SOLUTIONS:

Problem 1:

A.) $\alpha = \frac{I_C}{I_E} = \frac{1.00mA}{1.050mA} = \frac{20}{21}$

$$\beta = \frac{\alpha}{1-\alpha} = 20$$

B.) $\alpha = \frac{1.00mA*1.01}{1.0250*(1-.01)} = 0.995$

$$\beta = \frac{0.995}{1-0.995} = 212.63$$

$$Error = \frac{212.63-20}{20} = 0.906 = 90.6\%$$

Problem 2:

$$I_B = \frac{I_C}{\beta} = \frac{1.00mA}{20} = 50\mu A$$

$$\beta = \frac{I_C}{I_B} = \frac{1.00mA*1.0025}{50\mu A*0.9975} = 20.1$$

$$Error = \frac{20.1-20}{20} = 0.00501 = 0.501\%$$

Problem 3:

Assume BJT works in forward active region and the capacitors are very large so they can be treated as open circuits.

$I_B = \left(\frac{8-0.6}{400k}\right) = 18.5\mu A$

$I_C = \beta I_B = 100*18.5\mu A = 1.85mA$

$V_C = 10 - 4000*0.00185 = 0.6V$

$V_{out} = 0V$ (there is a capacitor creating an open circuit in DC.)

Problem 4:

For the MOSFET to be in saturation $V_{DS} \geq V_{GS} - V_T$

$V_{out} + 2 \geq 2 - 0.5 \rightarrow V_{out} \geq -0.5$

$$I_D = \frac{\mu_n C_{OX} W}{2L} (V_{GS} - V_T)^2 = \frac{4 - V_{out}}{R_1}$$

$$300 * 10^{-6} * \left(\frac{8}{4}\right) * (0 - (-2) - 0.5)^2 = \frac{4 - V_{out}}{R_1}$$

$V_{out} = 4 - 0.00135 * R_1 \geq -0.5V$

$\rightarrow R_1 \leq 3.33k\Omega$

Problem 5:

Assuming that M_1 and M_2 are in saturation

$$I_{D_1} = I_{D_2} \rightarrow \frac{\mu_n C_{OX} W_n}{2L_n} (V_{GS} - V_T)^2 = \frac{\mu_p C_{OX} W_p}{2L_p} (V_{GS} - V_T)^2$$

$$\rightarrow \frac{300 * 10^{-6} * 10}{2 * 2} (0 - (-2) - 0.5)^2 = \frac{75 * 10^{-6} * 50}{2 * 1} \left(V_{out} - 2 - (-0.5)\right)^2$$

$\rightarrow V_{out} = 0.55$ or 0.816. Since output has to be $V_{DD} \geq V_{out} \geq V_{SS}$ we will choose 0.55 V

Problem 6:

For quiescent values that capacitors act as open circuits, so the voltage is simply,

$$I_B = \frac{28 - V_B}{90K} - \frac{V_B}{10K} = \frac{28 - 10V_B}{90K}$$

$$I_E = (\beta + 1) I_B = (101) * \frac{28 - 10 * (V_E + 0.6)}{90K} = \frac{V_E}{2K} \rightarrow V_E \approx 0.4 \text{ V} \rightarrow V_B = 1 \text{ V}$$

$$I_C = \alpha * I_E = 0.99 * \frac{1}{2000} = 495\ \mu A \rightarrow V_C = 28 - 4000 * I_C = 26.02 \text{ V}$$

$V_{out} = 0V$

Problem 7:

a)for the same voltage drop, the ratio of currents between two BJT is a the same as the ratio of their areas (you can verify that to yourself) $\frac{I_{B1}}{I_{B2}} = \frac{A_{E1}}{A_{E2}} = \frac{1}{5}$

$I_B = I_{B1} + I_{B2} = 6\ I_{B1}$

$I_{IN} = I_{C1} + I_B = \beta I_{B1} + 6I_{B1}$

$I_{B1} = I_{in}\left(\frac{1}{\beta + 6}\right) -> I_{out} = \beta I_{B2} = \beta * 5I_{B1} = I_{in}\left(\frac{5\beta}{\beta + 6}\right)$

Assuming that β is large $\rightarrow I_{out} = 5 * I_{in} = 7.5\ mA$

b) Similarly to part (a), for two transistors in saturation with the same V_{GS}, their currents will be a ratio of their W/L

$$\frac{I_{D1}}{I_{D2}} = \frac{\frac{W_1}{L_1}}{\frac{W_2}{L_2}} = \frac{5}{20} = \frac{1}{4}$$

$I_{out} = 4I_{in} = 6\ mA$

Problem 8:

$BJT: I_{out} = \frac{A_{E2}}{A_{E1}} I_{in}$

$MOSFET: I_{out} = \frac{\frac{W_2}{L_2}}{\frac{W_1}{L_1}} I_{in}$

These are very useful structures that are called “Current mirrors”. They allow current to be mirrored over to other branches with a gain that is dependent on the geometric ratios of MOSFETS/BJT’s used.

Problem 9:

Code:

```
`timescale 1ns/1ps
module Reg4bit(In, Out, CLK, EN);
  input CLK, EN;
  input[3:0] In;
  output [3:0] Out;
    DFF FF0 (.D(In[0]),.Q(Out[0]), .CLK(CLK), .EN(EN));
    DFF FF1 (.D(In[1]),.Q(Out[1]), .CLK(CLK), .EN(EN));
    DFF FF2 (.D(In[2]),.Q(Out[2]), .CLK(CLK), .EN(EN));
    DFF FF3 (.D(In[3]),.Q(Out[3]), .CLK(CLK), .EN(EN));

endmodule
```

TestBench:

```
`timescale 1ns/1ps
module Reg4bit_tb();
  reg CLK, EN;
  reg[3:0] In;
  wire[3:0] Out;

    Reg4bit Reg0(.In(In), .Out(Out), .CLK(CLK), .EN(EN));

    initial
    begin
      In = 4'b0000;
      EN = 1'b1;
      CLK = 1'b0;
    end

  always
    #1 CLK = ~CLK;
  always
    #5 In = In + 1;
  always
    #7 EN = ~EN;

endmodule
```

Waveform Output: