Problem 1.

In on 0.5μ CMOS process,

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

$$R_{FET} = \frac{2V_{ds}}{2I_D} = \left[\mu_n * C_{OX} * \frac{W}{L} * \left(V_{gs} - V_T\right)\right]^{-1} = 3000$$

$$\frac{W}{L} = \frac{1}{3000 * (2 * 57.8 * 10^{-6}) * (3.5 - 0.79)} = 1.064$$

In the IBM 0.13 μ CMOS Process,

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

$$R_{FET} = \frac{2V_{ds}}{2I_D} = \left[\mu_n * C_{OX} * \frac{W}{L} * \left(V_{gs} - V_T\right)\right]^{-1} = 3000$$

$$\frac{W}{L} = \frac{1}{3000 * (2 * 308.0 * 10^{-6}) * (1.5 - 0.41)} = 0.496$$

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.

$$\left(\frac{1.8 - V_a}{1000}\right) = I_{D_1} + I_{D_2} = 200\mu^2 * \left(5\frac{fA}{\mu^2}\right) e^{\left(\frac{x}{0.0259}\right)} \rightarrow V_a = 0.543V$$

$I_{D_1} = 0.318mA\,; I_{D_2} = 0.955\ mA$

Problem 4

$$\frac{10-V_D}{4000}= I_D = 100\mu^2 * \left(1\frac{fA}{\mu^2}\right) * \ e^{\left(\frac{V_D}{0.0259}\right)} \to V_D = 0.618\,V$$

$$I_D = \ 100\mu^2 * \left(1\frac{fA}{\mu^2}\right) * \ e^{\left(\frac{0.618}{0.0259}\right)} = 2.305\,mA$$

Problem 5

$$\frac{0.520-V_D}{4000}= I_D = 100\mu^2 * \left(1\frac{fA}{\mu^2}\right) * \left(\ e^{\left(\frac{V_D}{0.0259}\right)} - 1\right) \to V_D = 0.478\,V$$

$$I_D = \ 100\mu^2 * \left(1\frac{fA}{\mu^2}\right) * \ e^{\left(\frac{0.478}{0.0259}\right)} = 10.356\ \mu A$$

Problem 6

$$I_{D1} \sim I_{D2} = 200\mu^2 * \left(1\frac{fA}{\mu^2}\right) * \ e^{\left(\frac{0.5}{0.0259}\right)} \sim 200\mu^2 * \left(1\frac{fA}{\mu^2}\right) * \ e^{\left(\frac{0.6}{0.0259}\right)} = 48.43\mu A \sim 2.30mA$$

Problem 7.

a. $\mathrm{I_{D_1}} = \left(100 * 10^{-6} * \frac{8}{3*2}(3-1)^2\right) = 0.533\mathrm{mA} \to 5 - 4000 * 0.0006 = 2.87\mathrm{V}$

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

c. $I_{D_3} = 33 * 10^{-6} * \frac{6}{6} * (2-1)^2 = 0.033mA \to 5 - 5k * 0.033m = 4.835V$

Problem 8.

$$\frac{9-V_{out}}{5000} = I_D = \ 100 * 10^{-6} * \frac{\mathrm{W}}{2\mu * 2}(V_{out} - 1)^2 \to W = 0.96\ \mu m$$

Problem 9

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

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

$$I_{D_2} = 100 * 10^{-6} * \left(\frac{2}{8*2}\right) * (6 - x - 1)^2 = 12.5 * 10^{-6} * (6 - x - 1)^2$$

$$I_{D_1} = I_{D_2} \to 1.5 * 10^{-4}(x-1)^2 = 12.5 * 10^{-6}(6 - x - 1)^2 \to V_{out} = x = 1.896\ V$$

b. $V_{DG1} = 0$ →Saturation

For $\text{M}_1, \text{I}_{\text{SD}} = \mu\text{C}_{\text{OX}}\left(\frac{\text{W}}{2\text{L}}\right)(\text{V}_{\text{GS}} - \text{V}_{\text{TP}})^2 = 33 * 10^{-5} * \left(\frac{8}{2*2}\right)\left(\text{V}_{\text{G}} - 10 - (-1)\right)^2$

