

Final Practice

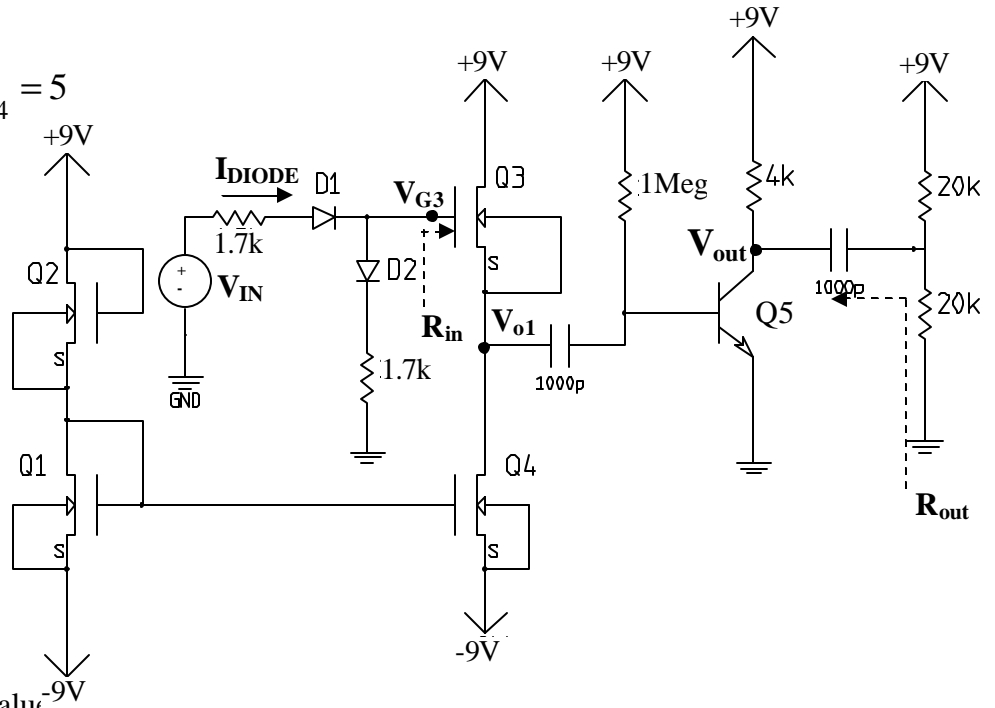
Problem 2

Use:

$$\left(\frac{W}{L}\right)_1 = \left(\frac{W}{L}\right)_2 = \left(\frac{W}{L}\right)_4 = 5$$

$$\left(\frac{W}{L}\right)_3 = 200$$

$V_t = 1V$
 $k_n' = 40mA/V^2$
 $I_{1,2,3,4} = 0$
 $V_{D0} = 0.6$
 $n = 1$
 $V_T = 25mV$
 ignore V_A
 $V_{BE} = 0.7$
 $\beta = 150$
 $V_{in} = 8 + 1m\sin\omega t$



- Find the following DC values.
 - I_{DIODE}
 - V_{G3}
 - V_{o1}
 - V_{out}
- Draw the AC small-signal circuit
- Find the AC values:
 - Find R_{in} .
 - Find R_{out} .
 - Find the overall gain, V_o/V_{IN} . State value as a numeric value.
- What is the maximum value that the resistor $R_C = 4k$ at the collector of transistor Q5 be changed to and still keep the transistor active? Explain in detail how this resistor changes the overall gain?

Problem 3

Use: $V_t=1V$ $k_n'=30mA/V^2$

$I=0$

$$\left(\frac{W}{L}\right)_1 = \left(\frac{W}{L}\right)_2 = \left(\frac{W}{L}\right)_3 = 10$$

$$\left(\frac{W}{L}\right)_4 = 100$$

$V_{D0}=0.6$

$n=2$

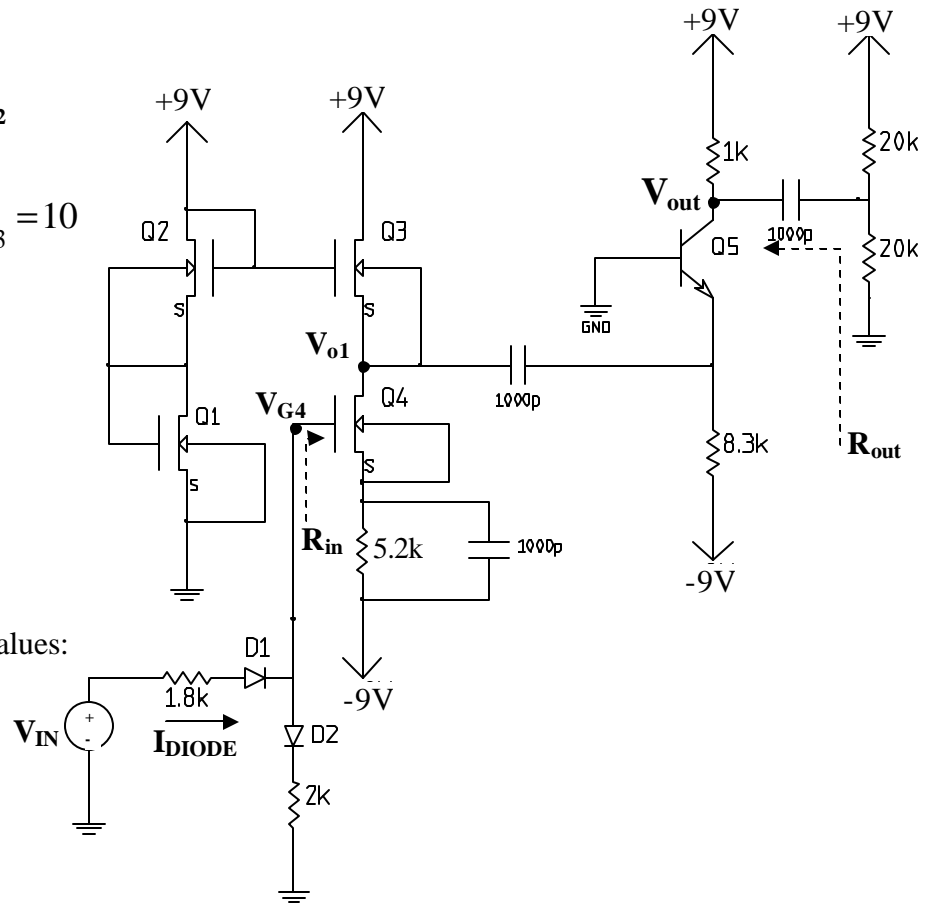
$V_T=25mV$

ignore V_A

$V_{BE}=0.7$

$\beta=150$

$V_{in}=5+2m\sin\omega t$



1. Find the following DC values:

(e) I_{DIODE}

(f) V_{G4}

(g) V_{o1}

(h) V_{out}

2. Draw the AC small-signal circuit

3. Find the AC parameters:

(a) r_π

(b) g_m for transistor Q4

(c) g_m for transistor Q5

(d) r_d for the diodes

4. Find the values for R_{in} and R_{out} .

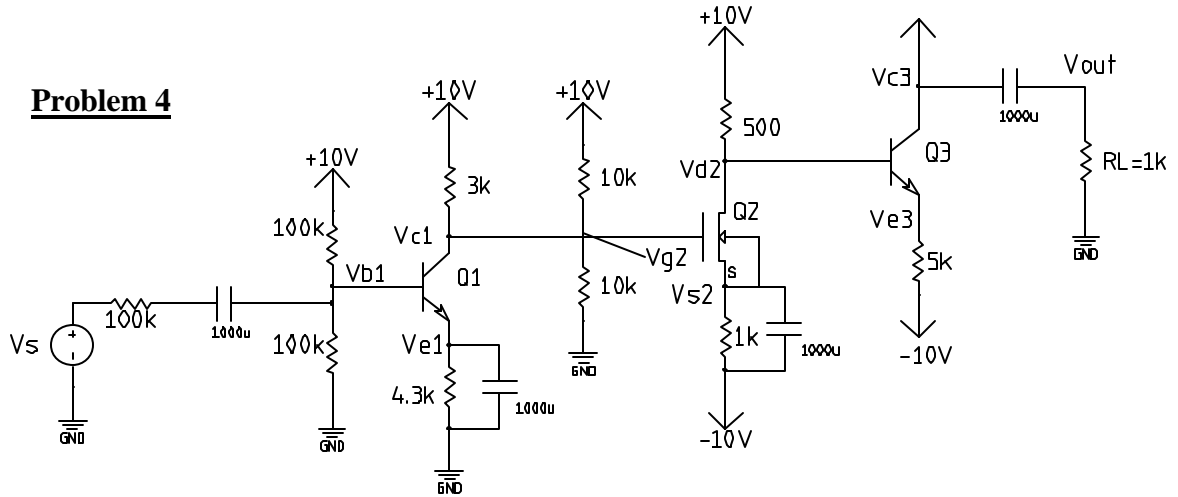
5. Find the gain: $\left(\frac{V_{o1}}{V_{IN}}\right)$

6. Find the gain: $\left(\frac{V_{out}}{V_{IN}}\right)$

7. Find the total instantaneous output voltage V_{out} . Draw the input, V_I , and the total output (DC and AC) on the same graph vs time for 2 periods. Mark the maximum and minimum peak values.

8. What is the maximum value that the resistor $R_C=1k$ at the collector of transistor Q5 be changed to and still keep the transistor in saturation? Explain in detail how this resistor changes the overall gain?

Problem 4



Solve the circuit when $n=1$, $V_T=25\text{mV}$, $V_i=+1\text{V}$, $k'(W/L)=2\text{mA/V}^2$, $\beta=100$, ignore V_A , $\lambda=0$, $V_{BE}=0.7\text{V}$

a. DC Values:

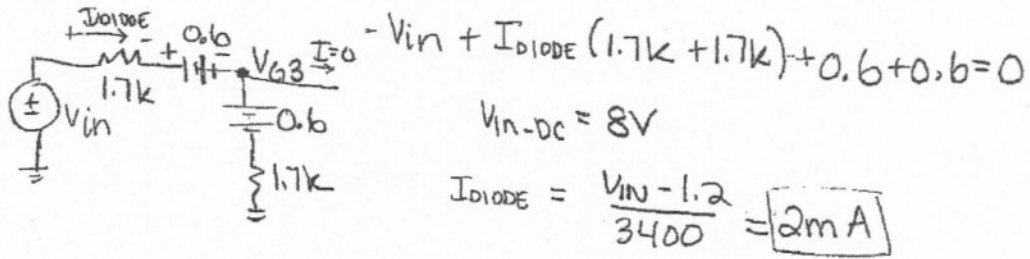
- i. I_{B1} , I_{C1} , I_{E1}
- ii. I_{D2} , I_{G2} , I_{S2}
- iii. I_{B3} , I_{C3} , I_{E3}
- iv. V_{B1} , V_{E1} , V_{C1}
- v. V_{G2} , V_{S2} , V_{D2}
- vi. V_{B3} , V_{E3} , V_{C3}

b. AC Values:

- i. R_{in} (do not include 100k)
- ii. R_{out} (do not include R_L)
- iii. Gain: V_{out}/V_s

#2

1. (a) I_{DIODE} :



(b) $V_{G3} \Rightarrow -V_{G3} + 0.6 + I_{DIODE}(1.7k) = 0$
 $V_{G3} = \boxed{4V}$

(c) $V_{o1} \Rightarrow$

$$\frac{1}{2} K_n \left(\frac{W}{L}\right) (V_{GS2} - V_{tn})^2 = \frac{1}{2} K_n \left(\frac{W}{L}\right) (V_{GS1} - V_{tn})^2$$

$$(9 - V_s - 1)^2 = (V_s + 9 - 1)^2$$

$$V_s = 0$$

$$I_4 = \frac{1}{2} (40\mu)(5)(9 - 0 - 1)^2 = 6.4mA$$

$$I_3 = I_4 = 6.4mA = \frac{1}{2} (40\mu)(200)(4 - V_{o1} - 1)^2$$

$$0 = -1.6 + 9 - 6V_{o1} + V_{o1}^2$$

$$0 = V_{o1}^2 - 6V_{o1} + 7.4$$

$$V_{o1} = \frac{+6 \pm \sqrt{36 - 4(7.4)(1)}}{2} = 4.25, \boxed{1.75}$$

$V_{GS} = 4 - 1.75 = 2.25V$
 $V_{GS} = 4 - 4.25 = -0.25 < V_t$
 X NO

★

(d) $V_{out} = 9 - I_c(4k) = \boxed{4.02}$

$$-9 + I_B(1Meg) + 0.7 = 0$$

$$I_B = \frac{9 - 0.7}{1Meg} = 8.3\mu$$

$$I_c = \beta I_B = 1.245mA$$

#1

2.

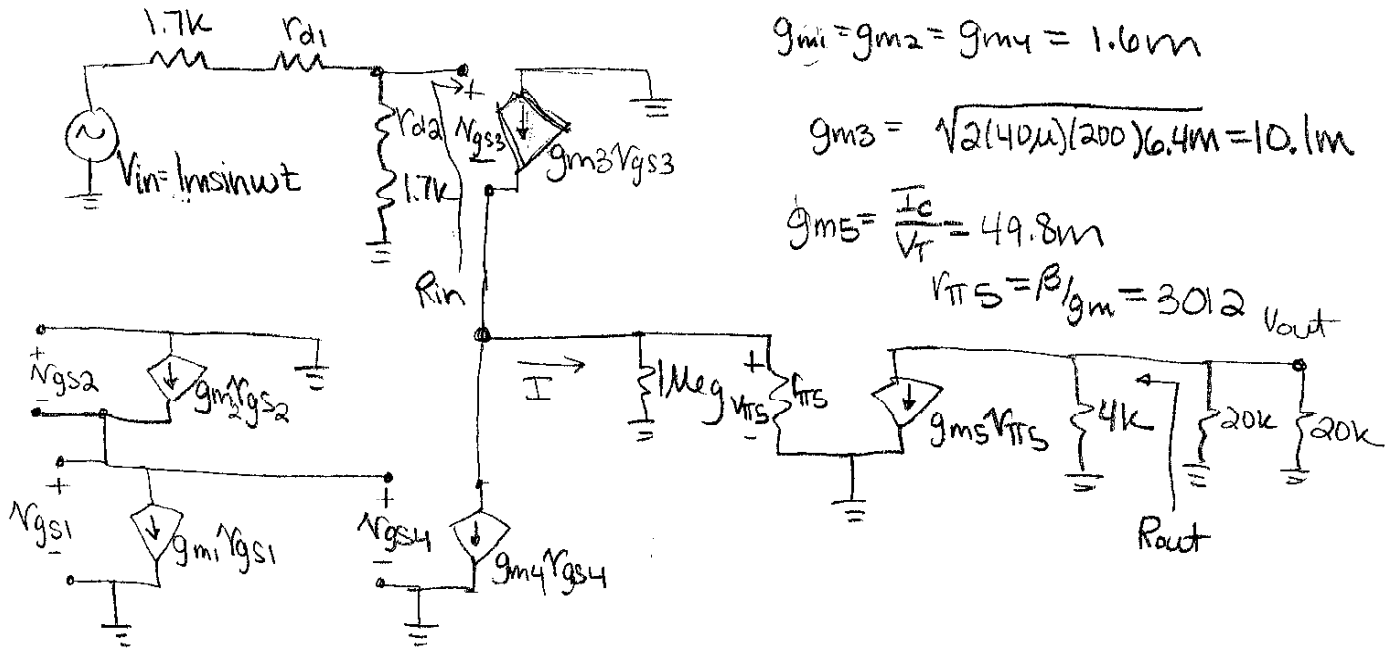
$$r_{d1} = r_{d2} = \frac{nV_T}{I_D} = \frac{(1)(25mV)}{2m} = 12.5 \Omega$$

$$g_{m1} = g_{m2} = g_{m4} = \sqrt{2k_n \left(\frac{W}{L}\right) I_D} = \sqrt{2(40\mu)(5)(6.4m)} = 1.6mS$$

$$g_{m3} = g_{m2} = g_{m4} = 1.6mS$$

$$g_{m5} = \frac{I_C}{V_T} = 49.8mS$$

$$r_{\pi 5} = \beta / g_m = 3012 \Omega$$



3. (a) $R_{in} = \infty$

(b) $R_{out} = 4k$

(c) $\frac{V_{out}}{V_{in}} \Rightarrow V_{out} = -g_{m5} V_{\pi 5} (4k \parallel 10k)$

$$V_{\pi 5} = I (1Meg \parallel r_{\pi 5})$$

$$g_{m3} V_{gs3} - I - g_{m4} V_{gs4} = 0$$

$$I = g_{m3} V_{gs3} - g_{m4} V_{gs4}$$

$$V_{gs4} = 0, V_{gs4} = 0 \Rightarrow V_{gs4} = 0$$

$$V_{gs3} = \frac{1}{2} V_{in}, V_{gs3} = V_{\pi 5}$$

$$V_{\pi 5} = g_{m3} \left(\frac{1}{2} V_{in} - V_{\pi 5}\right) (1Meg \parallel r_{\pi 5}) \Rightarrow V_{\pi 5} = \frac{g_{m3} V_{in} (1Meg \parallel r_{\pi 5})}{2(1 + g_{m3} (1Meg \parallel r_{\pi 5}))}$$

$$V_{out} = \frac{-g_{m5} g_{m3} (1Meg \parallel r_{\pi 5}) (4k \parallel 10k)}{2(1 + g_{m3} (1Meg \parallel r_{\pi 5}))} = \boxed{-69 V/V}$$

#2

4. $V_C = V_B$ is the point of transition between active and saturation.

$$V_C > V_B > V_E \Rightarrow \text{active}$$

$$V_C < V_B > V_E \Rightarrow \text{saturation}$$

$$V_B = 0.7 = V_C$$

$$V_C = 9 - I_C R_C$$

$$0.7 = 9 - (1.245\text{mA})R_C$$

$$R_C = \frac{9 - 0.7}{1.245\text{mA}} = \boxed{6.67\text{ k}\Omega}$$

3.

#1. $I_{\text{DIODE}} : (V_{\text{DO}} = 0.6) \quad V_{\text{IN}}(\text{DC}) = 5\text{V}$

$$-V_{\text{IN}} + I_{\text{DIODE}}(1.8\text{k} + 2\text{k}) + 0.6 + 0.6 = 0$$

$$I_{\text{DIODE}} = \frac{5 - 1.2}{3.8\text{k}} = \boxed{1\text{mA}}$$

$$V_{G4} = +0.6 + I_{\text{DIODE}}(2\text{k}) = \boxed{2.6\text{V}}$$

$V_{o1} \Rightarrow Q_1$ and Q_2 are equal so $V_{s2} = 4.5\text{V}$

$$I_2 = I_1 = \frac{1}{2}(30\mu)(10)(9 - 4.5 - 1)^2 = 1.8\text{mA}$$

$Q_3 : V_{G3} = V_o$ is the point between sat/triode

$$I_4 = \frac{1}{2}(30\mu)(100)(2.6 - I_4(5.2\text{k}) + 9 - 1)^2$$

gives $I_4 = 0.182e^{-2}, 0.23e^{-2}$

$V_{GS} = 2.1$

$V_{GS} = -0.36\text{V}$ off

$$I_4 = I_3 = 1.02\text{mA} = \frac{1}{2}(30\mu)(10)(9 - V_{o1} - 1)^2$$

$$V_{o1} = \boxed{4.5\text{V}}$$

$$V_{\text{out}} = 9 - I_c(1\text{k})$$

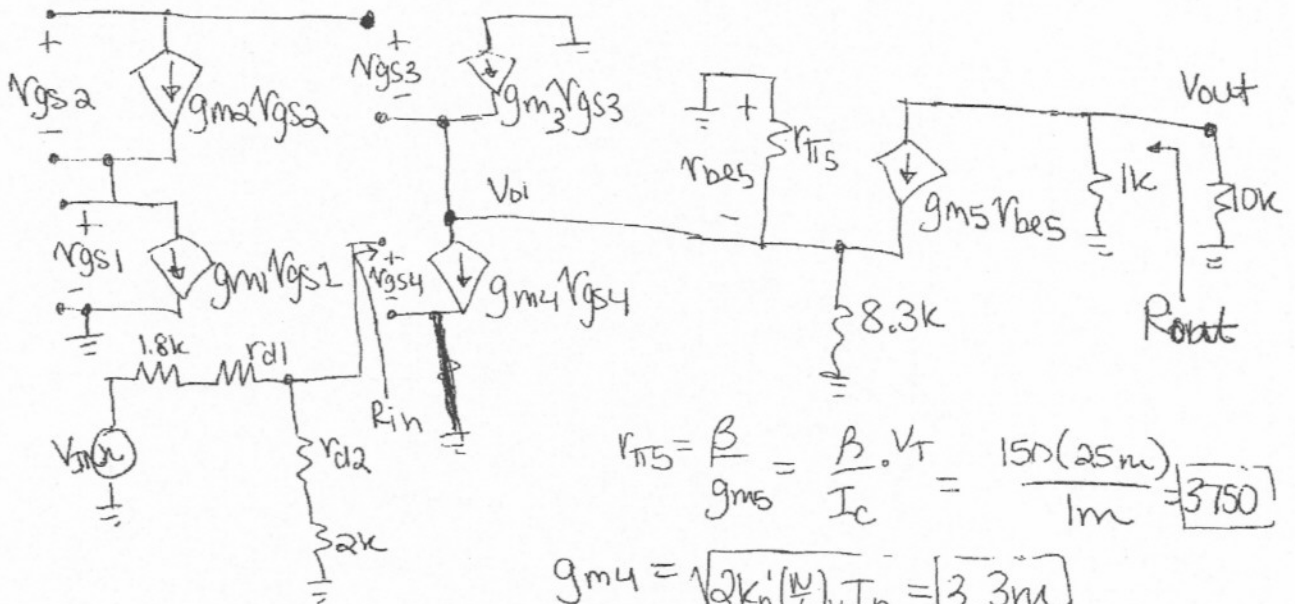
$$0 + 0.7 + I_E(8.3\text{k}) - 9 = 0$$

$$I_E = \frac{8.3}{8.3\text{k}} = 1\text{mA}$$

$$I_c = \alpha I_E = 0.99\text{mA}$$

$$V_{\text{out}} = \boxed{8.01\text{V}}$$

#3.



$$r_{\pi 5} = \frac{\beta}{g_{m5}} = \frac{\beta \cdot V_T}{I_c} = \frac{150(25m)}{1m} = \boxed{3750}$$

$$g_{m4} = \sqrt{2k_n' \left(\frac{W}{L}\right)_4 I_D} = \boxed{3.3m}$$

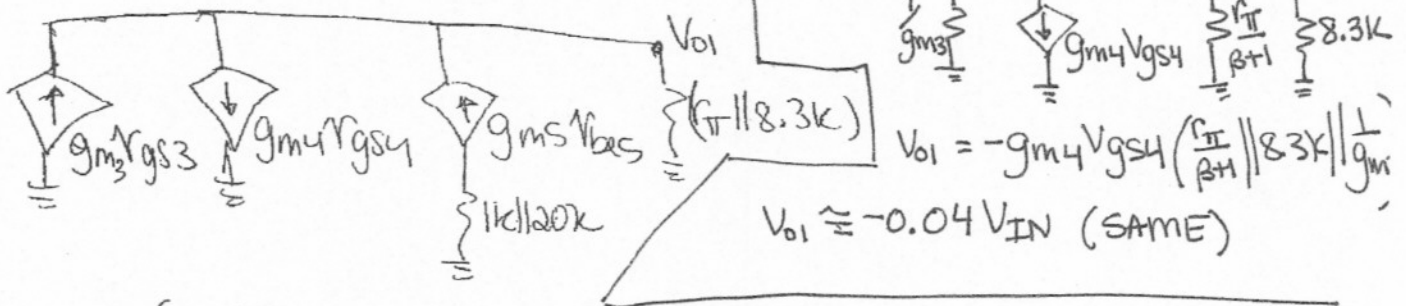
$$r_{d1} = r_{d2} = \frac{V_T}{I_D} = \frac{2(25m)}{1m} = \boxed{50\Omega}$$

$$g_{m5} = \frac{I_c}{V_T} = \frac{1m}{25m} = \boxed{0.04}$$

$$R_{in} = \infty$$

$$R_{out} = 1k$$

OR $V_{gs3} = -V_{o1}$ so
reflect $g_{m5}V_{be5}$



$$V_{o1} = -g_{m4}V_{gs4} \left(\frac{r_{\pi}}{\beta+1} \parallel 8.3k \parallel \frac{1}{g_{m5}} \right)$$

$$V_{o1} \approx -0.04 V_{IN} \text{ (SAME)}$$

$$(g_{m3}V_{gs3} - g_{m4}V_{gs4} + g_{m5}V_{be5})(r_{\pi} \parallel 8.3k) = V_{o1}$$

$$V_{gs3} = 0, V_{s3} = V_{o1}$$

$$V_{gs4} = \frac{V_{IN}(r_{d2} + 2k)}{1.8k + 2k + 2r_{d1}} = 0.5V_{IN}$$

$$V_{be5} = -V_{o1}$$

$$[-g_{m3}V_{o1} - g_{m4}(0.5V_{IN}) + g_{m5}(-V_{o1})](2583) = V_{o1}$$

$$V_{o1} = \frac{-g_{m4}(0.5 \times 2583)V_{IN}}{1 + (g_{m3} + g_{m5})2583}$$

$$\#3. \quad \frac{V_{o1}}{V_{IN}} = \frac{-g_{m4} (0.5) 2583}{1 + (g_{m3} + g_{m5}) 2583}$$

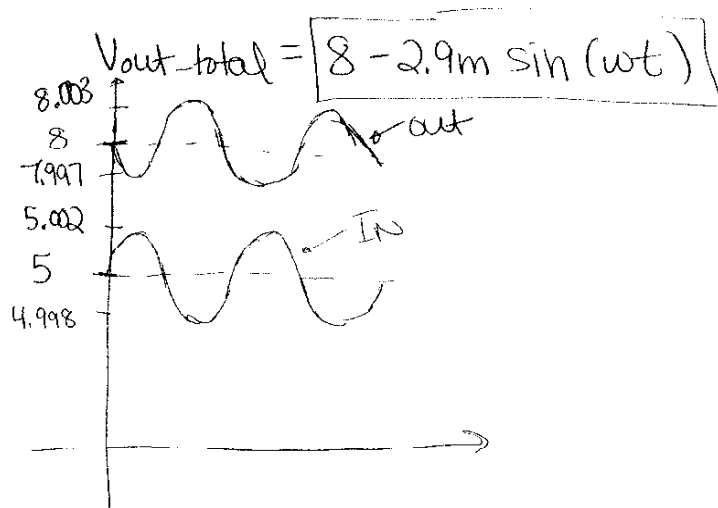
$$\frac{V_{o1}}{V_{IN}} = \frac{-4.3}{(1 + (1\text{m} + 0.04) 2583)} = -0.04$$

$$\frac{V_{out}}{V_{o1}} \Rightarrow -g_{m5} R_{bes} (1\text{k} \parallel 110\text{k}) = -g_{m5} (-V_{o1}) (909) = V_o$$

$$\frac{V_{out}}{V_{o1}} = 36.36$$

$$\frac{V_{out}}{V_{IN}} = \frac{V_{o1}}{V_{IN}} \cdot \frac{V_{out}}{V_{o1}} = 36.36 (-0.04) = \boxed{-1.45}$$

$$V_{out} = -1.45 (2\text{m} \sin \omega t) = -2.9\text{m} \sin(\omega t)$$



#3

frequency dependence:

★ $C_{s4} \Rightarrow \frac{1}{C_{s4}(\frac{1}{g_{m4}} \parallel 5.2k)} = \frac{1}{1000p(\frac{1}{3.3m} \parallel 5.2k)} = 3.5 \text{ Meg rad/sec.}$

