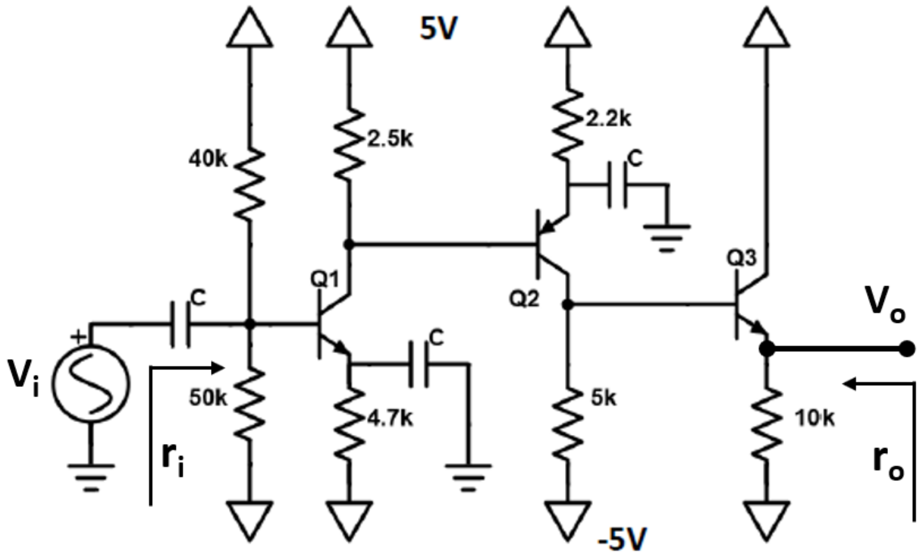
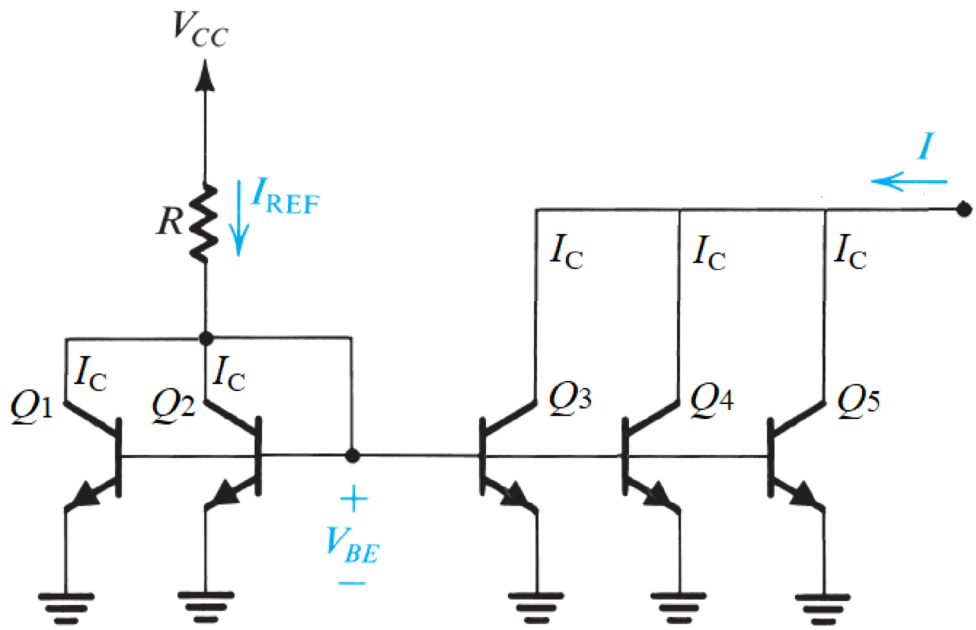
EHB222E INTRODUCTION TO ELECTRONICS (10745, 10747, 10748, 11201)
MT2 Exam 21 December 2021 🕓 12:30-14:30
Bora DÖKEN, Bülent YAĞCI, İbrahim ÇATALKAYA, İnci ÇİLESİZ

1. For the circuit shown find the small-signal voltage gain (V_o/V_i), input impedance (r_i) and output impedance expressions (r_0) in terms of g_m, r_π, and resistance (like g_{m1}, g_{m2}, $r_{\pi1}$, $r_{\pi2}$, and etc). It is assumed that DC analyses has been completed ($V_A = \infty$ for all transistors). (30 points)

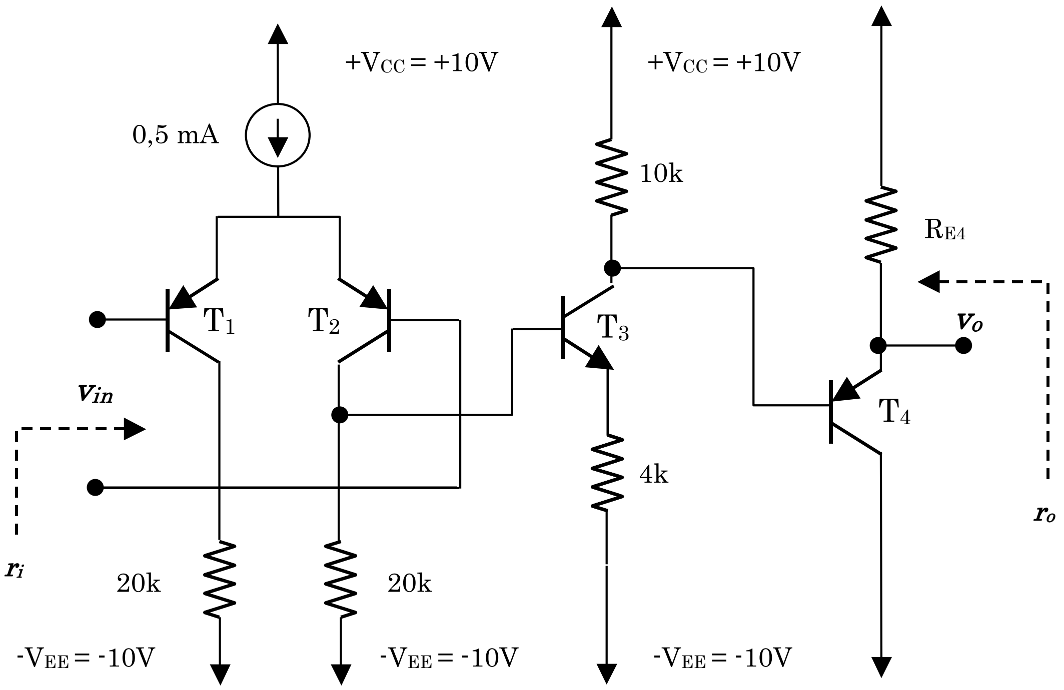


2. All transistors in the given figure are identical. Find the I_{REF}, I_C and I currents in terms of V_{CC}, V_{BE}, β and R. (30 points)



GOOD LUCK EVERYONE

3. Anaylze the circuit below for $|V_{BE}|$ = 0,6 V, β = h_{fe} = h_{FE} = 100, V_T = 25 mV: (40 points)
   - Design the current source of 0,5 mA. Use meaningful resistor values. (10 points)
   - What should be the value of R_{E4} so that clipping at the output of the circuit is minimal and symmetrical? If you cannot find the value of I_{C3} current, assume 1 mA. (15 points)
   - Find the input and output resistances (***r_i*** and ***r_o***). (10 points)
   - If this circuit is driven with a small signal source with an internal resistance of 1k and a load resistor of 1k is connected to the output, find the gain. (5 points)



Solution 1:

$r_\pi = \frac{\beta}{g_m}$ $\qquad r_e = \frac{V_T}{I_C}$ $\qquad r_e = \frac{1}{g_m}$ $\qquad h_{fe} = \beta$

3rd stage : Common collector (or emitter follower):

$A_v = \frac{R_e}{R_e+r_e}$ $\qquad r_i = h_{fe}(R_e + r_e)$ $\qquad r_o = R_e \;//\; r_e$

$A_{v3} = \frac{R_{e3}}{R_{e3}+r_{e3}} = \frac{10k}{10k+r_{e3}}$ $\qquad r_{i3} = h_{fe}(10k + r_{e3})$

2nd stage : Common emitter:

$A_v = -g_m(R_C \;//\; R_L) = -\frac{(R_C\,//R_L)}{r_e}$ $\qquad r_i = h_{fe}(R_e + r_e)$

$A_{v2} = -g_{m2}(5k\,//\,r_{i3})$ $\qquad r_{i2} = h_{fe}r_{e2}$

1st stage : Common emitter:

$A_{v1} = -g_{m1}(2.5k\,//\,r_{i2})$ $\qquad r_{i1} = h_{fe}r_{e1} = r_{\pi 1}$

Total gain:

$A_v = A_{v1} \cdot A_{v2} \cdot A_{v3} = g_{m1}(2.5k \,//\, r_{i2}) \cdot g_{m2}(5k \,//\, r_{i3}) \cdot \frac{10k}{10k + r_{e3}}$

Input impedance:

$r_i = r_{i1} = r_{\pi 1}$

Output impedance:

$r_o = r_{o3} = R_{e3} \,//\, r_{e3} = 10k \,//\, r_{e3}$

Solution 2:

$$V_{CC} = I_{REF} \cdot R + V_{BE} \Rightarrow I_{REF} = \frac{V_{CC} - V_{BE}}{R} \quad // \quad 10p$$

$$I_{REF} - 2I_C - 5I_B = 0$$

$$I_C = \frac{\beta I_{REF}}{(2\beta + 5)} = \frac{\beta (V_{CC} - V_{BE})}{(2\beta + 5) R} \quad // \quad 10p$$

$$I = 3I_C = \frac{3\beta (V_{CC} - V_{BE})}{(2\beta + 5) R} \quad // \quad 10p$$

Solution 3:

a. Assuming you all know about current mirrors, we omit that part; do NOT forget to make sure that both transistors operate in active region

b. for ***V_o* = 0 V** $V_{B4} = V_{BE4} = V_{C3} = V_{CC} - R_{C3}(I_{C3} - I_{B4}) = 10V - 10k \cdot (I_{C3} - I_{B4})$

<u>1st stage:</u>

$I_{C1} = I_{C2} = \underline{\underline{0{,}25mA}}$.

<u>2nd stage:</u>

20k – T3 – 4k loop $-20k(I_{C2}-I_{B3})+V_{BE3}+4k\cdot I_{E3}=0$ $I_{C3}=h_{FE}\dfrac{20k\cdot I_{C2}-V_{BE3}}{(h_{FE}+1)4k+20k}$ and

thus $I_{C3}=\underline{\underline{1{,}04mA}}$.

<u>3[rd] stage:</u>

$V_{B4}=V_{BE4}=-0{,}6V=10V-10k\cdot(I_{C3}-I_{B4})$ and here we made a mistake and found $I_{C4}=\underline{\underline{2mA}}$. In fact $I_{C4}=\underline{\underline{-1{,}05mA}}$.

with that mistake we found

$V_o=V_{CC}-R_{E4}I_{E4}=10V-R_{E4}(h_{FE}+1)I_{B4}=0V$ thus $R_{E4}=\dfrac{10V}{(h_{FE}+1)I_{B4}}=\underline{\underline{4k95}}$

$$r_{e1}=r_{e2}=\frac{V_T}{0{,}25mA}=\underline{\underline{100\Omega}};r_{e3}=\frac{V_T}{1{,}04mA}=\underline{\underline{24\Omega}};r_{e4}=\frac{V_T}{2mA}=\underline{\underline{12{,}5\Omega}}$$

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

$$r_{i3}=h_{fe}(r_{e3}+R_{e3})=100(24+4k)=\underline{\underline{402k4}};r_{i4}=h_{fe}(r_{e4}+R_{e4})=100(12{,}5+4k95)=\underline{\underline{496k25}}$$

$$K_v=\frac{v_o}{v_{in}}=\frac{4k95}{12{,}5+4k95}\cdot\left[-\frac{10k\parallel 496k25}{24+4k}\right]\cdot\left[-\frac{20k\parallel 402k4}{2\cdot 100}\right]=0{,}997\cdot(-2{,}436)(-95{,}265)\cong\underline{\underline{231{,}5}}$$

$r_i=2h_{FE}r_{e1}=\underline{\underline{20k}}$ and

$$r_o=R_{E4}\parallel(r_{e4}+\frac{R_{g4}}{h_{fe}})=R_{E4}\parallel(r_{e4}+\frac{R_{C3}}{h_{fe}})=4k95\parallel(12{,}5+\frac{10k}{100})=\underline{\underline{112{,}5\Omega}}$$

$$\frac{v_o}{v_{b4}}=\frac{R_{e4}\parallel 1k}{r_{e4}+R_{e4}\parallel 1k}$$

$$K_v^*=\frac{v_o}{v_{in}}=\frac{v_o}{v_{b4}}\cdot\frac{v_{b4}}{v_{b3}}\cdot\frac{v_{b3}}{v_{in}}=0{,}985\cdot(-2{,}436)\cdot(-95{,}265)=\underline{\underline{228{,}63}}.$$

$$K_{total}=\frac{v_o}{v_g}=\frac{r_i}{r_i+R_s}\cdot\frac{R_{e4}\parallel 1k}{r_{e4}+R_{e4}\parallel 1k}\cdot\left[-\frac{R_{C3}\parallel r_{i4}}{r_{e3}+R_{e3}}\right]\cdot\left[-\frac{R_{C2}\parallel r_{i3}}{2r_{e1}}\right]=\frac{20k}{20k+1k}\cdot 228{,}63=\underline{\underline{217{,}74}}$$