# EE 321 Analog Electronics, Fall 2011
# Homework #10 solution

**7.24. Consider the differential amplifier of Fig. 7.12 and let the BJT $\beta$ 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 $v_{CB} = 0$?**

**(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 $v_{id} = 0$)?**

**(c) If the available power supply $V_{CC} = 5\,\text{V}$, what value of $IR_C$ should you choose in order to allow a common-mode input signal of $\pm 3\,\text{V}$?**

**(d) for the value of $IR_C$ found in (c), select values for $I$ and $R_C$. Use the largest possible value for $I$ subject to the constraints that the base current of each transistor (when $I$ divides equally) should not exceed $2\,\mu\text{A}$. Let $\beta = 100$.**

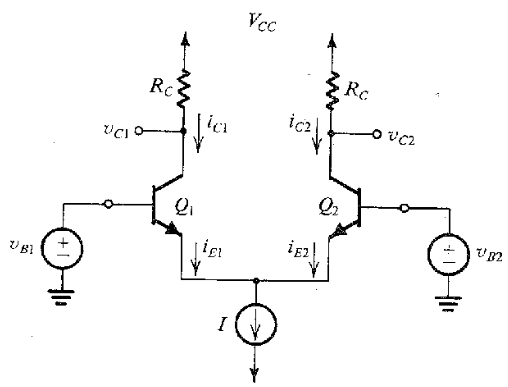


**FIGURE 7.12** The basic BJT differential-pair configuration.

(a) $v_{CB} = 0$ means $v_C = v_B$.

$$v_C = V_{CC} - \frac{IR_C}{2}$$

Thus the largest common-mode input is

$$v_{ic,\max} = V_{CC} - \frac{IR_C}{2}$$

(b) On one side the voltage will increase by $\frac{IR_C}{2}$, and on the other side it will decrease by $\frac{IR_C}{2}$.

(c) Inn that case we should make $V_C = 3\,\text{V}$ (assuming we will only go to $v_{CB} = 0\,\text{V}$ as in question (a), and thus

$$IR_C = 2\,(V_{CC} - V_C) = 2 \times (5 - 3) = 4\,\text{V}$$

(d) The relationship between $I$ and $I_B$ is

$$2\beta I_B = I$$

and thus the largest possible value of $I$ is

$$I = 2\beta I_B = 2 \times 100 \times 2 \times 10^{-6} = 0.4\,\text{mA}$$

and then the value for $R_C$ is

$$R_C = \frac{IR_C}{I} = \frac{4}{0.4 \times 10^{-3}} = 10\,\text{k}\Omega$$

**7.31. A BJT differential amplifier uses a 300 $\mu$A bias current. What is the value of $g_m$ of each device? If $\beta$ is 150, what is the differential input resistance?**
$g_m$ is defined as

$$g_m = \frac{I_C}{V_T} = \frac{\alpha I_E}{V_T} = \frac{\alpha\frac{I}{2}}{V_T} \approx \frac{I}{2V_T} = \frac{0.3}{2 \times 25} = 0.006\,\Omega^{-1}$$

The differential input resistance is

$$R_{id} = 2r_\pi = 2\frac{\beta}{g_m} = 2 \times \frac{150}{0.006} = 50\,\text{k}\Omega$$

**7.35. Design a BJT differential amplifier to amplify a differential input signal of 0.2 V and provide a differential output signal of 4 V. To ensure adequate linearity, it is required to limit the signal amplitude across each base-emitter junction to a maximum of 5 mV. Another design requirement is that the differential input resistance be at least 80 k$\Omega$. The BJTs available are specified to have $\beta \geq 200$. Give the circuit configuration and specify the values of all its components.**
To achieve this we need to add emitter resistors, $R_e$. We want the differential gain to be

$$A_D = \frac{4}{0.2} = 20$$

and we know that it is

$$A_D = \frac{R_C}{r_e + R_e}$$

We are also told that $v_{be}$ should be at most 5 mV. That constrains the voltage division between $r_e$ and $R_e$,

$$v_{be,\max} = \frac{r_e}{r_e + R_e}\frac{v_{id,\max}}{2}$$

Finally we are told that the differential input resistance should be at least 80 k$\Omega$,

$$R_{id} = 80\,\text{k}\Omega$$

where

$$R_{id} = 2\left[(\beta_{\min} + 1)\, r_e + R_e\right]$$

We should now be able to compute $R_e$, $R_C$, and $r_e$, the last of which gives us the bias current $I$.

Use the last two equations to get $r_e$ and $R_e$. First the second-last equation:

$$r_e + R_e = r_e \frac{v_{id,\max}}{2v_{be,\max}} = r_e \frac{0.2}{2 \times 5 \times 10^{-3}} = 20\, r_e$$

$$R_e = 19\, r_e$$

Insert that into the last equation:

$$R_{id} = 2\,(\beta_{\min} + 1) + 2R_e = 2\left[(\beta_{\min} + 1) + 19\right] r_e$$

$$r_e = \frac{R_{id}}{2\left[(\beta_{\min} + 1) + 19\right]} = \frac{80 \times 10^3}{2\left[(200 + 1) + 19\right]} = 182\,\Omega$$

Compute $R_e$

$$R_e = 19\, r_e = 19 \times 182 = 3.46\,\mathrm{k}\Omega$$

Compute $R_C$ from

$$R_C = A_D\,(r_e + R_e) = 20 \times \left(182 + 3.46 \times 10^3\right) = 72.8\,\mathrm{k}\Omega$$

Finally we should determine the current bias needed. We get that from

$$r_e = \frac{\alpha}{g_m} = \frac{\alpha}{\frac{I_C}{V_T}} = \frac{\alpha}{\frac{I}{2V_T}}$$

and thus

$$I = \frac{2\alpha V_T}{r_e} = \frac{2 \times 25 \times 10^{-3}}{182} = 0.27\,\mathrm{mA}$$