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

$$R_{of}' = \frac{\dfrac{R_o R_L (1+\beta G_m)}{R_o + R_L}}{1 + \dfrac{\beta G_m R_o}{R_o + R_L}} = R_o' \cdot \frac{1+\beta G_m}{1+\beta G_M}$$

where $R_o' = \dfrac{R_o R_L}{R_o + R_L}$ and $G_M = \dfrac{G_m R_o}{R_o + R_L}$

3. Current Shunt Feedback

The current shunt feedback topology is shown in figure below with the amplifier input and output circuits replaced by its Norton's model.

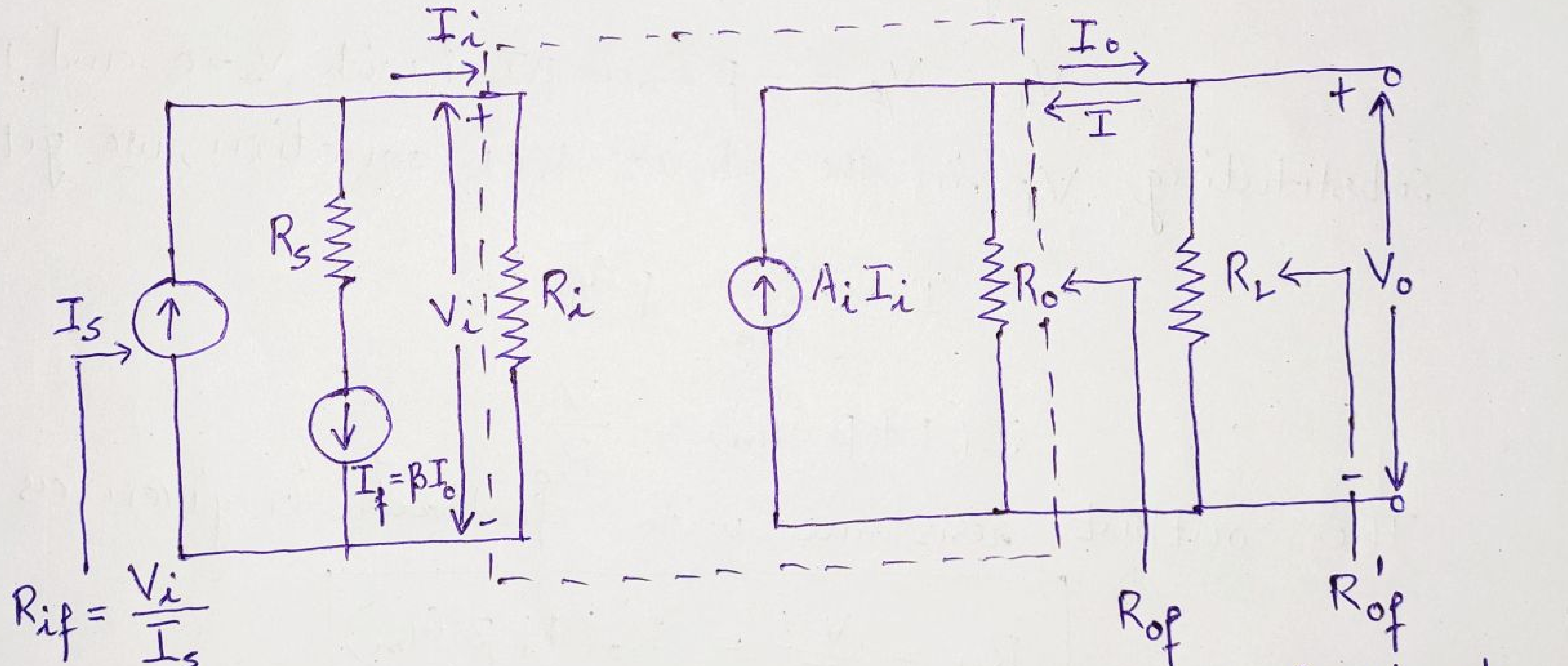


Fig. Equivalent circuit for current shunt feedback

Applying KCL to the input side, we get

$$I_s = I_i + I_f = I_i + \beta I_o$$

The output current is written as

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

where $A_I = \dfrac{I_o}{I_i} = \dfrac{A_i R_o}{R_o + R_L}$

Substituting the value of I_o in the above KCL equation, we get

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

The input resistance with feedback is given as,

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

where $A_i \rightarrow$ short circuit current gain without feedback

$A_I \rightarrow$ current gain without feedback taking the load R_L into account.

$$\therefore \quad A_i = \lim_{R_L \to 0} A_I$$

For finding R_{of}, R_L is disconnected (i.e $R_L = \infty$), the external source signal is made zero (i.e set $I_s = 0$) and V_o is replaced with V.

Applying KCL to the output node, we get

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

The input current is written as

$$I_i = -I_f = -\beta I_o = +\beta I \quad (\text{with } I_s = 0 \text{ and } I = -I_o)$$

Substituting I_i in the above KCL equation, we get

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

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

The output resistance with feedback is given as

$$\boxed{R_{of} = \frac{V}{I} = R_o(1+\beta A_i)}$$

where A_i is short-circuit current gain without taking R_L into account.

The output resistance with feedback R'_{of} including R_L as part of the amplifier is given by

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

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

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

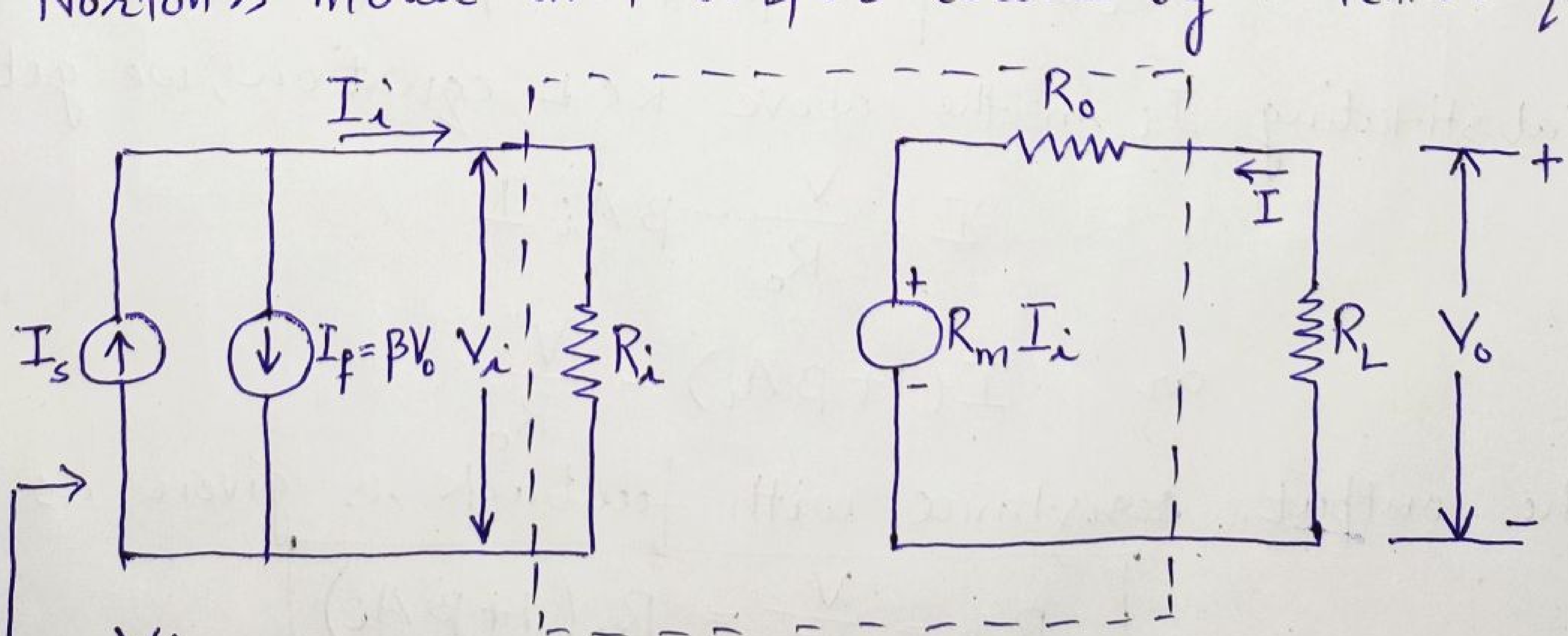
Dividing numerator and denominator by $(R_o + R_L)$, we get

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

where $$R'_o = \frac{R_o R_L}{R_o + R_L} \quad \text{and} \quad A_I = \frac{A_i R_o}{R_o + R_L}$$

4. Voltage Shunt Feedback

The voltage shunt feedback topology is shown in figure below with the amplifier input circuit represented by Norton's model and output circuit by Thevenin's equivalent.



$$R_i = \frac{V_i}{I_s}$$

Applying KCL to the input side, we get

$$I_s = I_i + I_f = I_i + \beta V_o$$

The output voltage is written as

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

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

Substituting the value of V_o in the above KCL equation, we get

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

The input resistance with feedback is given as

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

where R_m represents the open circuit transresistance without feedback and R_M is the transresistance without feedback taking the load R_L into account. Therefore

$$R_m = \lim_{R_L \to \infty} R_M$$

Now, for finding R_{of}, R_L is disconnected (i.e $R_L = \infty$), the external source signal is made zero (i.e set $I_s = 0$) and V_o is replaced with V.

Applying KVL to the output side, we get

$$I = \frac{V - R_m V_i}{R_o}$$

The input current is written as

$$I_i = -I_f = -\beta V \quad (\text{with } I_s = 0)$$

Substituting I_i in the above KVL equation, we get

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

The output resistance with feedback is given as

$$R_{of} = \frac{V}{I} = \frac{R_o}{1+\beta R_m}$$

where R_m represents the open circuit transresistance without taking the load R_L into account.

The output resistance with feedback R'_{of} including R_L as part of the amplifier is given by

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

Therefore,

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

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

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

$$R'_{of} = \frac{R_o R_L / (R_o + R_L)}{1 + [\beta R_m R_L / (R_o + R_L)]}$$

or

$$R'_{of} = \frac{R'_o}{1+\beta R_M}$$

where

$$R'_o = \frac{R_o R_L}{R_o + R_L} \quad \text{and} \quad R_M = \frac{R_m R_L}{R_o + R_L}$$

where R_M indicates the open-circuit transresistance taking the load R_L into account.

Distortion in Amplifiers

Due to non-linear characteristics of an active device, it is not possible to construct an ideal amplifier. Therefore, the output of an amplifier will differ from the input either in its waveform or frequency content. The difference between the output waveform and the input waveform in an amplifier is called distortion.

Types of Distortion

1. Harmonic Distortion
2. Frequency Distortion
3. Phase or Delay Distortion

1. Harmonic Distortion

In this type of distortion, the new frequencies are produced in the output, which are not present in the input signal. This harmonic distortion is sometimes called amplitude distortion.

* The intermodulation distortion is also a type of non-linear distortion which occurs when the input signal consists of more than one frequency. If an input signal contains two frequencies f_1 and f_2, then sum $(f_1 + f_2)$ and difference $(f_1 - f_2)$ frequencies are called intermodulation frequencies.

2. Frequency Distortion

In this type of distortion, the signal components at different frequencies are amplified by different amounts. Due to the capacitive and inductive components in the amplifier circuits, and the active device, there is a loss in gain at the lower and higher extremes of the frequency range.

3. Phase Distortion or Delay Distortion

In this type of distortion, the phase shift between input and output waveforms depends upon the signals of different frequencies.