1 Feedback Amplifiers

1.1 Introduction

Feedback plays an important role in almost all electronic circuits. It is almost invariably used in the amplifier to improve its performance and to make it more ideal. In the process of feedback, a part of output is sampled and fed back to the input of the amplifier. Therefore, at input we have two signals : Input signal, and part of the output which is fed back to the input. Both these signals may be in phase or out of phase. When input signal and part of output signal are in phase, the feedback is called positive feedback. On the other hand, when they are in out of phase, the feedback is called negative feedback. Use of positive feedback results in oscillations and hence not used in amplifiers.

In this chapter, we introduce the concept of feedback and show how to modify the characteristics of an amplifier by combining a portion or part of the output signal with the input signal. We also study the analysis of various feedback amplifiers.

1.2 Classification of Amplifiers

Before proceeding with the concepts of feedback, it is useful to understand the classification of amplifiers based on the magnitudes of the input and output impedances of an amplifier relative to the source and load impedances, respectively. The amplifiers can be classified into four broad categories : voltage, current, transconductance and transresistance amplifiers.

1.2.1 Voltage Amplifier

Fig. 1.1 shows a Thevenin's equivalent circuit of an amplifier.

If the amplifier input resistance R_i is large compared with the source resistance R_s then $V_i \approx V_s$. If the external load resistance R_L is large compared with the output resistance R_o of the amplifier, then $V_o \approx A_v V_i \approx A_v V_s$. Such amplifier circuit provides a voltage output proportional to the voltage input, and the proportionality factor does not depend on the magnitudes of the source and load resistances. Hence, this amplifier is called voltage amplifier. An ideal voltage amplifier must have infinite input resistance R_i and

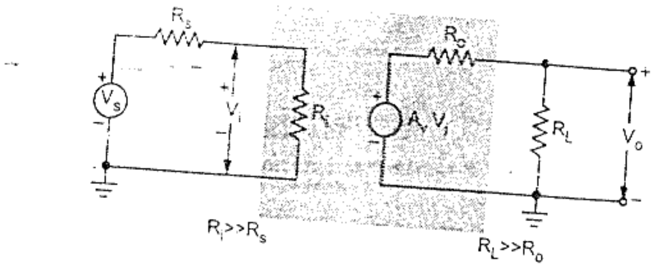


Fig. 1.1 Thevenin's equivalent circuits of a voltage amplifier

zero output resistance R_o. For practical voltage amplifier we must have $R_i >> R_s$ and $R_L >> R_o$.

1.2.2 Current Amplifier

Fig. 1.2 shows Norton's equivalent circuit of a current amplifier. If amplifier input resistance $R_i \to 0$, then $I_i \approx I_s$. If amplifier output resistance $R_o \to \infty$, then $I_L = A_i I_i$. Such amplifier provides a current output proportional to the signal current, and the proportionality factor is independent of source and load resistances. This amplifier is called current amplifier. An ideal current amplifier must have zero input resistance R_i and infinite output resistance R_o. For practical current amplifier we must have $R_i << R_s$ and $R_o >> R_L$.

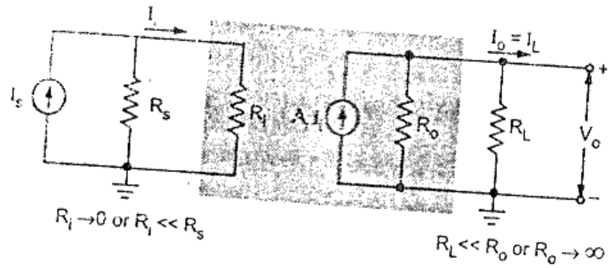


Fig. 1.2 Norton's equivalent circuits of a current amplifier

1.2.3 Transconductance Amplifier

Fig. 1.3 shows a transconductance amplifier with a Thevenin's equivalent in its input circuit and Norton's equivalent in its output circuit. In this amplifier, an output current is proportional to the input signal voltage and the proportionality factor is independent of the magnitudes of the source and load resistances. Ideally, this amplifier must have an infinite input resistance R_i and infinite output resistance R_o. For practical transconductance amplifier we must have $R_i >> R_s$ and $R_o >> R_L$.

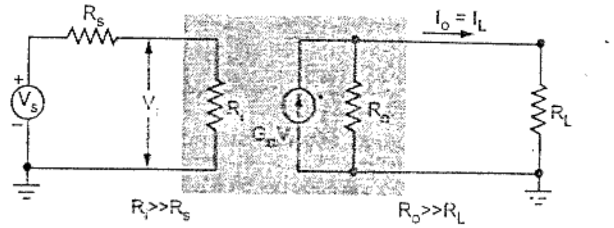


Fig. 1.3 Transconductance amplifier

1.2.4 Transresistance Amplifier

Fig. 1.4 shows a transresistance amplifier with a Norton's equivalent in its input circuit and a Thevenin's equivalent in its output circuit. In this amplifier an output voltage is proportional to the input signal current and the proportionality factor is independent on the source and load resistances. Ideally, this amplifier must have zero input resistance R_i and zero output resistance R_o. For practical transresistance amplifier we must have $R_i << R_s$ and $R_o << R_L$.

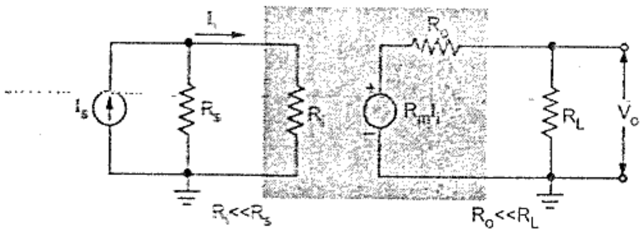


Fig. 1.4

1.3 Block Diagram

In the previous section we have seen four basic amplifier types and their ideal characteristics. In each one of these circuits we can sample the output voltage or current by means of a suitable sampling network and apply this signal to the input through a feedback two port network, as shown in the Fig. 1.5. At the input the feedback signal is combined with the input signal through a mixer network and is fed into the amplifier.

As shown in the Fig. 1.5 feedback connection has three networks :

- Sampling Network
- Feedback Network
- Mixer Network

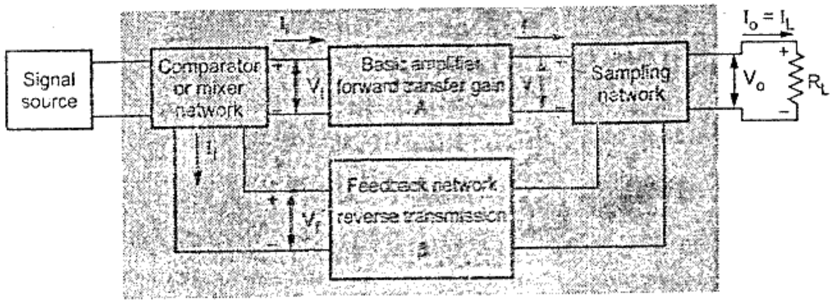
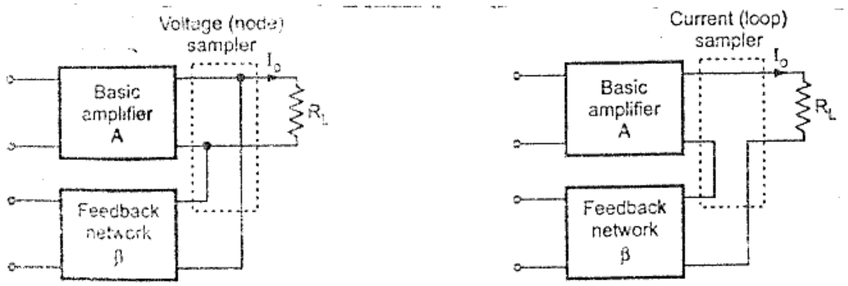


Fig. 1.5 Block diagram of amplifier with feedback

1.3.1 Sampling Network

There are two ways to sample the output, according to the sampling parameter, either voltage or current. The output voltage is sampled by connecting the feedback network in shunt across the output, as shown in the Fig. 1.6 (a). This type of connection is referred to as voltage, or node, sampling. The output current is sampled by connecting the feedback network in series with the output as shown in the Fig. 1.6 (b). This type of connection is referred to as current, or loop, sampling.



(a) Voltage or node sampling

(b) Current or loop sampling

Fig. 1.6

1.3.2 Feedback Network

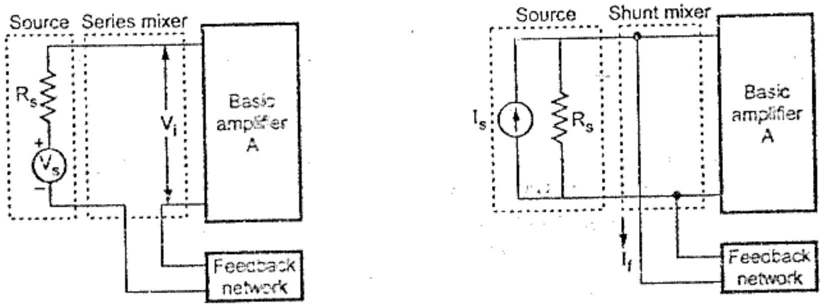
It may consists of resistors, capacitors, and inductors. Most often it is simply a resistive configuration. It provides reduced portion of the output as feedback signal to the input mixer network. It is given as

$$V_f = \beta V_o$$

where β is a **feedback factor** or **feedback ratio.** The symbol β used in feedback circuits represents feedback factor which always lies between 0 and 1. It is totally different from β symbol used to represent current gain in common emitter amplifier, which is greater than 1.

1.3.3 Mixer Network

Like sampling, there are two ways of mixing feedback signal with the input signal. These are : series input connection and shunt input connection. The Fig. 1.7 (a) and (b) show the simple and very common **series (loop)** input and **shunt (node)** input connections, respectively.



(a) Series mixing

(b) Shunt mixing

Fig. 1.7

1.3.4 Transfer Ratio or Gain

In Fig. 1.5, the ratio of the output signal to the input signal of the basic amplifier is represented by the symbol A. The suffix of A given next, represents the different transfer ratios.

$$\frac{V}{V_i} = A_v = \text{Voltage gain} \quad \dots (1)$$

$$\frac{I}{I_i} = A_i = \text{Current gain} \quad \dots (2)$$

$$\frac{I}{V_i} = G_m = \text{Transconductance} \quad \dots (3)$$

$$\frac{V}{I_i} = R_m = \text{Transresistance} \quad \dots (4)$$

The four quantities A_v, A_i, G_m and R_m are referred to as a transfer gain of the basic amplifier without feedback and use of only symbol A represent any one of these quantities.

The transfer gain with feedback is represented by the symbol A_f. It is defined as the ratio of the output signal to the input signal of the amplifier configuration shown in Fig. 1.5. Hence A_f is used to represent any one of the following four ratios :

$$\frac{V_o}{V_s} = A_{Vf} = \text{Voltage gain with feedback} \quad \text{... (5)}$$

$$\frac{I_o}{I_s} = A_{If} = \text{Current gain with feedback} \quad \text{... (6)}$$

$$\frac{I_o}{V_s} = G_{Mf} = \text{Transconductance with feedback} \quad \text{... (7)}$$

$$\frac{V_o}{I_s} = R_{Mf} = \text{Transresistance with feedback} \quad \text{... (8)}$$

Fig. 1.8 shows the schematic representation of a feedback connection around a basic amplifier. Recall that, when part of output signal and input signal are in out of phase the feedback is called **negative feedback**. The schematic diagram shown in Fig. 1.8 represents negative feedback because the feedback signal is fed back to the input of the amplifier out of phase with input signal of the amplifier.

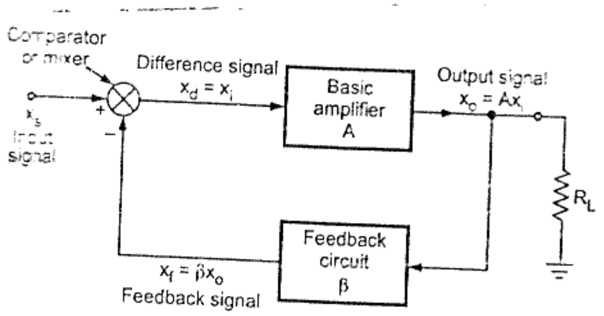


Fig. 1.8 Schematic representation of negative feedback amplifier

1.4 Advantages of Negative Feedback

It is possible to improve important characteristics of four basic amplifier types discussed in section 1.2 by the proper use of negative feedback.

- Normally high input resistance of a voltage amplifier can be made higher.
- Normally low output resistance of a voltage amplifier can be lowered.

- The transfer gain A_f of the amplifier with feedback can be stablized against variations of the h or hybrid-π parameters of the transistor or the parameters of the other active devices used in the amplifier.
- The proper use of negative feedback improves frequency response of the amplifier.
- There is a significant improvement in the linearity of operation of the feedback amplifier compared with that of the amplifier without feedback.

Key Point : *All the advantages mentioned above are obtained at the expense of the gain A_f with feedback, which is lowered in comparison with the transfer gain A of an amplifier without feedback.*

1.5 The Four Basic Feedback Topologies

The basic amplifier shown in Fig. 1.8 may be a voltage, current, transconductance, or transresistance amplifier. These can be connected in a feedback configuration as shown in the Fig. 1.9.

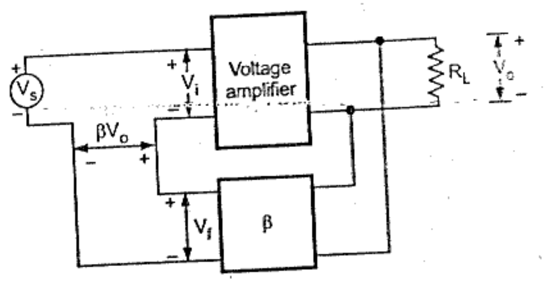


Fig. 1.9 (a) Voltage amplifier with voltage series feedback

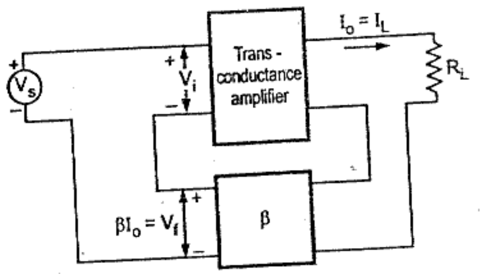


Fig. 1.9 (b) Transconductance amplifier with current series feedback

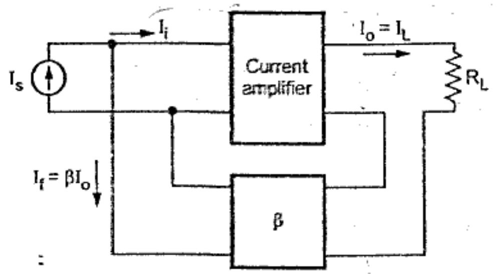


Fig. 1.9 (c) Current amplifier with current-shunt feedback

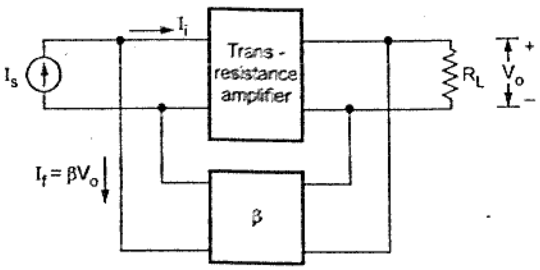


Fig. 1.9 (d) Transresistance amplifier with voltage shunt feedback

1.6 Gain with Feedback

We have seen, the symbol A is used to represent transfer gain of the basic amplifier without feedback and symbol A_f is used to represent transfer gain of the basic amplifier with feedback. These are given as

$$A = \frac{X_o}{X_i} \quad \text{and} \quad A_f = \frac{X_o}{X_s}$$

where X_o = Output voltage or output current

X_i = Input voltage or input current

X_s = Source voltage or source current

As it is a negative feedback the relation between X_i and X_s is given as

$$X_i = X_s + (-X_f)$$

where X_f = Feedback voltage or feedback current

$$\therefore \quad A_f = \frac{X_o}{X_s} = \frac{X_o}{X_i + X_f}$$

Dividing by X_i to numerator and denominator we get,

$$A_f = \frac{X_o / X_i}{(X_i + X_f) / X_i}$$

$$= \frac{A}{1 + X_f / X_i} \quad \because A = \frac{X_o}{X_i}$$

$$= \frac{A}{1 + (X_f / X_o)(X_o / X_i)}$$

$$\therefore \quad A_f = \frac{A}{1 + \beta A} \quad \because \beta = \frac{X_f}{X_o} \quad \text{... (1)}$$

where β is a feedback factor

Looking at equation we can say that gain without feedback (A) is always greater than gain with feedback (A/(1 + β A)) and it decreases with increase in β i.e. increase in feedback factor.

For voltage amplifier, gain with negative feedback is given as

$$\boxed{A_{vf} = \frac{A_v}{1 + A_v \beta}} \quad \text{... (2)}$$

where A_v = Open loop gain i.e. gain without feedback

β = Feedback factor

1.6.1 Loop Gain

The diference signal, X_d in Fig. 1.8 is multiplied by A in passing through the amplifier, is multiplied by β in transmission through the feedabck network, and is multiplied by − 1 in the mixing or difference network. A path of a signal from input terminals through basic amplifier, through the feedback network and back to the input terminals forms a loop. The gain of this loop is the product −Aβ. This gain is known as loop gain or return ratio.

1.6.2 Desensitivity of Gain

The transfer gain of the amplifier is not constant as it depends on the factors such as operating point, temperature, etc. This lack of stability in amplifiers can be reduced by introducing negative feedback.

We know that,

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

Differentiating both sides with respect to A we get,

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

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

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

Dividing both sides by A_f we get,

$$\frac{dA_f}{A_f} = \frac{dA}{(1-\beta A)^2} \times \frac{1}{A_f}$$

$$= \frac{dA}{(1-\beta A)^2} \times \frac{(1+\beta A)}{A} \qquad \text{since } A_f = \frac{A}{1+\beta A}$$

$$\left|\frac{dA_f}{A_f}\right| = \left|\frac{dA}{A}\right| \frac{1}{|(1+\beta A)|} \qquad \text{... (3)}$$

where

$\frac{dA_f}{A_f}$ = Fractional change in amplification with feedback

$\frac{dA}{A}$ = Fractional change in amplification without feedback

Looking at equation (3) we can say that change in the gain with feedback is less than the change in gain without feedback by factor $(1+\beta A)$. The fractional change in amplification with feedback divided by the fractional change without feedback is called the **sensitivity of the transfer gain**. Hence the sensitivity is $\frac{1}{(1+\beta A)}$. The reciprocal of the sensitivity is called the **desensitivity** D. It is given as

$$D = 1 + \beta A$$

Therefore, stability of the amplifier increases with increase in desensitivity.

If $\beta A >> 1$, then

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

$$= \frac{1}{\beta} \qquad \text{... (4)}$$

and the gain is dependent only on the feedback network.

Since A represents either A_V, G_M, A_I or R_M and A_f represents the corresponding transfer gains with feedback either A_{Vf}, G_{Mf}, A_{If} or R_{Mf} the equation signifies that :

- For voltage series feedback

$$A_{Vf} = \frac{1}{\beta} \quad \text{voltage gain is stabilized} \qquad \text{... (5)}$$

- For current series feed back

$$G_{Mf} = \frac{1}{\beta} \quad \text{transconductance gain is stabilized} \qquad \text{... (6)}$$

- For voltage shunt feedback

$$R_{Mf} = \frac{1}{\beta} \quad \text{transresistance gain is stabilized} \qquad \text{... (7)}$$

- For current shunt feedback

$$A_{If} = \frac{1}{\beta} \quad \text{Current gain is stabilized} \qquad \text{... (8)}$$

1.7 Cut Off Frequencies With Feedback

We know that,

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

Using this equation we can write,

$$A_{f\,mid} = \frac{A_{mid}}{1+\beta A_{mid}} \qquad \text{... (1)}$$

$$A_{f\,low} = \frac{A_{low}}{1+\beta A_{low}} \qquad \text{... (2)}$$

and

$$A_{f\,high} = \frac{A_{high}}{1+\beta A_{high}} \qquad \text{... (3)}$$

Now we analyse the effect of negative feedback on lower cutoff and upper cutoff frequency of the amplifier.

Lower cutoff frequency

We know that, the relation between gain at low frequency and gain at mid frequency, is given as,

$$\frac{A_{low}}{A_{mid}} = \frac{1}{1-j\left(\frac{f_L}{f}\right)} \quad \therefore A_{low} = \frac{A_{mid}}{1-j\left(\frac{f_L}{f}\right)} \qquad \text{... (4)}$$

Substituting value of A_{low} in equation (1) we get,

$$A_{f\,low} = \frac{\dfrac{A_{mid}}{1-j\left(\dfrac{f_L}{f}\right)}}{1+\beta\left(\dfrac{A_{mid}}{1-j\left(\dfrac{f_L}{f}\right)}\right)}$$

$$= \frac{A_{mid}}{1-j\left(\dfrac{f_L}{f}\right)+A_{mid}\beta}$$

$$= \frac{A_{mid}}{(1+A_{mid}\beta)-j\left(\dfrac{f_L}{f}\right)}$$

Dividing numerator and denominator by $(1+A_{mid}\beta)$ we get,

$$A_{f\,low} = \frac{\dfrac{A_{mid}}{1+A_{mid}\beta}}{1-j\left[\dfrac{\dfrac{f_L}{1+A_{mid}\beta}}{f}\right]}$$

$$= \frac{A_{f\,mid}}{1-j\left[\left(\dfrac{\dfrac{f_L}{1+A_{mid}\beta}}{f}\right)\right]} \quad \because A_f\,mid = \frac{A_{mid}}{1+A_{mid}\beta}$$

$$\therefore \quad \frac{A_{f\,low}}{A_{f\,mid}} = \frac{1}{1-j\left(\dfrac{f_{Lf}}{f}\right)} \qquad \ldots(5)$$

where

$$\text{Lower cutoff frequency with feedback} = f_{Lf} = \frac{f_L}{1+A_{mid}\beta} \qquad \ldots(6)$$

From equation (6), we can say that lower cutoff frequency with feedback is less than lower cutoff frequency without feedback by factor $(1+A_{mid}\beta)$. Therefore, by introducing negative feedback low frequency response of the amplifier is improved.

Upper Cutoff Frequency

We know that, the relation between gain at high frequency and gain at mid frequency is given as,

$$\frac{A_{high}}{A_{mid}} = \frac{1}{1-j\left(\dfrac{f}{f_H}\right)}$$

$$\therefore \quad A_{high} = \frac{A_{mid}}{1-j\left(\dfrac{f}{f_H}\right)} \qquad \ldots(7)$$

Substituting value of A_{high} in equation (11) we get,

$$A_f\,high = \frac{\dfrac{A_{mid}}{1-j\left(\dfrac{f}{f_H}\right)}}{1+\beta\left(\dfrac{A_{mid}}{1-j\left(\dfrac{f}{f_H}\right)}\right)} = \frac{A_{mid}}{1-j\left(\dfrac{f}{f_H}\right)+A_{mid}\beta}$$

Dividing numerator and denominator by $(1+A_{mid}\beta)$ we get,

$$A_{f\,high} = \frac{\dfrac{A_{mid}}{1+A_{mid}\beta}}{1-j\left[\dfrac{f}{(1+A_{mid}\beta)\,f_H}\right]}$$

$$A_{f\,high} = \frac{A_{f\,mid}}{1-j\left[\dfrac{f}{(1+A_{mid}\beta)\,f_H}\right]} \quad \because A_{f\,mid} = \frac{A_{mid}}{1+A_{mid}\beta}$$

$$= \frac{A_{f\,mid}}{1-j\left(\dfrac{f}{f_{Hf}}\right)}$$

where upper cutoff frequency with feedback is given as

$$f_{Hf} = (1+A_{mid}\beta)\,f_H \qquad \ldots(8)$$

From equation (8), we can say that upper cutoff frequency with feedback is greater than upper cutoff frequency without feedback by factor $(1+A_{mid}\beta)$. Therefore, by introducing negative feedback high frequency response of the amplifier is improved.

Bandwidth

The bandwidth of the amplifier is given as

$$BW = \text{Upper cutoff frequency} - \text{lower cutoff frequency}$$

∴ Bandwidth of the amplifier with feedback is given as

$$BW_f = f_{Hf} - f_{Lf} = (1 + A_{mid}\,\beta)\, f_H - \frac{f_L}{(1 + A_{mid}\,\beta)} \quad \ldots (9)$$

It is very clear that $(f_{Hf} - f_{Lf}) > (f_H - f_L)$ and hence bandwidth of amplifier with feedback is greater than bandwidth of amplifier without feedback, as shown in Fig. 1.10.

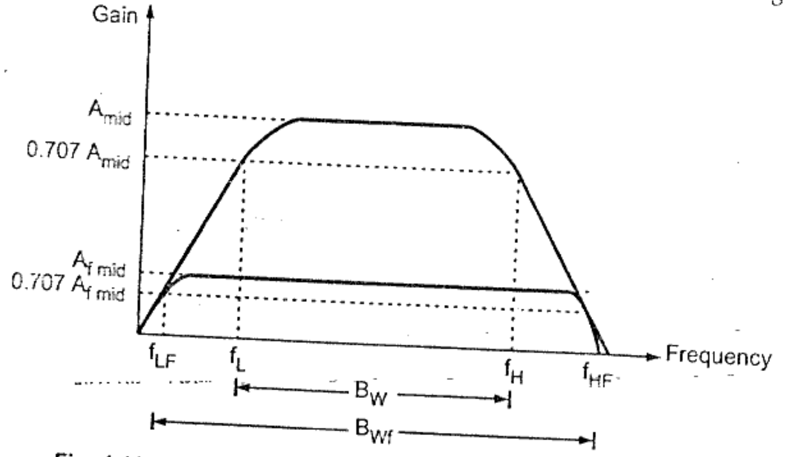


Fig. 1.10 Effect of negative feedback on gain and bandwidth

Key Point: *Since bandwidth with negative feedback increases by factor (1 + Aβ) and gain decreases by same factor, the gain-bandwidth product of an amplifier does not altered, when negative feedback is introduced.*

1.8 Distortion with Feedback

1.8.1 Frequency Distortion

From equation (8) of previous section 1.8 we can say that if the feedback network does not contain reactive elements, the overall gain is not a function of frequency. Under such conditions frequency and phase distortion is substantially reduced.

If β is made up of reactive components, the reactances of these components will change with frequency, changing the β. As a result, gain will also change with frequency. This fact is used in tuned amplifiers. In tuned amplifiers, feedback network is designed such that at tuned frequency $\beta \rightarrow 0$ and at other frequencies $\beta \rightarrow \infty$. As a result, amplifier provides high gain for signal at tuned frequency and relatively reject all other frequencies.

1.8.2 Noise and Nonlinear Distortion

Signal feedback reduces the amount of noise signal and non linear distortion. The factor (1 + βA) reduces both input noise and resulting nonlinear distortion for considerable improvement. Thus, noise and non linear distortion also reduced by same factor as the gain.

1.9 Input and Output Resistances

1.9.1 Input resistance

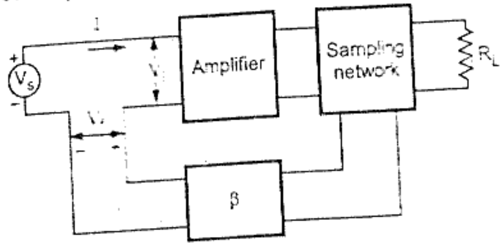


Fig. 1.11

If the feedback signal is added to the input in series with the applied voltage (regardless of whether the feedback is obtained by sampling the output current or voltage), it increases the input resistance. Since the feedback voltage V_f opposes V_s, the input current I_i is less than it would be if V_f were absent, as shown in the Fig. 1.11.

Hence, the input resistance with feedback $R_{if} = \frac{V_s}{I_i}$ is greater than the input resistance without feedback, for the circuit shown in Fig. 1.11.

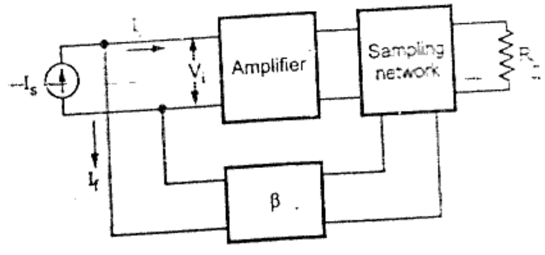


Fig. 1.12

On the otherhand, if the feedback signal is added to the input in shunt with the applied voltage (regardless of whether the feedback is obtained by sampling the output voltage or current), it decreases the input resistance. Since $I_s = I_i + I_f$, the current I_s drawn from the signal source is increased over what it would be if there were no feedback current, as shown in the Fig. 1.12.

Hence, the input resistance with feedback $R_{if} = \frac{V_i}{I_s}$ is decreased for the circuit shown in Fig. 1.12. Now we see the effect of negative feedback on input resistance in different topologies (ways) of introducing negative feedback and obtain R_{if} quantitatively.

Voltage series feedback

The voltage series feedback topology shown in Fig. 1.13 with amplifier is replaced by Thevenin's model. Here, A_v represents the open-circuit voltage gain taking R_s into account. since throughout the discussion of feedback amplifiers we will consider R_s to be part of the amplifier and we will drop the subscript on the transfer gain and input resistance (A_v instead of A_{vs} and R_{if} instead of R_{ifs}).

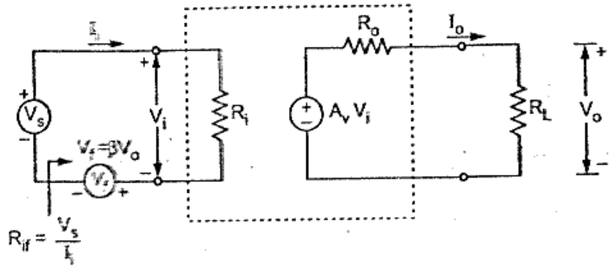


Fig. 1.13

Look at Fig. 1.13 the input resistance with feedback is given as

$$R_{if} = \frac{V_s}{I_i} \quad \text{... (1)}$$

Applying KVL to the input side we get,

$$V_s - I_i R_i - V_f = 0$$

$$\therefore \quad V_s = I_i R_i + V_f$$

$$= I_i R_i + \beta V_o \quad \text{... (2)}$$

The output voltage V_o is given as

$$V_o = \frac{A_v V_i R_L}{R_o + R_L}$$

$$= A_V I_i R_i = A_V V_i \quad \text{... (3)}$$

where $$A_V = \frac{V_o}{V_i}$$

$$= \frac{A_v R_L}{R_o + R_L}$$

Key Point: *A_v represents the open circuit voltage gain without feedback and A_V is the voltage gain without feedback taking the load R_L into account).*

Substituting value of V_o from equation (3) in equation (2) we get,

$$V_s = I_i R_i + \beta A_V I_i R_i$$

$$\therefore \quad \frac{V_s}{I_i} = R_i + \beta A_V R_i$$

$$\therefore \quad \boxed{R_{if} = R_i (1 + \beta A_V)} \quad \text{... (4)}$$

Current series feedback

The current series feedback topology is shown in Fig. 1.14 with amplifier input circuit is represented by Thevenin's equivalent circuit and output circuit by Norton's equivalent circuit.

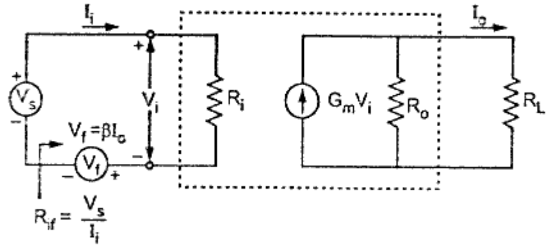


Fig. 1.14

Looking at Fig. 1.14 the input resistance with feedback is given as

$$R_{if} = \frac{V_s}{I_i}$$

Applying KVL to the input side we get,

$$V_s - I_i R_i - V_f = 0$$

$$\therefore \quad V_s = I_i R_i + V_f$$

$$= I_i R_i + \beta I_o \quad \text{... (5)}$$

The output current I_o is given as

$$I_o = \frac{G_m V_i R_o}{R_o + R_L} = G_M V_i \quad \text{... (6)}$$

where

$$G_M = \frac{G_m R_o}{R_o + R_L}$$

Key Point: *G_M represents the open circuit transconductance without feedback and G_M is the transconductance without feedback taking the load R_L into account.*

Substituting value of I_o from equation (6) into equation (5) we get,

$$V_s = I_i R_i + \beta G_M V_i$$

$$= I_i R_i + \beta G_M I_i R_i \quad \because V_i = I_i R_i$$

$$\frac{V_s}{I_i} = R_i\,(1+\beta G_M)$$

$$R_{if} = \frac{V_s}{I_i} = R_i\,(1+\beta G_M) \qquad \dots (7)$$

Current shunt feedback

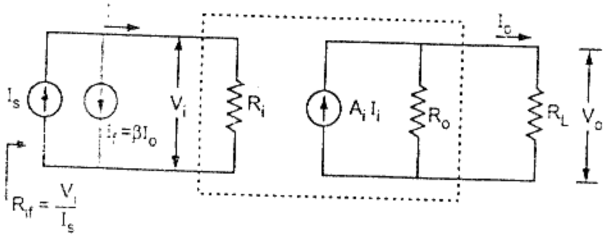


Fig. 1.15

The current shunt feedback topology is shown in Fig. 1.15 with amplifier input and output circuit replaced by Norton's equivalent circuit

Applying KCL to the input node we get

$$I_s = I_i + I_f$$

$$= I_i + \beta I_o \qquad \dots (8)$$

The output current I_o is given as

$$I_o = \frac{A_i\, I_i R_o}{R_o + R_L}$$

$$= A_I\, I_i \qquad \dots (9)$$

where $$A_I = \frac{A_i R_o}{R_o + R_L}$$

Key Point: A_i *represents the open circuit current gain without feedback and* A_I *is the current gain without feedback taking the load* R_L *into account.*

Substituting value of I_o from equation (9) into equation (8) we get,

$$I_s = I_i + \beta A_I I_i$$

$$= I_i\,(1+\beta A_I)$$

The input resistance with feedback is given as

$$R_{if} = \frac{V_i}{I_s} = \frac{V_i}{I_i\,(1+\beta A_I)}$$

$$R_{if} = \frac{R_i}{(1+\beta A_I)} \quad \because R_i = \frac{V_i}{I_i} \qquad \dots (10)$$

Voltage shunt feedback

The voltage shunt feedback topology is shown in Fig. 1.16 with amplifier input circuit is represented by Norton's equivalent circuit and output circuit represented by Thevenin's equivalent.

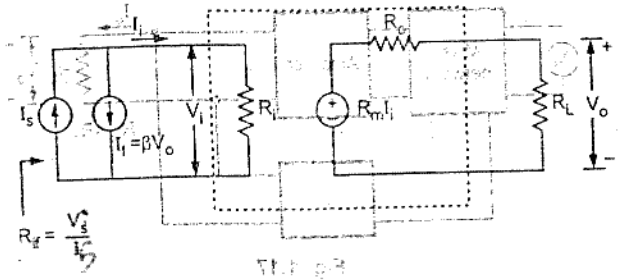


Fig. 1.16

Applying KCL at input node we get,

$$I_s = I_i + I_f$$

$$= I_i + \beta V_o \qquad \dots (11)$$

The output voltage V_o is given as

$$V_o = \frac{R_m\, I_i R_L}{R_o + R_L}$$

$$= R_M\, I_i \qquad \dots (12)$$

where $$R_M = \frac{R_m R_L}{R_o + R_L}$$

Key Point: R_m *represents the open circuit transresistance without feedback and* R_M *is the transresistance without feedback taking the load* R_L *into account.*

Substituting value of V_o from equation (12) into equation (11) we get,

$$I_s = I_i + \beta R_M I_i$$

$$= I_i\,(1+\beta R_M)$$

The input resistance with feedback R_{if} is given as

$$R_{if} = \frac{V_i}{I_s} = \frac{V_i}{I_i\,(1+\beta R_M)}$$

$$\therefore \quad R_{if} = \frac{R_i}{(1+\beta R_M)} \qquad \because R_i = \frac{V_i}{I_i} \qquad \ldots (13)$$

1.9.2 Output resistance

The negative feedback which samples the output voltage, regardless of how this output signal is returned to the input, tends to decrease the output resistance, as shown in the Fig. 1.17.

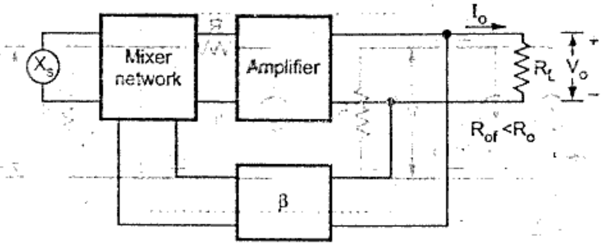


Fig. 1.17

On the other hand, the negative feedback which samples the output current, regardless of how this output signal is returned to the input, tends to increase the output resistance, as shown in the Fig. 1.18.

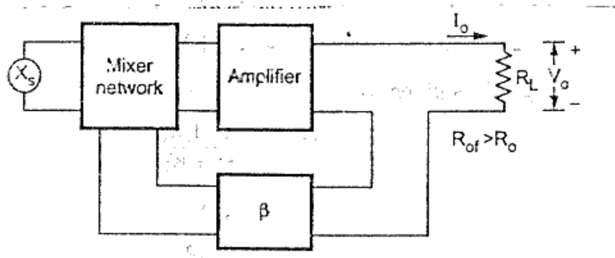


Fig. 1.18

Now, we see the effect of negative feedback on output resistance in different topologies (ways) of introducing negative feedback and obtain R_{of} quantitatively.

Voltage series feedback

In this topology, the output resistance can be measured by shorting the input source $V_s = 0$ and looking into the output terminals with R_L disconnected, as shown in the Fig. 1.19.

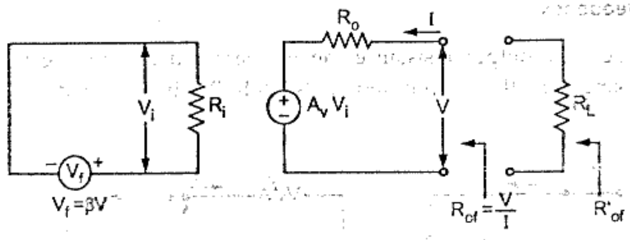


Fig. 1.19

Applying KVL to the output side we get,

$$A_V V_i + I R_o - V = 0$$

$$\therefore \quad I = \frac{V - A_V V_i}{R_o} \qquad \ldots (14)$$

The input voltage is given as

$$V_i = -V_f = -\beta V \qquad \because V_s = 0 \qquad \ldots (15)$$

Substituting the V_i from equation (32) in equation (31) we get,

$$I = \frac{V + A_V \beta V}{R_o} = \frac{V(1+\beta A_V)}{R_o}$$

$$\therefore \quad R_{of} = \frac{V}{I}$$

$$\therefore \quad R_{of} = \frac{R_o}{(1+\beta A_V)} \qquad \ldots (16)$$

Key Point: *Here A_V is the open loop voltage gain without taking R_L in account.*

$$R'_{of} = R_{of} \parallel R_L = \frac{R_{of} \times R_L}{R_{of} + R_L} = \frac{\left(\frac{R_o}{1+\beta A_V}\right) \times R_L}{\frac{R_o}{(1+\beta A_V)} + R_L}$$

$$= \frac{R_o R_L}{R_o + R_L(1+\beta A_V)} = \frac{R_o R_L}{R_o + R_L + \beta A_V R_L}$$

Dividing numerator and denominator by $(R_o + R_L)$ we get

$$R'_{of} = \frac{\frac{R_o R_L}{R_o + R_L}}{1 + \frac{\beta A_V R_L}{R_o + R_L}}$$

$$\therefore \quad R'_{of} = \frac{R'_L}{1+\beta A_V} \qquad \because R'_o = \frac{R_o R_L}{R_o + R_L} \text{ and } A_V = \frac{A_V R_L}{R_o + R_L} \qquad \ldots (17)$$

Key Point: *Here A_V is the open loop voltage gain taking R_L into account.*

Voltage shunt feedback

In this topology, the output resistance can be measured by shorting the input source $V_s = 0$ and looking into the output terminals with R_L disconnected, as shown in the Fig. 1.20.

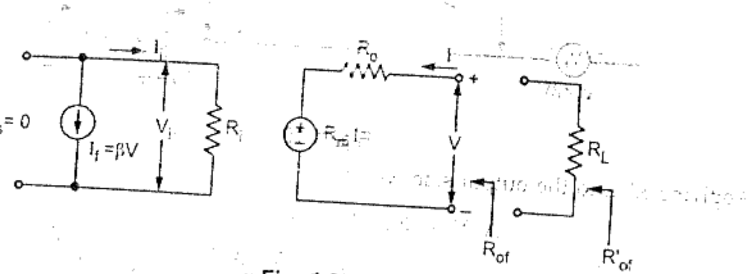


Fig. 1.20

Applying KVL to the output side we get,

$$R_m I_i + I R_o - V = 0$$

$$\therefore \quad I = \frac{V - R_m I_i}{R_o} \qquad \text{... (18)}$$

The input current is given as

$$I_i = -I_f = -\beta V. \qquad \text{... (19)}$$

Substituting I_i from equation (19) in equation (18) we get,

$$I = \frac{V + R_m \beta V}{R_o} = \frac{V(1 + R_m \beta)}{R_o}$$

$$\therefore \quad R_{of} = \frac{V}{I}$$

$$\therefore \quad \boxed{R_{of} = \frac{R_o}{1 + R_m \beta}} \qquad \text{... [20 (a)]}$$

Key Point: *Here, R_m is the open loop transresistance without taking R_L in account.*

$$R'_{of} = R_{of} \parallel R_L = \frac{R_{of} \times R_L}{R_{of} + R_L}$$

$$= \frac{\frac{R_o \times R_L}{1 + R_m \beta}}{\frac{R_o}{1 + R_m \beta} + R_L} = \frac{R_o R_L}{R_o + R_L (1 + R_m \beta)}$$

Dividing numerator and denominator by $R_o + R_L$ we get,

$$R'_{of} = \frac{\frac{R_o R_L}{R_o + R_L}}{1 + \frac{\beta R_m R_L}{R_o + R_L}}$$

$$\boxed{R'_{of} = \frac{R'_o}{1 + \beta R_m}} \qquad \text{... (20)}$$

Key Point: *Here, R_m is the open loop transresistance taking R_L in account.*

Current shunt feedback

In this topology, the output resistance can be measured by open circuiting the input source $I_s = 0$ and looking into the output terminals, with R_L disconnected, as shown in the Fig. 1.21.

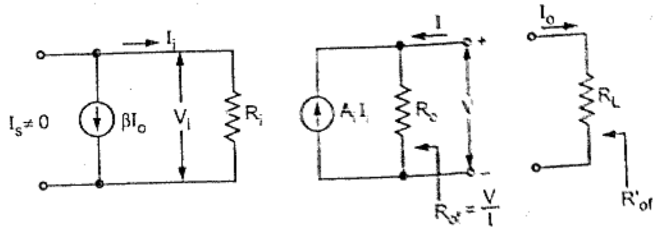


Fig. 1.21

Applying the KCL to the output node we get,

$$I = \frac{V}{R_o} - A_i I_i \qquad \text{... (21)}$$

The input current is given as

$$I_i = -I_f = -\beta I_o \qquad \because I_s = 0$$

$$= \beta I \qquad \because I = -I_o \qquad \text{... (22)}$$

Substituting value of I_i from equation (22) in equation (21) we get,

$$I = \frac{V}{R_o} - A_i \beta I$$

$$\therefore \quad I(1 + A_i \beta) = \frac{V}{R_o}$$

$$\therefore \quad \boxed{R_{of} = \frac{V}{I} = R_o (1 + \beta A_i)} \qquad \text{... (23)}$$

Key Point: *Here, A_i is the open loop current gain without taking R_L in account.*

$$R'_{of} = R_{of} \parallel R_L = \frac{R_{of} \times R_L}{R_{of} + R_L}$$

$$= \frac{R_o (1 + \beta A_i) R_L}{R_o (1 + \beta A_i) + R_L} = \frac{R_o R_L (1 + \beta A_i)}{R_o + R_L + \beta A_i R_o}$$

Dividing numerator and denominator by $R_o + R_L$ we get,

$$R'_{of} = \frac{\dfrac{R_o R_L (1+\beta A_i)}{R_o + R_L}}{1+\dfrac{\beta A_i R_o}{R_o + R_L}}$$

$$\therefore \quad \boxed{R'_{of} = \frac{R'_o (1+\beta A_I)}{(1+\beta A_I)}}$$

$$\because R'_o = \frac{R_o R_L}{R_o + R_L} \text{ and } A_I = \frac{A_i R_o}{R_o + R_L} \qquad \ldots(24)$$

Key Point: *Here, A_I is the open loop current gain taking R_L in account.*

Current series feedback

In this topology the output resistance can be measured by shorting the input source $V_i = 0$ and looking into the output terminals with R_L disconnected, as shown in the Fig. 1.22.

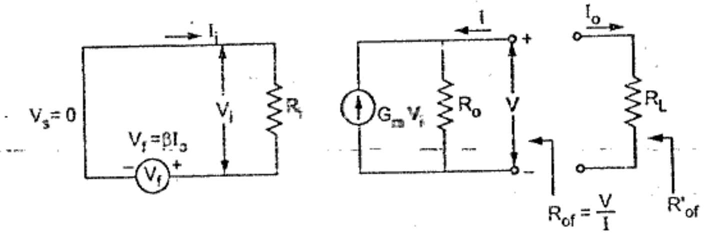


Fig. 1.22

Applying KCL to the output node we get,

$$I = \frac{V}{R_o} - G_m V_i \qquad \ldots(25)$$

The input voltage is given as $\quad V_i = -V_f = -\beta I_o$

$$= \beta I \qquad \because I_o = -I \qquad \ldots(26)$$

Substituting value of V_i from equation (26) in equation (25) we get,

$$I = \frac{V}{R_o} - G_m \beta I$$

$$\therefore \quad I(1 + G_m \beta) = \frac{V}{R_o}$$

$$\therefore \quad \boxed{R_{of} = \frac{V}{I} = R_o (1 + G_m \beta)} \qquad \ldots(27)$$

Key Point: *Here, G_m is the open loop transconductance without taking R_L in account.*

$$R'_{of} = R_{of} \parallel R_L = \frac{R_{of} \times R_L}{R_{of} + R_L}$$

$$= \frac{R_o (1+\beta G_m) R_L}{R_o (1+\beta G_m) + R_L} = \frac{R_o R_L (1+\beta G_m)}{R_o + R_L + \beta G_m R_o}$$

Dividing numerator and denominator by $R_o + R_L$

we get $\quad R'_{of} = \dfrac{\dfrac{R_L R_o (1+\beta G_m)}{R_o + R_L}}{1+\dfrac{\beta G_m R_o}{R_o + R_L}}$

$$\boxed{R'_{of} = \frac{R'_o (1+\beta G_m)}{1+\beta G_M}} \quad \because R'_o = \frac{R_o R_L}{R_o + R_L} \text{ and } G_M = \frac{G_m R_o}{R_o + R_L} \qquad \ldots(28)$$

Key Point: *Note that here, G_M is the open loop current gain taking R_L in account.*

1.10 Summary of Effect of Negative Feedback on Amplifier

Table 1.1 summarizes the effect of negative feedback on amplifier.

Parameter	Voltage series	Current series	Current shunt	Voltage shunt
Gain with feedback	$A_{vf} = \frac{A_v}{1+\beta A_v}$ decreases	$G_{mf} = \frac{G_m}{1+\beta G_m}$ decreases	$A_{if} = \frac{A_i}{1+\beta A_i}$ decreases	$R_{mf} = \frac{R_m}{1+\beta R_{mf}}$ decreases
Stability	Improves	Improves	Improves	Improves
Frequency response	Improves	Improves	Improves	Improves
Frequency distortion	Reduces	Reduces	Reduces	Reduces
Noise and Non linear distortion	Reduces	Reduces	Reduces	Reduces
Input resistance	$R_{if} = R_i(1+\beta A_V)$ increases	$R_{if} = R_i(1+\beta G_M)$ increases	$R_{if} = \frac{R_i}{1+\beta A_I}$ decreases	$R_{if} = \frac{R_i}{1+\beta R_M}$ decreases
Output resistance	$R_{of} = \frac{R_o}{1+\beta A_v}$ decreases	$R_{of} = R_o(1+\beta G_M)$ increases	$R_{of} = R_o(1+\beta A_i)$ increases	$R_{of} = \frac{R_o}{1+\beta R_m}$ decreases

Table 1.1

1.11 Method of Identifying Feedback Topology and Analysis of a Feedback Amplifier

To analyse the feedback amplifier it is necessary to go through the following steps.

Step 1 : Identify Topology (Type of feedback)

a) To find the type of sampling network

1. By shorting the output i.e. $V = 0$, if feedback signal (x_f) becomes zero then we can say that it is "Voltage Sampling".
2. By opening the output loop i.e. $I = 0$, if feedback signal (x_f) becomes zero then we can say that it is "Current Sampling".

b) To find the type of mixing network

1. If the feedback signal is subtracted from the externally applied signal as a voltage in the input loop, we can say that it is "series mixing".
2. If the feedback signal is subtracted from the externally applied signal as a current in the input loop, we can say that it is "shunt mixing".

Thus by determining type of sampling network and mixing network, type of feedback amplifier can be determine. For example, if amplifier uses a voltage sampling and series mixing then we can say that it is a voltage series amplifier.

Step 2 : Find the input circuit

1. For voltage sampling make $V = 0$ by shorting the output
2. For current sampling make $I = 0$ by opening the output loop.

Step 3 : Find the output circuit.

1. For series mixing make $I = 0$ by opening the input loop.
2. For shunt mixing make $V = 0$ by shorting the input

Step 2 and step 3 ensure that the feedback is reduced to zero without altering the loading on the basic amplifier.

Step 4 : Optional. Replace each active device by its h-parameter model at low frequency.

Step 5 : Find the open loop gain (gain without feedback), A of the amplifier.

Step 6 : Indicate X_f and X_o on the circuit and evaluate $\beta = X_f\, X_o$.

Step 7 : From A and β, find D, A_f, R_{if}, R_{of}, and R'_{of}.

Characteristics	Topology			
	Voltage series	Current series	Current shunt	Voltage shunt
Sampling signal X_o	Voltage	Voltage	Current	Current
Mixing signal	Voltage	Current	Current	Voltage
To find input loop, set	$V_o = 0$	$I_o = 0$	$I_o = 0$	$V_o = 0$
To find output loop, set	$I_i = 0$	$I_i = 0$	$V_i = 0$	$V_i = 0$
Single source	Thevenin	Thevenin	Norton	Norton
$\beta = X_f / X_o$	V_f / V_o	V_f / I_o	I_f / I_o	I_f / V_o
$A = X_o / X_i$	$A_V = V_o / V_i$	$G_M = I_o / V_i$	$A_I = I_o / I_i$	$R_M = V_o / I_i$
$D = 1 + \beta A$	$1 + \beta A_V$	$1 + \beta G_M$	$1 + \beta A_I$	$1 + \beta R_M$
A_f	A_V/D	G_M/D	A_I/D	R_M/D
R_{if}	$R_i D$	$R_i D$	R_i/D	R_i/D
R_{of}	$\frac{R_o}{1+\beta A_v}$	$R_o(1 + \beta G_M)$	$R_o(1 + \beta A_I)$	$\frac{R_o}{1+\beta R_m}$
$R'_{of} = R_{of} \parallel R_L$	$\frac{R'_o}{1+\beta A_v}$	$\frac{R'_o(1+\beta G_M)}{1+\beta G_M}$	$\frac{R'_o(1+\beta A_i)}{1+\beta A_I}$	$\frac{R'_o}{1+\beta R_M}$

Table 1.2

1.12 Analysis of Feedback Amplifiers

1.12.1 Voltage Series Feedback

In this section, we will see two examples of the voltage series amplifier, First we will analyse transistor emitter follower circuit and then source follower using FET.

1.12.1.1 Transistor Emitter Follower

Fig. 1.23 shows the transistor emitter follower circuit. Here feedback voltage is the voltage across R_e and sampled signal is V_o across R_E.

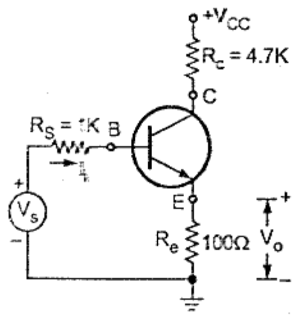


Fig. 1.23

Analysis

Step 1 : Identify Topology

By shorting output voltage ($V_o = 0$), feedback signal becomes zero and hence it is voltage sampling. Looking at Fig. 1.23 we can see that feedback signal V_f is subtracted from the externally applied signal V_s and hence it is a series mixing. Combining two conclusions we can say that it is a voltage series feedback amplifier.

Step 2 and Step 3 : Find input and output circuit

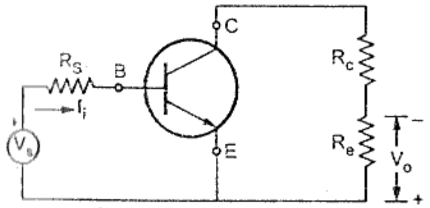


Fig. 1.24

To find the input circuit, set $V_o = 0$, and hence V_s in series with R_s appears between B and E. To find the output circuit, set $I_i = I_b = 0$, and hence R_e appears only in the output loop. With these connections we obtain the circuit as shown in the Fig. 1.24.

Step 4 : Replace transistor by its h-parameter equivalent circuit

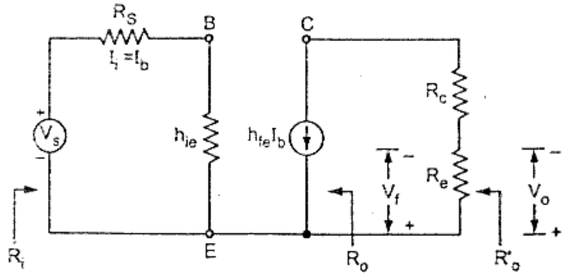


Fig. 1.25 Transistor replaced by its approximate h-parameter equivalent circuit

Step 5 : Find open loop voltage gain

$$A_V = \frac{V_o}{V_s} = \frac{h_{fe} I_b R_e}{V_s}$$

Applying KVL to input loop we get

$$V_s = I_b (R_s + h_{ie})$$

Substituting value of V_s we get

$$A_V = \frac{h_{fe} R_e}{R_s + h_{ie}} = \frac{50 \times 100}{1\,K + 1.1\,K} = 2.38$$

Step 6 : Indicate V_o and V_f and calculate β

We have $\beta = \frac{V_f}{V_o} = 1$ $\quad \because$ both voltage present across R_e

Step 7 : Calculate D, A_{vf}, R_{if}, R_{of} and R'_{of}

$$D = 1 + \beta A_V = 1 + 1 \times 2.38 = 2.38$$

$$A_{Vf} = \frac{A_V}{1 + \beta A_V} = \frac{A_V}{D} = \frac{2.38}{3.38} = 0.7$$

$$R_i = R_s + h_{ie} = 1K + 1.1K = 2.1K$$

$$R_{if} = R_i D = 2.1k \times 3.38 = 7.098K$$

$$R_o = \infty$$

$$R_{of} = \infty$$

$$R'_{of} = \frac{R'_o}{D} \quad \text{where } R'_o = R_e$$

$$R'_{of} = \frac{R_e}{D} = \frac{100}{3.38} = 29.58\ \Omega$$

1.12.1.2 FET Source Follower

Fig. 1.26 shows the FET source follower circuit. Here feedback voltage is the voltage across R_s and sampled signal is V_o across R_e.

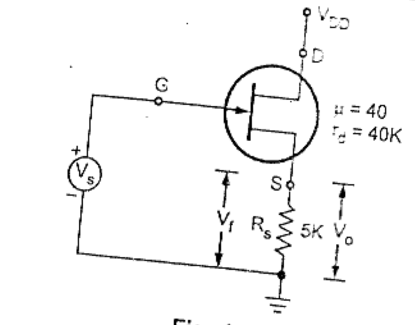


Fig. 1.26

Analysis :

Step 1 : Identify Topology

By shorting output voltage $V_o = 0$, feedback signal becomes zero and hence it is voltage sampling. Looking at Fig. 1.26 we can see that feedback signal V_f is subtracted from the externally applied signal V_s and hence it is a series mixing. Combining two conclusions we can say that it is a voltage series feedback amplifier.

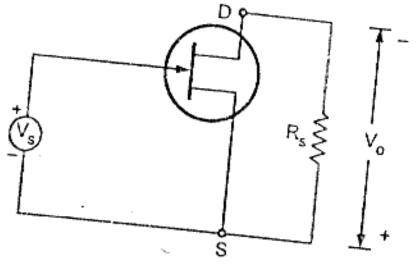


Fig. 1.27

Step 2 and Step 3 : Find input and output circuit

To find the input circuit, set $V_i = 0$, and hence V_s appears between G and S. To find the output circuit, set $I_i = I_G = 0$, and hence R_s appears in the output loop. With these connections we obtain the circuit as shown in the Fig. 1.27.

Step 4 : Replace FET by its equivalent circuit

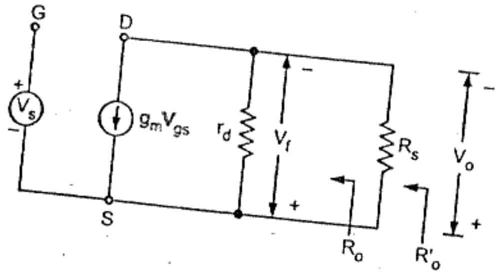


Fig. 1.28

Step 5 : Find open loop voltage gain

$$A_V = \frac{V_o}{V_s} = \frac{g_m V_{gs} r_d R_s}{(r_d + R_s) V_s}$$

$$= \frac{g_m r_d R_s}{r_d + R_s} \quad \because V_{gs} = V_s \qquad \text{... (1)}$$

$$= \frac{\mu R_s}{r_d + R_s} \quad \because \mu = g_m r_d \qquad \text{... (2)}$$

$$= \frac{40 \times 5\text{ K}}{40\text{ K} + 5\text{ K}} = 4.44$$

Step 6 : Indicate V_o and V_f and calculate β

$$\beta = \frac{V_f}{V_o} = 1 \quad \because \text{both voltages present across } R_s$$

Step 7 : Calculate D, A_{vf}, R_{if}, R_{of} and R'_{of}

$$D = 1 + \beta A_V = 1 + 1 \times 4.44$$

$$= 5.44 \qquad \text{... (3)}$$

$$A_{vf} = \frac{A_v}{1 + \beta A_v} = \frac{A_v}{D}$$

$$= \frac{4.44}{5.44} = 0.816$$

$$R_i = \infty \text{ and hence } R_{if} = R_i\, D = \infty \qquad \text{... (4)}$$

$$R_o = r_d = 40\text{ k}\Omega \qquad \text{... (5)}$$

$$R_{of} = \frac{R_o}{D} = \frac{40\text{K}}{5.44} = 7.35\text{ K} \qquad \text{... (6)}$$

$$R'_{of} = \frac{R'_o}{D}$$

where

$$R'_o = R_s \,||\, r_d$$

$$= \frac{R_s r_d}{R_s + r_d} = \frac{5\text{ K} \,||\, 40\text{ K}}{5\text{ K} \,||\, 40\text{ K}} = 4.44\text{ K}$$

$$\therefore \quad R'_{of} = \frac{4.44\text{ K}}{5.44} = 816.2\ \Omega \qquad \text{... (7)}$$

1.12.1.3 Voltage Series Feedback Pair

Fig. 1.29 shows two cascaded stages. The output of second stage is connected through feedback network to the input of first stage in opposition to the input signal V_s.

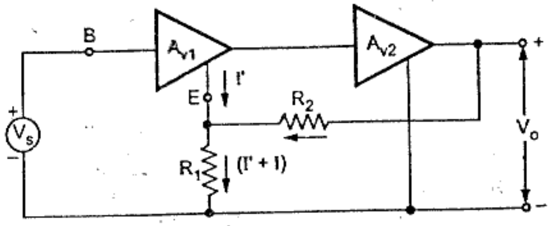


Fig. 1.29 Voltage series feedback pair

Analysis :

Step 1 : Identify Topology

By shorting output voltage $V_o = 0$, feedback signal becomes zero and hence it is voltage sampling. Looking at Fig. 1.29 we can see that feedback signal V_f is subtracted from the externally applied signal V_s and hence it is a series mixing. Combining two conclusions we can say that it is a voltage series feedback amplifier.

Step 2 and Step 3 : Find input and output circuit

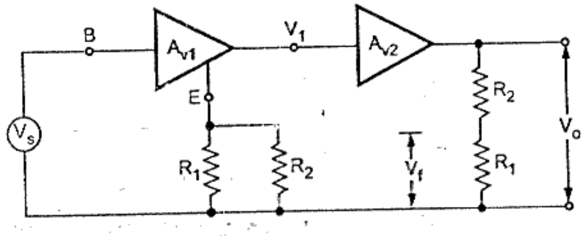


Fig. 1.30

To find input circuit, set $V_o = 0$, and hence R_2 appears in parallel with R_1 at first emitter. To find the output circuit, set $I_i = 0$ and hence R_1 appears in series with R_2 across output. The resulting circuit is shown in Fig. 1.30.

For this circuit, feedback factor β can be calculated as

$$\beta = \frac{V_f}{V_o} = \frac{R_1}{R_1 + R_2} \qquad \text{... (8)}$$

Example 1.11 : *Transistors in the feedback amplifier shown in Fig. 1.31 are identical and their 'h' parameters are $h_{ie} = 1100\ \Omega$, $h_{fe} = 100$, $h_{re} = h_{oe} = 0$ Neglect capacitances of all capacitors.*

i) State topology with justification.

ii) Calculate β, A_V, A_{Vf}, R_{if}, R_{of} and R'_{of}.

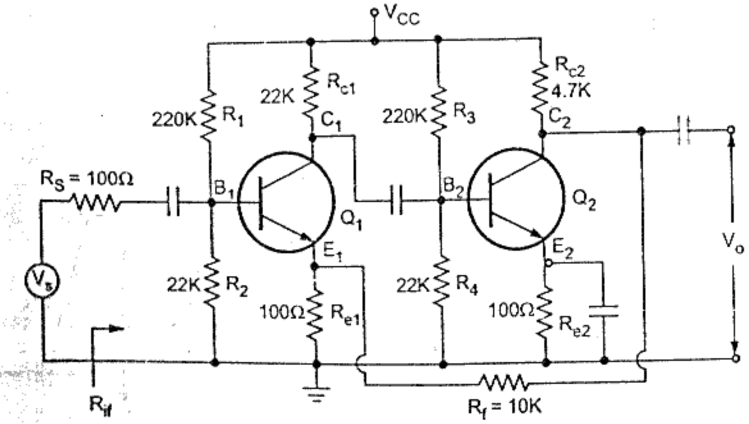


Fig. 1.31

Solution : Step 1 : Identify topology

The feedback voltage is applied across the resistance R_{e1} and it is in series with input signal. Hence feedback is voltage series feedback.

Step 2 and Step 3 : Find input and output circuit

To find input circuit, set $V_o = 0$ (connecting C_2 to ground), which gives parallel combination of R_e with R_f at E_1. To find output circuit, set $I_i = 0$ (opening the input node E_1 at emitter of Q_1), which gives series combination of R_f and R_{e1} across the output. The resultant circuit is shown in Fig. 1.32.

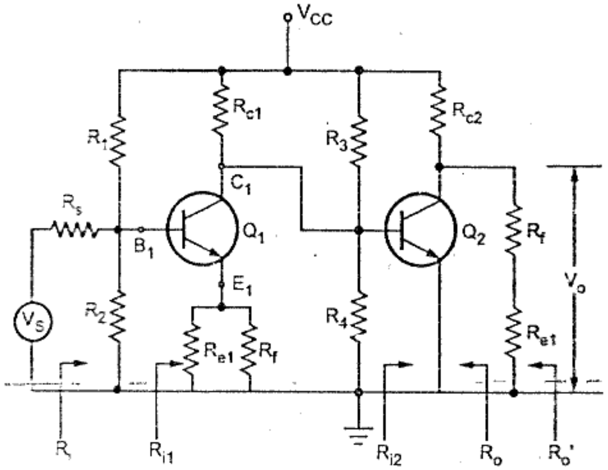


Fig. 1.32

Step 4 : Find open loop voltage gain (A_V)

$$R_{L2} = 4.7\text{ K} \parallel (100 + 10\text{ K})$$
$$= 3.21\text{ k}\Omega$$
$$A_{i2} = -h_{fe} = -100$$
$$R_{i2} = h_{ie} = 1100\ \Omega$$
$$A_{v2} = \frac{A_{i2} R_{L2}}{R_{i2}} = \frac{-100 \times 3.21\text{ K}}{1100\ \Omega}$$
$$= -291.82$$
$$A_{i1} = -h_{fe} = -100$$
$$R_{L1} = R_{C1} \parallel R_1 \parallel R_2 \parallel R_{i2} = 22\text{K} \parallel 220\text{ K} \parallel 22\text{K} \parallel 1100$$
$$= 995\ \Omega$$
$$R_{i1} = h_{ie} + (1 + h_{fe}) R_e$$

$$= 1100 + (1 + 100)\ (100\ \Omega \parallel 10\ K)$$

$$= 11.099\ k\Omega$$

$$A_{v1} = \frac{A_{i1} R_{L1}}{R_{i1}} = \frac{-100 \times 995}{11.099 \times 10^3}$$

$$= -8.96$$

The overall gain without feedback is given as

$$A_v = A_{v1} \times A_{v2} = -291.82 \times -8.96$$

$$= 2614.7$$

The overall gain taking R_s in account is given as

$$A_V = \frac{V_o}{V_s} = \frac{A_v R_{i1}}{R_{i1} + R_s} = \frac{2614.7 \times 11.099 \times 10^3}{11.099 \times 10^3 + 100}$$

$$= 2591.35$$

Step 5 : Calculate β

Looking at Fig. 1.33

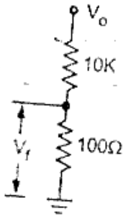


Fig. 1.33

$$\beta = \frac{V_f}{V_o} = \frac{100}{100 + 10 \times 10^3}$$

$$= 0.0099$$

$$D = 1 + \beta A_V = 1 + 0.0099 \times 2591.35$$

$$= 26.65$$

$$\therefore \quad A_{Vf} = \frac{A_V}{D} = \frac{2591.35}{26.65}$$

$$= 97.23$$

$$R_{if} = R_{i1}\ D = 11.099 \times 10^3 \times 26.65$$

$$= 295.788\ k\Omega$$

$$R'_{if} = R_{if} \parallel R_1 \parallel R_2 = 295.788\ K \parallel 220\ K \parallel 22\ K$$

$$= 18.73\ k\Omega$$

$$R_{of} = \frac{R_o}{D} = \frac{\infty}{D} = \infty$$

$$\therefore \quad R'_{of} = \frac{R'_o}{D} \quad \text{where } R'_o = R_{L2}$$

$$\therefore \quad R'_{of} = \frac{3.21 \times 10^3}{26.65} = 120.45\ \Omega$$

1.12.2 Current Series Feedback

In this section, we will see two examples of the current series feedback amplifier. First we will analyse transistor common emitter circuit with unbypassed emitter resistance and then common source with unbypassed source resistance.

1.12.2.1 Common Emitter Configuration with Unbypassed R_e

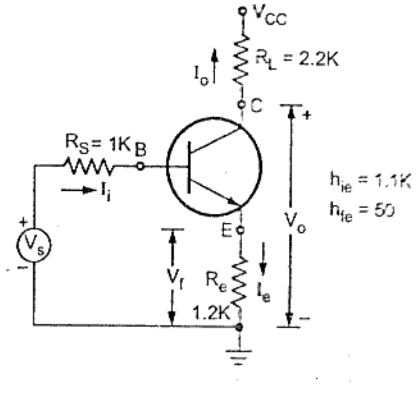


Fig. 1.34

Fig. 1.34 shows the common emitter circuit with unbypassed R_e. The common emitter circuit with unbypassed R_e is an example of current series feedback. In this configuration resistor R_e is common to base to emitter input circuit as well as collector to emitter output circuit and input current I_b as well as output current I_c both flow through it. The voltage drop across R_e, $V_f = (I_b + I_c) = I_e R_e = I_c R_e = -I_o R_e$. This voltage drop shows that the output current I_o is being sampled and it is converted to voltage by feedback network. At input side voltage V_f is subtracted from V_s to produce V_i. Therefore, the feedback applied in series.

Analysis

Step 1 : Identify topology

By opening the output loop, (output current, $I_o = 0$), feedback signal becomes zero and hence it is current sampling. Looking at Fig. 1.34 we can see that feedback signal V_f is subtracted from the externally applied signal V_s and hence it is a series mixing. Combining two conclusions we can say that it is a current series feedback amplifier.

Step 2 and Step 3 : Find input and output circuit

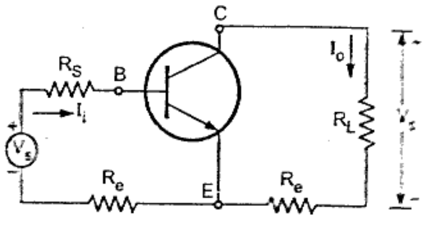


Fig. 1.35

To find input circuit set $I_o = 0$, then R_e appears at the input side. To find output circuit set $I_i = 0$, then R_e appears in the output circuit. The resulting circuit is shown in the Fig. 1.35.

Step 4 : Replace transistor with its approximate h-parameter equivalent circuit

Fig. 1.36 shows the approximate h-parameter equivalent circuit

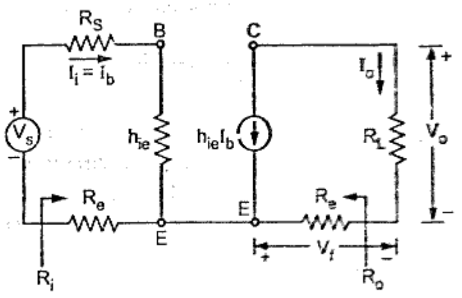


Fig. 1.36 Approximate h-parameter equivalent circuit

Step 5 : Find open loop transfer gain

$$G_M = \frac{I_o}{V_i} = \frac{-h_{fe}I_b}{V_s} \quad \text{... (9)}$$

$$= \frac{-h_{fe}I_b}{I_b(R_s + h_{ie} + R_e)}$$

$$= \frac{-h_{fe}}{R_s + h_{ie} + R_e} = \frac{50}{1\,K + 1.1\,K + 1.2\,K}$$

$$= -0.015$$

Step 6 : Indicate $\mathbf{I_o}$ and $\mathbf{V_f}$ and calculate β

$$\beta = \frac{V_f}{I_o} = \frac{I_e R_e}{I_o} \quad \text{...(10)}$$

$$= \frac{-I_o R_e}{I_o} = -R_e \qquad \because I_e = -I_o$$

$$= -1.2\text{ K}$$

Step 7 : Calculate D, G_{Mf} , A_{Vf} , R_{if} , R_{of} and R'_{of}

$$D = 1 + \beta G_M = 1 + (-1.2\,K) \times (-0.015) \quad \text{... (11)}$$

$$= 19.18$$

$$G_{Mf} = \frac{G_M}{D} = \frac{-0.015}{19.18} \quad \text{... (12)}$$

$$= -0.782 \times 10^{-3}$$

The voltage gain A_{Vf} is given as

$$A_{Vf} = \frac{V_o}{V_s} = \frac{I_o R_L}{V_s} = G_{Mf}\,R_L \qquad \because G_{Mf} = \frac{I_o}{V_s} \quad \text{... (13)}$$

$$= -0.782 \times 10^{-3} \times 2.2\,K$$

$$= -1.72$$

Looking at Fig. 1.36 R_i can be given as

$$R_i = R_s + h_{ie} + R_e \quad \text{... (14)}$$

$$= 1K + 1.1\,K + 1.2\,K = 3.3\,K$$

$$R_{if} = R_i\,D = 3.3\,K \times 19.18 \quad \text{... (15)}$$

$$= 63.294\text{ K}$$

Looking at Fig. 1.36 R_o is given as

$$R_o = \infty \quad \text{... (16)}$$

$$\therefore \quad R_{of} = R_o\,D = \infty \quad \text{... (17)}$$

$$R'_{of} = R_{of} \parallel R_L \quad \text{... (18)}$$

$$= R_L \qquad \because R_{of} = \infty$$

$$= 2.2\text{ K}$$

1.12.2.2 Common Source Configuration With R_s Unbypassed

Fig. 1.37 shows the common source circuit with unbypassed R_s. Here, the feedback signal is a voltage across R_s and the sampled signal is the load current I_o.

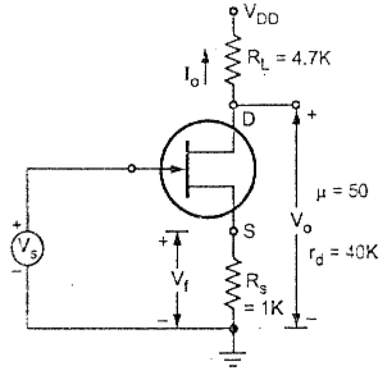


Fig. 1.37

Analysis

Step 1 : Identify topology

By setting V_o = 0, drain current does not become zero therefore feedback does not become zero. Hence this is not voltage sampling. On the other hand, by setting I_o = 0, we have $V_f = 0$. Hence this is current sampling. The feedback voltage V_f is mixed in series with the input source. Hence the topology used is a current series feedback.

Step 2 and step 3 : Find input and output circuit

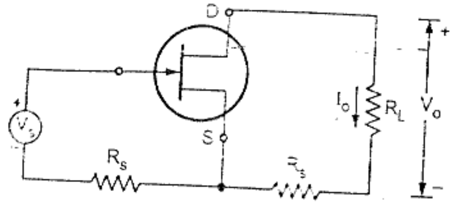


Fig. 1.38

To find input circuit set $I_o = 0$, then R_s appears at the input side. To find output circuit set $I_i = 0$, then R_s appears in the output circuit. The resulting circuit is shown in the Fig. 1.38.

Step 4 : Replace FET with its equivalent circuit

Fig. 1.39 shows the equivalent circuit

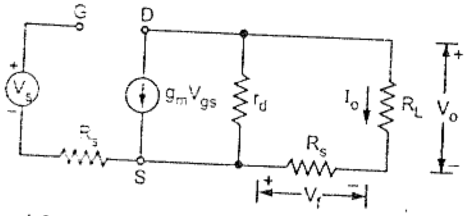


Fig. 1.39 FET replaced by its equivalent circuit

Step 5 : Find the open loop transconductance

$$G_M = \frac{I_o}{V_s} = \frac{\dfrac{-g_m V_{gs} r_d}{r_d + R_L + R_s}}{V_s}$$

$$= \frac{-g_m r_d}{r_d + R_L + R_s} \quad \because V_s = V_{gs} \qquad \dots (19)$$

$$= \frac{-\mu}{r_d + R_L + R_s} \quad \because \mu = g_m r_d \qquad \dots (20)$$

$$= \frac{-50}{40\text{ K} + 4.7\text{ K} + 1\text{K}} = -1.09 \times 10^{-3}$$

Step 6 : Calculate β

$$\beta = \frac{V_f}{I_o} = \frac{-I_o R_s}{I_o} \qquad \dots (21)$$

$$= -R_s = -1\text{K}$$

Step 7 : Calculate D, G_{Mf}, A_{vf}, R_{if}, R_{of} and R'_{of}

$$D = 1 + \beta G_M \qquad \dots (22)$$

$$= 1 + (-1\text{K})(-1.09 \times 10^{-3})$$

$$= 2.09$$

$$G_{Mf} = \frac{G_M}{D} = \frac{-1.09 \times 10^{-3}}{2.09} \qquad \dots (23)$$

$$= -0.5215 \times 10^{-3}$$

$$A_{Vf} = \frac{V_o}{V_s} = \frac{I_o R_L}{V_s}$$

$$= G_{Mf} R_L \quad \because G_{Mf} = \frac{I_o}{V_s} \qquad \dots (24)$$

$$= (-0.5215 \times 10^{-3}) \times (4.7\text{ K})$$

$$= -2.45$$

Looking at Fig. 1.39 R_i can be given as

$$R_i = \infty \qquad \dots (25)$$

$$\therefore \quad R_i = R_i\, D = \infty \qquad \dots (26)$$

Looking at Fig. 1.39 R_o can be given as

$$R_o = r_d + R_s = 40\text{ K} + 1\text{ K} = 41\text{ K} \qquad \dots (27)$$

$$R_{of} = R_o (1 + \beta G_m) \text{ where } G_m = \lim_{R_L \to 0} G_M \qquad \dots (28)$$

$$\therefore \quad 1 + \beta G_m = \frac{r_d + (1+\mu) R_s}{r_d + R_s}$$

$$\therefore \quad R_{of} = (r_d + R_s) \times \frac{r_d + (1+\mu) R_s}{r_d + R_s}$$

$$= r_d + (1+\mu) R_s \qquad \dots (29)$$

$$= 40\text{ K} + (1 + 50) \times 1\text{ K} = 91\text{ K}$$

$$R'_{of} = R_L \parallel R_{of} \qquad \dots (30)$$

$$= 4.7\text{ K} \parallel 91\text{ K} = 4.47\text{ K}$$

1.12.3 Current Shunt Feedback

Fig. 1.40 shows two transistors in cascade connection with feedback from second emitter to first base through resistor R′. Here, the feedback network formed by R′ and R_{e2} divides the current I_e. Since $I_e = -I_o$, the feedback network gives current feedback. At input side, we see that $I_i = I_s - I_f$, i.e. I_f is shunt subtracted from I_s to get I_i. Therefore, this configuration is a current shunt feedback.

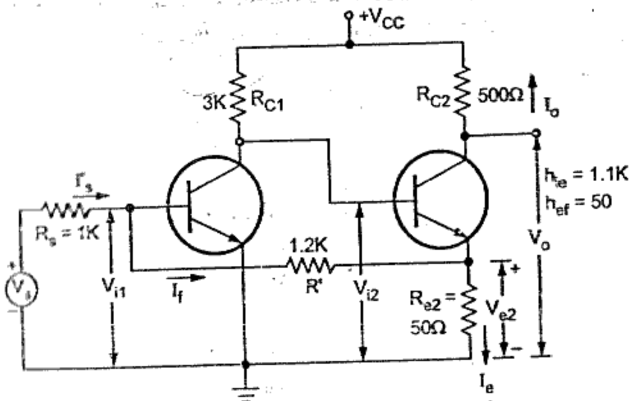


Fig. 1.40

Step 1 : Identify topology

By shorting output voltage ($V_o = 0$), feedback signal does not become zero and hence it is not voltage sampling. By opening the output loop ($I_o = 0$), feedback signal becomes zero and hence it is a current feedback. The feedback signal appears in shunt with input ($I_i = I_s - I_f$) hence the topology is current shunt feedback amplifier.

Step 2 and Step 3 : Find input and output circuit

The input circuit of the amplifier without feedback is obtained by opening the output loop at the emitter of Q_2 ($I_o = 0$). This places R' in series with R_e from base to emitter of Q_1. The output circuit is found by shorting the input node (the base of Q_1), i.e. making $V_i = 0$. This places R' in parallel with R_e. The resultant equivalent circuit is shown in Fig. 1.41.

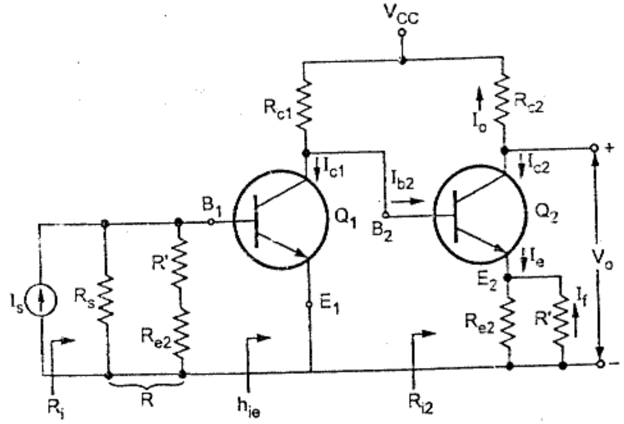


Fig. 1.41

Step 4 : Find open circuit transfer gain

$$A_I = \frac{-I_{c2}}{I_s} = \frac{-I_{c2}}{I_{b2}} \frac{I_{b2}}{I_{c1}} \frac{I_{c1}}{I_{b1}} \frac{I_{b1}}{I_s} \quad \ldots (31)$$

We know that,

$$\frac{-I_{c2}}{I_{b2}} = A_{i2} = -h_{fe} = -50 \text{ and} \quad \ldots (32)$$

$$\frac{-I_{c1}}{I_{b1}} = A_{i1} = -h_{fe} = -50$$

$$\therefore \quad \frac{I_{c1}}{I_{b1}} = 50 \quad \ldots (33)$$

Looking at Fig. 1.41 we can write

$$\frac{I_{b2}}{I_{c1}} = \frac{-R_{c1}}{R_{c1} + R_{i2}} \quad \ldots (34)$$

where

$$R_{i2} = h_{ie} + (1 + h_{fe})(R_{e2} \parallel R')$$

$$= 1.1 + (51)\left(\frac{50 \times 1.2\text{ K}}{50 + 1.2\text{ K}}\right)$$

$$= 3.55\text{ K}$$

$$\therefore \quad \frac{I_{b2}}{I_{c1}} = \frac{-3\text{ K}}{3\text{ K} + 3.55\text{ K}} = -0.457$$

Looking at Fig. 1.41 we can write

$$\frac{I_{b1}}{I_s} = \frac{R}{R + h_{ie}} \quad \ldots (35)$$

$$\text{where } R = R_s \parallel (R' + R_e) = \frac{1.2\text{ K} \times 1.25\text{ K}}{1.2\text{ K} + 1.25\text{ K}}$$

$$= 0.612\text{ K}$$

$$\therefore \quad \frac{I_{b1}}{I_s} = \frac{0.612\text{ K}}{0.612 + 1.1\text{ K}} = 0.358$$

Substituting the numerial values obtained from equations 32, 33, 34 and 35 in equation 31 we get,

$$A_I = (-50) \times (-0.457) \times (50) \times (0.358)$$

$$= 406$$

Step 5 : Calculate β

Looking at Fig. 1.41 we can write,

$$I_f = \frac{-I_e R_{e2}}{R_e + R'}$$

$$= \frac{-I_c R_{e2}}{R_e + R'} \qquad \because I_e \cong I_c$$

$$= \frac{I_o R_{e2}}{R_{e2} + R'} \qquad \because I_o = -I_c$$

$$\therefore \quad \beta = \frac{I_f}{I_o} = \frac{R_{e2}}{R_{e2} + R'} = \frac{50}{50 + 1.2\text{ K}}$$

$$= 0.04$$

Step 6 : Calculate D, R_i, R_{if}, A_{If}, A_{vf}, R_o, R_{of}

$$D = 1 + \beta A_I = 1 + (0.04) \times 406$$

$$= 17.2$$

$$A_{If} = \frac{A_I}{D} = \frac{406}{17.2}$$

$$= 23.6$$

$$A_{vf} = \frac{V_o}{V_s} = \frac{-I_{c2} R_{c2}}{I_s R_s}$$

$$= \frac{A_{If} R_{c2}}{R_s} \qquad \because \frac{-I_{c2}}{I_s} = A_{If}$$

$$= \frac{(23.6)(500)}{1.2\text{ K}}$$

$$= 9.83$$

$$R_i = R \parallel h_{ie} = \frac{0.612\text{ K} \times 1.1\text{K}}{0.612\text{ K} + 1.1\text{K}}$$

$$= 0.394\text{ K}$$

$$R_{if} = \frac{R_i}{D} = \frac{0.394\text{ K}}{17.2}$$

$$= 23\ \Omega$$

$$R_o = \infty \qquad \because h_{oe} = 0$$

$$\therefore \quad R_{of} = R_o D = \infty$$

$$R'_o = R_o \parallel R_{c2} = \infty \parallel 500 = 500\ \Omega$$

[illegible] calculation for A_{If} we note that [illegible] is independent of the load $R_L = R_{c2}$. Hence [illegible] A_I

$$R'_{of} = R'_o \frac{1+\beta A_I}{1+\beta A_I} = R'_o = R_{c2}$$

$$= 500\ \Omega$$

[illegible] Voltage Shunt Feedback

Fig. 1.42 shows a common emitter amplifier with a resistor R' connected from the [illegible] to the input.

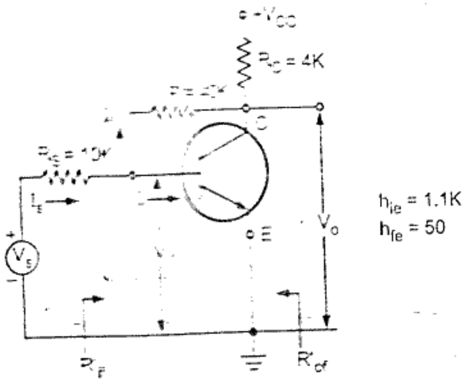


Fig. 1.42

Step 1 : Identify topology

The feedback current I_f is given as

$$I_f = \frac{V_i - V_o}{R'} \qquad \text{But } V_o > \beta V_i$$

$$I_f = \frac{-V_o}{R'}$$

By shorting output voltage ($V_o = 0$), feedback reduces to zero and hence it is a voltage sampling. As $I_i = I_s - I_f$, the mixing is shunt type and topology is voltage shunt feedback amplifier.

Step 2 and Step 3 : Find input and output circuit.

To find input circuit, set $V_o = 0$, this places R' between base and ground. To find output circuit, set $V_i = 0$, this places R' between collector and ground.

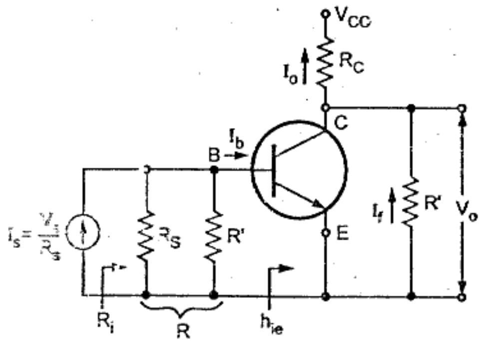


Fig. 1.43

The resultant circuit is shown in Fig. 1.43.

The feedback signal is the current I_f in the resistor R' which is in the output circuit as shown in the Fig. 1.43.

We have seen that

$$I_f = \frac{V_i - V_o}{R'} = \frac{-V_o}{R'} \qquad \because V_o > V_i$$

$$\therefore \quad \frac{I_f}{V_o} = \beta = \frac{-1}{R'}$$

$$R_{Mf} = \frac{R_M}{1+\beta R_M} = \frac{1}{\beta} \qquad \because \beta R_M >> 1$$

$$= -R'$$

$$\therefore \quad A_{vf} = \frac{V_o}{V_s} = \frac{V_o}{I_s R_s}$$

$$\approx \frac{1}{\beta R_s} = \frac{-R'}{R_s}$$

Step 4 : Find the open circuit transresistance

$$R_M = \frac{V_o}{I_s} = \frac{I_o R'_c}{I_s} = \frac{-I_c R'_c}{I_s} \qquad \dots (36)$$

where

$$R'_c = R_c \parallel R' = 4 K \parallel 40 K$$

$$= 3.636 K$$

and

$$\frac{-I_c}{I_s} = \frac{-I_c}{I_b} \frac{I_b}{I_s}$$

$$\frac{-I_c}{I_b} = A_i = -h_{fe} = -50 \text{ and} \qquad \dots (37)$$

$$\frac{I_b}{I_s} = \frac{R}{R+h_{ie}} \qquad \text{where } R = R_S \parallel R' = 10 K \parallel 40 K = 8 K$$

$$\therefore \quad \frac{I_b}{I_s} = \frac{8 K}{8 K + 1.1 K}$$

$$= 0.879 \qquad \dots (38)$$

Substituting values of equation 37 and 38 in equation 36 we have

$$R_M = \frac{-I_c R'_c}{I_s} = \frac{-I_c}{I_b} \frac{I_b}{I_s} \times R'_c$$

$$= (-50) \times (0.879) \times 3.636 K$$

$$= -159.8 K$$

Step 5 : Calculate β

$$\beta = \frac{-1}{R'} = \frac{-1}{40 K}$$

$$= -2.5 \times 10^{-5}$$

Step 6 : Calculate D, R_{MF}, A_{VF}, R_{iF}, R_{of} and R'_{of}

$$D = 1 + \beta R_M$$

$$= 1 + (-2.5 \times 10^{-5})(-159.8 \times 10^3)$$

$$= 4.995$$

$$R_{MF} = \frac{R_M}{D} = \frac{-159.8 K}{4.995}$$

$$= -32 K$$

$$A_{VF} = \frac{V_o}{V_s} = \frac{V_o}{I_s R_s} = \frac{R_{MF}}{R_s}$$

$$= \frac{-32 K}{10 K} = -3.2$$

Looking at Fig. 1.43 we can write

$$R_i = R \parallel h_{ie} = \frac{R h_{ie}}{R + h_{ie}}$$

$$= \frac{8 K \times 1.1 K}{8 K + 1.1 K} = 0.967 K$$

$$R_{if} = \frac{R_i}{D} = \frac{0.967 K}{4.995}$$

$$= 193.59 \Omega$$

$$R_o = \infty \qquad \because h_{oe} = 0$$

$$\therefore \quad R_{of} = \frac{\infty}{D} = \infty$$

$$R'_o = R_o \,||\, R'_c = \infty \,||\, 3.636 \text{ K}$$

$$= 3.636 \text{ K}$$

$$R'_{of} = \frac{R'_o}{D} = \frac{3.636 \text{ K}}{4.995}$$

$$= 728\ \Omega$$

1.13 Nyquist Criterion for Stability of Feedback Amplifiers

A negative feedback amplifier designed for a particular frequency range may break out into oscillation at some high or low frequency. This stability problem arises in feedback amplifiers when the loop gain has more than two real poles. The existence of pole with a positive real part result in a disturbance increasing exponentially with time. When such transient disturbance persists indefinitely or increases, the system becomes unstable.

Hence, the condition which must 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. If the system without feedback is stable, the poles of A do lie in the left-hand half plane. Therefore, from equation $A_f = A/1 + A\beta$ we can say that the stability condition requires that the zeroes of $1 + A\beta$ all lie in the left-hand half of the complex-frequency plane.

The Nyquist criterion forms the basis of a steady-state method of determining whether or not an amplifier is stable. The Nyqist criteria express condition for stability in terms of the steady-state, or frequency response, characteristics. Let us see the Nyquist criterion.

Since the product $A\beta$ is a complex number, it may be represented as a point in the complex plane where the real component being plotted along the X axis and the j component along the Y axis. We know that, the $A\beta$ is a function of frequency. Consequently, points in the complex plane are obtained for the values of $A\beta$ corresponding to all values of f from $-\infty$ to $+\infty$. The locus of all these points forms a closed curve. The criterion of Nyquist is that **the amplifier is unstable if this curve encloses the point $-1 + j0$, and the amplifier is stable if the curve does not enclose this point.** (See Fig. 1.44).

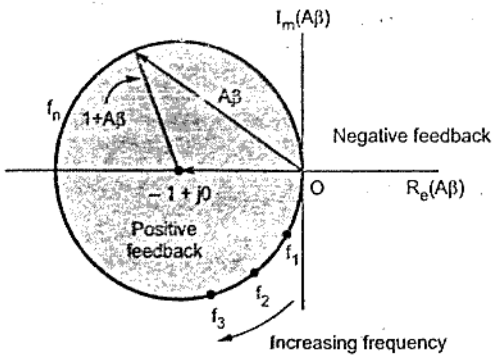
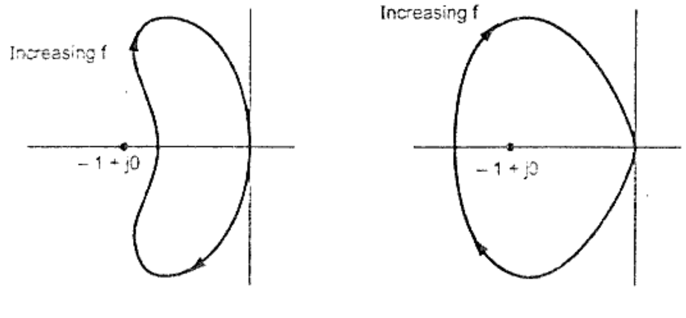


Fig. 1.44 Locus of $|1 + A\beta| = 1$

The Fig. 1.44 shows the locus of $|1 + A\beta| = 1$. It is a circle of unit radius, with its center at $-1 + j0$. If for any frequency, $A\beta$ extends outside this circle, the feedback is negative since $|1 + A\beta| > 1$. If, however, $A\beta$ lies within this circle, then $|1 + A\beta| < 1$, and the feedback is positive.

An example of the Nyquist crieterion is illustrated in Fig. 1.45. The locus in Fig. 1.45(a) is stable since it does not enclose the $-1 + j0$ point, whereas the locus shown in Fig. 1.45(b) is unstable since the curve does enclose the $-1 + j0$ point.



(a) Stable (b) Unstable

Fig. 1.45 Stability condition using Nyquist criterion

Examples with Solutions

Example 1.2 : *A feedback amplifier has an open loop gain of 600 and feedback factor $\beta = 0.01$. Find the closed loop gain with negative feedback.* **(Nov./Dec.-2004)**

Solution :

$$A_{vf} = \frac{A}{1+A\beta} = \frac{600}{1+600\times 0.01}$$

$$= 85.714$$

Example 1.3 : *The distortion in an amplifier is found to be 3%, when the feedback ratio of negative feedback amplifier is 0.04. When the feedback is removed, the distortion becomes 15%. Find the open and closed loop gain.* **(April/May-2005)**

Solution : Given : $\beta = 0.04$ Distortion with feedback = 3%, Distortion without feedback = 15 %

$$\therefore \quad D = \frac{15}{3} = 5 \quad \text{where } D = 1 + A\beta = 5$$

$$\therefore \quad 5 = 1 + A\beta = 1 + A \times 0.04$$

$$\therefore \quad A = 100$$

Example 1.4 : *An amplifier has mid-band voltage gain ($A_{v\,mid}$) of 1000 with $f_L = 50$ Hz and $f_H = 50$ kHz, if 5% feedback is applied then calculate gain f_L, and f_H with feedback.*

Solution : Given $\beta = \frac{5}{100} = 0.05$, $f_L = 50$, $f_H = 50$ kHz and $A_{v\,mid} = 1000$

a) Gain with feedback

$$A_{v\,mid\,f} = \frac{A_{v\,mid}}{1+\beta A_{v\,mid}} = \frac{1000}{1+0.05\times 1000}$$

$$= 19.6$$

b)

$$f_{Lf} = \frac{f_L}{1+\beta A_{v\,mid}} = \frac{50}{1+0.05\times 1000}$$

$$= 0.98 \text{ Hz}$$

c)

$$f_{Hf} = f_H \times (1+\beta A_{v\,mid}) = 50\times 10^3 \times (1+0.05\times 1000)$$

$$= 2.55 \text{ MHz}$$

Example 1.5 : *An amplifier with open loop voltage gain of 1000 delivers 10 W of power output at 10% second harmonic distortion when i/p is 10 mV. If 40 dB negative feedback is applied and output power is to remain at 10W, determine required input signal V_s and second harmonic distortion with feedback.*

Solution : Given $A_v = 1000$, Output power = 10W,

a) β :

$$-40 = 20\log\left[\frac{1}{1+\beta A}\right]$$

$\therefore$ $1+\beta A = 100$

$\therefore$ $\beta A = 99$

$\therefore$ $\beta = \frac{99}{1000} = 0.099$

Gain of the amplifier with feedback is given as

$$A_{vf} = \frac{A_v}{1+\beta A_v} = \frac{1000}{100} = 10$$

b) To maintain output power 10W, we should maintain output voltage constant and to maintain output voltage constant with feedback gain required V_s is

$$V_{sf} = V_s \times 100 = 10\text{mV} \times 100$$

$$= 1\text{V}$$

c) Second harmonic distortion is reduced by factor $1+\beta A$.

$\therefore$

$$D_{2f} = \frac{D_2}{1+\beta A} = \frac{0.1}{1+\beta A}$$

$$= \frac{0.1}{100} = 0.001$$

$$= 0.1\ \%$$

Example 1.6 : *An amplifier with open loop gain of $A = 2000 \pm 150$ is available. It is necessary to have the amplifier whose voltage gain varies by not more than $\pm$ 0.2%. Calculate β and A_f*

Solution : a) We know that

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

$\therefore$ $\frac{0.2}{100} = \frac{1}{1+\beta A}\times\frac{150}{2000}$

$\therefore$ $1+\beta A = 37.5$

$\therefore$ $\beta A = 36.5$

$\therefore$ $\beta = \frac{36.5}{2000} = 0.01825$

$$= 1.825\%$$

b) A_F :

$$A_F = \frac{A}{1+\beta A} = \frac{2000}{1+0.01825\times 2000}$$

$$= 53.33$$

Example 1.7 : *If an amplifier has a bandwidth of 300 kHz and voltage gain of 100, what will be the new bandwidth and gain if 10% negative feed back is introduced? What will be the gain bandwidth product before and after feed back? What should be the amount of feedback if the bandwidth is to be limited to 800 kHz.*

Solution : The voltage gain of the amplifier with feedback is given as

$$A_{vf} = \frac{A}{1+A\beta} \quad \text{Where } \beta = 0.1 \text{ and } A = 100$$

$\therefore$ $A_{vf} = \frac{100}{1+100\times 0.1}$

$$= 9.09$$

The bandwidth of an amplifier with feedback is given as

$$B_{wf} = (1+A_{mid}\beta) f_H - \frac{f_L}{(1+A_{mid}\beta)}$$

Assuming $f_H >> f_L$ we have

$$B_w = f_H \text{ and } B_{wf} = (1 + A_{mid}\beta) B_w$$

$$\therefore \quad B_{wf} = (1+100\times 0.1)\times 300 \text{ kHz}$$

$$= 3300 \text{ kHz}$$

The gain bandwidth product before feedback can be given as

Gain bandwidth product = A_v Bw

$$= 100\times 300 \text{ kHz} = 30\times 10^6$$

Gain bandwidth product after feedback

$$= A_{vf}\times B_{wf}$$

$$= 9.09\times 3300 \text{ kHz}$$

$$= 30\times 10^6$$

If bandwidth is to be limited to 800 kHz we have f_{Hf} = 800 kHz assuming $f_{Hf} >> f_{Lf}$

we know that

$$B_{wf} = (1+A_{vmid}\beta) f_H$$

$$\therefore \quad 800K = (1+100\beta)\, 300 \text{ K}$$

$$\therefore \quad \beta = \frac{\frac{800}{300}-1}{100} = 0.01667$$

Example 1.8 : *For the feedback amplifier whose block diagram is shown in Fig. 1.46 compute the changes in ΔA_f when*
i) A_1 changes by an amount ΔA_1 and
ii) A_2 changes by an amount ΔA_2

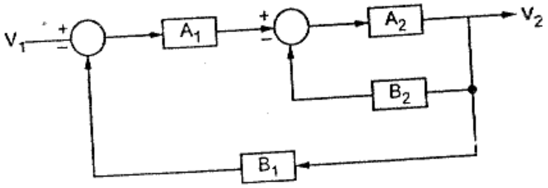


Fig. 1.46

Solution : For above circuit voltage gain with feedback is given as

$$A_f = \frac{A_1\left[\dfrac{-A_2}{1+A_2B_2}\right]}{1+A_1\left[\dfrac{A_2}{1+A_2B_2}\right]B_1}$$

i)

$$\Delta A_f = \frac{A_1\left[\dfrac{A_2}{1+A_2B_2}\right]}{1+A_1\left[\dfrac{A_2}{1+A_2B_2}\right]B_1} - \frac{|A_1-\Delta A_1|\times\left[\dfrac{A_2}{1+A_2B_2}\right]}{1+|A_1-\Delta A_1|\times\left[\dfrac{A_2}{1+A_2B_2}\right]B_1}$$

ii)

$$\Delta A_f = \frac{A_1\left[\dfrac{A_2}{1+A_2B_2}\right]}{1+A_1\left[\dfrac{A_2}{1+A_2B_2}\right]B_1} - \frac{A_1\left[\dfrac{|A_2-\Delta A_2|}{1+|A_2-\Delta A_2|\times B_2}\right]}{1+A_1\left[\dfrac{|A_2-\Delta A_2|}{1+|A_2-\Delta A_2|\times B_2}\right]B_1}$$

Example 1.9 : *An amplifier has a voltage gain of 4000. It's input impedance is 2K and output impedance is 60K. Calculate the voltage gain, input and output impedance of the circuit is 5% of the feedback is fed in the form of series negative voltage feedback.*

Solution : The voltage gain with feedback can be given as

$$A_{vf} = \frac{A_v}{1+A_v\beta} = \frac{4000}{1+4000\times 0.05}$$

$$= 19.9$$

In a voltage series feedback input resistance with feedback is given as

$$R_{if} = R_i\,(1+\beta A_v)$$

$$= 2K(1+0.05\times 4000)$$

$$= 402 \text{ k}\Omega$$

In a voltage series feedback output resistance with feedback is given as

$$R_{of} = \frac{R_o}{1+\beta A_v} = \frac{60K}{1+0.05\times 4000}$$

$$= 298.5\ \Omega$$

Example 1.10 : *An amplifier without feedback gives a fundamental output of 36 V with 7% second harmonic distortion when the input is 0.028 V.*
i) If 1.2 percent of the output is fedback into the input in a negative voltage series feedback circuit, what is the output voltage
ii) If the fundamental output is maintained at 36 V but the second harmonic distortion is reduced to 1 percent what is the input voltage?

Solution : The voltage gain of amplifier can be given as

$$A_v = \frac{V_o}{V_{in}}$$

$$= \frac{36}{0.028}$$

$$= 1285.7$$

i) $\beta = 0.012$

∴ The gain of the amplifier with feedback is given as

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

$$= \frac{1285.7}{1+1285.7\times 0.012}$$

$$= 78.26$$

The output voltage with feedback is given as

$$V_o = A_f V_{in} = 78.26 \times 0.028$$

$$= 2.19 \text{ V}$$

ii) If the output remains constant at 36 V, then the distortion produced within the active devices of the amplifier is unchanged. However, since the distortion at the output is less than in part i) by a factor of 7, it follows that the feedback now increased by 7 and hence, the voltage gain decreased by 7. Thus, the input signal required to produce the same output (as in part i) without feedback must be:

$$V_{in} = 7\ (0.028 \text{ V})$$

$$= 0.196 \text{ V}$$

Example 1.11 : *An amplifier having a voltage gain of 60 dB uses $1/20^{th}$ of it output in negative feedback. Calculate the gain with feedback, the percentage change in gain without and with feedback consequent on 50% change in g_m.*

Solution : i) The gain of the amplifier is given as

$$60\text{dB} = 20 \log \frac{V_o}{V_s}$$

$$\therefore \quad A_v = \frac{V_o}{V_s} = 1000$$

$$\beta = \frac{1}{20} = 0.05$$

∴ The gain of amplifier with feedback is

$$A_{vf} = \frac{A_v}{1+\beta A_v}$$

$$= \frac{1000}{1+0.05\times 1000}$$

$$= 19.6$$

ii) The gain of the amplifier is directly proportional to the g_m. Therefore, the gain of the amplifier without feedback changes as same amount as g_m changes

$$\therefore \quad A_v = A_V \pm 0.5A_V$$

$$= 1000 \pm 500$$

The gain of the amplifier with feedback is now given as

$$A_{vf} = \frac{1000\pm 500}{1+0.05(1000\pm 500)} = \frac{1000\pm 500}{1+(50\pm 25)}$$

$$= 19.23 \text{ or } 19.73$$

Example 1.12 : *A single stage RC coupled amplifier has a midband gain of 1000 is made into a negative feedback amplifier by feeding 10% of the output voltage in series with input opposing.*
i) What is the ratio of half power frequencies with feedback to those without feedback?
ii) If f_L = 20Hz and f_H = 50 kHz for the amplifier without feedback. Find the corresponding values after feedback is incorporated.

Solution : $A_v = 1000$ and $\beta = 0.1$

i) $$\frac{f_{Hf}}{f_H} = 1 + \beta A_v$$

$$= 1 + 0.1 \times 1000$$

$$= 101$$

and $$\frac{f_{Lf}}{f_L} = \frac{1}{1+\beta A_V} = \frac{1}{1+0.1\times 1000}$$

$$= \frac{1}{101}$$

$$= 0.0099$$

ii) With f_L = 20 Hz and f_H = 50 kHz

$$f_{Lf} = 20\times 0.0099$$

$$= 0.198 \text{ Hz} \quad \text{and } f_{Hf} = 50 \text{ kHz} \times 101$$

$$= 5.05 \text{ MHz}$$

Example 1.13 : *An amplifier without feedback gives an output of 50 V into 6% second harmonic distortion when the input is 0.2 V. If the negative feedback is applied to amplifier so that the second harmonic distortion is reduced to 1%. What value of feedback ratio must be used? What input voltage will be required to produce the same output voltage of 50 V?*

Solution : The voltage gain of the amplifier is given as

$$A_v = \frac{V_o}{V_{in}}$$

$$= \frac{50}{0.2}$$

$$= 250$$

We know that,

$$B_{2f} = \frac{B_2}{1+A_v\beta}$$

$$\therefore \quad 0.01 = \frac{0.06}{1+250\beta}$$

$$\therefore \quad \text{Feedback ratio, } \beta = \frac{\frac{0.06}{0.01}-1}{250}$$

$$= 0.02$$

ii)

$$A_{vf} = \frac{A_V}{1+A_V\beta}$$

$$= \frac{250}{1+250\times 0.02} = 41.66$$

To produce output voltage of 50 V V_{in} must be

$$V_{in} = \frac{50}{A_{vf}} = \frac{50}{41.66} = 1.2 \text{ V}$$

Example 1.14 : *An amplifier with negative feedback has a voltage gain of 120. It is found that without feedback an input signal of 60 mV is required to produce a particular output, whereas with feedback the input signal must be 0.5 V to get the same output. Find A_v and β of the amplifier.*

Solution : Given $A_{vf} = 120$

$$A_v = \frac{V_o}{V_s} = \frac{V_o}{60 \text{ mV}}$$

and

$$A_{vf} = \frac{V_o}{0.5}$$

$$\therefore \quad V_o = 0.5\times 120 = 60 \text{ V}$$

with $V_o = 60$ V we have,

$$A_v = \frac{60}{60\text{mV}} = 1000$$

We know that,

$$A_{vf} = \frac{A_v}{1+A_v\beta}$$

$$\therefore \quad 120 = \frac{1000}{1+1000\beta}$$

$$\therefore \quad \beta = 0.00733$$

Example 1.15 : *Identify topology, with justification for the circuit shown in Fig. 1.47 Transistors used are identical and have parameters h_{ie} = 2K, h_{fe} = 50 and $h_{re} = h_{oe} = 0$. Determine A_{vf}.*

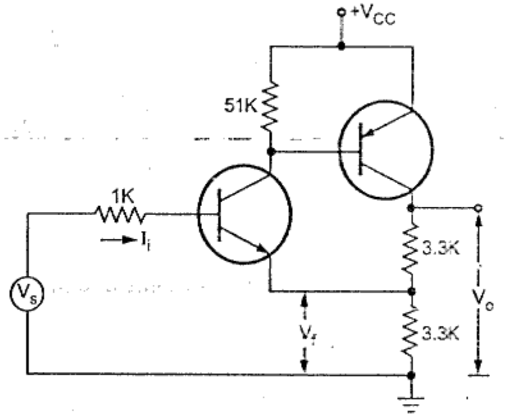


Fig. 1.47

Solution : Step 1 : Identify topology

By shorting output voltage (V_o = 0) feedback voltage V_f becomEs zero, hence it is a voltage sampling. Since feedback is mixed in series with input the topology is voltage series feedback amplifier.

Step 2 and Step 3 : Find input and output circuit

To find input circuit set V_o = 0. This places the parallel combination of 3.3 K and 3.3 K at first emitter. To find output circuit set I_i = 0. This places resistors 3.3 K and 3.3 K in series across the output. The resultant circuit is shown in Fig. 1.48.

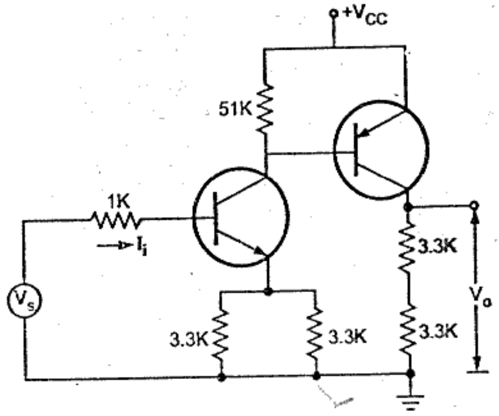


Fig. 1.48

Step 4 : Replace transistors with their h-parameter equivalent circuits

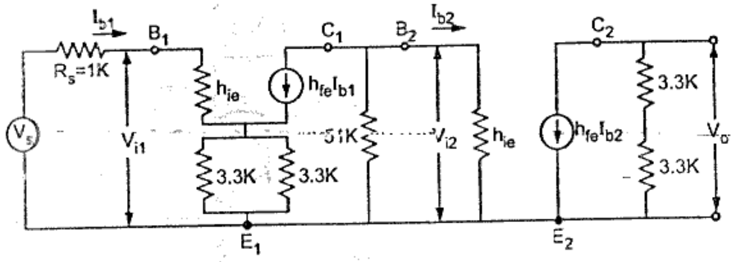


Fig. 1.49 h-parameter equivalent circuit

Step 5 : Find open loop transfer gain

The voltage gain without feedback

$$A_V = A_{v1} A_{v2} = \frac{V_{i2}}{V_{i1}} \times \frac{V_o}{V_{i2}}$$

$$= \frac{V_o}{V_{i2}} = \frac{-h_{fe} R_{L2}}{R_{i2}}$$

where $R_{L2} = 3.3\text{ K} + 3.3\text{ K} = \mathbf{6.6\text{ K}}$

and $R_{i2} = h_{ie} = 2\text{ K}$

$\therefore$ $$A_{v2} = \frac{V_o}{V_{i2}} = \frac{-50 \times 6.6 \times 10^3}{2 \times 10^3}$$

$$= -165$$

$$\frac{V_{i2}}{V_{i1}} = \frac{-h_{fe} R_{L1}}{R_{i1}}$$

where $R_{L1} = 51\text{ K} \parallel R_{i2} = 51\text{ K} \parallel 2\text{ K}$

$= \mathbf{1.92\text{ k}\Omega}$

and $R_{i1} = h_{ie} + (1 + h_{fe})(3.3\text{ K} \parallel 3.3\text{ K})$

$= 2 \times 10^3 + (1 + 50)(1.65 \times 10^3)$

$= \mathbf{86.15\text{ k}\Omega}$

$\therefore$ $$A_{v1} = \frac{V_{i2}}{V_{i1}} = \frac{-50 \times 1.92 \times 10^3}{86.15 \times 10^3} = -1.114$$

$\therefore$ $A_V = -165 \times -1.114 = \mathbf{183.86}$

Step 6 : Calculate β

$$\beta = \frac{V_f}{V_o} = \frac{3.3\text{K}}{3.3\text{K} + 3.3\text{K}} = 0.5$$

We know that, $D = 1 + \beta A_v$

$$A_{vf} = \frac{A_V}{D} = \frac{183.86}{92.93}$$

$= \mathbf{1.978}$

Example 1.16 : *For the circuit shown in Fig. 1.50. Calculate A_{vf}, R_{if} and R'_{of}. Transistors are identical and their parameters are h_{ie} = 1.1 K, h_{fe} = 50. Neglect h_{re} and h_{oe}.*

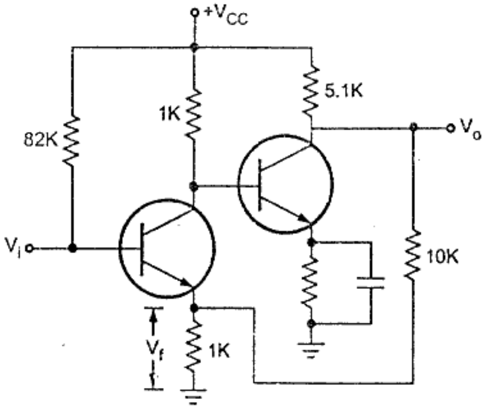


Fig. 1.50

Solution : Step 1 : Identify topology

By shorting output voltage ($V_o = 0$), feedback voltage V_f becomes zero. The feedback voltage is mixed in series feedback.

Step 2 and Step 3 : Find input and output circuit

To find input circuit, set $V_o = 0$. This places the parallel combination of resistors 10 K and 1 K at the first emitter. To find output circuit, set $I_i = 0$. This places resistors 10K and 1K is series across the output. The resultant circuit is shown in the Fig. 1.51.

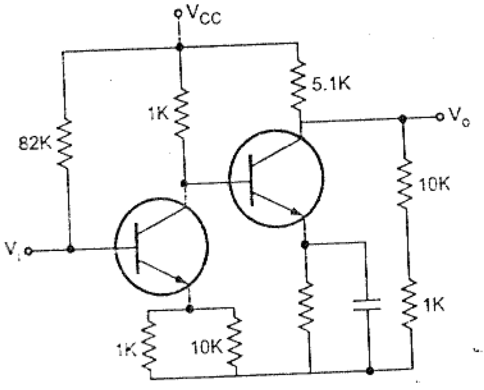


Fig. 1.51

Step 4 : Replace transistors with h-parameter equivalent circuits.

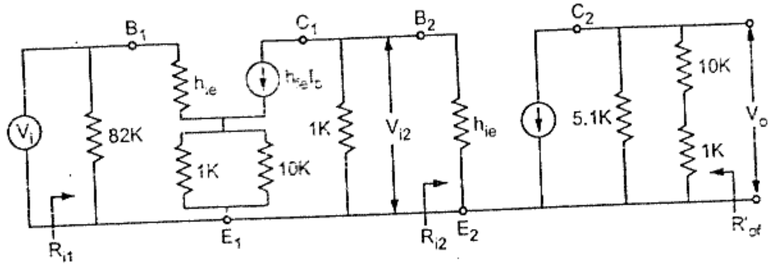


Fig. 1.52 h-parameter equivalent circuit

Step 5 : Find open loop transfer gain

$$A_v = A_{v1} A_{v2}$$

$$= \frac{V_{i2}}{V_{i1}} \times \frac{V_o}{V_{i2}}$$

$$\frac{V_o}{V_{i2}} = \frac{-h_{fe} R_{L2}}{R_{i2}}$$

where

$$R_{L2} = 5.1\text{ K} \parallel (10\text{ K} + 1\text{K})$$

$$= 3.484\text{ k}\Omega$$

and

$$R_{i2} = h_{ie} = 1.1\text{ K}$$

$\therefore$

$$\frac{V_o}{V_{i2}} = \frac{-50 \times 3.484 \times 10^3}{1.1 \times 10^3}$$

$$= -158.36$$

$$\frac{V_{i2}}{V_{i1}} = \frac{-h_{fe} R_{L1}}{R_{i1}}$$

where

$$R_{L1} = R_{i2} \parallel 1\text{ K} = 1.1\text{ K} \parallel 1\text{ K}$$

$$= 523.8\text{ k}\Omega$$

and

$$R_i = 82\text{ K} \parallel [h_{ie} + (1 + h_{fe})(1\text{K} \parallel 10\text{K})]$$

$$= 82\text{K} \parallel [1.1\text{K} + (1 + 50)(0.909\text{ K})]$$

$$= 30\text{ k}\Omega$$

$\therefore$

$$\frac{V_{i2}}{V_{i1}} = \frac{-50 \times 523.8}{30 \times 10^3} = -0.888$$

$\therefore$

$$A_v = -158.36 \times -0.888$$

$$= 140.62$$

Step 6 : Calculate β

$$\beta = \frac{V_f}{V_o} = \frac{1\text{K}}{10\text{ K}}$$

$$= 0.1$$

Step 7 : Calculate A_{vf}, R_{if} and R'_{of}

$$D = 1 + \beta A_v = 1 + 0.1 \times (140.62)$$

$$= 15.062$$

$$A_{vf} = \frac{A_v}{D} = \frac{140.62}{15.062}$$

$$= 9.336$$

$$R_{if} = R_i \times D = 30 \times 10^3 \times 15.062$$

$$= 451.86 \text{ k}\Omega$$

$$R'_o = R_{L2} = 3.484 \text{ k}\Omega$$

$$R'_{of} = \frac{R'_o}{D} = \frac{3.484\times 10^3}{15.062}$$

$$= 231.31\Omega$$

Example 1.17 : *The two stage feedback shown in Fig. 1.53 uses FET. The parameters are r_d = 10K and μ = 40.*

i) Identify the topology of feedback

ii) Calculate D, A_{vf}, R_{if}, R_{of} and R'_{of}.

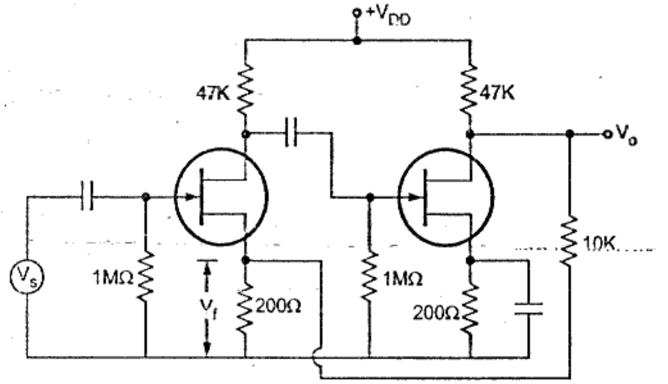


Fig. 1.53

Solution : **Step 1 :** Identify topology

By shorting output voltage (V_o = 0), feedback voltage V_f becomes zero and hence it is voltage sampling. The feedback voltage is applied in series with the input voltage hence the topology is voltage series feedback.

Step 2 and Step 3 : Find input and output circuit.

To find input circuit, set V_o = 0. This places the parallel combination of resistors 10K and 200 Ω at first source. To find output circuit, set I_i = 0. This places the resistors 10 K and 200 Ω in series across the output. The resultant circuit is shown in Fig. 1.54.

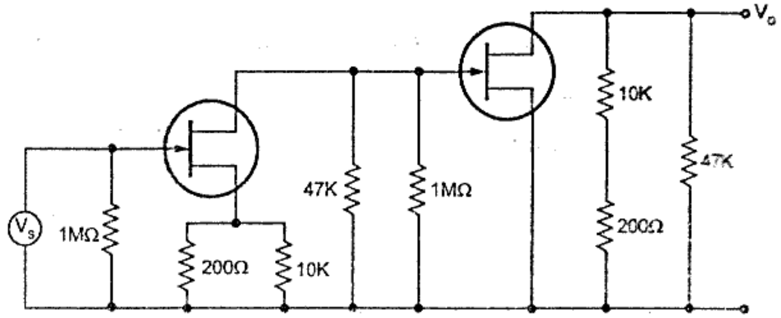


Fig. 1.54

Step 4 : Replace FET with its equivalent circuit

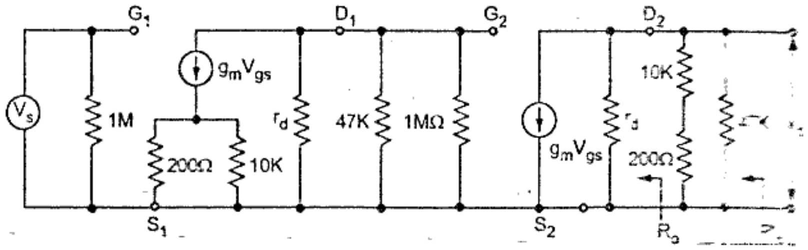


Fig. 1.55

Step 5 : Find open loop transfer gain

$$A_v = \frac{V_o}{V_s} = A_{v1} A_{v2}$$

$$A_{v2} = \frac{-\mu R_{L2}}{R_{L2} + r_d}$$

where $R_{L2} = (10K + 200\Omega) \parallel 47K$

$$= 8.38 \text{ K}$$

$$\therefore \quad A_{v2} = \frac{-40\times 8.38\times 10^3}{8.38\times 10^3 + 10\times 10^3}$$

$$= -18.237$$

$$A_{v1} = \frac{\mu R_{Deff}}{r_d + R_{Deff} + (1+\mu) R_s}$$

where $R_{Deff} = R_D \parallel R_{G2} = 47K \parallel 1 \text{ M}\Omega$

$$= 44.89 \text{ k}\Omega$$

$$A_{v1} = \frac{-40 \times 44.98 \times 10^3}{10 \times 10^3 + 44.89 \times 10^3 + (1+40)(10K \parallel 200)}$$

$$= -28.59$$

$$\therefore \quad A_V = -28.59 \times -18.237$$

$$= 521.39$$

Step 6 : Calculate β

$$\beta = \frac{V_f}{V_o} = \frac{200}{10 \times 10^3}$$

$$= 0.02$$

Step 7 : Calculate D, A_{Vf}, R_{if}, R'_{of}

$$D = 1 + \beta A_V = 1 + 0.02 \times 521.39$$

$$= 11.4278$$

$$A_{Vf} = \frac{A_V}{D} = \frac{521.39}{11.4278} = 45.62$$

$$R_i = R_G = 1 M\Omega$$

$$R_{if} = R_i \times D = 1 \times 10^6 \times 11.4278$$

$$= 11.4278\ M\Omega$$

$$R_o = r_d$$

$$= 10\ K$$

$$R_{of} = \frac{R_o}{D} = \frac{10 \times 10^3}{11.4278} = 875\ \Omega$$

$$R'_o = r_d \parallel R_{L2} = 10\ K \parallel 8.38\ K$$

$$= 4.559\ k\Omega$$

$$\therefore \quad R'_{of} = \frac{R'_o}{D} = \frac{4.559 \times 10^3}{11.4278}$$

$$= 399\ \Omega$$

Example 1.18 : *The circuit shows three stage FET amplifier.*

The identical FETs have following parameters

$r_d = 8\ k\Omega$, $g_m = 5\ mA/V$, $R_g = 1 M\Omega$,

$R_s = R_1 + R_2$, $R_1 = 50\ \Omega$, $R_d = 40\ k\Omega$

Calculate voltage gain including feedback.

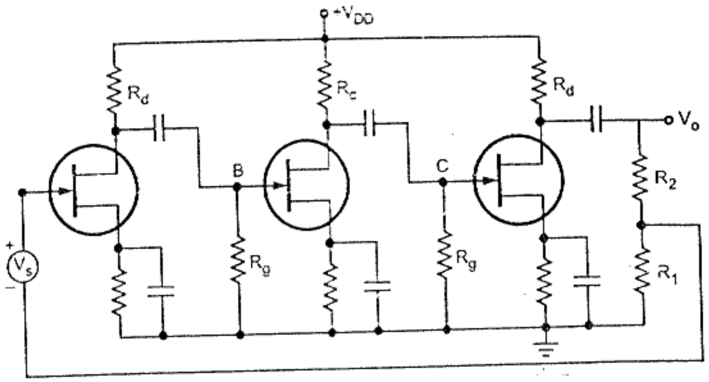


Fig. 1.56

Solution : Here, output voltage is sampled and fed in series with the input signal. Hence the topology is voltage series feedback.

The open loop voltage gain for one stage is given as

$$A_V = -g_m R_{eq}$$

Where

$$R_{eq} = r_d \parallel R_d \parallel (R_{i2} + R_2) = 8K \parallel 40K \parallel (1\ M\Omega)$$

$$= 6.62\ k\Omega$$

$$A_V = -5 \times 10^3 \times 6.62 \times 10^3$$

$$= -33.11$$

$$\text{Overall voltage gain} = |A_{v\,mid}|^3 = |-33.11|^3$$

$$= -36306$$

$$\beta = \frac{R_1}{R_1 + R_2} = \frac{50}{1 \times 10^6}$$

$$= 5 \times 10^{-5}$$

$$\therefore \quad D = 1 + \beta\,|A_v| = 1 + (5 \times 10^{-5}) \times (36306)$$

$$= 2.8153$$

$$\therefore \quad |A_{Vf}| = \frac{A_{Vf}}{1 + |A_V|\beta}$$

$$= \frac{36306}{2.8153} = 12.895 \times 10^3$$

$$\therefore \quad A_{Vf} = -12.895 \times 10^3$$

Example 1.19 : *In the Ex. 1.18, if output is taken between point B and ground, calculate A_{vf}.*

Solution : We know that

$$A_V = -33.11$$

Here

$$\beta = \frac{V_f}{V_B} = \frac{V_f}{V_o} \times \frac{V_o}{V_C} \times \frac{V_C}{V_B}$$

where V_B and V_C are voltages at point B and C, respectively

$$\beta = \frac{V_f}{V_o} \times A_{V3} \times A_{V2} \qquad \because \frac{V_o}{V_C} = A_{V3} \text{ and } \frac{V_C}{V_B} = A_{V2}$$

$$\beta = 5 \times 10^{-5} \times (-33.11) \times (-33.11)$$

$$= 0.0548$$

$$|A_{Vf}| = \frac{A_{Vf}}{1+\beta|A_V|} = \frac{33.11}{1-0.0548 \times 33.11} = 11.76$$

$$A_{Vf} = -11.76$$

Example 1.20 : *For the circuit shown in Fig. 1.57.*

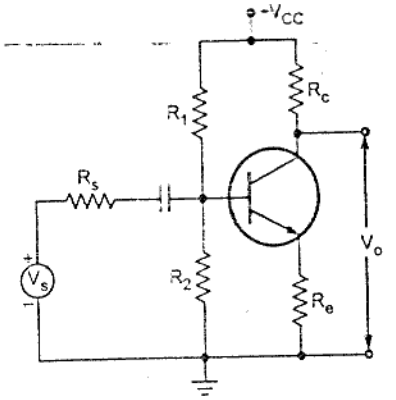


Fig. 1.57

i) Identify topology used in feedback amplifier

ii) Show that voltage gain with feedback

$$A_{Vf} = \frac{V_o}{V_s} = \frac{-h_{fe} R_c \left(\dfrac{1}{1+\dfrac{R_s}{R_b}} \right)}{R_s' + h_{ie} + (1+h_{fe}) R_e}$$

where $R_s' = R_s \,||\, R_1 \,||\, R_2$

Solution : Step 1 : Identify topology

By shorting output ($V_o = 0$), feedback voltage does not become zero. By opening the output loop feedback becomes zero and hence it is current sampling. The feedback is applied in series with the input signal, hence topology used is current series feedback.

Step 2 and Step 3 : Find input and output circuit

To find input circuit, set $I_o = 0$. This places R_e in series with input. To find output circuit $I_i = 0$. This places R_e in the output side. The resultant circuit is shown in Fig. 1.58.

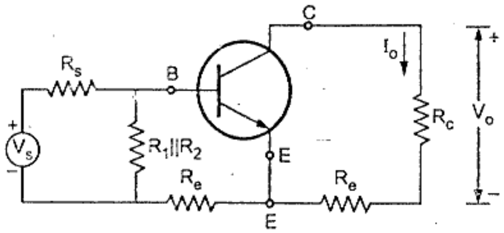


Fig. 1.58

Step 4 : Replace transistor with its h-parameter equivalent

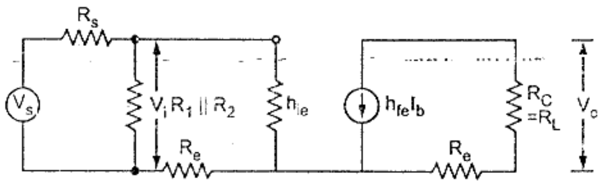


Fig. 1.59

Step 5 : Find open loop transfer gain

From equation (13) of section 1.12 we have

$$A_{Vf} = \frac{I_o R_L}{V_i} = G_{Mf} R_L$$

$$= \frac{-h_{fe} R_L}{R_s' + h_{ie} + (1+h_{fe}) R_e}$$

Here

$$R_s' = R_s \,||\, R_1 \,||\, R_2$$

$$= R_s \,||\, R_b \qquad \because R_b = R_1 \,||\, R_2$$

$$\therefore \quad \frac{V_o}{V_s} = \frac{V_o}{V_i} \times \frac{V_i}{V_s}$$

where

$$\frac{V_i}{V_s} = \frac{R_b}{R_s + R_b}$$

$$\therefore \quad \frac{V_o}{V_s} = \frac{-h_{fe}R_L}{R'_s + h_{ie} + (1+h_{fe})R_e} \times \frac{R_b}{R_s + R_b}$$

Dividing both numerator and denominator by $R_s + R_b$ we get

$$A_{Vf} = \frac{V_o}{V_s} = \frac{-h_{fe}R_c \times \dfrac{R_b}{R_b + R_s}}{R'_s + h_{ie} + (1+h_{fe})R_e} \quad \because R_L = R_c$$

$$= \frac{-h_{fe}R_c\left(\dfrac{1}{1+\dfrac{R_s}{R_b}}\right)}{R'_s + h_{ie} + (1+h_{fe})R_e}$$

Example 1.21 : *Identify the topology of feedback in the circuit of Fig. 1.60 giving justification. Two transistors are identical with h_{ie} = 2K and h_{fe} = 100, Calculate*

i) R_{if} ii) A_{if} iii) A_{vf}

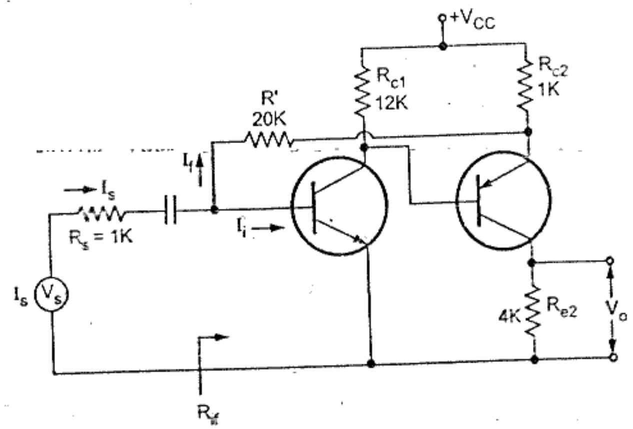


Fig. 1.60

Solution : Step 1 : Identify topology

Making output voltage zero (V_o = 0); feedack does not become zero and hence it is not voltage sampling. By opening the output loop feedback becomes zero and hence it is a current sampling. As $I_i = I_s - I_f$, the feedback current appears in shunt with the input signal and hence the topology is current shunt feedback.

Step 2 and Step 3 : Find input and output circuit

To find input circuit, set I_o = 0. This gives series combination of resistors 20K and 1K across of the input of the first transistor. To find output circuit, set V_i = 0. This gives parallel combination of resistors 20K and 1K at emitter of the second transistor. The resultant circuit is shown in Fig. 1.61.

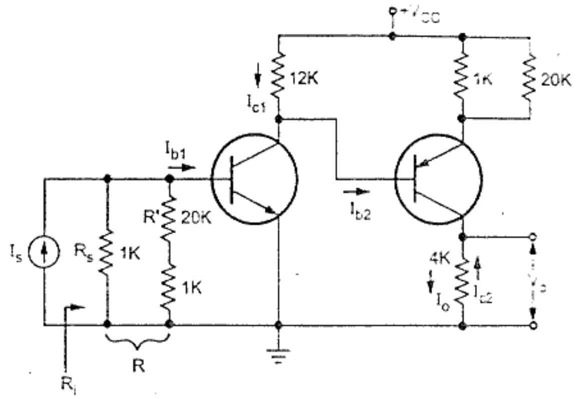


Fig. 1.61

Step 4 : Find open circuit current gain

$$A_I = \frac{I_o}{I_s} = \frac{-I_{c2}}{I_s} = \frac{-I_{c2}}{I_{b2}} \times \frac{I_{b2}}{I_{c1}} \times \frac{I_{c1}}{I_{b1}} \times \frac{I_{b1}}{I_s}$$

$$\frac{-I_{c2}}{I_{b2}} = -h_{fe} = -100$$

$$\frac{I_{b2}}{I_{c1}} = \frac{-R_{c1}}{R_{c1} + R_{i2}}$$

where $R_{i2} = h_{ie} + (1 + h_{fe})\,R_e = 2 \times 10^3 + (1 + 100)\,(1K \,||\, 20K)$

$= 98.19$ K

$$\therefore \quad \frac{I_{b2}}{I_{c1}} = \frac{-12\,K}{12\,K + 98.19\,K} = -0.109$$

$$\frac{I_{c1}}{I_{b1}} = h_{fe} = 100$$

$$\frac{I_{b1}}{I_s} = \frac{1K||(20K+1K)}{h_{ie} + 1K||(20K+1K)}$$

$= 0.323$

$\therefore \quad A_I = (-100) \times (-0.109) \times (100) \times (0.323)$

$= 352$

Step 5 : Calculate β

$$\beta = \frac{I_f}{I_o} = \frac{R_{e2}}{R_{e2} + R'} = \frac{4\,K}{4\,K + 20\,K}$$

$$= 0.1667$$

$$\therefore \quad D = 1 + \beta A_I = 1 + (0.1667) \times 352$$

$$= 59.67$$

$$A_{If} = \frac{A_I}{1+\beta A_I} = \frac{A_I}{D} = \frac{352}{59.67}$$

$$= 5.90$$

$$R_i = 1K \parallel (1K + 20K) \parallel R_{i1}$$

$$= 1K \parallel 21K \parallel 2K \qquad \because R_{i1} = h_{ie} = 2K$$

$$= 646\ \Omega$$

$$R_{if} = \frac{R_i}{1+\beta A_I} = \frac{R_i}{D} = \frac{646}{59.67}$$

$$= 10.82\ \Omega$$

$$R_o = \infty \qquad \therefore R_{of} = \infty \qquad \because h_{oe} = 0$$

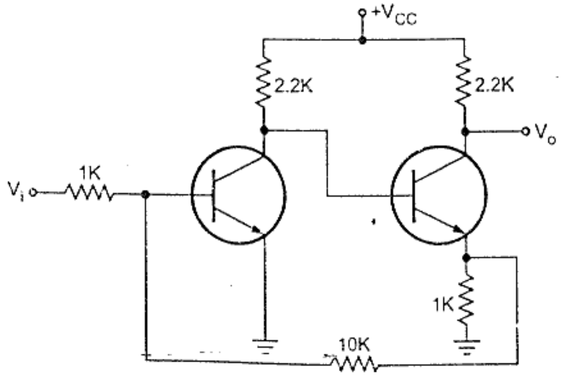
$$R'_o = R_o \parallel R_{c2} = \infty \parallel 4K = 4K$$

$$R'_{of} = R'_o \frac{(1+\beta A_I)}{(1+\beta A_I)} = R'_o = 4K$$

$$A_{Vf} = \frac{A_{If} R_L}{R_s} = \frac{5.9 \times 4K}{1K}$$

$$= 23.6$$

Example 1.22 : *For the circuit shown in Fig. 1.62. Calculate A_{Vf}, R_{if} and R_{of}. Transistor parameters are h_{ie} = 1K, h_{fe} =100, h_{oe} = 0.*



Solution : Step 1 : Identify topology

V_o = 0, does not make feedback zero, but I_o = 0 makes feedback to become zero and hence it is current sampling. The feedback is fed in shunt with the input signal, hence topology is current shunt feedback.

Step 2 and Step 3 : Find input and output circuit

To find input circuit, set I_o = 0. This gives series combination of R_{e2} and 10K across the input. To find output circuit, set V_i = 0. This gives parallel combination of R_{e2} and 10K at E_2. The resultant circuit is shown in Fig. 1.63.

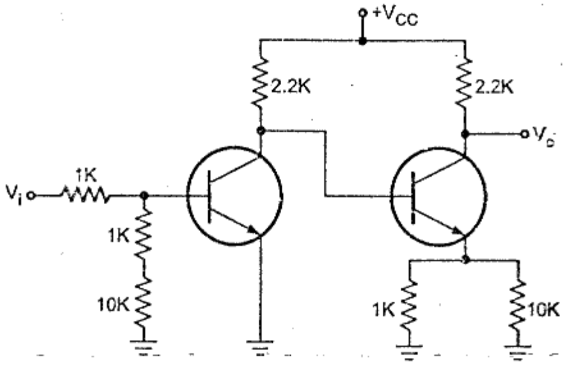


Fig. 1.63

Step 4 : Replace transistor with its h-parameter equivalent

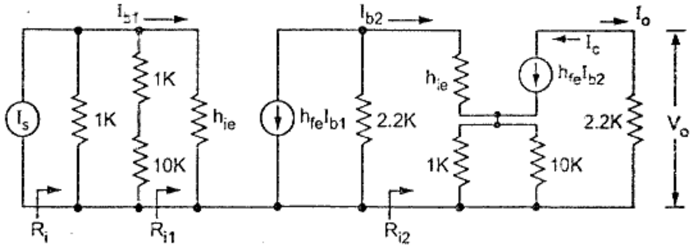


Fig. 1.64 h-parameter equivalent circuit

Step 5 : Find open loop current gain

$$A_I = \frac{I_o}{I_s} = \frac{-I_c}{I_s}$$

$$= \frac{I_o}{I_{b2}} \frac{I_{b2}}{I_{c1}} \frac{I_{c1}}{I_{b1}} \frac{I_{b1}}{I_s}$$

$$\frac{I_o}{I_{b2}} = -h_{fe} = -100$$

$$\frac{I_{c1}}{I_{b1}} \times \frac{I_{b2}}{I_{c1}} = \frac{-h_{fe}R_{c1}}{R_{c1}+R_{i2}} \qquad \because \frac{I_{b2}}{I_{c1}} = \frac{R_{c1}}{R_{c1}+R_{i2}}$$

where

$$R_{i2} = h_{ie} + (1 + h_{fe})\,(1K \,||\, 10\,K)$$

$$= 1K + (1 + 100)\,(1K \,||\, 10\,K)$$

$$= 92.818\ K$$

$$\frac{I_{b2}}{I_{b1}} = \frac{-100 \times 2.2 \times 10^3}{92.818 \times 10^3 + 2.2 \times 10^3}$$

$$= -2.315$$

$$\frac{I_{b1}}{I_s} = \frac{1K \,||(1K+10K)}{h_{ie}+1K \,||\, (10K+1\,K)}$$

$$= 0.478$$

$$A_I = (-100) \times (-2.315) \times 0.478$$

$$= 110.7$$

Step 6 : Calculate β

$$\beta = \frac{R_{e2}}{R_{e2}+R'} = \frac{1K}{1K+10K} = 0.09$$

Step 7 : Calculate D, A_{If}, R_{if}, R_{of} and A_{vf}

$$D = 1 + \beta\, A_I = 1 + (0.09)\,(110.7)$$

$$= 11.063$$

$$A_{If} = \frac{A_I}{1+\beta A_I} = \frac{A_I}{D} = \frac{110.7}{11.063}$$

$$= 10$$

$$R_i = 1K \,||\, (10K + 1K) \,||\, R_{i1}$$

$$= 1K \,||\, (11K) \,||\, 1K \qquad \because R_{i1} = h_{ie} = 1\,K$$

$$= 478\ \Omega$$

$$R_{if} = \frac{R_i}{D} = \frac{478}{11.063} = 43.20\ \Omega$$

$$R_o = \infty$$

$$\therefore \quad R_{of} = R_o\, D = \infty \quad \because h_{oe} = 0$$

$$R'_o = 2.2\ k\Omega$$

$$R'_{of} = R'_o \frac{(1+\beta A_i)}{(1+\beta A_I)} = R'_o$$

$$= 2.2\ k\Omega$$

Example 1.23 : *For the circuit shown in Fig. 1.65 has following parameters :* $h_{fe} = 100$ $h_{ie} = 1.1$ *K, and* h_{re} *and* $h_{oe} = 0$. *Determine*

i) $R_{mf} = \frac{V_o}{I_s}$, ii) $A_{Vf} = \frac{V_o}{V_s}$

iii) R_{if} *and* iv) R'_{of}

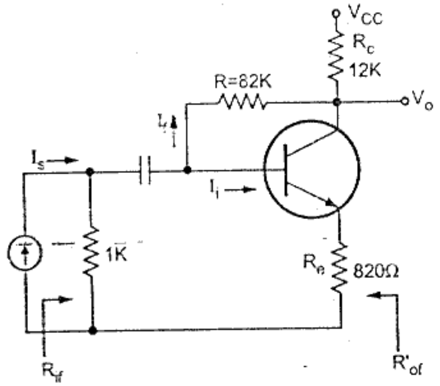


Fig. 1.65

Solution : Step 1 : Identify topology

Here output voltage is sampled and fed in shunt with the input signal, such that, $I_s - I_f = I_i$ hence topology is voltage shunt feedback.

Step 2 : Find input and output circuit

To find input circuit, set $V_o = 0$. This places resistor R across the input. To find output circuit, set $V_i = 0$. This places resistor R across the output. The resultant circuit is shown in Fig. 1.66.

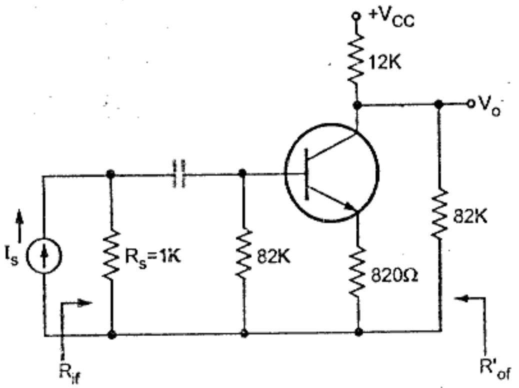


Fig. 1.66 h-parameter equivalent circuit

Step 4 : Replace transistor with its h-parameter equivalent circuit

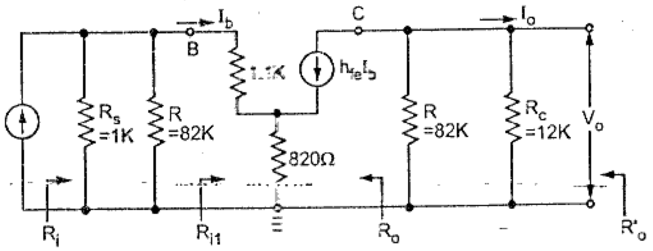


Fig. 1.67

Step 5 : Find the open circuit tranresistance

$$R_M = \frac{V_o}{I_s} = \frac{R_c I_o}{I_s} = \frac{-R_c I_c}{I_s}$$

$$= R_c \cdot \frac{-I_c}{I_b} \frac{I_b}{I_s}$$

$$\frac{-I_c}{I_b} = \frac{-h_{fe} R}{R+R_c} = \frac{-100 \times 82 \times 10^3}{82 \times 10^3 + 12 \times 10^3}$$

$$= -87.23$$

$$\frac{I_b}{I_s} = \frac{R_s || R}{R_s || R + R_{i1}}$$

where $R_{i1} = h_{ie} + (1 + h_{fe}) R_e$

$$= 1.1 \times 10^3 + (101)\ 820$$

$$= 83.92 \text{ K}$$

$$\therefore \quad \frac{I_b}{I_s} = \frac{(1 \times 10^3) || (82 \times 10^3)}{(1 \times 10^3) || (82 \times 10^3) + 83.92 \times 10^3}$$

$$= 0.0116$$

$$\therefore \quad R_M = \frac{V_o}{I_s} = 12 \times 10^3 \times (-87.23) \times 0.0116$$

$$= -12.142 \text{ K}$$

Step 6 : Calculate β

$$\beta = \frac{I_f}{I_o} = \frac{V_i - V_o}{V_o R}$$

$$= \frac{-1}{R} \quad \because V_o > V_i$$

$$\therefore \quad \beta = \frac{-1}{82K} = -1.22 \times 10^{-5}$$

Step 7 : Calculate D, R_{Mf}, A_{Vf}, R_{if} and R'_{of}

$$D = 1 + \beta R_M$$

$$= 1 + (-1.22 \times 10^{-5})(-12.142 \times 10^3)$$

$$= 1.148$$

$$R_{Mf} = \frac{R_M}{D} = \frac{-12.142 \text{ K}}{1.148} = -10.57 \text{ K}$$

$$A_{Vf} = \frac{V_o}{V_s} = \frac{V_o}{I_s R_s}$$

$$= \frac{R_{Mf}}{R_s} = \frac{-10.57 \times 10^3}{1 \times 10^3} \quad \because R_{Mf} = \frac{V_o}{I_s}$$

$$= -10.57$$

$$R_i = R_s || R || R_{i1} = 1 \text{ K} || 82 \text{ K} || 83.92 \text{ K}$$

$$= 0.976 \text{ K}$$

$$\therefore \quad R_{if} = \frac{R_i}{D} = \frac{0.976 \times 10^3}{1.148} = 850\Omega$$

$$R_o = \infty \quad \therefore R_{of} = \frac{\infty}{D} = \infty \quad \because h_{oe} = 0$$

$$R'_o = R_c || R = 12 \text{ K} || 82 \text{ K}$$

$$= 10.468 \text{ K}$$

$$R'_{of} = \frac{R'_o}{D} = \frac{10.468 \times 10^3}{1.148}$$

$$= 9.118 \text{ K}$$

Example 1.24 : *The two stage amplifier shown in the Fig. 1.68 has identical transistors with parameters h_{ie} = 2 K, h_{fe} = 100, and h_{re} = 0. Calculate a) A_{vf} b) R_{if} c) R'_{of}*

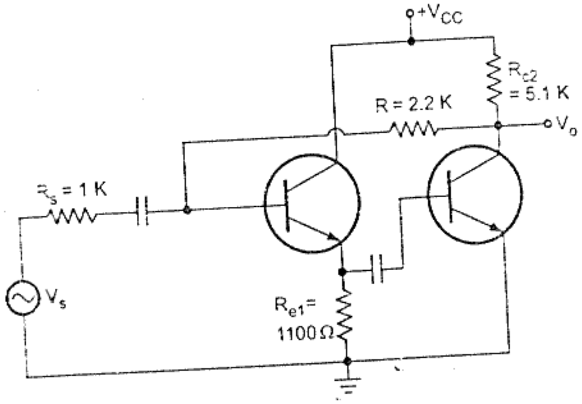


Fig. 1.68

Solution : Step 1 : Identify topology

Here output voltage is sampled and fed in shunt with the input signal such that, $I_s - I_f = I_i$, hence topology is voltage shunt feedback.

Step 2 and Step 3 : Find input and output circuit

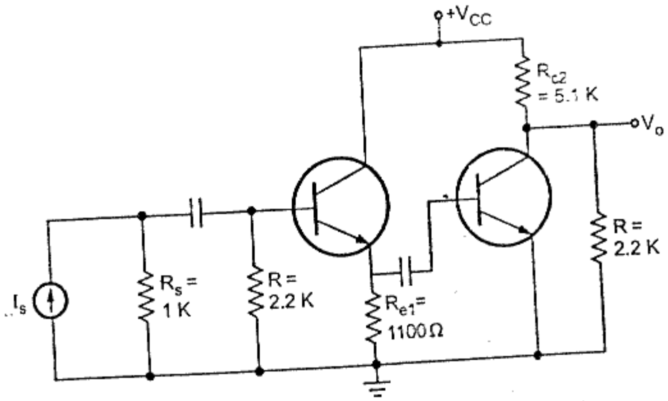


Fig. 1.69

To find input circuit, set V_o = 0. This places resistor R across the input. To find output circuit, set V_i = 0. This places resistor R across input. The resultant circuit is as shown in the Fig. 1.69. The circuit shows voltage source replaced by curent source.

Step 4 : Replace transistors with their h-parameter equivalent circuits.

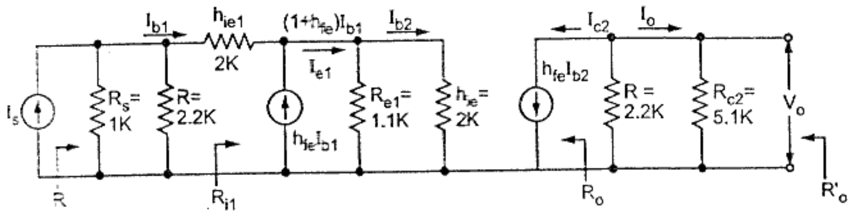


Fig. 1.70 h-parameter equivalent circuit

Step 5 : Find open loop transfer gain

$$R_M = \frac{V_o}{I_s} = \frac{R_{c2} I_o}{I_s}$$

$$= R_{c2} \cdot \frac{I_o}{I_{b2}} \frac{I_{b2}}{I_{e1}} \frac{I_{e1}}{I_{b1}} \frac{I_{b1}}{I_s}$$

$$\frac{I_o}{I_{b2}} = \frac{-h_{fe} R}{R + R_{c2}} = \frac{-100 \times 2.2 \times 10^3}{2.2 \times 10^3 + 5.1 \times 10^3}$$

$$= -30.137$$

$$\frac{I_{b2}}{I_{e1}} \times \frac{I_{e1}}{I_{b1}} = \frac{(1 + h_{fe}) R_{e1}}{R_{e1} + h_{ie}} = \frac{101 \times 1.1 \times 10^3}{1.1 \times 10^3 + 2 \times 10^3}$$

$$= 35.84$$

$$\frac{I_{b1}}{I_s} = \frac{R_s \| R}{(R_s \| R) + R_{i1}}$$

where $R_{i1} = h_{ie} + (1 + h_{fe}) R_e$

$$= 2 \times 10^3 + (101) \times 1.1 \times 10^3$$

$$= \mathbf{113.1\ k\Omega}$$

$$\frac{I_{b1}}{I_s} = \frac{1 \times 10^3 \| 2.2 \times 10^3}{1 \times 10^3 \| 2.2 \times 10^3 + 113.1 \times 10^3}$$

$$= 6.04 \times 10^{-3}$$

$$\therefore \quad R_M = 5.1 \times 10^3 \times (-30.137) \times 35.84 \times 6.04 \times 10^{-3}$$

$$= \mathbf{-33.539\ K}$$

Step 6 : Calculate β

$$\beta = \frac{I_f}{I_o} = \frac{V_i - V_o}{V_o R}$$

$$= \frac{-1}{R} \qquad \because V_o > V_i$$

$$= -\frac{1}{2.2 \times 10^3}$$

$$= -4.545 \times 10^{-4}$$

Step 7 : Calculate D, R_{Mf}, A_{vf}, R_{if} and R'_{of}

$$D = 1 + \beta R_M$$

$$= 1 + (-4.545 \times 10^{-4})\,(-33.539 \times 10^3)$$

$$= 16.245$$

$$R_{Mf} = \frac{R_M}{D} = \frac{-33.539 \times 10^3}{16.245}$$

$$= -2.065\ K$$

$$A_{vf} = \frac{V_o}{V_s} = \frac{V_o}{I_s R_s}$$

$$= \frac{R_{Mf}}{R_s} = \frac{-2.065 \times 10^3}{1 \times 10^3}$$

$$= -2.065$$

$$R_i = R_s \parallel R \parallel R_{i1} = 1\ K \parallel 2.2\ K \parallel 113.1\ K$$

$$= 638\ \Omega$$

$$R_{if} = \frac{R_i}{D} = \frac{683}{16.245}$$

$$= 42\ \Omega$$

$$R_o = \infty \qquad \therefore R_{of} = \frac{\infty}{D} = \infty$$

$$R'_o = R \parallel R_{c2} = 2.2 \times 10^3 \parallel 5.1 \times 10^3$$

$$= 1.537\ k\Omega$$

$$R'_{of} = \frac{R'_o}{D} = \frac{1.537 \times 10^3}{16.245}$$

$$= 94.61\Omega$$

Example 1.25 : *In the FET amplifier shown in Fig. 1.71 has the following parameters r_d = 40 kΩ g_m = 2.5 mA/V. Assume all capacitors to be rbitrarily large. Calculate D. R_{Mf}, A_{vf}, R_{if}, R_{of} and R'_{of}.*

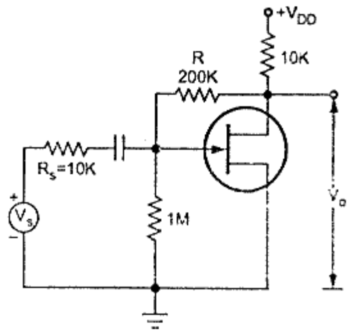


Fig. 1.71

Solution : Step 1 : Identify topology

By making V_o = 0, feedback current becomes zero. Hence it is a voltage sampling. The feedback is fed in shunt with the input signal and thus the topology is voltage shunt feedback.

Step 2 and Step 3 : Find input and output circuit.

To find input circuit, set V_o = 0. This places resistor R across the input. To find output circuit, set V_i = 0. This places resistor R across output. The resultant circuit is shown in Fig. 1.72.

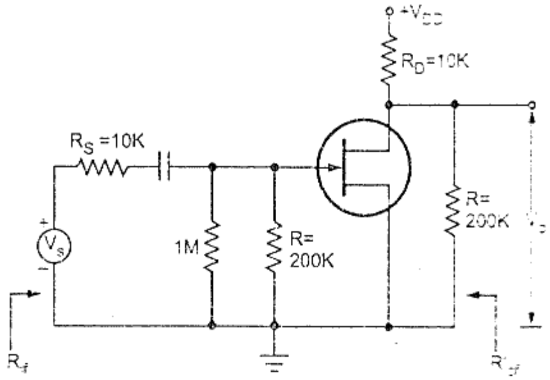


Fig. 1.72

Step 4 : Replace FET with its equivalent circuit

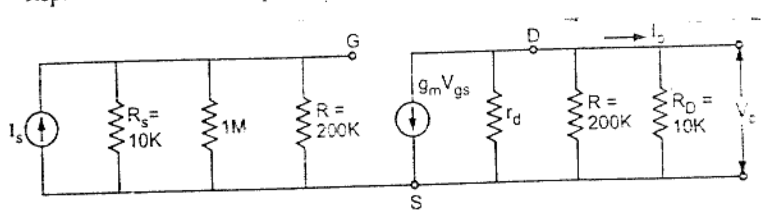


Fig. 1.73

Step 5 : Find open loop transresistance

$$R_M = \frac{V_o}{I_s} = \frac{-g_m V_{gs} R_{eff}}{I_s}$$

where

$$R_{eff} = r_d \parallel R \parallel R_D = 40\text{ K} \parallel 200\text{ K} \parallel 10\text{ K}$$

$$= 7.69\text{ k}\Omega$$

and

$$V_{gs} = I_s R_i = I_s \times R_s \parallel 1\text{M} \parallel R$$

$$= I_s \times 10\text{ K} \parallel 1\text{M} \parallel 200\text{ K}$$

$$= 9.43 \times 10^3\ I_s$$

$$R_M = \frac{-g_m \times 9.43 \times 10^3 I_s \times 7.69 \times 10^3}{I_s}$$

$$= -2.5 \times 10^{-3} \times 9.43 \times 10^3 \times 7.69 \times 10^3$$

$$= -181.29\text{ K}$$

Step 6 : Calculate β

$$\beta = \frac{I_f}{I_o} = \frac{V_i - V_o}{V_o R}$$

$$= \frac{-1}{R} \qquad \because (V_o > V_i)$$

$$= -\frac{1}{200 \times 10^3} = -5 \times 10^{-6}$$

Step 7 : Calculate D, R_{Mf}, A_{Vf}, R_{of} and R'_{of}

$$D = 1 + \beta R_M$$

$$= 1 + (-5 \times 10^{-6})(-181.29 \times 10^3)$$

$$= 1.9$$

$$R_{Mf} = \frac{R_M}{D} = \frac{-181.29\text{ K}}{1.9}$$

$$= 95.415\text{ K}$$

$$A_{Vf} = \frac{V_o}{V_s} = \frac{V_o}{I_s R_s} = \frac{R_{Mf}}{R_s} = \frac{95.415 \times 10^3}{10 \times 10^3}$$

$$= 9.5415$$

$$R_i = R_s \parallel M \parallel R = 10\text{ K} \parallel 1\text{ M} \parallel 200\text{ K}$$

$$= 9.43 \times 10^3$$

$$\therefore \quad R_{if} = \frac{R_i}{D} = \frac{9.43 \times 10^3}{1.9}$$

$$= 4.963\ \Omega$$

$$R'_o = R_{eff} = r_d \parallel R \parallel R_D$$

$$= 40\text{ K} \parallel 200\text{ K} \parallel 10\text{ K}$$

$$= 7.69\text{ k}\Omega$$

$$\therefore \quad R_{of} = \frac{R'_o}{D} = \frac{7.69 \times 10^3}{1.9}$$

$$= 4\text{ k}\Omega$$

Example 1.26 : *For the feedback amplifier shown in Fig. 1.74, calculate A_{vf}, R_{if}, R_{of}. Assume h_{fe} = 50 and h_{ie} = 1.2 kΩ.*

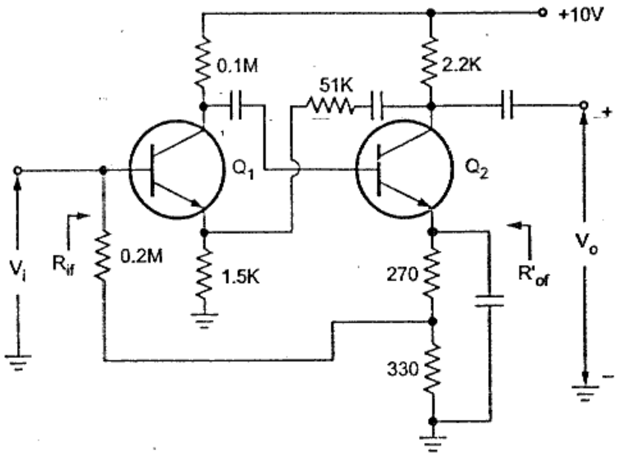


Fig. 1.74

Solution : Step 1 : Identify topology

The feedback voltage is applied across the resistance R_{e1} and it is in series with input signal. Hence feedback is voltage series feedback.

Step 2 and Step 3 : Find input and output circuit

To find input circuit, set $V_o = 0$, which gives parallel combination of R_{e1} with R_f at E_1 as shown in the Fig. 1.75. To find output circuit, set $I_i = 0$ opening the input node E_1 at emitter of Q_1, which gives series combination of R_f and R_{e1} across the output. The resultant circuit is shown in Fig. 1.75.

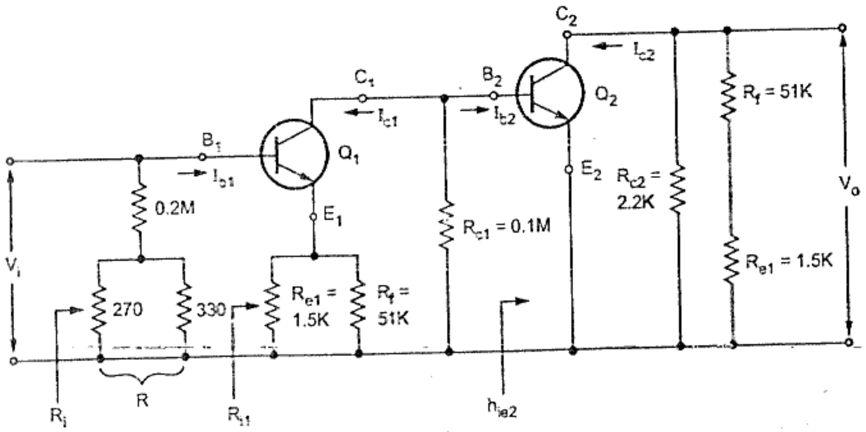


Fig. 1.75

Step 4 : Find open loop voltage gain (A_v)

$$R_{L2} = R_{c2} \parallel (R_f + R_{e1}) = 2.2\text{ K} \parallel (51\text{K} + 1.5\text{ K})$$
$$= 2.11\text{ K}$$
$$A_{i2} = -h_{fe} = -50$$
$$R_{i2} = h_{ie} = 1.2\text{ k}\Omega$$
$$\therefore \quad A_{v2} = \frac{A_{i2} R_{L2}}{R_{i2}} = \frac{-50 \times 2.11\text{ K}}{1.2\text{K}}$$
$$= -87.91$$
$$R_{L1} = R_{C1} \parallel R_{i2} = 0.1\text{ M} \parallel 1.2\text{ K}$$
$$= 1.185\text{ K}$$
$$A_{i1} = -h_{fe} = -50$$

$$R_{i1} = h_{ie} + (1 + h_{fe}) R_e$$
$$= 1.2\text{ K} + (1 + 50)(1.5\text{ K} \parallel 51\text{ K})$$
$$= 75.51\text{ K}$$
$$\therefore \quad A_{v1} = \frac{A_{i1} R_{L1}}{R_{i1}} = \frac{50 \times 1.185\text{ K}}{75.51\text{ K}}$$
$$= -0.784$$

The overall gain without feedback is given is

$$A_v = A_{v1} \times A_{v2} = (-0.784) \times (-87.91)$$
$$= 68.92$$

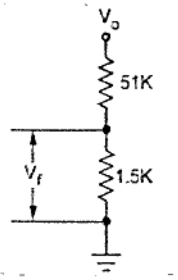


Fig. 1.76

Step 5 : Calculate β

$$\beta = \frac{V_f}{V_o} = \frac{1.5\text{K}}{51\text{K} + 1.5\text{K}}$$
$$= 0.0285$$

Step 6 : Calculate D, A_{vf}, R_{if} and R_{of}

$$D = 1 + \beta A_v$$
$$= 1 + (0.0285) \times 68.92$$
$$= 2.964$$
$$\therefore \quad A_{vf} = \frac{A_v}{D} = \frac{68.92}{2.964}$$
$$= 23.25$$
$$R_i = R_{i1} \parallel R = 75.51\text{ K} \parallel (0.2\text{ M} + (270 \parallel 330))$$
$$= 75.51\text{ K} \parallel 200.1485\text{ K}$$
$$= 54.82\text{ K}$$
$$\therefore \quad R_{if} = R_i \times D = 54.82\text{ K} \times 2.964$$
$$= 162.48\text{ K}$$
$$R_o = \infty \qquad \because \quad h_{oe} = 0$$
$$R'_o = R_o \parallel R_{c2} \parallel (R_f + R_{e1}) = R_o \parallel R_{L2}$$
$$= \infty \parallel 2.11\text{ K}$$
$$= 2.11\text{ K}$$

$$R'_{of} = \frac{R'_o}{D} = \frac{2.11\text{K}}{2.964}$$

$$\therefore \quad = 712\ \Omega$$

Example 1.27 : *For the circuit shown in Fig. 1.77.*

a. Identify the topology of feedback with proper reasoning

b. Find A_{if}, A_{vf}, R_{if}, R_{of}, A_I.

The transistor Q_1 and Q_2 have the following h-parameters : h_{ie} = 1.5 K and h_{fe} = 50 . Assume C to be large enough to act as short at operating frequency.

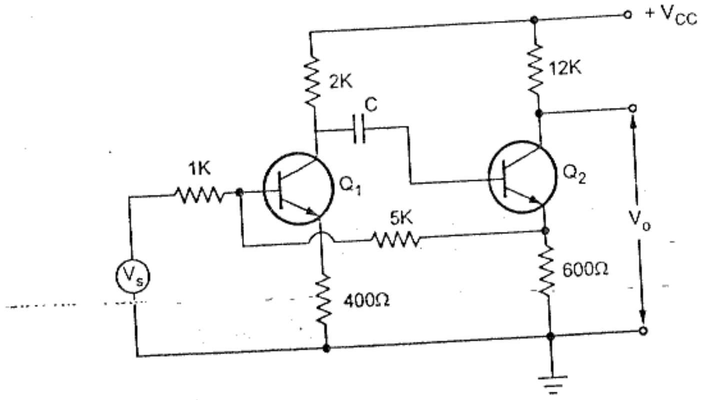


Fig. 1.77

Solution : Step 1 : Identify topology

The feedback is given from emitter of Q_2 to the base of Q_2. If I_o = 0 then feedback current through 5 K register is zero, hence it is current sampling. As feedback signal is mixed in shunt with input, the amplifier is current shunt feedback amplifier.

Step 2 and Step 3 : Find input and output circuit

The input circuit of the amplifier without feedback is obtained by opening the output loop at the emitter of Q_2 (I_o = 0). This places R' (5K) in series with R_e from base to emitter of Q_1. The output circuit is found by shorting the input node, i.e. making V_i = 0. This places R' (5K) in parallel with R_e. The resultant equivalent circuit is shown in Fig. 1.78.

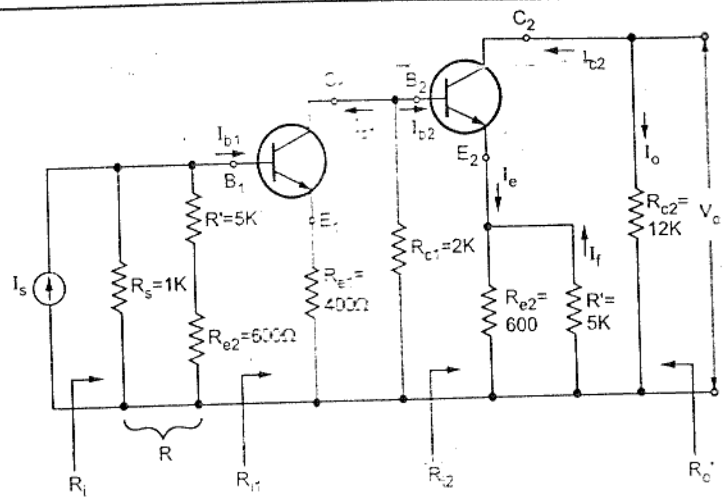


Fig. 1.78

Step 4 : Find open circuit transfer gain

$$A_I = \frac{I_o}{I_s} = \frac{-I_c}{I_s}$$

$$= \frac{-I_{c2}}{I_{b2}} \cdot \frac{I_{b2}}{I_{c1}} \cdot \frac{I_{c1}}{I_{b1}} \cdot \frac{I_{b1}}{I_s}$$

We know that

$$\frac{-I_{c2}}{I_{b2}} = A_{i2} = -h_{fe} = -50 \text{ and}$$

$$\frac{-I_{c1}}{I_{b1}} = A_{i1} = -h_{fe} = 50$$

$$\therefore \quad \frac{I_{c1}}{I_{b1}} = 50$$

Looking at Fig. 1.77 we can write

$$\frac{I_{b2}}{I_{c1}} = \frac{-R_{c1}}{R_{c1} + R_{i2}}$$

where

$$R_{i2} = h_{ie} + (1 + h_{fe})\,(R_{e2} \parallel R')$$

$$= 1.5\text{ K} + (1 + 50)\,(600 \parallel 5\text{K})$$

$$= 28.82\text{ K}$$

$$\therefore \quad \frac{I_{b2}}{I_{c1}} = \frac{-2\text{K}}{2\text{K}+28.82\text{K}}$$

$$= -0.0649$$

Looking at Fig. 1.78 we can write

$$\frac{I_{b1}}{I_s} = \frac{R}{R+R_{i1}}$$

where

$$R = R_3 \parallel (R' + R_e) = \frac{1K \times 5.6K}{1K+5.6K}$$

$$= 848\ \Omega$$

and

$$R_{i1} = h_{ie} + (1 + h_{fe})\, R_{e1}$$

$$= 1.5\ K + (1 + 50) \times 400 = 21.9\ K$$

$$\frac{I_{b1}}{I_s} = \frac{848}{848+21.9K}$$

$$= 0.0372$$

Substituting the numerical values obtained in equations of A_I we get,

$$A_I = (-50) \times (-0.0649) \times (50) \times (0.0372)$$

$$= 6$$

Step 5 : Calculate β

$$\beta = \frac{I_f}{I_s} = \frac{R_{e2}}{R_{e2}+R'} = \frac{600}{600+5K}$$

$$= 0.107$$

Step 6 : Calculate D, A_{If}, A_{Vf}, R_{if}, R_{of}

$$D = 1 - \beta A_I = 1 - (0.107) \times 6$$

$$= 1.642$$

$$A_{If} = \frac{A_I}{D} = \frac{6}{1.642}$$

$$= 3.654$$

$$A_{Vf} = \frac{V_o}{V_s} = \frac{-I_{c2} R_{c2}}{I_s R_s}$$

$$= \frac{A_{If} R_{C2}}{R_S} = \frac{(3.654)(12\ K)}{1\ K}$$

$$= 43.848$$

$$R_i = R \parallel R_{i1} = 848 \parallel 21.9\ K$$

$$= 816.38\ \Omega$$

$$R_{if} = \frac{R_i}{D} = \frac{816.38}{1.642}$$

$$= 497.2\ \Omega$$

$$R_o = \infty \quad \because \quad h_{oe} = 0$$

$$\therefore \quad R_{of} = R_o D = \infty$$

$$R'_o = R_o \parallel R_{c2} = \infty \parallel 12\ K$$

$$= 12\ K$$

$$R'_{of} = R'_o \frac{1+\beta A_i}{1+\beta A_I} = R'_o = R_{c2} = 12\ K$$

Example 1.28 : *For feedback amplifier shown in Fig. 1.79, identify the feedback topology with proper justification.*

The transistors used are identical with the following parameters :

$h_{fe} = 200$, $h_{ie} = 2\ k\Omega$, $h_{re} = 10^{-4}$, $h_{oe} = 10^{-6}$ A/V

Calculate

i) A_{vf} *ii)* R_{if} *iii)* R_{of}

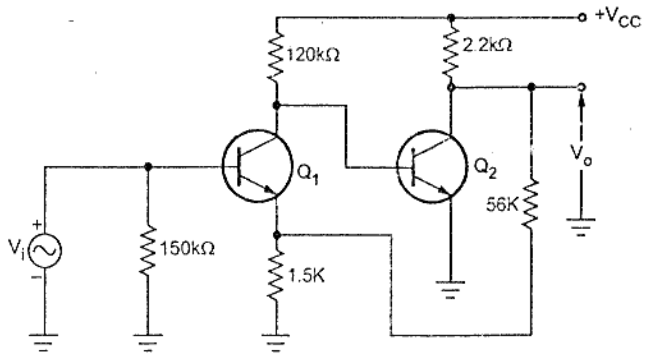


Fig. 1.79

Solution : Step 1 : Identify topology

The feedback voltage is applied across $R_{e1} = 1.5$ K, which is in series with input signal. Hence feedback is voltage series feedback.

Step 2 and Step 3 : Find input and output circuit

To find input circuit, set $V_o = 0$, which gives parallel combination of R_{e2} with R_f at E_1 as shown in the Fig. 1.80. To find output circuit, set $I_i = 0$ by opening the input node, E_1 at emitter of Q_1, which gives the series combination of R_f and R_{e1} across the output. The resultant circuit is shown in Fig. 1.80.

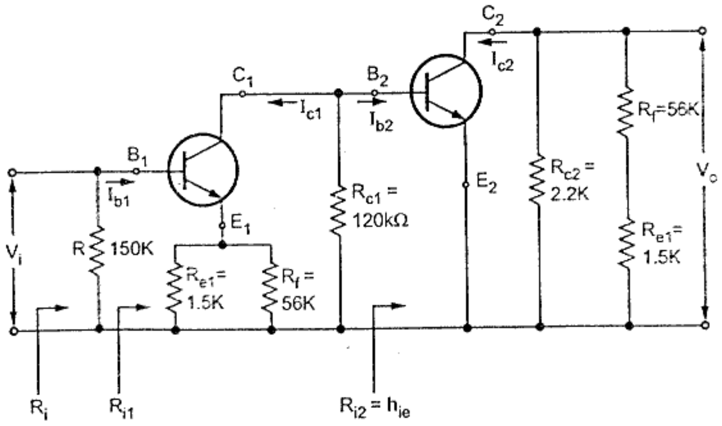


Fig. 1.80

Step 4 : Find the open loop voltage gain (A_V)

$$R_{L2} = R_{C2} \parallel (R_f + R_{e1})$$
$$= 2.2\text{ K} \parallel (56\text{ K} + 1.5\text{ K})$$
$$= \mathbf{2.119\text{ K}}$$

Since $h_{oe} R_{L2} = 10^{-6} \times 2.119\text{ K} = 0.002119$ is less than 0.1 we use approximate analysis

$$A_{i2} = -h_{fe} = -200$$
$$R_{i2} = h_{ie} = 2\text{ k}\Omega$$
$$\therefore \quad A_{v2} = \frac{A_{i2} R_{L2}}{R_{i2}} = \frac{-200 \times 2.119\text{ K}}{2\text{K}}$$
$$= \mathbf{-211.9}$$
$$R_{L1} = R_{C1} \parallel R_{i2} = 120\text{ K} \parallel 2\text{ K}$$
$$= \mathbf{1.967\text{ K}}$$

Since $h_{oe} R_{L1} = 10^{-6} \times 1.967 = 0.001967$ is less than 0.1 we use approximate analysis

$$A_{i1} = -h_{fe} = -200$$
$$R_{i1} = h_{ie} + (1 + h_{fe}) R_e$$

$$= 2\text{K} + (1 + 200)(1.5\text{ K} \parallel 56\text{ K})$$
$$= 295.63\text{ K}$$
$$\therefore \quad A_{v1} = \frac{A_{i1} R_{L1}}{R_{i1}} = \frac{-200 \times 1.967\text{ K}}{295.63\text{ K}}$$
$$= -1.33$$

The overall gain without feedback is

$$A_v = A_{v1} \times A_{v2} = (-1.33) \times (-211.9)$$
$$= 281.82$$

Step 5 : Calculate β

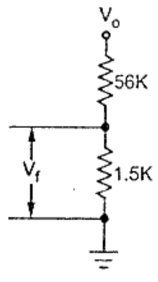


Fig. 1.81

$$\beta = \frac{V_f}{V_o}$$
$$= \frac{1.5\text{ K}}{56\text{ K} - 1.5\text{ K}}$$
$$= 0.026$$

Step 6 : Calculate D, A_{Vf}, R_{if}, R_{of}

$$D = 1 + \beta A_V$$
$$= 1 + (0.026) \times 281.82 = 8.327$$
$$\therefore \quad A_{Vf} = \frac{A_V}{D} = \frac{281.82}{8.327}$$
$$= \mathbf{33.84}$$
$$R_i = R_{i1} \parallel R = 295.63\text{ K} \parallel 150\text{ K}$$
$$= \mathbf{99.5\text{ K}}$$
$$\therefore \quad R_{if} = R_i \times D = 99.5 \times 8.327$$
$$= \mathbf{828.53\text{ K}}$$
$$R_o = \frac{1}{h_{oe}} = \frac{1}{10^{-6}}$$
$$= \mathbf{1M\Omega}$$
$$R_{of} = \frac{R_o}{D} = \frac{1\text{M}}{8.327}$$
$$= \mathbf{120\text{ K}}$$
$$R'_o = R_o \parallel R_{C2} \parallel (R_f + R_{e1}) = R_o \parallel R_{L2}$$

$$= 1M \parallel 2.119\ K$$

$$= 2.1145\ K$$

$$R'_{of} = \frac{R'_o}{D} = \frac{2.1145\ K}{8.327}$$

$$= 254\ \Omega$$

Example 1.29 : *For the circuit shown in Fig. 1.82, calculate : i) A_{vf} ii) R_{if} iii) R_{of} where these parameters have their usual meaning. The transistor parameters are : $h_{ie} = 1K$, $h_{re} = 0$, $h_{fe} = 100$ and $h_{oe} = 0$.*

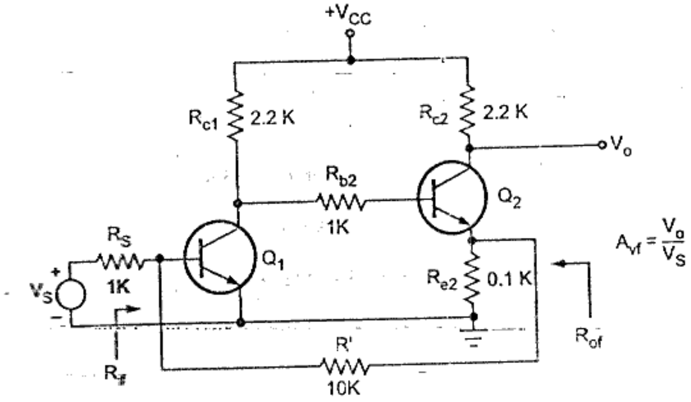


Fig. 1.82

Solution : This is a current shunt feedback amplifier open circuit transfer gain.

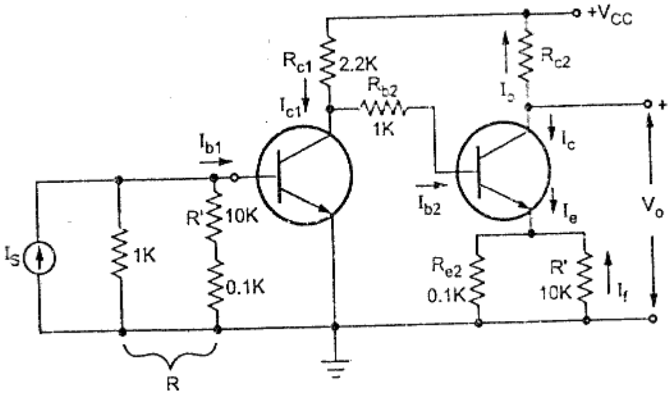


Fig. 1.83

$$A_I = -\frac{I_{c2}}{I_s} = -\frac{I_{c2}}{I_{b2}}\frac{I_{b2}}{I_{c1}}\frac{I_{c1}}{I_{b1}}\frac{I_{b1}}{I_s}$$

$$-\frac{I_{c2}}{I_{b2}} = A_{i2} = -h_{fe} = -100$$

$$-\frac{I_{c1}}{I_{b1}} = 100$$

$$R_{i2} = h_{ie} + (1+h_{fe})(R_{e2} \parallel R') = 1\ k + (101)(0.1\ K \parallel 10\ K)$$

$$= 11\ K$$

$$\frac{I_{b2}}{I_{c1}} = \frac{-R_{c1}}{R_{c1} + (R_{i2} + R_{b2})}$$

$$= \frac{-2.2\ K}{2.2\ K + (11\ K + 1\ K)}$$

$$\frac{I_{b2}}{I_{c1}} = -0.155$$

$$\frac{I_{b1}}{I_s} = \frac{R}{R + h_{ie}}$$

$$R = R_s \parallel (R' + R_e) = 1\ K \parallel (10\ K + 0.1\ K)$$

$$= 909.9\ \Omega$$

$$\therefore \frac{I'_b}{I_s} = \frac{909.9}{909.9 + 1\ K}$$

$$= 0.476$$

$$\therefore A_I = (-100) \times (0.155) \times (100) \times (0.476) = 737.8$$

Calculation of β :

$$I_f = -\frac{I_e R_{e2}}{R_{e2} + R'} = -\frac{I_c R_{e2}}{R_{e2} + R'}$$

$$= \frac{I_o R_{e2}}{R_{e2} + R'}$$

$$\beta = \frac{I_f}{I_o} = \frac{R_{e2}}{R_{e2} + R'} = \frac{100}{100 + 10\ K}$$

$$D = 1 + \beta A_I = 1 + (9.9 \times 10^{-3}) \times 737.8$$

$$D = 8.3$$

$$A_{if} = \frac{A_I}{D} = 88.89$$

$$A_{vf} = \frac{V_o}{V_s} = -\frac{I_{c2}\, R_{c2}}{I_s\, R_s} = \frac{A_{if}\, R_{c2}}{R_s}$$

$$= \frac{88.89 \times 2.2\ K}{1\ K}$$

$$A_{vf} = 195.558$$

$$R_{i1} = R \parallel h_{ie} = 909.9 \parallel 1000 = 476\ \Omega$$

$$R_{if} = \frac{R_i}{D} = \frac{476}{8.3} = 57.35\ \Omega$$

$$R_{of} = R_{c2} = 2.2\ k\Omega$$

Example 1.30 : *In a negative feedback amplifier A = 100, β = 0.02 and input signal volatge is 40 mV. Determine :*

(i) Voltage gain with feedback

(ii) Feedback voltage

(iii) Output voltage

Solution : Given :

$A = 100,\ \beta = 0.02,\ V_i = 40 \times 10^{-3}\ V$

i) Voltage gain with feedback $\qquad A_f = \frac{A_v}{D}$

Where, $\qquad D = 1 + \beta A_v = 1 + 0.02 \times 100 = 3$

$\therefore \qquad A_{vf} = \frac{100}{3} = 33.33$

ii) Feedback voltage $\qquad V_f = \beta \cdot V_o = \beta \times A_{vf} \times V_i$

$= 0.02 \times 33.33 \times 40 \times 10^{-3}$

$= 26.66\ mV$

iii) Output voltage $\qquad V_o = A_{vf} \times V_i = 33.33 \times 40 \times 10^{-3}$

$= 1.333\ V$

Example 1.31 : *Determine the voltage gain, input and output impedance with feedback for voltage series feedback having A = – 100, R_i = 10 k Ω, R_o = 20 k Ω for feedback of (a) β = – 0.1 and (b) β = – 0.5.*

Solution : For $\beta = -0.1$, $D = 1 + \beta A_v = 1 + (-0.1)(-100) = 11$

i) Voltage gain $\qquad A_{vf} = \frac{A_v}{D}$

$\therefore \qquad A_{vf} = \frac{-100}{11} = -9.09$

ii) Input impedance $\qquad R_{if} = R_i D = 10 \times 11 = 110\ k\Omega$

iii) Output impedance $\qquad R_{of} = \frac{R_o}{D} = \frac{20K}{11}$

$= 1.81\ k\Omega$

For $\beta = -0.5$, $D = 1 + \beta A_v = 1 + (-0.5)(-100) = 51$

i) Voltage gain $\qquad = \frac{A_v}{D} = \frac{-100}{51}$

$= -1.96$

ii) Input impedance $\qquad R_{if} = R_i D = 10 \times 51 = 510\ k\Omega$

iii) Ouput impedance $\qquad R_{of} = \frac{R_o}{D} = \frac{20K}{51} = 0.392\ k\Omega$

Example 1.32 : *Which is the most commonly used feedback arrangement in cascaded amplifiers and why ?*

Solution : Voltage series feedback is the most commonly used feedback arrangement in cascaded amplifiers. Voltage series feedback increases input resistance and decreases output resistance. Increase in input resistance reduces the loading effect of previous stage and the decrease in output resistance reduces the loading effect of amplifier itself for driving the next stage.

Example 1.33 : *Voltage gain of an amplifier without feedback is 60 dB. It decreases to 40 dB with feedback. Calculate the feeback factor.*

Solution : Given A_v = 60 dB and A_{vf} = 40 dB

We know that,

$$A_{vf} = \frac{A_v}{1 + \beta A_v}$$

$$\therefore \qquad A_{vf} + \beta A_v A_{vf} = A_v$$

$$\beta = \frac{A_v - A_{vf}}{A_v A_{vf}} = \frac{60-40}{60 \times 40}$$

$$= 8.33 \times 10^{-3}$$

Example 1.34 : *An R-C coupled amplifier has a mid frequency gain of 400 and lower and upper 3 dB frequencies of 100 Hz and 15 kHz. A negative feedback with β = 0.01 is incorporated into amplifier circuit. Calculate :*

(i) Gain with feedback *(ii) New bandwidth*

Solution : Given : $A_v = 400$, $F_L = 100$ Hz, $f_H = 15$ kHz

$\beta = 0.01$

i) $A_{vf} = \frac{A_v}{1+\beta A_v} = \frac{400}{1+(0.01 \times 400)} = 80$

ii) $f_{Lf} = \frac{f_L}{1+\beta A_v} = \frac{100}{1+(0.01 \times 400)} = 20$ Hz

iii) $f_{Hf} = f_H \times (1+\beta A_v)$

$= 15 \times 10^3 \times [1+(0.01 \times 400)]$

$= 75$ kHz

iv) New Bandwidth $= f_{Hf} - f_{Lf} = 75$ kHz $- 20$ Hz

$= 74.980$ kHz

Review Questions

1. *What do you mean by voltage amplifier and current amplifier ? Give their equivalent circuit.*
2. *Draw the equivalent circuit of a transconductance amplifier.* **(Nov./Dec.-2003, April/May 2005, 2 marks)**
3. *Explain the sampling and mixing networks.*
4. *Define the feedback factor β.*
5. *Define negative and positive feedback.*
6. *Give topology for various types of feedback amplifiers.*
7. *Using a block diagram, derive the closed loop form transfer ratio of a feedback system in terms of the open gain.* **(April/May-2004, 8 Marks)**
8. *Using a block diagram, derive the expression of closed loop forward transfer ratio with positive and negative feedbacks introduced in an amplifier.* **(April/May-2005, 8 Marks)**
9. *Draw the block schematic of amplifier with negative feedback.*
10. *"The gain bandwidth product of an amplifier is not altered, when negative feedback introduced". Justify the statement.* **(Nov./Dec.-2004, 5 Marks)**

11. *What are the effects of negative feedback on distortion and gain of an amplifier ?* **(April/May-2003, 2 Marks)**
12. *What are the advantages of negative feedback in amplifiers ?* **(April/May-2004, 2 Marks)**
13. *Explain the consequences of introducing negative feedback in small signal amplifier.*
14. *Define desensitivity D ? For large values of D what is A_f ? What is the significance of this result ?*
15. *Discuss the effects of negative feedback on the frequency response of an amplifier.* **(April/May-2005, 8 Marks)**
16. *Define 'Desensitivity' of transfer gain.* **(April/May-2004, 2 Marks)**
17. *Compare the frequency response characteristics of an amplifier with and without negative feedback.* **(April/May-2004, 8 Marks)**
18. *What are the steps to be carried out for the complete analysis of a feedback amplifier ?* **(April/May-2004, 8 Marks, April/May-2005, 8 Marks)**
19. *With typical example compare current series and voltage shunt feedback amplifiers.* **(April/May-2004, 8 Marks)**
20. *Draw the equivalent circuit of a voltage amplifier.* **(Nov./Dec.-2004, 2 Marks)**
21. *A feedback amplifier has an open loop gain of 600 and feedback factor β = 0.01. Find the closed loop gain with negative feedback.* **(Nov./Dec.-2004, 2 Marks)**
22. *The gain and distortion of an amplifier are 100 and 4% respectively. If a negative feedback with β = 0.2 is applied, find the new distortion in the system.* **(Nov./Dec.-2004, 5 Marks)**
23. *List out the steps that are carried out in obtaining the complete analysis of a feedback amplifier.* **(April/May-2005, 8 Marks)**
24. *Write a note on voltage series feedback circuits.*
25. *Write a note on current series feedback circuits.*
26. *Write a note on current shunt feedback circuits.*
27. *Write a note on voltage shunt feedback circuits.*
28. *The distortion in an amplifier is found to be 3%, when the feedback ratio of negative feedback amplifier is 0.04. When the feedback is removed, the distortion becomes 15%. Find the open loop and closed loop gain.* **(April/May-2005, 2 Marks)**
29. *Derive using a block diagram the closed loop forward transfer ratio A_f of a feedback system.* **(Nov./Dec.-2003, 2 Marks)**
30. *Derive the input impedance R_{if} of a voltage series and current shunt feedback amplifiers.* **(April/May-2005, 8 Marks)**
31. *For the amplifier circuit given in Fig. 1.84 with $h_{fe} = 50$, $h_{ie} = 1.1$ KΩ, $h_{re} = h_{oe} = 0$.* **(Nov./Dec.-2003, 3 + 3+ 10 Marks)**

    i) Identify the type of negative feedback present.

    ii) Obtain the basic amplifier circuit.

    iii) Calculate the voltage gain, input resistance and output resistance of the given amplifier.

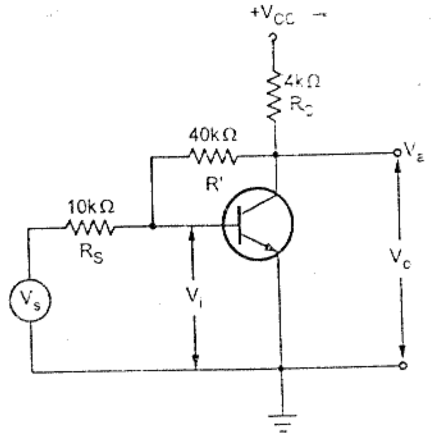


Fig. 1.84

32. *The circuit given in Fig. 1.85 has the following parameters* $R_C = 4\ k\Omega$, $R_S = 10\ k\Omega$, $h_{ie} = 1.1\ K$, $h_{fe} = 50$ *and* $h_{re} = h_{oe} = 0$. *Find* A_{vf}, R_{if} *and* R_{of}.

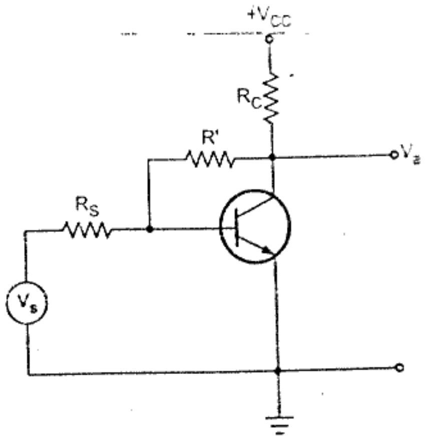


Fig. 1.85

(Nov./Dec.-2003, 16 Marks, Nov./Dec.-2004, 3 + 3 + 10 Marks)

33. *What is Nyquist criterion for stability of feedback amplifier ?*

Exercise Problems on Feedback Amplifiers

1. *Determine* A_{vf} *for a feedback amplifier shown in Fig. 1.86 in which transistors used are identical and* $h_{ie} = 2\ K$, $h_{fe} = 50$, h_{re} *and* h_{oe} *negligible.*

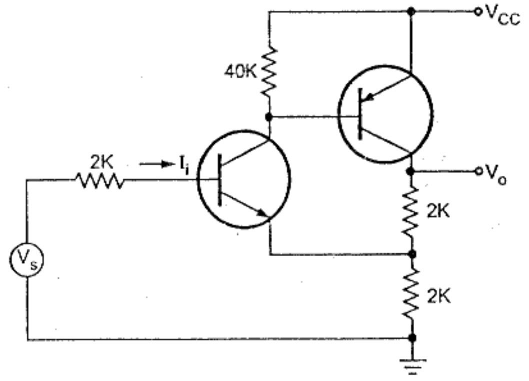


Fig. 1.86

(Ans. : $A_{vf} = 1.977$)

2. *Calculate* β, A_V, A_{Vf}, R_{if}, R_{of}, R'_{of} *for the feedback amplifier shown in Fig. 1.87.*
Given : $h_{ie} = 1100\ \Omega$, $h_{fe} = 50$, $h_{re} = 2.5 \times 10^{-4}$, $h_{oe} = 25 \times 10^{-6}$ *A/V.*

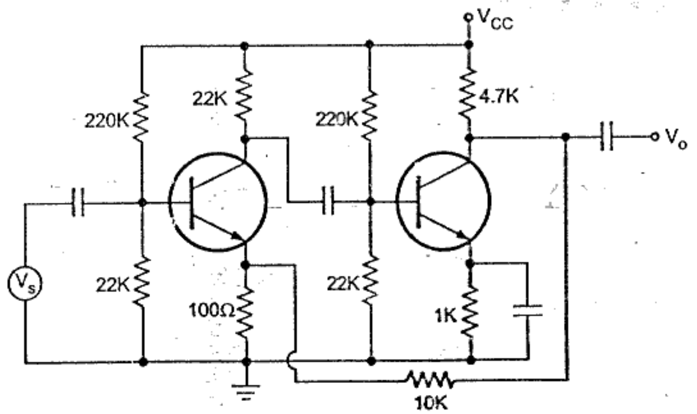


Fig. 1.87

(Ans. : i) $\beta = 0.0099$, ii) $A_v = 1177$, iii) $A_{vf} = 93.04$, iv) $R_{if} = 77.8$ K, v) $R_{of} = \infty$, vi) $R'_{of} = 253\ \Omega$)

3. *For the feedback amplifier shown in Fig. 1.88, $R_s = 0$, $h_{fe} = 50$, $h_{ie} = 1.1$ K, $h_{re} = h_{oe} = 0$ and transistors are identical. Calculate A_{vf}, R_{of}, R_{if}.*

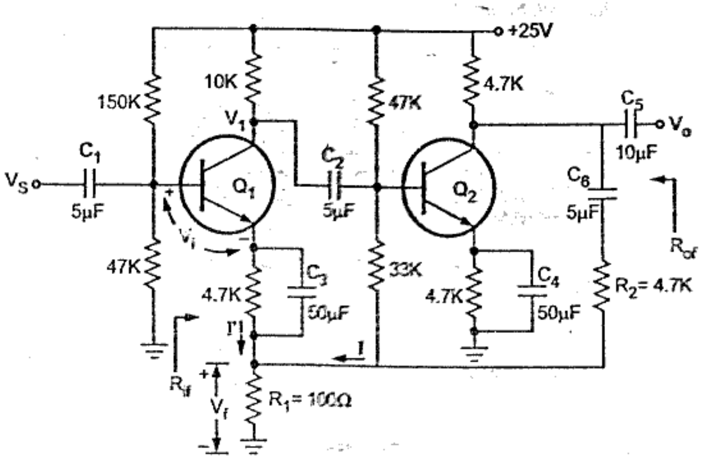


Fig. 1.88

(Ans. : i) A_{vf} = 47.5, ii) R_{of} = 24.4 Ω, iii) R_{if} = 106 K)

4. *Determine A_{vf}, R_{if} and R'_{of} for the circuit shown in Fig. 1.89.*
Given: h_{ie} = 1 K, h_{fe} = 50, h_{re} and h_{oe} negligible.

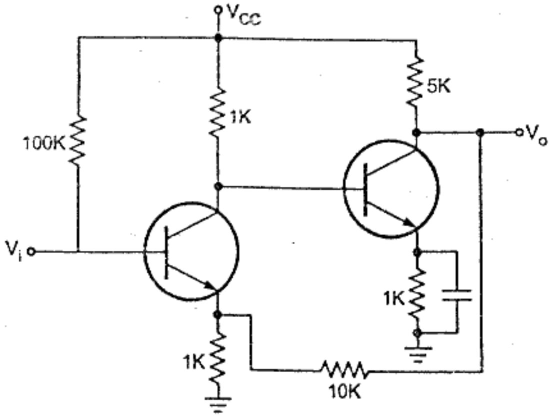


Fig. 1.89

(Ans.: i) A_{vf} = 9.9, ii) R_{if} = 294 K, iii) R_{of} = 374 Ω)

5. *For the circuit shown in Fig. 1.90 R_{c1} = 3 K, R_{c2} = 500 Ω, R_{e2} = 50 Ω, R' = R_s = 1.2K, h_{fe} = 50, h_{ie} = 1.1 K and $1/h_{oe}$ = 40 K. Calculate*
i) $A'_v = V_{c2}/V_{i1}$, ii) R_{if} iii) Resistance seen by the source, iv) A_{vf}

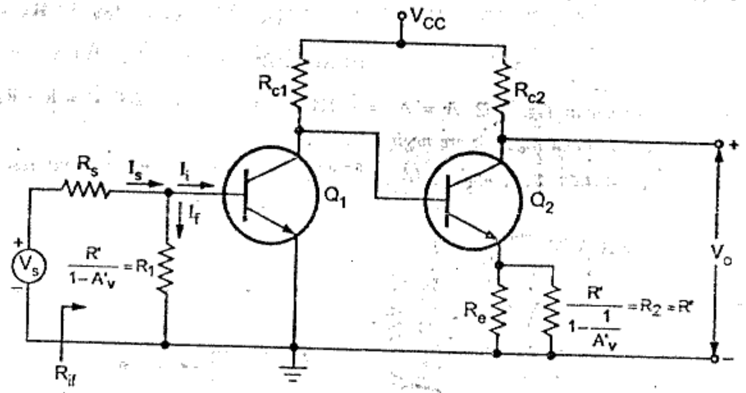


Fig. 1.90

(Ans. : i) A'_v = − 52.5 ii) R_{if} = 22 Ω
iii) Resistance seen by the source = 1.22 K, iv) A_{vf} = 9.3)

6. *The feedback amplifier is shown in Fig. 1.91. The transistors are identical and h_{fe} = 100, h_{ie} = 1.5 K, h_{re} and h_{oe} are negligible, reactances of all capacitors are negligible. Calculate : i) A_{vf}, ii) R_{if}, iii) R_{of}, iv) R'_{of}.*

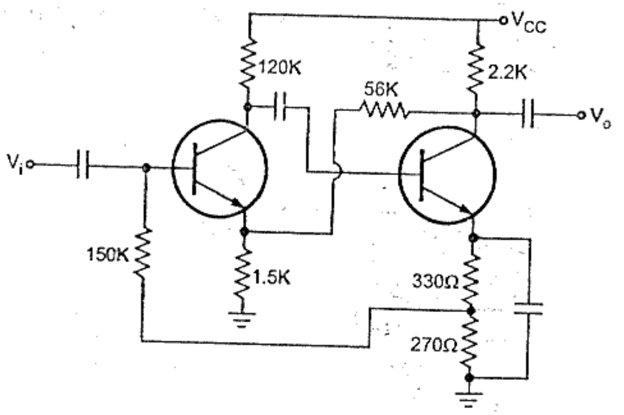


Fig. 1.91

(Ans. : i) A_{vf} = 30.14, ii) R_{if} = 345.43 K.
iii) R_{of} = ∞ , iv) R'_{of} = 456 Ω.)

7. *For the voltage shunt negative feedback circuit,* $R_c = 4$ K, $R_{CB} = 40$ K, $R_s = 10$ K, $h_{ie} = 1.1$K, $h_{fe} = 50$, $1/h_{oe} = 40$ K.

Calculate, i) A_v *ii)* R_{if}, *iii) Resistance seen by* V_s, *iv)* A_{vf}.

(Ans. : i) $A_v = -166$ ii) $R_{if} = 200\ \Omega$ iii) Resistance seen by V_s, iv) $A_{vf} = -3.26$.)

8. *For the circuit shown in Fig. 1.92,* $A = A_v = -1000$, $B = V_f/V_o = 1/100$, $R_s = R_c = R_e = 1\,k\Omega$, $h_{ie} = 1\,k\,\Omega$, $h_{fe} = 100$ *and* h_{re}, h_{oe} *are negligible.*

Find i) V_i *as a function of* V_s *and* V_f *(Assume that the inverting amplifier input resistance is infinite.),*

ii) $A_{vf} = V_o/V_s = A.\ V_i/V_s$.

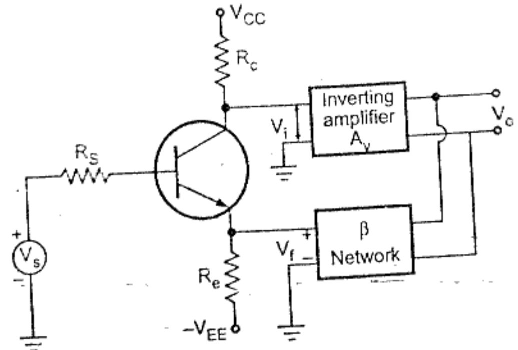


Fig. 1.92

(Ans. : i) $V_i = -50\ (V_s - V_f)$, ii) $A_{vf} = 100$.)

9. *The two-stage amplifier using JFET is shown in Fig. 1.93 Given :* $r_d = 10$ K, $\mu = 30$. A_{vf}, R_{if} *and* R'_{of}.

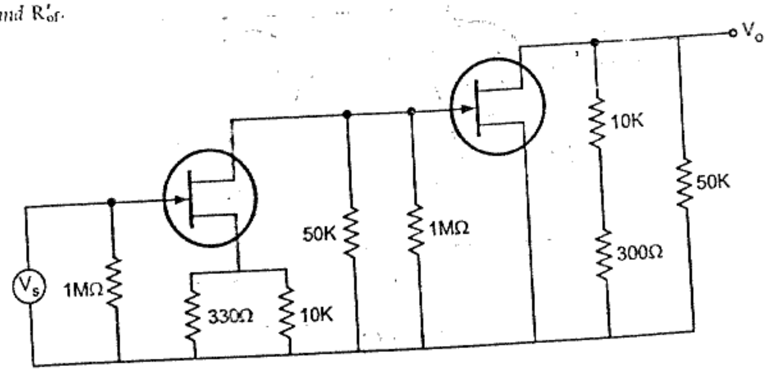


Fig. 1.93

(Ans. : i) $A_{vf} = 30.65$, ii) $R_{if} = 1\ M\Omega$ iii) $R'_{of} = 498\ \Omega$.)

10. *For the current series feedback amplifier an overall transconductance gain of –1 mA/V, a voltage gain of – 4 (a) desensitivity of 50,* $R_s = 1$ K, $h_{fe} = 150$. *Find* R_e, R_L *and* R_{if}.

(Ans. : i) $R_e = 1$ K, ii) $R_L = -4$ K, iii) $R_{if} = 150$ K.)

11. *For the two stage amplifier circuit shown in Fig. 1.94 , the transistors are identical,* $h_{fe} = 50$, $h_{ie} = 2$ K, h_{re} *and* h_{oe} *negligible.*

Find $A_{If} = I_o/I_s$, $R_i = V_i/I_i$,

$A'_{If} = I_o/I_i$ *and* $A_{Vf} = V_o/V_s$

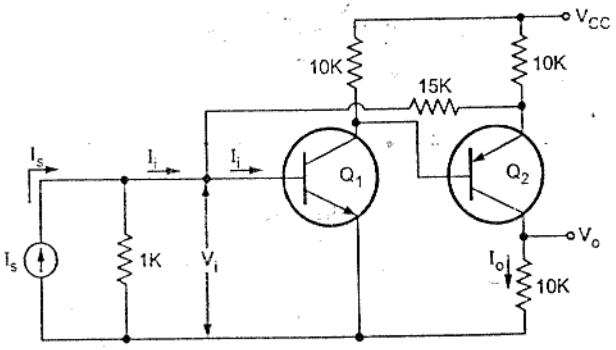


Fig. 1.94

(Ans. : $A_I = 15.5$, $\beta = 0.4$, $A_{If} = 2.15$, $R_i = 650\ \Omega$, $R_{if} = 90.27\ \Omega$, $A_{vf} = 21.5$)

12. *For the circuit shown in Fig. 1.95* $h_{fe} = 50$, $h_{ie} = 1.1$ K, h_{oe} *and* h_{re} *are negligible. Find* A_{Vf}, A_{IF}, R_{if}, R_{of} *and* R'_{of}.

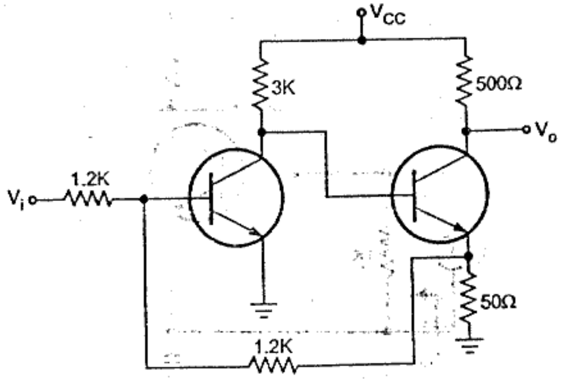


Fig. 1.95

(Ans. : i) $A_{Vf} = 9.79$, ii) $A_{If} = 23.5$, iii) $R_{if} = 22.6\ \Omega$, iv) $R_{of} = \infty$ v) $R'_{of} = 500\ \Omega$)

13. For the two stage amplifier circuit shown in Fig. 1.96.

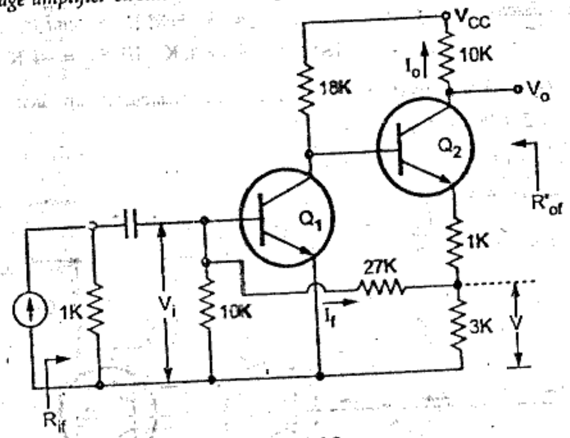


Fig. 1.96

h_{fe} = 50, h_{ie} = 2 K, h_{re} and h_{oe} are negligible and transistors are identical.

Find

i) $A_{If} = \frac{I_o}{I_s}$, ii) R_{if}, iii) $A_{Vf} = \frac{V_o}{V_s}$, iv) R'_{of}.

(Ans. : i) A_{If} = 8.69, ii) R_{if} = 80.2 Ω
iii) A_{Vf} = 86.9, iv) R'_{of} = 10 K)

14. For the voltage shunt feedback amplifier circuit shown in Fig. 1.97.
h_{fe} = 100, h_{ie} = 1 K and h_{re}, h_{oe} negligible.
Calculate : i) $R_{mf} = \frac{V_o}{I_s}$, ii) $A_{Vf} = \frac{V_o}{V_s}$, iii) R_{if} and iv) R'_{of}

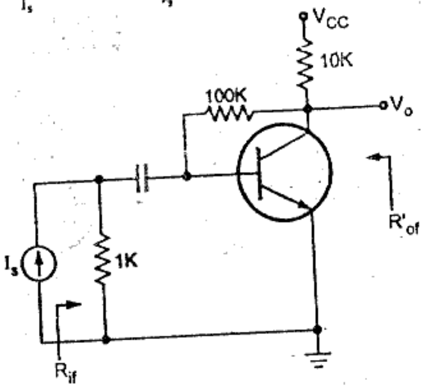


Fig. 1.97

(Ans. : i) R_{Mf} = – 81.98 K, ii) A_{Vf} = – 82
iii) R_{if} = 90 Ω , iv) R'_{of} = 1.63 K)

15. For the current shunt feedback amplifier shown in Fig. 1.98.
h_{ie} = 1 K, h_{fe} = 100, h_{re} and h_{oe} negligible. Calculate A_{Vf} , R_{if} and R'_{of}.

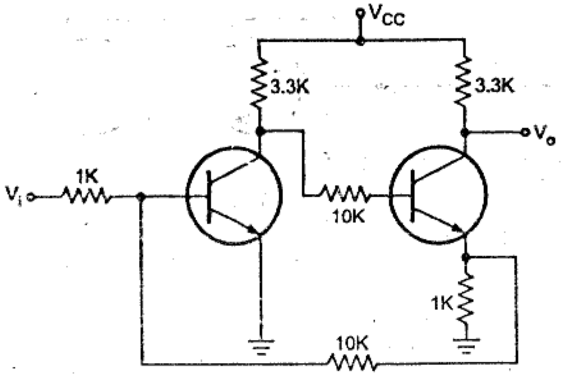


Fig. 1.98

(Ans. : i) A_{vf} = 34.14, ii) R_{if} = 33.28 Ω, iii) R_{of} = ∞)

16. For the CE amplifier shown in Fig. 1.99 , R_1 = 10 MΩ , R_2 = 1.6 MΩ, R_3 = 8K, V_{CC} = 20 V and h_{fe} = 100. Calculate R_{Mf}

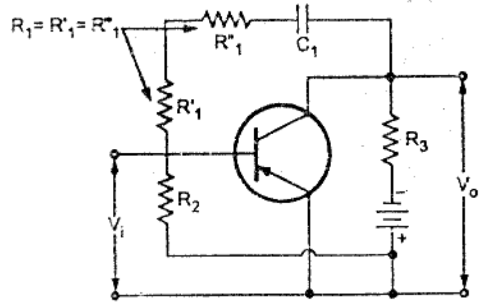


Fig. 1.99

(Ans. : R_{Mf} = – 733.19 K)

17. For the circuit shown in Fig. 1.100 transistors are identical with h_{fe} = 100, h_{ie} = 2K, h_{re} and h_{oe} negligible. Calculate A_{Vf} , R_{if} , R'_{of}.

(Ans. : i) A_{Vf} = –22.9, ii) R_{if} = 23.35 Ω, iii) R'_{of} = 483 Ω)

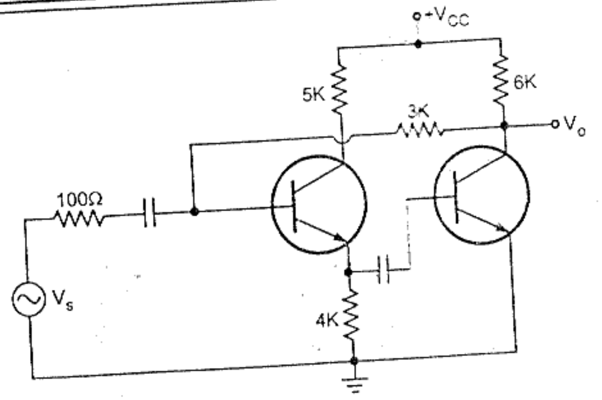


Fig. 1.100

18. *For the circuit shown in Fig. 1.101*

Calculate $R_{Mf} = V_o/I_s$, $A_{vf} = V_o/V_s$, R_{if} *and* R'_{of}.

Given : $h_{fe} = 100$, $h_{ie} = 1K$, h_{re} *and* h_{oe} *negligible.*

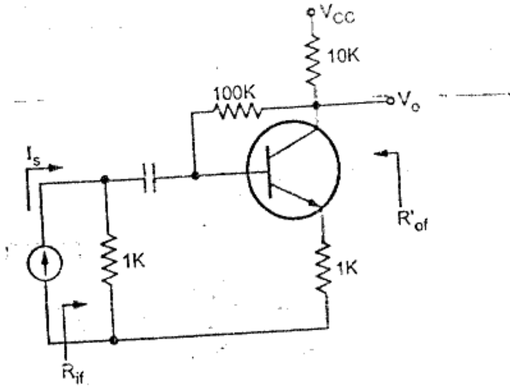


Fig. 1.101

(Ans. : i) R_{Mf} = – 8.031 K, ii) A_{vf} = – 8.03

iii) R_{if} = 901.5 Ω , iv) R'_{of} = 8.36 K)

□□□

2 Oscillators

2.1 Introduction

The operation of the feedback amplifiers in which the negative feedback is used, has been discussed earlier. In this chapter, a device which works on the principle of positive feedback is discussed. The device is called an **Oscillator.**

Key Point : *An oscillator is a circuit which basically acts as a generator, generating the output signal which oscillates with constant amplitude and constant desired frequency.*

An oscillator does not require any input signal. An electrical device, alternator generates a sinusoidal voltage at a desired frequency of 50 Hz in our nation but electronic oscillator can generate a voltage of any desired waveform at any frequency. An oscillator can generate the output waveform of high frequency upto gigahertz.

In short, an oscillator is an amplifier, which uses a positive feedback and without any external input signal, generates an output waveform at a desired frequency. This chapter explains the various types of oscillator circuits.

2.2 Basic Theory of Oscillators

The feedback is a property which allows to feedback the part of the output, to the same circuit as its input. Such a feedback is said to be positive whenever the part of the output that is fed back to the amplifier as its input, is in phase with the original input signal applied to the amplifier. Consider a non-inverting amplifier with the voltage gain A as shown in the Fig. 2.1.

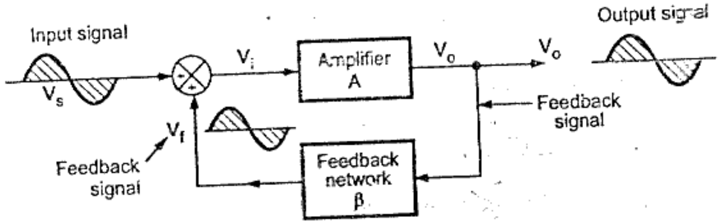


Fig. 2.1 Concept of positive feedback