Problem 1

For the circuit on the left, the anode voltage can’t exceed the cathode voltage of 15 V, so diode is off.

\[ I_1 = \frac{10}{2k + 2k} = 2.5 \text{ mA} \]

For the circuit on the right, the resistors act as a voltage divider so \( V_D = \frac{15}{2} = 7.5 \text{ V} \), so diode is off.

\[ I_1 = \frac{15}{2k + 2k} = 3.75 \text{ mA} \]

Problem 2

Minimum sized transistor is \( \frac{1.5 \mu m}{0.6 \mu m} \) and \( R_{SW} \cong 2k \) and \( 6k \) for NMOS and PMOS respectively

Using NMOS \( \frac{W}{L} = \frac{10}{1} \) and PMOS \( \frac{W}{L} = \frac{20}{1} \) \( \rightarrow \) \( \frac{W}{L} \text{Actual} = \frac{W}{L} \text{Min} = 4 \) for NMOS and 8 for PMOS

Higher \( W \) increases current, which decreases resistance so \( R_{SW,N} = \frac{2k}{4} = 500 \text{ } \Omega \), \( R_{SW,P} = \frac{6k}{8} = 750 \text{ } \Omega \)

More area for each transistor so \( C_{GSN} = 1.5 * \frac{10}{0.9} = 16.7 \text{ } fF \), \( C_{GSP} = 1.5 * \frac{20}{0.9} = 33.3 \text{ } fF \)
Problem 3

Left: Assume MOSFET is in saturation and BJT is in forward active

\[ V_{BE} = 0.6V \]

\[ I = \frac{\mu_p C_{OX} W}{2L} (0.6 - 6 - V_{TP}) = \frac{33 \times 10^{-6} \times 15}{2 \times 10} (-5.4 - (-1))^2 = 0.479 \, mA \]

Assuming both MOSFETs are in saturation

\[ I_D = \frac{\mu_n C_{OX} W}{2L_1} (V_0 - V_{TN})^2 = \frac{\mu_n C_{OX} W_2}{2L_2} (V_{dd} - V_0 - V_{TN})^2 \]

\[ I_D = \frac{100 \times 10^{-6} \times 40}{2(5)} (V_0 - 1)^2 = \frac{100 \times 10^{-6} \times 15}{2(5)} (8 - V_0 - 1)^2 \rightarrow V_0 = 3.279 \, V \]

\[ I_D = 2.078 \, mA \]

Problem 4

By connecting the NMOS’s like so and sizing them all the same:

\[ \frac{W_1}{L_1} = \frac{W_2}{L_2} = \frac{W_3}{L_3} = \frac{W_4}{L_4} = \frac{W_5}{L_5} = \frac{1.5 \, \mu m}{0.6 \, \mu m} \]

The \( V_{OS} \) of Q5 will be one fifth of the VDD = 2 V
Problem 5

Using BJTs, like with MOSFETS we have only one degree of freedom, for BJTs this is the Area.

There is no limit to the number of BJTs and each BJT with the same Area works as a resistor with equal resistance. So 5 BJTs in series with equal area. Meaning that

\[ A_{E1} = A_{E2} = A_{E3} = A_{E4} = A_{E5} = 100 \, \mu m^2 \]

Will give 2V output between the fourth and fifth BJT.

Problem 6

Assuming both are in Forward Active Region, starting with the left circuit

\[ I_B = \frac{(8 - 0.6)}{600k} = 12.3 \, \mu A, \text{Using} \ \beta = 100 \]

\[ I_C = \beta I_B = 100 \times 12.3 \, \mu A = 1.23 \, mA \]

\[ V_{out} = 8V - 4k \times 0.00123 = 3.08 \, V \]

The right circuit is very similar, but

\[ I_C = \beta I_B = 100 \times \frac{(8 - 0.6)}{300k} = 2.47 \, mA \]

\[ V_{out} = 8V - 12k \times 0.00247 = -26.2 \, V \]

As we can see, the circuit isn’t in forward active so guess saturation

\[ I_B = \frac{(8 - 0.6)}{300k} = 24.7 \, \mu A \]

\[ I_C = \frac{8 - 0.2}{12k} = 650 \, \mu A \]

\[ V_{out} = 8V - 12k \times 650 \times 10^{-6} = 0.2 \, V \]

Verify saturation region \( \beta I_B = 2.47 \, mA > 650 \, \mu A \)
As with problem 3, as long as we assume forward active the left one is simply,

\[ I_C = \beta I_B = 100 \left( \frac{12 - 0.6}{400k} \right) = 2.85 \text{mA} \]

\[ V_{out} = 12 - 3000 \times 0.00285 = 3.45 \text{V} \]

The right problem has an input of 0\sin(1000t) into the circuit, which is equivalent to an open circuit, so the same as the left circuit,

\[ V_{out} = 3.45 \text{V} \]

With \( \beta = 90 \),

\[ V_{out} = 12 - \left( 1500 \times 90 \times \left( \frac{12 - 0.6}{400k} \right) \right) = 8.15 \text{V} \]

With \( \beta = 120 \),

\[ V_{out} = 12 - \left( 1500 \times 120 \times \left( \frac{12 - 0.6}{400k} \right) \right) = 6.87 \text{V} \]

In the previous circuit when \( \beta = 100 \), \( V_{out} = 7.725 \). Neglecting \( I_B \) in the fixed-biasing circuit,

\[ V_B = 0.6 + 0.5k \times I_C = 0.6 + 500 \times 2.85 \times 10^{-3} = 2.025 \text{V} \]

\[ V_B = 12 \left( \frac{R_2}{R_1 + R_2} \right) = 12 \left( \frac{R_2}{40k + R_2} \right) = 2.025 \text{V} \]

\[ R_2 = 8.12 \text{ k\Omega} \]
Problem 11

Continuing from problem 7, if we include $I_B$ we can write the following equation to approximate $I_B$

$$12 - V_B = I_B + \frac{V_B}{40K}$$

and $V_B - 0.6 = (I_B + \beta I_B)500\Omega$

$$V_{OUT} = 12 - 1500I_C$$

For $\beta = 90$

$$(I_B + 90I_B) * 500 = V_B - 0.6$$

$$V_B = 43000I_B + 0.6$$

$$\frac{12 - 43000I_B + 0.6}{40000} = I_B + \frac{43000I_B + 0.6}{8120} \rightarrow I_B = 27.27 \mu A$$

$$I_C = \beta I_B = 27.27 \times 10^{-6} * 90 = 2.454 mA$$

$$V_{OUT} = 12 - 1500 * 0.002454 = 8.32 V$$

With $\beta=120$,

$$(I_B + 90I_B) * 500 = V_B - 0.6$$

$$V_B = 60500I_B + 0.6$$

$$\frac{12 - 60500I_B + 0.6}{40000} = I_B + \frac{60500I_B + 0.6}{8120} \rightarrow I_B = 21.19 \mu A$$

$$I_C = \beta I_B = 2.54 mA$$

$$V_{OUT} = 12 - 1500 * 0.00254 = 8.191 V$$

Note the relatively small change in $V_{OUT}$ with this compared to the much larger change from problem 6.

Problem 12

Code:

```
`timescale 1ns/1ps
module UpDownCounter (sel, clk, out);
  input sel, clk;
  output [3:0] out;
  reg [3:0] out;

  initial out = 4'b0000;

  always @(posedge clk)
    if (sel == 0) begin
      out <= out+1;
    end
    else begin
      out <= out-1;
    end
endmodule
```
Testbench:

```verilog
module UpDown_tb();
    reg s, c;
    wire [3:0] out;
    UpDownCounter count(.sel(s), .clk(c), .out(out));

    initial begin
        s = 0;
        c = 0;
        end

    always #1 c <= ~c;
    always #34 s <= ~s;

endmodule
```

Output: