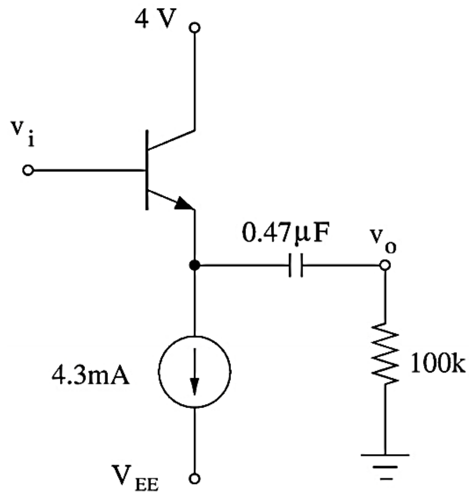
Major Quiz 2 Solution

Date – 11.04.2019

Name: ______________________ Roll No.: ___________ Section: ________ Total Marks: 40

Q1. Find the bias point (I_C and V_{CE}) and the amplifier parameters (R_{in}, R_o, A_v and cut-off frequency f_p) of the circuit below. (Si BJT with $\beta = 200$, $V_A = 150$ V, ignore Early effect in bias calculations). [12]



Sol.: Assume BJT is in Active mode.

$$V_{BE} = 0.7\,V, \qquad I_C > 0 \; and \; V_{CE} > 0.7\,V$$
$$I_E = 4.3\,mA \approx I_C$$
$$I_B = \frac{I_C}{\beta} = 21.5\,\mu A$$
$$V_{BE} = 0 - V_E \;\rightarrow\; V_E = -0.7\,V$$
$$V_{CE} = 4 - V_E = 4.7\,V > 0.7\,V$$
$$g_m = \frac{I_C}{V_T} = \frac{4.3 \times 10^{-3}}{26 \times 10^{-3}} = 165\,mA/V$$
$$r_0 \approx \frac{V_A}{I_C} = \frac{150}{4.3 \times 10^{-3}} = 34.9\,k\Omega, \qquad r_\pi = \frac{V_T}{I_B} = \frac{\beta}{g_m} = 1212\Omega$$

Amplifier Parameters: This is an emitter follower ($R_E = \infty$).

$$\frac{v_0}{v_i} = \frac{g_m(r_0||R_E||R_L)}{1 + g_m(r_0||R_E||R_L)}$$

$$r_0||R_E||R_L = 34.9k||\infty||100k = 25.9k$$
$$g_m(r_0||R_E||R_L) = 4269$$

$$A_v = \frac{v_0}{v_i} = \frac{4269}{1 + 4269} \approx 1$$

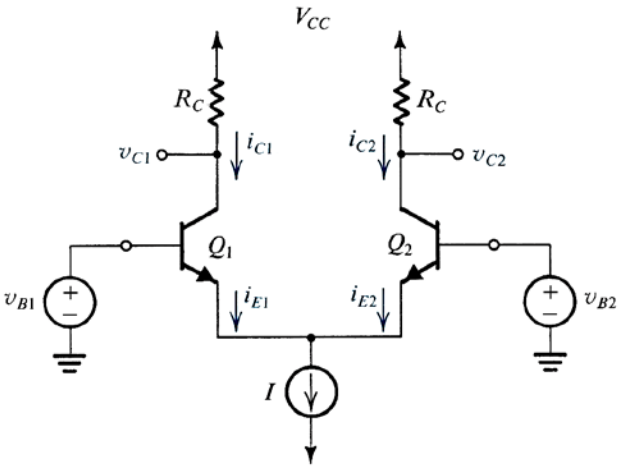
$$R_i = R_B||\left[r_\pi + (1+\beta)\left(r_0\middle|\middle|R_E\middle|\middle|R_L\right)\right] = 1212 + 201 \times 25.9k = 5.2\,M\Omega$$

$$R_0 \approx R_E||\frac{r_\pi + R_B||R_{sig}}{1+\beta} \approx \frac{r_\pi}{\beta} = 6.06\,\Omega$$

Cut-off frequency:

$$f_p = \frac{1}{2\pi[R_L + R_0]C_{c2}} = \frac{1}{2\pi(100 \times 10^3 + 6.06) \times 0.47 \times 10^{-6}} = 3.39\,Hz$$

Q3. Consider the differential amplifier in figure shown below, and let the BJT β be very large:



(a) What is the largest input common-mode signal that can be applied while the BJTs remain comfortably in the active region with $V_{CB} = 0$? [2]

(b) If an input difference signal is applied that is large enough to steer the current entirely to one side of the pair, what is the change in voltage at each collector (from the condition for which $V_{id} = 0$)? [2]

(c) If the available power supply V_{CC} is 5 V, what value of $I * R_c$ should you choose in order to allow a common-mode input signal of ±3 V? [2]

(d) For the value of $I * R_c$ found in (c), select values for I and R_C. Use the largest possible value for I subject to the constraint that the base current of each transistor (when I divides equally) should not exceed $2\mu A$. Let $\beta = 100$. [4]

Sol.:

a)

$$V_{CMmax} = V_{C1} = V_{C2} = V_{CC} - \frac{I}{2} * R_C$$

b) if the current is steered to Q_1, then

$$V_{C1} = V_{CC} - IR_C \rightarrow a\ change\ of\ -\frac{I}{2}R_C$$

$$V_{C2} = V_{CC} \rightarrow a\ change\ of + \frac{I}{2}R_C$$

c) For V_{CC} = 5V,

$$V_{CMmax} = 3 = 5 - \frac{I}{2}R_C \rightarrow I * R_C = 4V$$

d)

$$\frac{I/2}{\beta + 1} \leq 2\mu A \rightarrow I \leq 4(\beta + 1)\mu A$$

$$I = 4 * 101\mu A = 0.404mA$$

Let's select $I = 0.4mA$.

