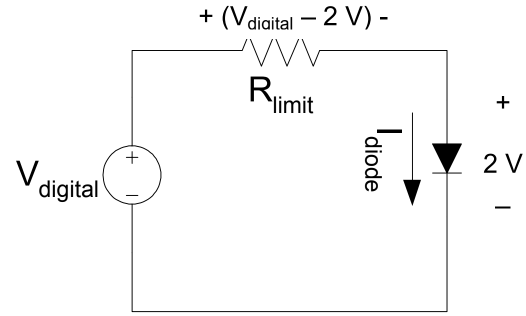
EE 42

Homework #5 Solutions

Problem 1:



For there to be between 20 mA and 100 mA of current flowing, the diode must be forward biased. The diode will take 2 V of $V_{digital}$, and the resistor will take the rest of $V_{digital}$.

The current flowing through the circuit will thus be

$I_{diode} = (V_{digital} – 2\text{ V})/R_{limit}$

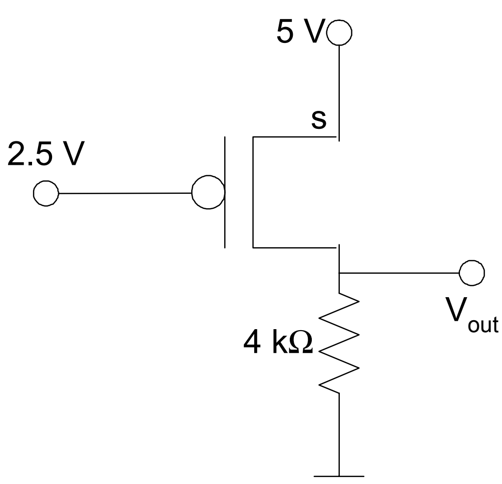
R_{limit} must be small enough so that I_{diode} is at least 20 mA when $V_{digital}$ is at its smallest, 4 V.

$(4\text{ V} – 2\text{ V})/R_{limit} \geq 20\text{ mA}$ $\qquad$ $R_{limit} \leq 100\ \Omega$

R_{limit} must be big enough so that I_{diode} is less than 100 mA when $V_{digital}$ is at its biggest, 5 V.

$(5\text{ V} – 2\text{ V})/R_{limit} \leq 100\text{ mA}$ $\qquad$ $R_{limit} \geq 30\ \Omega$

Problem 2:



$V_{GS} = 2.5\text{ V} – 5\text{ V} = -2.5\text{ V}$

Transistor is not cutoff.

Guess saturation mode:

$I_D = -(1\text{ mA/V}^2)(1/2)(-2.5\text{ V} - -1\text{ V})^2(1+0\ V_{DS})$

$I_D = -1.125\text{ mA}$

By KVL,

$(4\text{ k}\Omega)I_D + V_{DS} + 5\text{ V} = 0$ so $V_{DS} = -0.5\text{ V}$

For saturation, $V_{DS} < V_{GS} – V_{TH(p)}$ **Not true!**

So transistor must be in triode mode.

$I_D = -(1\text{ mA/V}^2)(-2.5\text{ V} - -1\text{ V} - (V_{DS}/2))(V_{DS})$

It's still true that $(4\text{ k}\Omega)I_D + V_{DS} + 5\text{ V} = 0$ so substitute to get

$-(5\text{ V} + V_{DS})/ 4\text{ k}\Omega = -(1\text{ mA/V}^2)(-2.5\text{ V} - -1\text{ V} - (V_{DS}/2))(V_{DS})$

Solutions: $V_{DS} = \{-1\text{ V}, - 2.5\text{ V}\}$

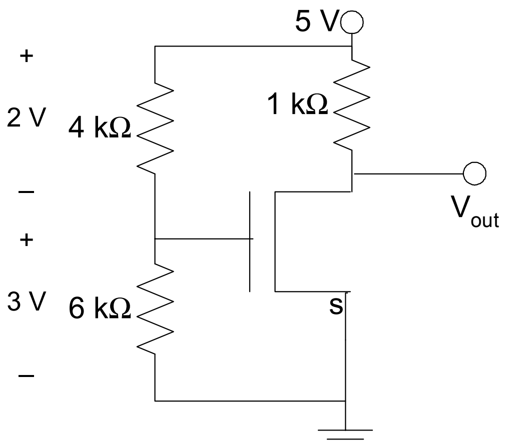
$V_{DS} = -2.5\text{ V}$ not possible for triode mode (need $V_{DS} > V_{GS} – V_{TH(p)}$) so $V_{DS} = -1\text{ V}$

$I_D = -(1\text{ mA/V}^2)(-2.5\text{ V} - -1\text{ V} - (-1\text{ V}/2))(-1\text{ V}) = –1\text{ mA}$

$V_{out} = V_{DS} + 5\text{ V} = 4\text{ V}$

(Typically, the numbers do not work out this nicely!)

Problem 3:



Notice that no current goes into or out of the gate.
So the 4 k and 6 k transistors have the same current.

Voltage division or Ohm's law tells us that the 4 k resistor has 2 V and the 6 k resistor has 3 V as shown.

So V_{GS} = 3 V (over the 6 k resistor).

The transistor is not cutoff.

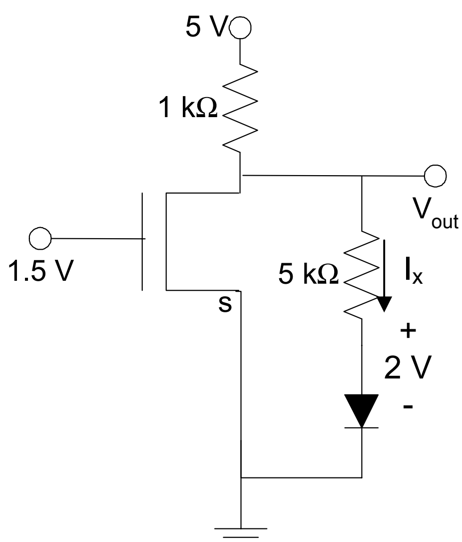
Guess saturation mode:

$I_D = (1\text{ mA/V}^2)(1/2)(3\text{ V} - 1\text{ V})^2(1+0\,V_{DS})$ $\qquad I_D = 2\text{ mA}$

By KVL, $(1\text{ k}\Omega)I_D + V_{DS} - 5\text{ V} = 0$ so $V_{DS} = 3\text{ V}$

For saturation, $V_{DS} > V_{GS} - V_{TH(n)}$ **Yes!** Saturation was the right guess. $\qquad V_{out} = V_{DS} = 3\text{ V}$

Problem 4:



V_{GS} = 1.5 V Transistor is not cutoff. Guess saturation:

$I_D = (1\text{ mA/V}^2)(1/2)(1.5\text{ V} - 1\text{ V})^2(1+0\,V_{DS})$ $\qquad I_D = 125\ \mu\text{A}$

Now we must find V_{DS}. The only way to do this is by KVL.
Guess that the diode is forward biased (small V_{in} means big V_{out} for our inverter). For large-signal model, this means diode has V_F = 2 V and some positive current. Now starting KVL at ground and going clockwise,

$-V_{DS} + 5\text{ k}\Omega\ I_x + 2\text{ V} = 0$ $\qquad$ Need to find I_x.

KVL again, starting at ground, going up diode branch and 1k resistor branch, dropping back to ground over 5 V source:

$-2\text{ V} - 5\text{ kW}\ I_x - 1\text{ k}\Omega\,(I_x + 125\ \mu\text{A}) + 5\text{ V} = 0$

$I_x = 479\ \mu\text{A}$

$V_{DS} = 5\text{ k}\Omega\ I_x + 2\text{ V}$ (by previous KVL) $\qquad V_{DS} = 4.395\text{ V}$

For saturation, $V_{DS} > V_{GS} - V_{TH(n)}$ **Yes!** Saturation was the right guess. $\qquad V_{out} = V_{DS} = 4.395\text{ V}$