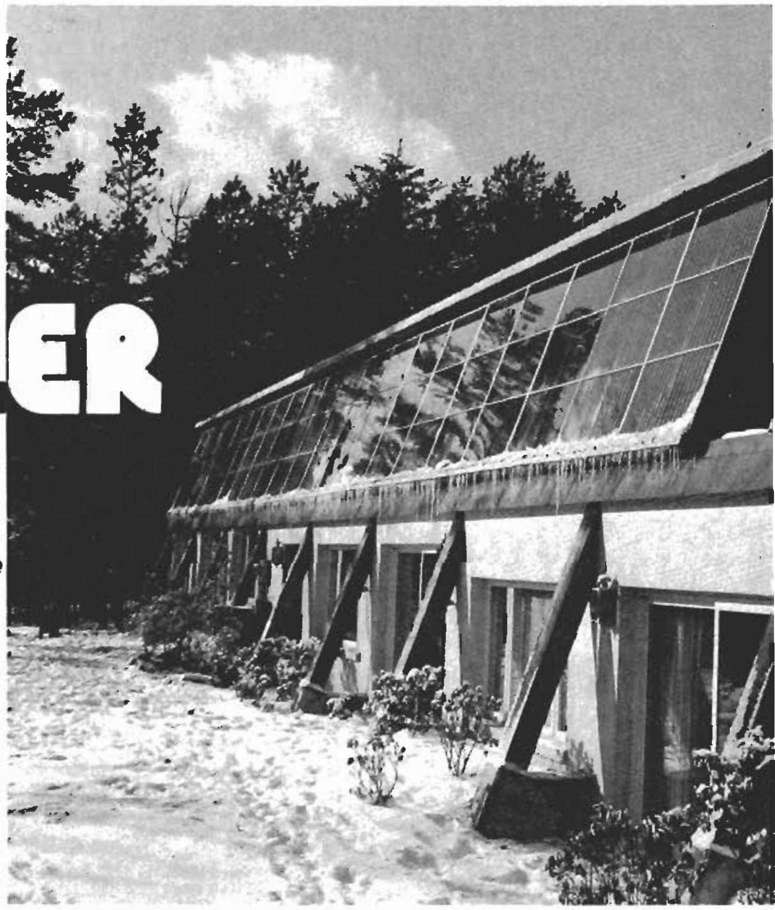
# SOLAR CONTROLLER



*During the present energy crisis, the sun is in the running as the most viable alternate energy source. Here's how basic electronics can be adapted to solar heating in home and industry.*

**RODNEY A. KREUTER**

SOLAR ENERGY, IT SEEMS, HAS BECOME almost a universal interest. Companies offering solar collectors and associated hardware are springing up like glitches on a TTL breadboard. However, most companies sell complete systems and most "do-it-yourself" magazines concentrate on collectors or storage system. Very little information seems to be available concerning the instrumentation or control portion of the systems.

This article attempts to proceed one step further by providing an understanding of a simple instrumentation and control system. It is not meant to be a blow-by-blow construction guide because no two solar systems are quite the same. It is hoped that it will enable you to design a system that will meet your special needs.

### Hot-water preheater

A good way to get started in solar energy is with a solar hot-water preheater. A substantial amount of the average utility bill goes to feed standard preheaters. Another advantage of a solar preheater is that the payback time is not too great and the cash outlay to get started is within reason.

A preheater is a rather straightforward device. All it does is warm up the cold-water inlet to an existing hot-water tank so that the tank itself won't need as much energy to warm the water to the required temperature. (Note the phrase "as much.") A small solar collector in a less-than-ideal climate will not supply all your needs; it will, however, help save a great deal of energy.

Figure 1 is a diagram of a hot-water preheater system. Basically, what happens is that the sun warms a water-antifreeze solution in loop 1. The pump sends the warmed solution around from the collector to a storage tank that is filled with colored water. (Colored water can be used to warn of leaks in the system.) The water in the storage tank heats up and, if the tank is well insulated, will stay warm for quite some time.

When cold water enters into loop 2, it gains heat from the storage tank and enters the hot-water heater. If the system has been well designed, the water will need just a little more energy to bring it to the necessary temperature.

The system sounds simple enough, doesn't it? Well, it has a few flaws! The sun will warm the collectors only if there is sufficient radiant energy. The storage tank will only absorb heat from loop 1 if loop 1 is warmer than the water in the storage tank. Loop 2 will be warmed only if the tank is warmer than the cold-water inlet and the hot water tank isn't full. If you don't know what the temperature of each component is, you shouldn't waste the energy used by the pump. This brings us to the LM3911.

### Temperature transducers

National Semiconductor's LM3911 and the LX5600 are temperature transducers; they provide an answer to most of our temperature-measuring problems. The output of the sensors is 10 mV-per-degree Kelvin. Don't let the word Kelvin concern you; the output can be modified to read any temperature scale, but for a one-time system, the Kelvin scale is as good as any other scale. If you must convert the formula, it is: °C = °K+273.

The working temperature of the LM3911 is −25 °C to 85 °C (−13 °F to 185 °F); while the LX5600 has a range of −55°C to 125°C (−67 °F to 257 °F). Except for their range and cost, the two devices are similar.

The operation of the transducers is quite simple: Two diodes operated at two different current levels produce a voltage difference between them that is proportional to their absolute temperatures (hence, Kelvin). The output of the transducers will be about 3 volts or so, depending on how hot the IC is. (Very simple indoor-outdoor analog thermometer if you have a good VOM.)

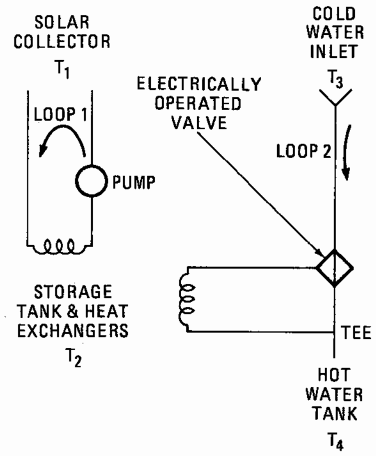


**FIG. 1—BASIC SOLAR ENERGY hot-water preheater showing important temperature measuring points.**

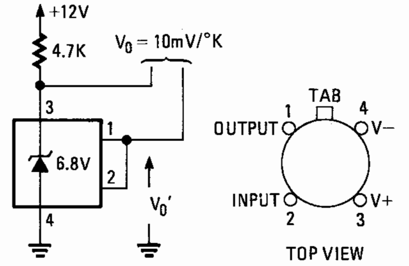


**FIG. 2—BASIC SENSOR CONNECTION and pin location.**

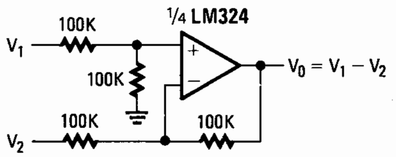


**FIG. 3—DIFFERENTIAL AMPLIFIER; the power connections are not shown.**

Figure 2 shows the basic connection and pin location of the transducers. Note that the output voltage of the devices is *not* referenced to ground but to pin 3.

## Differential thermometer

It's useful to know the temperature of each component of the solar energy system, but it's not essential. What *is* essential is to know that component A is somewhat warmer than component B. This is the principle of the differential thermometer. The output of the thermometer is proportional to the difference of the two input temperatures. This requires a differential amplifier, which is easy to obtain using an op-amp such as the one shown in Fig. 3.

Note that the differential amplifier is based on two input voltages that are referenced to ground. Since the output of the transducers is not referenced to ground, this would seem to complicate the circuit somewhat. Luckily, there is a simple solution to this problem.

Referring to Fig. 2, note the 6.8-volt Zener diode from pin 3 to ground. This Zener diode is internal to the transducer and maintains the voltage from pin 3 to ground at 6.8.

Since $V_o$ increases at a rate of 10-mV-per °K, and the sum of $V_o$ and $V'_o$ must equal 6.8 volts, $V'_o$ must decrease at 10-mV-per °K.

Using this data, we can arrive at the differential thermometer shown in Fig. 4. The output will be proportional to the difference between temperatures $T_1$ and $T_2$ and will rise as $T_1$ rises, assuming that $T_2$ remains constant. When $T_1$ equals $T_2$, the output may not be exactly zero, because op-amps are not perfect and the 6.8-volt Zener diodes may not be exactly matched. This will not affect the operation of the circuit, and, as a matter of fact, may be used to an advantage. You should interchange the sensors if you don't get a small positive voltage (about 30 mV to 100 mV) when the sensors are at the same temperature.

## Hysteresis

All control systems need some type of hysteresis, which is a type of "deadband" or buffer zone. For example, thermostats have a built-in hysteresis of about 2 °F. Assume that the hysteresis is plus or minus 1 °F of the setting. If the thermostat is set at 68 °F, the furnace will come on when the temperature falls to 67 °F and stay on until the temperature rises to 69 °F. If no hysteresis was built into the system, the furnace would cycle on and off continuously.

The hysteresis in a solar system should be fairly large—5 °F to 10 °F is not unreasonable. Figure 5 shows a comparator that is used to provide an adjustable amount of hysteresis. The LED lights as a status indicator and alarm when the set amount of temperature difference has been attained.

## Interfacing

At this point, the system monitors temperature, subtracts one temperature from another, compares this value to some preset value, and lights an LED if all the conditions are met. It still won't pump much water or close a valve.

Lighting an LED has a purpose other than just providing an output of the system. When devices must be operated at 117 VAC, such as a pump or a motor, it is necessary to isolate the control system from the AC lines. By using an LED and a phototransistor sealed in a light-tight tube, a very high degree of isolation can be achieved. You can even use two LED's—one as an output and the other as part of the photocoupler.

A circuit that handles the control of the pump is shown in Fig. 6. The components might have to be scaled up or down depending on the amount of load current. And don't forget to heat-sink the triac.

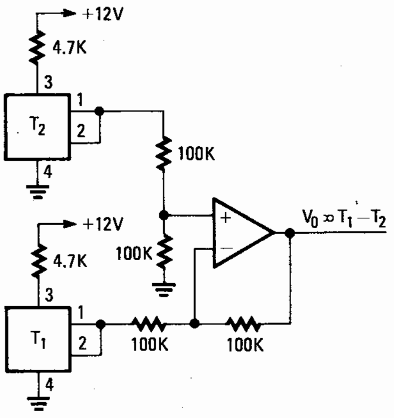


**FIG. 4—DIFFERENTIAL THERMOMETER measures temperature difference.**

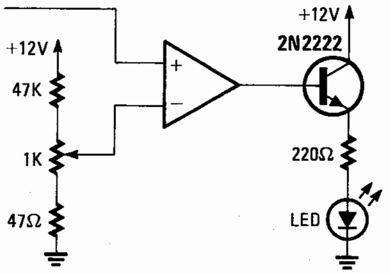


**FIG. 5—COMPARATOR with hysteresis control.**

## Assembling the system

The complete control system is shown in Fig. 7. A regulated 12-volt power supply (see Fig. 8) is also necessary to power the system. The cost of such a supply is very low, so there is no reason to use an unregulated supply.

If you want to measure the actual temperature of one of the system components, you can use a good voltmeter.

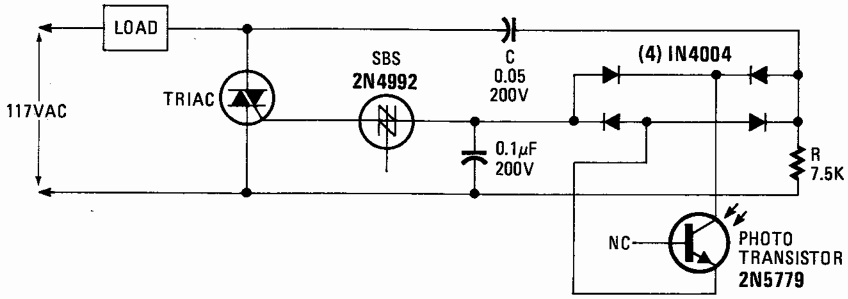


**FIG. 6—LIGHT-CONTROLLED TRIAC circuit. For diac triggering, C = 0.22 μF, R = 10K. Substitute diac for 2N4992 (silicon bilateral switch) and phototransistor with $V_{ceo}$ of 80 volts or two 2N5779's connected in series.**

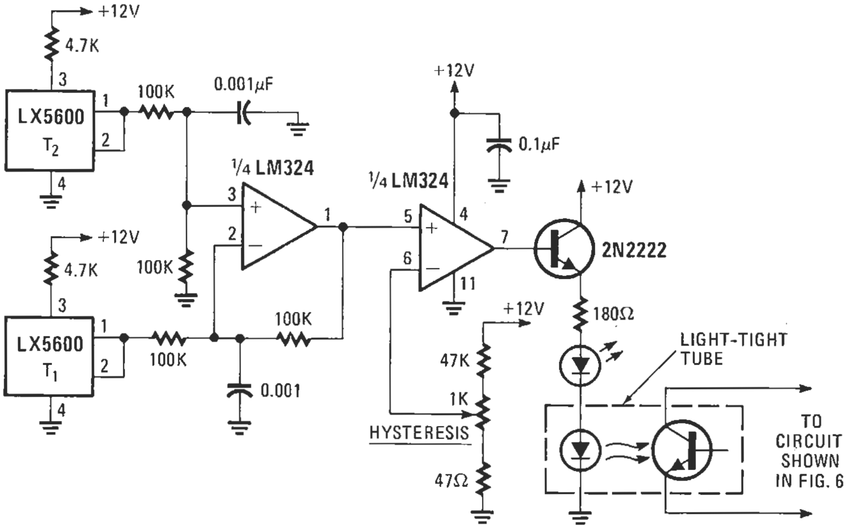


**FIG. 7—SCHEMATIC DIAGRAM of complete control system. Note bypass capacitors for greater noise immunity and slight change of some component values. The LM324 contains four op-amps, so two complete loops could be handled by one IC.**

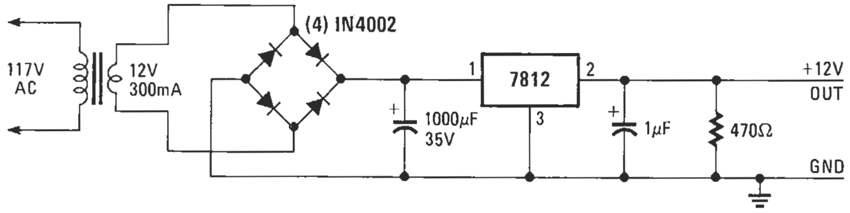


**FIG. 8—12-VOLT POWER SUPPLY consists of bridge rectifier and regulator.**

First, measure voltage $V_s$ of each sensor. This ($V_s$) is measured from pin 3 to ground and should read about 6.8 volts. Write it down for each sensor because it will not change but will be different for each one. Any time that you want to know the actual temperature, measure voltage $V_0$ from the output to ground. The temperature can be found from: $°C = 100 (V_s - V_0 - 2.73)$.

A voltmeter, calibrated in degrees, can even be permanently installed in your system if you desire.

Next, you must consider the sensor. The LX5600 costs a little more than the LM3911, but it has an extended operating range and slightly better absolute accuracy. Naturally, the sensors must be thermally connected to the device to be monitored. A recommended technique would be to fabricate a heat sink that the sensor will slip into. (Use the T0-5 case.) The heat sink can then be mounted to the device. Grease the sensor with heat-sink compound (silicon grease) and slip it into the heat sink. This will prevent damage to the sensor. A solar collector should be monitored in the center if possible.

It will also be necessary to insulate and weatherproof the sensor leads. Some RTV insulation should work well. It may be possible to immerse the sensor in water if you are careful. The top of the case should have very little RTV on it to make sure it isn't thermally insulated. Another method would be to seal it in a test tube. Just make sure that the leads are well insulated.

Run shielded cable to your sensors to reduce noise pickup since open wire runs of longer than a few inches tend to produce too much noise.

Check the pump and valve specifications and choose the triac accordingly. Many different types of triacs are available, and most should work with this trigger system. Don't be afraid to experiment with different triac types.

Make sure that the phototransistor is rated at 80 volts $V_{ceo}$ or more if you plan to use a diac to trigger the triac. The silicon bilateral switch (shown in Fig. 6) might be hard to locate, although a GE semiconductor parts supplier should have it and the 2N5779 photo-Darlington transistor.

Calibrating the hysteresis control will be somewhat time-consuming. Allow one sensor to reach room temperature. This will represent the cooler component (storage tank). Feed this output into the noninverting input of the op-amp.

Prepare a warm water bath and place the other sensor in the bath (insulate the leads). This represents the warmer component (the solar collector). Feed the output of this sensor into the inverting input of the op-amp.

Now use a good thermometer to measure each temperature. Rotate the hysteresis control until the LED lights up. At this point, mark down on the dial the difference between the two temperatures. Repeat this at least five times. The total range, with the component values given, will be from about 1 °C to 20 °C. Therefore, do not raise the temperature of the bath to any warmer than room temperature plus 20 °C. **R-E**

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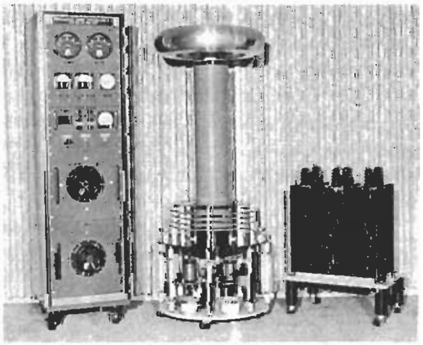
## Custom-built high-voltage Tesla coils now available

The Ultra High Voltage Division of Professional Sound Systems now manufactures a line of Tesla coils, kits and components that can be custom-built to fit individual needs. The coils are modular and symmetrically constructed, conservative in design and can be used in high-voltage applications and for demonstrations.



There are 10 basic configurations from which to choose, with spark-discharge lengths ranging from 1.5 inches to over 15 feet. A full line of stock components is also available, from power-supply control consoles to oscillation transformer assemblies. All of these can also be tailored to a customer's special requirements. For information, write Professional Sound Systems, Ultra High Voltage Division, 4914 Baldwin Avenue, Temple City, CA 91780.

## Report states service industry salares are rising

It appears that salaries in the service industry are on the rise, according to a report entitled *Salaries and Related Matters in the Service Department—1978,* published by Abbott, Langer & Associates, Park Forest, IL.

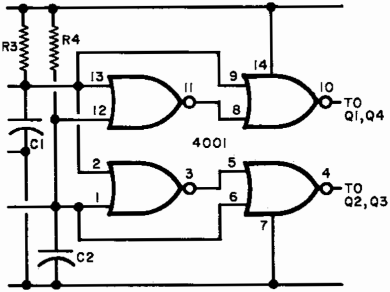
For example, the report lists that the average national service manager's salary is presently $25,658 and that of field service representative, $13,291. The report categorizes these and other job listings by type of product or service (also by the size of the service company or manufacturer involved), as well as containing data on various types of employers. More than 25,000 positions in over 200 organizations are listed, including salaries for national regional and local service managers; field service supervisors, engineers and senior representatives; parts managers; service training instructors; technical writing supervisors; and more. Employers represented include firms manufacturing business, electrical and communications equipment; consumer electronics; computers and allied products; and medical and scientific equipment.

The report is available for $60 from Abbott, Langer & Associates, Box 275, Park Forest, IL 60466.

# Letters

## Sundial Improvement

In the "Solar-Powered Sundial" (March 1980), it is possible for the NiCad batteries to be damaged when light sensors are fully illuminated and all four FETs are turned on. In this case, the FETs form a low-resistance path, effectively shorting the solar cells and the battery.



Here is a simple circuit I propose as a substitute. It replaces the CD4069 hex inverter with a CD4001 quad 2-input NOR gate connected in what is essentially an exclusive-OR function. In this case, the voltage applied to the FETs is low when both light sensors are fully illuminated or both are dark. The FET bridge functions normally when there is a difference in illumination on the light sensors.—*D. O Shelton, Virginia Beach, VA 23460.*

# Solar Tracking System

*Solar-energy collectors work best when constantly oriented to trap the most energy from the sun. This electronic servo system swivels the collector panel so it follows the sun across the sky.*

**RODNEY A. KREUTER**

THE MOST COMMON USES FOR SOLAR energy systems today are space heating and hot-water preheating. These systems generally use nonmovable flat-plate collectors; and for a low-temperature system, flat plate is probably the best choice. If, however, your system needs high-temperature water or steam, or uses solar cells to generate electricity, a tracking system is the only way to go.

A solar tracking system consists of a motor-sensor combination that locates the sun and points a collector toward it. A non-sensing system can even be built using a constant speed motor, but such a system has more disadvantages than advantages.

The solar collector tracking system discussed in this article is intended as a guide, not as an absolute system. (For example, why track the sun if there is little or no energy to be gained?) We'll examine how to construct a simple circuit using a comparator that will not let the motor operate until a certain level of sunlight is present.

## The basic system

Figure 1 shows a block diagram of the solar tracking system, which consists of four basic modules: 1) a pair of phototransistor sensors; 2) a difference amplifier; 3) a deadband amplifier; and 4) a servomotor and motor drive transistors.

Figure 2 shows how the phototransistor sensor is constructed. Note that the phototransistors are mounted on perpendicular surfaces so that a shadow effect occurs when the sun is not directly overhead.

The difference amplifier (see Fig. 1) subtracts the output of sensor B from the output of sensor A and multiplies the result by about 4.7.

The deadband amplifier is a fairly unique device. It amplifies the output of the difference amplifier by about 2.5 only if the output of the difference amplifier is greater than 0.6 volt

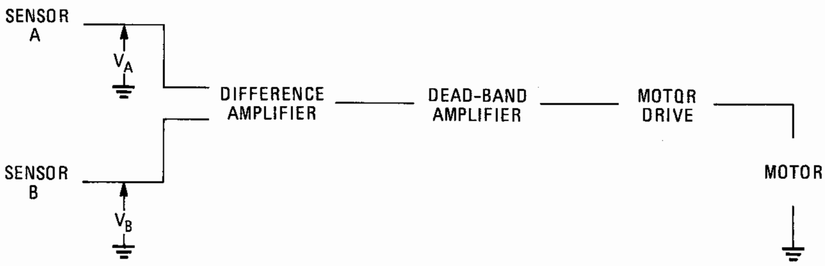


FIG. 1—SOLAR TRACKING SYSTEM uses phototransistor sensors to detect the position of the sun. Circuitry drives motor to position solar energy panels and minimize the difference in output from the two sensors.

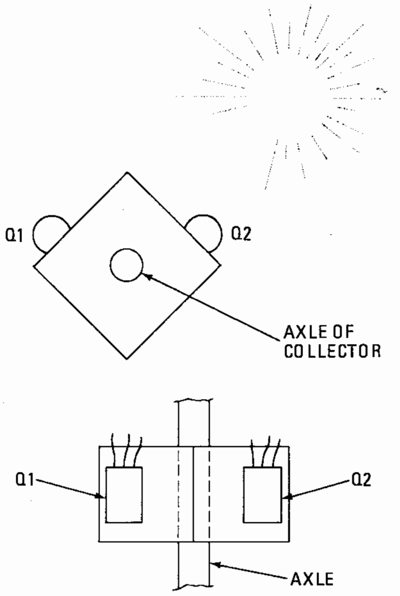


FIG. 2—PHOTOTRANSISTOR SENSORS are mounted at right angles to each other. The output of the sensors are equal when the sun is directly over the apex.

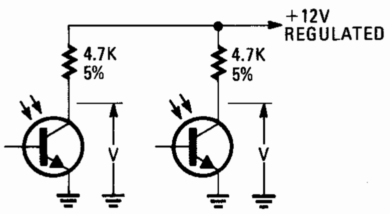
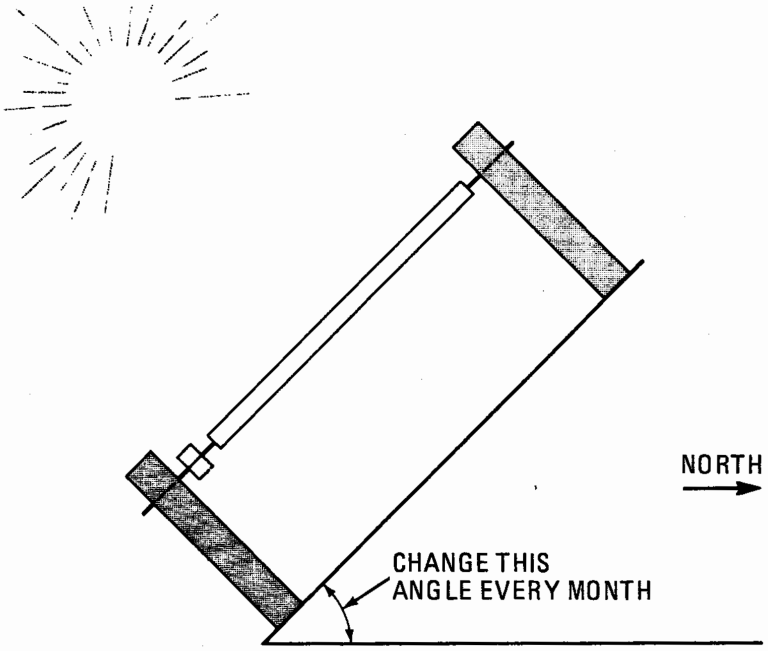


FIG. 3—PHOTOTRANSISTOR SENSORS must have matched outputs for correct circuit operation. Circuit above provides easy method for obtaining matched outputs.



or less than −0.6 volt. If the output of the difference amplifier is between −0.6 volt and 0.6 volt, the deadband amplifier provides a stable zero volt output.

The servomotor drive circuit consists of four push-pull Darlington connected transistors, which produce enough current to drive a fair-sized 12-volt motor.

### Circuit operation

Two phototransistors are used as brightness sensors. When operated from a constant-voltage power supply, the collector current of each transistor is proportional to the amount of illumination they receive. Due to variations in manufacturing processes, the phototransistors may not be well matched, so it is a good idea to buy a few extra phototransistors and match them yourself. The procedure is very simple.

First, breadboard the circuit shown in Fig. 3. Place two phototransistors side by side with the flat side down. Shine a *diffused* light source (a handkerchief placed over a bare high-intensity bulb will do) on the transistors. Note that the base connection is not used.

Apply power to the circuit and measure the voltage from one of the collectors to ground; this will be your reference transistor. Adjust the distance of the light source so that the reference voltage reads about 3. Measure the collector voltage of the second transistor and write it down. Repeat this procedure with a reference voltage of 6 and 9, measuring all the transistors against the same reference transistor. Select the two transistors that give the closest results for your sensors.

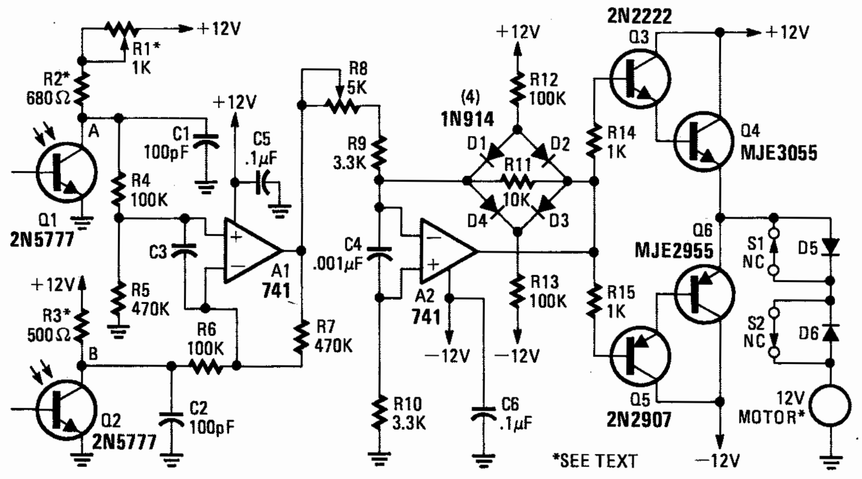


**FIG. 4—CIRCUITRY detects difference in output from phototransistor sensors and switches the Darlington motor-drive transistors to minimize the difference.**

## PARTS LIST

**All resistors ½ watt, 10%.**
R1—1000 ohms (to start—see text)
R2—680 ohms (to start—see text)
R3—500-ohm trimmer (to start—see text)
R4, R6, R12, R13—100,000 ohms
R5, R7—470,000 ohms
R8—5000-ohm trimmer
R9, R10—3300 ohms
R11—10,000 ohms
R14, R15—1000 ohms
C1-C4—0.0001 µF
C5, C6—0.1 µF
D1-D4—1N914
D5, D6—50-volt rectifiers (current rating depends on motor current)
Q1, Q2—2N5777 photodarlington or equal
Q3—2N2222
Q4—MJE3055
Q5—2N2907
Q6—MJE2955
A1, A2—Op-amps, dual 741, 1558, 747, two 741's, two 301's, etc. Pin numbers depend on type and case style; 3900 or 324 types not recommended.
S1, S2—Normally closed switches
M1—12-volt reversible motor
Misc.—Power supply, case, shielded cable for sensors, etc.

This matching may sound confusing but remember, you need two transistors that will give equal output voltages when illuminated equally. Small variations can be compensated for by the circuit, so it's not critical if the transistors are not matched exactly.

Figure 4 shows the schematic diagram of the tracking system. Difference amplifier A1 is fairly straightforward. Its output can vary from about −11 to 11 volts. The output polarity determines the direction the collector must move and the magnitude determines how far it must move. The whole idea is to move the collector and sensors so that the two phototransistors are equally illuminated by the sun. This condition occurs when the outputs from the two phototransistors are equal.

In electronics, two voltages are almost never equal for any period of time. I learned this the hard way by trying to get a simple comparator to output zero volts when the two input voltages were "equal." I didn't take drift into account.

The deadband circuit is an "almost equal" circuit. If the output of the difference amplifier is almost zero (meaning the two sensor outputs are almost equal), the output of the deadband amplifier will be zero. If the output of the difference amplifier exceeds the "deadband range," the output of the deadband amplifier heads for the rails (positive or negative saturation, in this case −12 or 12 volts). The amount of deadband output is adjustable by R8, and, with the values shown, can vary from about ±0.37 volt to ±0.95 volt.

Transistors Q3–Q6 are used as current amplifiers since the output of the op-amp cannot drive a motor directly. Almost any transistor types can be used as long as they can handle the motor current.

Normally closed switches S1 and S2 are placed at the two travel limits of the collector. When the collector reaches one of these limits, a switch opens, and this places a diode in the motor's current path. If the motor and diodes are connected correctly, this will prevent the collector from moving any farther in this direction but will allow the motor to reverse the current. You may have to reverse the polarity of both diodes depending on the type motor used.

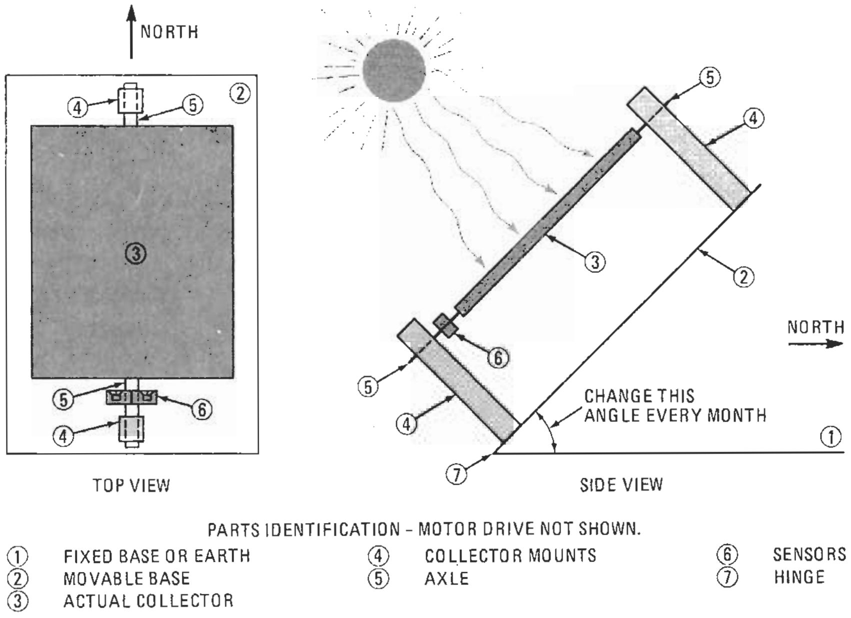


**FIG. 5—SENSOR UNIT is correctly mounted on the axis of the solar energy panels.**

## Construction

Since only one IC is used for the tracking system, almost any type of construction is possible, including PC or perforated board construction and the component layout is not critical.

Heat-sink output transistors Q4 and Q6 if your motor draws more than 500 mA.

Use trimmers for R1 and R8 since they are only set once.

Mount the sensors on the axle of the collector, not on the collector itself. Mounting them on the collector would cause the collector to overshadow the sensors in the morning (see Fig. 5). Paint the area around the sensors with flat black paint so that they will not respond to reflections.

Use a 12-volt reversible motor that draws less than approximately 6 amps with the transistors shown. The power supply must be able to handle the total motor load so make sure it is sized accordingly. It's a good idea to provide the final transistors with their own unregulated power supply, and the rest of the circuit should have a regulated 12-volt supply. The total current drawn by the op-amps is negligible, so a pair of Zener diodes should be adequate.

The motor should be geared down so that running flat out, the collector takes about 10 minutes to travel from one limit to the other. A small motor geared down as much as this will move a fair-sized collector.

## Adjustments

Since the angle of the sun changes very slowly throughout the year, changing the angle of the collector once a month should be sufficient.

For the following electrical adjustments you will need: a bright sunny day; the circuit described in this article and a geared-down motor connected to a collector-sensor; a VOM; and a 12-volt bipolar power supply.

With the collector and sensors pointed *directly* at the sun and the motor disconnected, measure the output of the two sensors. Resistors R1, R2 and R3 may have to be changed to compensate for transistor variations. Even though they should be matched, the light current can vary by a factor of 100. For example, with a white light source of 2 mw-per-cm$^2$ falling on a 2N5777, the collector current can vary from 0.5 mA to 50 mA. (Remember that while you are testing, the sun is moving, so you must keep the collector pointed directly at the sun.)

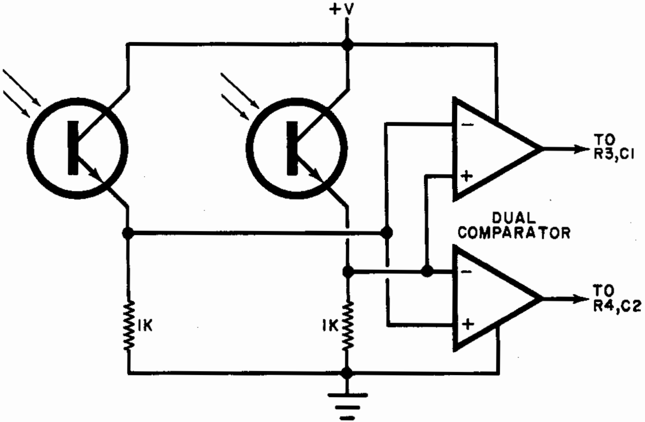
Select an R3 resistor that will yield an output of about 3 volts with a bright sun. Raising the resistance will drop the voltage. Resistor R2 should equal about 70% of resistor R3 and resistor R1 about 60%; use the closest standard values.

After selecting R1, R2 and R3, point the sensors directly at the sun again and measure $V_a$ and $V_b$. Adjust R1 until these values are equal, and connect the motor.

The setting of R8 determines how far the sun must move before the tracking system compensates for the movement. Your system requirements will determine your choice. If the system seems to "hunt," increase the setting of R8. **R-E** across the jacks.—*H. D. Mohr, Gahanna, OH.*

## SUBSTITUTE FOR LM1890 IN SUNDIAL

*It has come to our attention that the LM1890 light-to-current converter used in the "Solar Powered Sundial" (March 1980) is in short supply since it is no longer in production. The circuit below, using conventional light-sensitive transistors and a dual comparator, can be substituted easily for the LM1890 circuit.—Ed.*



# Tester determines solar cell's sunlight-gathering efficiency

by Sudarshan Sarpangal
*ISRO Satellite Centre, Bangalore, India*

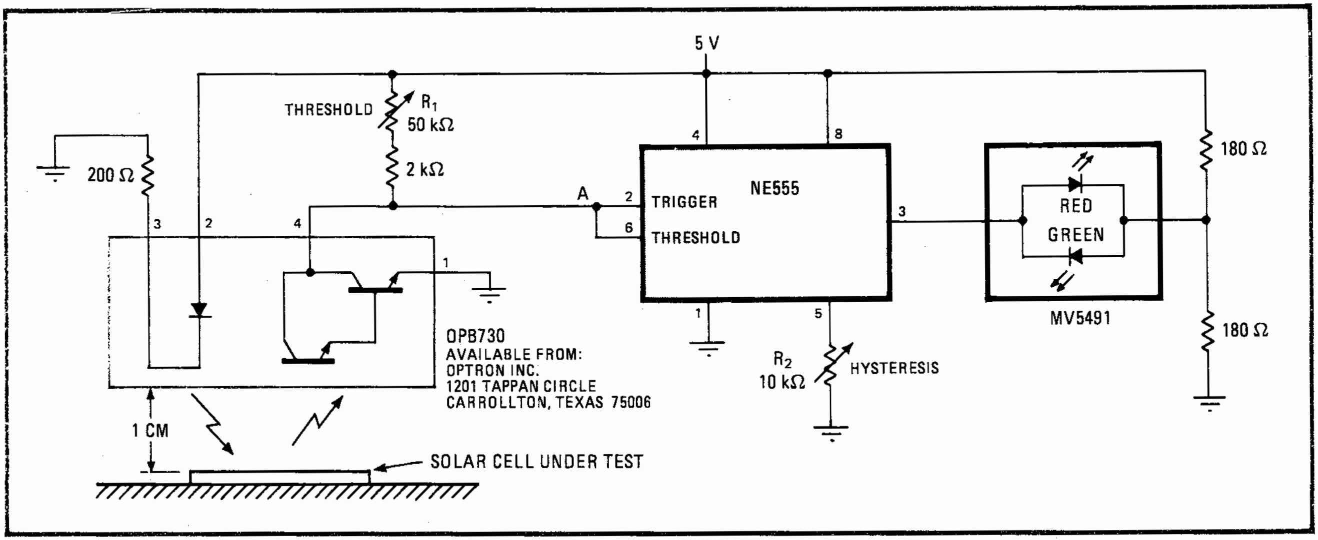
The low-cost circuit shown in the figure performs a go/no-go test on the light-gathering efficiency of solar cells by checking the quality of its antireflection coating. A light-reflective transducer, a universal timer, and a dual light-emitting-diode package form the checker, which can be useful in production-line testing.

The overall conversion efficiency of a solar cell is directly proportional to the amount of sunlight converted to electricity, which in turn is equal to $K(1-R)$, where K is a constant and R is the reflectivity factor of the cell's antireflection coating. R can be expected to lie in the range 0.015 to 0.03 for space applications. An R equal to 0.05 would be considered undesirable.

In this circuit, the reflective transducer (OPB730), which is actually an infrared photodiode transmitter and a photo-Darlington transistor receiver, discovers whether the value of R exceeds preset limits. Then it uses the 555 timer and the red-green light-emitting diode array to display the results.

The OPB730 should be placed 1 centimeter from the cell's antireflection surface. Both should be contained in a test fixture that shields them against external light.

Part of the infrared energy emitted by the optical device will be reflected by the solar cell's coating, which is very often titanium, zirconium, or cerium dioxide, ($TiO_2$, $ZrO_2$, or $CeO_2$, respectively), and this reflected energy will be detected by the photo-Darlington transistor in the receiver. If the antireflection coating is of relatively high quality (little reflection), the voltage at point A will climb above the preset limit set by $R_1$, and the output of the 555, which is configured as a Schmitt trigger, will go low. Then the green LED will glow, indicating a good solar cell. If the antireflection coating is substandard (high R), the output voltage from the photo-Darlington output of the receiver will be relatively low. If the voltage is below the preset limit, pin 3 of the timer will go high and turn the red LED on. □



**Light work.** Circuit performs qualitative check of solar cell's efficiency by determining if relative value of its antireflection coating exceeds preset limits. $R_1$ sets limits, $R_2$ controls hysteresis in 555 timer, which operates as Schmitt trigger. If coating is of relatively high quality, Schmitt trigger moves low, lighting green LED. Otherwise, output voltage from OPB730 will be low, and red LED will glow. Circuit cost is under $10.

Popular Electronics
DECEMBER 1977

BY BILL GREEN

# POWER YOUR PROJECTS WITH SOLAR ENERGY!

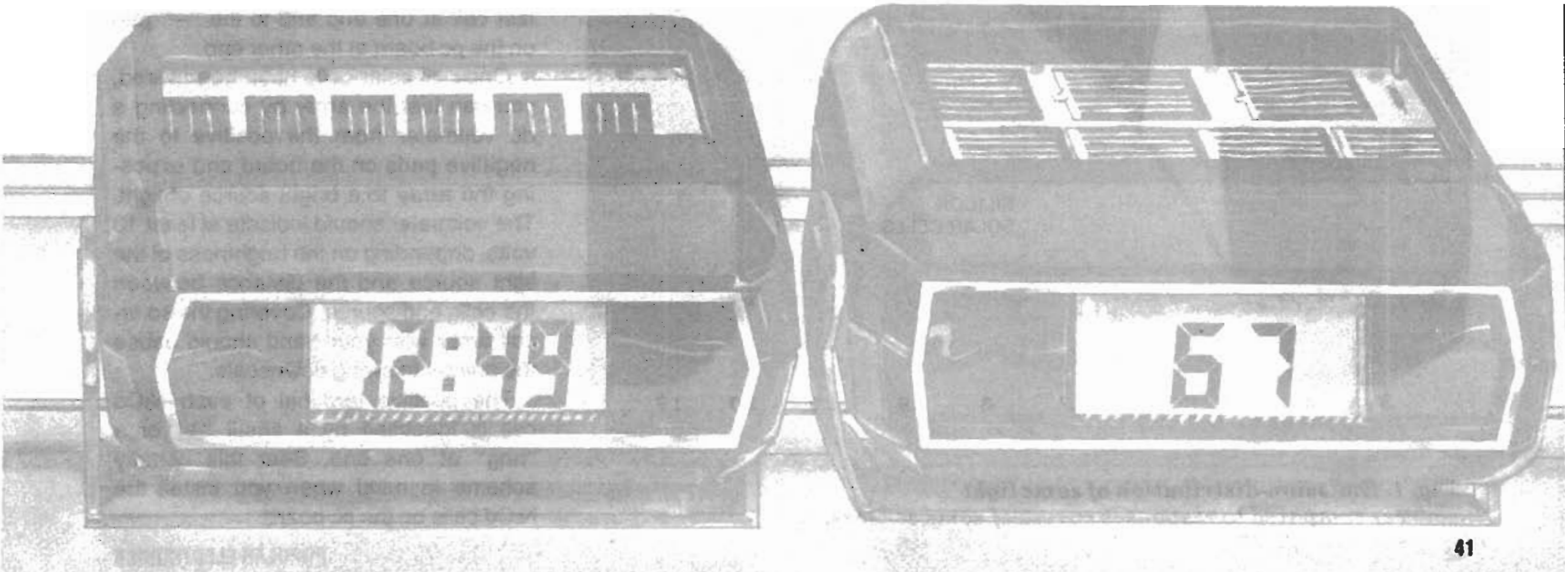
## DIGITAL CLOCK AND THERMOMETER PROJECTS USE SUN OR ARTIFICIAL LIGHT TO AUTOMATICALLY RECHARGE BATTERIES.

THE IDEA of building a simple solar-cell power supply for small appliances in your home is not as far-fetched as you might think. Here is a supply that can deliver 10 volts dc at 100 mA for one hour. Alternatively, it can deliver 10 mA for 11 hours. The power capability of the supply is sufficient to drive a transistor radio, emergency light, smoke detector, and other types of low-to-medium-power devices.

To illustrate typical uses of the solar-cell power supply, this article also presents construction details for a digital clock calendar and a digital thermometer. Both projects employ CMOS IC's and liquid-crystal displays to minimize the drain on the solar-cell power supply. The two projects employ variations of the basic solar array to recharge (either by sunlight or artificial lighting) their internal nickel-cadmium cells.

**Solar Cells.** Silicon solar cells are photovoltaic light sensors that convert incidental light directly into electrical energy. Solar cells have been used in all the earth satellites and space probes to keep the internal batteries "topped up." Such solar cells have formed the exterior "skin" of many satellites; and in other cases, such as the Skylab, they have been on "wings." They have also been used to power electronic equipment far from a convenient source of power.

The impinging photons of light energy break a valence bond within the pn junction area of the silicon cell and create electron-hole pairs that cause a potential difference across the cell. The cells are designed to maximize the light-sensitive nature of the pn junction. Those used in the projects in this article are shallow-diffused types that have a special blue coating to enhance the re-



sponse at the blue end of the visible-light spectrum. The emission-distribution and response curves of some light sources and sensors are illustrated in Fig. 1.

