Problem Set 3 Solutions

6.101 Analog Electronics Lab

March 9, 2007

Problem 1 (a) (8pts)

$$R_{TH} = R_1||R_2 = 1.2k\Omega$$
$$V_{TH} = 1.0V$$
$$I_{BQ} = \frac{V_{TH} - V_{BE}(on)}{R_{TH} + (1+\beta)R_E} = \frac{1.0 - 0.7}{1.2 + (181)(0.1)} = 15.5\mu A$$
$$I_{CQ} = 2.8mA,\ I_{EQ} = 2.81mA$$
$$V_{CEQ} = V^+ - I_{CQ}R_C - I_{EQ}R_E = 5 - (2.8mA)(1k\Omega) - (2.81mA)(0.1k\Omega) = 1.92V$$

(b) (8pts)

$$r_\pi = \frac{\beta V_T}{I_{CQ}} = \frac{(180)(0.026V)}{2.8mA} = 1.67k\Omega$$
$$g_m = \frac{I_{CQ}}{V_t} = \frac{2.8mA}{0.026V} = 108m\ mho$$
$$r_o = \infty$$

(c) (8pts)

$$A_v = \frac{-g_m(R_1||R_2||R_\pi)}{R_1||R_2||R_\pi + R_s}(R_C||R_L = -(100m\ mho)\frac{722\Omega}{722\Omega + 200\Omega}(1k\Omega||1.2k\omega) = -45.8$$

Problem 2 (a) (8pts)

$$I_{BQ} = \frac{0.5k\Omega}{81} = 6.17\mu A$$
$$V_B = I_{BQ}R_B = (6.17\mu A)(10k\Omega) = 0.0617V$$
$$V_E = V_B + 0.7 = 0.7617V$$

(b) (8pts)

$$I_{CQ} = (0.5mA)\frac{80}{81} = 0.494mA$$
$$r_\pi = \frac{\beta V_T}{I_{CQ}} = \frac{(80)(0.026V)}{0.494mA} = 4.21k\Omega$$
$$g_m = \frac{I_{CQ}}{V_t} = \frac{0.494mA}{0.026V} = 19m\ mho$$
$$r_o = \frac{V_A}{I_{CQ}} = \frac{150V}{0.494mA} = 304k\Omega$$

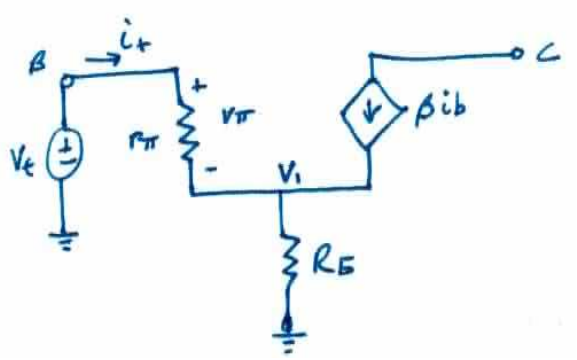

Figure 1: Small signal drawing for 3a.

(c) (8pts)

$$A_v = \frac{V_o}{V_s} = \frac{(1+\beta)(R_L||r_o)}{r_\pi + (1+\beta)(R_L||r_o)} = \frac{81(0.5k\Omega||304k\Omega)}{4.21k\Omega + 81(0.5k\Omega||304k\Omega)}$$

$$\approx \frac{81(0.5k\Omega)}{4.21k\Omega + 81(0.5k\Omega)} = 0.906$$

$$A_i = \frac{I_o}{I_s} = (1+\beta)\frac{R_B}{R_B + r_\pi + (1+\beta)(R_L||r_o)}\frac{r_0}{r_o + R_L}$$

$$\approx 81\frac{10k\Omega}{10k\Omega + 44.7k\Omega} = 14.8$$

(d) (8pts) Same as above except the voltage divider on the input decreases the voltage gain.

$$R_{in} = R_B||(\beta+1)R_L = 8.02k\Omega$$

$$A_v = \frac{V_o}{V_s} = \frac{(1+\beta)(R_L||r_o)}{r_\pi + (1+\beta)(R_L||r_o)}\frac{R_{in}}{R_{in} + R_{source}} = 0.906\frac{8.02k\Omega}{8.02k\Omega + 2k\Omega} = 0.728$$

A_i remains unchanged, =14.8.

Problem 3 (a) See figure - (10pts).

(b) (10pts)

$$i_t = i_b$$

$$\frac{V_1}{R_E} = \beta i_t + it = (\beta+1)i_t \Rightarrow \frac{V_1}{i_t} = (\beta+1)R_E$$

$$\frac{v_t - v_1}{r_\pi} = i_t$$

$$r_t = \frac{v_t}{i_t} = r_\pi + \frac{V1}{i_t} = r_\pi + (\beta+1)R_E$$

Problem 4 (24pts)

$$V_G = \frac{R_2}{R_1 + R_2} V_{DD} = \frac{60k\Omega}{140k\Omega + 60k\Omega} 20V = 6V$$

$$I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2 = \frac{V_S}{R_S} = \frac{V_G - V_{GS}}{R_S}$$

$$(8mA)(2k\Omega)\left(1 - \frac{V_{GS}}{-4}\right)^2 = 6 - V_{GS}$$

$$16\left(1 + \frac{V_{GS}}{2} + \frac{V_{GS}^2}{16}\right) = 6 - V_{GS}$$

$$V_{GS}^2 + 9V_{GS} + 10 = 0$$

$$V_{GS} = \frac{-9 \pm \sqrt{9^2 - 4(10)}}{2} \Rightarrow V_{GS} = -1.30V$$

$$I_D = 8mA\left(1 - \frac{-1.30}{-4}\right)^2 = 3.65mA$$

$$V_{DS} = V_{DD} - I_D(R_S + R_D) = 20 - (3.65mA)(2k\Omega + 2.7k\Omega) = 2.85V$$

$$V_{DS} > V_{DS(sat)} = V_{GS} - V_P = -1.3 - (-4) = 2.7V$$

The transistor is saturated so all our equations and thus the Q point are valid.