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

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

For $M_2, I_{SD} = \mu\text{C}_{\text{OX}}\left(\frac{\text{W}}{2\text{L}}\right)(\text{V}_{\text{GS}} - \text{V}_{\text{TP}})^2 = 33 * 10^{-6} * \left(\frac{12}{2*6}\right)(1.46 + 1)^2$

$$I_{SD} = 200\mu A = I_{OUT}$$

Check: $V_D = (1.5k * 200\mu) = 0.3, V_{DS} = 0.3V - 10V = -9.7V$

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

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

Problem 10.

a) Saturation for M_1 and M_2

$$I_{D_1} = \frac{100 * 10^{-6}}{2} * \frac{W}{L}(3-1)^2 = I_{D_2} = 100 * 10^{-6} * \frac{8}{2*2} * (5 - 3.5 - 1)^2$$

$$\to \frac{\frac{W}{L}}{\frac{8}{2}} = \frac{1}{16} \to \frac{W}{L} = \frac{1}{4} \to W = 2\mu m, L = 8\mu m$$

b) Vout=0.5V < Vin-1V=2V → M_1 is in triode region.

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

$$\to \frac{W}{L} = \frac{28}{1} \to W = 28\mu m, \qquad L = 1\mu m$$

Problem 11.

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

$$A * J_{SX}\left[T^m e^{\frac{-V_{go}}{V_t}}\right] * e^{\frac{0.575}{V_t}} = \frac{0.5A}{\mu^2} * [1.63 * 10^{-18}] * 200\mu^2 * 287.19 * 10^9$$

$$V_{OUT} = 1.043V$$

B. $V_{OUT} = 145V \to 20V$ (clipping)

C. $V_{OUT} = 12.8kV \to 20V$ (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 $C_{J0}A = 500fF$

With $V_b = -4$, $C = \frac{500*10^{-15}}{\left(1-\left(-\frac{4}{.6}\right)\right)^{0.5}} = 180.6fF$

With $V_b = 0.25V$ $C = \frac{500*10^{-15}}{\left(1-\left(\frac{.25}{.6}\right)\right)^{0.5}} = 654.7fF$

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

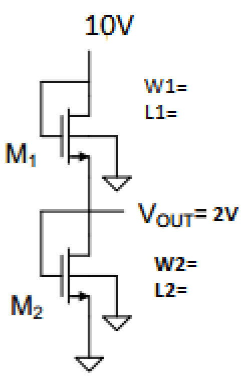
For HBM2 $I_D = 1000\mu^2 * \left(10^{-20}\frac{A}{\mu^2}\right) * e^{\left(\frac{5.972-5}{0.0259}\right)} = 198.89\,mA$

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

Problem 15.

$2.5 * 10^{-12} = \left(\frac{2*10^{-12}}{\left(1-\left(\frac{V}{0.6}\right)^{0.5}\right)}\right) \rightarrow V = 0.216V$ so we can design a circuit that provides 0.216V when 4V 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 $0.216 = \frac{x}{1k+x} * 4 \rightarrow x = 57.081\Omega$

Problem 16.



$V_{out} = 2.5$

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

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

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 $I_{D_1} = I_{D_2}$
$\rightarrow W_2 = 93.89\mu m$

Problem 17.

Verilog Code:

```
Ln#

`timescale 1ns/1ps

module Full_Adder_1b(A, B, Cin, Sum, Cout);
  input A, B, Cin;
  output Sum, Cout;
  reg AxorB, Sum, Cout;

  always @(A, B, Cin) begin
    AxorB <= A^B;
    Sum <= AxorB^Cin;
    Cout <= (Cin*AxorB)|(A*B);
  end

endmodule
```

Testbench:

```
`timescale 1ns/1ps

module Full_Adder_1b_tb();
  reg A, B, Cin;
  wire S, Co;

  Full_Adder_1b test(.A(A), .B(B), .Cin(Cin), .Sum(S), .Cout(Co));

  initial begin
    A = 0;
    B = 0;
    Cin = 0;
  end

  always #10 A <= ~A;
  always #20 B <= ~B;
  always #40 Cin <= ~Cin;

endmodule
```

Output: