SOLUTIONS:

Problem 1:

Using https://www.pvlighthouse.com.au/resistivity to obtain ρ = 2.346 Ω*cm

$$R = \rho * \frac{L}{w * t} = 2.346 * \frac{30}{2 * 0.5} * 10^2 = 7.038\ k\Omega$$

Problem 2:

$$I_d = J_s A\left(e^{\frac{V_D}{V_T}} - 1\right) = \left(100um^2 * \frac{10^{-15}A}{um^2}\right) * \left(e^{\frac{0.5V}{26mV}} - 1\right) = 22.5\ uA$$

$$I_d = J_s A\left(e^{\frac{V_D}{V_T}} - 1\right) = \left(100um^2 * \frac{10^{-15}A}{um^2}\right) * \left(e^{\frac{0.6V}{26mV}} - 1\right) = 1.05\ mA$$

Problem 3:

$$I_d = \left(\frac{10^{-15}A}{um^2} * 100\ um^2\right)\left(e^{\frac{V_D}{26mV}} - 1\right)$$

$$5V = 2k\Omega * I_d + V_D$$

Solve system of equations, $I_d = 2.19$ mA

Problem 4:

$$I_d = \left(\frac{10^{-15}A}{um^2} * 100\ um^2\right)\left(e^{\frac{V_D}{26mV}} - 1\right)$$

$$520mV = 2k\Omega * I_d + V_D$$

Solve system of equations, $I_d = 16.2$ μA

Problem 5:

In TSMC 0.18μ CMOS process,

$V_{gs} = 1.8V, V_{th} = 0.50V, \frac{\mu C_{OX}}{2} = \frac{171.8\mu s}{v^2}$

$$R_{FET} = \frac{V_{ds}}{I_D} = \left[\mu_n * C_{OX} * \frac{W}{L} * \left(V_{gs} - V_T\right)\right]^{-1} = 4000$$

$$\frac{W}{L} = \frac{1}{4000 * (2 * 171.8 * 10^{-6}) * (1.8 - 0.50)} = 0.5597$$

In the AMIS 0.5 μ CMOS Process,

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

$$R_{FET} = \frac{V_{ds}}{I_D} = \left[\mu_n * C_{OX} * \frac{W}{L} * \left(V_{gs} - V_T\right)\right]^{-1} = 4000$$

$$\frac{W}{L} = \frac{1}{4000 * (2 * 57.8 * 10^{-6}) * (3.5 - 0.79)} = 0.7980$$

In the IBM 0.13 μ CMOS Process,

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

$$R_{FET} = \frac{V_{ds}}{I_D} = \left[\mu_n * C_{OX} * \frac{W}{L} * \left(V_{gs} - V_T\right)\right]^{-1} = 4000$$

$$\frac{W}{L} = \frac{1}{4000 * (2 * 308.0 * 10^{-6}) * (1.5 - 0.41)} = 0.3723$$

Problem 6:

For a minimum sized transistor in IBM 0.13μ CMOS process, with V_{GS} = 1.5V and W/L = 0.16μ/0.12μ, POLY-N+active capacitance = 11176 aF/μm^2 ,POLY-P+active capacitance = 10496 aF/μm^2

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

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

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

For a minimum sized transistor in TSMC 0.18μ CMOS process. With V_{GS} = 1.5V, V_{TH} = 0.5V and W/L = 0.27μ/0.18μ, $\frac{\mu C_{OXn}}{2} = \frac{171.8\mu s}{v^2}, \frac{\mu C_{OXp}}{2} = \frac{-36.3\mu s}{v^2}$

$$R_{SWN} = \left(\frac{2 * 171.8 * 10^{-6} * 0.27}{0.18} * (1.5 - 0.5)\right)^{-1} = 1.940\ k\Omega$$

$$R_{SWP} = \left(\frac{2 * -36.3 * 10^{-6} * 0.27}{0.18} * (-1.5 - 0.5)\right)^{-1} = 9.183\ k\Omega$$

$T_{HL} = 1.940k * 416.102a = 0.807pS$
$T_{LH} = 9.183k * 416.102a = 3.821pS$

Problem 7:

$$I_{D1} = \left(\frac{5 * 10^{-15} A}{um^2} * 200\ um^2\right)\left(e^{\frac{V_D}{258mV}} - 1\right)$$

$$I_{D2} = \left(\frac{5 * 10^{-15} A}{um^2} * 800\ um^2\right)\left(e^{\frac{V_D}{258mV}} - 1\right)$$

$$I_{D2} = 4 * I_{d1}$$

$$\left(\frac{1.5 - V_D}{1000}\right) = I_{D_1} + I_{D_2} = 5I_{D1} = (5 * 10^{-12})(e^{\frac{V_D}{258mV}} - 1)$$

Solve for $V_D \approx 0.493$ V

$I_{D1} \approx$ 0.198 mA

Problem 8:

a) Assume saturation:

$$I_{D_1} = \left(300 * 10^{-6} * \frac{6}{2 * 2}(1 - 0.5)^2\right) = 0.1125\text{mA} \rightarrow V_{out} = 1.8 - 4 * 0.1125 = 1.35\text{V}$$

b) Assume triode:

$$\frac{(1.8 - V_{DS})}{25k} = 300 * 10^{-6} * \frac{12}{1.5} * \left(1.2 - 0.5 - \frac{V_{DS}}{2}\right) V_{DS}$$

Solve for $V_{DS} = V_{out} =$ 0.043V

c) Assume saturation:

$$I_{D_3} = \frac{300}{4} * 10^{-6} * \frac{6}{4} * (0.8 - 0.5)^2 = 10.125\ \mu A \rightarrow V_{out} = 25k * 10.125\mu = 0.253\ V$$

Problem 9:

a) Assuming saturation for both transistors, $V_{out} = x$

$$I_{ds1} = \left(\frac{300\mu}{2}\right)\left(\frac{6}{2}\right)(x - 0.5)^2 \;\;\&\;\; I_{ds2} = \left(\frac{300\mu}{2}\right)\left(\frac{2}{6}\right)(1.8 - x - 0.5)^2$$

$I_{ds1} = I_{ds2}$, solve for $x = V_{out} =$ 0.7 V

b) Assuming saturation for both transistors

$$150\ \mu A = \left(\frac{300\mu}{8}\right)\left(\frac{8}{2}\right)(V_G - 1.8 + 0.5)^2 \;\rightarrow V_G = 0.3\ V$$

$$I_{DS2} = \left(\frac{300\mu}{8}\right)\left(\frac{12}{4}\right)(0.3 - 1.8 + 0.5)^2 = 112.5\ \mu A$$

$$V_{out} = 1.8 - 112.5\mu * 8k = 0.9\ V$$

Problem 10:

Code:

```
module decoder(A,B,C,Y);
 input A,B,C;
 output reg[7:0] Y;
 always @ *
  case({A,B,C})
   3'b000: Y = 8'b00000001;
   3'b001: Y = 8'b00000010;
   3'b010: Y = 8'b00000100;
   3'b011: Y = 8'b00001000;
   3'b100: Y = 8'b00010000;
   3'b101: Y = 8'b00100000;
   3'b110: Y = 8'b01000000;
   3'b111: Y = 8'b10000000;
  endcase
endmodule
```

Test Bench:

```
module decoder_tb();
reg A,B,C;
wire[7:0] Y;
decoder D(A,B,C,Y);

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

always
#10 C = ~C;
always
#20 B = ~B;
always
#40 A = ~A;

endmodule
```

Waveform: