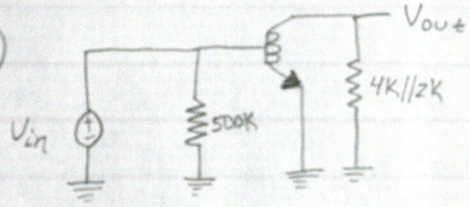
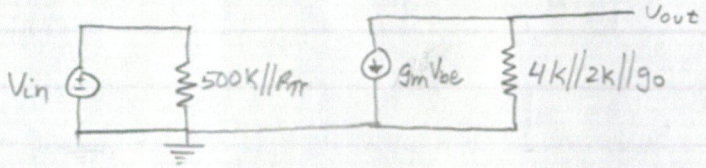
EE 330
HW 9 - solution
Due 10/19/2012

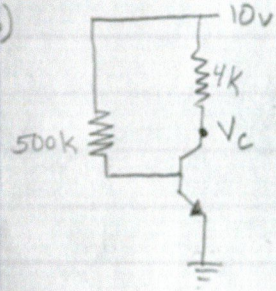
1(a)
10 points



$\Rightarrow$



(b)



$V_{OUT} = 0V$ since C_2 is large

$J_S A_E = 10^{-12}$ A $\quad \beta = 100$

$$I_B = \frac{10-(V_B-0)}{500K} = \frac{10^{-12}A}{100} e^{\frac{(V_B-0)}{26mV}} \qquad V_B = V_{BE} = 0.555\ V$$

$$I_C = \frac{10-V_C}{4k} = 10^{-12}[A] \cdot e^{\frac{V_B-0}{26mV}}$$

$V_C = 2.444$ [V]

(c) $A_V = -g_m \cdot R \qquad g_m = \frac{I_C}{V_t} \qquad I_C = \frac{10-2.444}{4K}$

$V_t = 26mV$

$g_m = 290.604$

$A_V = -g_m(4K//2K)$

$A_V = -96.87 \left[\frac{V}{V}\right]$

(d) $V_{in} = 200mV \cdot \sin(\omega t + \theta)$

$V_{out} = A_V \cdot V_{in}$

$V_{out} = -19.374 \sin(\omega t + \theta)$ [V]

$V_{gs} - V_{ds}$

$(0+2) - (V_d + 2) < V_T$

$V_d > V_T$

2 (a) for saturation $V_{gd} < V_T$ $V_{gs} \geq V_T$

10 points $V_T = 0.5$ $V_{IN} = 0$ $V_{gs} = 2$ $(2 - V_{ds}) < (V_T = 0.5)$

$V_{ds} > 1.5$ $V_s = -2$

so $V_d \geq -0.5$ V

or $V_d > -V_T$

$$I_{d_{min}} = \frac{4 + 0.5}{R_1} = 100 \frac{\mu A}{V^2} \cdot \left(\frac{12\mu}{2\mu}\right) \cdot \left(\frac{1}{2}\right)(2 - 0.5)^2$$

$$\boxed{R_1 = 6.67 k\Omega}$$

(b) $R_{1max} = 6.67 k\Omega$

then $R_1 = \frac{1}{3} R_{1max} = 2.22 k\Omega$

saturation? $I_d = \frac{4 - V_d}{2.22k} = 100 \frac{\mu A}{V^2} \cdot \left(\frac{12}{2}\right)\left(\frac{1}{2}\right)(2 - 0.5)^2$ $V_d = 2.5$ V $V_d > -V_T$ ✓

we have saturation

$$A_V = -g_m R_{OUT} = -\left(100 \frac{\mu A}{V^2} \cdot \left(\frac{12}{2}\right) \cdot (2 - 0.5)\right) \cdot 2.22k$$

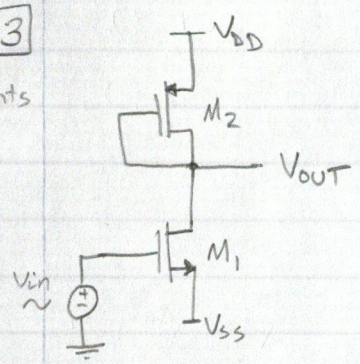
$$\boxed{A_V = -2 \left[\frac{V}{V}\right]}$$

(c) $V_d = V_{OUT} = 2.5$ V ← part b

$V_{in} = 0.001 \sin(5000t + 75°)$

$$\boxed{V_{out} = 2.5 - 0.002 \sin(5000t + 75°)}$$

3 10 points



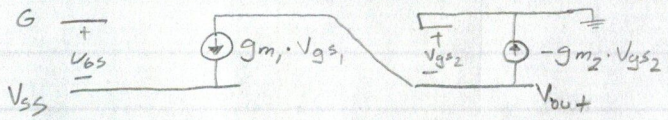
$V_{in} = V_M \cos(\omega t + \theta)$

$M_2 \Rightarrow$ saturation

$M_1 \Rightarrow$ saturation (given)

then $I_{D_1} = I_{D_2}$

$$A_v = \frac{V_{out}}{V_{in}} = \frac{-g_{m1}}{g_{m2}}$$



$g_{m_1} \cdot V_{in} = -g_{m_2} \cdot V_{out}$

$$\boxed{V_{out} = -\frac{g_{m_1}}{g_{m_2}} \cdot V_m \cos(\omega t + \theta)}$$

4 5 points

$V_{DD} = 5V$ $V_{SS} = -2V$ $\frac{W_1}{L_1} = \frac{15\mu}{2\mu}$ $\frac{W_2}{L_2} = \frac{4.5\mu}{1\mu}$ $\mu_n C_{ox} = 100\mu A/V^2$ $V_{T_n} = 0.5$ $\mu_p C_{ox} = 30\mu A/V^2$ $V_{T_p} = -0.5$

$V_{OUT} \Rightarrow I_{D_1} = I_{D_2}$ $100\frac{\mu A}{V^2} \cdot \frac{15}{2}\left(\frac{1}{2}\right)\left((0+2)-0.5\right)^2 = 30\frac{\mu A}{V^2} \cdot \frac{4.5}{1}\left(\frac{1}{2}\right)\left((V_{OUT}-5)+0.5\right)^2$

$V_{OUT} = 0.9645$ [V]

$g_m = \mu C_{ox} \cdot \frac{W}{L} \cdot (V_{gs} - V_t)$

$g_{m_1} = 100\frac{\mu A}{V^2}\left(\frac{15}{2}\right)(0+2) - 0.5)$ $g_{m_1} = 0.001125$

$\frac{g_{m_1}}{g_{m_2}} = 2.357$

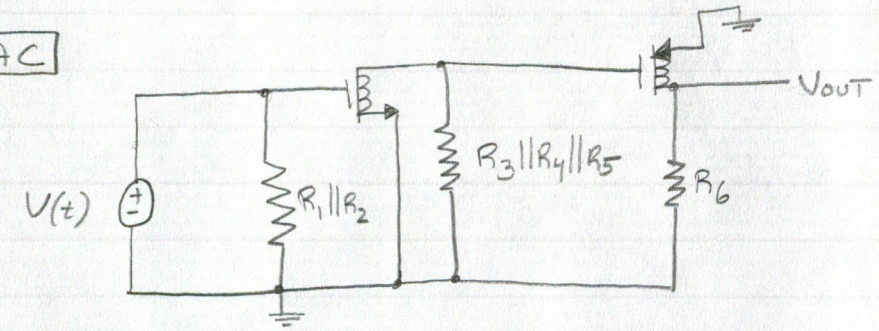
$g_{m_2} = -30\frac{\mu A}{V^2}\left(\frac{4.5}{1}\right)\left((0.9645-5)+0.5\right)$ $g_{m_2} = 0.0004773$

$V_{out} = -2.357 \cdot V_M \cdot \cos(\omega t + \theta)$

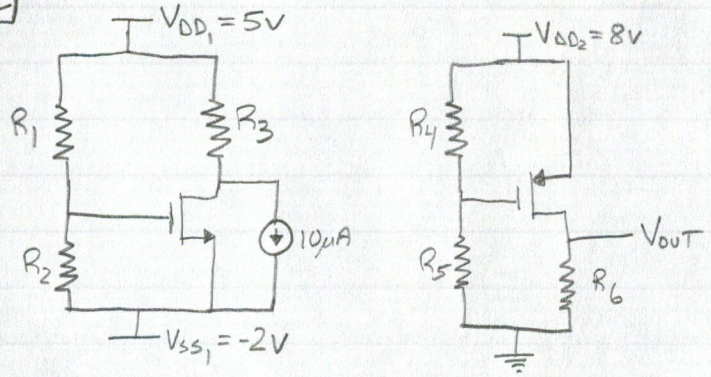
$$\boxed{V_{out} = 0.9645 - 2.357 \cdot V_M \cdot \cos(\omega t + \theta)}$$

5 points

5 **AC**

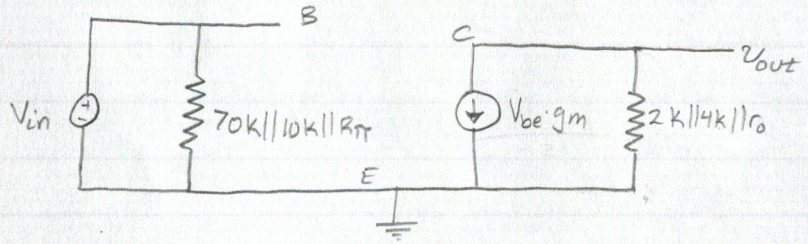


DC

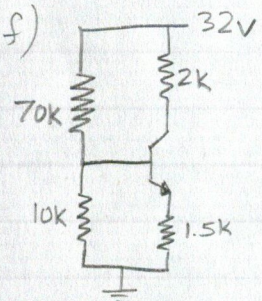


10 points

6 e) **AC**



f)



$$\frac{32-V_B}{70K} = I_B + \frac{V_B}{10K} \qquad I_B = \frac{J_S A_E}{\beta} e^{V_{be}/V_t} = \frac{10^{-12}}{100} e^{\frac{V_{BE}}{26mV}}$$

$$\text{(eq 1)} \quad \frac{32-V_B}{70K} = \frac{10^{-12}}{100} e^{\frac{V_{BE}}{26mV}} + \frac{V_B}{10K}$$

$$I_E = \frac{V_E}{1.5K} = I_B + I_C \qquad I_B = \frac{I_C}{100} \qquad I_E = \frac{101}{100}(I_C) \quad \text{and} \quad V_E = V_B - V_{BE}$$

$$\text{(eq 2)} \quad \frac{V_B - V_{BE}}{1.5K} = \frac{101}{100}\left(10^{-12}\right) e^{\frac{V_{BE}}{V_t}}$$

$V_{BE} = 0.5587$ v

$V_B = 3.8121$ v

$$I_C = \frac{32 - V_C}{2K} = 10^{-12} \cdot e^{\frac{0.5587}{26mV}}$$

$V_C = 27.705$ [V]

$V_{OUT} = 0$ [V]

g) $V_{out} = (-V_{be} \cdot g_m)(2K \| 4K)$ $\quad V_{be} = V_{in}$

$A_V = \frac{V_{out}}{V_{in}} = -g_m \cdot (2K \| 4K)$ $\quad g_m = \frac{I_C}{V_t}$ $\quad I_C = \frac{3.2 - V_C}{2K}$ $\quad V_t = 26mV$

$g_m = 0.082595$

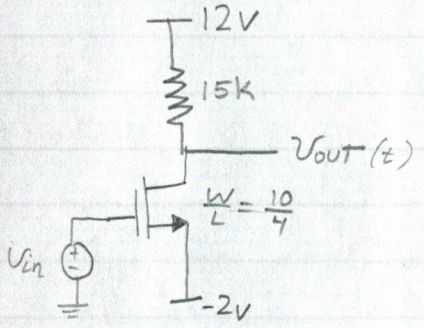
$$\boxed{A_V = -110.127 \ \frac{V}{V}}$$

h) $V_m = 200mV$

$V_{in} = 0.2 \sin(\omega t + \theta)$

$V_{out} = A_V \cdot V_{in}$ $\quad \boxed{V_{out} = -22.025 \sin(\omega t + \theta)}$

7
10 points



for DC $\quad V_{gs} > V_T \quad (0+2) > 1$ ✓

$V_{gd} < V_T$ ← check

$I_D = \frac{12 - V_{OUT}}{15K} = 100\frac{\mu A}{V^2} \cdot \frac{10}{4}\left(\frac{1}{2}\right)(2-1)^2$

$V_{OUT} = V_D = 10.125 \ V$

so $(V_{gd} = (0 - 10.125)) < (V_T = 1)$ ✓ saturation

$I_D = \frac{12 - 10.125}{15K}$ $\quad I_D = 125\mu A$

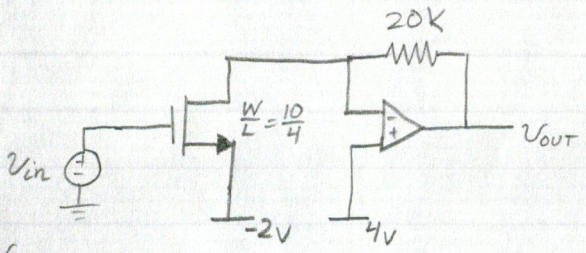
$A_V = -g_m R_{OUT}$

$A_V = \frac{2 \cdot 100 \cdot R}{V_{SS} + V_T} = \frac{2 \cdot 125\mu A \cdot 15K}{-2+1}$

$$\boxed{\begin{aligned} A_V &= -3.75 \ \left[\frac{V}{V}\right] \\ V_D &= 10.125 \ [V] \end{aligned}}$$

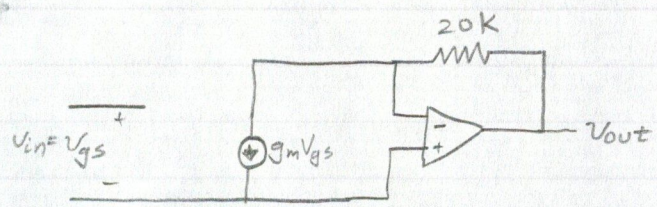
8

10 points



V_{in} = 1KHz 25mVp

AC



$$\frac{V_{out}-0}{20K} = -g_m \cdot V_{gs} \qquad V_{gs} = V_{in}$$

$$\frac{V_{out}}{V_{in}} = g_m \cdot 20K$$

$$g_m = \mu_n C_{ox} \frac{W}{L}(V_{gs}-V_{Tn})$$

$$= 100\frac{\mu A}{V^2}\cdot\left(\frac{10}{4}\right)\left((0+2)-1\right)$$

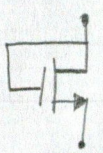
$$g_m = 2.5\times 10^{-4}$$

$$V_{out} = 20K\cdot(2.5\cdot 10^{-4})\cdot(0.025\sin(1000(2\pi)t))$$

$$\boxed{V_{out} = 0.125\sin(2000\pi t)\ [V]}$$

9

5 points



← saturation small signal impedance is equal to $\frac{1}{g_m}$

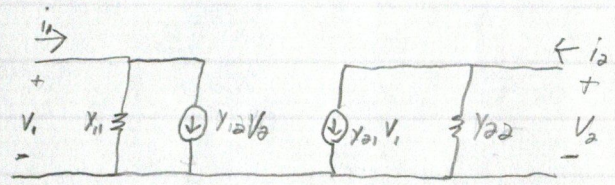
$$g_m = \mu C_{ox}\frac{W}{L}(V_{GSQ}-V_T) = \sqrt{2\mu C_{ox}\frac{W}{L}}\cdot\sqrt{I_{DQ}}$$

$$\boxed{\frac{1}{g_m} = \frac{1}{\sqrt{2\mu C_{ox}\frac{W}{L}}\cdot\sqrt{1mA}}}$$

$$g_m = \frac{I_{CQ}}{V_t} \qquad \frac{1}{g_m} = \frac{26mV}{1mA} = \boxed{26\,\Omega}$$

10

15 points



a) $y_{11} = \left.\frac{dI_1}{dV_1}\right|_Q$ $y_{12} = \left.\frac{dI_1}{dV_2}\right|_Q$ $y_{21} = \frac{dI_2}{dV_1}$ $y_{22} = \frac{dI_2}{dV_2}$

$I_1 = V_1^2 V_2^2$ $I_2 = 0.1e^{0.2V_1V_2}$

$\boxed{y_{11} = 2V_1V_2^2 \quad y_{12} = 2V_1^2V_2 \quad y_{21} = 0.02V_2e^{0.2V_1V_2} \quad y_{22} = 0.02V_1e^{0.2V_1V_2}}$

b) $V_{1Q} = 5V$ $V_{2Q} = 1V$

$\boxed{y_{11} = 10 \quad y_{12} = 50 \quad y_{21} = 0.0544 \quad y_{22} = 0.2718}$

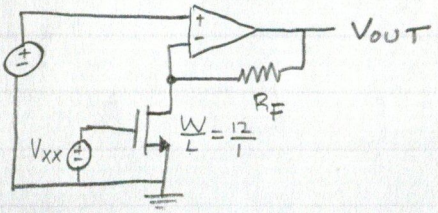
c) $\boxed{I_{1Q} = V_{1Q}^2 V_{2Q}^2 = 25A \qquad I_{2Q} = 0.1e^{0.2V_{1Q}V_{2Q}} = 271.8mA}$

d) $i_1 = y_{11}V_1 + y_{12}V_2 = \boxed{110mA_{RMS}}$

$i_2 = y_{22}V_2 + y_{21}V_1 = \boxed{0.598mA_{RMS}}$

11

10 points



(a)

$$R_{FET} = \frac{1}{\mu C_{ox} \frac{W}{L} (V_{gs} - V_T)} \qquad R_{FET} = \frac{1}{100 \frac{\mu A}{V^2} \left(\frac{12}{1}\right)(2-1)} \qquad R_{FET} = 833.33\ \Omega$$

A_V for non-inverting amplifier $= 1 + \frac{R_F}{R_{FET}}$

$$\boxed{A_V = 1 + \frac{R_F}{833.33} \left[\frac{V}{V}\right]}$$

(b) $1.5 < V_{xx} < 4$

$$R_{FET}\ (V_{xx}=1.5) = \frac{1}{100 \frac{\mu A}{V^2} \left(\frac{12}{1}\right)(1.5-1)} \qquad R_{FET} = 1666.667\ \Omega$$

$$\boxed{A_V (V_{xx}=1.5) = 1 + \frac{R_F}{1666.67}}$$

$$R_{FET}\ (V_{xx}=4) = \frac{1}{100 \frac{\mu A}{V^2} \left(\frac{12}{1}\right)(4-1)} \qquad R_{FET} = 277.77$$

$$\boxed{A_V (V_{xx}=4) = 1 + \frac{R_F}{277.77}}$$

if R_F is large then $\frac{A_V (V_{xx}=1.5V)}{A_V (V_{xx}=4V)} \approx \frac{1}{6}$

as V_{xx} increases, the gain increases as well.

10pts 12a) $R_{FET} = \frac{1}{\frac{W}{L}\mu C_{ox}(V_{xx} - V_T)} = 3.33K\Omega = \frac{3.33K}{(V_{xx} - .5)}$

$I = \frac{V_{in}}{R_{FET}}$ $\quad V_{out} = V_{in} + I\left(\frac{1}{40K} + .1E\text{-}6 \cdot s\right)^{-1}$

$V_{out} = V_{in}\left(1 + V/R_{FET}\left(1/40K + .1E\text{-}6 \cdot s\right)^{-1}\right)$

$\frac{V_{out}}{V_{in}} = 1 + \frac{1}{R_{FET}(1/40K + .1E\text{-}6 s)}$

$\frac{V_{out}}{V_{in}} = \frac{R_{FET}/40K + .1E\text{-}6 \cdot R_{FET} \cdot s + 1}{R_{FET}/40K + .1E\text{-}6 \cdot R_{FET} \cdot s}$

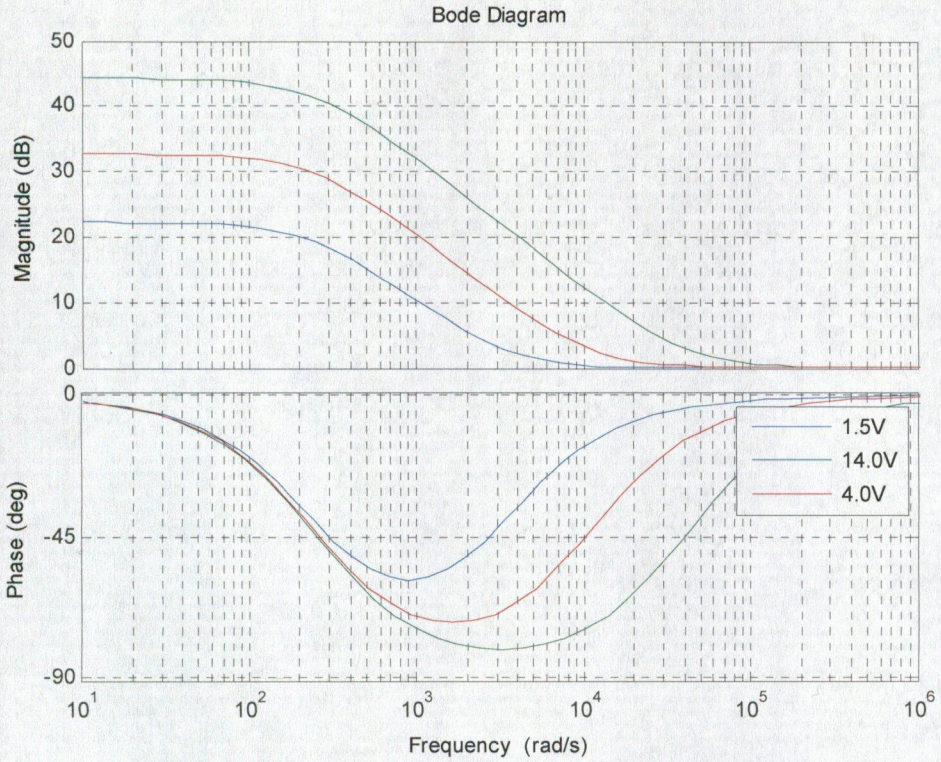
b) see attached graphs

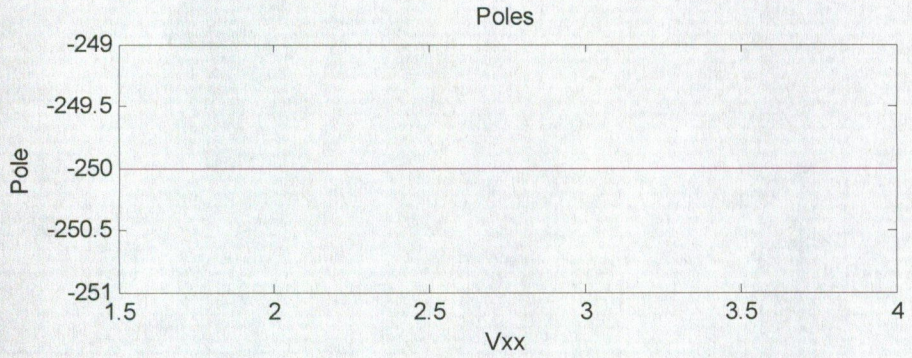
c) $-\frac{1/40K}{1E\text{-}6} = \text{poles} = -250$

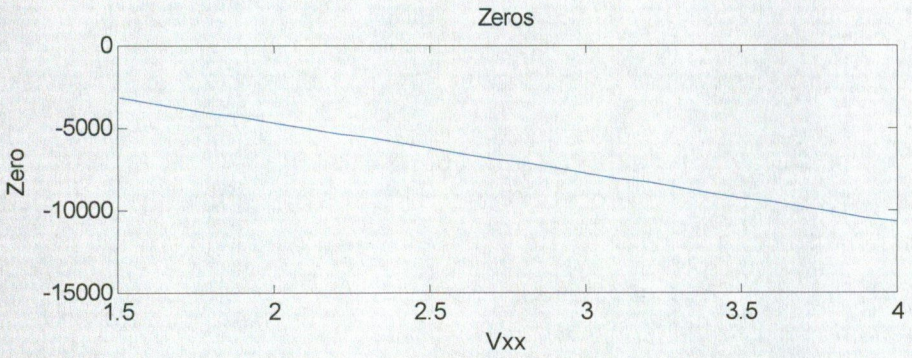
$\text{zeros} = -1/.1E\text{-}6\left(1/40K + 1/R_{FET}\right)$

see attached plot

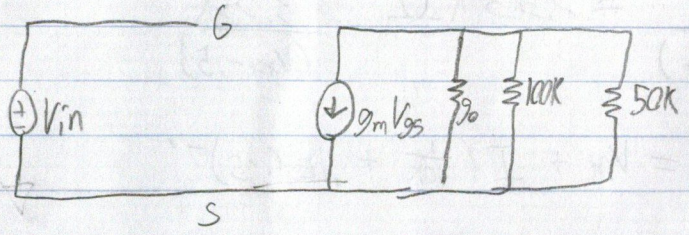
12)


Bode Diagram
Magnitude (dB)
50
40
30
20
10
0
Phase (deg)
0
-45
-90
10^1
10^2
10^3
10^4
10^5
10^6
Frequency (rad/s)
1.5V
14.0V
4.0V


Poles
Pole
-249
-249.5
-250
-250.5
-251
1.5
2
2.5
3
3.5
4
Vxx


Zeros
Zero
0
-5000
-10000
-15000
1.5
2
2.5
3
3.5
4
Vxx

13a)



b) $I_D = 100E\text{-}6 \frac{8}{20}(2-1)^2 = 4E\text{-}5\,A$

$V_D = 5 - 4E\text{-}5 \cdot 100K = \boxed{1\,V}$ Saturation $V_{GS} \geq V_T$ $V_{DS} \geq V_{GS} - V_T$

$V_{out} = \boxed{0\,V}$

c) $g_o = \lambda \cdot I_{DQ}$ $\lambda = 1/100$ $g_o = 4E7$ $R_o = 2.5E6$

$g_m = \frac{2 I_{DQ}}{V_{GSQ} - V_T} = 8E\text{-}5$ $A_V = -g_m (1/g_o + 1/100K + 1/50K)^{-1}$

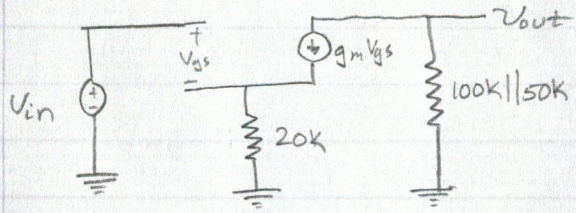
$= \boxed{-2.6}$

d) $20mV \cdot -2.6 = -52mV$

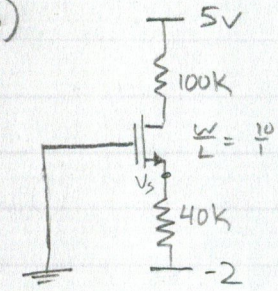
$\boxed{v_{out} = -52mV \cdot \sin(\omega t + \theta)}$

14 (a)

10 points



(b)



Guess saturation

$$I_D = 100\mu A/V^2 \left(\frac{10}{1}\right)\left(\frac{1}{2}\right)\left((0-V_S)-1\right)^2$$

$$I_D = \frac{V_S+2}{40K} \qquad V_S = -1.2\ V \qquad I_D = 20\mu A$$

$V_{gd} < V_T$ $\quad V_d = 5 - 100K \cdot 20\mu A$ $\quad V_d = 3\ V$

$V_{gs} > V_T$ $\quad V_S = -2 + 40K \cdot 20\mu A$ $\quad V_S = -1.2V$

$V_{gd} = -3 < V_T$ ✓

$V_{gs} = 1.2 > V_T$ ✓ saturation

$\boxed{V_D = 3\ V}$

$\boxed{V_{OUT} = 0\ V}$

(c) $v_{out} = -g_m v_{gs} (100K||50K)$

$v_{gs} = v_{in} - (g_m v_{gs} \cdot 20K) \qquad v_{gs} = \frac{v_{in}}{1 + g_m 20K}$

$$\frac{v_{out}}{v_{in}} = -\frac{g_m}{1+g_m 20K}(100K||50K) \qquad g_m = \mu C_{ox}\frac{W}{L}(V_{gs}-V_t)$$

$= 100\mu A \cdot \left(\frac{10}{1}\right)\cdot(1.2-1)$

$g_m = 2\times10^{-4}$

$\boxed{A_V = -1.333\ \left[\frac{V}{V}\right]}$

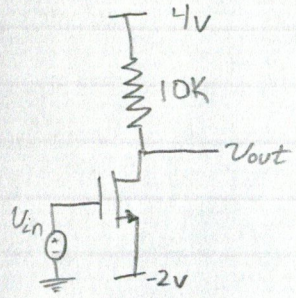
(d) $V_m = 200mV$

$v_{out} = A_V \cdot v_{in} \qquad v_{in} = V_m \cdot \sin(\omega t + \theta)$

$\boxed{v_{out} = -0.2667 \sin(\omega t + \theta)}$

15

10 points



$A_V = -8$

$$A_V = \frac{2 \cdot I_{DQ} \cdot R_{OUT}}{V_{SS} + V_T}$$

$$A_V = -8 = \frac{2 \cdot I_{DQ} \cdot 10K}{-2+1}$$

$$I_{DQ} = 0.4mA$$

$$0.4mA = 100\frac{\mu A}{V^2} \cdot \left(\frac{W}{L}\right)\left(\frac{1}{2}\right)(V_{gs}-1)^2 \qquad V_{gs} = (0+2)$$

$\frac{W}{L} = 8$

let $W = 8\mu$

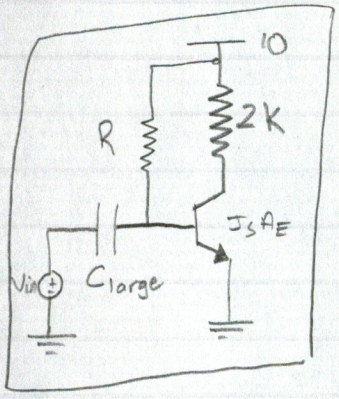
$L = 1\mu$

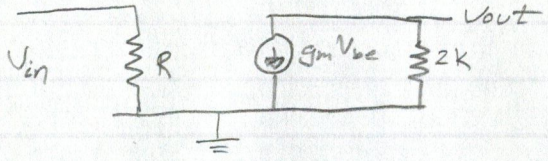
check saturation $\quad V_D = 4 - 10K \cdot I_{DQ} \quad V_D = 0V$

$V_{gd} = (0-0) < 1$

$V_{gs} = 0+2 \geq 1$ ✓ saturation

16





$$A_V = -8 = \frac{V_{out}}{V_{in}}$$

$V_{out} = -2K \cdot g_m \cdot V_{be} \qquad V_{be} = V_{in}$

$$g_m = \frac{I_C}{V_t} \qquad \frac{V_{out}}{V_{in}} = -8 = \frac{-2K \cdot I_C}{26mV}$$

$I_C = 0.104mA$

$$I_C = J_S A_E e^{\frac{V_{be}}{V_t}} \qquad \text{let } V_{be} = 0.6$$

$$I_B = \frac{I_C}{100} = \frac{10 - V_{be}}{R}$$

then $R = 9M\Omega$

$J_S A_E = 9.882 \times 10^{-15}$

EE 330 - F12
HW 9 – Solution
Problem 17 – Extra Credit
+ 20 Points

Verilog Code – **7 points**

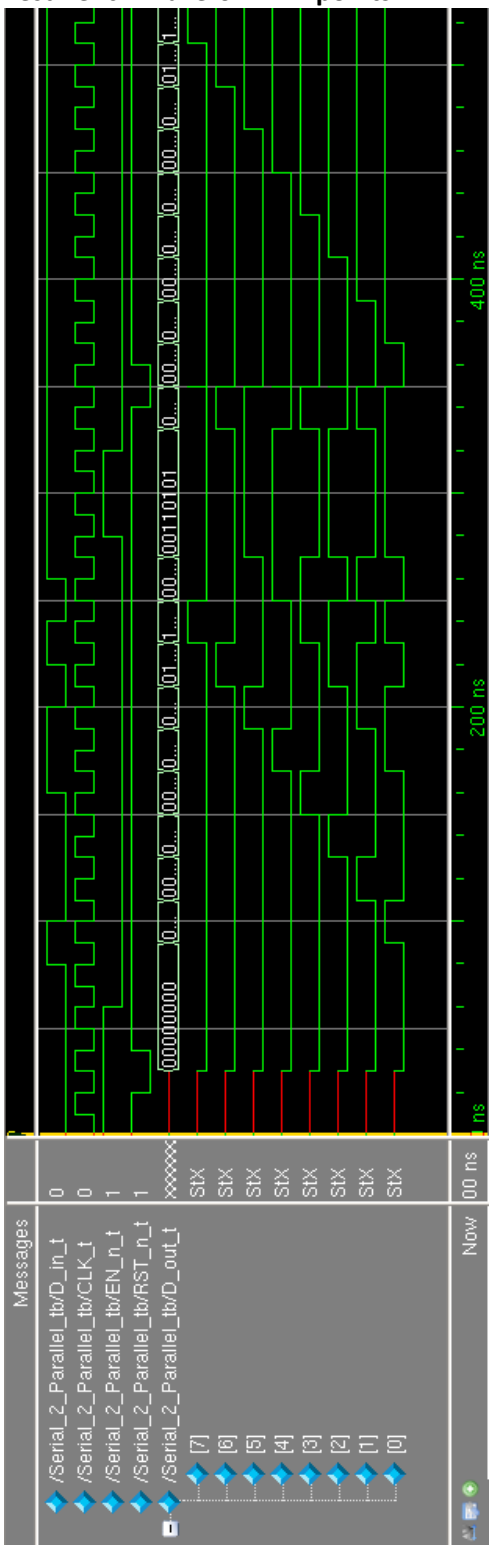
```
module Serial_2_Parallel(D_in, D_out, CLK, RST_n, EN_n);
  input CLK;
  input D_in;
  input RST_n;
  input EN_n;
  output reg [7:0] D_out;

  always @(posedge(CLK))
  begin
    case(RST_n)
      0: begin//reset data (active low)
        D_out <= 8'b00000000;
      end
      1: begin//do nothing
    end
    endcase
    case(EN_n)
      0: begin //enable (active low)
        D_out = (D_out << 1) | D_in;
      end
      1: begin //do nothing
      end
    endcase
  end
endmodule
```

Verilog Test Bench simulation code – **6 points**

```
`timescale 1ns/1ps

module Serial_2_Parallel_tb();
  reg D_in_t;
  reg CLK_t;
  reg EN_n_t;
  reg RST_n_t;
  wire [7:0] D_out_t;

  Serial_2_Parallel test(D_in_t, D_out_t, CLK_t, RST_n_t, EN_n_t);

  always #10 CLK_t <= ~CLK_t;
  initial begin

    D_in_t = 0; CLK_t = 0; EN_n_t = 1; RST_n_t = 1; // start in complete disabled state
    #20 RST_n_t = 0;
    #20 RST_n_t = 1;//data has been reset
    #20 EN_n_t = 0; //device enabled
    #20 D_in_t = 1; //Data
    #20 D_in_t = 0;
    #20 D_in_t = 0;
    #20 D_in_t = 0;
    #20 D_in_t = 1;
    #20 D_in_t = 1;
    #20 D_in_t = 0;
    #20 D_in_t = 1; //8 bits sent
    #20 D_in_t = 0; //send 2 more to show operation
    #20 D_in_t = 1;
    #20 EN_n_t = 1; //disable
    #20 D_in_t = 1; //shouldn't appear in D_out
    #20 EN_n_t = 0; //reenable
    #20 RST_n_t = 0;//show RST works
    #20 RST_n_t = 1;
  end
endmodule
```

EE 330 - F12
HW 9 – Solution
Problem 17 – Extra Credit
+ 20 Points

Test Bench Waveform – **7 points**



NOTE: operation of data shifting, reset and enable location