UNIVERSITY OF CALIFORNIA AT BERKELEY
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Discussion Notes #8

EE 105 **Spring 2007**
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BJT Biasing

In the following discussion, we will go over how to design a BJT biasing circuit. The analysis is similar to MOSFETS however there are important differences. The topology shown in figure 1 is designed with the following features:

1) $I_1 >> I_B$ to lower sensitivity to β.
2) V_{RE} must be large enough to suppress uncertainties in V_X and V_{BE}.

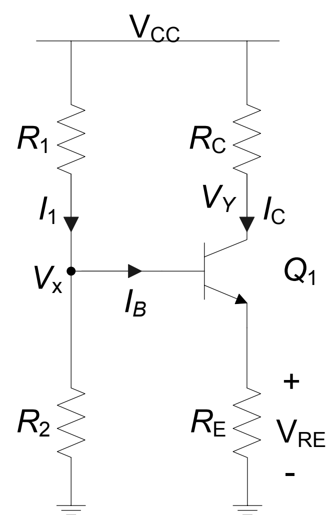

Figure 1: Robust BJT biasing circuit

Problem

a) Design the circuit in figure 1 so as to provide $V_{RE} = 1V$ and $I_1 \geq 100 I_B$. Assume V_{CC}=5V, β=100, and I_S = 5e-17 A, and $I_C = 1mA$.
b) Find the input impedance
c) Find the output impedance
d) Find the small signal gain,

a) Design the circuit in figure 1 so as to provide $V_{RE} = 1V$ and $I_1 \geq 100I_B$. Assume V_{CC}=5V, β=100, and I_S = 5e-17 A, and $I_C = 1mA$.

Find the small signal parameters g_m and r_π.

$$g_m = \frac{I_C}{V_T} = \frac{1mA}{26mV} = 0.0385S \tag{1}$$

$$r_\pi = \frac{\beta}{g_m} = 2600\Omega \tag{2}$$

Find the values of resistors R_1, R_2, R_C, and R_E.

R_E: Since we want an output of V_{RE} =1V, and the current I_C = 1mA, we can calculate the value of R_E.

$$\frac{V_{RE}}{R_E} = I_E \approx 1mA \tag{3}$$

$$\boxed{R_E = 1000\Omega} \tag{4}$$

R_C: The value of R_C will be needed to put the transistor in the active region. Recall that active region is defined when $V_C > V_B$. In order find the minimum V_C, let's find the value of V_X.

$$I_C = I_S \exp\left(\frac{V_{BE}}{V_T}\right) \tag{5}$$

Using equation 5, we can calculate V_{BE} = 0.797V.

$$V_X = V_{BE} + V_{RE} = 0.797V + 1V = 1.797V \tag{6}$$

To be in active region, $V_C > V_B = V_X$. Now let's find the maximum R_C to set the device in active region.

$$V_C = V_{CC} - I_C R_C \tag{7}$$

$$V_{CC} - I_C R_C > V_X = 1.797V \tag{8}$$

$$R_C < 3203\Omega \tag{9}$$

Using equation 7, and plugging it into the boundary condition for active region in equation 8, we can find that the maximum R_C to keep the device in active region is 3203Ω. As long as we pick an R_C above the maximum value, the circuit will work properly. Therefore, we will pick

$$\boxed{R_C = 3000\Omega} \tag{10}$$

R1 & R2: The value of R_1 and R_2 will be determined by the requirement of $I_1 = 100I_B$ and V_X.

$$\left(\frac{R_2}{R_1 + R_2}\right)V_{CC} = V_X \tag{11}$$

$$I_1 = \left(\frac{V_{CC}}{R_1 + R_2}\right) = 100I_B \tag{12}$$

$$I_B = \frac{I_C}{\beta} = 10\mu A \tag{13}$$

We can use the voltage divider equation to solve for V_X as in equation 11. Also, we can use the condition $I_C = 100I_B$ as in equation 12. Now we have 2 equations and 2 unknowns, solving for R1 and R2, we get

$$\boxed{R1 = 3203\Omega} \tag{14}$$
$$\boxed{R2 = 1797\Omega} \tag{15}$$

b) Find the input impedance

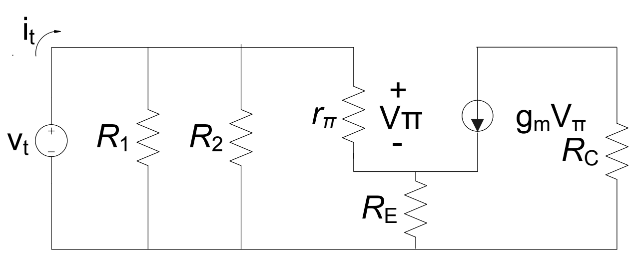

Figure 2: Small Signal Model for finding R_{in}

Instead of finding the input impedance by the small signal given in figure 2, we can notice that R1 and R2 are in parallel with a CE stage with emitter degeneration. The input impedance of an emitter degenerated CE stage is:

$$r_\pi + (1+\beta)R_E \tag{16}$$

Equation 16 comes from noticing that the current through R_E is amplified by the current gain, β. Therefore the input impedance is enhanced. For more information, refer to the bottom of **page 198 in Razavi**.

Now, we can easily read off the input impedance as,

$$\boxed{R_{in} = R_1 \| R_2 \| (r_\pi + (1+\beta)R_E) = 1138.5\Omega} \quad (17)$$

c) Find the output impedance.

To find the output impedance, we must zero out the source. As a result, the current source also zeros out resulting in an output impedance of

$$\boxed{R_{out} = R_C = 3000\Omega} \quad (18)$$

For more information, refer to **page 199 in Razavi**.

d) Find the small signal gain

From the current loop at the output,

$$g_m v_\pi = -\frac{v_{out}}{R_C} \quad (19)$$

Obtaining,

$$v_\pi = -\frac{v_{out}}{g_m R_C} \quad (20)$$

Applying KVL,

$$V_t = v_\pi + v_{RE} \quad (21)$$

$$V_t = v_\pi + \left(\frac{v_\pi}{r_\pi} + g_m v_\pi\right) R_E \quad (22)$$

Substituting equation 20 into equation 22, we can get,

$$\frac{V_{out}}{V_t} = \frac{g_m R_C}{1 + \left(\frac{1}{r_\pi} + g_m\right) R_E} \approx \frac{-R_C}{\frac{1}{g_m} + R_E} \quad (23)$$

$$\boxed{\frac{Vout}{Vt} = 4.87} \quad (24)$$