E190V - Lab 1

The Setup:
You're working on a video game peripheral that may be powered by up to 4 AA batteries. Obviously, it is desirable to maximize the lifetime of your device by minimizing its power draw. Including an off/sleep mode wouldn't hurt either.

The device is communicating with a central video game console that is much less power constrained. However, the console is already out on the market, so you need to work with one of its existing receivers. The receiver is sensitive to visible light LED signals.

You need to construct a prototype of the video game peripheral which transmits information about the positions of a joystick, which we'll model as a potentiometer, over an LED to the video game console, which we'll model with MATLAB/Numpy/etc.

We'll be paying particular attention to the accuracy (read: noise performance) and power of the peripheral. You will evaluate accuracy by reporting the percent error in the estimate of your potentiometer value. If noise affects your estimate (it probably will) then you should report the accuracy assuming one standard deviation of noise is present. This error must be less than 2%. Minimizing the transmit power needed to achieve that minimum accuracy is the goal of the project.

This is a thinker's lab. It is very possible to build simple circuits that achieve this task if you carefully consider how you're going to encode information onto the LED.

How to Do This:
This lab can seem daunting, but if can be broken down into smaller steps which can be more readily digested.

The first step is to study your assumptions and look for hidden constraints. One particularly relevant assumption to look at is that the transmitter only needs to convey information about a mechanical input controlled by a human hand: the video game peripheral is presumably driven by a person. This means that the sensor/transmit circuit don't necessarily need to be very fast. Be sure to read the lab writeup carefully.

Next it is a good idea to conduct a rough analysis of the design space. Do some calculations about noise, power and bandwidth to get an idea of how much power you need to supply to your LED and what your noise constraints look like.

At this point, look up and read datasheets for all available components if you're not already familiar with them: be sure to understand your building blocks.

Once you have a good picture of your constraints, tools and design space, you can start making more detailed design decisions. This design is best approached in two phases. The first is deciding how to encode your data: Will you transmit an analog value? A digital value? Timing information? ADC samples? Making a careful decision in this step can save you lots of work. Second, figure out how to implement that encoding scheme in a circuit. Naturally, these two design steps are tightly linked, and some paper iteration may save you some time in the lab.

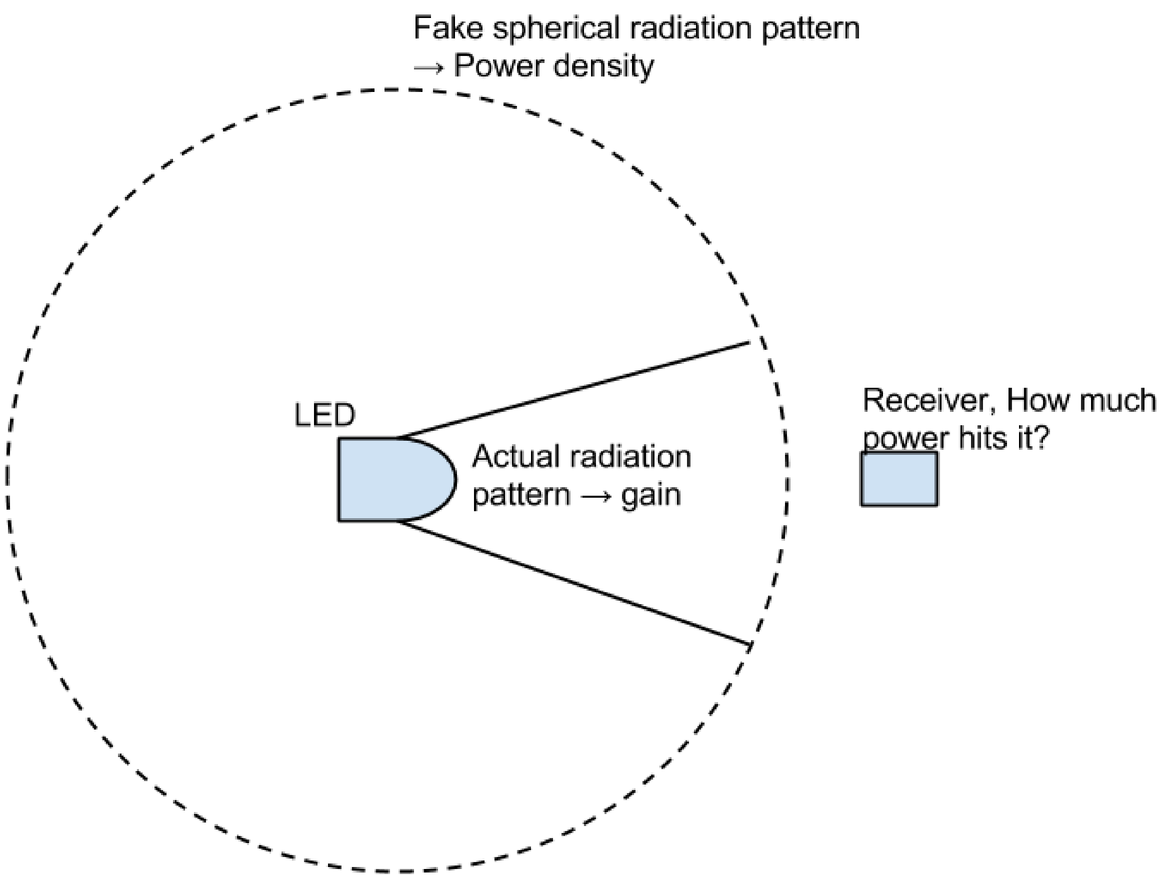
There is information about batteries and LED radiation below that will make this design process easier.

LED Loss Calculations:

The optical power emitted from your LED is proportional to the current running through it since each electron has some chance of combining with a hole and creating a photon. The constant that relates current to total optical power (radiant flux, measured in Watts) is called the luminous efficiency. In your case, assume it is 0.7.

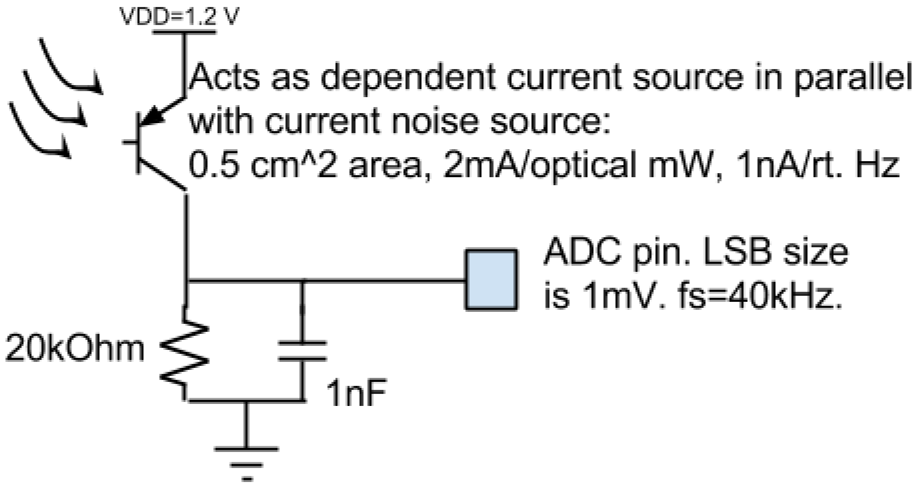
The LED light will propagate through free space. We model that by first assuming it radiates in a sphere and finding the energy per unit area on the optical sphere at a distance of the receiver (2 meters). This power density (irradiance) is artificially low because our LED doesn't actually radiate in all directions. The next step in the calculation is to multiply the irradiance by the angle through which you radiate divided by 4*pi. This quantity is called the gain and you may assume that yours is 10.

The amount of power received by the receiver is determined by the irradiance, multiplied by the gain, multiplied by the area of the receiver (0.5 cm^2). You can find the irradiance by taking your current waveform and multiplying by luminous efficiency. This process is illustrated in the cartoon below.



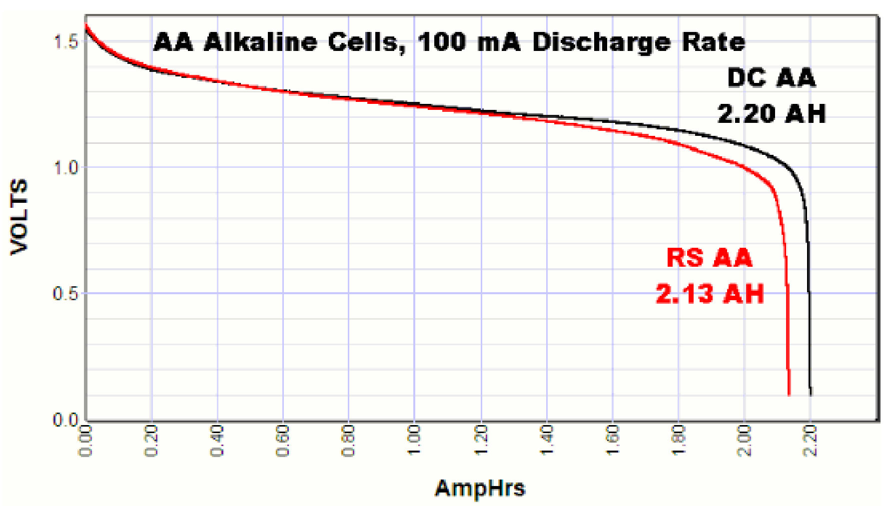
Receiver Circuit:

The receiver circuit is pictured in the schematic below. The upper device is a phototransistor, and a current of 2 mA/(incident optical milliwatt) passes through it. The phototransistor has a noise current density of 1nA/rt. Hz. The microcontroller pin this receiver is attached to has an internal ADC with a sample rate of 40kHz and a LSB size of 1mV.



AA Battery Discharge Curve:
Batteries don't have a constant voltage over their lifetimes. Usually the voltage across a battery varies with both the total amount of charge it has supplied and the rate at which it has supplied that charge. A plot that captures this behavior is called a discharge curve.

We'll be assuming that our batteries have the discharge curve below. Your power dram may be much less or much more than 100mA, but we'll ignore the effect of rate on battery discharge properties. However, you should be interested in the behavior of your circuit both when the batteries are fresh and when they are used. Use the curve below to figure out what voltages you need to apply to your circuit for testing and how long it is expected to operate.



http://madscientisthut.com/wordpress/wp-content/uploads/2011/01/AA-100mA.png

After figuring out the best and worst case conditions for your circuit, you should be sure to test your circuit under those conditions. The labs don't have AA batteries lying around, and discharging them to exactly the right spot for testing would require hours. Instead, decide on some interesting voltage levels and simulate those levels using DC power supplies.

If we were making a more complete model of our batteries you would also need to add series resistors to the DC supply to reflect the loss of current driving capability of the battery. We are neglecting that issue for this lab.

Deliverables:

- Prototype Circuit which has a potentiometer at the input and drives an LED at the output.
- Several measured LED current waveforms from the circuit under best and worst case conditions for your power supply and inputs. Be sure you define your best and worst case conditions in the report.
- A program (probably in MATLAB or Numpy) which simulates the optical power of the LED, the loss of the optical signal in free space, noise added to the signal by the receiver, and an algorithm which estimates the user input. Simulate the receiver noise by creating a series of random noise value at each time sample in your MATLAB program with an appropriate variance and adding it to your received voltage waveform before running your potentiometer estimation algorithm.
- A report documenting major design decisions of the above with a special emphasis on the following: analysis of noise and dynamic range in your system, analysis of power consumption in your system, comparison of your analysis with measured values, and justification of your design decisions.

Available Parts:

- Any 74LS logic
- LM741, OP07
- 555 Timers
- ADC0820CC-N+
- Discrete MOSFETs and BJTS
- Any resistors, caps and inductors you can find.

If you want to use any other parts, ask me. I'll probably say yes.

You can pick up your breadboards from Sam in the stock room. You are free to work in the MicroPs lab at any time and in the analog lab before noon. I'll distribute the codes soon. ADCs are in my office and other chips are in the stockroom