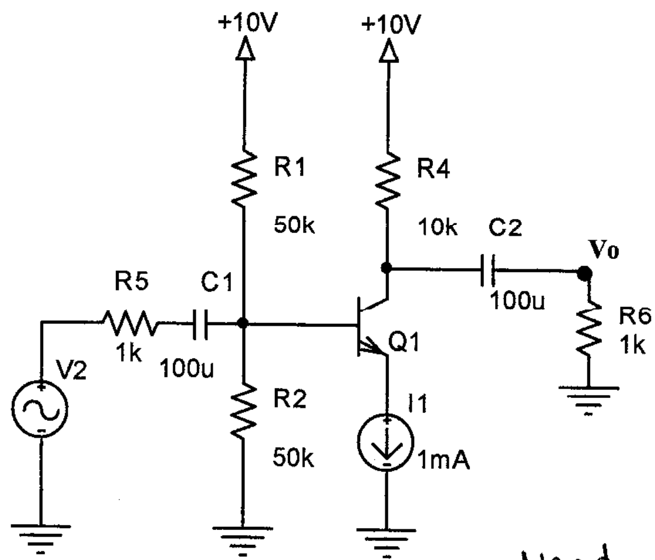
Solution

Problem 1 (10 points)

V2 = 0.1m sin(ωt) and β can vary from 20 to 200. The circuit shown below is suppose to amplify but does not. You expect the output at Vo to amplify V2. When you are testing the circuit, you find that it does not amplify. Explain why it does not and what exact resistor can be changed to allow it to amplify. I1 is not an ideal current source and can have a voltage drop across it.



$V_B = 5V$

$V_C \approx 0V$

$V_C < V_B$

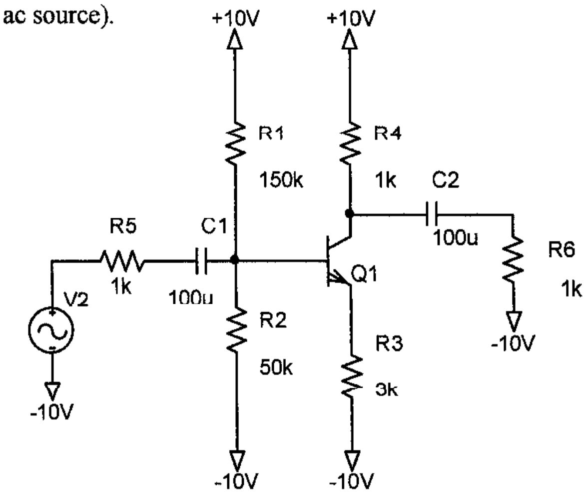
Not in active region. Therefore, it will not amplify.

Need to decrease R_4 so that $V_C > V_B > V_E$

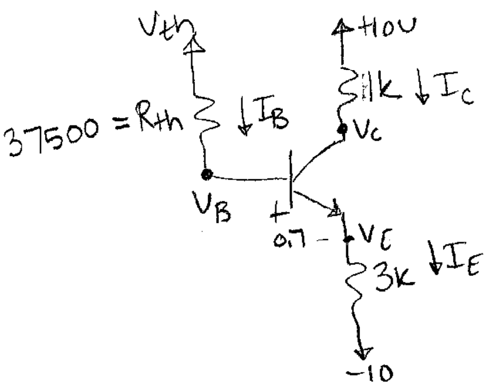
Problem 2 (35 points)

Use $|V_{BE}|=0.7$, $\beta=100$, $V_T=25mV$ (V2 is an ac source).

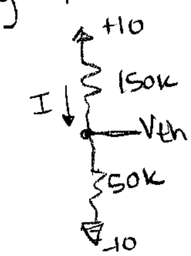
- Find the DC values for the following
  a. I_{E1} **(15 points)**
  b. I_{C1} **(3 points)**
  c. V_{E1} **(6 points)**
  d. V_{C1} **(6 points)**
  e. V_{B1} **(5 points)**



Thevenin of R_1 and R_2:



$V_{th} \Rightarrow$ (Thevenin is calculated by finding open-circuit voltage)



$I = \frac{20}{150k+50k} = \frac{20}{200k}$

$I = 100\mu$

$-V_{th} + I(50k) - 10 = 0$

$V_{th} = 100\mu(50k) - 10$

$V_{th} = -5V$

$R_{th} \Rightarrow$ (short sources and find resistive network) $\Rightarrow 150k \| 50k$

$-V_{th} + I_B(37500) + 0.7 + I_E(3k) - 10 = 0$

$I_B = \frac{I_E}{\beta+1}$

$I_E = 1.3mA$

$I_C = \alpha I_E = 1.26m$

$I_B = 12.7\mu$

$V_E = I_E(3k) - 10 = -6.1$

$V_B = V_{th} - I_B(R_{th}) = -5.4$

$V_C = 10 - I_C(1k) = 8.74$

$V_C > V_B > V_E$

Problem 3 (55 points)

Use $|V_{BE}|=0.7$, $\beta=20$, $V_T=25mV$ (Vs is an ac source), ignore r_o.

This small-signal model circuit is drawn below. The original circuit is also shown below. It was found through a DC analysis that $I_{C1}=50\mu$ and $I_{C2}=25\mu$.

(a) Find the ac parameters

a. $r_{\pi1}$ **(3 points)** $= \frac{\beta}{g_{m1}} = \frac{20}{2m} = \boxed{10K}$

b. $r_{\pi2}$ **(3 points)** $= \beta/g_{m2} = 20/1m = \boxed{20K}$

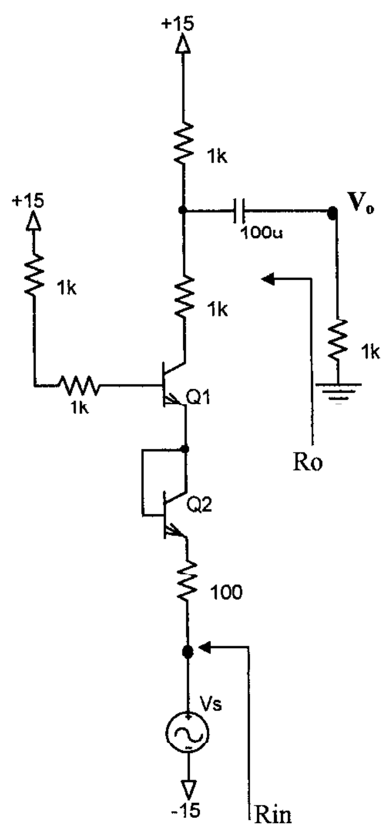
c. gm_1 **(3 points)** $= I_{C1}/V_T = 50\mu/25m = \boxed{2m}$

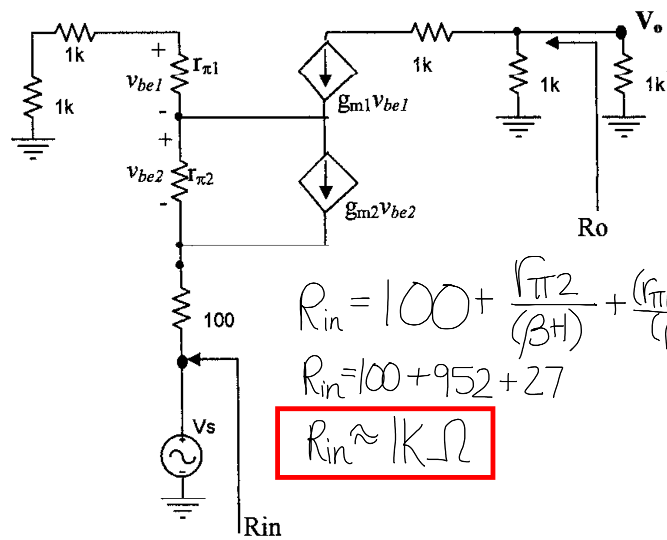
d. gm_2 **(3 points)** $= I_{C2}/V_T = 25\mu/25m = \boxed{1m}$

(b) Find that input resistance, R_{in}. (Ignore the AC input source Vs, include the 100 ohm) **(12 points)**

(c) Find the output resistance, R_o. (Ignore the load resistor of 1k to the right of arrow) **(6 points)**

