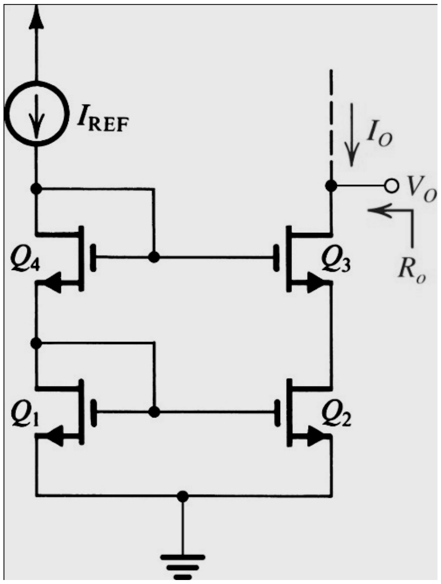
Examples #3

1. For a cascade MOS mirror utilizing devices with V_t=0.5V, $\mu_n C_{ox}$=387µA/V^2, W/L=3.6µm/ 0.36µm, V_A'=10V/µm , and I_{REF}=100µA. Find the minimum voltage required at the output and the output resistance.



$$I_{D1} = I_{D2} = I_{D3} = I_{D4} = I_{REF} = 100\ \mu A$$

Since $I_D = \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)V^2{}_{OV}$

$$V_{OV} = \sqrt{\frac{2I_D}{\mu_n C_{ox}\left(\frac{W}{L}\right)}} = \sqrt{\frac{2(100\ \mu A)}{(387\ \mu A/V^2)\left(\frac{3.6}{0.36}\right)}}$$

$= 0.23$ V

The minimum output voltage is

$$V_{Kn} + 2V_{ov} = 0.5\ V + 2(0.23\ V) = 096\ V$$

To obtain the output resistance, R_O, we need g_{m3}.

$$g_{m3} = \frac{I_{D3}}{V_{OV}/2} = \frac{2(0.1\ mA)}{0.23\ V} = 0.87\ mA/V$$

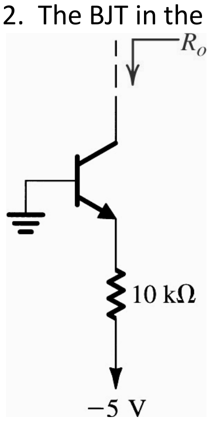
$$r_{O2} = r_{O3} = \frac{V_{A'}(L)}{I_D} = \frac{(5V/\mu m)(0.36\ \mu m)}{0.1\ mA}$$

$= 18$ kΩ. From eq. (7.77)

$$R_o \approx g_{m3} r_{o3} r_{o2} = (0.87\ mA/V)(18\ k\Omega)^2$$

$= 282$ kΩ

2. The BJT in the circuit below has v_{BE}=0.7V, β=100 and V_A=50V. Find Ro.



$$I_E = \frac{V_E - V_{EE}}{R_E} = \frac{-0.7-(-5)}{10\ k\Omega} = 0.43\ mA$$

$$g_m = \frac{I_c}{V_t} = \frac{0.43\ mA}{25\ mV} = 17.2\ mA/V$$

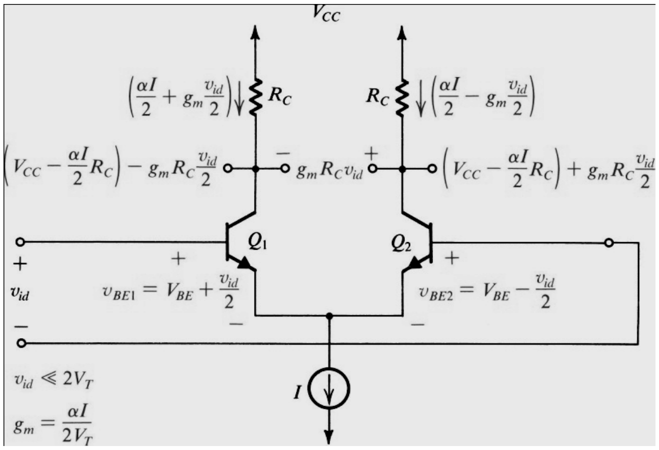
$$r_o = \frac{V_A}{I_c} = \frac{50\ V}{0.43\ mA} = 116.3\ k\Omega$$

$$r_\pi = \frac{\beta}{g_m} = \frac{100}{17.2\ mA/V} = 5.8\ k\Omega$$

$$R_O = r_o[1 + g_m(Re \parallel r_\pi)]$$

$$R_O = (116.3\ k\Omega)$$
$$[1 + (17.2\ mA/V)(10\ k\Omega \parallel 5.8\ k\Omega)] = 7.46\ M\Omega$$

3. Design the basic BJT differential amplifier shown below to provide a differential input resistance of at least 10kΩ and a differential voltage gain of 100 V/V. The transistor β is specified to be at least 100. The available positive power supply is 5V.



$R_{id} \geq 10\ \text{k}\Omega \quad A_d = 100\ \text{V/V} \quad V_{CC} = 5\ \text{V}$

$$R_{id} = 10^4 = 2r\pi = 2 \times \frac{\beta}{g_m}$$

$$g_m = \frac{2\beta}{R_{id}} = 20\ \text{mA/V}$$

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

$$I_C = g_m V_T = 20\ \text{mA/V} \cdot 25\ \text{mV} = 0.5\ \text{mA}$$

$$I = 2I_C = 1\ \text{mA}$$

Eqn 8.93 $A_d = g_m R_C$

$$R_C = \frac{A_d}{g_m} = \frac{100}{20\ \text{mA/V}} = 5\ \text{k}\Omega$$

4. A BJT differential amplifier is biased from a 1mA constant-current source and includes a 200Ω resistor in each emitter. The collectors are connect to V_{CC} via 12kΩ resistors. A differential input signal of 0.1V is applied between the two bases.

(a) Find the signal current in the emitters (i_o) and the signal voltage v_{be} for each BJT.

(b) What is the total emitter current in each BJT?

(c) What is the signal voltage at each collector? Assume α=1.

(d) What is the voltage gain realized when the output is taken between the two collectors?

$I = 1\text{mA} \quad R_E = 200\text{ V} \quad R_C = 12\text{ kV}$

$V_{id} = 100\text{ mV}$

$$r_e = \frac{V_T}{I_E} = \frac{25\text{ mV}}{1\text{ mA}/2} = 50\ \Omega$$

$$\text{(a) } i_e = \frac{V_{id}}{2(r_e + R_E)} = \frac{100\text{ mV}}{2(250\ \Omega)} = 0.2\text{ mA}$$

$$V_{be} = \frac{r_e}{r_e + R_E}\left(\frac{V_{id}}{2}\right) = 10\text{ mV}$$

(b)

$$i_{E1} = \frac{I}{2} + i_e = 0.5\text{ mA} + 0.2\text{ mA} = 0.7\text{ mA}$$

$$i_{E2} = \frac{I}{2} - i_e = 0.5\text{ mA} - 0.2\text{ mA} = 0.3\text{ mA}$$

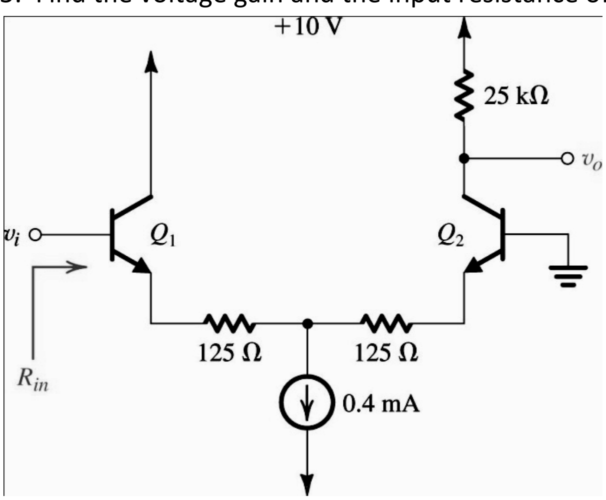
(c)

$$V_{C1} = -i_C R_C \approx -i_e \cdot R_C = -0.2\text{ mA} \cdot 12\text{ k}\Omega = -2.4\text{ V}$$

$$V_{C2} = +i_C R_C \approx i_e \cdot R_C = 0.2\text{ mA} \cdot 12\text{ k}\Omega = +2.4\text{ V}$$

$$\text{(d) } A_d = V_{od}/V_{id} = \frac{4.8\text{ V}}{100\text{ mV}} = 48\text{ V/V}$$

5. Find the voltage gain and the input resistance of the amplifier shown below assuming β=100.



$$\frac{v_o}{v_i} = \frac{\alpha R_{C2}}{(2r_e + 2R_e)}$$

$$r_e = \frac{V_T}{I_E} = \frac{V_T}{I/2} = \frac{25\text{ mV}}{0.4\text{ mA}/2} = 125\ \Omega$$

Assuming $\alpha \simeq 1$,

$$\frac{v_o}{v_i} \simeq \frac{25\text{ k}}{(2)(125) + 2(125)} = 50\text{ V/VS}$$

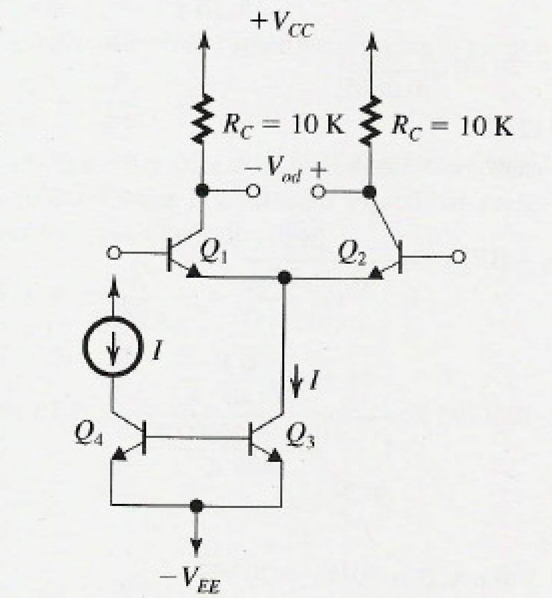
$$R_i = (\beta + 1)(2r_e + 2R_e) = (101)[2(125) + 2(125)] = 50.5\text{ k}\Omega$$

6. A bipolar differential amplifier with I=0.5mA utilizes transistors for which V_A=10V and β=100 and R_C=10kΩ.

(a) the differential gain

(b) the common mode gain and the CMRR if the bias current I is generated using a simple current mirror.

(c) the common mode gain and the CMRR if the bias current I is generated using a Wilson mirror.



Equivalent

$$R_{EE} = r_{o3} = \frac{V_A}{I} = \frac{10\text{ V}}{0.5\text{ mA}} = 20\text{ k}\Omega$$

$$r_{e2} = r_{e1} = r_e = \frac{V_T}{I/2} = \frac{25\text{ mV}}{0.5\text{ mA}/2} = 100\ \Omega$$

$$\text{Since } \alpha = \frac{\beta}{\beta+1} = \frac{100}{101} = 1,$$

$$A_d \simeq \frac{R_C}{r_e} = \frac{10\text{ k}}{0.1\text{ k}} = 100\text{ V/V}$$

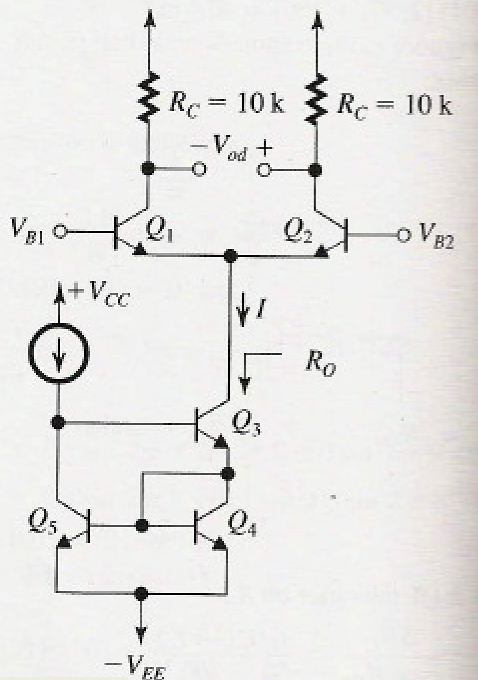
(b) $$A_{cm} \equiv \frac{\alpha \Delta R_C}{2R_{EE} + r_e} = \frac{(0.02)(10\text{ k})}{2(20\text{ k}) + 0.1\text{ k}}$$

$= 0.00499$ V/V

$$\text{CMRR(dB)} = 20\log_{10}\left|\frac{A_d}{A_{cm}}\right| = 20\log_{10}\left|\frac{100}{0.00499}\right|$$

$= 86$ dB

(c)



$$R_o \simeq \frac{1}{2}\beta_3 r_{o3}$$

$$R_o \simeq \frac{1}{2}(100)(20\text{ k}) = 1\text{ M}\Omega$$

$$A_{cm} \simeq \frac{\Delta R_C}{2R_o + r_o} \simeq$$

$$\frac{(0.02)(10\text{ k})}{2(1\text{ m}) + 0.1\text{ k}} = 0.0001\text{ V/V}$$

$$\text{CMRR(dB)} = 20\log_{10}\left|\frac{A_d}{A_{cm}}\right| = 20\log_{10}\left|\frac{100}{0.000}\right|$$

$= 120$ dB

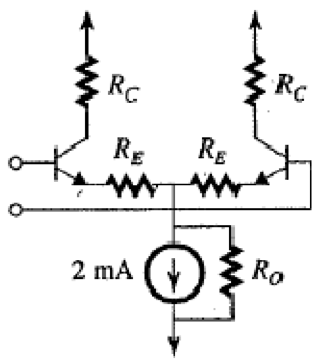
7. Design a BJT differential amplifier that provides two single-ended outputs (at the collectors). The amplifier is to have a differential gain (to each of the two outputs) of at least 100 V/V, a differential input resistance ≥10kΩ and a common mode gain (to each of the two outputs) no greater than 0.1 V/V. Use a 2mA current source for biasing. Give the complete circuit with component values and suitable power supplies that allow for ±2V swing at each collector. Specify the minimum value that the output resistance of the bias current source must have. The BJTs available have β≥100. What is the value of the input common mode resistance when the bias source has the lowest acceptable resistance?

At $I_C = 1$ mA, $r_e = 25\ \Omega$

$R_{id} = (\beta + 1)\, 2r_e = 5.05\ \text{k}\Omega < 10\ \text{K}$

$\Rightarrow$ need emitter resistors

In this case:



$$R_{id} = (\beta + 1)(2r_e + 2R_E) = 10\ \text{k}\Omega$$

$$A_d = 100 = \frac{R_C}{2(R_E + r_e)}$$

$$\Rightarrow R_C = 10\ \text{K}$$

$$A_{cm} = 0.1 \geq \frac{R_C}{2R_o + R_E + r_e}$$

$$\Rightarrow R_o \geq 50\ \text{k}\Omega$$

For ± 2 swing $V_{C1} = V_{C2}$

$$= V_{CC} - \frac{I}{2}R_C = 2$$

$$\Rightarrow V_{CC} = 2 + 10^{-3} \times 10^4 = 12\ \text{V}$$

Choose $V_{CC} = \pm 15$ V although 12 V is ok.

$$2R_{icm} = (\beta + 1)(2R_o + R_E + r_e)$$

$$\Rightarrow R_{icm} = 5\ \text{M}\Omega$$