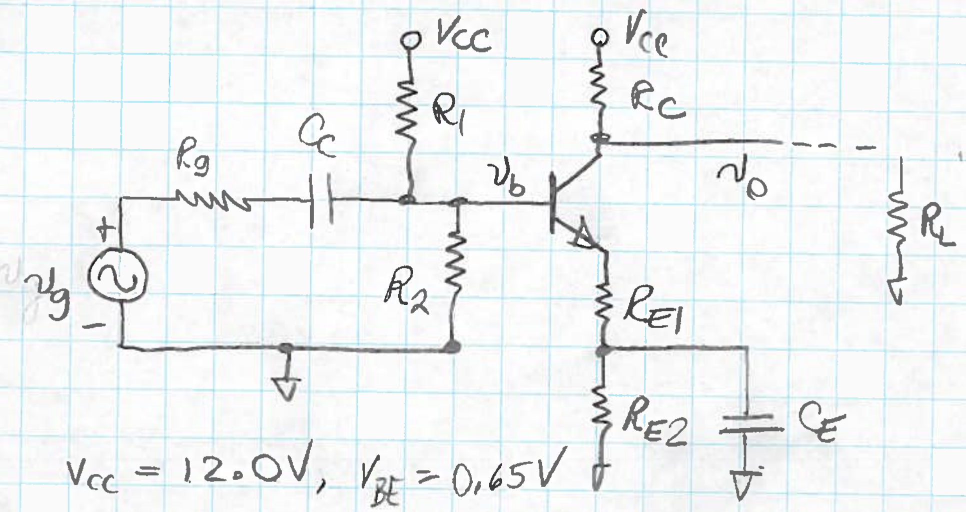
BJT biasing, gain, paramter interaction Claude Abraham 10 Jun 2013



$V_{CC} = 12.0V$, $V_{BE} = 0.65V$

$R_C' = R_C \| R_L$

Compute gain of bjt amp stage from voltage source v_g, to output v_o, at load.

We will also compute "beta-dependency", i.e. gain variation w/ beta.

Let h_{FE} = min value of 50, $R_{E1} = 100\Omega$, $R_{E2} = 1.0k\Omega$, $R_1 = 10k\Omega$, $R_2 = 4.7k\Omega$, $R_C = 2.2k\Omega$, $R_L = 10k\Omega$, $R_g = 1.0k\Omega$. C_E and C_C are large enough to be shorts at the signal frequency involved.

<u>dc bias</u> $R_E = R_{E1} + R_{E2} = 0.10 + 1.0 = 1.10\ k\Omega$. R_E' is the value of R_E seen from the base: $R_E' = (h_{FE}+1)R_E = (50+1)(1.10k\Omega)$

$R_E' = 56.1k\Omega$. This value is in parallel w/ R_2, so that R_2' is $R_2 \| R_E' = 4.7k \| 56.1k = 4.337\ k\Omega$. $V_B' = V_{CC}\dfrac{R_2'}{R_1 + R_2'}$

$V_B' = (12.0V)\dfrac{4.337k\Omega}{10k\Omega + 4.337k\Omega} = 3.630V$; $V_B'' = V_{BE}\dfrac{R_1 \| R_2}{R_E' + (R_1 \| R_2)}$

$V_B'' = (0.65V)\dfrac{10k\Omega \| 4.7k\Omega}{56.1k\Omega + (10k\Omega \| 4.7k\Omega)} = 0.0350V$, so that $V_B = V_B' + V_B''$

$V_B = 3.630V + 0.0350V = 3.665\ V$. $V_E = V_B - V_{BE} = 3.665 - 0.65V$

$V_E = 3.015V$. $I_E = \dfrac{V_E}{R_E} = \dfrac{3.015V}{1.10k\Omega} = \underline{2.741\ mA} = \underline{I_E}$

$$I_C = \alpha I_E, \quad \alpha = \frac{\beta}{\beta+1} = \frac{50}{50+1} = 0.980, \quad I_C = 0.980(2.741\ mA)$$

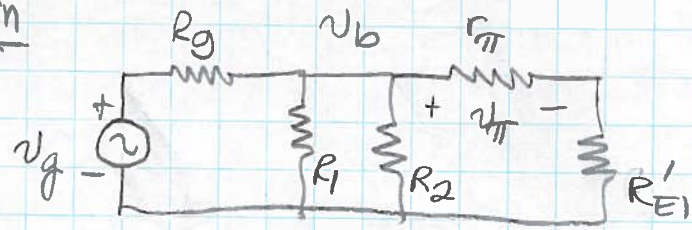
$$I_C = 2.687\ mA; \quad \text{at } T = 25\ ^\circ C,\ 298\ ^\circ K, \quad V_T = \frac{kT}{q}, \text{ so that}$$

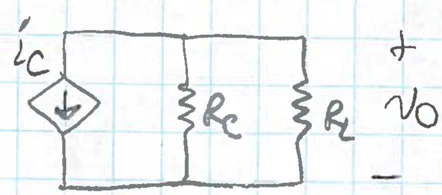
$$V_T = \frac{(1.3806 \times 10^{-23}\ J/^\circ K)(298\ ^\circ K)}{1.602 \times 10^{-19}\ C} = 0.02568\ V.$$

$$g_m = \frac{I_C}{V_T} = \frac{2.687\ mA}{25.68\ mV} = 0.10463\ \mho.$$

$$i_c = g_m v_\pi = h_{fe}\, i_b$$

<u>ac signal gain</u>





$v_o = -i_c (R_C \| R_L)$, $i_c = g_m v_\pi$, but r_π is needed to know v_π.

$r_\pi = \dfrac{h_{fe}}{g_m}$, $h_{fe} \approx h_{FE}$ for bjt device with very high f_T.

$$r_\pi = \frac{50}{0.10463\ \mho} = 477.87\ \Omega, \quad R_{E1}' = (h_{fe}+1) R_{E1} = (51)(0.10\ k\Omega)$$

$$R_{E1}' = 5.10\ k\Omega; \quad v_\pi = v_b \frac{r_\pi}{R_{E1}' + r_\pi} = \frac{0.47787\ k\Omega}{5.1\ k\Omega + 0.47787\ k\Omega} v_b$$

$v_\pi = 0.085673\, v_b$. To determine $v_b = v_g \dfrac{R_1 \| R_2 \| (r_\pi + R_{E1}')}{R_g + (R_1 \| R_2 \| (r_\pi + R_{E1}'))}$

$$v_b = v_g \frac{10 \| 4.7 \| (0.47787 + 5.10)}{1.0 + (10 \| 4.7 \| (0.47787 + 5.10))} = 0.67022\, v_g$$

$$v_\pi = (0.085673)(0.67022)\, v_g = 0.05742\, v_g.$$

Thus $i_c = g_m v_\pi = (0.10463\,\mho)(0.05742 v_g) = 0.006078\, v_g$

$R_C' = R_C \| R_L = 2.2\,k\Omega \| 10\,k\Omega = 1.8033\,k\Omega$, so that $i_c R_C'$

$= g_m v_\pi R_C' = v_o = (0.006078 v_g)(1.8033\,k\Omega) = \underline{10.960\, v_g}$

v_o / v_g = signal gain $= \underline{-10.960}$ ← The 10.96 value must be less than $\dfrac{R_C'}{R_{E1}}$, the asymptotic limit. R_C' / R_{E1} $= 1.803\,k\Omega / 0.10\,k\Omega = \underline{18.03}$, which exceeds $\underline{10.96}$.

<u>gain = 10.96, with $h_{FE} = 50$ min value.</u>

We now compute w/ $h_{FE} = 500$ max value.

<u>dc bias</u> $R_E' = (h_{FE}+1) R_E = (500+1)(1.10\,k\Omega) = 551.1\,k\Omega$

$R_2' = R_2 \| R_E' = 4.7\,k\Omega \| 551.1\,k\Omega = 4.660\,k\Omega$; $V_B' = V_{CC} \dfrac{R_2'}{R_1 + R_2'}$

$V_B' = (12.0V) \dfrac{4.660\,k\Omega}{10\,k\Omega + 4.660\,k\Omega} = 3.815\,V$; $V_B'' = \dfrac{R_1 \| R_2}{R_E' + (R_1 \| R_2)} V_{BE}$

$V_B'' = (0.65V) \dfrac{10\,k\Omega \| 4.7\,k\Omega}{551.1\,k\Omega + (10\,k\Omega \| 4.7\,k\Omega)} = 0.00375\,V \Rightarrow V_B = V_B' + V_B''$

$V_B = 3.815V + 0.00375V = 3.818\,V$; $V_E = V_B - V_{BE}$

$V_E = 3.818V - 0.65V = 3.168V.$ $I_E = \frac{V_E}{R_E} = \frac{3.168V}{1.10k\Omega} = \underline{2.880\ mA}$

$I_C = \alpha I_E = \left(\frac{500}{501}\right)(2.880\ mA) = \underline{2.875\ mA}$

<u>ac signal gain</u> $g_m = \frac{I_C}{V_T} = \frac{2.875\ mA}{25.68\ mV} = 0.11194\ \mho$

$r_\pi = \frac{h_{FE}}{g_m} = \frac{500}{0.11194\mho} = 4.4668\ k\Omega$; $R_{E1}' = (h_{FE}+1)R_{E1}$

$R_{E1}' = (501)(0.10k\Omega) = 50.1\ k\Omega.$ $\frac{v_\pi}{v_b} = \frac{r_\pi}{R_{E1}' + r_\pi}$

$\frac{v_\pi}{v_b} = \frac{4.4668}{50.1 + 4.4668} = 0.08186$;

$\frac{v_b}{v_g} = \frac{R_1 \| R_2 \| (r_\pi + R_{E1}')}{R_g + (R_1 \| R_2 \| (r_\pi + R_{E1}'))} = \frac{10 \| 4.7 \| (4.4668 + 50.1)}{1.0 + (10 \| 4.7 \| (4.4668 + 50.1))} = \underline{0.75126}$

$\frac{v_\pi}{v_g} = \frac{v_\pi}{v_b}\frac{v_b}{v_g} = (0.08186)(0.75126) = \underline{0.06150}$

$v_o = i_c R_L' = g_m v_\pi R_C' \Rightarrow \frac{v_o}{v_g} = \text{gain} = -g_m R_C' \frac{v_\pi}{v_g}$

$\frac{v_o}{v_g} = -0.11194\mho(1.8033k\Omega)(0.06150) = \underline{\underline{-12.414\ \frac{V}{V}}}$

Thus h_{FE} increased by 900% (50 → 500), and gain increased by 13.3%. Larger R_{E1} provides less variation.

Claude