EE330 Homework 7 Fall 2017 TA: Joseph Aymond

Problem 1

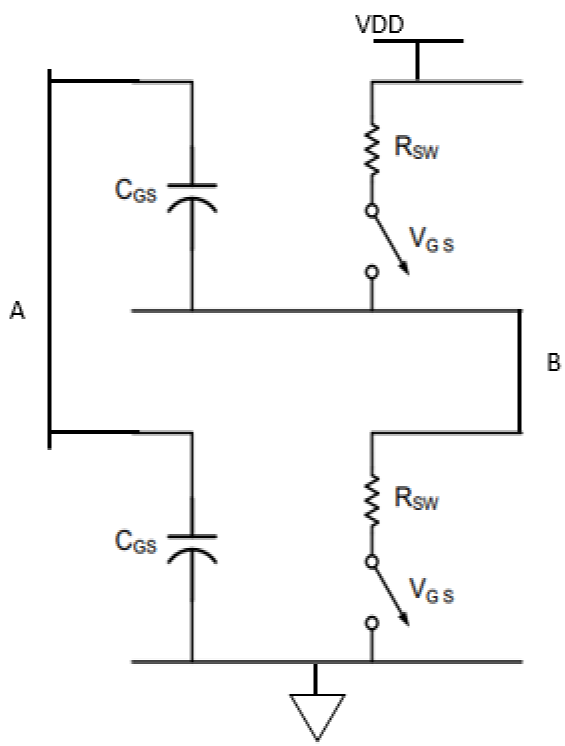
For the circuit on the left, the anode voltage can't exceed the cathode voltage of 15 V, so diode is off.

$$I_1 = \frac{10}{2k + 2k} = 2.5\ mA$$

For the circuit on the right, the resistors act as a voltage divider so V_D = 15/2 = 7.5 V, so diode is off.

$$I_1 = \frac{15}{2k + 2k} = 3.75\ mA$$

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 $NMOS\ \frac{W}{L} = \frac{10}{1}\ and\ PMOS\ \frac{W}{L} = \frac{20}{1} \rightarrow \frac{\frac{W}{L}_{Actual}}{\frac{W}{L}_{Min}} = \ 4\ for\ NMOS\ and\ 8\ for\ PMOS$

Higher W increases current, which decreases resistance so $R_{SW_N} = \frac{2k}{4} = 500\ \Omega, R_{SW_P} = \frac{6k}{8} = 750\ \Omega$

More area for each transistor so $C_{GS_N} = 1.5 * \frac{10}{0.9} = 16.7\ fF, C_{GS_P} = 1.5 * \frac{20}{0.9} = 33.3\ fF$

Problem 3

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

$V_{BE} = 0.6V$

$I = \frac{\mu_p C_{OX} W}{2L}\left(0.6 - 6 - V_{T_P}\right) = \frac{33 * 10^{-6} * 15}{2 * 10}\left(-5.4 - (-1)\right)^2 = 0.479\ mA$

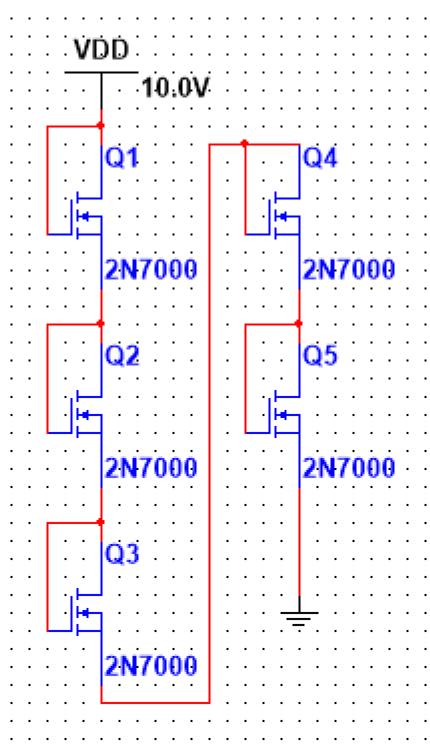
Assuming both MOSFETs are in saturation

$$I_D = \frac{\mu_n C_{OX} W_1}{2L_1}(V_o - V_{TN})^2 = \frac{\mu_n C_{OX} W_2}{2L_2}(V_{dd} - V_o - V_{TN})^2$$

