

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 $R_F \gg R_L$ and $r_o \gg R_L$. 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

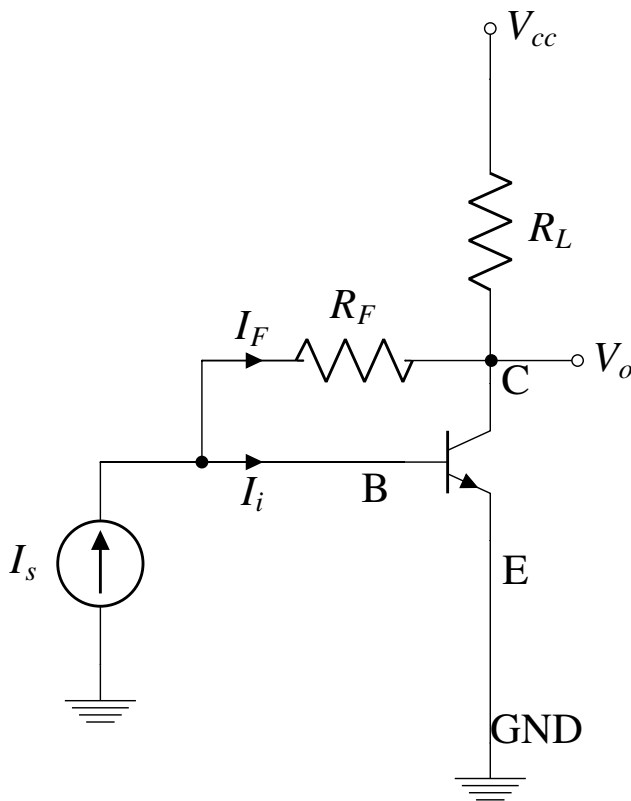


Fig. 1.1

Solution: see Fig. 1.2

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

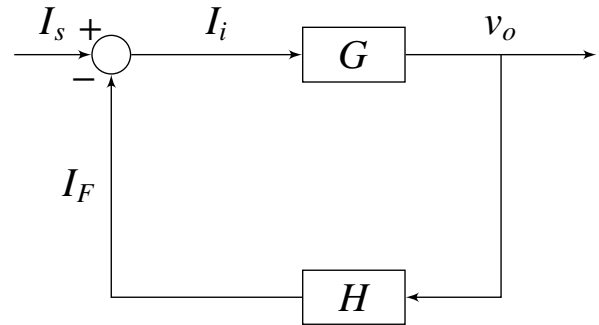


Fig. 1.2

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 parameters 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 Collector 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.

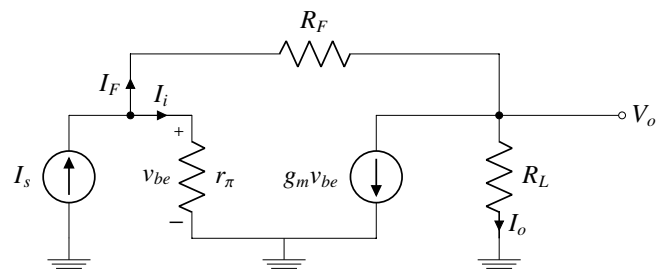


Fig. 2: Small Signal Model

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)

$$g_m = \frac{I_C}{V_T} \quad (3.1)$$

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$$r_\pi = \frac{V_T}{I_B} \quad (3.2)$$

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

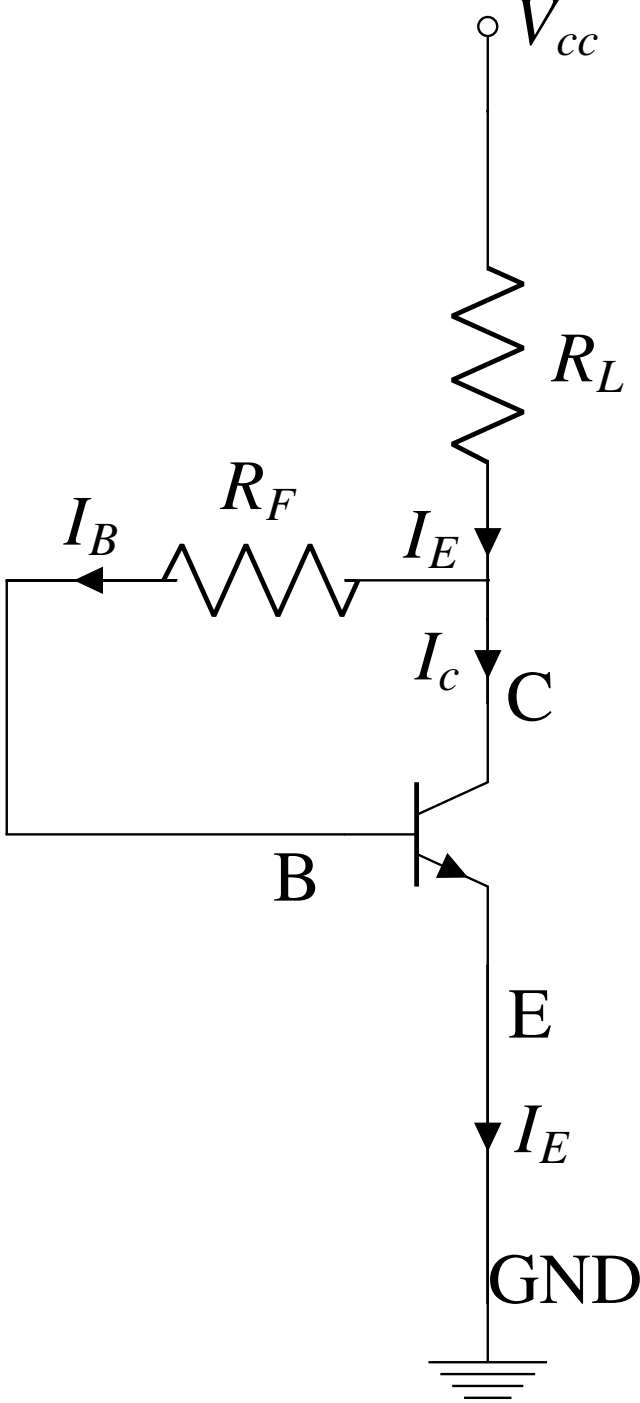


Fig. 3: Large signal model

Where $V_T = 25\text{mvolts}$

$$V_{BE} = 0.7\text{volts} \implies V_B = 0.7\text{volts} \quad (3.3)$$

$$I_E = I_B + I_C \quad (3.4)$$

$$I_C = \beta I_B \quad (3.5)$$

From applying KVL and KCL on Fig.

$$V_{cc} - I_E R_L - I_B R_F - 0.7 = 0 \quad (3.6)$$

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

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

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

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

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

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

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

Solution:

$$v_{be} = I_i r_\pi \quad (4.1)$$

$$v_{be} - I_F R_F = V_o \quad (4.2)$$

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

5. Find the expression for feedback factor H.

Solution:

$$H = \frac{I_F}{V_o} \quad (5.1)$$

substituting (4.2) in (4.3)

$$V_o = (I_F - g_m V_o - g_m I_F R_F) R_L \quad (5.2)$$

$$\implies (1 + g_m R_L) V_o = I_F (R_L - g_m R_F R_L) \quad (5.3)$$

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

$$\implies H \approx -\frac{1}{R_F} \quad (5.5)$$

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 substituting I_F from (5.4)

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

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

Upon approximating since $R_F \gg R_L$

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

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

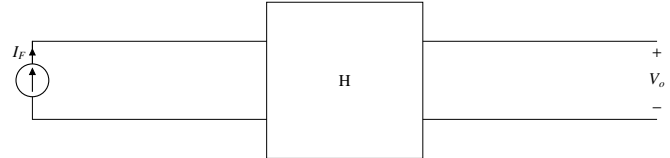


Fig. 9.5: Feedback block diagram

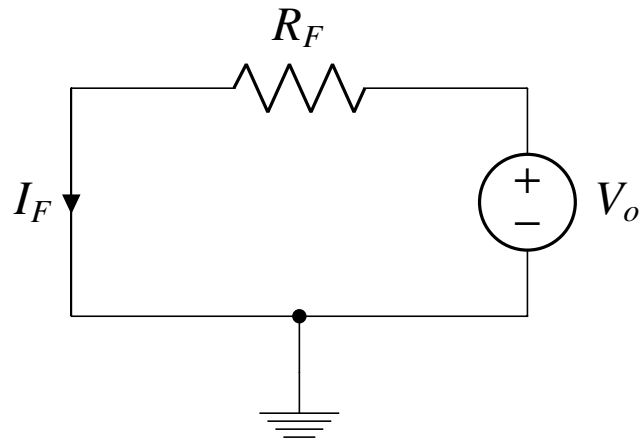


Fig. 9.6: Feedback circuit

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} remove 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

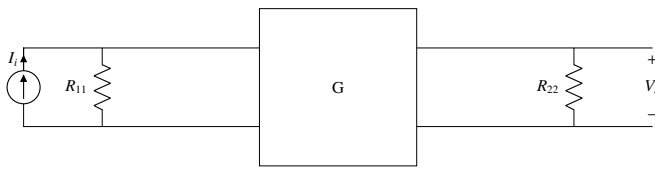


Fig. 11.7: Open loop block diagram

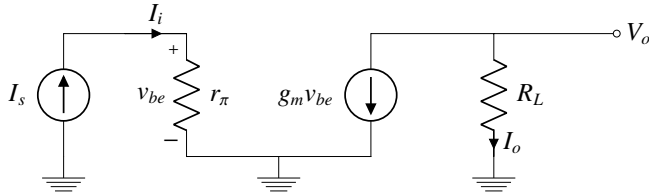


Fig. 11.8: Open loop block circuit diagram

12. Find G

Solution: From fig.11.8,

$$V_{be} = I_i r_\pi \quad (12.1)$$

From KCL at node V_o ,

$$I_o = -g_m I_i r_\pi \quad (12.2)$$

$$V_o = -g_m I_i r_\pi R_L \quad (12.3)$$

Therefore,

$$G = \frac{V_o}{I_i} = -g_m r_\pi R_L \quad (12.4)$$

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 which gives I_c vs V_{be} characteristics of bjt.

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

From I_c vs V_{be} slope at Q-point(middle point of linear region) gives g_m

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

The I_c vs V_{be} characteristics obtained from spice are plotted in fig.13.9

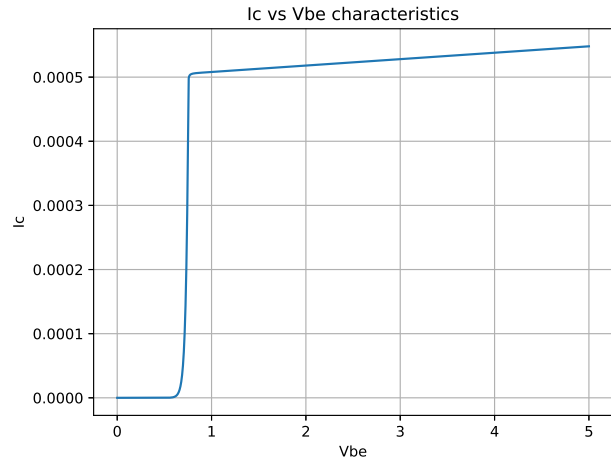


Fig. 13.9: I_c vs V_{be}

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

The following netlist simulates dc analysis of circuit which gives V_{be} vs I_b characteristics of bjt.

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

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

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

The V_{be} vs I_b characteristics obtained from spice are plotted in fig.13.10

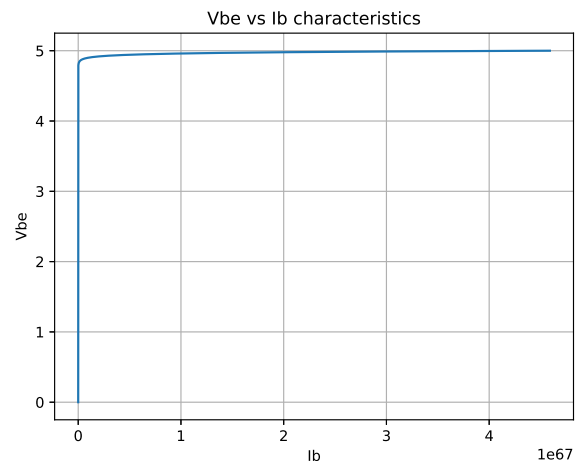


Fig. 13.10: V_{be} vs I_c

```
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.13.11

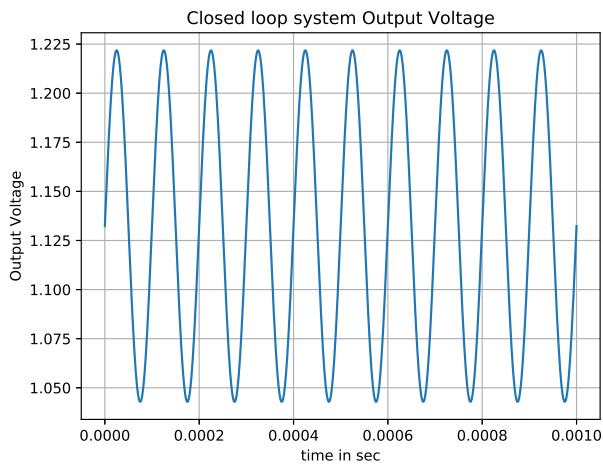


Fig. 13.11: Output Voltage

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

We can observe that V_o is sum of input sine wave amplified by a factor of 89500 for small signal input and large signal output V_C which is close to the calculated values.