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Electronics II: 3ed Year - 2015/2016
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Feedback Amplifiers

❖ *Feedback Concepts:*

A typical feedback connection is shown in Fig.1. The input signal ,V_S ,is applied to a mixer network, where it is combined with a feedback signal, *Vf*. The difference of these signals, *Vi*, is then the input voltage to the amplifier. A portion of the amplifier output (sampled signal), *Vo*, is connected to the feedback network (β), which provides a reduced portion of the output as feedback signal to the input mixer network.

There are two basic types of feedback in amplifiers *positive feedback* and *negative 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°. The result is a 360° phase shift around the loop, When the feedback energy (voltage or current) is out of phase with the input signal and thus opposes it, it is called *negative feedback* the amplifier introduces a phase shift of 180° into the circuit while the feedback network is so designed that it introduces no phase shift if the feedback signal is of opposite polarity to the input signal, as shown in Fig.1, negative feedback results. While negative feedback results in reduced overall voltage gain, a number of improvements are obtained, among them being:

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

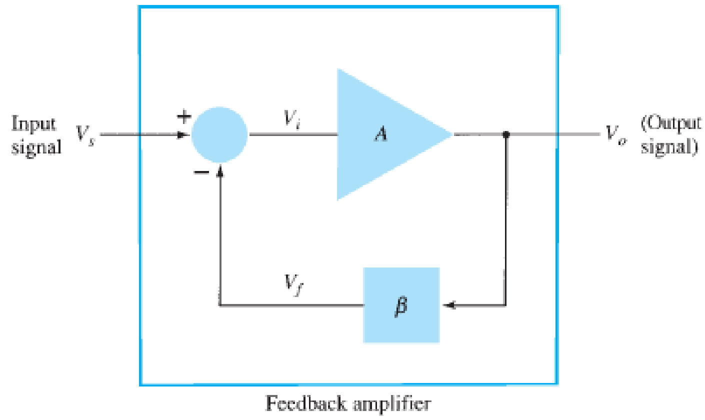


Fig.1

❖ *Feedback Connection Types:*

There are four basic ways of connecting the feedback signal. Both voltage and current can be fed back to the input either in series or parallel. Specifically, there can be:

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

In the list above, *voltage* refers to connecting the output voltage as input to the feedback network; *current* refers to tapping off some output current through the feedback network. *Series* refers to connecting the feedback signal in series with the input signal voltage; *shunt* refers to connecting the feedback signal in shunt (parallel) with an input current source.

Generally, series feedback connections tend to increase the input resistance, while shunt feedback connections tend to decrease the input resistance. Voltage feedback tends to decrease the output impedance, while current feedback tends to increase the output impedance.

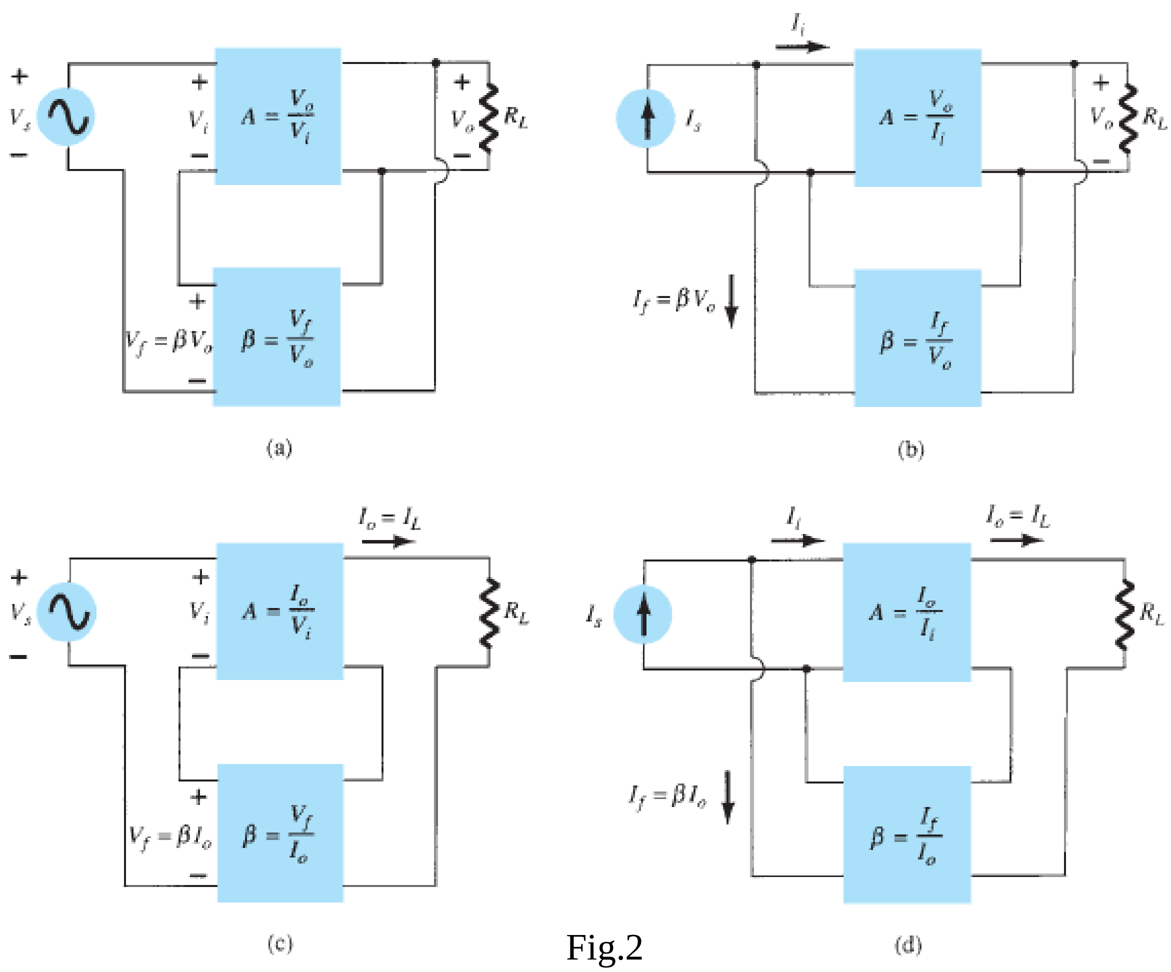


Fig.2

❖ *Gain With Feedback:*

The gain without feedback, A, is that of the amplifier stage. With feedback, β, the Overall gain of the circuit is reduced by a factor $(1 + \beta A)$, as detailed below. A summary of the gain, feedback factor, and gain with feedback of Fig. 2 is provided for reference in Table 1.

Table 1

Parameters		**Feedback Types**			
		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:*

From Fig. 2a and Table 1;

$$A_f = \frac{V_o}{V_s} = \frac{V_o}{V_i + V_f} = \frac{V_o}{V_i + \beta V_o} = \frac{AV_i}{V_i + \beta AV_i},$$

The gain with feedback is:

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

➢ *Voltage-Shunt Feedback:*

From Fig. 2b and Table 1;

$$Af = \frac{V_o}{I_s} = \frac{V_o}{I_i + I_f} = \frac{V_o}{I_i + \beta V_o} = \frac{AI_i}{I_i + \beta AI_i},$$

The gain with feedback is:

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

➢ *Current-Series Feedback:*

From Fig. 2c and Table 1;

$$Af = \frac{I_o}{V_s} = \frac{I_o}{V_i + V_f} = \frac{I_o}{V_i + \beta I_o} = \frac{AV_i}{V_i + \beta AV_i},$$

The gain with feedback is:

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

➢ *Current-Shunt Feedback:*

From Fig.2d and Table 1;

$$Af = \frac{I_o}{I_s} = \frac{I_o}{I_i + I_f} = \frac{I_o}{I_i + \beta I_o} = \frac{AI_i}{I_i + \beta AI_i},$$

The gain with feedback is:

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

❖ *Input Impedance with Feedback:*

The input impedance for the connections of Fig. 2 is dependent on whether series or shunt feedback is used. For series feedback, the input impedance is increased, while shunt feedback decreases the input impedance.

➢ *Series Feedback:*

From Fig.3 with voltage-series feedback;

$$Z_{if} = \frac{V_s}{I_i} = \frac{V_i + V_f}{I_i} = \frac{V_i + \beta V_o}{I_i} = \frac{V_i + \beta AV_i}{I_i} = Z_i + (\beta A)Z_i,$$

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

The input impedance with series feedback is seen to be the value of the input impedance without feedback multiplied by the factor $(1 + \beta A)$ and applies to both voltage-series (Fig.2a) and current-series (Fig.2c) configurations.

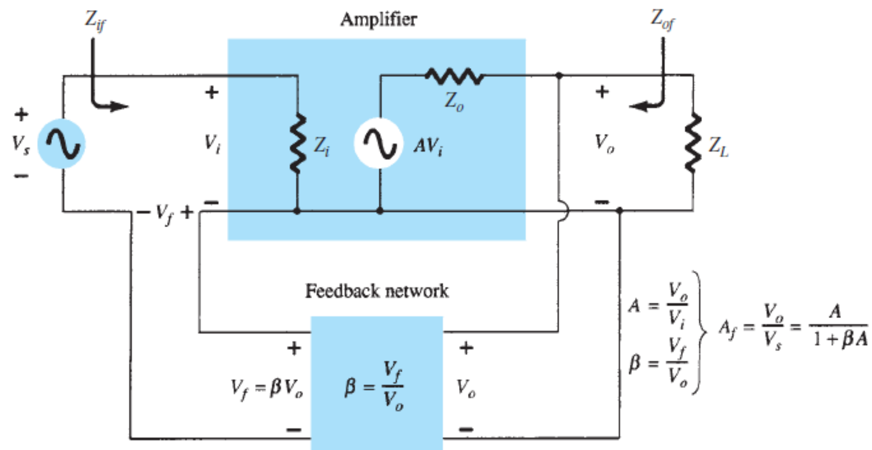


Fig.3

- ***Shunt Feedback:***

From Fig.4 with voltage-shunt feedback;

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

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

This reduced input impedance applies to the voltage-shunt connection of Fig.2b and the current-shunt connection of Fig.2d.

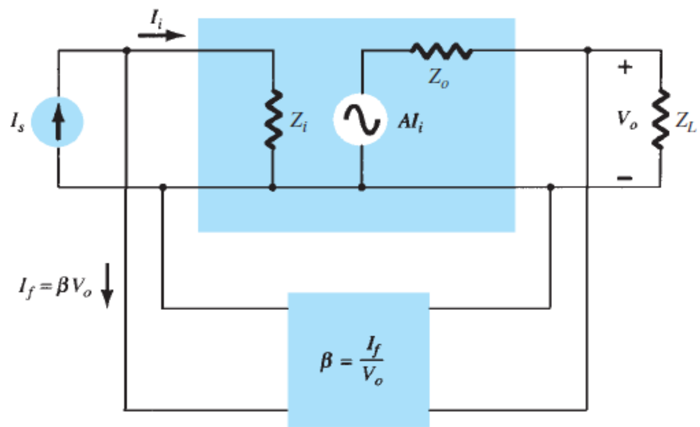


Fig.4

❖ *Output Impedance with Feedback:*

The output impedance for the connections of Fig.2 is dependent on whether voltage or current feedback is used. For voltage feedback, the output impedance is decreased, while current feedback increases the output impedance.

➢ *Voltage Feedback:*

For the voltage-series feedback circuit of Fig.3, the output impedance is determined by applying a voltage, V, resulting in a current, I, with V_s shorted out ($V_s = 0$). The voltage V is then

$$V = IZ_o + AV_i,$$

$$V_i = -V_f \; for \; V_s = 0,$$

$$V = IZ_o - AV_f = IZ_o - A(\beta V) => V + A(\beta V) = IZ_o,$$

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

The above equation shows that with voltage feedback the output impedance is reduced from that without feedback by the factor $(1 + \beta A)$.

➢ ***Current Feedback:***

From Fig.5 with current-series feedback;

$$V_i = V_f \quad for\ V_s = 0,$$

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

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

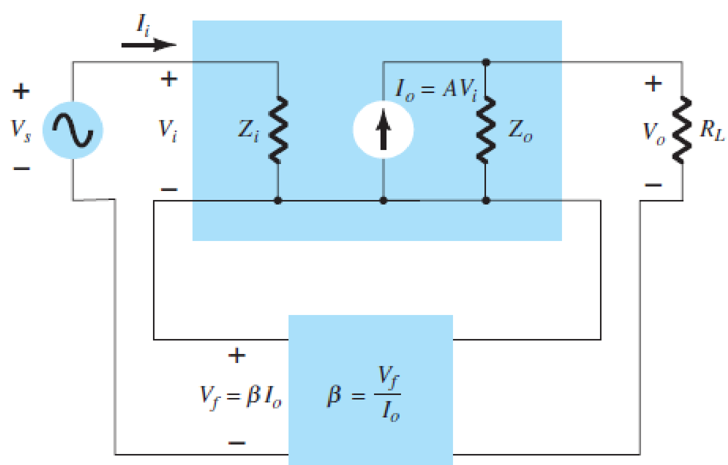


Fig.5

A summary of the effect of feedback on input and output impedance is provided in Table 2.

Table 2

Impedances		**Feedback Types**			
		Voltage-series	Voltage- shunt	Current-series	Current- shunt
Input	Z_{if}	$Z_i(1+\beta A)$ (increased)	$\frac{Z_i}{(1+\beta A)}$ (decreased)	$Z_i(1+\beta A)$ (increased)	$\frac{Z_i}{(1+\beta A)}$ (decreased)
Output	Z_{of}	$\frac{Z_o}{(1+\beta A)}$ (decreased)	$\frac{Z_o}{(1+\beta A)}$ (decreased)	$Z_o(1+\beta A)$ (increased)	$Z_o(1+\beta A)$ (increased)

❖ ***Gain Stability (Sensitivity and Desensitivity) with Feedback:***

The fractional change in amplification with feedback divided by the fractional change without feedback is called the *sensitivity* of the gain. If the equation $A_f = A/(1+\beta A)$ is differentiated with respect to A, the absolute value of resulting equation is:

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

Hence the sensitivity is $1/|1+\beta A|$. This shows that magnitude of the relative change in gain with feedback is reduced by the $|1+\beta A|$ compared to that without feedback. The reciprocal of sensitivity is called the desensitivity D, or

$$D = 1 + \beta A$$

The fractional change in gain without feedback is divided by the *desensitivity D* when feedback is added.

In particular, if $|\beta A|$ >>1, then

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

and the gain may be made to depend entirely on the feedback network. The worst offenders with respect to stability are usually the active devices (transistors) involved. If the feedback network contains only stable passive elements, the improvement in stability may indeed be pronounced.

❖ *Bandwidth with Feedback:*

Fig. 6 shows that the amplifier with negative feedback has more bandwidth (β_f) than the amplifier without feedback *(β)*. The feedback amplifier has a higher upper 3-dB frequency and smaller lower 3-dB frequency.

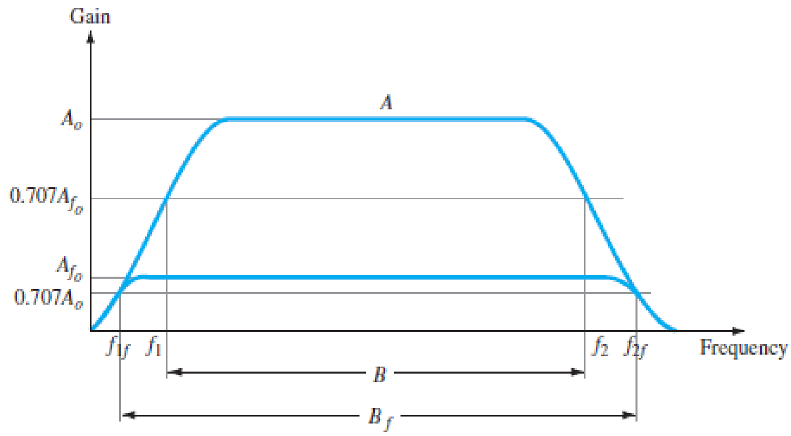


Fig.6

❖ *Method of Analysis of a Feedback Amplifier:*

It is desirable to separate the feedback amplifier into two blocks, the basic amplifier *A* and the feedback network *β*, because with a knowledge of *A* and *β*, we can calculate the important parameters of the feedback amplifier, namely, *Af*, *Zif*, and *Zof*. The basic amplifier configuration without feedback but taking the loading of the *β* network into account is obtained by applying the following rules:

To find the input circuit:

1. Set $V_o = 0$ for voltage feedback (sampling). In other words, short the output node.

2. Set $I_o = 0$ for current feedback (sampling). In other words, open the output loop.

To find the output circuit:

1. Set Vi = 0 for shunt feedback. In other words, short the input node.

2. Set Ii = 0 for series feedback. In other words, open the input loop.

Table 3 summarizes the above procedure and should be referred to when carrying out the analyses of the feedback circuits discussed in the following examples.

Table 3

Parameters	**Feedback Types**			
	Voltage-series	Voltage- shunt	Current-series	Current- shunt
Sampled signal X_o	Voltage (shunt)	Voltage (shunt)	Current (series)	Current (series)
Feedback signal X_f	Voltage (series)	Current (shunt)	Voltage (series)	Current (shunt)
To find input loop, set	$V_o = 0$	$V_o = 0$	$I_o = 0$	$I_o = 0$
To find output loop, set	$I_i = 0$	$V_i = 0$	$I_i = 0$	$V_i = 0$
Signal source	Thevenin	Norton	Thevenin	Norton
$A = X_o/X_i$	$A_v = V_o/V_i$	$A_z = V_o/I_i$	$A_g = I_o/V_i$	$A_i = I_o/I_i$
$\beta = X_f/X_o$	$\beta_v = V_f/V_o$	$\beta_g = I_f/V_o$	$\beta_z = V_f/I_o$	$\beta_i = I_f/I_o$
$D = 1 + \beta A$	$1 + \beta_v A_v$	$1 + \beta_g A_z$	$1 + \beta_z A_g$	$1 + \beta_i A_i$
A_f	A_v/D	A_z/D	A_g/D	A_i/D
Z_{if}	$Z_i\, D$	Z_i/D	$Z_i\, D$	Z_i/D
Z_{of}	Z_o/D	Z_o/D	$Z_o\, D$	$Z_o\, D$

Example (1):- Calculate A_{vf} , Z_{if} ,and Z_{of} for the amplifier of Fig.1(a). Assume $h_{fe} = 50$, $h_{ie} = 1.1\text{k}\Omega$, $h_{re} = h_{oe} = 0$, and identical transistors?

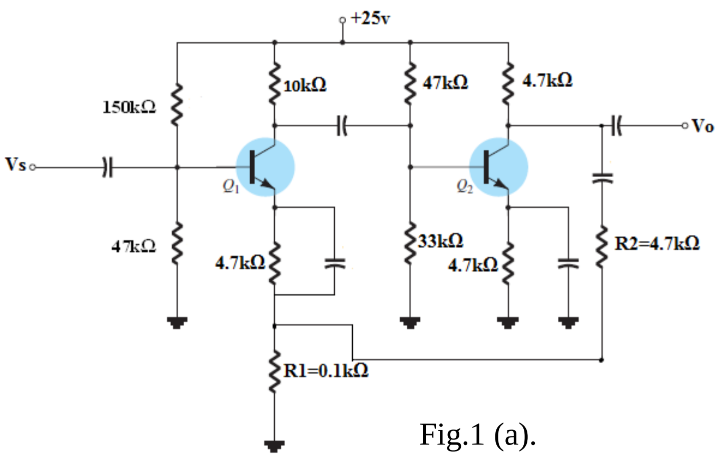


Fig.1 (a).

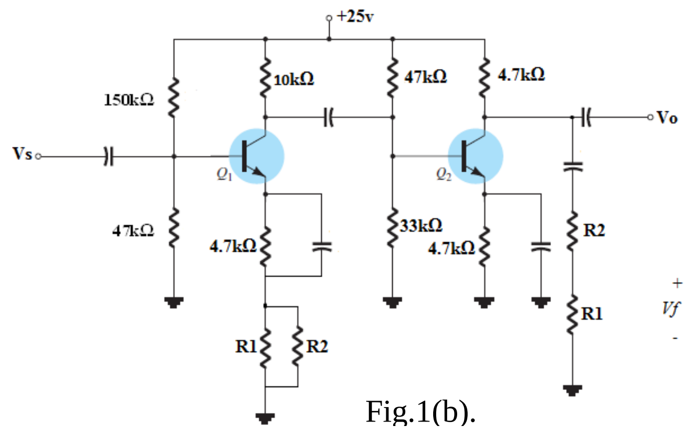


Fig.1(b).

Solution: this is (voltage-Series feedback) type.

$R_{L1} = 10k \| 47k \| 33k \| 1.1k = 942\Omega$, $\quad R_{E1} = R_1 \| R_2 = 0.1k \| 4.7k = 98\Omega$

$$A_{v1} = \frac{-h_{fe} R_{L1}}{h_{ie} + h_{fe} R_{E1}} = \frac{-50(942)}{1.1k + 50(98)} = -7.8$$

$R_{L2} = 4.7k \| (4.7k + 0.1k) = 2.37k\Omega$, $\quad A_{v2} = \frac{-h_{fe} R_{L2}}{h_{ie}} = \frac{-50(2.37k)}{1.1k} = -1.8$

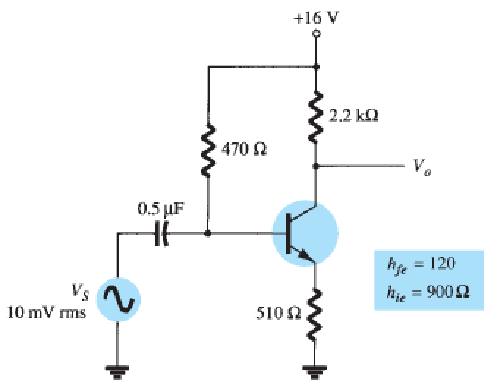
$$A_v = \frac{V_o}{V_i} = A_{v1} A_{v2} = (-7.8)(-1.8) = 842 \text{ , } \beta_v = \frac{V_f}{V_o} = \frac{R_1}{R_1 + R_2} = \frac{1.1k}{0.1k + 4.7k} = \frac{1}{48} = 0.0208$$

$D = 1 + \beta_v A_v = 1 + (842)(0.0208) = 18.5$, $\quad A_{vf} = \frac{A_v}{D} = \frac{842}{18.5} = 45.5$

$Z_i = h_{ie} + h_{fe} R_{E1} = 1.1k + 50(98) = 6k\Omega$, $\quad Z_{if} = Z_i D = 6k(18.5) = 111k\Omega$

$Z_o = R_{L2} = 2.37k\Omega$, $\quad Z_{of} = \frac{Z_o}{D} = \frac{2.37k}{18.5} = 128\Omega$

Example (2):- Calculate A_{vf} , Z_{if} ,and Z_{of} for the amplifier of Fig.2(a) Assume h_{fe} = 120, h_{ie} = 900Ω , and identical transistors?



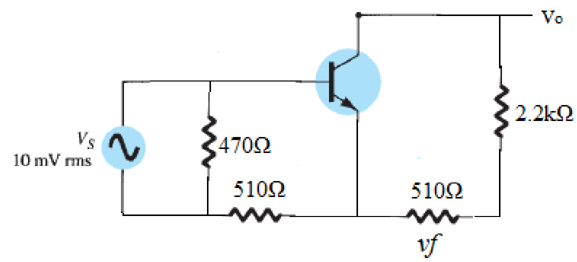


Fig.2 (b).

Solution: this is (Current-Series feedback) type.

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

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

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

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

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

$$Z_i = R_B \| (h_{ie} + R_E) = 470\Omega \| (900\Omega + 510\Omega) = 352.5\Omega$$

$$Z_{if} = Z_i D = 352.2 \times 44.35 = 15.62k\Omega$$

$$Z_o = R_C = 2.2k\Omega$$

$$Z_{of} = Z_o D = 2.2k\Omega \times 44.35 = 97.57k\Omega$$

Example (3):- Calculate A_{vf} , Z_{if} ,and Z_{of} for the amplifier of Fig.3(a) ,Assume h_{fe} = 50, h_{ie} = 1.1kΩ , and identical transistors?

