Problem 1 (12 points) For What Is Mechatronics Good?

Problem Statement:

High-precision high-speed motors, such as in disk drives, typically use ball bearings on the motor shaft to keep the motor shaft precisely centered, and to reduce friction. As with all mechanical components, the balls and tracks in the bearing are not perfect. In a disk drive, wobble of the motor shaft can make head tracking difficult, reducing data storage density.

A magnetic bearing approach has been proposed to reduce shaft wobble and eliminate motor friction. The magnetic bearing can be thought of as a set of electromagnets which, without contact with the shaft, can apply forces to translate the shaft while it rotates, keeping it centered. Active control is required to keep the bearing centered.

[2 pts.] a) Briefly explain how you would implement a mechatronic approach to the precision motor bearing problem.

[3 pts.] b) List required sensors and actuators, and estimate the required resolution and sampling rate. (Assume motor turns at 1,000 revolutions per second, motor shaft is 5mm diameter, and maximum allowable wobble is $0.5\mu m$.)

[3 pts.] c) Draw a block diagram of a closed-loop controller for the bearing.

[2 pts.] **d)** Discuss software requirements for the active magnetic bearing, including self-test and self-check.

[2 pts.] **e)** List advantages and disadvantages of the mechatronic approach to this problem.

Problem 2 (8 points)

Consider the NMOS motor drive shown below:

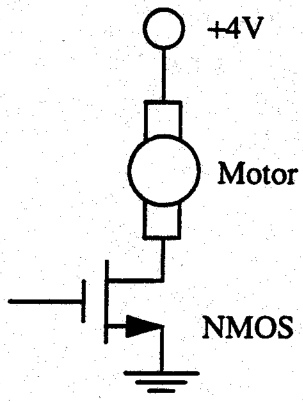


Figure 1

Typical Electrical Characteristics

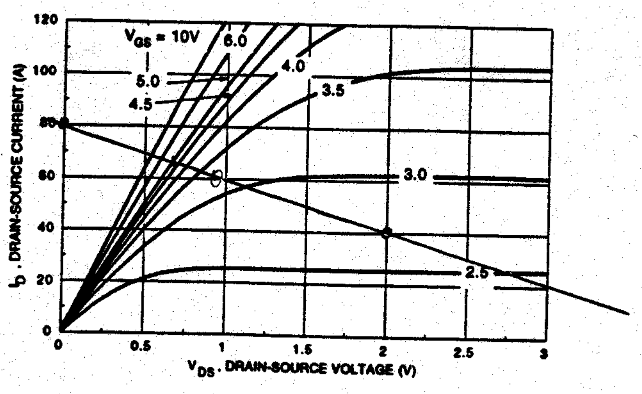


Figure 2: On-region Characteristics

The motor resistance is 0.05 ohm. Recall $P = I^2R, P = VI$. Assume the motor is stalled.

[4 pts.] **a)** Given that the NMOS transistor is able to dissipate 50 Watts, estimate the minimum V_{GS} required to prevent NMOS failure.

[4 pts.] **b)** What is the efficiency $\left(\frac{P_{motor}}{P_{motor} + P_{transistor}}\right)$ of the circuit when $V_{GS} = 5\text{V}$?

Problem 3 (6 points) — PWM (Pulse Width Modulation)

[2 pts.] **a)** Explain how PWM can be used to drive a DC motor at 50% of peak current, using sketches of motor current and voltage versus time.

[2 pts.] **b)** Why is PWM used instead of driving a power transistor and motor in a linear fashion?

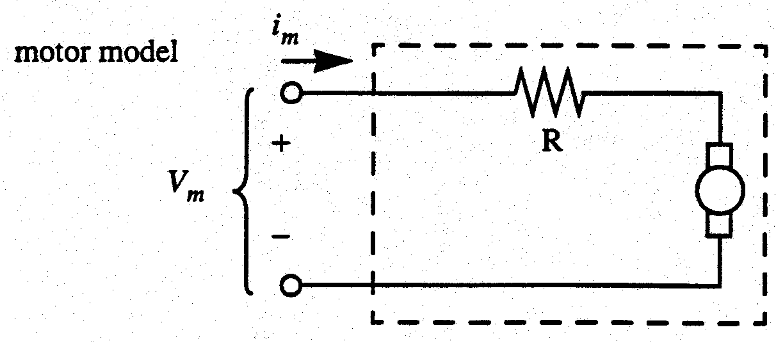
[2 pts.] **c)** In EECS 192, we generated PWM signals in hardware in the Xilinx FPGA. PWM could also be generated in software, toggling a bit on a simple digital output port.

Briefly explain the advantages and disadvantages of executing PWM code in the top level (foreground) as opposed to a background (interrupt-driven) process.

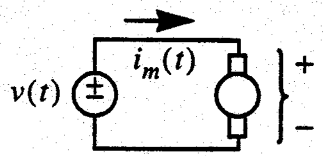
Problem 4 (8 points)

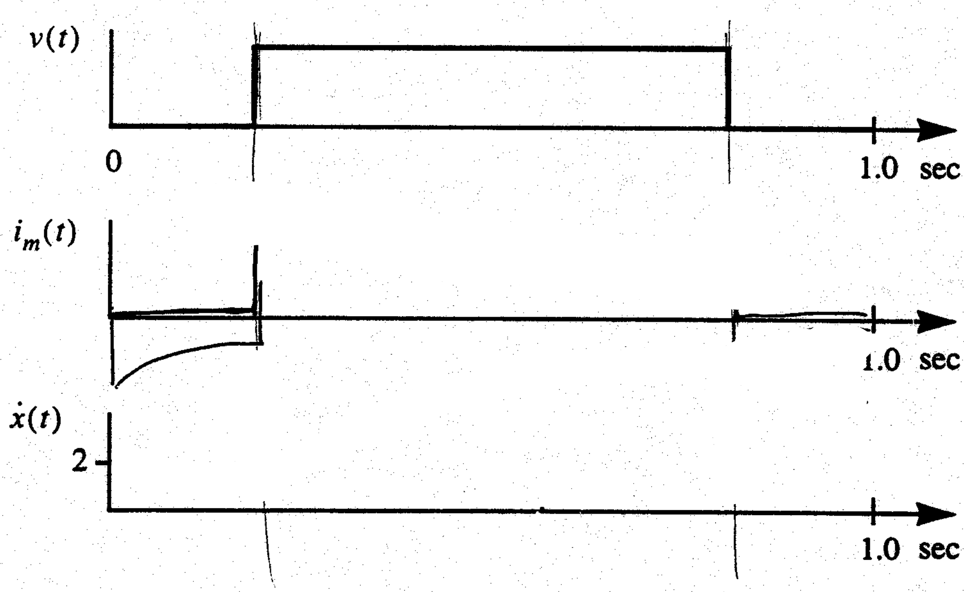
For this problem, consider a DC permanent magnet motor (as used in your car). The car is on a carpet and moves in a straight line with no slip between the wheels and the carpet. The car is initially moving at a speed of 2 meters per second.

You can assume a motor model as shown below. The qualitative shape of the curves is more important than magnitudes.



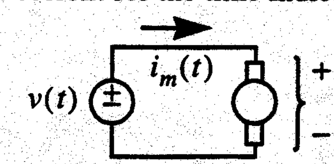
[4 pts.] **a)** Consider the motor driven from a voltage source with voltage $v(t)$, as shown. Sketch car velocity $\dot{x}(t)$ and motor terminal current for the time indicated.

