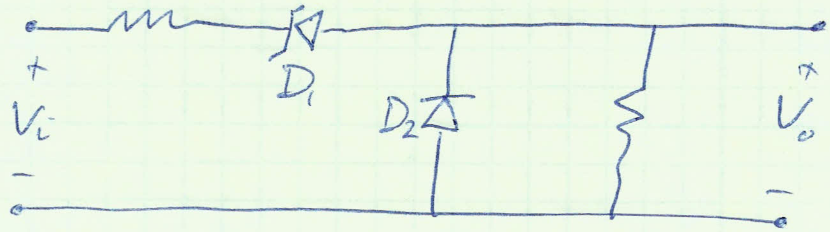
Problem 1:

find the transfer function, v_o for all v_i, and plot it



$V_{D0} = 0.7v$

$V_Z = 4v$

As V_i is decreased from 0v, V_o will remain 0 until D_1 turns ON at −0.7v

for $V_i < -0.7v$, $V_o = \frac{V_i + 0.7}{2}$, $D1$ is ON and $D2$ is OFF

as V_i is decreased from −0.7v, D_2 will remain OFF until $V_o = -0.7v$

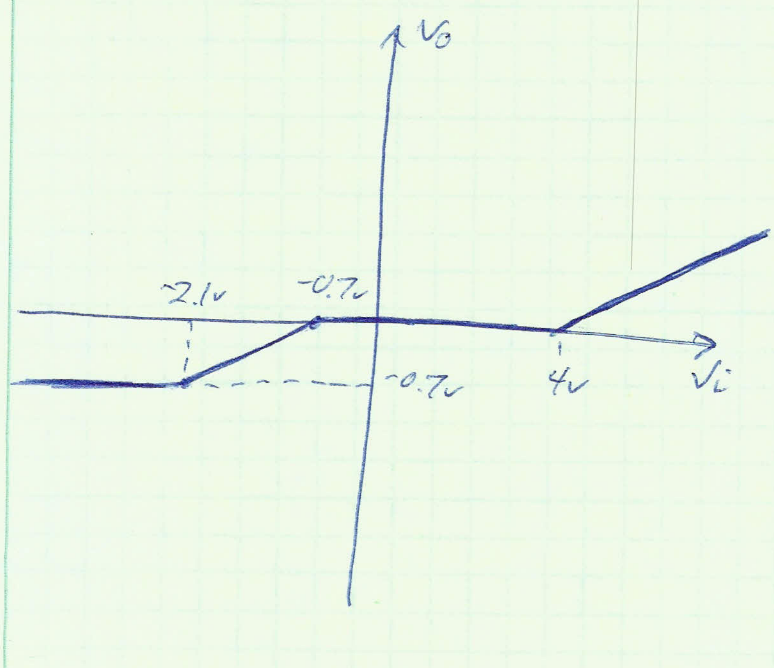
$$\frac{V_i + 0.7}{2} = -0.7$$

$$V_i = -2.1v$$

for $V_i < -2.1v$, $V_o = -0.7v$

As V_i is increased from 0v, V_o will remain 0 until $V_i > V_Z$

for $V_i > 4v$, $V_o = \frac{V_i - 4}{2}$



for $V_i < -2.1v \rightarrow V_o = -0.7v$

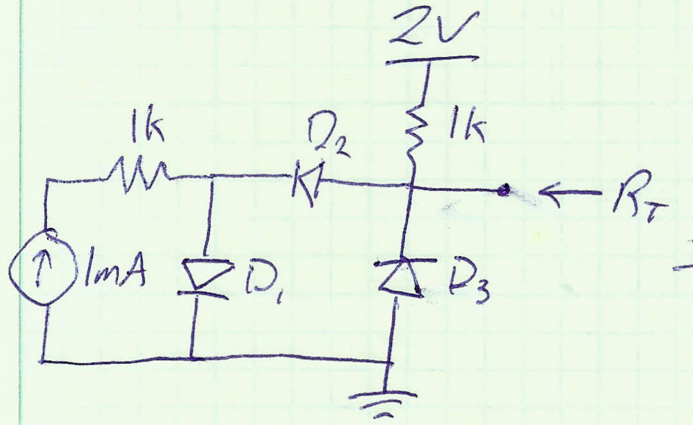
for $-2.1v < V_i < -0.7 \rightarrow V_o = \frac{V_i + 0.7}{2}$

for $-0.7 < V_i < 4 \rightarrow V_o = 0$

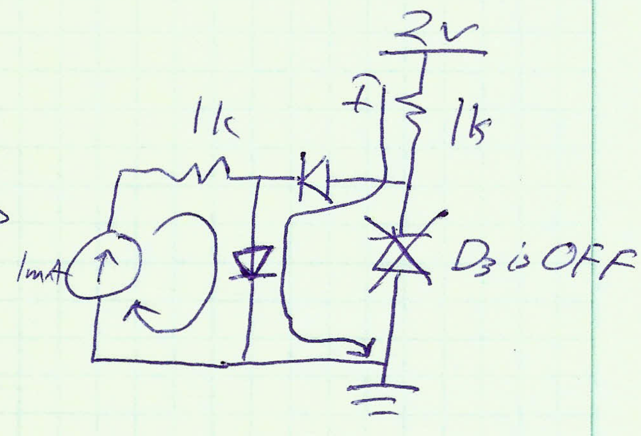
for $V_i > 4 \rightarrow V_o = \frac{V_i - 4}{2}$

Problem 2:

Find the small signal Thevenin resistance at the node shown.
Assume discrete silicon diodes at 300°K.



$\Rightarrow$



$$2V - I \cdot 1k - V_{D0} - V_{D0} = 0$$

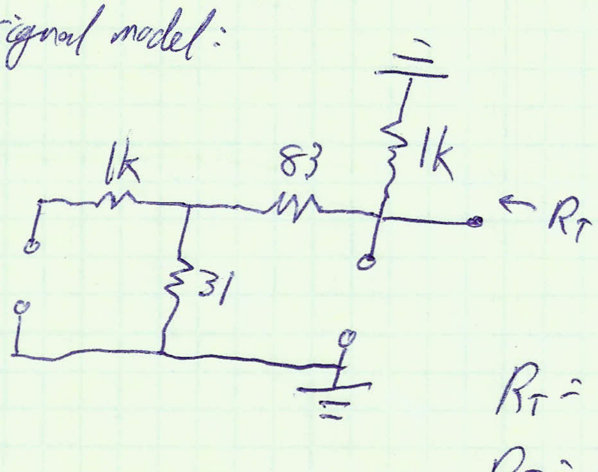
$$2 - 1.4 = I \cdot 1k$$

$$I = \frac{0.6}{1k} = 0.6mA$$

$$I_{D2} = 0.6mA \rightarrow r_{D2} = \frac{nV_T}{0.6mA} = \frac{2 \times 25mV}{0.6mA} = \frac{0.05}{0.6mA} = 83\Omega$$

$$I_{D1} = 1.6mA \rightarrow r_{D1} = \frac{0.05V}{1.6mA} = 31\Omega$$

small signal model:



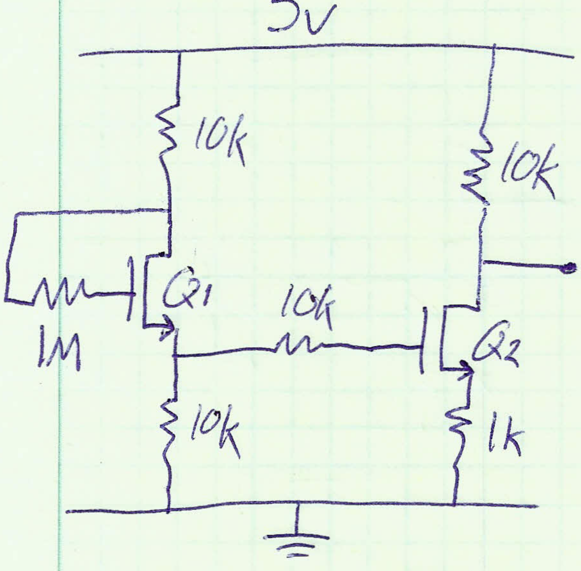
$$R_T = 1k \,\|\, (83 + 31)$$

$$\underline{R_T = 102\Omega}$$

Problem 3:

Determine the state of both transistors, and V_o

Assume $k_n' \frac{W}{L} = 1mA/V^2$ and $V_T = 1V$



Self-bias ensures that Q_1 in saturation

$5v - 10k \cdot I_{D1} - V_{GS1} - 10k \cdot I_{D1} = 0$

$I_D = \frac{5v - V_{GS1}}{20k} = \frac{1}{2} k_n' \frac{W}{L} (V_{GS1} - V_t)^2$

$5 - V_{GS1} = 10 (V_{GS1}^2 - 2V_{GS1} + 1)$

$5 - V_{GS1} = 10V_{GS1}^2 - 20V_{GS1} + 10$

$10V_{GS1}^2 - 19V_{GS1} + 5 = 0$

$V_{GS1} = \frac{19 \pm \sqrt{361 - 4 \times 10 \times 5}}{20}$

$V_{GS1} = \frac{19 \pm 13}{20} = 1.6v$ or $0.3v$

0.3v would be in cutoff, not consistent

$V_{GS1} = 1.6V$

$I_{D1} = \frac{5v - 1.6v}{20k} = 0.17mA$

$V_{S1} = 1.7v = V_{G2}$

$V_{GS2} = 1.7v - 1k \cdot I_{D2}$

$I_{D2} = \frac{1.7v - V_{GS2}}{1k} = \frac{1}{2} k_n' \frac{W}{L} (V_{GS2} - V_T)^2$

$1.7v - V_{GS2} = 0.5 (V_{GS2}^2 - 2V_{GS2} + 1)$

$3.4 - 2V_{GS2} = V_{GS2}^2 - 2V_{GS2} + 1$

$V_{GS2}^2 = 2.4$

$V_{GS2} = 1.5v$ or $-1.5v$

$-1.5v$ is not physical

$V_{GS2} = 1.5v$

$I_{D2} = \frac{1.7v - 1.5v}{1k} = 0.2mA$

$V_o = 5v - 10k \cdot 0.2mA$

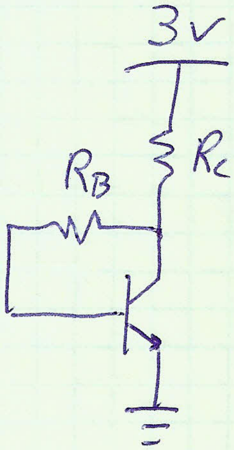
$V_o = 3v$

$V_{DS2} = 3v - 1k \cdot 0.2mA = 2.8v$

$V_{DS2} > V_T \rightarrow$ saturation ✓

Problem 4:

Design the following bias circuit so that it is stable with respect to variations in β from 100 to 200. Also design the circuit so that $I_C = 1mA$.



$$V_{CC} - (I_B + I_C)R_C - I_B R_B - V_{BE} = 0$$

$$V_{CC} - R_C I_C - (R_C + R_B)\frac{I_C}{\beta} - V_{D0} = 0$$

$$I_C = \frac{V_{CC} - V_{D0}}{R_C + (R_C + R_B)/\beta}$$

stable with respect to β if $\frac{R_C + R_B}{\beta} \ll R_C$

$$R_C + R_B \ll \beta R_C$$

$$R_B \ll (\beta - 1) R_C$$

then $I_C \simeq \frac{V_{CC} - V_{D0}}{R_C}$

$$1mA = \frac{3 - 0.7}{R_C}$$

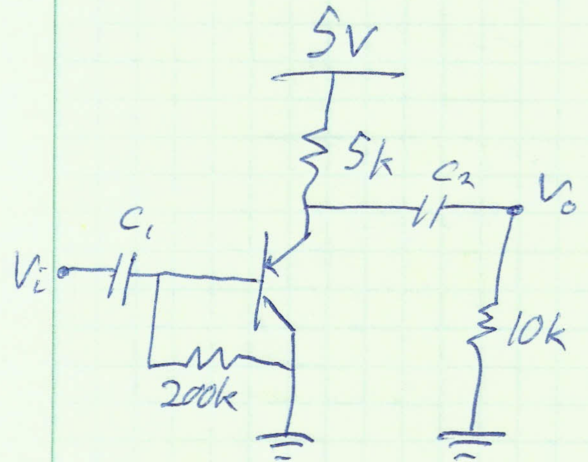
$$R_C = \frac{3 - 0.7}{1mA} = \underline{2.3k\Omega}$$

$$R_B = 0.1 \times (\beta - 1) R_C = 0.1 \times 99 \times 2.3k\Omega$$

$$R_B = \underline{22k\Omega}$$

Problem 5:

Find A_v, R_i, and R_o for the amplifier below.
Assume $\beta = 200$, $V_A = 50v$, for Silicon discrete BJT at 300°K.
Ignore the Early effect for determining bias conditions.



Identify as Emitter Follower

$$5v - 5k(\beta+1)I_B - 0.7v - 200k I_B = 0$$

$$4.3v = 1.2M \cdot I_B$$

$$I_B = 3.6\mu A$$

$$I_c = \beta I_B = 0.72mA$$

$$V_{EC} = 5 - 5k \cdot 0.72$$

$$V_{EC} = 1.4v$$

$$g_m = \frac{I_c}{nV_T} = \frac{0.72mA}{0.05v} = 14mA/v$$

$$r_\pi = \frac{nV_T}{I_B} = \frac{0.05v}{3.6\mu A} = 14k\Omega$$

$$r_o = \frac{V_A + V_{EC}}{I_c} = \frac{51.4v}{0.72mA} = 72k\Omega$$

$$r_e = \frac{1}{g_m} = 71\Omega$$

$$A_v = \frac{R_E \| R_L}{R_E \| R_L + r_e} = \frac{3.3k}{3.3k + 71}$$

$$A_v = 0.98$$

$$R_i = R_B \| \left[r_\pi + (1+\beta)(r_o \| R_E \| R_L) \right]$$

$$R_i = 153k\Omega$$

$$R_o = r_\pi \| r_e$$

$$R_o = 71\Omega$$

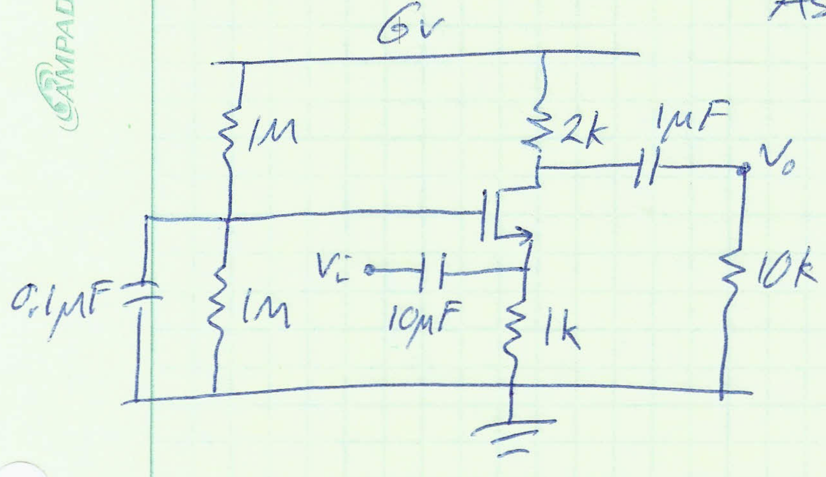
Problem 6:

Determine the low frequency cutoff for this amplifier.

Assume $k_n' \frac{W}{L} = 1mA/V^2$, $\lambda = 0.02\ V^{-1}$, and $V_T = 1V$

Ignore channel width modulation for determining bias conditions.

Assume $R_{sig} = 0$.



Identify as common gate.

$R_i = R_S || \left[\frac{1}{g_m} + (R_D || R_L)/g_m r_o\right]$

$R_i = 1k || \left[770 + (2k||10k)/82\right]$

$R_i = 440\Omega$

$f_1 = \frac{1}{2\pi C_1 R_i} = 36\ Hz$

$f_2 = \frac{1}{2\pi C_2 (R_L + R_D || R_{out})} = 13\ Hz$

$R_{out} = r_o(1 + g_m R_s) = 145k$

$f_b = \frac{1}{2\pi C_b R_G} = 3.2\ Hz$

$\uparrow = 500k$

$f = f_1 + f_2 + f_b = 36 + 13 + 3.2$

$f = \underline{52\ Hz}$

$V_G = 3v$

$V_{GS} = 3v - 1k \cdot I_D$

$\frac{3v - V_{GS}}{1k} = I_D = \frac{1}{2} k_n' \frac{W}{L} (V_{GS} - V_T)^2$

$6 - 2V_{GS} = V_{GS}^2 - 2V_{GS} + 1$

$V_{GS} = \sqrt{5} = 2.2v$

$I_D = \frac{3 - 2.2}{1k} = 0.80\ mA$

$g_m = \frac{2I_D}{V_{GS} - V_T} = \frac{2 \times 0.80mA}{2.2 - 1} = 1.3mA/V$

$r_o = \frac{V_A}{I_D} = \frac{50v}{0.8mA} = 63k\Omega$

$\frac{1}{g_m} = 770\Omega$