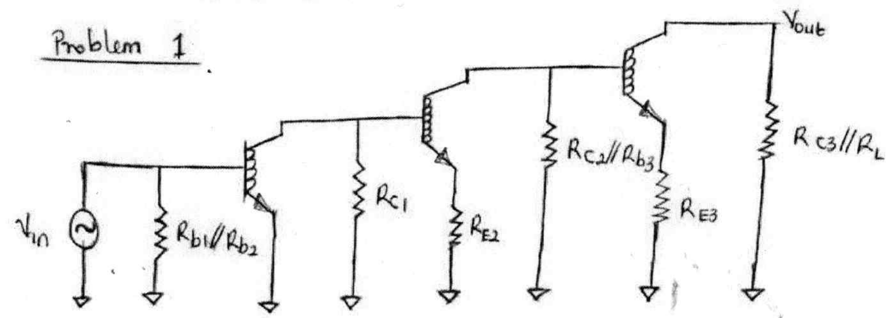
EE 330 HW 10 Solutions Spring 2024

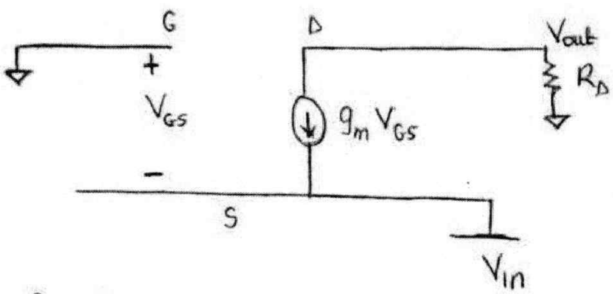
EE 330 HW10

Problem 1



Problem 2

(a)



Solving for $\frac{V_{out}}{V_{in}}$;

$$\Rightarrow \frac{V_{out}}{R_D} + g_m(-V_{in}) = 0 \Rightarrow \frac{V_{out}}{R_D} = V_{in}\, g_m$$

$$\Rightarrow \frac{V_{out}}{V_{in}} = g_m R_D$$

(b) In terms of the quiescent operating point of the transistor,

$$g_m = \frac{2I_{DQ}}{V_{GSQ} - V_T}$$

therefore,

$$\frac{V_{out}}{V_{in}} = \frac{2I_{DQ}}{V_{GSQ} - V_T} R_D$$

Problem 3 For the p-channel device operating in saturation

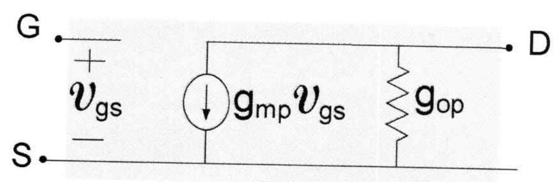
$$I_D = -\mu_p C_{OX} \frac{W}{2L}(V_{GS} - V_{THP})^2 (1 - \lambda_p V_{DS})$$

Note $\lambda_p > 0$ when expressed in this form. It thus follows that

$$g_{mp} = \left.\frac{\partial I_D}{\partial V_{GS}}\right|_{Q-pt} = -2\mu_p C_{OX} \frac{W}{2L}(V_{GS} - V_{THP})(1 - \lambda_p V_{DS})\Big|_{Q-pt} \simeq -2\mu_p C_{OX} \frac{W}{2L}(V_{GSQ} - V_{THP})$$

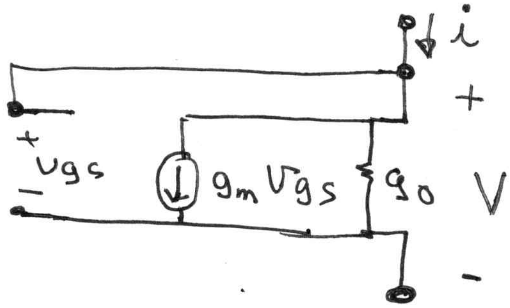
$$g_{0p} = \left.\frac{\partial I_D}{\partial V_{DS}}\right|_{Q-pt} = -\mu_p C_{OX} \frac{W}{2L}(V_{GS} - V_{THP})^2 (-\lambda_p)\Big|_{Q-pt} \simeq \mu_p C_{OX} \frac{W}{2L}(V_{GSQ} - V_{THP})^2 \lambda_p \simeq -\lambda_p I_{DQ}$$

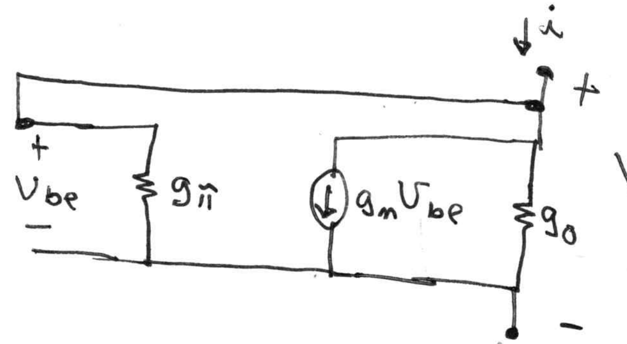
A small-signal equivalent circuit is shown below.



Problem 4

a)





$$\left.\begin{aligned} i &= g_m V_{gs} + g_o V \\ V_{gs} &= V \end{aligned}\right\}$$

$\therefore$ $\dfrac{V}{i} = \dfrac{1}{g_m + g_o} \simeq \dfrac{1}{g_m}$

Impedanc $= \dfrac{1}{g_m}$

$$\left.\begin{aligned} i &= g_m V_{be} + V g_o + g_\pi V_{be} \\ V &= V_{be} \end{aligned}\right\}$$

$\therefore$ $\dfrac{V}{i} = \dfrac{1}{g_m + g_\pi + g_o} \simeq \dfrac{1}{g_m}$

Impedance $= \dfrac{1}{g_m}$

b) small signal for both are resistors of value $\dfrac{1}{g_m}$

c) $R_{eq} = \dfrac{1}{\sqrt{\mu C_{ox} \frac{W}{L}}\sqrt{2 I_{DQ}}}$

$= \dfrac{1}{\sqrt{(10^{-4})(2E-3)}} = 2.2K\Omega$

$R_{eq} = \dfrac{1}{I_{CQ}/V_t} = \dfrac{25mV}{1mA} = 25\Omega$

Problem 5

a) Must have $V_{DS} > V_{GS} - V_{TH}$

$\therefore\ 4V - I_D R_1 > (2V - 0.75V)$

$\Rightarrow\ R_1 < \dfrac{4V - 1.25V}{I_D} = 3.9K\Omega$

$I_D = \dfrac{\mu C_{ox} W}{2L}(V_{GS} - V_{TH})^2$

$= (10^{-4})\dfrac{18}{2 \times 2}(2 - .75)^2$

$= .703\ ma$

b) $A_V = -g_m R_{INEW}$ where $R_{INEW} = \dfrac{3.9k}{3} = 1.3K$

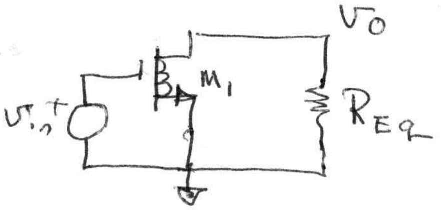
$A_V = -\dfrac{2 I_{DQ}}{V_{GS} - V_{TH}}(1.3k) = \dfrac{(-2)(.703mA)}{(1.25V)} \times 1.3k = -1.46$

c) $V_O = 4 - I_{DQ} R_{INEW} + A_V(.001 \sin(5000t + 75°))$

$V_O = 3.09 - .00146 \sin(5000t + 75°)$

Problem 6

From Problem 4, diode connected transistor M_2 is a small signal resistor of value $R_{EQ} = \dfrac{1}{g_{m2} + g_{o2}} \simeq \dfrac{1}{g_{m2}}$

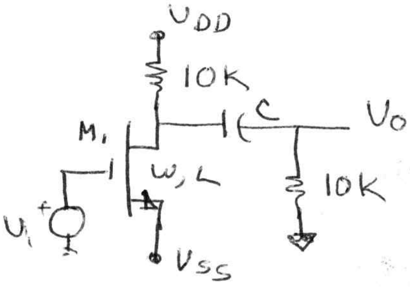


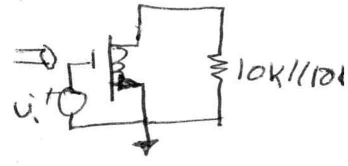
so $A_V \simeq -g_{m1} R_{EQ} = -\dfrac{g_{m1}}{g_{m2}}$

$\therefore\ V_o = -\left(\dfrac{g_{m1}}{g_{m2}}\right) V_m \cos(\omega t + \theta)$

Problem 7

will present one solution





Assume $V_{DD} = 4V$, C large

To keep M_1 in sat, set $V_{DQ} = 1V$

$\therefore\ I_{DQ} = \dfrac{4V - 1V}{10K} = .3\ mA$

$A_V = (-g_{m1})(5k) = -10$ so $g_{m1} = 2E{-3}$

Let $V_{EB} = V_{GSQ} - V_{TH}$

$\therefore\ \dfrac{2 I_{DQ}}{V_{EB}} = 2E{-3} \Rightarrow V_{EB} = \dfrac{I_{DQ}}{1E{-3}} = 0.3V$ so pick $V_{SS} = -.75 - .3$

$V_{SS} = -1.05\ V$

Now obtain W/L $\quad .3mA = \dfrac{\mu C_{ox} W}{2L}(V_{EB})^2 \Rightarrow \dfrac{W}{L} = \dfrac{(.3mA)(2)}{(10^{-4})(.3V)^2} = 67$

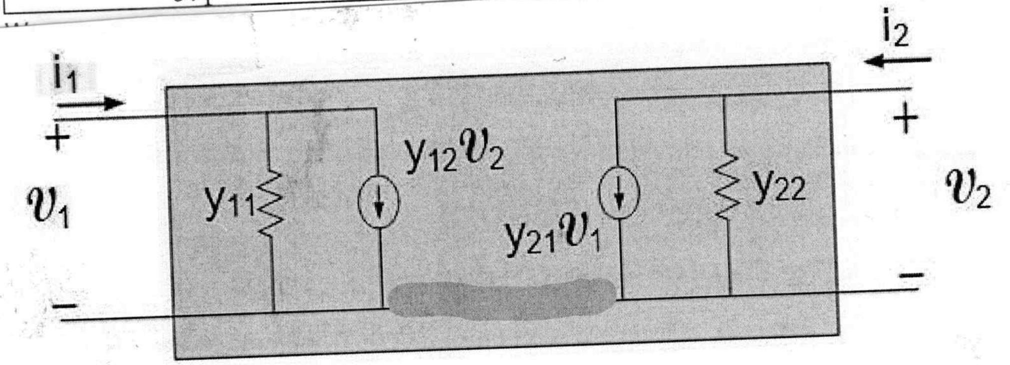
So let $L = 1\mu$, $W = 67\mu$

Problem 8

a)

Below is a matrix of the derived small signal parameters

$y_{11} = \frac{\partial I_1}{\partial V_1} = V_{2Q}^2$	$y_{12} = \frac{\partial I_1}{\partial V_2} = 2V_{1Q}V_{2Q}$
$y_{21} = \frac{\partial I_2}{\partial V_1} = 0.04V_{1Q}V_{2Q}e^{0.2V_{1Q}^2V_{2Q}}$	$y_{22} = \frac{\partial I_2}{\partial V_2} = 0.02V_{1Q}^2e^{0.2V_{1Q}^2V_{2Q}}$



b) Using the equations derived in the previous step, we can find numerical values for the small-signal parameters

$y_{11} = \frac{\partial I_1}{\partial V_1} = V_{2Q}^2 = \frac{1}{\Omega}$	$y_{12} = \frac{\partial I_1}{\partial V_2} = 2V_{1Q}V_{2Q} = \frac{10}{\Omega}$
$y_{21} = \frac{\partial I_2}{\partial V_1} = 0.04V_{1Q}V_{2Q}e^{0.2V_{1Q}^2V_{2Q}} = \frac{0.2e^5}{\Omega}$	$y_{22} = \frac{\partial I_2}{\partial V_2} = 0.02V_{1Q}^2e^{0.2V_{1Q}^2V_{2Q}} = \frac{0.5e^5}{\Omega}$

c) $I_{1Q} = V_{1Q} V_{2Q}^2 = (5V)(1V)^2 = 25\ A$

$I_{2Q} = (.1)\, e^{(.2) V_{1Q}^2 V_{2Q}} = (.1)\, e^{(.2)(25)(1)} = 14.8\ A$

d) $i_1 = y_{11} v_1 + y_{12} v_2 = (1)(1E-3) + (10)(2E-3) = 21\ mA$

$i_2 = y_{21} v_1 + y_{22} v_2 = (.2e^5)(1E-3) + (.5e^5)(2E-3) = 178\ mA$

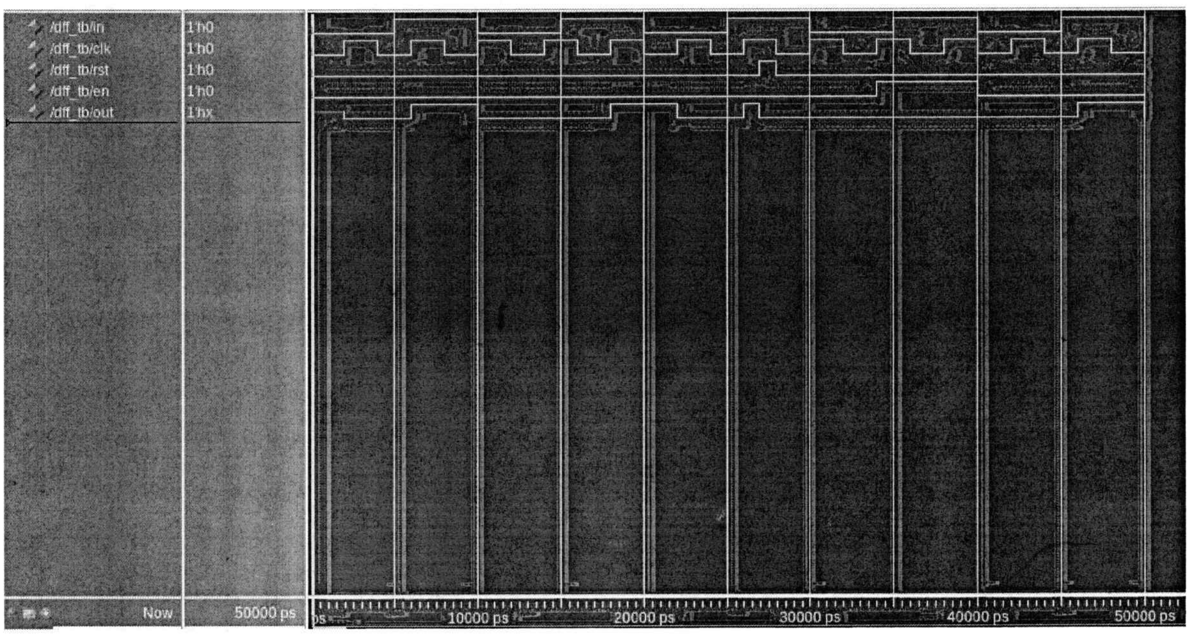
Problems 9 & 10

```
`timescale 1ns/1ps                                          //nice timescale for simulation
module dff(in, out, clk, rst, en);                          //instantiate module
        input in, clk, rst, en;                             //instantiate inputs
        output reg out;                                     //instantiate output
        always @ (posedge clk or posedge rst) begin         //any time clk or reset goes high execute following code
                if (en == 1) begin                          //if device is disabled
                        out = 0;                            //hold output low
                end
                else begin                                  //if device is enabled
                        if (rst == 1) begin                 //if device is being reset
                                out = 0;                    //change output to low
                        end
                        else begin                          //if receiving a clock pulse
                                out <= in;                  //assign input to output
                        end
                end
        end
endmodule
```

D flip-flop code

```
`timescale 1ns/1ps                                                      //nice timescale for simulation
module dff_tb();                                                        //instantiate testbench
        reg in, clk, rst, en;                                           //instantiate input registers
        wire out;                                                       //instantiate output wires
        dff DUT(.in(in),.clk(clk),.rst(rst),.en(en),.out(out));         //instantiate DUT
        initial clk = 0;                                                //set initial values for inputs
        initial rst = 0;
        initial en = 0;
        initial in = 0;
        always #5 in <= ~in;                                            //toggle in every five time units
        always #2 clk <= ~clk;                                          //toggle clk every two time units
        initial begin                                                   //used to force certain values
                #27;rst = 1;#1;rst = 0;                                 //force rst at time 27, high for one time unit
                #6;en=1;#6;en=0;                                        //force en at time 34, high for six time units
        end
endmodule
```

D flip-flop testbench code



D flip-flop testbench results. Proves functionality by

- Capturing value at input on rising edge of clock when en=0 (active low enable)
- Driving output low with asynchronous reset signal
- Output stays low on rising edge of clock when en = 1 (active low enable)