• $C_{s3} \Rightarrow \frac{1}{C_{s3}(\frac{1}{g_{m3}} + r_{\pi 5} \parallel 8.3k \parallel \frac{1}{g_{m5}})} = \frac{1}{1000p(\frac{1}{1m} + 3750 \parallel 8.3k \parallel \frac{1}{0.04})} = 976k \text{ rad/sec.}$

• $C_{s3} \Rightarrow \frac{1}{C_{s3}(1k + 10k)} = 91k \text{ rad/sec.}$

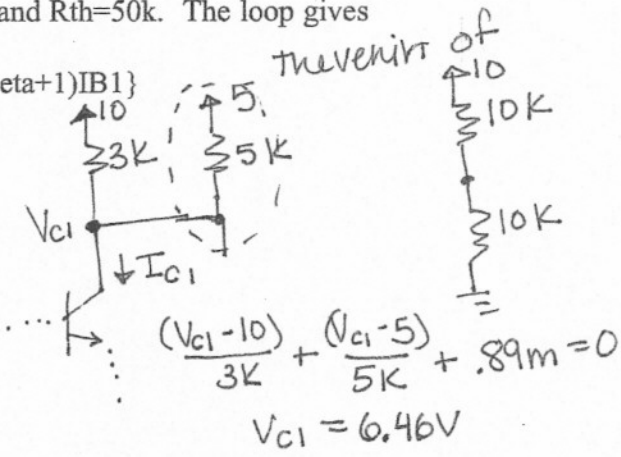
★ #4

Thevenin equivalent at base of Q1: $5V = V_{th}$ and $R_{th} = 50k$. The loop gives

$-5 + I_{B1}(50k) + V_{BE} + I_{E1}(4.3k) = 0$ { $I_{E1} = (\beta + 1)I_{B1}$ }

$I_{B1} = 4.3 / (50k + 434k) = 8.9 \mu$
 $I_{E1} = 101 * 8.9 \mu = .899 \text{ mA}$
 $I_{C1} = \beta * I_{B1} = .89 \text{ mA}$

$V_{B1} = 5 - I_{B1}(50k) = 4.6 \text{ V}$
 $V_{E1} = I_{E1}(4.3k) = 3.9 \text{ V}$



$6.46 \text{ V} > 4.6 \text{ V} > 3.9 \text{ V}$ ✓ ACTIVE

Q2: $V_{G2} = V_{C1} = 6.5$

$V_s = I_{D2}(1k) - 10 \Rightarrow I_{D2} = 1/2k^2 (W/L)(V_{GS} - V_t)^2 = 1/2k^2 (W/L)(6.5 - I_{D2}(1k) + 10 - 1)^2 \Rightarrow I_{D2} = 12 \text{ mA}$

$V_{D2} = V_{B3} = 10 - (12.03 \text{ mA})500 \approx 4 \text{ V}$

NOT SAT

$\times 4 < (6.5 - 1)$

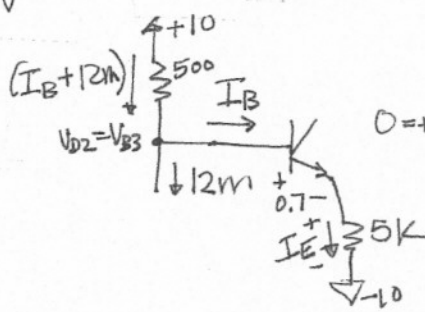
Q3: $V_{B3} = V_{D2} = 4$

$I_C = 2.63 \text{ mA}$

$V_E = I_{E3}(5k) - 10 = 3.3 \text{ V}$

$V_C = 10 \text{ V}$

Sat $\Rightarrow \{10 > 4 > 3.3\}$



$V_s = 10$
 $V_{GS} = -3.5 < V_t$
 $\times NO$
 $0 = +10 - (I_B + 12 \text{ mA})500 - 0.7 - I_E(5k) - 10$
 $I_E = 2.66 \text{ mA}$
 $I_B = 26.3 \mu$

(b) $R_{in} = 2809 \text{ ohm}$, $R_{out} = \text{infinity}$, Nonlinear gain due to Q2 not being saturated