SOLUTIONS:

Problem 1:

First we solve for quiescent I_{DS}:

$$I_{DSQ} = \frac{\mu C_{ox}}{2}\frac{W}{L}(V_{GS} - V_T)^2 = \frac{350\mu}{2}\frac{12}{2}(1 - 0.5)^2 = 0.2625\ mA$$

Then we will use I_{DSQ} to get g_m:

$$g_m = \frac{2I_{DSQ}}{V_{GS} - V_T} = \frac{2 * 0.2625\ m}{1 - 0.5} = 1.05\ mA/V$$

Solving for small signal gain we get the following (we will ignore g_{ds}):

$$-g_m V_{gs} = V_{ds}\frac{1}{R_L} \rightarrow \frac{V_{ds}}{V_{gs}} = \frac{V_{out}}{V_{in}} = -g_m * R_L = -1.05m * 5k = -5.25\ V/V$$

Problem 2:

First we solve for quiescent I_{DS}:

$$I_{DSQ} = \frac{\mu C_{ox}}{2}\frac{W}{L}(V_{GS} - V_T)^2 = \frac{350\mu}{2}\frac{6}{4}(1 - 0.5)^2 = 0.065625\ mA$$

Then we will use I_{DSQ} to get g_m:

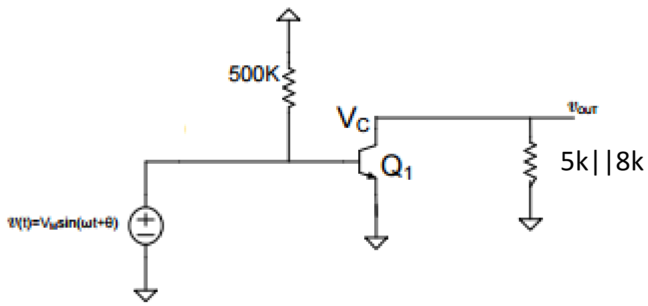
$$g_m = \frac{2I_{DSQ}}{V_{GS} - V_T} = \frac{2 * 0.065625\ m}{1 - 0.5} = 0.2625\ mA/V$$

Solving for small signal gain we get the following (we will ignore g_{ds}):

$$-g_m V_{in} = V_{out}\frac{1}{R_L} \rightarrow \frac{V_{out}}{V_{in}} = -g_m * R_L = -0.2625m * 4k = -1.05\ V/V$$

Problem 3:

a)



b) $V_{cq} = 10V - (5k * I_{cq})$

$$I_{cq} = \frac{\beta(10 - 0.6)}{500k} = 1.88\ mA$$

$V_{cq} = 10V - (5k * 1.88m)$

$V_{cq} = 0.6V$

$V_{outq} = 0$

c) $v_{out} = (-g_m v_{IN}) * (\frac{1}{g_o} // R_L)$

$$A_v = \frac{v_{OUT}}{v_{in}} = -g_m\ (\frac{1}{g_o}||RL)$$

d) Approximate gain, $A_V = -g_m R_L$

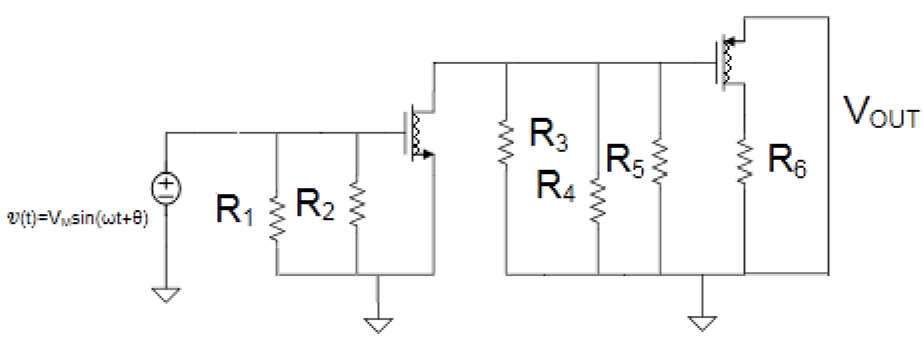
$A_V = -g_m(5k||8k) = -gm(3.077k)$

$$gm = \frac{I_Q}{V_t} = \frac{1.88\ m}{0.0258} = 0.0729V$$

$A_V = -0.0729 * 3077$

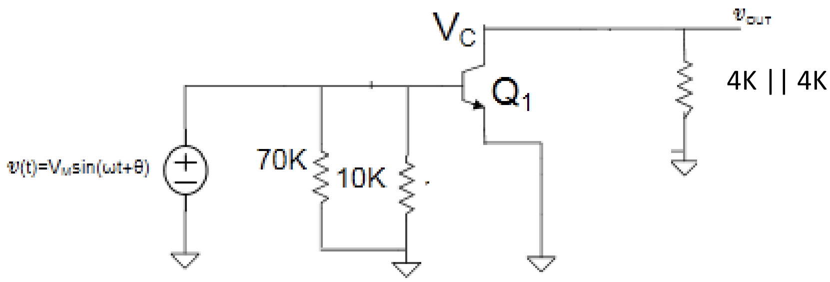
$A_V = -224.22\ V/V$

Problem 4:



Problem 5:

a)



b)

$V_B = 32 * \left(\frac{10}{10+70}\right) k = 4V$

$I_{CQ} = \frac{4-0.6}{2k} = 1.7\ mA$

$V_{CQ} = 32 - (2k)(I_{CQ})$

$V_{CQ} = 26.6V$

$V_{outq} = 0V$

c) $v_{out} = (-g_m v_{IN}) * (\frac{1}{g_o} // R_L)$

$A_v = \frac{v_{OUT}}{v_{in}} = -g_m(\frac{1}{g_o} // R_L) \approx -g_m R_L$

d)

$A_v = \frac{I_{cq} R_L}{v_t} = \frac{2000 * 0.0017}{0.0258} = 131.783 \frac{V}{V}$

Problem 6:

MOSFET:

$V_{gs} = V_{ds}$, putting a test voltage V_{test} and solving for current we get:

$$I_{test} = g_m * V_{test} + V_{test} * g_0 \rightarrow \frac{V_{test}}{I_{test}} = \frac{1}{g_m + g_0} \approx \frac{1}{g_m}$$

$$g_m = \sqrt{2 * \mu_n C_{ox} \left(\frac{W}{L}\right) * I_D} = 1.183\ m$$

$R_{eq} = gm^{-1} = 845.15\ k\Omega$

BJT:

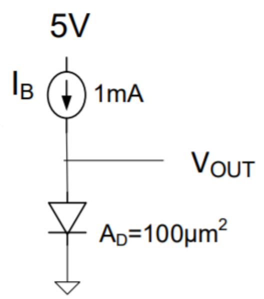
$$V * (g_m + g_\pi + g_o) = I \rightarrow R_{eq} = \frac{1}{(g_m + g_\pi + g_o)} \cong \frac{1}{g_m}$$

$$g_m = \frac{I_{CQ}}{V_t} = \frac{2\ mA}{0.0258}$$

$R_{eq} = 12.9\ \Omega$

Problem 7:

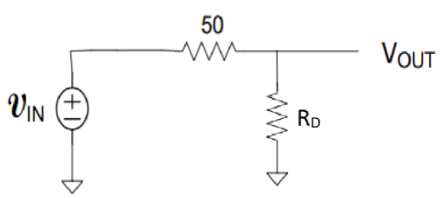
a.) DC equivalent circuit



$$I_{DQ} = 1mA, \qquad V_t = 0.0258V$$

$$I_{DQ} = J_s A_D e^{\frac{V_D}{Vt}} \rightarrow V_D = V_{OUT} = V_t * \ln\left(\frac{I_{DQ}}{J_S A_D}\right)$$

$$V_{OUT} = (0.0258) * \ln\left(\frac{1mA}{\frac{0.5fA}{\mu m^2} * 200\mu m^2}\right) = 0.594\ V$$



b)

c.) Treat Diode as a box with Vd as one terminal and Id as another, we know that $V_D = V_t * \ln\left(\frac{I_{DQ}}{J_S A_D}\right)$

$$\frac{dV_D}{dI_{DQ}} = V_t * \frac{J_S A_D}{I_{DQ}} * J_S A_D = \frac{V_t}{I_{DQ}} = R_D$$

$$R_D = \frac{V_t}{I_{DQ}} = \frac{0.0258}{1mA} = 25.8\ \Omega$$

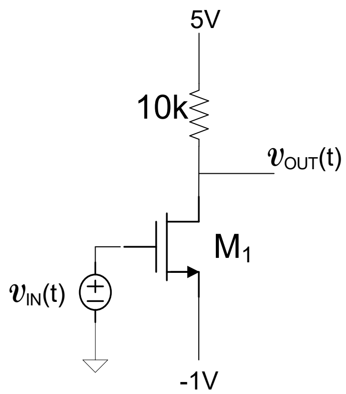
$$v_{out} = \frac{R_D}{R_D + 50\Omega} v_{in}$$

$$A_v = \frac{v_{out}}{v_{in}} = \frac{R_D}{R_D + 50\Omega} = \frac{25.8\ \Omega}{25.8\Omega + 50\Omega} = 0.34\ V/V$$

d) $R_D = \frac{V_t}{I_{DQ}} = \frac{0.0258}{5mA} = 5.16\ \Omega \rightarrow A_v = \frac{v_{out}}{v_{in}} = \frac{R_D}{R_D+50\Omega} = \frac{5.16\ \Omega}{5.16\Omega+50\Omega} = 0.0935\ V/V$

Problem 8:

There are multiple approaches to this problem, one is shown below:



I will start from my gain and load specifications, I know that for my circuit choice, my gain has the following relationship:

$$A_v = \frac{v_{OUT}}{v_{in}} = -g_m(\frac{1}{g_o}//R_L) \approx -g_m R_L = -15 \rightarrow gm = \frac{A_v}{R_L} = \frac{15}{10000} = 1.5\ mA/V$$

I also know $g_m = \frac{2I_{DSQ}}{V_{GS}-V_T}$, I can set V_s = -1V and solve for I_{DSQ} to get 0.375 mA

$V_{outQ} = V_{DD} - I_{DSQ} * R_L$ and for the transistor to be in saturation (and for our models to hold) we need $V_{outQ} \geq V_{GS} - V_t \geq 0.5$, solving this inequality:

$$0.5 \leq V_{DD} - I_{DSQ} * R_L \rightarrow V_{DD} \geq 0.5 + I_{DSQ} * R_L \geq 4.25\ V$$

I will choose V_{DD} to be 5V.

Problem 9:

Code:

```
`timescale 1ns/1ps
module demux(F, a,b,c, Y1,Y2,Y3,Y4,Y5,Y6,Y7,Y8);
input F, a, b, c;                //inputs
output Y1,Y2,Y3,Y4,Y5,Y6,Y7,Y8; // output variables
reg y1,y2,y3,y4,y5,y6,y7,y8;    //internal variables

assign Y1 = y1;
assign Y2 = y2;
assign Y3 = y3;
assign Y4 = y4;
assign Y5 = y5;
assign Y6 = y6;
assign Y7 = y7;
assign Y8 = y8;

always @ (F or a or b or c)
 begin
  case({a,b,c})
   3'b000: begin
        y1 = F;
        {y2,y3,y4,y5,y6,y7,y8} = 7'b0000000;
        end
   3'b001: begin
        y2 = F;
        {y1,y3,y4,y5,y6,y7,y8} = 7'b0000000;
        end
   3'b010: begin
        y3 = F;
        {y1,y2,y4,y5,y6,y7,y8} = 7'b0000000;
        end
   3'b011: begin
        y4 = F;
        {y2,y3,y1,y5,y6,y7,y8} = 7'b0000000;
        end
   3'b100: begin
        y5 = F;
        {y2,y3,y4,y1,y6,y7,y8} = 7'b0000000;
        end
   3'b101: begin
        y6 = F;
        {y2,y3,y4,y5,y1,y7,y8} = 7'b0000000;
        end
   3'b110: begin
        y7 = F;
        {y2,y3,y4,y5,y6,y1,y8} = 7'b0000000;
        end
   3'b111: begin
        y8 = F;
        {y2,y3,y4,y5,y6,y7,y1} = 7'b0000000;
        end
endcase
end
endmodule
```

Testbench:

```
`timescale 1ns/1ps
module demux_tb();
 reg F,a,b,c;
 wire Y1,Y2,Y3,Y4,Y5,Y6,Y7,Y8;

demux d(F, a,b,c, Y1,Y2,Y3,Y4,Y5,Y6,Y7,Y8);

  initial
  begin
    F = 1;
    a = 0;
    b = 0;
    c = 0;
  end

always
  #10 c = -c;
always
  #20 b = -b;
always
  #40 a = -a;

endmodule
```

Waveform: