Problem 1

Assume BJT works in forward active region

\[ I_B = \left( \frac{10 - 0.6}{500k} \right) = 18.8\mu A \]

\[ I_C = \beta I_B = 100 \times 18.8\mu A = 1.88mA \]

\[ V_C = 10 - 4000 \times 0.00188 = 2.48V \]

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

Small signal equivalent circuit:

Problem 2

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

\[ V_{out} + 2 \geq 2 - 0.5 \Rightarrow V_{out} \geq -0.5 \]

\[ I_D = \frac{\mu_n C_{OX} V}{2L} (V_{GS} - V_T)^2 = 4 - \frac{V_{out}}{R_1} \Rightarrow V_{out} = 4 - 337.5 \times 10^{-6} \times R_1 \geq -0.5V \]

\[ \Rightarrow R_1 \leq 13.3k\Omega \]

Problem 3

\[ R_1 = 6.666k\Omega \]

\[ A_V = \frac{2I_{DQ}R}{V_{SS} + V_T} = \frac{4.5V}{-1.5V} = -3 \]
Problem 4

Assuming that $M_1$ and $M_2$ are in saturation

\[
I_D_1 = I_D_2 \rightarrow \frac{\mu_n C_{ox} W_n}{2L_n} (V_{GS} - V_T)^2 = \frac{\mu_p C_{ox} W_p}{2L_p} (V_{GS} - V_T)^2
\]

\[
\rightarrow 100 \times 10^{-6} \times \frac{10}{2 \times 2} (0 - (-2) - 0.5)^2 = \frac{30 \times 10^{-6} \times 3}{2 \times 1} (V_{out} - 5 - (-0.5))^2
\]

\[
\rightarrow V_{out} = 0.96447V
\]

Problem 5

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

\[
I_B = \frac{32 - V_B}{90K} - \frac{V_B}{10K} = 32 - 10 \times V_B
\]

\[
I_E = (\beta + 1)I_B = (101) \times \frac{32 - 10 \times (V_E + 0.6)}{90K} \rightarrow V_E = 2.454 V \rightarrow V_B = 3.054 V
\]

\[
I_C = 101 \times 16.222 \mu A \rightarrow V_C = 32 - 3000 \times I_C = 27.085 V
\]

\[
V_{out} = 0V
\]

Problem 6

\[
V_{out} = 12 - (12000 \times i_{DQ})
\]

\[
I_{DQ} = 100 \times 10^{-6} \times \left( \frac{6}{2 \times 3} \right) (0 - (-2) - 1)^2
\]

\[
I_{DQ} = 75\mu A
\]

\[
V_{out} = 11.1V
\]

Problem 7

a)

\[
I_{DQ} = 100 \times 10^{-6} \times \left( \frac{6}{2 \times 3} \right) (2 - 1)^2
\]

\[
I_{DQ} = 100 \mu A
\]

\[
V_{outq} = 4 + 100 \mu * 20k = 6V
\]

b)

When $V_{in} = 0V, V_{out1} = V_{outQ} = 6V$

When $V_{in} = 25mV, V_{out2} = V_{outQ} + \Delta V$

\[
g_m = 100 \times 10^{-6} \left( \frac{6}{3} \right) (1) = 200 \frac{\mu A}{V}
\]

\[
\Delta V = (g_m \times \Delta V_{in}) \times 20k = 0.1V
\]

\[
V_{out2} = 6.1V
\]
Problem 8

\[ R_{FET} = \frac{1}{\mu_n C_{OX}} \left( \frac{L}{W} \right) (2 - 1) \]

\[ \frac{V_{out} - V_{in}}{R_F} = \frac{V_{in}}{R_{FET}} \]

\[ \frac{V_{out}}{V_{in}} = 1 + \frac{R_F}{R_{FET}} \]

\[ \frac{V_{out}}{V_{in}} = 1 + \mu_n C_{OX} \left( \frac{W}{L} \right) R_F = 1 + \frac{R_F}{2500} \]

Problem 9

a) \[ \frac{I_{B1}}{I_{B2}} = \frac{A_{E1}}{A_{E2}} = \frac{1}{4} \]

\[ I_B = I_{B1} + I_{B2} = 5 I_{B1} \]

\[ I_{IN} = I_{C1} + \beta I_B = \beta I_{B1} + 5 I_{B1} \]

\[ I_{B1} = I_{IN} \left( \frac{1}{\beta + 5} \right) \rightarrow I_{OUT} = \beta I_{B2} = \beta \times 4 I_{B1} = I_{IN} \left( \frac{4}{1 + \frac{5}{\beta}} \right) \]

Assuming that \( \beta \) is large \( \rightarrow I_{OUT} = 4 \times I_{IN} = 4 \text{ mA} \)

b) \[ \frac{I_{D1}}{I_{D2}} = \frac{W_1}{L_1} = \frac{10}{20} = \frac{1}{2} \]

\[ I_{OUT} = 2I_{IN} = 2 \text{ mA} \]

Problem 10

BJT: \( I_{OUT} = \frac{A_{E2}}{A_{E1}} I_{IN} \)

MOSFET: \( I_{OUT} = \frac{W_2}{L_2} I_{IN} \frac{W_1}{L_1} \)
Problem 11

At the basics, \( I_d = \mu C_{ox} \left( \frac{w}{2l} \right) (V_{gs} - V_T)^2 \), and all three have the same total length and width. Because the length/width is the one degree of freedom we have to modify the MOSFET, they should behave the same.

Problem 12

Yes, this does behave as a rectifier, but it does not work particularly well. It is “Diode Connected” and behaves as a diode, but it’s I-V curve is not as good as the standard diodes used in class, but may be better than some LEDs.

Problem 13

As always, we will assume we are operating in saturation region,

\[
I_D = \mu n C_{ox} \left( \frac{W}{2L} \right) (V_{gs} - V_T)^2 = \frac{V_{dd} - V_{out1}}{R_1}
\]

\[
I_D = \frac{(4 - 3)}{10k} = 0.1mA
\]

\[
100 \times 10^{-6} \times \left( \frac{W}{2L} \right) (2 - 1)^2 = 0.0001
\]

\[
\frac{W}{2L} = 1 \rightarrow W = 2L
\]

\[
W = 0.6\mu, L = 0.3\mu
\]
Problem 14

Code:

<table>
<thead>
<tr>
<th>Ln#</th>
<th></th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>module DFF (D, Q, notQ, clk);</td>
</tr>
<tr>
<td>2</td>
<td>input D, clk;</td>
</tr>
<tr>
<td>3</td>
<td>output Q, notQ;</td>
</tr>
<tr>
<td>4</td>
<td>reg Q, notQ;</td>
</tr>
<tr>
<td>5</td>
<td>always@ (posedge clk) begin</td>
</tr>
<tr>
<td>6</td>
<td>Q &lt;= D;</td>
</tr>
<tr>
<td>7</td>
<td>notQ &lt;= ~D;</td>
</tr>
<tr>
<td>8</td>
<td>end</td>
</tr>
<tr>
<td>9</td>
<td>endmodule</td>
</tr>
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Testbench:

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Output: