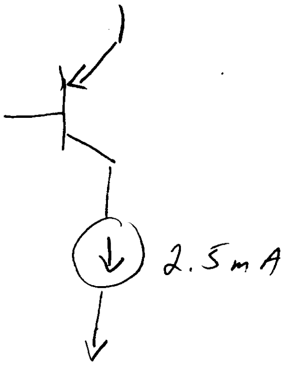
EE 321

Fall 2002

Homework #9

Solutions

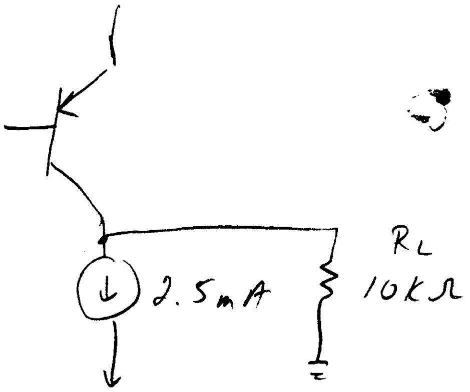
4.44



$$\alpha = \frac{\beta}{\beta+1} = \frac{50}{51} = 0.98$$

$$g_m = \frac{I_C}{V_T} = \frac{2.5mA}{25mV} = 100\ mA/V$$

$$r_e = \frac{\alpha}{g_m} = \frac{0.98}{0.1\ A/V} = 9.8\Omega$$



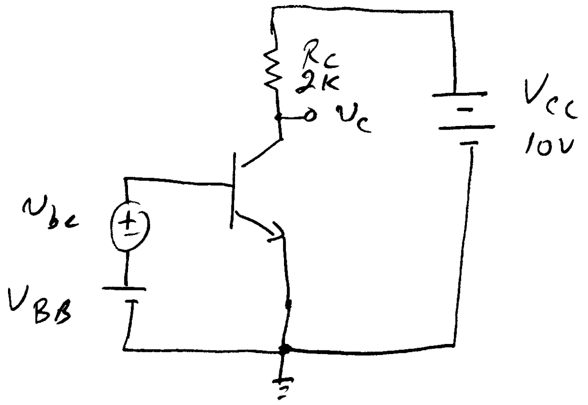
$$i_c = g_m v_{be}$$

$$v_c = i_c R_L = g_m v_{be} R_L$$

$$= (100\ mA/V)(10\ mV)(10k\ \Omega)$$

$$= 10\ V$$

4.48



$$I_C = \frac{V_{CC} - V_C}{R_C} = \frac{10V - 2V}{2K} = 4mA$$

$$i_c = I_C + \frac{I_C}{V_T} v_{be}$$

$$= 4mA + \frac{4mA}{25mV}(0.004 \sin \omega t)$$

$$= 4mA + 0.64 \sin(\omega t)\ mA$$

$$v_C = V_{CC} - i_C R_C = 10V - (4mA + 0.64 \sin(\omega t)\ mA)\ 2k\Omega$$

$$= 10V - 8V - 1.28 \sin(\omega t)\ V$$

$$= 2V - 1.28 \sin(\omega t)\ V$$

$$i_B = i_C/\beta = 40\mu A + 6.4 \sin(\omega t)\ \mu A$$

$$A_v = \frac{v_c}{v_i} = \frac{-1.28 \sin \omega t\ V}{0.004 \sin \omega t\ V} = -320\ V/V$$

4.55

$I_E = 0.80\ mA$

$\alpha = 0.99$

$$g_m = \frac{I_C}{V_T} = \frac{\alpha I_E}{V_T} = \frac{(0.99)(0.80\,mA)}{25\,mV} = 32\,mA/V$$

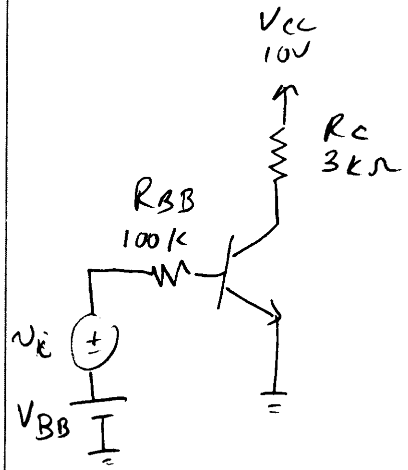
$$r_e = \frac{\alpha}{g_m} = \frac{0.99}{32\,mA/V} = 31\,\Omega$$

$$r_\pi = (\beta+1)\, r_e$$

$$\alpha = \frac{\beta}{\beta+1} \Rightarrow \beta = \frac{\alpha}{1-\alpha} = \frac{0.99}{1-0.99} = 99$$

$$r_\pi = (\beta+1)\, r_e = 100\, r_e = 3.1\,k\Omega$$

4.58



$$I_B = \frac{V_{BB} - V_{BE}}{R_B} = 0.023\,mA$$

$$V_C = V_{CC} - I_C R_C$$
$$= V_{CC} - \beta I_B R_C$$

Saturates when $V_C = 0.7V \Rightarrow V_{CC} - \beta I_B R_C = 0.7V$

$$\Rightarrow \beta = \frac{V_{CC} - 0.7V}{I_B R_C} = 135$$

For $\beta = 25$:

$$I_C = \beta I_B = 0.575\,mA$$

$$g_m = \frac{I_C}{V_T} = 23\,mA/V$$

$$r_e = \frac{\alpha}{g_m} = \frac{\beta/(\beta+1)}{g_m} = 41.8\,\Omega$$

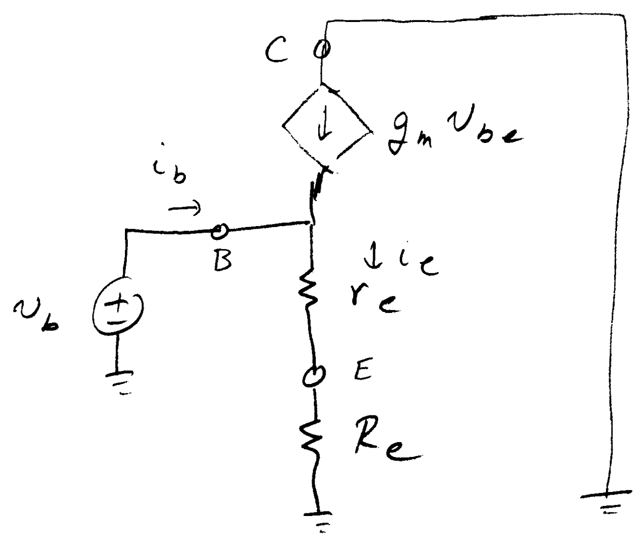
$$r_\pi = (\beta+1)\, r_e = 1.09\,k\Omega$$

$$v_o = -g_m v_{be} R_C$$

$$v_{be} = \frac{r_\pi}{r_\pi + R_{BB}}\, v_i$$

$$\frac{v_o}{v_i} = -g_m R_C \frac{r_\pi}{r_\pi + R_{BB}}$$
$$= -0.74\,V/V$$

4.61



(a) Base voltage is v_b. Find v_e using resistor divider

$$v_e = \frac{R_e}{r_e + R_e} v_b$$

$$r_e = \frac{V_T}{I_E} = \frac{25\,mV}{1\,mA} = 25\,\Omega$$

$$v_e / v_b = \frac{1\,k\Omega}{25\,\Omega + 1} = 0.976$$

(b) $$i_e = \frac{v_b}{r_e + R_e}$$

$$g_m v_{be} + i_b = i_e \qquad g_m = \frac{\alpha}{r_e} \qquad v_{be} = v_b - v_e$$

$$\frac{\alpha}{r_e}(v_b - v_e) + i_b = \frac{v_b}{r_e + R_e}$$

$$\frac{\alpha}{r_e}\left(v_b - \frac{R_e}{r_e + R_e} v_b\right) + i_b = \frac{v_b}{r_e + R_e}$$

$$i_b = \frac{\alpha R_e v_b}{r_e(r_e + R_e)} - \frac{\alpha}{r_e} v_b + \frac{v_b}{r_e + R_e}$$

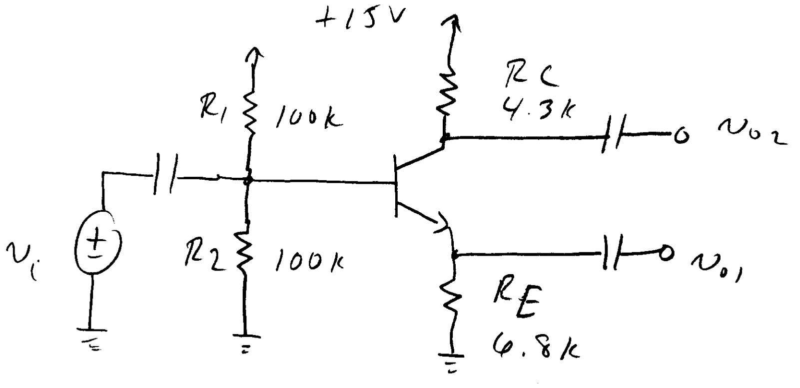
$$= \left[\frac{\alpha R_e}{r_e(r_e + R_e)} - \frac{\alpha(r_e + R_e)}{r_e(r_e + R_e)} + \frac{r_e}{r_e(r_e + R_e)}\right] v_b$$

$$= \frac{r_e(1-\alpha)}{r_e(r_e + R_e)} v_b = \frac{1 - \frac{\beta}{\beta+1}}{r_e + R_e} v_b = \frac{v_b}{(\beta+1)(r_e + R_e)}$$

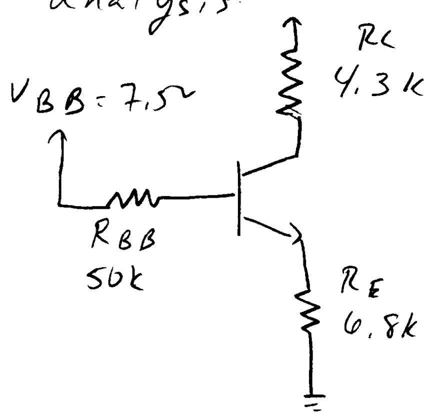
$$R_i = \frac{v_b}{i_b} = \frac{v_b}{\dfrac{v_b}{(\beta+1)(r_e+R_e)}} = (\beta +)(r_e+R_e)$$

$$R_i = 101(25\,\Omega + 1\,k\Omega) = 104\ k\Omega$$

4.64



DC analysis



$$V_{BB} = \frac{R_2}{R_1+R_2} V_{CC} = \frac{1}{2} V_{CC} = 7.5V$$

$$R_{BB} = R_1 \parallel R_2 = 50\,k\Omega$$

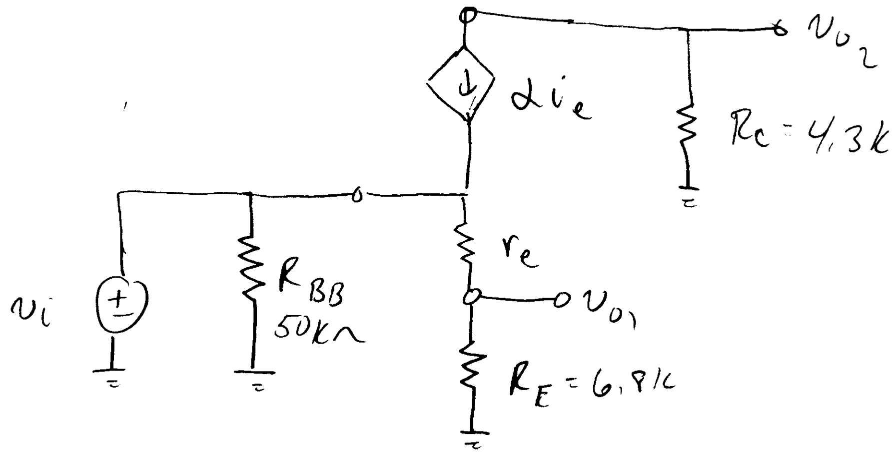
For large β, $I_B = 0 \Rightarrow V_B = V_{BB} = 7.5V$

$V_E = V_B - V_{BE} = 7.5V - 0.7V = 6.8V$

$$I_E = \frac{V_E}{R_E} = \frac{6.8V}{6.8k} = 1\,mA$$

$$I_C = \frac{\beta}{\beta+1} I_E \simeq I_E = 1\,mA$$

Small - signal analysis



$$r_e = \frac{V_T}{I_E} = \frac{25mV}{1mA} = 25\Omega$$

$$i_e = \frac{v_i}{r_e + R_E}$$

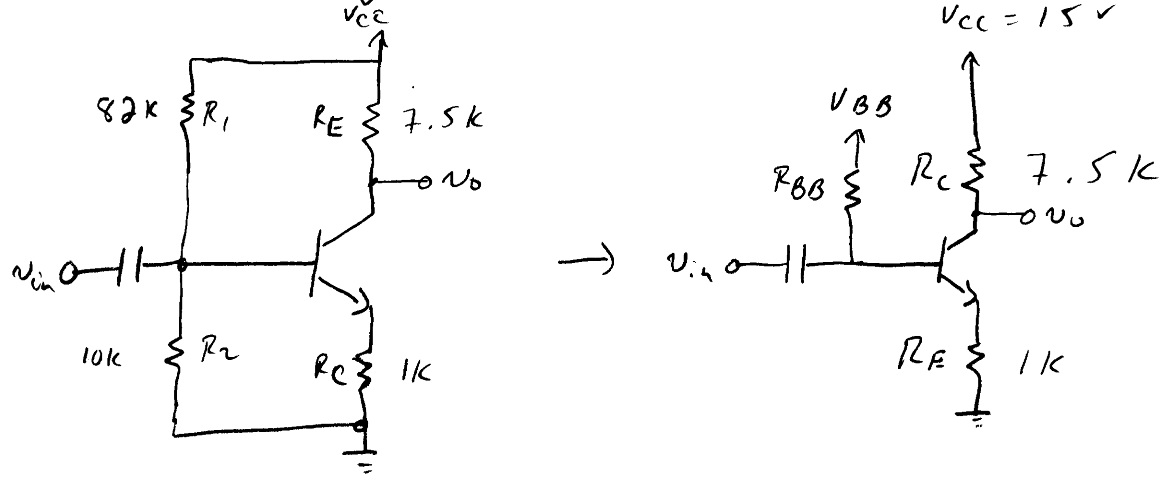
$$v_{o1} = i_e R_E = \frac{R_E}{r_e + R_E} v_i$$

$$\frac{v_{o1}}{v_i} = \frac{R_E}{r_e + R_E} = \frac{6.8k}{25\Omega + 6.8k} = 0.996 \text{ V/V}$$

$$v_{o2} = -\alpha i_e R_c = \frac{-\alpha R_C}{r_e + R_E} v_i$$

$$\frac{v_{o2}}{v_i} = \frac{-\alpha R_C}{r_e + R_E} = \frac{-1(4.3k)}{25\Omega + 6.8k} = 0.63 \text{ V/V}$$

Gain of Fig 1 of Lab 8



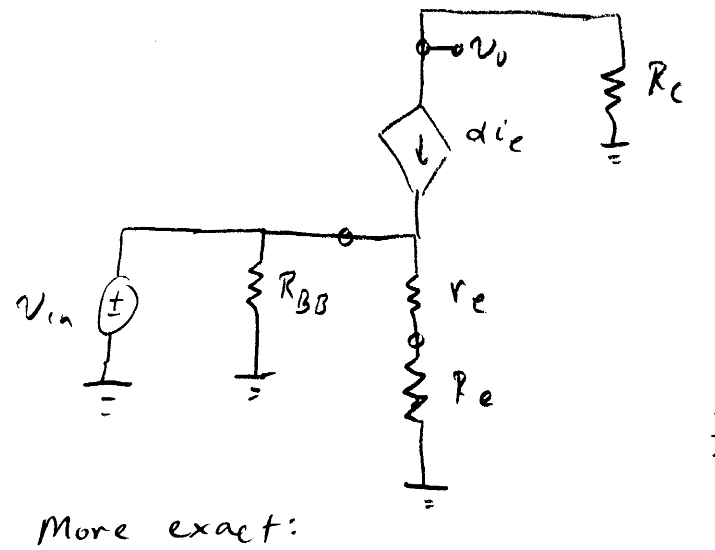
$$V_{BB} = \frac{R_2}{R_1+R_2} V_{CC} = \frac{10k}{10k+82k} 15\,V = 1.63\,V$$

$$R_{BB} = R_1 // R_2 = 8.9k$$

$$V_{BB} = I_B R_{BB} + V_{BE} + (\beta+1) I_B R_E$$

$$I_B = \frac{V_{BB} - V_{BE}}{R_{BB} + (\beta+1) R_E} = 6.2\,\mu A \text{ for } \beta = 150$$

Small signal model:



$$v_o = -\alpha i_e R_c$$

$$i_e = \frac{v_b}{r_e + R_E} = \frac{v_{in}}{r_e + R_E}$$

$$\frac{v_o}{v_{in}} = \frac{-\alpha R_C}{r_e + R_E} \simeq \frac{-R_c}{R_E}$$

$$\frac{v_o}{v_{in}} \simeq -\frac{7.5k}{1k} = -7.5\,V/V$$

More exact:

$$r_e = \frac{V_T}{I_E} = \frac{V_T}{(\beta+1) I_B} = 27\,\Omega \text{ for } \beta = 150$$

$$\frac{v_o}{v_{in}} = \frac{-\alpha R_c}{r_e + R_E} = -7.25 \text{ for } \beta = 150$$

approximation is quite close

$$\frac{v_o}{v_{in}} \simeq \frac{-R_c}{R_E} = -7.5$$