Approaching the Final Frontier

Near Space

Making a Light Sensor for the HOBO Data Logger

By using a photocell (CdS) as one element in a voltage divider, you can construct a simple light sensor. Because it uses a photocell, the light sensor's spectral sensitivity is very similar to that of the human eye. After you finish reading about how to build this light sensor for your HOBO data logger, I'll explain a very interesting finding about designing voltage divider-based sensors.

Any two resistors wired in series with a voltage source (battery) form a voltage divider. In the voltage divider, the voltage dropped across one resistor element is proportional to its resistance in sum with the second resistor element. The voltage drop across the resistor of interest is given by the following formula:

Vdrop = Vapplied X (Ri / Ri + Ro)

In this formula, Ri is the resistor of interest and Ro is the other resistor.

By itself, the voltage divider circuit is not very interesting. However, things do get interesting when one element becomes variable and changes its resistance due to changes in some environmental condition. Now, by measuring the voltage drop across the variable resistor, you can measure the environmental variable of interest.

The cadmium sulfide (CdS) photocell is a light sensitive resistor. Its resistance decreases when exposed to bright light and increases when exposed to dim light. The photocell responds very quickly to changing light conditions, but not as fast as a phototransistor or photodiode.

You will need the following components to make a CdS light sensor for your HOBO data logger:

- Cadmium sulfide cell (My particular cell has a resistance that ranges from 100 Ω in bright light to 20K in the dark.)
- Fixed resistor (A 1/4 watt resistor is sufficient.)
- 3/32" stereo jack kit
- Thin heat shrink tubing
- #24 AWG stranded wire (preferably three colors, to keep the wires differentiated)

Note: The value of the fixed resistor depends on the resistance range of the CdS cell. For my light sensor, I used a 1.5K resistor. At the end of this article, I'll explain how you can determine the best resistor value for your particular CdS cell.

Each input to the HOBO is through a 3/32" stereo jack. The stereo jack has three contacts: tip, ring, and base. Voltage to operate the sensor comes from the tip. The signal to be digitized is connected to the ring of the stereo jack and the ground is connected to the base. The diagram in Figure 1 illustrates the connections.

I placed the fixed resistor close to the stereo jack and ran a long extension out to the CdS cell. I decided to keep the fixed resistor close to the HOBO to minimize the amount of wire my sensor needed. Note that the HOBO is digitizing the voltage drop across the CdS cell because the ground is connected to one end of the CdS cell and the signal is connected to the other end.

Figure 1. CdS light sensor diagram.

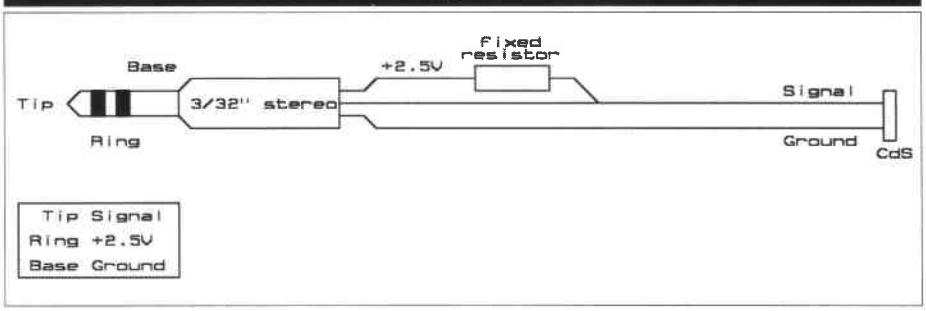
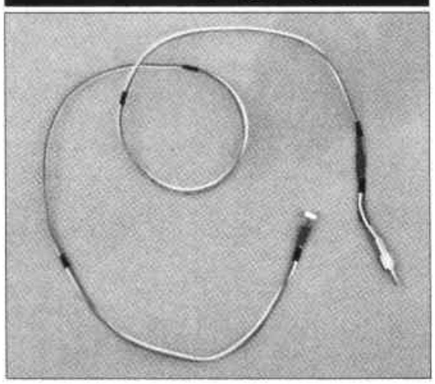


Figure 2. The completed light sensor — minus the ping pong ball.



CdS						
	1,000	1,200	1,400	1,600	1,800	Fixed
100	= 2.5*[$A$3/($A$3+B2)]					
20,000	= 2.5*[$A$4/($A$4+B2)]					
Range	= +B4-B3					

Table 1

Lay out the components of the light sensor on a table. Be attentive to the fact that you may want to locate the light sensor some distance from the HOBO. This allows you to store the HOBO well inside the near spacecraft (NS craft), where it will remain warmer and still be able to expose the CdS cell to the elements. In my light sensor, I made the cable two feet long.

I'll refer to red wire for 2.5 volts, white for signal, and green for ground. Adjust my directions for any color changes in your light sensor. Cut the wires to length and strip about 1/4" of insulation from one end of each wire. From the remaining ends of the wires, you can strip 1/2" of insulation. Twist the strands of the wires and tin them. The short ends of the wires are soldered to the 3/32" stereo jack. The red wire goes to the tip, the white wire to the ring, and the green wire to the base. There's not a lot of room to work on the stereo jack, so work slowly and avoid shorting it out. After soldering the wires to the stereo jack, use a DMM to ensure there are no shorts.

Cut the leads of the fixed resistor and CdS cell to about 1/2" and tin the leads. Slide a length of heat shrink tubing over the red wire. Hold the red wire against one lead of the fixed resistor and heat both wires with a soldering iron. Solder will flow from the tinned lead and wire, soldering them together. Let the solder cool and cover the connection in heat shrink. Repeat this process with the green wire and one lead of the CdS cell.

Determine where the fixed resistor will solder to the signal wire. At that point in the white wire, use wire strippers and cut a 1/2" band of insulation. You'll need to use a sharp Exacto knife to remove the band of insulation from the wire. Do this carefully or your light sensor will suffer from nicks. Slide a larger diameter heat shrink over the resistor and the area where it solders to the signal wire.

Slide a short length of thin diameter heat shrink over the white wire and solder the remaining end to the free lead of the CdS cell. At this point, your light sensor is complete. However, there is a problem with the current design. The CdS is sensitive to its pointing direction. This may not be a problem in some cases, but, when you want to measure the brightness of the sky, it becomes a problem when the NS craft rotates the CdS cell into and out of the sun. Here's my solution to this problem.

A photographer's light meter records the average light background by using a diffuser. The diffuser is a hemisphere of white plastic (glass?) covering the light-sensitive element of the light meter. After giving it some thought, I concluded that a ping pong ball can make a great diffuser. So, I used an Exacto knife to drill a small hole in the surface of a ping pong ball. I made sure to drill the hole through the portion of the ball that was stamped with lettering.

This left the rest of the unmarked ping pong ball to diffuse sunlight. The hole I drilled was made just large enough to admit the CdS cell. After placing the CdS cell just inside the ping pong ball, I glued it into place with hot glue. The final product reminds me of a large eyeball with a copper-based optic nerve. In one of my NS missions this year, I plan to dangle the eyeball from beneath the bottom module of the NS craft and record the voltage across the CdS cell.

Calibration

I have yet to find a data sheet explaining how the resistance of a typical CdS cell varies according to light intensity. Eventually, I'll experiment with the light sensor to find out. I'll record the voltage drop across the CdS cell in a dark room as I bring a light source closer to the eyeball. Remember that light intensity drops off as $1/r^2$. So, when the light source is brought to one half the distance away from the sensor, the light intensity increases by a factor of four.

In my spreadsheet, I'll record the voltage drop across the CdS cell and the distance of the light source. Distance will then be converted into intensity by the formula, 1/(distance * distance). In the next column of the spreadsheet, I'll convert intensity into relative intensity by dividing each intensity by the intensity at the greatest distance. Then, I'll graph the CdS voltage and relative intensity.

I can generate an equation from the graph and use it to analyze the changes in brightness as a function of altitude during an experiment. In a future column, I will explain how to create an equation from discrete values such as these and how to

Near Space Seeds Project (NSSP)

My NS mission of 21 March 2004 carried four sets of seeds to an altitude of 85,140 feet. I want to share these seeds with elementary school students as part of a science experiment. I hope this will be a long term project, where students plant the seeds, keeping each group of plants isolated from the other groups.

After the plants go to seed, students will collect the seeds, document the group to which they belong, and return them for another flight into NS. After the mission, the seeds will be returned to the students for planting and seed harvesting. Perhaps, over many generations, variations between the groups due to the differences in their exposure will begin to show up.

Table 2 explains the difference between the seed groups in each set.

Note: This first set of exterior exposed seeds was stored in a plastic bag suspended outside the NS craft.

If you're a teacher who is interested in being a part of this experiment and you can carry out the following procedure, please contact me at the Email address in the About the Author box. I will send one set of seeds to the first four teachers to contact me. There is no charge for participating. More seeds will be launched in future flights, so there will be more opportunities.

Procedure

1. Find a location with sunlight and air for the plants.

Note: Remember, you need to plant three groups of seeds and there needs to be enough space between the groups to prevent them from cross-pollinating plants from a different group.

2. Prepare planters for the seeds and document your materials.

Note: You will need to use identical procedures for future generations of seeds.

3. Water and feed the groups identically.

Note: The only difference should be the seeds' level of NS exposure.

4. Document plant growth in each group.

Note: Suggested characteristics to document include (but are not limited to) the following:

A. Number of days to germination.
B. Percentage of seeds that germinate.
C. The average height of plants over time.
D. Average number of leaves per plant.
E. Number of days until flowers form.
F. Average number of flowers per plant.
G. Number of seeds produced per plant.

If the class is mathematically inclined, they can also calculate the standard deviation for each measurement. Also note that a digital camera comes in handy.

5. Erect a barrier between the seeds.

Note: It's *critical* that plants from different groups don't pollinate each other.

6. Harvest seeds from several plants in each group and prepare them for another flight into NS.

Note: It would be best if the seeds are placed inside a clean, dry test tube and covered with a small cotton ball. The test tube is then covered with a stopper containing a hole. The hole lets air out of the test tube during the flight without popping the stopper off. The cotton is to keep the seeds from spilling during the flight, especially during the rough descent and landing.

7. Label each test tube with the group that the seeds belong to (control, interior, or exterior).

* Note: Write the group name on a small piece of masking tape and stick it to the test tube. For added security, cover the writing on the tape with clear tape. This will keep the name from rubbing off during handling. Place the name near the top of the test tube where it cannot protect the exterior seeds from exposure to UV during the mission.

8. Through Email, arrange for the seeds to go up on the next available flight.

Note: If you send the seeds through the mail, carefully pack them in a cardboard box for shipping. The test tubes should be packed so that they cannot bang against each other and break.

9. Each test tube of seeds will be placed where they were on previous flights.

Note: After recovery, the seeds will be returned for planting and the procedure repeats over again.

On a final note, you can purchase your own seeds for a flight into NS. Please contact me first, however, so I can schedule a flight for your seeds. It would be best if classes from the same school sent their seeds in single test tubes and divided up the seeds after they are returned. Sharing room in the same test tube will simplify scheduling.

Name of Group	Location of Group	Minimun Pressure Experienced	Minimum Temperature Experienced	UV Exposure	Maximum Cosmic Ray Count
Control	Left on ground	Sea level (1,013 mb)	Room temperature	Not significant	Approximately 4 CPM
Interior	Inside near spacecraft	3% sea level (30.5 mb)	-30 degrees Farenheit	Not significant	Approximately 700 CPM
Exterior	Outside near spacecraft	3% sea level (30.5 mb)	-70 degrees Farenheit	Significant *	Approximately 700 CPM

Table 2

calculate the quality of the resulting equation.

Best Fixed Resistor Value

How did I determine the best value for my fixed resistor? I considered the best fixed resistor value to be the one that generates the greatest range of voltage drops across the variable resistor.

Initially, I created a spreadsheet and calculated the range of voltage drops across the variable resistor. The spreadsheet has four rows and seven columns. The rows contain the expected maximum and minimum values of the variable resistor. The columns contain the several fixed resistor values that I'm testing. The spreadsheet calculates the range of voltages I can expect from the variable resistor. After looking at the results, I changed the fixed resistor values in the columns and updated the spreadsheet. With every iteration, I was homing in closer to the optimum fixed resistor value.

The spreadsheet equations I used are shown in Table 1. Copy and paste the first row of equations into the cells of the remaining rows.

Juggle the fixed resistor values and rerun the spreadsheet until you find the fixed resistor value yielding the greatest voltage range. Now, you would think there must be a better way to do this. In fact, I found one.

I swim for exercise. The problem with swimming — besides chilly pool water — is that the scenery never changes. This gives you lots of time to think about things. One day in early February, I was thinking about the difference between arithmetic and geometric means and, for some inexplicable reason, it dawned on me that one of these means might be useful in determining the best value for a fixed resistor in a voltage divider. For those readers who are fuzzy with their math, here's short definitions of arithmetic and geometric means.

For calculating the best value for a fixed resistor, I'm only interested in calculating a mean from two numbers, so my definitions use only two values (you can calculate means for more than two numbers). The arithmetic mean is the result when you add two numbers together and divide the resulting sum by two. The arithmetic mean is the number that is equally far from either of the two numbers used to calculate it. So, the arithmetic mean of the numbers 4 and 8 is 6, which is the same distance away from both numbers.

The geometric mean of two numbers is the number that is an equal *factor* away from both numbers. As an example, the geometric mean of 2 and 32 is 8. The number 8 is four times higher than 2 and 32 is four times higher than 8. How do you calculate the geometric mean of two numbers? To calculate it, multiply the two numbers in question and take the square root of the result. In the above example, you get, 2 x 32 = 64 and the square root of 64 is 8.

When I got back home, I fired up the old PC and pulled up my Excel spreadsheet. Sure enough, the maximum voltage range in a voltage divider is generated when the fixed resistor is the geometric mean of the maximum and minimum range of the variable resistor.

I was amazed when I saw this. Why should this be the case? I don't know why at this time, but I tried to visualize a mathematical solution based on a square with the same volume as any given rectangle. The sides of that square are the geometric mean of the sides of the rectangle. So far, though, I have come up empty-handed.

If a reader can provide a proof that the geometric mean always generates a maximum voltage range of the voltage divider, I'll give credit in this column and send a memento that has been carried into near space. This offer is only for the first proof Emailed to me at nearspace@yahoogroups.com

Good luck and thanks for your efforts.

Onwards and Upwards, Your Near Space Guide **NV**