$$I_D = \frac{100 * 10^{-6} * 40}{2(5)}(V_o - 1)^2 = \frac{100 * 10^{-6} * 15}{2(5)}(8 - V_o - 1)^2 \rightarrow V_o = 3.279\ V$$

$I_D = 2.078\ mA$

Problem 4

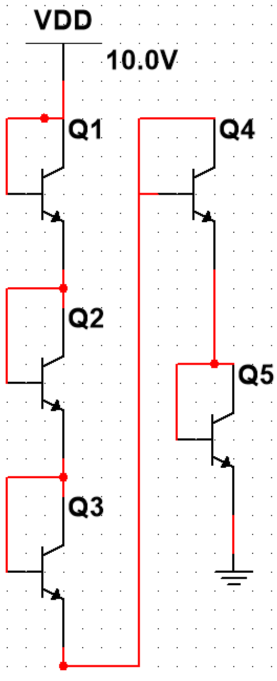


By connecting the NMOS's like so and sizing them all the same:

$$\frac{W_1}{L_1} = \frac{W_2}{L_2} = \frac{W_3}{L_3} = \frac{W_4}{L_4} = \frac{W_5}{L_5} = \frac{1.5\ um}{0.6\ um}$$

The V_{DS} 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

$$A_{E1} = A_{E2} = A_{E3} = A_{E4} = A_{E5} = 100\ um^2$$

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

Problem 6

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

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

$$I_C = \beta I_B = 100 * 12.3\ \mu A = 1.23\ mA$$

$$V_{out} = 8V - 4k * 0.00123 = 3.08\ V$$

The right circuit is very similar, but

$$I_C = \beta I_B = 100 * \frac{(8-0.6)}{300k} = 2.47\ mA$$

$$V_{out} = 8V - 12k * 0.00247 = -26.2\ V$$

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

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

$$I_C = \frac{8-.2}{12k} = 650\ \mu A$$

$$V_{out} = 8V - 12k * 650 * 10^{-6} = 0.2\ V$$

Verify saturation region $\beta I_B = 2.47\ mA > 650\ \mu A$

Problem 7

Problem 8

As with problem 3, as long as we assume forward active the left one is simply,

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

$V_{out} = 12 - 3000 * 0.00285 = 3.45\ V$

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

$V_{out} = 3.45\ V$

Problem 9

With β=90,

$V_{out} = 12 - \left(1500 * \left(90 * \left(\frac{12-0.6}{400k}\right)\right)\right) = 8.15V$

With β=120,

$V_{out} = 12 - \left(1500 * \left(120 * \left(\frac{12-0.6}{400k}\right)\right)\right) = 6.87V$

Problem 10

In the previous circuit when β=100, $V_{out} = 7.725$.

Neglecting I_B in the fixed-biasing circuit,

$V_B = 0.6 + 0.5k * I_C = 0.6 + 500 * 2.85 * 10^{-3} = 2.025V$

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

$R_2 = 8.12\ k\Omega$

Problem 11

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

$$\frac{12 - V_B}{40K} = I_B + \frac{V_B}{8.12k} \; and \; V_B - 0.6 = (I_B + \beta I_B)500\Omega$$

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

$$For \; \beta = 90$$

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

$$V_B = 43000 I_B + 0.6$$

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

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

$$V_{out} = 12 - 1500 * 0.002454 = 8.32 \; V$$

With β=120,

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

$$V_B = 60500 I_B + 0.6$$

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

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

$$V_{out} = 12 - 1500 * 0.00254 = 8.191 \; V$$

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:

```
`timescale 1ns/1ps
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: