{15})(-300)} = \frac{-300}{21} = \underline{-14.3}$$

$$R_{if} = (1+\beta A) R_i = 21\,(1.5\text{k}\Omega) = \underline{31.5\ \text{k}\Omega}$$

$$R_{of} = \frac{R_o}{1+\beta A} = \frac{50\ \text{k}\Omega}{21} = \underline{2.4\ \text{k}\Omega}$$

4. $$R_L = \frac{R_o R_D}{R_o + R_D} = 40\ \text{k}\Omega \parallel 8\ \text{k}\Omega = 6.7\ \text{k}\Omega$$

$$A = -g_m R_L = -(5000\times10^{-6})(6.7\times10^{3}) = \underline{-33.5}$$

$$\beta = \frac{-R_2}{R_1+R_2} = \frac{-200\ \text{k}\Omega}{200\ \text{k}\Omega + 800\ \text{k}\Omega} = \underline{-0.2}$$

$$A_f = \frac{A}{1+\beta A} = \frac{-33.5}{1+(-0.2)(-33.5)} = \frac{-33.5}{7.7}$$

$$= \underline{-4.4}$$

5. DC Bias:

$$I_B = \frac{V_{cc} - V_{BE}}{R_B + (\beta+1)R_E} = \frac{16V - 0.7V}{600k\Omega + 76(1.2k\Omega)} = \frac{15.3V}{691.2k\Omega} = 22.1\mu A$$

$$I_E = (1+\beta)\, I_B = 76(22.1\mu A) = 1.68mA$$

$$[V_{CE} = V_{cc} - I_C(R_C + R_E) = 16V - 1.68mA(4.7k + 1.2k) \cong 6.1V]$$

$$r_e = \frac{26mV}{I_E(mA)} = \frac{26}{1.68} \cong 15.5\Omega$$

$$h_{ie} \cong (1+\beta)\, r_e = 76(15.5\Omega) = 1.18k\Omega = Z_i$$

$$Z_o = R_C = 4.7k\Omega$$

$$A = \frac{-h_{fe}}{h_{ie} + R_E} = \frac{-75}{1.18k\Omega + 1.2k\Omega} = -31.5 \times 10^{-3}$$

$$\beta = -R_E = -1.2 \times 10^3$$

$$(1+\beta A) = 1 + (-1.2\times10^3)(-31.5\times10^{-3}) = 38.8$$

$$A_f = \frac{A}{1+\beta A} = \frac{-31.5\times10^{-3}}{38.8} = 811.86 \times 10^{-6}$$

$$A_{vf} = -A_f \cdot R_c = -(811.86\times10^{-6})(4.7\times10^3) = \underline{-3.82}$$

$$Z_{if} = (1+\beta A)\, Z_i = (38.8)(1.18k\Omega) = \underline{45.8k\Omega}$$

$$Z_{of} = (1+\beta A)\, Z_o = (38.8)(4.7k\Omega) = \underline{182.4k\Omega}$$

without feedback (R_E bypassed):

$$A_v = \frac{-R_C}{r_e} = -\frac{4.7k\Omega}{15.5\Omega} = \underline{-303.2}$$

Assist. Lecturer: AMMAR ISSA ISMAEL