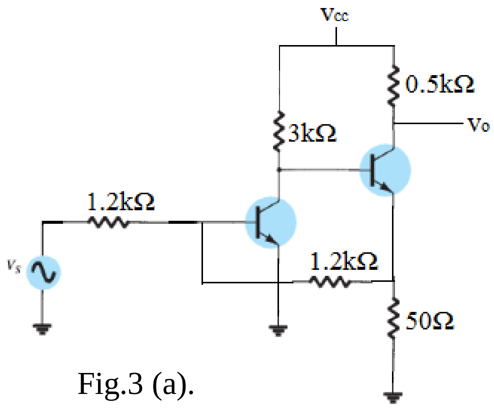


Fig.3 (a).

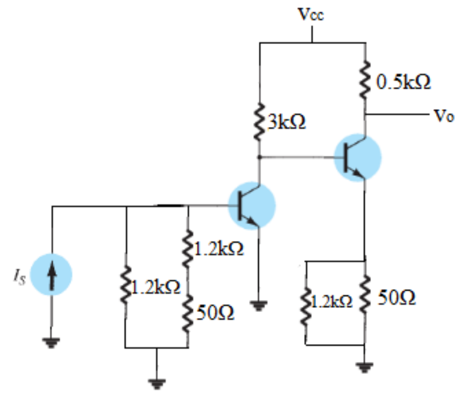


Fig.3 (b).

Solution: this is (Current-Shunt feedback) type.

$$Z_{i2} = h_{ie} + h_{fe}(R_{E2} \| R_F) = 1.1k + 50(50\|1.2k) = 3.5k\Omega$$

$$R = R_S \| (R_F + R_{E2}) = 1.2k\|(1.2k + 50) = 1.2k\|1.25k = 612\Omega$$

$$A = \frac{I_o}{I_i} = \frac{-I_{C2}}{I_S} = \frac{-I_{C2}}{I_{b2}} . \frac{I_{b2}}{I_{c1}} . \frac{I_{c1}}{I_{b1}} . \frac{I_{b1}}{I_s} = -h_{fe} . \frac{-R_{C1}}{R_{C1} + Z_{i2}} . h_{fe} . \frac{R}{R + h_{ie}}$$

$$= (-50)\left(\frac{-3k}{3k + 3.5k}\right)(50)\left(\frac{612}{612 + 1.1k}\right) = (-50)(-0.462)(50)(0.358) = 413$$

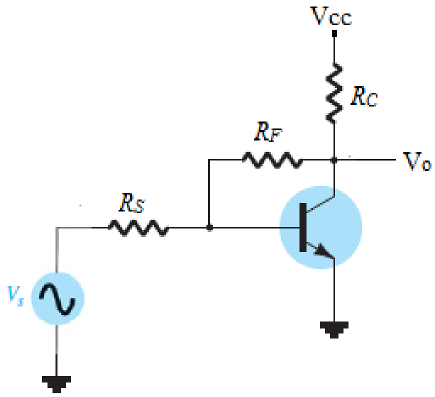
$$\beta = \frac{I_f}{I_o} = \frac{R_{E2}}{R_F + R_{E2}} = \frac{50}{1.2k + 50} = \frac{50}{1250} = 0.04, D = 1 + \beta A = 1 + (0.04)(413) = 17.5$$

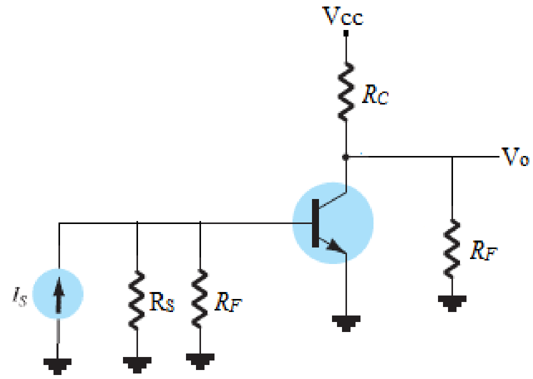
$$A_f = \frac{A}{D} = \frac{413}{17.5} = 23.6 , \qquad A_{vf} = \frac{V_o}{V_S} = \frac{-I_{C2}R_{C2}}{I_S R_S} = \frac{A_f R_{C2}}{R_S} = \frac{(23.6)(0.5k)}{1.2k} = 9.8$$

$$Z_{i1} = R \| h_{ie} = 612\|1.1k = 393\Omega , \qquad Z_{if} = \frac{Z_{i1}}{D} = \frac{393}{17.5} = 23\Omega$$

$$Z_o = R_{C2} = 0.5k \ , \qquad Z_{of} = Z_o D = (0.5k)(17.5) = 8.75k\Omega$$

Example (4):- Calculate A_{vf} , Z_{if} ,and Z_{of} for the amplifier of Fig.4(a), has the following parameters : $R_C = 4\text{k}\Omega$, $R_F = 40\text{k}\Omega$, $R_S = 10\text{k}\Omega$, $h_{fe} = 50$, $h_{ie} = 1.1\text{k}\Omega$, and identical transistors?





Solution: this is (Voltage-Shunt feedback) type.

$$R_B = R_S \| R_F = 10k \| 40k = 8k\Omega$$

$$R_L = R_C \| R_F = 4k \| 40k = 3.64k\Omega$$

$$A = \frac{V_O}{I_i} = \frac{V_o}{I_S} = \frac{-h_{fe} I_b R_L}{I_S} = \frac{-h_{fe} R_L R_B}{R_B + h_{ie}} = \frac{(-50)(3.64k)(8k)}{8k + 1.1k} = -160k$$

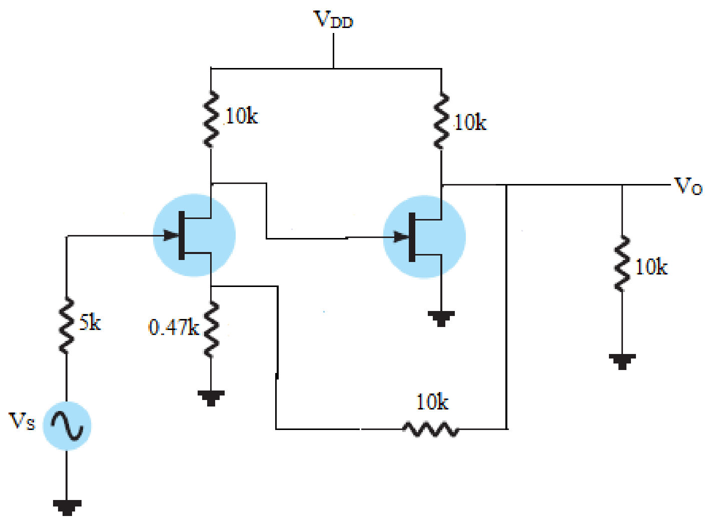
$$\beta = \frac{I_f}{V_o} = -\frac{1}{R_F} = -\frac{1}{40k} = -0.025 , \qquad D = 1 + \beta A = 1 + (-0.025)(-160) = 5$$

$$A_f = \frac{A}{D} = \frac{-160}{5} = -32k , \qquad A_{vf} = \frac{V_o}{V_s} = \frac{V_o}{I_s R_s} = \frac{A_f}{R_s} = \frac{-32k}{10k} = -3.2$$

$$Z_i = R_B \| h_{ie} = 8k \| 1.1k = 967\Omega , \qquad Z_{if} = \frac{Z_i}{D} = \frac{967}{5} = 193\Omega$$

$$Z_o = R_L = 3.64k\Omega , \qquad Z_{of} = \frac{Z_o}{D} = \frac{3.64k}{5} = 728\Omega$$

H.W:- Calculate A_{vf} , Z_{if} ,and Z_{of} for the amplifier circuit shown , given : g_m = 1mv , r_d = 20k



H.W :- Calculate A_{vf} , Z_{if} ,and Z_{of} for the amplifier circuit ,Assume h_{fe} = 50, h_{ie} = 1.1kΩ , and identical transistors?