$$R_C = \frac{4V}{I} = \frac{4V}{0.4mA} = 10K\Omega$$

Q3. In a differential amplifier using a 6-mA emitter bias current source, the two BITs are not matched. Rather, one has one-and-a-half times the emitter junction area of the other. For a differential input signal of zero volts, what do the collector currents become? What difference input is needed to equalize the collector currents? Assume α = 1. [6]

Sol.: The current will divide in the two transistors in proportion of their emitter areas. Thus, with no input,

$$I_{E1} = 1.5\, I_{E2}$$

$$I_{E1} + I_{E2} = 6mA$$

$$I_{E2} \cong I_{C2} = 2.4mA$$

$$I_{E1} \cong I_{C1} = 3.6mA$$

To equalize the collector currents, we apply a differential signal $V_d = V_{B2} - V_{B1}$.

Now, we know that,

$$i_{E1} = I_{SE1}\, e^{(V_{B1}-V_E)/V_T}, i_{E2} = I_{SE2}\, e^{(V_{B2}-V_E)/V_T}$$

Now, we have

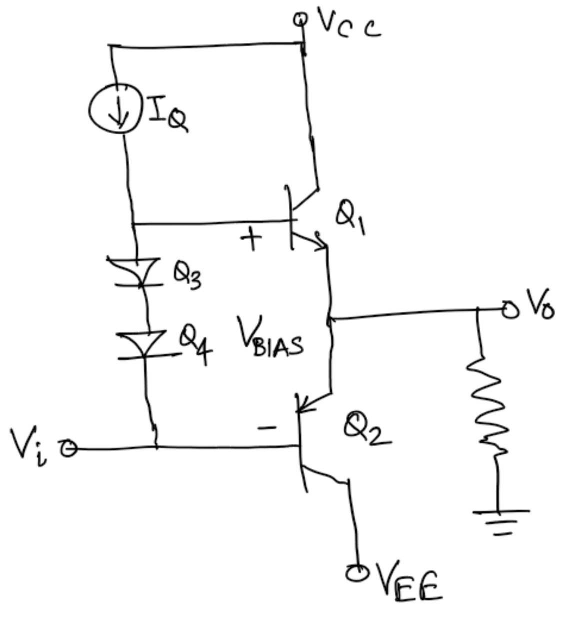
$$I_{SE1} = 1.5\, I_{SE2}$$

For $I_{E1} = I_{E2}$, we have,

$$1 = 1.5\, e^{(V_{B1}-V_{B2})/V_T}$$

$$V_{B2} - V_{B1} = 10.1mV$$

Q4. Choose the saturation currents of the diode connected transistors Q_3 and Q_4 (both are identical) in the circuit shown below, such that V_{BIAS} = 1.1V for I_Q = 100µA. Now, if each of the output transistors (Q_1 and Q_2) has its area four times that of Q_3 (or Q_4, same area), determine the standby power dissipation of the circuit. Assume V_{CC} = -V_{EE} = 5V. [12]



Sol.:

Diodes Q_3 and Q_4 are identical, and they are carrying the same bias currents I_Q. Hence, the voltage drop across each of Q_3 and Q_4 will be same, denoted by V_D. Then the bias voltage V_{BIAS} can be written as,

$$V_{BIAS} = 2V_D = 2V_T \ln\left(\frac{I_Q}{I_S}\right)$$

Where I_S is the saturation current of Q_3 (and also of Q_4). Noting that V_{BIAS} = 1.1V and I_Q = 100µA, we get

$$I_S = \frac{I_Q}{e^{\frac{V_{BIAS}}{2V_T}}} = \frac{100 * 10^{-6}}{e^{\frac{1.1}{2*0.026}}} = 6.5 * 10^{-14} A$$

This is the required saturation current of Q_3 (and Q_4) i.e.

$$I_{S3} = I_{S4} = 6.5 * 10^{-14} A$$

As Q_1 and Q2 have four times area, we have

$$I_{S1} = I_{S2} = 4I_{S3} = 26 * 10^{-14} A$$

To compute standby power, we need to find standby current as follows.

$$V_{BIAS} = V_{BE3} + V_{BE4} = V_{BE1} + V_{BE2}$$

Under standby condition V_o = 0, which makes Q_1 and Q_2 carry the same quiescent current (= $I_{standby}$). Neglecting base currents of Q_1 and Q_2, the current in Q_3 and Q_4 is equal to bias current I_Q. Thus,

$$V_T \ln\left(\frac{I_Q}{I_{S3}}\right) + V_T \ln\left(\frac{I_Q}{I_{S4}}\right) = V_T \ln\left(\frac{I_{standby}}{I_{S1}}\right) + V_T \ln\left(\frac{I_{standby}}{I_{S2}}\right)$$

$$V_T \ln\left(\frac{{I_Q}^2}{I_{S3} * I_{S4}}\right) = V_T \ln\left(\frac{{I_{standby}}^2}{I_{S1} * I_{S2}}\right)$$

Or,

$$I_{standby} = I_Q \sqrt{\frac{I_{S1} * I_{S2}}{I_{S3} * I_{S4}}}$$

Using this equation in our case,

$$I_{standby} = I_Q \frac{I_{S1}}{I_{S3}} = 4I_Q = 400\mu A$$

$$P_{standby} = I_{standby} * (V_{CC} - V_{EE}) = 4mW$$