(d) Find the overall gain, Vo/Vs. **(25 points)**



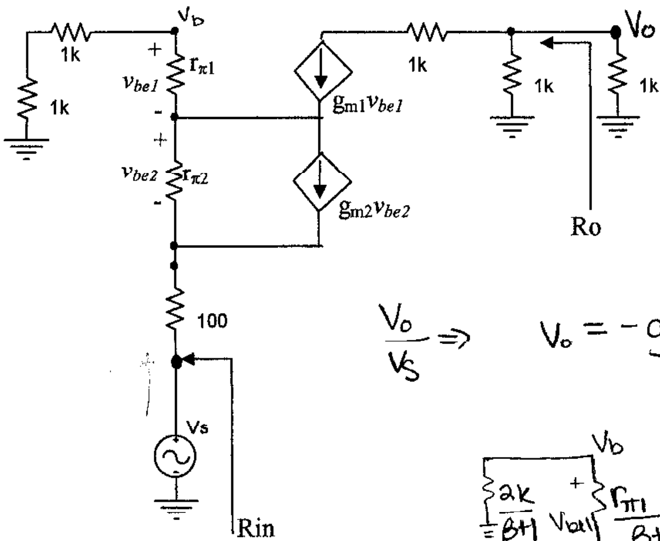


$$R_{in} = 100 + \frac{r_{\pi2}}{(\beta+1)} + \frac{(r_{\pi1}+2K)}{(\beta+1)^2}$$

$$R_{in} = 100 + 952 + 27$$

$$\boxed{R_{in} \approx 1K\Omega}$$

$\boxed{R_o = 1K}$ ⇒ $g_{m1}v_{be1}$ becomes open so that the 1K tied to it is floating.



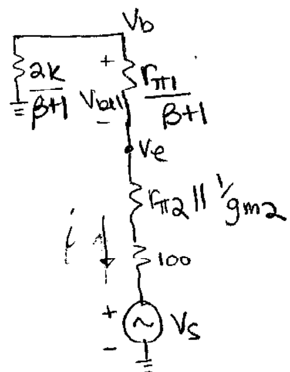
$r_{\pi1} = 10K$

$r_{\pi2} = 20K$

$g_{m1} = 2m$

$g_{m2} = 1m$

$\frac{V_o}{V_s} \Rightarrow \quad V_o = -g_{m1} V_{be1} (1k \| 1k)$



$i = \frac{-V_s}{R_{in}} = 616\mu \cdot V_s$

$V_{be} = +i \frac{r_{\pi1}}{\beta+1} = -0.29 V_s$

$$V_{be} = \frac{-r_\pi}{\beta+1} \cdot \frac{V_s}{R_{in}}$$

$$V_o = -g_{m1}\left(-\frac{r_{\pi1}}{\beta+1}\right)\frac{V_s}{R_{in}}(500)$$

$$\frac{V_o}{V_s} = -2m\left(-\frac{10K}{21}\right)\frac{500}{1623} = +0.3 \ V/V$$

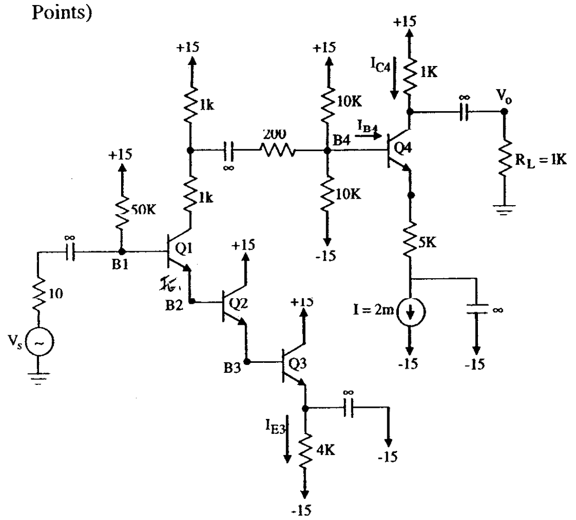
Using voltage divider:

$$V_e = \frac{\left(\frac{r_{\pi1}}{\beta+1} + \frac{2k}{\beta+1}\right)V_s}{\frac{(r_{\pi1}+2k)}{\beta+1} + r_{\pi2} \| 1/g_{m2} + 100} = 0.35\,V_s$$

$$V_b = \frac{\frac{2k}{\beta+1} \cdot V_e}{\frac{r_{\pi1}}{\beta+1} + \frac{2k}{\beta+1}} = .166\,V_e = 0.058\,V_s$$

