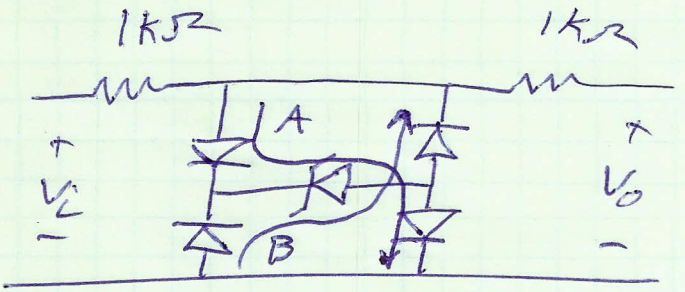
ECE 65 | Spring 2012 | Final

Question 1



Current can flow in either direction (path A or B above) with a voltage drop across the diodes of $2V_{D_o} + V_z$

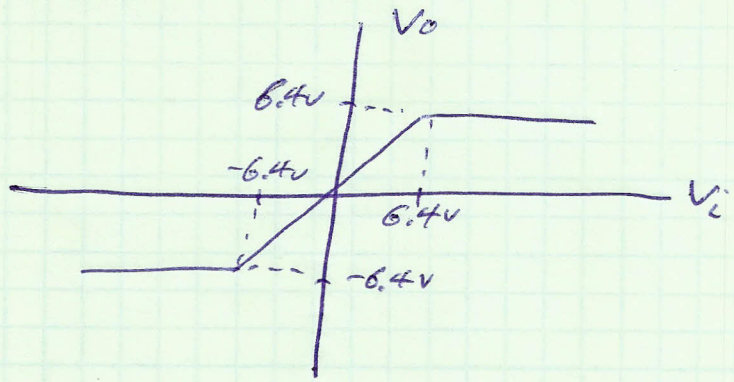
$$2V_{D_o} + V_z = 2(0.7) + 5 = 6.4v$$

a) For $V_i < -6.4v$, $V_o = -6.4v$

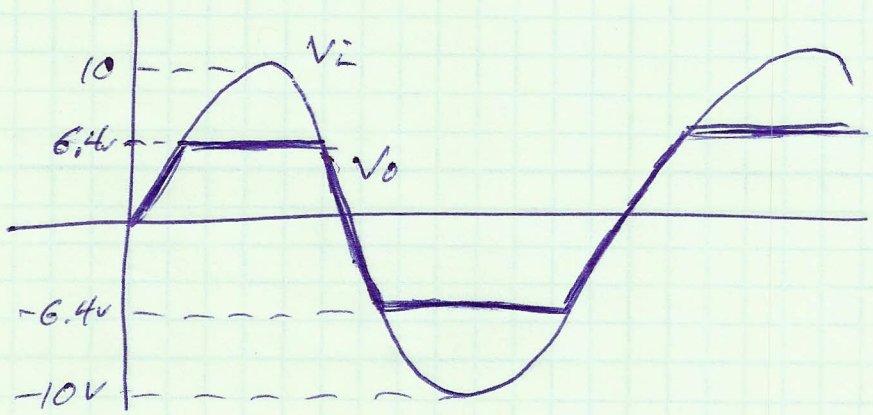
For $-6.4v < V_i < 6.4v$, $V_o = V_i$

For $V_i > 6.4v$, $V_o = 6.4v$

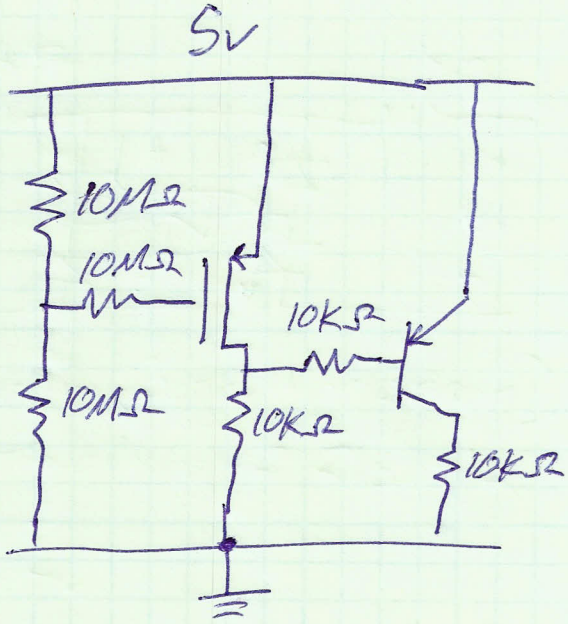
b)



c)



Question 2



$V_{sg} = 2.5v$

assume FET is ~~in~~ saturation mode

$I_D = \frac{1}{2}\mu_p C_{ox}\frac{W}{L}(V_{sg} - |V_T|)^2$

$I_D = \frac{1}{2}\cdot 1\,(2.5-1)^2 = 1.1mA$

$V_{SD} = 5 - 1.1\times 10 = -6v$

FET is <u>not</u> in saturation mode, assume triode mode

$I_D = \frac{1}{2}\mu_p C_{ox}\frac{W}{L}\left[2(V_{sg} - |V_T|)V_{SD} - V_{SD}^2\right]$

$I_D = \frac{5 - V_{SD}}{10k\Omega}$

$5 - V_{SD} = 10\cdot\frac{1}{2}\cdot 1\left[2(1.5)V_{SD} - V_{SD}^2\right]$

$5 - V_{SD} = 15V_{SD} - 5V_{SD}^2$

$5V_{SD}^2 - 16V_{SD} + 5 = 0 \rightarrow V_{SD} = \frac{16 \pm \sqrt{16^2 - 4\cdot 5\cdot 5}}{10} = 2.8v \text{ or } 0.35v$

Only 0.35v is consistent with triode mode

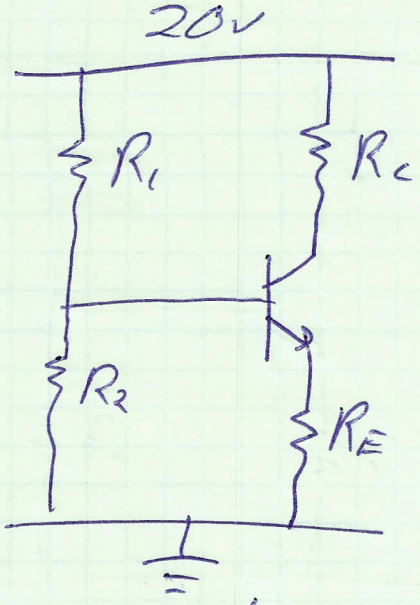
a) FET is in <u>triode</u> mode

b) $I_D = \frac{5 - V_{SD}}{10k} = 0.46mA$

c) BJT is in <u>cut-off</u> mode because $V_{EB} < V_{DO}$

d) $I_c = 0$

Question 3



Set $I_E R_E = 1v \gg 0.1v$

$R_E = 500\Omega$

$V_{BB} = 20\frac{R_2}{R_1+R_2}$, $R_B = \frac{R_1 R_2}{R_1+R_2}$

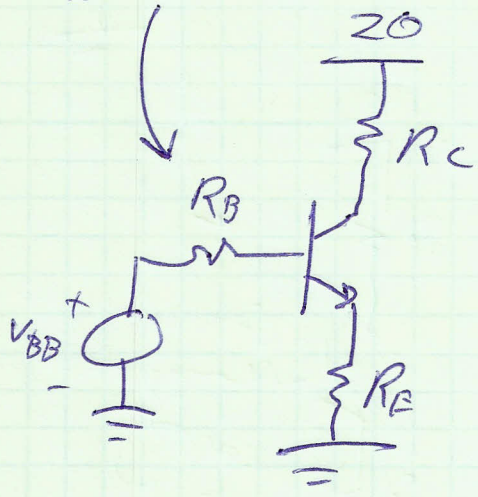
$V_{BB} - I_B R_B - 0.7 = V_E = 1v$

choose $R_B \ll (\beta_{min}+1)R_E = 51 \times 500$

$R_B = 2.5k\Omega$

$V_{BB} - 2.5k\Omega \cdot 20\mu A - 0.7 = 1$

$V_{BB} = 1.75v$



$20\frac{R_2}{R_1+R_2} = 1.75v$

$\frac{R_1 R_2}{R_1+R_2} = 2.5$ → $\frac{20}{R_1} = \frac{1.75}{2.5}$

$R_1 = 29k\Omega$

$R_1 R_2 = 2.5(R_1+R_2)$

$29R_2 = 72.5 + 2.5R_2$

$26.5R_2 = 72.5$

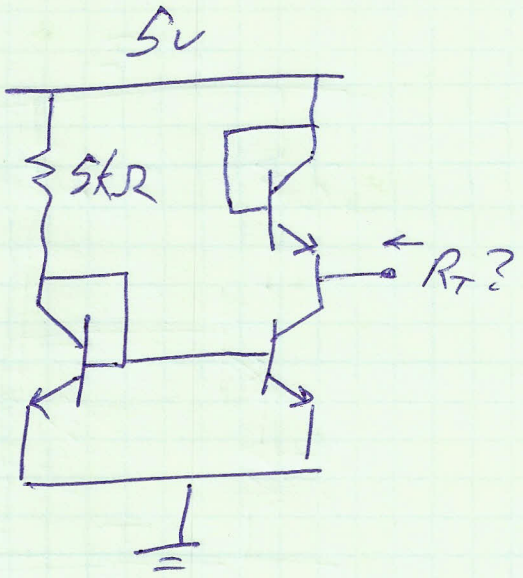
$R_2 = 2.7k\Omega$

$20 - I_C R_C - 10 = 1v$

$R_C = \frac{9v}{2mA} = 4.5$

$R_C = 4.5k\Omega$

Question 4



$$I_{ref} = \frac{5-0.7}{5} = 0.86\,mA$$

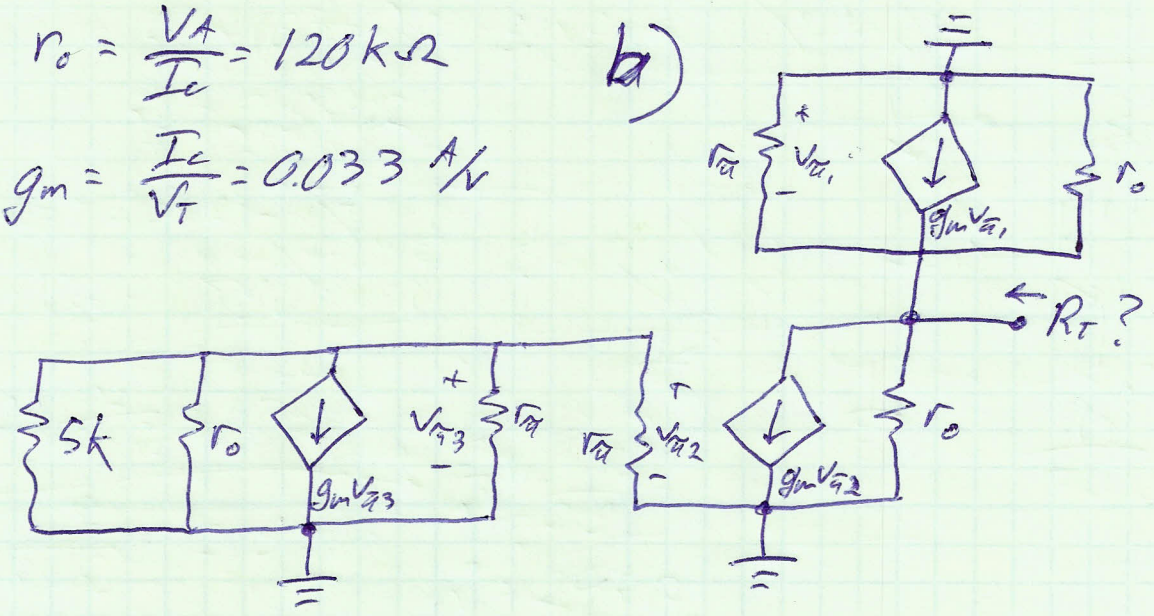
All transistors have $I_C = 0.86\,mA$ and $I_B = 8.6\,\mu A$

a) $$r_\pi = \frac{V_T}{I_B} = 3k\Omega$$

$$r_o = \frac{V_A}{I_C} = 120k\Omega$$

$$g_m = \frac{I_C}{V_T} = 0.033\ A/V$$

b)



c) $v_{\pi 2} = v_{\pi 3} = 0$ Apply test source V_x, determine I_x

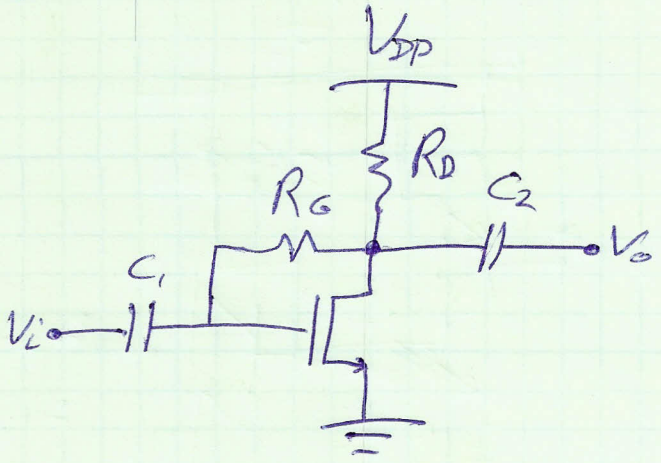
$$v_{\pi 1} = -V_x$$

$$I_x = \frac{V_x}{r_\pi} + g_m V_x + \frac{V_x}{r_o} + \frac{V_x}{r_o}$$

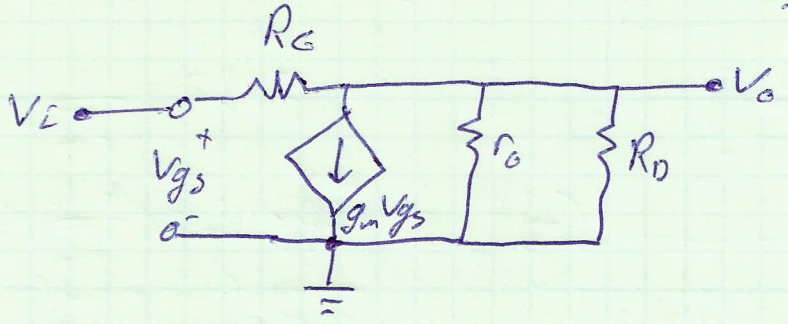
$$\frac{V_x}{I_x} = r_\pi \,||\, \frac{1}{g_m} \,||\, r_o \,||\, r_o \simeq \frac{1}{g_m}$$

$$R_T = 30\Omega$$

Question 5



a)



b) Apply test source V_x to output and zero (short) the input $\rightarrow V_{gs} = 0$

$$I_x = \frac{V_x}{R_G} + \frac{V_x}{r_o} + \frac{V_x}{R_D}$$

$$\underline{R_o = R_G \| r_o \| R_D}$$

c) $V_i = V_{gs}$

at the output node,

$$\frac{V_o - V_i}{R_G} + V_i g_m + \frac{V_o}{r_o} + \frac{V_o}{R_D} = 0$$

$$V_i\left(\frac{1}{R_G} + g_m\right) = V_o\left(\frac{1}{R_G} + \frac{1}{r_o} + \frac{1}{R_D}\right)$$

$$A_{V_o} = \frac{V_o}{V_i} = \frac{\frac{1}{R_G} - g_m}{\frac{1}{R_G} + \frac{1}{r_o} + \frac{1}{R_D}} = \frac{R_G \| r_o \| R_D}{R_G \| \left(\frac{-1}{g_m}\right)}$$