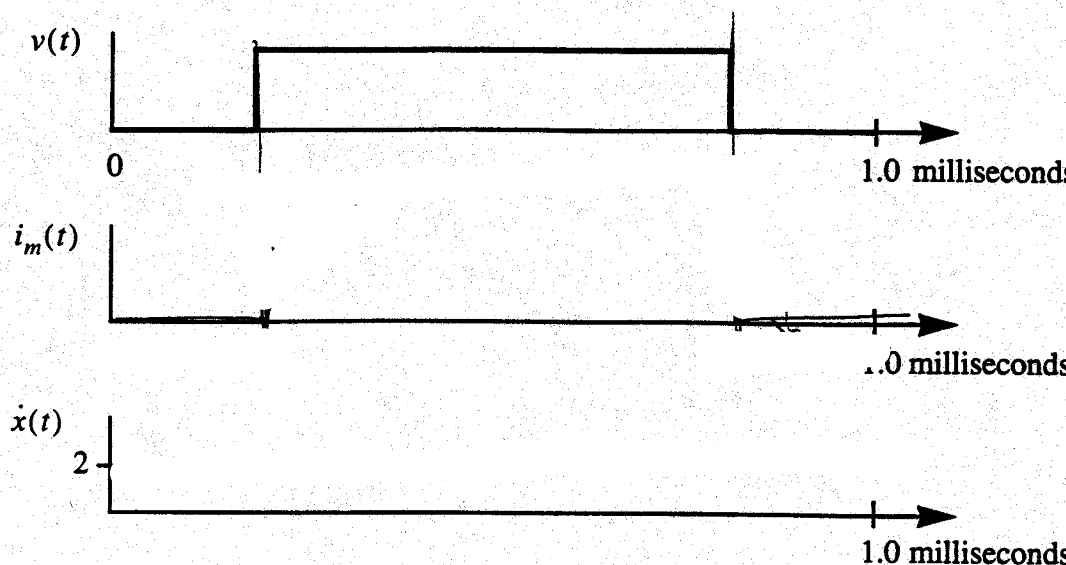




[4 pts.] **b)** Consider the motor driven from a voltage source with voltage $v(t)$, as shown. Sketch car velocity $\dot{x}(t)$ and motor terminal current for the time indicated.

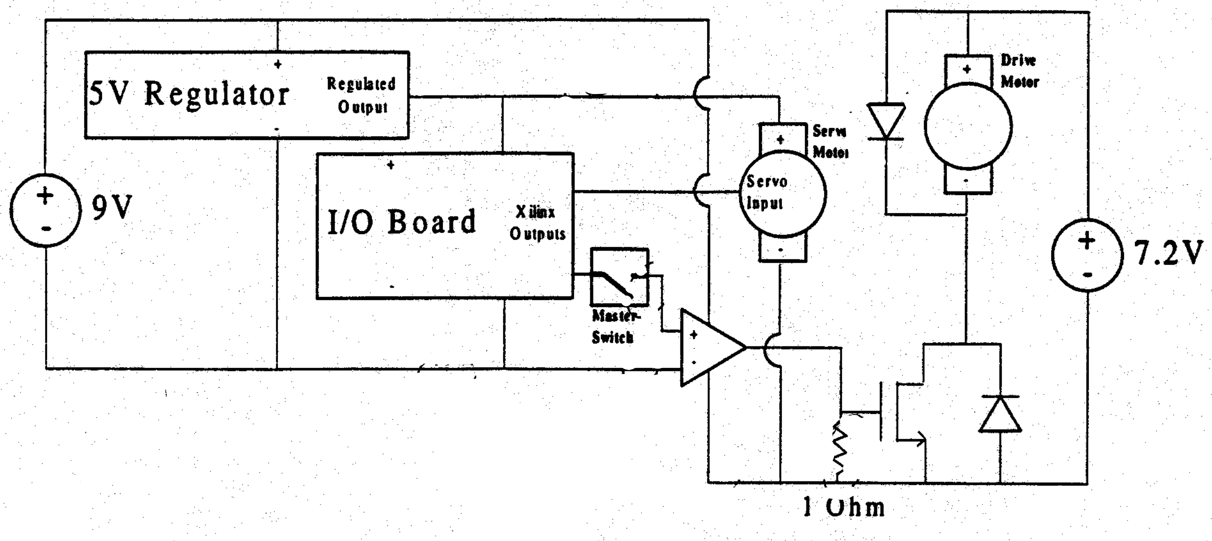
(1.0ms) (5m/s²) = .005m/s



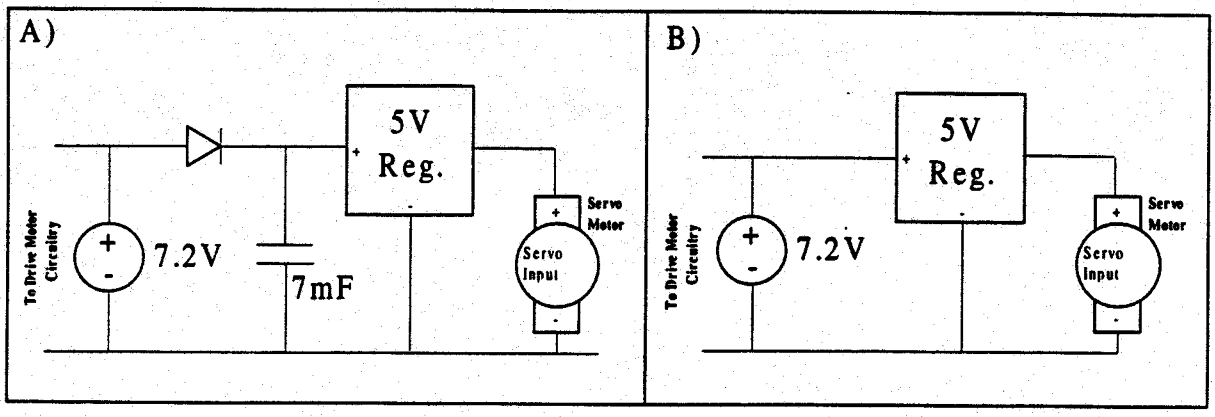


Problem 5 (8 points)

During the up-coming spring semester, Professor Fearing requests that the students lay out a complete schematic for their project proposal. Shown below is one of the many schematics that Fearing receives. As he is sure to notice, there are several problems with this schematic. Help Prof. Fearing grade this schematic by circling the areas that are poorly designed and by labeling each of these areas with a different number. Below the schematic, write the numbers that correspond to the problems that you have found, followed by an explanation telling the student why that part of the circuit is flawed and what should be done to fix it. (Hint: None of the components are ideal; they are the same types of parts that we used in the lab. Assume that the operational amplifier can drive 100 mA at its output.)



Problem 6 (6 points)

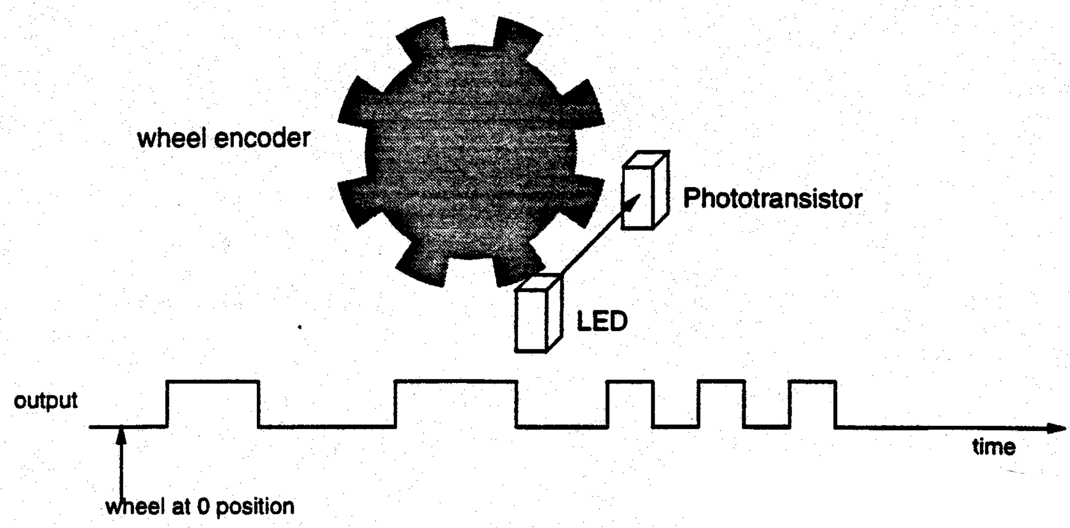


[4 pts.] a) Both schematics A and B show two different ways of connecting a servo to a 7.2V power supply, which also powers a drive motor. Explain why schematic A is a better way of regulating a servo's 5V supply than schematic B. You can assume that the regulator does not need any extra capacitors to keep its output from fluctuating under normal conditions (in which the + terminal is either 5V or above). (Hint: Be sure to explain the function of each component that was added to circuit A.)

[2 pts.] b) A student measures a voltage of 8.3 V across his 9V battery, which is powering his I/O board. When he plugs the battery into his I/O board, however, the Xilinx chip keeps on resetting during its initialization. He then measures the regulator's output voltage with the hand-held multimeter from the EE 192 laboratory and gets a value of 4.8 V. The student concludes from this that one of the chips on his board is bad because he knows that his I/O board will run off of a 4.8V supply. Is the student correct in making this assumption? If so, why do you think he is? If not, what else could be happening?

Problem 7 (8 points)

Consider the single-channel incremental encoder and its output shown in the figure below.



[2 pts.] **a)** If the wheel initially starts at 0, is it possible to estimate the final wheel position? Why or why not?

[2 pts.] **b)** Is it possible to estimate the maximum velocity from this data? Why or why not?

[4 pts.] **c)** Assuming the car always goes forward, list two methods of estimating velocity from the incremental encoder signal. Explain advantages and disadvantages of each method.

Method #1:

Advantages–

Disadvantages–

Method #2:

Advantages—

Disadvantages-

Problem 8 (3 points)

Defective sensors are a big problem in EE 192 (and also in real life). Suggest 3 possible ways of recognizing in software that a magnetic sensor has failed (observations):

a)

b)

c)

Problem 9 (3 points)

Explain how limited magnetic sensor resolution may affect EECS 192 car performance.

Problem 10 (3 points)

In the EECS 192 car, what factors limit magnetic sensor resolution? Suggest a software method of improving sensor resolution.

Problem 11 (6 points)

Due to control instability, cars can get lost off the track.

[3 pts.] **a)** Suggest two software strategies for detecting the car getting lost:

[3 pts.] **b)** Suggest a software strategy for getting back on the track:

Problem 12 (6 points)

Embedded systems can be required to run without operator intervention for many decades. Explain how some of the 6811 features can be used to make a more robust (crash-resistant) system.

Problem 13 (10 points) Steering Control

[5 pts.] a) Explain, with the aid of diagrams or equations, why steering overshoot is likely using a simple proportional controller on a lateral error signal.

[5 pts.] b) Explain, with the aid of diagrams or equations, why steering overshoot is less likely using a simple proportional-plus-derivative controller on a lateral error signal.

Problem 14 (5 points) Control

In discussing control principles for steering, we examined simple proportional and proportional-plus-derivative control, assuming that the steering system was adequately described by a linear differential equation, a "linear plant." In practice, at least at the vehicle speeds people were using, this mostly worked okay.

List 5 situations where or reasons why this assumption is not valid.

1)

2)

3)

4)

5)

Problem 15 (6 points)

Several groups proposed to control the car's speed using the following algorithm running at 100 Hz:

- measure car's speed
- if speed is too low, increase PWM by adding a constant to current PWM value
- if speed is too high, decrease PWM by adding a constant to current PWM value

Explain why or why not this method would work well for speed control.