ELE222E INTRODUCTION TO ELECTRONICS (21271)
Midterm Exam #2 ✎ 14 April 2004 ◷ 10.00-12.00
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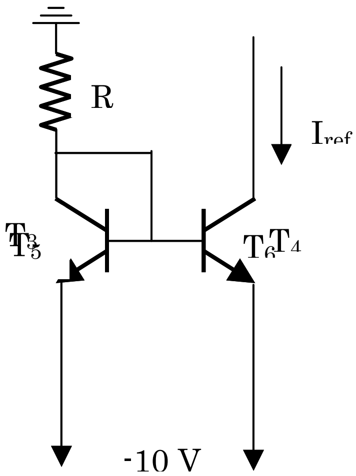
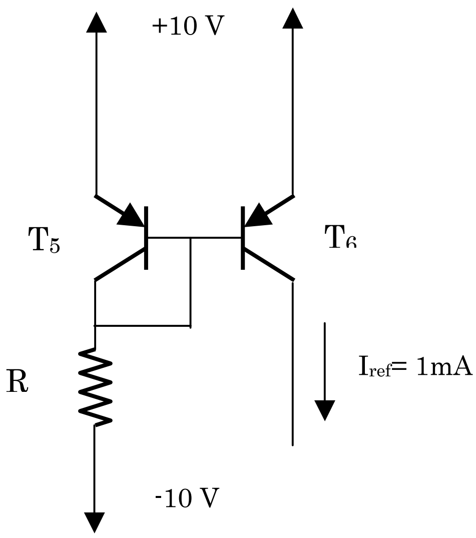
SOLUTIONS



1. Design a current mirror based constant current source for 1 mA DC current using pnp transistors. **HINT:** On the left is a current mirror designed with npn transistors. (30 points)

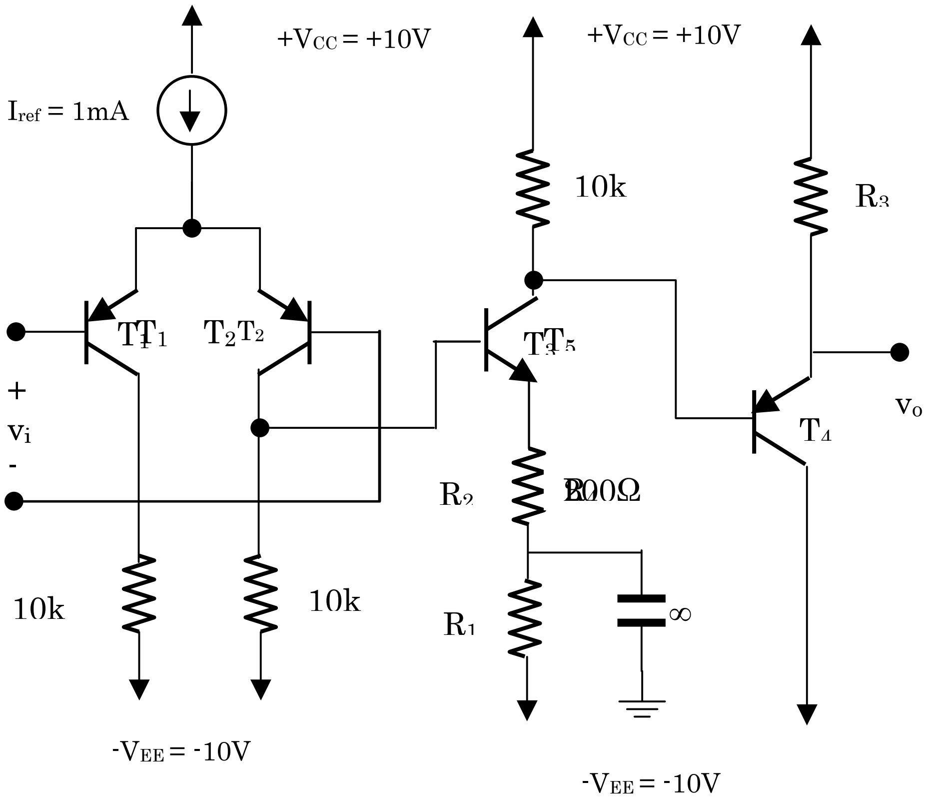


The current mirror shown on the left is not suitable for use with the 3-stage amplifier of (2) because of the direction I_{ref} flows. However, with a simple modification like shown on the right we can use that current mirror to bias the differential first stage in (2).

Neglecting base currents we can find the resistor value as follows

$$R = \frac{+10V - (-10V) - 0{,}6V}{1mA} = 19k\,.$$

2. Using the current mirror designed in (1) find R_1, R_3, I_{C3} and I_{C4} in the 3-stage amplifier circuit given below for V_o = 0V and r_o = 50Ω. **Note,** $h_{FE} = h_{fe} = 250$, V_T = 25 mV, $|V_{BE}|$ = 0,6 V, $h_{oe} = h_{re} = 0$. (30 points)



Since the last stage on the right is an emitter follower, the 50 Ω output resistance will be determined by the AC output resistance

$$r_o = R_{e4} \parallel R_3 \cong R_{e4}$$

where

$$R_{e4} = r_{e4} + \frac{r_{o3}}{h_{fe}} = \frac{V_T}{I_{C4}} + \frac{10k}{250}$$

Thus

$$I_{C4} = \frac{25mV}{50\Omega - \frac{10k}{250}} = \underline{\underline{2{,}5mA}}$$

$$\Rightarrow I_{E4} = 2{,}51mA$$

$$R_3 = \frac{+V_{CC} - V_o}{I_{E4}} = \frac{10V - 0V}{2{,}51mA} = \underline{\underline{3{,}98k\Omega}}$$

Let's check the output resistance:

$$r_o = R_{e4} \parallel R_3 = 50\Omega \parallel 3k98 = 49{,}4\Omega$$

Using R_4, T_4, R_3 loop

$$(I_{C3} - I_{B4})R_4 + V_{BE4} - I_{E4}R_3 = 0$$

$$\Rightarrow I_{C3} = \frac{I_{E4}R_3 + I_{B4}R_4 - V_{BE4}}{R_4} = \frac{2{,}51mA * 3k98 + 10\mu A * 10k + 0{,}6V}{10k} = \underline{\underline{1{,}07mA}}$$

Using R_{C2}, T_3, R_2 loop

$$-(0{,}5mA - I_{B3})R_{C2} + V_{BE3} + I_{E3}(R_1 + R_2) = 0$$

$$\Rightarrow R_1 = \frac{(0{,}5mA - I_{B3})R_{C2} - V_{BE3}}{I_{E3}} - R_2 = \frac{(0{,}5mA - 4{,}28\mu A)10k - 0{,}6V}{1{,}073mA} - 200\Omega = \underline{\underline{3k86}}$$

3. Using the biasing current values you found in (2) do the AC analysis of the circuit below and find the total voltage gain, CMRR, and the differential input resistance. (40 points)

   If you could not find the collector currents correctly in (2), use the following values and do the AC analysis:
   $R_1 = R_3 = 4k$;
   $I_{C3} = I_{C4} = 1$ mA

Let's first find the transistor AC resistances:

$$r_{e1} = r_{e2} = \frac{V_T}{0{,}5mA} = 50\Omega; r_{e3} = \frac{V_T}{1{,}07mA} = 23{,}3\Omega; r_{e4} = \frac{V_T}{2{,}5mA} = 10\Omega$$

$$A_v = \frac{v_o}{v_i} = \frac{v_o}{v_{b4}} \cdot \frac{v_{b4}}{v_{b3}} \cdot \frac{v_{b3}}{v_i} = + \frac{R_{e4}}{r_{e4} + R_{e4}} \cdot \left[- \frac{R_{C3} \parallel r_{i4}}{r_{e3} + R_{e3}} \right] \cdot \left[- \frac{R_{C2} \parallel r_{i3}}{2r_{e1}} \right]$$

$$r_{i3} = h_{fe}(r_{e3} + R_{e3}) = 250(23{,}3 + 200) = \underline{\underline{55k8}}; r_{i4} = h_{fe}(r_{e4} + R_{e4}) = 250(10 + 3k98) = \underline{\underline{997k5}}$$

$$\Rightarrow A_v = \frac{3k98}{10 + 3k98} \cdot \left[- \frac{10k \parallel 997k5}{23{,}3 + 200} \right] \cdot \left[- \frac{10k \parallel 55k8}{100} \right] \cong \underline{\underline{3748}}$$

$CMRR = 20 \log \left| \frac{2R_e + r_{e1}}{r_{e1}} \right|$, since the current source is ideal R_e is infinite, thus $CMRR \to \infty$

and finally $r_{id} = 2h_{fe}r_{e1} = 2 * 250 * 50 = \underline{\underline{25k}}$