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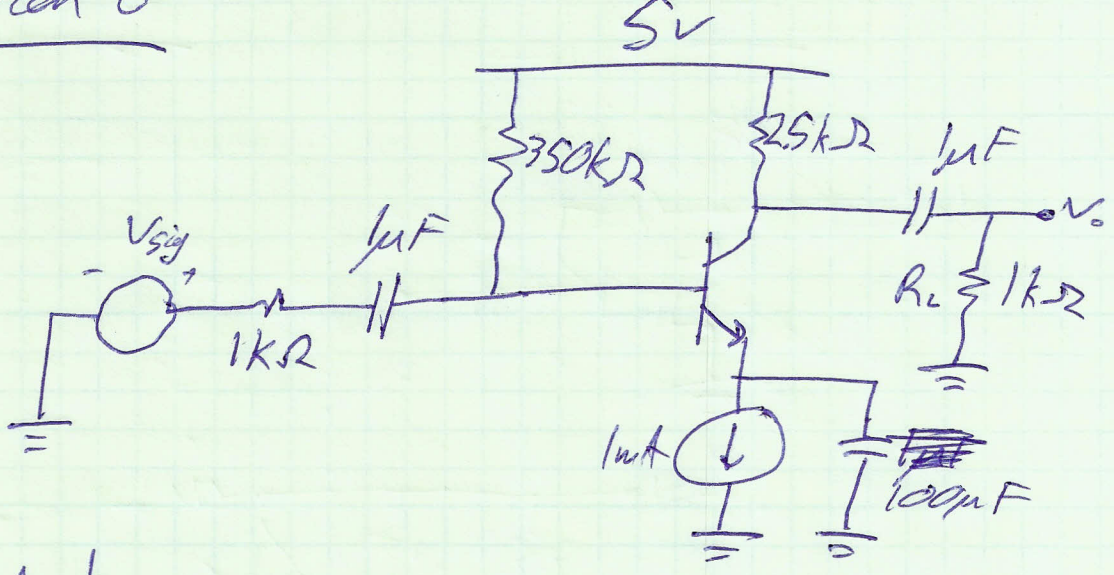
Question 6



a) $A_{vo} = A_v|_{R_L \to \infty}$

$A_{vo} = -g_m(r_o \| R_c)$

$g_m = \frac{I_c}{V_T} = \frac{1mA}{26mV} = 0.039 A/V$

$r_o = \frac{V_A}{I_c} = \frac{100}{1mA} = 100k\Omega$

$A_{vo} = 95$

$R_i = R_B \| r_\pi$

$R_i = 350k \| 2.6k$

$R_i = 2.6k\Omega$

$r_\pi = \frac{V_T}{I_B} = \frac{26mV}{10\mu A} = 2.6k$

$R_o = R_c \| r_o$

$R_o = 2.5k \| 100k$

$R_o = 2.4k\Omega$

b) $f_{p1} = \frac{1}{2\pi C_1 (R_i + R_{sig})} = 44Hz$

$f_{p2} = \frac{1}{2\pi C_2 (R_L + R_o)} = 47Hz$

$f_{p3} = \frac{1}{2\pi C_E [R_E \| (1/g_m + (R_B \| R_{sig})/\beta)]} = 45Hz$

$f_l = \sum_n f_{pn} = 44 + 47 + 45$

$f_l = 136Hz$