EE 321 Analog Electronics, Fall 2008
Exam #2, 2008/10/22

Rules

You may use your calculator, your text book, and your notes. I cannot answer clarification questions. Answer what you think the question asks. Each sub-question counts equally. Include units in all numbers that you compute. Do your calculations in symbolic form and only insert numbers at the end. None of these problems require long derivations. If you find yourself doing long derivations you might be on the wrong track.

Question 1: Voltage regulator

In this question you will use a 12 V power supply with zero output resistance and a 6 V Zener diode.

(a) CCombine the Zener diode, the power supply, and a resistor, to make a 6 V power supply which can supply up to 100 mA to the load before dropping the voltage. What is the value of the resistor?

(b) What is the largest current through the Zener diode? And what is the corresponding power dissipation in the Zener?

(c) If the Zener diode has a Zener resistance $r_z = 5\,\Omega$, by how much does the output voltage vary as the output current varies over the designed range?

Answers:

(a) The resistance should be such that at $I_{\mathrm{max}} = 100\,\mathrm{mA}$ the voltage across it creates exactly the voltage difference between the Zener and the supply:

$$V_{\mathrm{supply}} - V_z = I_{\mathrm{max}} R$$

$$R = \frac{V_{\mathrm{supply}} - V_z}{I_{\mathrm{max}}} = \frac{12-6}{0.1} = 60\,\Omega$$

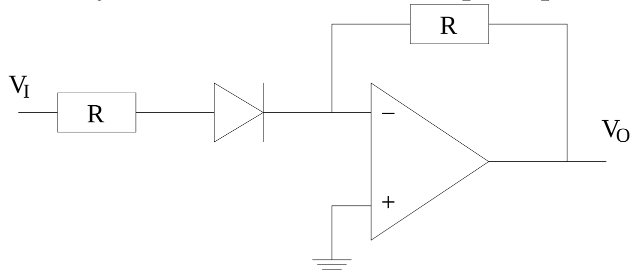
(b) The largest current through the Zener occurs when there is no current going through the load. In that case, the current is

$$I_Z = \frac{V_{\mathrm{supply}} - V_Z}{R} = I_{\mathrm{max}} = 100\,\mathrm{mA}$$

(c) The variation in the voltage is equal to the variation in current times the Zener resistance,

$$\Delta V_z = r_z\left(I_{\mathrm{max}} - I_{\mathrm{min}}\right) = r_z I_{\mathrm{max}} = 5 \times 0.1 = 0.5\,\mathrm{V}$$

Question 2: Diode and op-amp

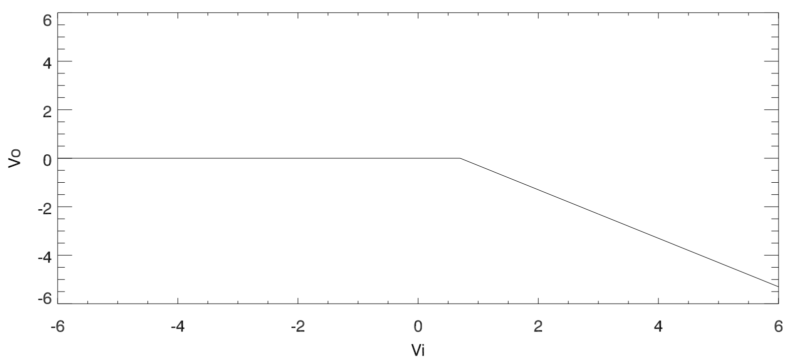


(a) What is the relationship between V_I and V_o in the above circuit? Assume the fixed 0.7 V forward drop model for the diode.
(b) How does the relationship change if you reverse the order of the input resistor and the diode?
Answers:
(a) As long as the voltage on the input is less than 0.7 V the diode does not conduct. So no current flows and the output is zero. Once the diode begins to conduct the current becomes

$$I = \frac{V_I - V_D}{R}$$

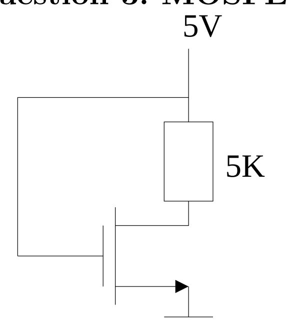
and the output becomes

$$V_o = -IR = -(V_I - V_D)$$



(b) Reversing the order of the input resistor and the diode does not change the IV characteristics.

Question 3: MOSFET



This MOSFET has $V_t = 0.5\,\text{V}$ and $\frac{W}{L}k'_n = 100\,\mu\text{A/V}^2$
(a) What mode is the MOSFET operating in?
(b) What is the drain current? (Think of an approximation that might simplify the math)
Answers:
(a) We begin with

$$i_D = \frac{W}{L}k'_n\left[(v_{GS} - V_t)\,v_{DS} - \frac{v_{DS}^2}{2}\right]$$

The question is whether the voltage drop across the resistor is smaller or greater than V_t. If the drop is smaller than V_t then the MOSFET is operating in the saturation region. If it is larger than V_t the MOSFET is operating in the triode region. Let's first try to assume saturation operation. In that case

$$i_D = \frac{1}{2}\frac{W}{L}k_n' \left(v_{GS} - V_t\right)^2$$

With $v_{GS} = 5\,\mathrm{V}$, $V_t = 0.5\,\mathrm{V}$, and the rest given we get

$$i_D = \frac{1}{2}100 \times \left(5 - 0.5\right)^2 = 1.01\,\mathrm{mA}$$

For that current the voltage drop across the resistor is

$$\Delta V_R = i_D R = 1.01 \times 10^{-3} \times 5 \times 10^3 = 5.05\,\mathrm{V}$$

At most $0.5\,\mathrm{V}$ drop is allowed for saturation operation, so we must be operationg in the triode region.

(b) From the previous result I am guessing that $v_{DS} \ll v_{GS} - V_t$, so I can use the resistive approximating for the IV characteristics:

$$i_D = \frac{W}{L}k_n' \left(v_{GS} - V_t\right) v_{DS}$$

And we have $v_{DS} = V_{DD} - i_D R$. Inserting we get

$$i_D = \frac{W}{L}k_n' \left(v_{GS} - V_t\right)\left(V_{DD} - i_D R\right)$$

$$i_D \left[1 + \frac{W}{L}k_n' \left(v_{GS} - V_t\right) R\right] = \frac{W}{L}k_n' \left(v_{GS} - V_t\right) V_{DD}$$

$$i_D = \frac{\frac{W}{L}k_n' \left(v_{GS} - V_t\right) V_{DD}}{1 + \frac{W}{L}k_n' \left(v_{GS} - V_t\right) R}$$

Now inserting values we get

$$i_D = \frac{100 \times 10^{-6} \times (5 - 0.5)5}{1 + 100 \times 10^{-6} \times (5 - 0.5)5 \times 10^3} = 692\,\mu\mathrm{A}$$