$V_{be} = V_b - V_e = -.29 V_s$

Points)



a) a. I_{E_3} ✓
b. I_{C4} ✓
c. I_{B4} ✓
d. V_{C4} ✓
E. V_{B2} ✓

$$15 - I_{B_1}(50k) - 0.7 - 0.7 - 0.7 - I_E(4k) + 15 = 0$$

$$I_{B_1} = (1-\alpha)I_{E_1}$$

$$I_{E_1} = I_{B_2}$$

$$I_{E_1} = (1-\alpha)I_{E_2}$$

$$I_{E_2} = I_{B_3}$$

$$I_{E_2} = (1-\alpha)I_{E_3}$$

$$I_{B_1} = (1-\alpha)(1-\alpha)(1-\alpha)I_{E_3} =$$

$$\alpha = \beta/_{\beta+1} = 100/_{101}$$

$$(1 - 100/_{101})^3 I_{E_3} = I_{B_1}$$

$$15 - (1 - \tfrac{100}{101})^3 I_{E_3}(50k) - 2.1 - I_{E_3}(4k) + 15 = 0$$

$$I_{E_3}\left(-(1 - \tfrac{100}{101})^3(50k) - 4k\right) = -15 + 2.1 - 15$$

$$I_{E_3}(-4k) = -27.9$$

$$\boxed{I_{E_3} = 6.975 mA}$$

$$I_{C4} = \alpha I_{E_4}$$

$$I_{C4} = \left(\tfrac{100}{101}\right)2m$$

$$\boxed{I_{C4} = 1.98 mA}$$

$$I_{B4} = (1-\alpha)I_E$$

$$I_{B4} = \left(1 - \tfrac{100}{101}\right)(2m)$$

$$\boxed{I_{B4} = 19.8 \mu A}$$

$$V_{C4} = 15 - I_{C4}(1000)$$

$$= 15 - (1.98m)1000$$

$$\boxed{V_{C4} = 13.02 V}$$

$$V_{B2} = 15 - I_{B_1}(50k) - 0.7$$

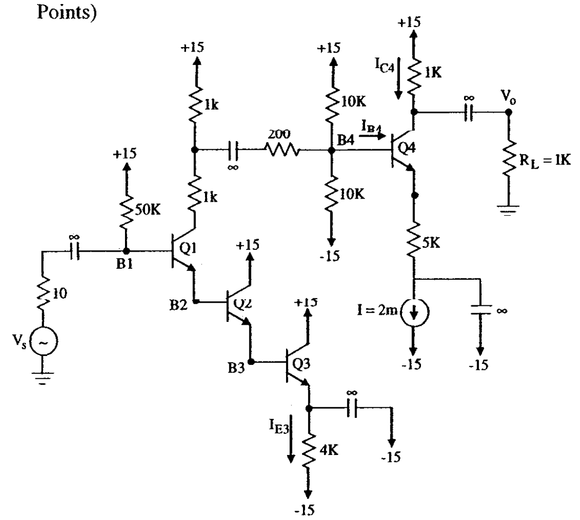
$$= 15 - (1-\alpha)(1-\alpha)(1-\alpha)I_{E_3}(50k) - 0.7$$

$$= 15 - (1-\alpha)^3(6.975m)50k - 0.7$$

$$\boxed{V_{B2} = 14.2997 V}$$

a.) a) $I_{E_3} = 6.975$ mA ✓
b) $I_{C4} = 1.98$ mA ✓
c) $I_{B4} = 19.8 \mu A$ ✓
d) $V_{C4} = 13.02 V$ ✓
e) $V_{B2} = 14.2997 V$ ✓

Points)



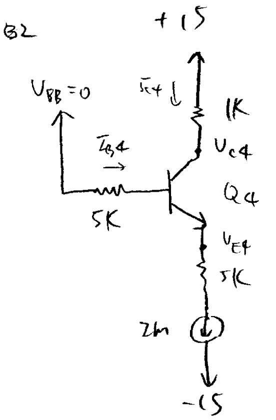
I_{E3}

I_{C4}

I_{B4}

V_{C4}

V_{B2}



a)

$$15 = 50K \frac{I_{E1}}{\beta+1} + 2.1 + 4K \cdot I_{E3} - 15$$

$I_{C1} = I_{B2}$, $I_{E2} = I_{B2}(\beta+1) = I_{B3}$, $I_{E3} = I_{B3}(\beta+1)$

$I_{B2}(\beta+1) = \frac{I_{E3}}{\beta+1}$ $\quad I_{B3} = \frac{I_{E3}}{\beta+1}$

$I_{E1} = I_{B2} = \frac{I_{E3}}{(\beta+1)^2}$ $\quad I_{E1} = 683n$

$$29.9 = 50K \cdot \frac{I_{E3}}{(101)^3} + 4K\, I_{E3}$$

$$= I_{E3}\left(\frac{50K}{(101)^3} + 4K\right)$$

$I_{E3} = $ **6.99 mA** ✓

$V_{E3} = -15 + 4K\, I_{E3}$
$= 12.88$

$V_{B3} = 12.88 + 0.7$
$= 13.58V$

$V_{B2} = 12.88 + 1.4$ ✓
$=$ **14.28 V**

$V_{E2} = 13.58V$

$V_{E1} = 14.28V$

$V_{B1} = 14.98V$

$I_{C1} = 0.99\, I_{E1}$
$= 676n$

$V_{C1} = 15 - I_{C1} \cdot 2K$
$= 14.99V$

$\therefore V_{C1} \geq V_{B1} > V_{E1}$ $\quad Q_1$ act.

$V_{C2} \geq V_{B2} > V_{E2}$ $\quad Q_2$ act

$V_{C3} \geq V_{B3} > V_{E2}$ $\quad Q_3$ act

$V_{BB} = \frac{30}{2} - 15$
$= 0$

$V_{E4} = -15 + 10$
$= -5V$

$I_{B4} = \frac{2m}{101}$
$=$ **19.8 μA** ✓

$V_{B4} = -4.3V$

$V_{B4} = 5K \cdot I_{B4}$
$= 99mV$

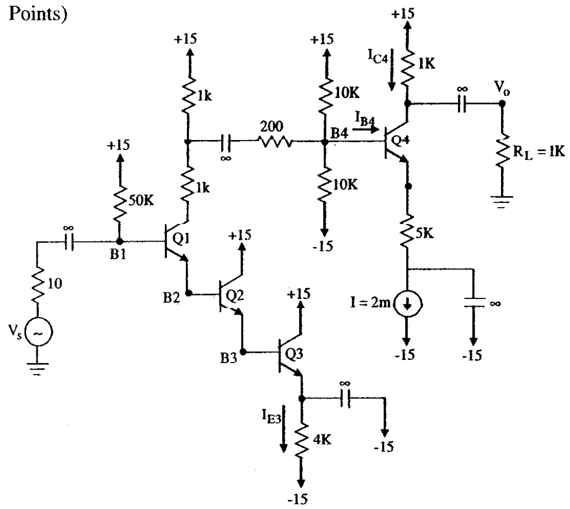
$I_{C4} = 2m - 19.8\mu$
$=$ **1.9802mA** ✓

$V_{C4} = 15 - I_{C4}\, 1K$
$=$ **13.0198V** ✓

$\therefore V_{C4} \geq V_{B4} > V_{E4}$
Q_4 act

$\therefore$ assume is act is correct.

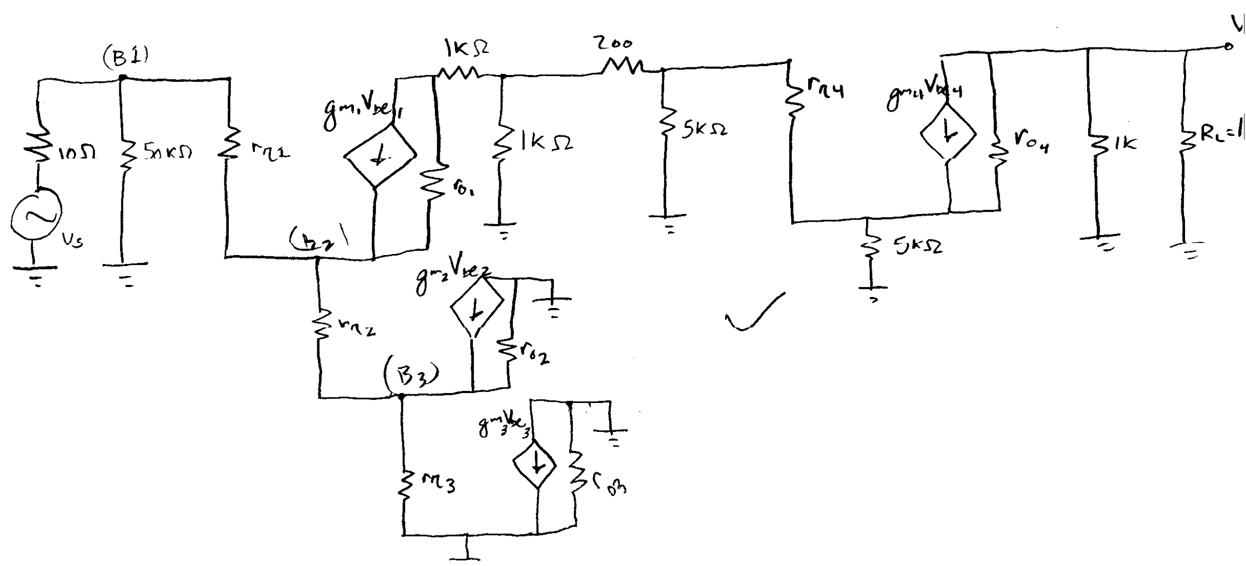
Points)



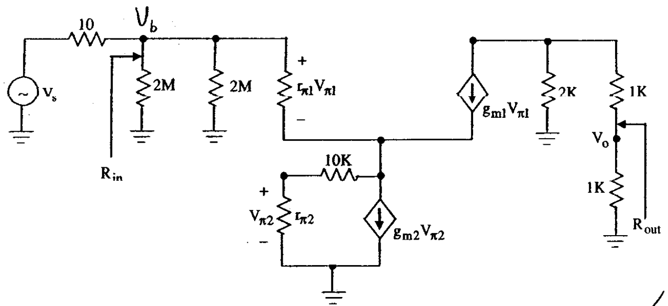
b.)

$r_\pi = \beta / g_m$

$g_m = I_C / V_T$



Points)



$I_{E1} = 2.525m$

$I_{E2} = 1.2625m$

$r_{\pi 1}$

$r_{\pi 2}$

g_{m1}

g_{m2}

a) $I_{B1} = \frac{I_{E1}}{\beta+1} = 25\mu$ $r_{\pi 1} = \frac{25m}{I_{B1}} = \boxed{1k\Omega}$ ✓ $g_{m1} = \frac{\beta}{r_{\pi 1}} = \boxed{100m\frac{A}{V}}$ ✓

$I_{B2} = \frac{I_{E2}}{\beta+1} = 12.5\mu$ $r_{\pi 2} = \frac{25m}{I_{B2}} = \boxed{2k\Omega}$ ✓ $g_{m2} = \frac{\beta}{r_{\pi 2}} = \boxed{50m\frac{A}{V}}$ ✓

b) $R_{in} = 2M \parallel 2M \parallel \left[r_{\pi 1} + 101\left(10k + r_{\pi 2}\right) \right]$

$= 1M \parallel 1.213M$

$= \boxed{548k\Omega}$ ✓

c) $R_{out} = 1K + 2K = \boxed{3K\Omega}$ ✓

d) $v_o = \frac{-g_{m1}v_{\pi 1}}{2} \cdot 1K$ ✓

$V_b = v_s \cdot \frac{R_{in}}{10 + R_{in}}$

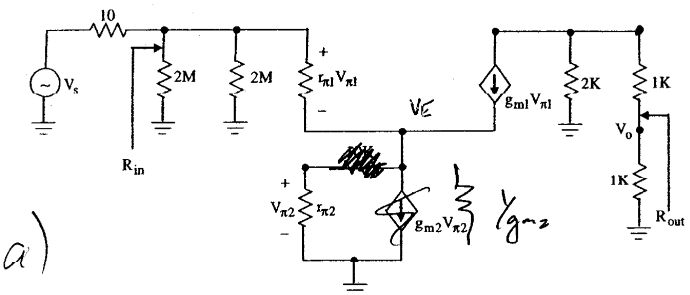
$\cong v_s$ ✓

$V_{\pi 1} = V_b \cdot \frac{r_{\pi 1}}{r_{\pi 1} + (10K + r_{\pi 2})101} = v_s \cdot 824.4\mu$

