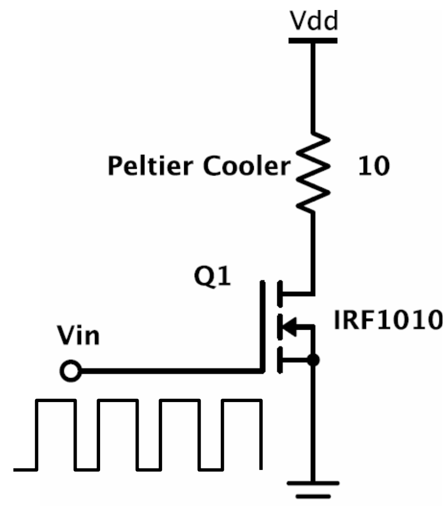
Physics 3150
Problem Set 4, 2016

Due Monday, March 21, 2016

Exam: The midterm exam will be on Wednesday, March 23 (administered in class) and will cover all the material on the first four problem sets. You are permitted to use **one textbooks and your class notes.**

1. (15 points — easy but long) An n-channel power MOSFET is used to control a solid-state refrigeration unit that has a resistance of 10 Ω. A power supply provides Vdd = 15 V. The power to the cooler is varied in the range 0-10W to maintain a fixed temperature. The MOSFET, an IRF1010N, is an inexpensive but amazingly capable device that can control up to 85A with proper heat-sinking. When fully switched on by applying a positive gate voltage $V_{GS} > 10$V, the effective drain-to-source resistance is guaranteed to be $R_{DS} < 0.011\ \Omega$.



   (a) For systems with long time constants such as heaters or coolers, it is common to rapidly switch the power on and off, controlling the average power output by varying the *duty cycle*, the ratio of (on time): (cycle time). This is called *pulse-width modulation*. Assume that a 10 kHz pulse train is used to switch the MOSFET, with a 10 V amplitude at the gate and a duty cycle variable from 0-100%. What is the worst-case power dissipation in the MOSFET due to R_{DS}, when the cooler is operating at a full 10W?

   (b) According to the IRF1010N data sheet, the total charge on the gate is about 80 nC when V_{GS} = 10V. Given this information, how much average input power at V_{in} is needed to repeatedly charge up the gate capacitance as the MOSFET is switched at 10 kHz? Assume that the stored energy is completely lost to heating in the driving circuitry each time the gate is switched off.

   (c) Now assume that the MOSFET is instead operated with a steady-state dc voltage at Vin, which is varied to adjust the drain voltage V_D in order to control the power to the cooler. How much power is now dissipated in the MOSFET, as a function of V_D? What is the worst-case value of V_D in Volts? For this value, how much more power is wasted in the MOSFET than with a pulse-width modulation scheme, adding together the average wasted power from parts (a) and (b)?

2. Eggleston 6-2.

3. Eggleston 6-8.

4. Eggleston 6-9.

(continued)

5. Solve for the complex voltage gain of the op-amp circuit shown below. What kind of filter is it? What is the characteristic frequency, and what happens to the amplitude and phase as the frequency is changed from low values to high values? What are the advantages of this design over a simple RC filter without an op amp?