Problem 1.

In on 0.5μ CMOS process,

$V_{gs} = 3.5V$, $V_{th} = 0.79V$, $\frac{\mu C_{OX}}{2} = \frac{57.8\mu s}{v^2}$

$$R_{FET} = \frac{2V_{ds}}{2I_D} = \left[\mu_n * C_{OX} * \frac{W}{L} * \left(V_{gs} - V_T\right)\right]^{-1} = 3500$$

$$\frac{W}{L} = \frac{1}{3500 * (2 * 57.8 * 10^{-6}) * (3.5 - 0.79)} = 0.912$$

In the IBM 0.13 μ CMOS Process,

$V_{gs} = 1.5V$, $V_{th} = 0.41V$, $\frac{\mu C_{OX}}{2} = \frac{308.0\mu s}{v^2}$

$$R_{FET} = \frac{2V_{ds}}{2I_D} = \left[\mu_n * C_{OX} * \frac{W}{L} * \left(V_{gs} - V_T\right)\right]^{-1} = 3500$$

$$\frac{W}{L} = \frac{1}{3500 * (2 * 308.0 * 10^{-6}) * (1.5 - 0.41)} = 0.426$$

Problem 2.

Minimum sized inverter:

$V_{gs} = 1.5V$, in IBM 0.13 $\mu \frac{W}{L} = \frac{0.16}{0.12}$

$$C_{GSN} = (0.16)(0.12)(11176 * 10^{-18}) = 214.579aF$$

$$C_{ASP} = (0.16)(0.12)(10496 * 10^{-18}) = 201.523aF$$

$$C_L = C_{ASP} + C_{GSN} = 416.102aF = 0.416fF$$

in ON 0.5μ: $\frac{W}{L} = \frac{3.0}{0.6}$

$$R_{SWN} = \left(\frac{2 * 57.8 * 10^{-6} * 3.0}{0.6} * (1.5 - 0.79)\right)^{-1} = 2.437k\Omega$$

$$R_{SWP} = \left(\frac{2 * -19.1 * 10^{-6} * 3.0}{0.6} * (-1.5 - 0.79)\right)^{-1} = 9.027k\Omega$$

$$\rightarrow T_{HL} = 2.437k * 416.102a = 1.014pS$$

$$T_{LH} = 9.027k * 416.102a = 3.756pS$$

Problem 3.

$$\left(\frac{1.6 - V_a}{1000}\right) = I_{D_1} + I_{D_2} = (50 + 250)\mu^2 * \left(5\frac{fA}{\mu^2}\right)e^{\left(\frac{x}{0.0259}\right)} \rightarrow V_a = 0.528V$$

$$I_{D_1} = 0.178mA \, ; I_{D_2} = 0.892\ mA$$

Problem 4

$$\frac{15-V_D}{2000} = I_D = 100\mu^2 * \left(1\frac{fA}{\mu^2}\right) * e^{\left(\frac{V_D}{0.0259}\right)} \rightarrow V_D = 0.647\ V$$

$$I_D = 100\mu^2 * \left(1\frac{fA}{\mu^2}\right) * e^{\left(\frac{0.647}{0.0259}\right)} = 7.063\ mA$$

Problem 5

$$\frac{0.520-V_D}{4000} = I_D = 100\mu^2 * \left(1\frac{fA}{\mu^2}\right) * \left(e^{\left(\frac{V_D}{0.0259}\right)} - 1\right) \rightarrow V_D = 0.510\ V$$

$$I_D = 100\mu^2 * \left(1\frac{fA}{\mu^2}\right) * e^{\left(\frac{0.478}{0.0259}\right)} = 35.62\ \mu A$$

Problem 6

$$I_{D1} \sim I_{D2} = 200\mu^2 * \left(1\frac{fA}{\mu^2}\right) * e^{\left(\frac{0.55}{0.0259}\right)} \sim 200\mu^2 * \left(1\frac{fA}{\mu^2}\right) * e^{\left(\frac{0.65}{0.0259}\right)} = 333.81\ \mu A \sim 15.86\ mA$$

Problem 7.

a. $\mathrm{I_{D_1}} = \left(100 * 10^{-6} * \frac{8}{3*2}(3-1)^2\right) = 0.533\mathrm{mA} \rightarrow 5 - 4000 * 0.0006 = 2.87\mathrm{V}$
b. $\mathrm{I_{D_2}} = \left(100 * 10^{-6} * \left(\frac{12}{3}\right) * (2-1)^2\right) = 0.4\mathrm{mA} \rightarrow 5 - 30\mathrm{k} * .4\mathrm{m} = -7 \rightarrow$ Must not be in saturation region.
   $V_{DS} < V_{GS} - V_T \rightarrow Triode\ Region$
   $$\frac{(5-\mathrm{V_{DS}})}{30\mathrm{k}} = 100 * 10^{-6} * \frac{12}{1.5} * \left(2 - 1 - \frac{\mathrm{V_{DS}}}{2}\right)\mathrm{V_{DS}}, (\mathrm{V_{GS}} - \mathrm{V_T} = 1\mathrm{V})$$
   $\mathrm{V_{DS}} = 0.224$ or $\mathrm{V_{DS}} = 1.86$ as it is in triode region, $V_{out} = 0.224V$
c. $I_{D_3} = 33 * 10^{-6} * \frac{6}{6} * (2-1)^2 = 0.033mA \rightarrow 5 - 5k * 0.033m = 4.835V$

