Trans-resistance Feedback Circuits

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For the feedback transresistance amplifier in 1.1), use small-signal analysis to find the open-loop gain 'G', Feedback factor 'H' and Closed-loop gain 'T'. Let $R_F >> R_L$ and $r_o >> R_L$. Find the value of T for $R_L = 10K\Omega$, $R_F = 100K\Omega$ and the transistor current gain $\beta = 100$.

1. Draw the equivalent control system for the feedback Transresistance amplifier shown in 1.1

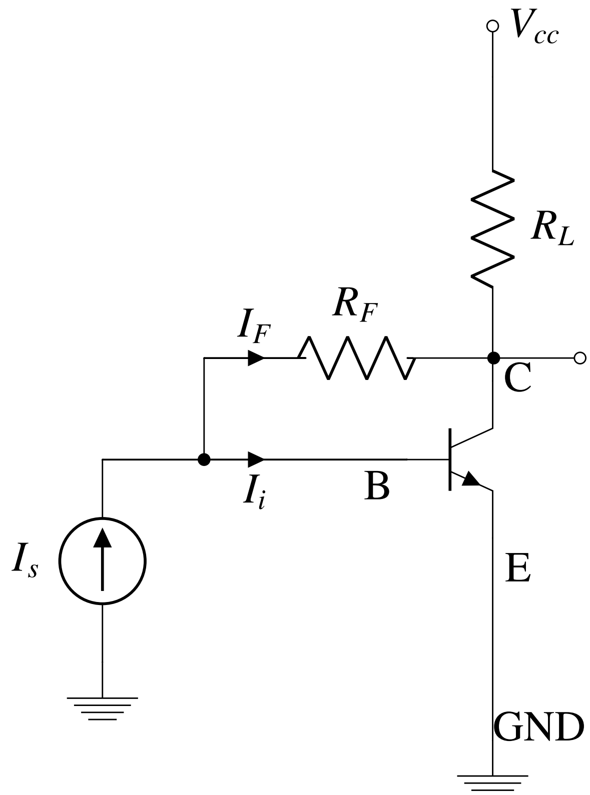

Fig. 1.1

Solution: see Fig. 1.2

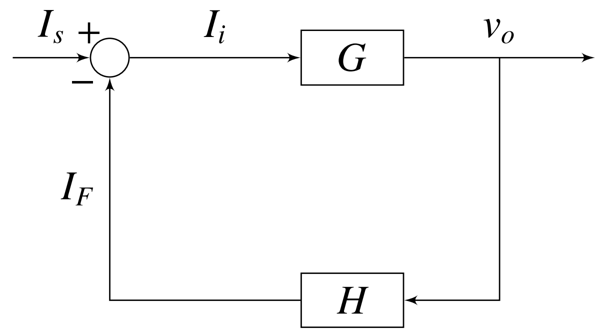

Fig. 1.2

2. For the feedback Transresistance amplifier shown in 1.1, Draw its small signal model. Early effect in Transistor is neglected.

Solution: see Fig. 2
While drawing a Small-Signal Model, we ground all constant voltage sources and open all constant current sources. All Small-Signal paramters are obtained from DC-Analysis of the circuit. Neglecting Early effect, in SmallSignal Analysis a npn-Transistor is modelled as a Current Source with value of current equal to $g_m V_{be}$ flowing from Collextor to Emitter. Whereas a pnp-Transistor is modelled as a Current Source with value of current equal to $g_m V_{be}$ flowing from Emitter to Collector.

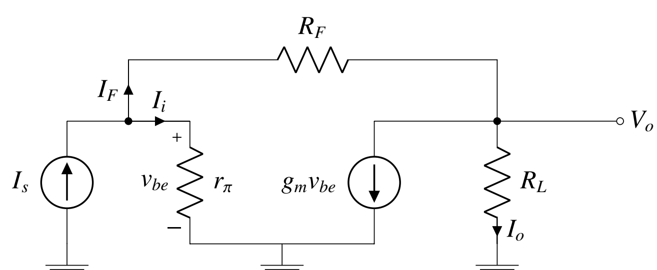

Fig. 2: Small Signal Model

3. Find small signal parameters g_m and v_{be} using DC analysis
Solution: small signal parameters of bjt are given in (3.1) and (3.2)

$$g_m = \frac{I_C}{V_T} \tag{3.1}$$

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$$r_\pi = \frac{V_T}{I_B} \tag{3.2}$$

The Large signal model of circuit becomes as shown in figure 3

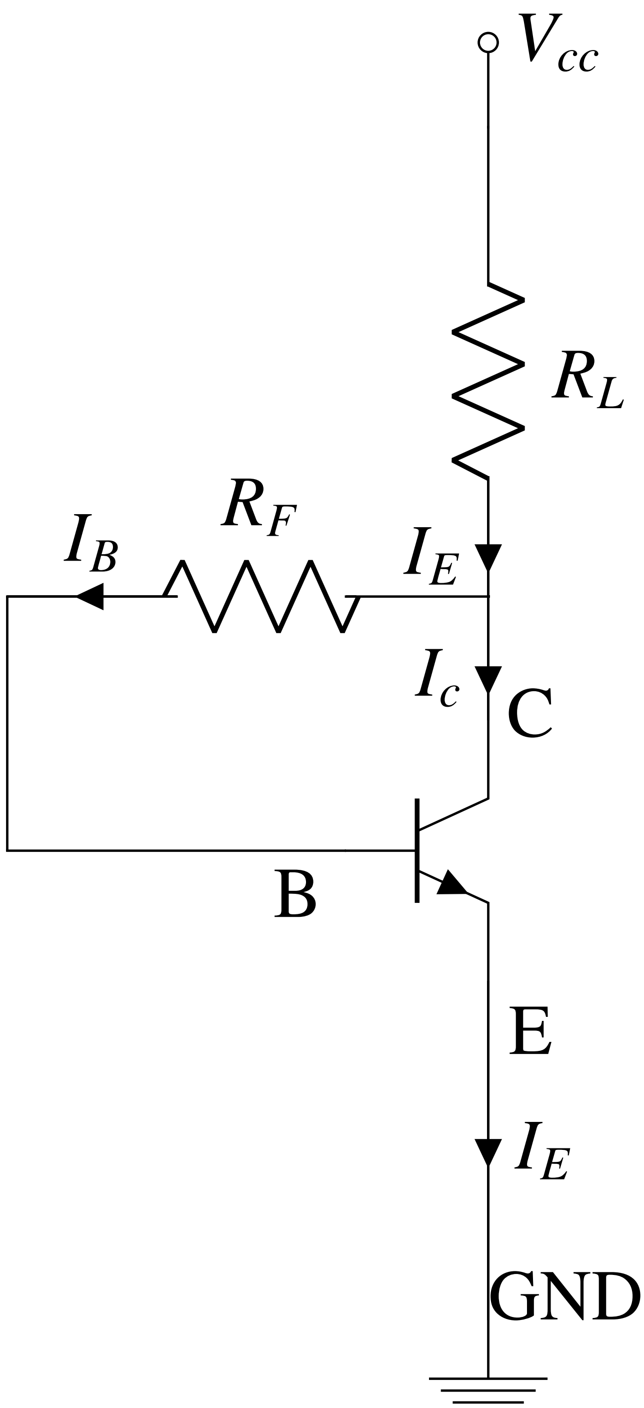

Fig. 3: Large signal model

Where $V_T = 25m$volts

$$V_{BE} = 0.7volts \implies V_B = 0.7volts \tag{3.3}$$

$$I_E = I_B + I_C \tag{3.4}$$

$$I_C = \beta I_B \tag{3.5}$$

From applying KVL and KCL on Fig.

$$V_{cc} - I_E R_L - I_B R_F - 0.7 = 0 \tag{3.6}$$

$$\implies V_{cc} - (\beta + 1) I_B R_L - I_B R_F - 0.7 = 0 \tag{3.7}$$

$$I_B = \frac{V_{cc} - 0.7}{(\beta + 1) R_L + R_F} \tag{3.8}$$

$$I_C = \beta \frac{V_{cc} - 0.7}{(\beta + 1) R_L + R_F} \tag{3.9}$$

from (3.1), (3.2),I_B and I_C

$$g_m = \frac{\beta}{V_T} \frac{V_{cc} - 0.7}{(\beta + 1) R_L + R_F} \tag{3.10}$$

$$r_\pi = V_T \frac{(\beta + 1) R_L + R_F}{V_{cc} - 0.7} \tag{3.11}$$

4. Write all node/loop equations of Small-Signal model using KCL/KVL.Given that $R_F >> R_L$
Solution:

$$v_{be} = I_i r_\pi \tag{4.1}$$

$$v_{be} - I_F R_F = V_o \tag{4.2}$$

$$V_o = (I_F - g_m v_{be}) R_L \tag{4.3}$$

5. Find the expression for feedback factor H.
Solution:

$$H = \frac{I_F}{V_o} \tag{5.1}$$

substituting (4.2) in (4.3)

$$V_o = (I_F - g_m V_o - g_m I_F R_F) R_L \tag{5.2}$$

$$\implies (1 + g_m R_L) V_o = I_F (R_L - g_m R_F R_L) \tag{5.3}$$

$$H = \frac{I_F}{V_o} = \frac{1 + g_m R_L}{R_L (1 - g_m R_F)} \tag{5.4}$$

$$\implies H \approx -\frac{1}{R_F} \tag{5.5}$$

6. Find the expression for Open loop Gain G.

Solution:

$$G = \frac{V_o}{I_i} \quad (6.1)$$

Substituting (4.1) in (4.2) and subisstituting I_F from (5.4)

$$I_i r_\pi - \left(\frac{1 + g_m R_L}{R_L (1 - 1 + g_m R_F)}\right) R_F V_o = V_o \quad (6.2)$$

$$\implies G = \frac{V_o}{I_i} = \frac{r_\pi R_L (1 - g_m R_F)}{R_F + R_L} \quad (6.3)$$

Upon approximating since $R_F >> R_L$

$$G = -g_m r_\pi R_L \quad (6.4)$$

7. Find the expression for Closed Loop Gain $T = \frac{V_o}{I_s}$
We know that Closed Loop Gain

$$T = \frac{G}{1 + GH} \quad (7.1)$$

Substituting expressions from (5.5) and (6.3)

$$T = -\frac{g_m r_\pi R_L}{1 + \left(\frac{g_m r_\pi R_L}{R_F}\right)} \quad (7.2)$$

For significantly large R_L and R_F we can approximate G, H and T. Then, since $g_m r_\pi = \beta$ we can see that H, G and T are not depending on V_{cc}

8. For the parameters given in table 8 . Find G,H and T. **Solution:** Substituting the parameters in

Parameters	Value
V_{cc}	5V
I_s	1μ
R_F	$100K\Omega$
R_L	$10K\Omega$
β	100

TABLE 8

(3.10) and (3.11) gives,

$$r_\pi = 6.6667 \times 10^3 \Omega \quad (8.1)$$

$$g_m = 0.015S \quad (8.2)$$

Substituting g_m, r_π obtained in (5.5)

$$H = -10^{-5} \quad (8.3)$$

Substituting g_m, r_π obtained in (6.4)

$$G = -10^6 \quad (8.4)$$

Substituting g_m, r_π obtained in (7.2)

$$T = -90909.09 \quad (8.5)$$

9. Draw the block diagram and circuit diagram for H.
Solution: see figs 9.5 and 9.6

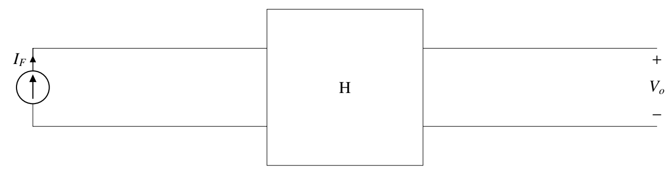

Fig. 9.5: Feedback block diagram

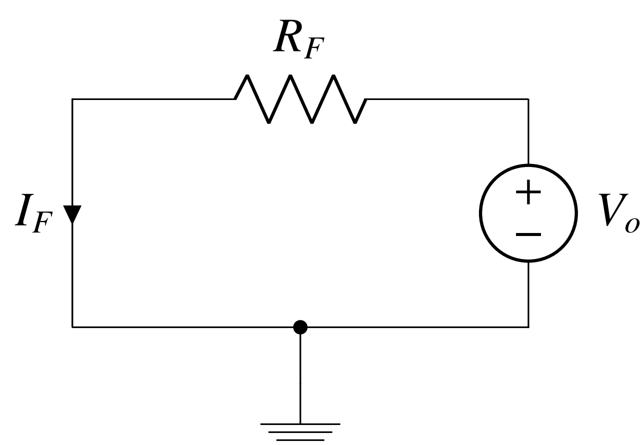

Fig. 9.6: Feedback circuit

From KVl on 9.6 we can see that

$$H = \frac{I_F}{V_o} = -\frac{1}{R_F} \quad (9.1)$$

10. Find the input and output resistances of the feedback network.
Solution: From the feedback amplifier circuit fig.9.6 To find the input resistance R_{11} short the output node V_o to ground.

$$R_{11} = R_F \quad (10.1)$$

To find the output resistance R_{22} rempve the current source and short input terminals.

$$R_{22} = R_F \quad (10.2)$$

11. Draw the block diagram and circuit diagram for G.

Solution: see figs 11.7 and 11.8

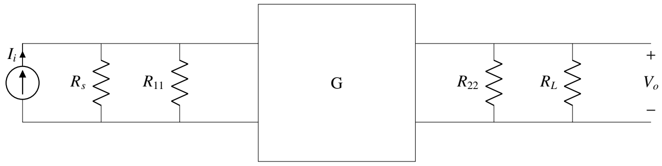

Fig. 11.7: Open loop block diagram

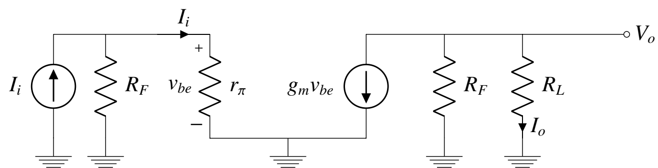

Fig. 11.8: Open loop block circuit diagram

12. Find G
Solution: From fig.11.8, There is no R_S in the circuit and

$$V_{be} = I_i\,(r_\pi \| R_L) \tag{12.1}$$

From KCL at node V_o,

$$I_o = -g_m I_i\,(r_\pi \| R_L) \tag{12.2}$$

$$V_o = -g_m I_i\,(r_\pi \| R_L)\,(R_L \| R_F) \tag{12.3}$$

Since normally $R_F >> R_L$ and $R_F >> r_\pi$. Therefore, $(r_\pi \| R_L)$ becomes r_π and $(R_F \| R_L)$ becomes R_L Therefore,

$$G = \frac{V_o}{I_i} = -g_m r_\pi R_L \tag{12.4}$$

13. Simulate the circuit using ngspice
Solution: The following file gives instructions on how to simulate the circuit.

```
codes/ee18btech11046/spice/README
```

The following netlist simulates dc analysis of circuit shown in 13.9 by varying voltage source V_{BE},which gives I_c vs V_{be} characteristics of bjt.

```
codes/ee18btech11046/spice/
    ee18btech11046_spice2.net
```

The I_c vs V_{be} characteristics obtaines from spice are plotted in fig.13.10
From I_c vs V_{be} graph, Slope at Q-point(middle point of linear region) gives g_m

$$g_m = \frac{\partial I_c}{\partial V_{be}} = 0.0104943S\ (approx) \tag{13.1}$$

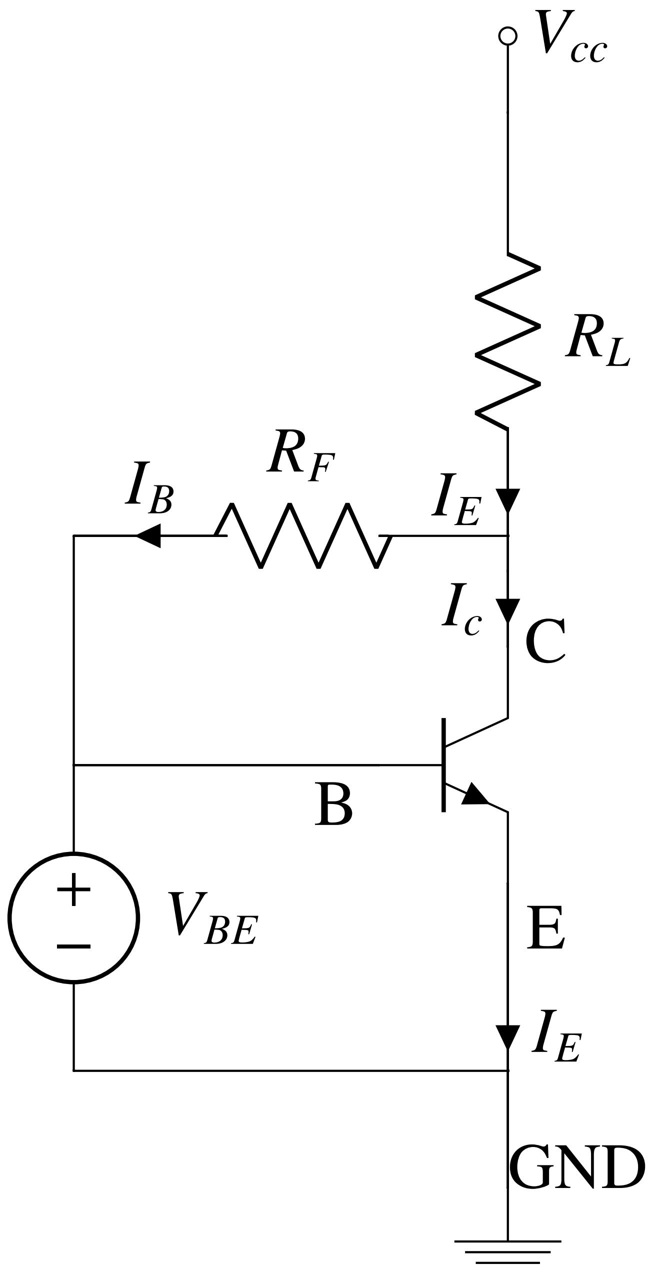

Fig. 13.9

```
codes/ee18btech11046/spice/
    ee18btech11046_spice2.py
```

The following netlist simulates dc analysis of circuit shown in 13.9 by varying voltage source V_{BE}, which gives V_{be} vs I_b characteristics of bjt.

```
codes/ee18btech11046/spice/
    ee18btech11046_spice3.net
```

The V_{be} vs I_b characteristics obtaines from spice are plotted in fig.13.11

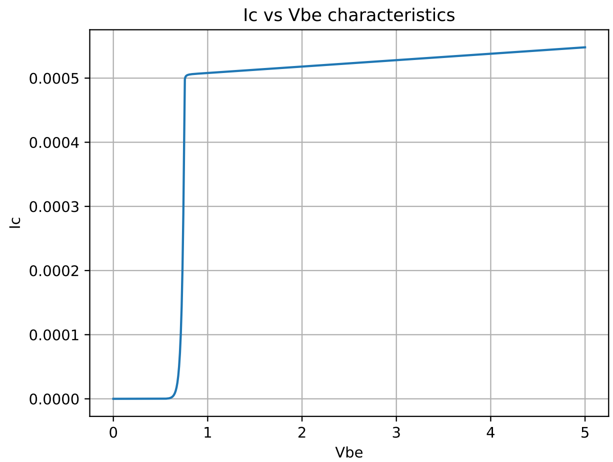

Fig. 13.10: Ic vs Vbe

From V_{be} vs I_b grah, Slope at Q-point(middle point of linear region) gives r_π

$$r_\pi = \frac{\partial V_{be}}{\partial I_b} = 9528.921\Omega\,(approx) \tag{13.2}$$

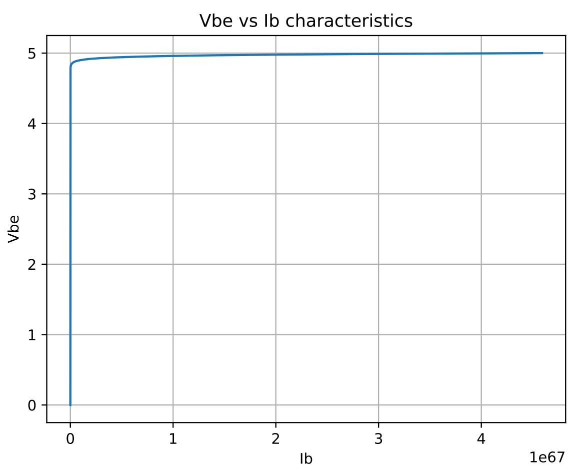

Fig. 13.11: Vbe vs Ic

```
codes/ee18btech11046/spice/
    ee18btech11046_spice3.py
```

The g_m and r_π are almost same as the values calculated above.
The following netlist simulates the feedback amplifier using parameters in table 8.

```
codes/ee18btech11046/spice/
    ee18btech11046_bjt.net
```

The Output Voltage obtained from spice is plotted in fig.13.12

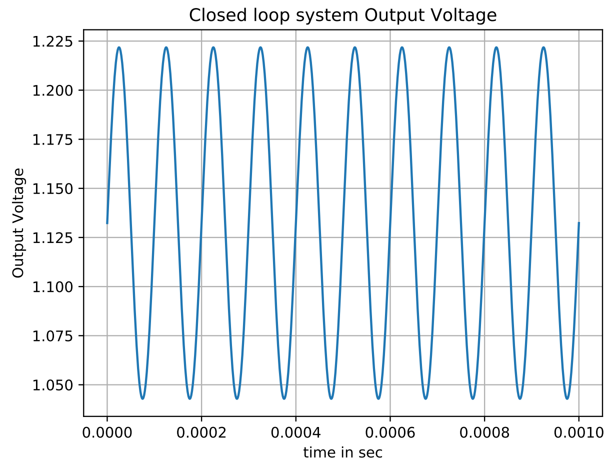

Fig. 13.12: Output Voltage

```
codes/ee18btech11046/spice/
    ee18btech11046_spice1.py
```

We can observe that V_o is a sine wave with amplitude 0.08952 oscillating around 1.1323. Where 1.1323 is the DC output of circuit and sine wave of amplitude 0.08952 is the amplified small signal output of input sine wave with amplitude 1μ. From this we can see that the amplification factor due to circuit is $\frac{0.08952}{1\mu} = 89520$, which is close to the calculated Closed loop Gain of the circuit.