# Trans-Resistance Amplifier

Sudeep Veggalam*

## Contents

For the feedback transresistance amplifier in Fig. , use small-signal analysis to find the open-loop gain G, the feedback H, and the closed loop gain $G_m$. Neglect $r_o$ of each of the transistors and assume $R_C << \beta_2 R_E$ and $R_E << R_F$, and that the feedback causes the signal voltage at the input node to be nearly zero. Evaluate $/fracV_oI_s$ for the following component values: $\beta_1 = \beta_2 = 100$ , $R_C = R_E = 10k\Omega$ and $R_F = 100k\Omega$.

1. Draw the small-signal equivalent of the circuit in Fig.**??**.

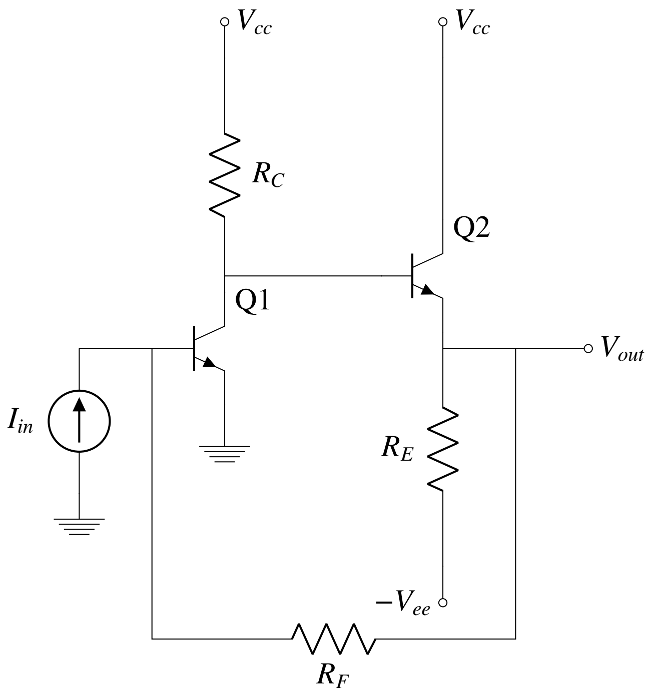


Fig. 1

**Solution:**
The equivalent circuit is Fig.**??**

2. Find the expression for the open loop Gain(G) of the system.

*The author is with the Department of Electrical Engineering, Indian Institute of Technology, Hyderabad 502285 India. 

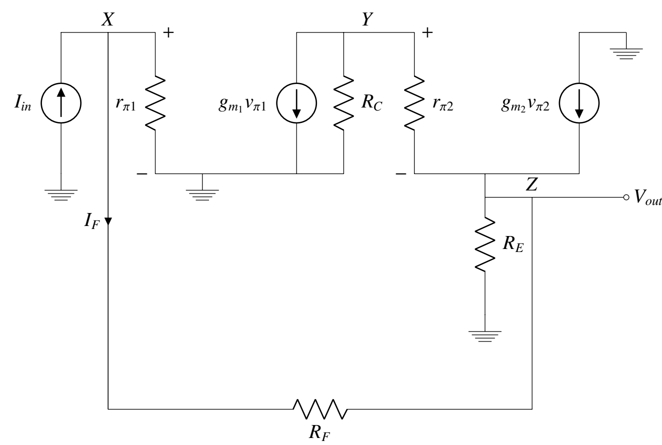


Fig. 1

**Solution:**
The given system is a cascaded system of $Q_1$ and $Q_2$. The signal flow graph is illustrated in Fig. **??**

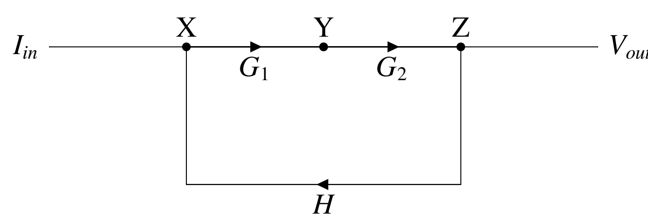


Fig. 2

So, if the gain of $Q_1$ and $Q_2$ are $G_1$ and $G_2$ respectively, the open-loop gain ($G$) is given by:

$$G = G_1 G_2 \tag{2.1}$$

$Q_1$ is in CE(Common-emitter) stage. The input signal is $I_{in}$. From fig. **??**,

$$I_X = I_{in} \tag{2.2}$$

$$\beta = \frac{I_c}{I_b} \tag{2.3}$$

Applying Kirchoff's Law in the loop connecting Y to ground,

$$\implies V_Y = \beta I_{in} R_C \tag{2.4}$$

$$G_1 = \frac{V_{out}}{I_{in}} = \frac{V_Y}{I_X} \tag{2.5}$$
$$= \beta R_c \tag{2.6}$$

$Q_2$ is in emitter follower topology.

$$V_{\pi 2} = V_Y - V_Z \tag{2.7}$$

Applying Kirchoff's Law,

$$\frac{V_Y - V_Z}{r_\pi} + g_{m2}(V_Y - V_Z) = \frac{V_Z}{R_E} \tag{2.8}$$

$$\implies \frac{V_Z}{V_Y} = \frac{R_E}{\frac{1}{g_{m2}} + R_E} \tag{2.9}$$

$$\implies G_2 = \frac{R_E}{\frac{1}{g_{m2}} + R_E} \tag{2.10}$$

From (**??**), the open loop gain ($G$):

$$G = (\beta_1 R_c)\left(\frac{R_E}{\frac{1}{g_{m2}} + R_E}\right) \tag{2.11}$$

3. Find the feedback factor(H) of the given circuit.
**Solution:**
From Fig.**??**, the feedback circuit consists of only a resistor $R_F$:

$$\therefore H = \frac{I_F}{V_{out}} = \frac{1}{R_F} \tag{3.1}$$

4. Find the closed loop gain of the system.
**Solution:**
The closed loop gain of a system is given by:

$$G_L = \frac{G}{1 + GH} \tag{4.1}$$

From (**??**) and (**??**). The closed loop gain of the circuit is given by:

$$G_L = \frac{(\beta_1 R_c)\left(\frac{R_E}{\frac{1}{g_{m2}}+R_E}\right)}{1 + \frac{(\beta_1 R_c)\left(\frac{R_E}{\frac{1}{g_{m2}}+R_E}\right)}{R_F}} \tag{4.2}$$
$$= \frac{R_F R_C R_E \beta}{\beta R_C R_E + R_F\left(\frac{1}{g_{m2}} + R_E\right)} \tag{4.3}$$

5. Find G,H and $G_L$ for the given problem. Parameters are summarised in table **??**.

| Parameters | Value |
|---|---|
| $V_{cc}$ | $5V$ |
| $\beta_1$ | 100 |
| $\beta_2$ | 100 |
| $R_C$ | $10K\Omega$ |
| $R_E$ | $10K\Omega$ |
| $R_F$ | $100K\Omega$ |

TABLE 5

**Solution:**
To calculate the bias values of Q1, Q2. Remove the input and output, the resultant circuit is shown in fig.**??**
Applying KVL to the circuit, we get:

$$0.7 + I_{b1}R_F + (I_{b1} - (\beta+1)I_{b2})R_E = -V_{ee} \tag{5.1}$$

$$0.7 + I_{b1}R_F + 0.7 + (\beta I_{b1} + I_{b2})R_C = V_{cc} \tag{5.2}$$

Solving the above equations, we get:

$$I_{b1} = \frac{\frac{V_{cc}-1.4}{R_C} - \frac{V_{ee}+0.7}{R_E(\beta+1)}}{\frac{R_F+\beta R_C}{R_C} + \frac{R_E+R_F}{R_E(\beta+1)}} \tag{5.3}$$
$$= 3.22 * 10^{-6} \tag{5.4}$$

$$I_{b2} = \frac{\frac{V_{cc}-1.4}{\beta R_C+R_F} + \frac{V_{ee}+0.7}{R_E+R_F}}{\frac{R_C}{R_F+\beta R_C} + \frac{R_E(\beta+1)}{R_E+R_F}} \tag{5.5}$$

we know,

$$g_m = \frac{I_c}{V_T} \tag{5.6}$$

where, $V_T$ = 26mV, and

$$r_\pi = \frac{\beta}{g_m} \tag{5.7}$$

$$\therefore g_{m1} = \frac{\beta I_{b1}}{V_T} \tag{5.8}$$
$$= 0.0123 \tag{5.9}$$

$$r_{\pi 1} = \frac{\beta}{g_{m1}} \tag{5.10}$$
$$= 8130\Omega \tag{5.11}$$