Problem 8.

$$\frac{9-V_{out}}{5000} = I_D = 100 * 10^{-6} * \frac{\mathrm{W}}{2\mu * 2}(V_{out} - 1)^2 \rightarrow W = 12.0\ \mu m$$

Problem 9

a. Assuming Saturation, $V_{out} = x$

$$I_{D_1} = \mu C_{OX}\left(\frac{W}{2L}\right)(V_{GS} - V_T)^2 = 100 * 10^{-6} * \frac{6}{2*2} * (\mathrm{x} - 1)^2 \; = 1.5 * 10^{-4} * (x - 1)^2$$

$$I_{D_2} = 100 * 10^{-6} * \left(\frac{2}{12*2}\right) * (6 - x - 1)^2 = 8.33 * 10^{-6} * (6 - x - 1)^2$$

$$I_{D_1} = I_{D_2} \rightarrow 1.5 * 10^{-4}(x - 1)^2 = 8.33 * 10^{-6}(6 - x - 1)^2 \rightarrow V_{out} = x = 1.763\ V$$

b. $V_{DG1} = 0$ →Saturation

For $\mathrm{M_1}, \mathrm{I_{SD}} = \mu\mathrm{C_{OX}}\left(\frac{\mathrm{W}}{\mathrm{2L}}\right)(\mathrm{V_{GS}} - \mathrm{V_{TP}})^2 = 33 * 10^{-5} * \left(\frac{8}{2*2}\right)\left(\mathrm{V_G} - 10 - (-1)\right)^2$

$$\rightarrow \; 400 * 10^{-6} = 33 * 10^{-6} * \frac{8}{4} * (V_G - 9)^2 \rightarrow V_G = 6.54V\ or\ 11.46V$$

$$\rightarrow V_{GS} = -3.46V\ or\ 1.46V$$

For $M_2, I_{SD} = \; \mu\mathrm{C_{OX}}\left(\frac{\mathrm{W}}{\mathrm{2L}}\right)(\mathrm{V_{GS}} - \mathrm{V_{TP}})^2 = 33 * 10^{-6} * \left(\frac{10}{2*6}\right)(1.46 + 1)^2$

$$I_{SD} = 166\ \mu A = I_{OUT}$$

Check: $V_D = (1.5k * 166\mu) = 0.249, V_{DS} = 0.249V - 10V = -9.751V$

$$V_{GS} - V_{TP} = 1.46 + 1 = 2.46$$

$$V_{DS} < V_{GS} - V_{TP} \rightarrow Saturation$$

Problem 10.

a) Saturation for M_1 and M_2

$$I_{D_1} = \frac{100 * 10^{-6}}{2} * \frac{W}{L}(2 - 1)^2 = I_{D_2} = 100 * 10^{-6} * \frac{8}{2*2} * (5 - 3.5 - 1)^2$$

$$\rightarrow \frac{\frac{W}{L}}{\frac{8}{2}} = \frac{1}{4} \rightarrow \frac{W}{L} = 1 \rightarrow W = 2\mu m, L = 2\mu m$$

b) Vout=0.8 V < Vin-1V=1V → M_1 is in triode region.

$$I_{D_1} = I_{D_2} = 100 * 10^{-6} * \frac{W}{L} * \left(3 - 1 - \frac{V_{out}}{2}\right)V_{out} = 100 * 10^{-6} * \left(\frac{8}{4}\right) * (5 - .5 - 1)^2$$

$$\rightarrow \frac{W}{L} = \frac{16}{1} \rightarrow W = 16\mu m, \qquad L = 1\mu m$$

Problem 11.

A. $V_{OUT} = I(10k\Omega) + 0.575V, V_t = \frac{kT}{q}, I(T) = \left[J_{SX}\left(T^m e^{\frac{-V_{go}}{V_t}}\right)\right] A * e^{\frac{V_D}{V_t}}$

$$A * J_{SX}\left[T^m e^{\frac{-V_{go}}{V_t}}\right] * e^{\frac{0.575}{V_t}} = \frac{0.5A}{\mu^2} * [1.66 * 10^{-18}] * 100\mu^2 * 284.47 * 10^9 = 23.64\ \mu A$$

$$V_{OUT} = 0.811V$$

B. $V_{OUT} = 72.7V \rightarrow 20V$ (clipping)

C. $V_{OUT} = 10.86kV \rightarrow 20V$ (clipping)

Problem 12.

Assuming saturation:

$$I_{D_1} = 33 * 10^{-6} * \frac{5}{2*5} * (5-3-1)^2 = I_{D_2} = 100 * 10^{-6}\left(\frac{5}{10}\right)(V_{out}-1)^2$$

$$V_{out} = 1.5745V$$

Problem 13.

C= $\frac{C_{j0}*A}{\left(1-\frac{V_d}{\phi_b}\right)^n}$ where $\phi \approx 0.6V$ and $n \approx 0.5$. At $V_b = 0$ the denominator→ 1, so $C_{J0}A = 200fF$

With $V_b = -3$, $C = \frac{200*10^{-15}}{\left(1-\left(-\frac{3}{.6}\right)\right)^{0.5}} = 81.65fF$

With $V_b = 0.25V$ $C = \frac{200*10^{-15}}{\left(1-\left(\frac{.25}{.6}\right)\right)^{0.5}} = 261.86fF$

Problem 14.

a) Since there's no protection circuitry the whole voltage will be applied to the IC.
   HBM1 V_{INT} = 250V, HBM2 V_{INT} = 2000 V

b) For HBM1 $V_D > V_{DD}$ so diode 2 is on

$$\frac{250 - V_{INT}}{10K} = I_D = 1000\mu^2 * \left(10^{-20}\frac{A}{\mu^2}\right) * e^{\left(\frac{V_{INT}-5}{0.0259}\right)} \rightarrow V_{INT} = 5.918\,V$$

   For HBM2 $V_D > V_{DD}$ so diode 2 is on

$$\frac{2000-V_{INT}}{10K} = I_D = 1000\mu^2 * \left(10^{-20}\frac{A}{\mu^2}\right) * e^{\left(\frac{V_{INT}-5}{0.0259}\right)} \rightarrow V_{INT} = 5.972\,V$$

c) For HBM1 $I_D = 1000\mu^2 * \left(10^{-20}\frac{A}{\mu^2}\right) * e^{\left(\frac{5.918-5}{0.0259}\right)} = 24.73\,mA$

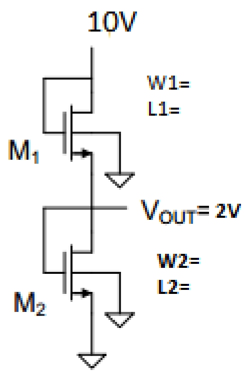
   For HBM2 $I_D = 1000\mu^2 * \left(10^{-20}\frac{A}{\mu^2}\right) * e^{\left(\frac{5.972-5}{0.0259}\right)} = 198.89\,mA$

d) The resistor reduces the current the flows through the diode. The disadvantage is it dissipates a lot of heat.

Problem 15.

$2.5 * 10^{-12} = \left(\frac{2*10^{-12}}{\left(1-\left(\frac{V}{0.6}\right)\right)^{0.5}}\right) \rightarrow V = 0.216V$ so we can design a circuit that provides 0.216V when 3.8V is applied. This is easiest with a voltage divider. Using 1KΩ as the resistor in series with the capacitor the resistor in parallel will be $0.216 = \frac{x}{1k+x} * 3.8 \rightarrow x = 60.268\Omega$

Problem 16.



$V_{out} = 2.0\,V, V_{DD} = 6.0\,V$

$I_{D_1} = 100 * 10^{-6} * \left(\frac{W_1}{2L_1}\right)(6 - V_{out} - 1)^2$

$I_{D_2} = 100 * 10^{-6} * \left(\frac{W_2}{2L_2}\right)(V_{out} - 1)^2$

We can set 3 variables to find the fourth, so $L_1 = L_2 = 1\mu m$

$W_1 = 5\mu m$ and we know that $I_{D_1} = I_{D_2}$

$\rightarrow W_2 = 45\ \mu m$

Problem 17.

Testbench:

```
`timescale 1ns/1ps

module JKFF_tb();
  reg J, K, CLK;
  wire Q, Q_not;

  JKFF ff1(.iJ(J), .iK(K), .oQ(Q), .oQ_not(Q_not), .iCLK(CLK));

  initial begin
    J = 1'b0;
    K = 1'b0;
    CLK = 1'b0;
  end

  always #10 CLK = ~CLK;
  always #20 J = ~J;
  always #40 K = ~K;
endmodule

```

Verilog Code:

```verilog

module JKFF(iJ, iK, oQ, oQ_not, iCLK);
  input iJ, iK, iCLK;
  output oQ, oQ_not;

  reg Q;

  assign oQ = Q;
  assign oQ_not = ~Q;

  initial begin
    Q = 1'b0;
  end

  always @(posedge iCLK) begin
    if(iJ==1 & iK==1) begin
      Q = ~Q;
    end else if(iJ==0 & iK==1) begin
      Q = 0;
    end else if(iJ==1 & iK==0) begin
      Q = 1;
    end else begin
      Q = Q;
    end


  end


endmodule

```

Output: