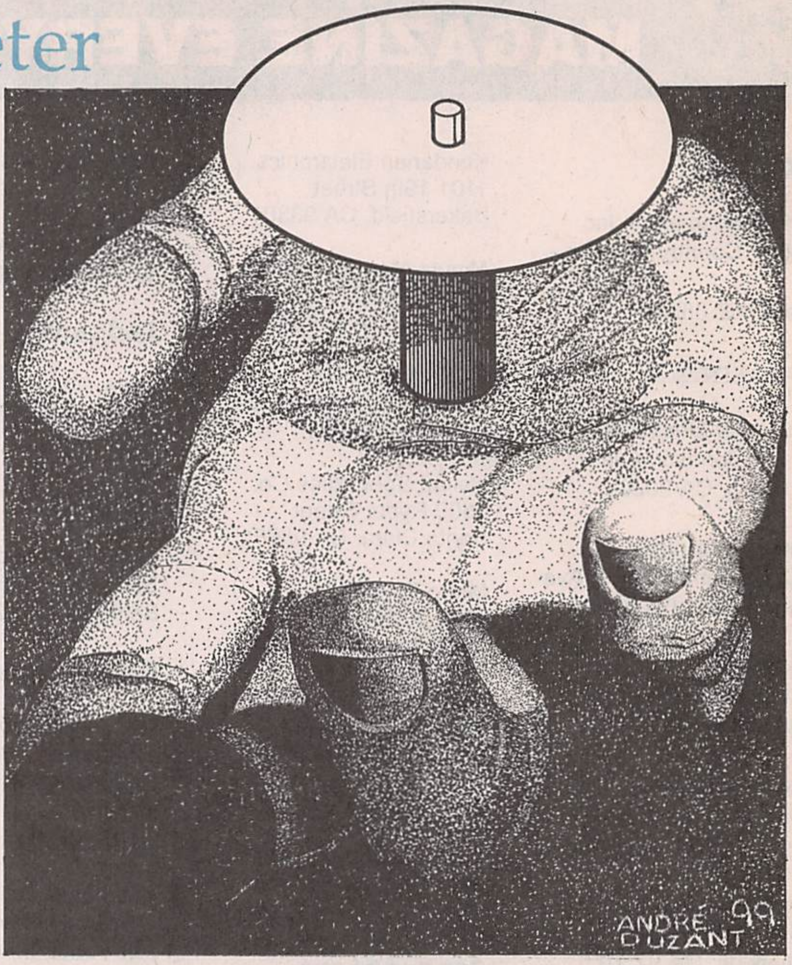
Measure the Sun's Intensity with a Solar Dosimeter

You can achieve suprisingly accurate results with this simplest of circuits.

PAUL NEHER



There are many times where you would want to know how much sunlight a particular location receives—though some of them are not so obvious. Many of us are aware of the health risks that are associated with ultraviolet radiation; recent studies have linked cancer and premature aging of the skin to ultraviolet radiation exposure. Even older people can be at risk of developing cataracts and should be wearing ultraviolet-absorbing sunglasses whenever they are outdoors. If you are looking into setting up photovoltaic or solar-heating panels, the choice of whether to install a tracking mechanism, with its increased cost, depends on the site location and how many hours of direct sunlight the panels will receive. Vegetable and flower gardens are another area of concern—do they receive too little or too much sunlight?

Whether planning a solar installation, measuring how much sunshine a potential garden spot gets, or just curious about how many hours per day you are exposed to the sun, an instrument that can measure the total number of hours of sunlight per day would be a handy tool to have. Of course, such "solar-site analyzers" exist and can be purchased for a couple of hundred dollars, but there is a less-expensive alternative.

In this article, we'll take a look at how solar-radiation monitors, or *dosimeters,* have worked in the past, and how to build a modern version that, while not exactly the most accurate instrument in the world, can't be beat for cost. In fact, you probably have the components needed in your "junk drawer". If, on the other hand, you purchase all of the items needed, you would be hard-pressed to spend much over a dollar.

Sunshine Recorders. Meteorological instruments designed to record the duration of sunshine have been used since the mid-nineteenth Century. One particularly clever recorder is the Campbell-Stokes device, dating from about 1880. It uses a glass sphere to focus sunlight onto a strip of paper. Like a magnifying glass, the strip of paper is held at the lens' focal point. The intense heat from the focused spot of light burns the paper. As the sun moves across the sky, a black trace is left on the paper showing how long the sun was unobstructed. It can record the sun's movement from horizon to horizon if it is properly aligned, and it can reveal fixed obstructions, such as buildings and trees, as well as variable amounts of cloud cover if several days worth of readings are taken and compared. Although there is a certain aesthetic quality to a recording instrument that is self-powered, that style of recorder lacks portability.

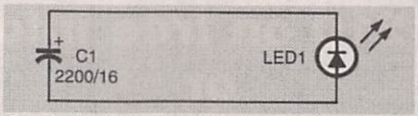


Fig. 1. Don't be fooled by the simplicity of the solar dosimeter's circuit—it is suprisingly accurate for such a low-cost device.

Electronic Dosimeters. While many different types of electronic dosimeter circuits are available, most of them are based on active components to record the collected data; the elegant simplicity of a self-powered device is not taken into account.

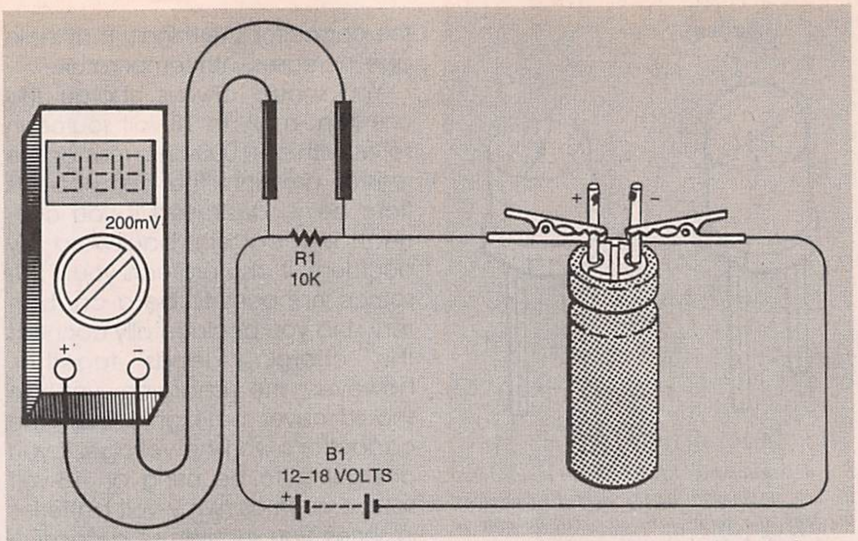


Fig. 2. Measuring the voltage drop across a resistor in series between the capacitor and a battery is an easy way to measure the capacitor's leakage current.

Consider the electrical characteristics of a light-emitting diode. In its usual method of connection, an LED has a constant voltage drop across it, producing light when about 10 mA of current flows through it. When the voltage is reversed, the LED doesn't produce light and the current flowing through it is very small—on the order of nanoamps. On the manufacturer's data sheets, that current is referred to as *leakage current*. However, that is not entirely correct when it comes to LEDs.

Although an LED is designed as a light-producing device, it is also a small-area photovoltaic diode that is capable of passing a current when it is exposed to light. Under normal room lighting, the conductivity of an LED is only in the nanoamp range, but in bright sunlight the photocurrent is about one microamp.

Most low-cost LEDs that are used as panel indicators are only tested for forward operation. The reverse-breakdown voltage is typically specified at five volts. That doesn't mean that the device can't withstand higher reverse voltages; it's just the maximum voltage that the manufacturer tests the LED for. All of the LEDs that the author has tested have shown actual reverse-breakdown voltages of at least 50 volts; most units are greater than 100 volts.

In the region of the LED's reverse-voltage characteristic between the breakdown voltage and zero volts, the device acts like a constant-current element, with the current depending only on the intensity of the light.

Now that we have a light-dependent constant-current source, we need some way to record the overall amount of current that passes through the LED.

A capacitor stores an electric charge in proportion to the voltage across its terminals. The formula for that relationship is

$$Q=CV$$

where the total charge (Q), in coulombs, is a product of the capacitance (C), in farads and the voltage (V), in volts. A constant current flowing into (or out of) a capacitor will change the voltage across its terminals at a rate that is proportional to the current. For example; a 1-μF capacitor being charged with a constant one-microamp current will increase its voltage by one volt per second.

The capacitor's voltage is also proportional to the amount of current that has been accumulated over a period of time; that function is a near-perfect integrator. The same one microamp current in the above example, applied for 100 seconds, will change the voltage on the capacitor by 100 volts.

Based on that knowledge, let's put an LED in parallel with a capacitor. There are few electronic circuits that can match the simplicity of Fig. 1, but that's all that it takes to build a simple, self-powered solar dosimeter that can be used to measure the amount of sunlight that falls on a given area over a period of time.

If you charge up C1 in a dark room, very little current will flow through LED1; C1 will stay charged up for a long time. Place the unit in bright sunlight and a larger constant current will flow through LED1, discharging C1 at a rate that is proportional to the intensity of the light. For example, if C1 discharges at a rate of 1.25 volts per hour in bright sunlight, the voltage should change by 5 volts if it is exposed to the same intensity of light for 4 hours.

Typically, you would charge up C1 to about 15 volts; that voltage and the values shown will let the solar dosimeter be used for over a day before needing a recharge. In bright sunlight, such as the southwestern

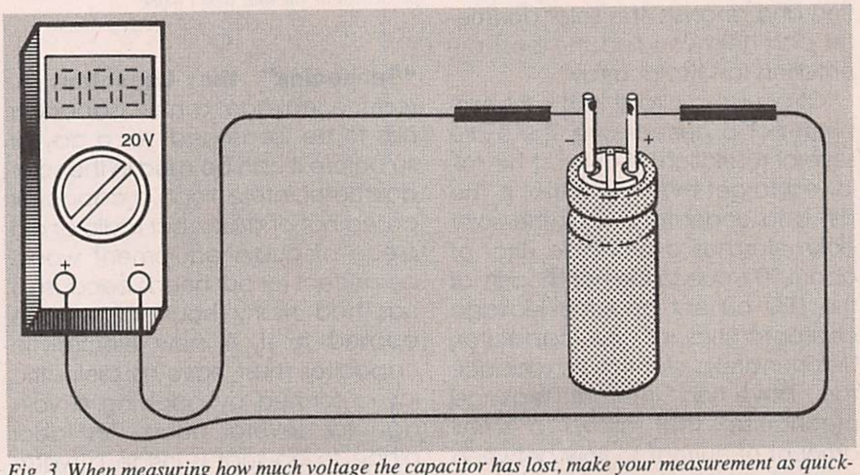


Fig. 3. When measuring how much voltage the capacitor has lost, make your measurement as quickly as possible—even the most sophisticated digital voltmeter consumes some of the capacitor's charge when taking a reading.

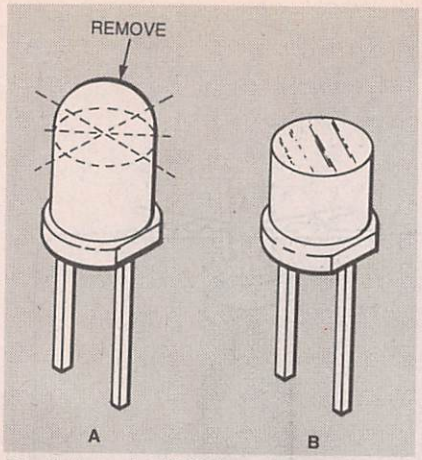


Fig. 4. A standard LED has a lens molded into its case to concentrate the light. By flattening the lens, the solar dosimeter will be able to sense sunlight from almost any angle.

US, the capacitor discharges at a rate of about one volt per hour.

Another advantage of the solar dosimeter is that it directly simulates the performance of a solar panel or photovoltaic array—the change in capacitor voltage is directly proportional to the amount of ampere-hours that the array would produce for that day. If you would like to investigate whether a tracking array would be worth the extra money, simply compare the results from first leaving the solar dosimeter pointed in one direction, and from pointing it at the sun by changing its position about once every hour. Many locations, such as southern California, have morning fog and hazy skies until mid-morning. Mountains and other obstructions can reduce the amount of direct sun that your location receives. With a little data collection and analysis, the solar dosimeter can help you find the best orientation for a solar array.

Of course, a circuit that is this simple is not a perfect one. There are several restrictions that must be followed to get the most out of it. The first is to understand that the solar dosimeter has a probable error of about 10% due to the nonlinearity of the LED current and the leakage characteristics of the capacitor. Unfortunately, electrolytic capacitors have an internal leakage mechanism that allows a small amount of current to flow between its "insulated" plates. You can think of that leakage as a resistor across the capacitor's terminals. That leakage increases with temperature.

You should always charge the unit from a 12- to 18-volt source in series with a 10,000-ohm resistor. The resistor prevents the components from being destroyed if you connect the battery backward by accident; it also protects you if the source happens to be a car battery and you accidentally connect the charging leads together. However, the charging voltage should never be higher than the capacitor's working voltage. If you are going to be using an 18-volt source, such as two 9-volt batteries in series, you should use a capacitor that is rated higher than the 16-volt rating that is specified here—25 or 35 volts would be better.

That being said, let's see what we need to do to build our solar dosimeter.

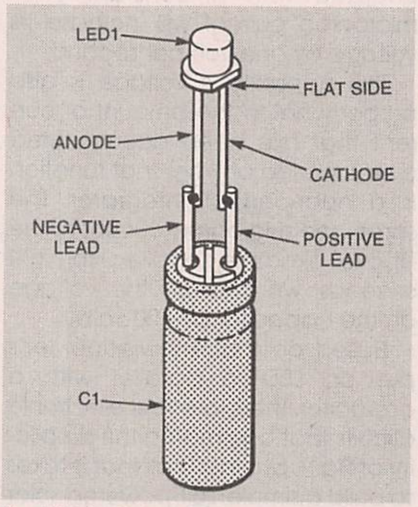


Fig. 5. To build the solar dosimeter, simply solder an LED onto a capacitor. Be careful of polarities or the unit won't work.

"Seasoning" the Capacitor. To reduce leakage, a new capacitor has to be "seasoned" for a day or so before it can be used in the solar dosimeter. Interestingly, a capacitor pulled out of a junk car radio or old piece of audio equipment would be perfect for our needs because it has had many hours of voltage applied to it. A new electrolytic capacitor must have its dielectric layers formed by applying a voltage for several hours. An ideal place to do that is inside a warm parked car using the 12-volt lighter jack as the voltage source. Alternatively, you can charge the capacitor from a pair of nine-volt batteries and leave it connected for a day inside your home, perhaps on a sunny windowsill.

Once a capacitor is "aged", its internal leakage needs to be tested; there is always the possibility that a particular unit might not be suitable. After charging the capacitor for several minutes, connect a digital voltmeter across the resistor. Do not use an older style "moving-needle" meter. Those instruments draw a bit of current from the circuit being measured and will introduce errors in your readings. The voltage drop across the resistor will show the capacitor's leakage current; a reading of 10 mV indicates a leakage of 1 microamp. At first the leakage might be quite large, perhaps a few microamps. After several hours, the meter should read zero mV, indicating an internal leakage of less than $^{1}/_{10}$ microamp. That is a good indication that the capacitor is forming well. The general arrangement for that test is shown in Fig. 2

Next, disconnect the capacitor from the charging source and voltmeter, and let it sit for an hour in its charged condition. Measure its voltage by connecting the meter only long enough to get a reading as shown in Fig. 3, and again at least 12 hours later. If the capacitor is a "good one", it will have lost only a few tenths of a volt between readings. A capacitor that loses more than about one volt will be marginal for use in the solar dosimeter because of the error it introduces.

Construction. The first step in building the solar dosimeter is to modify

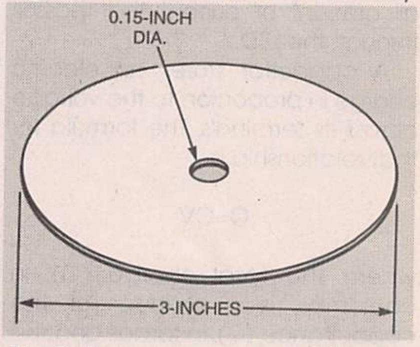


Fig. 6. To increase accuracy of the solar dosimeter, the capacitor must be kept cool. This disc, cut from an index card, will act as an umbrella, shielding the capacitor from the sun.

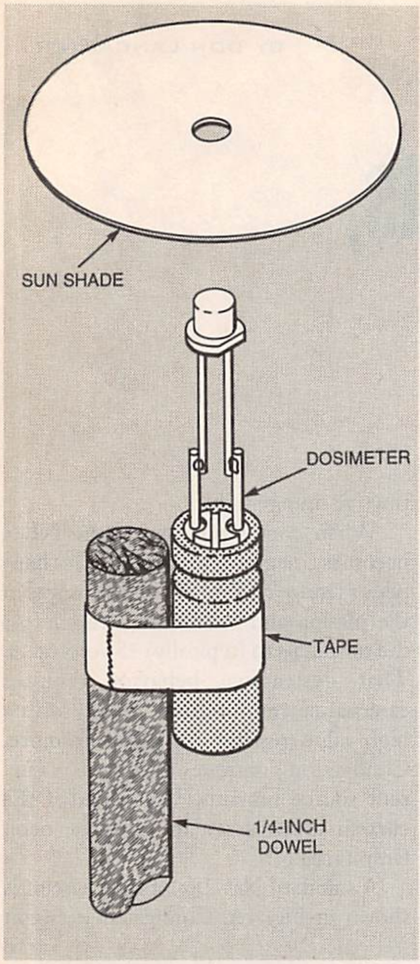


Fig. 7. With the solar dosimeter mounted on a dowel and wearing its "hat", it's ready to measure the amount of sunlight anywhere that you want it to.

the LED by filing or sanding off its top. Most LEDs have a rounded lens as shown in Fig. 4A. By removing the lens, you will have an angular sensitivity of almost 180 degrees. The LED should look like Fig. 4B.

The two components are soldered together as shown in Fig. 5. Obviously, there is a right way and a wrong way to connect the two polarized components together. The positive lead of C1 should be connected to the cathode of LED1; the cathode lead of LEDs is usually physically longer in length and a flat spot is molded into the case. If you get the connections backwards, the LED will glow when you try to charge the unit and you won't be able to go above about two volts.

Cut a 3-inch-diameter disc out of a piece of index card. Punch a hole in the center of the disc the same diameter as LED1. Dimensions for the disc are shown in Fig. 6. The disc will act as a sunshade to keep C1 from becoming too warm. Remember, the capacitor's leakage current will rise with temperature.

Mount the dosimeter on a stick such as a ¼-inch wood dowel that is about a foot long, using white masking tape to hold the capacitor in place. That way, the dosimeter can be "planted" in the ground and away from the heat of the soil. The sunshade is placed over LED1 so that C1 is always shaded. The final assembly is shown in Fig. 7.

Calibration. Pick a bright, sunny day to calibrate the dosimeter, preferably at noon when the sun is directly overhead; intense sunlight is needed. Charge the dosimeter for at least an hour before measuring its voltage. Charging the dosimeter is done in the same way that the capacitor was tested for leakage: a 10,000-ohm resistor in series with a 12- to 18-volt battery. Place the dosimeter in the sun with the flat surface (cathode) of LED1 facing the sun's direction of travel and note the time. After one hour or more, measure the voltage across C1, recording that along with the time. The difference in voltage divided by the difference in time will tell you how many volts per hour the dosimeter registers in bright sunlight. We'll call that ratio the *exposure constant*. To measure the number of hours of sunlight that a spot receives in a day, measure the change in voltage and dividing it by the exposure constant.

Troubleshooting. The solar dosimeter is based on commonly-available parts and some basic physics. What if it doesn't work as advertised? The green LED is inexpensive; if one doesn't work satisfactorily, try another one. Some LEDs might be more efficient photodiodes than others, causing the capacitor to run out of charge before the day is over. Some capacitors have less actual capacitance than marked on the can, causing the same problem. In either case, you can reduce the rate at which the voltage drops by either using two capacitors in parallel or putting a neutral filter over the LED. Such a filter can be made from a few layers of clear tape, a thin layer of white nail polish, or placing the dosimeter into a white plastic film canister.

If you've used a capacitor with a higher voltage rating, you can charge the capacitor up to a higher voltage to start off with. If you've been using a 12-volt source, try seasoning the capacitor at 18 volts.

If the capacitor has too much leakage, that is, it self-discharges by more than a volt in twelve hours, try charging it to a lower voltage initially, or season it longer at about 100 degrees F.

Do not let moisture get between the capacitor terminals. Dew or rain will cause the capacitor to discharge rapidly. Place the dosimeter in a watertight enclosure, such as the 35-mm film canister mentioned earlier, if that is a problem.

PARTS LIST FOR THE SOLAR DOSIMETER

LED1—Light-emitting diode, green, T-1¾ size, diffused lens, (Mouser 351-5023, RadioShack 276-022 or similar)
C1—2200-µF, 16-WVDC, electrolytic capacitor, low-leakage, radial leads
R1—10,000-ohm, ¼-watt, 5% carbon resistor
B1—12-volt battery
Wooden dowel, tape, etc.

Sample Applications. Suppose you have a southeast-facing sloped roof on your house, and you are wondering how well a photovoltaic array would work, mounted in that same orientation. Simply orient the solar dosimeter with its flat surface parallel to the roof and expose it for a full day. Measure the change in voltage and you have a number equivalent to the amount of ampere-hours a photovoltaic array will put out. Compare that with how much the dosimeter registers with different orientations and angles, and you'll know if odd-angle mounting or tracking mechanisms are worth the extra complexity and expense.

An unusual location to mount the solar dosimeter is inside a hat. The LED could be mounted on a small hole punched in the brim with C1 taped underneath with the leads bent at a right angle.

A final note on sun exposure:

(Continued on page 83)

SOLAR DOSIMETER

(continued from page 77)

Note that the solar dosimeter responds only to the blue-green portion of the visible spectrum; it does not directly measure ultraviolet radiation. You can use it, however, to estimate your UV exposure in the six hours around noon when UV intensity is proportional to visible radiation. Also note that due to the nature of the Earth's atmosphere, the amount of visible light is not necessarily an accurate indicator of the amount of UV radiation. Ω