$\frac{v_o}{v_s} = \frac{-g_{m1}\, 824.4\mu \cdot 1K}{2}$

$= -\boxed{41.2m\frac{V}{V}}$ ✓

Points)



a) a) $r_{\pi 1}$
b) $r_{\pi 2}$
c) g_{m1}
d) g_{m2}

a)

a.) $r_{\pi 1} = V_T / I_{B1}$; $I_{E1} = 2.525m$

$I_{B1} = (1-\alpha)(2.525m)$

$(1 - \frac{100}{101})(2.525m) = 25\mu A$

$r_{\pi 1} = 1000\Omega$ ✓

b. $r_{\pi 2} = \frac{V_T}{I_{B2}}$; $I_{E2} = 1.2625m$

$I_{B2} = (1-\alpha)(1.2625m) = 12.5\mu A$

$r_{\pi 2} = 2000\Omega$ ✓

c.) $g_{m1} = I_C / V_T$

$I_{C1} = \alpha I_{E1} = (\frac{100}{101})(2.525m) = 2.5mA$

$g_{m1} = 100 mA/V$ ✓

d.) $g_{m2} = I_{C2} / V_T$

$I_{C2} = \alpha I_{E2} = 1.25m$

$g_{m2} = 50 mA/V$ ✓

$\frac{1k}{1k+1k}$

$V_o = -g_{m1} V_{be} (1k) \left(\frac{1}{2}\right)$

$V_b = V_s \left(\frac{1M}{1M + 10}\right) \approx V_s$

$V_E = V_b \left(\frac{(1/g_{m2} // r_{\pi 2})(\beta+1)}{(1/g_{m2} // r_{\pi 2})(\beta+1) + r_{\pi 1}} \right)$

$= \frac{1004.975}{1004.975 + 1000} =$

$V_E \approx \frac{1}{2} V_b$

$V_o = -(100m)(V_s - \frac{1}{2}V_s) 1k$

$V_o = -100m\, V_s (1 - \frac{1}{2}) 1k$

$V_o / V_s = -.1(\frac{1}{2}) 1k$

$V_o / V_s = -50\, V/V$ ✓

(-2) $\Leftarrow \frac{V_o}{V_s} = -25 V/V$

$I = g_{m2} V_{\pi 2}$ $V = V_{\pi 2}$

b.)

R_{eq} $\frac{V_{\pi 2}}{g_{m2} V_{\pi 2}} = \frac{1}{g_{m2}}$

$R_{in} = 1M // (r_{\pi 1} + (\beta+1)(r_{\pi 2} // 1/g_{m2})) = 1M // (1000 + (101)(2000 // 1/50m))$

$= 2,991\Omega$

$R_{in} = 2,991\Omega$ ✓

c.) $R_{OUT} = 2k52$ ✗

(-3)

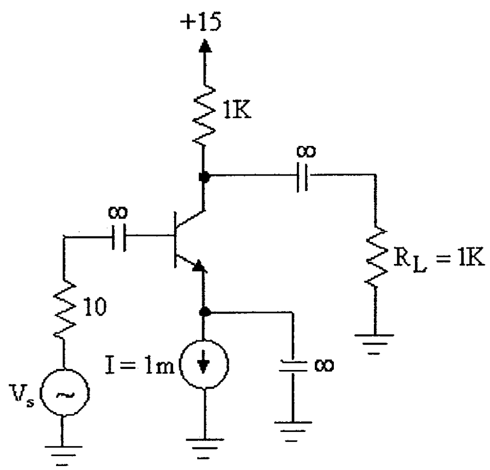
6

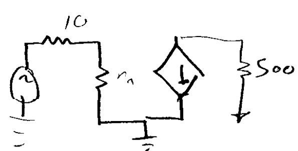
Problem 3 – (5 points)

Use $|V_{BE}|$=0.7, β=100, V_T=25mV (Vs is an ac source), ignore r_o.

Will this circuit work as an amplifier? Why or why not?

✓





NO, IT WILL NOT

THE BASE IS DISCONNECTED WHEN ANALYZING THE DC PARAMETERS. THUS WE CAN'T BIAS OUR CIRCUIT BECAUSE OF THIS FLOATING NODE.