When coupled with some device (such as a rechargeable battery) that can store the electrical energy generated by a solar cell, the system can be used to power many different electrical and electronic devices at essentially no cost but the original investment. At night, the solar-cell array can be placed near a bright incandescent lamp to reclaim energy that would otherwise be wasted.

**Solar-Cell Power Supply.** This basic solar-charged power supply consists of up to 26 silicon solar cells, the actual number depending on the desired output voltage. The system can deliver up to 40 mA in bright sunlight. If all 26 cells are used, the terminal potential will be 10 volts (see Parts Lists for Solar-Cell Array).

The fully-charged NiCd cells used in this circuit can deliver about 100 mA of current for an hour (10 mA per hour for 11 hours, for a total of 110 mAh). Two or more of these supplies can be connected in parallel to deliver more current. Alternatively, two or more supplies can be connected in series to provide a higher output voltage.

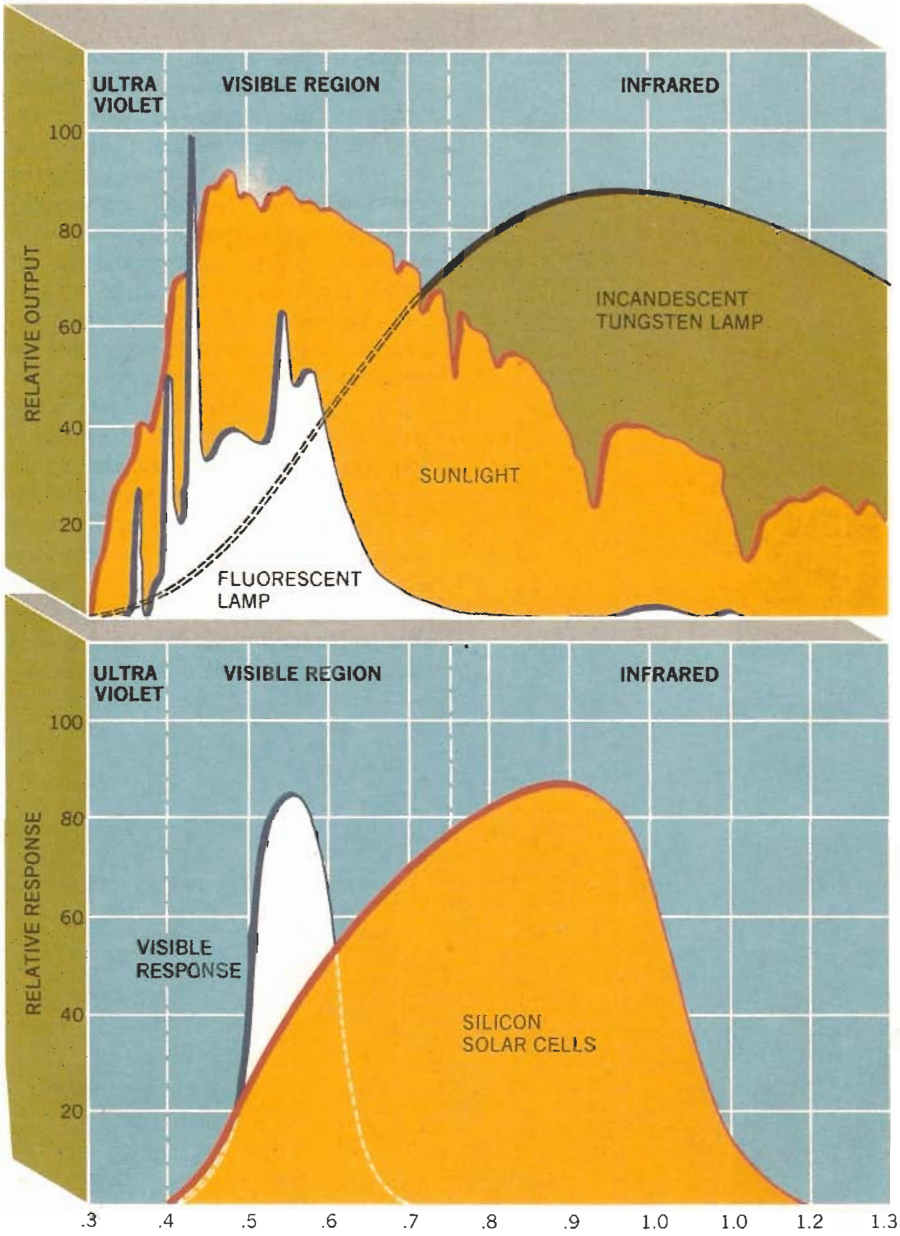


*Fig. 1. Emission-distribution of some light sources compared to responses curves of some sensors.*

Approximately 13 hours of exposure at a distance of about 8" (20.3 cm) from a 100-watt incandescent lamp or about five hours in direct sunlight should be sufficient to fully recharge the NiCd cells. If you live in a bright, sunlit area of the country, take care to prevent overcharging that can damage the NiCd cells. The maximum continuous charging rate to the cells in the supply should be limited to 10 mA.

**Construction.** The supply can be assembled on a single-sided printed circuit board, the etching and drilling and component-placement guides for which are shown in Fig. 2. In this supply, the full complement of solar cells and nickel-cadmium cells is used.

Each solar cell has its light-sensitive surface finished in a deep blue color, with silver leads just under the surface and a thin metallic "land" along one edge. The upper metal land is the negative terminal.

The solar cells must be epoxied to the blank side of the pc board, making certain that the positive metal land on the bottom side of each cell is facing toward the large hole through the board at each solar cell location. Use a low-wattage soldering iron and fine solder for the wiring operation. Start from the diode end and very carefully solder a thin lead from the positive side of the adjacent solar cell to the pad at the diode's anode. Continue working very carefully with the soldering iron and interconnect each of the solar cells as follows. Solder a thin wire to the negative terminal of the cell. Pass this wire through the small hole near the cell and solder it to the positive terminal of the next cell through the large hole in the board. Repeat this procedure until all 26 cells are wired in series, with the final piece of wire connected to the negative terminal of the last cell at one end and to the "−" pad on the pc board at the other end.

Once all solar cells have been wired, you can test the array by connecting a dc voltmeter from the positive to the negative pads on the board and exposing the array to a bright source of light. The voltmeter should indicate at least 10 volts, depending on the brightness of the light source and the distance between the cells and source. Covering the solar-cell array with your hand should cause the pointer to swing downscale.

The positive terminal of each NiCd cell is identified by a small "+" or a "ring" at one end. Bear this polarity scheme in mind when you install the NiCd cells on the pc board.

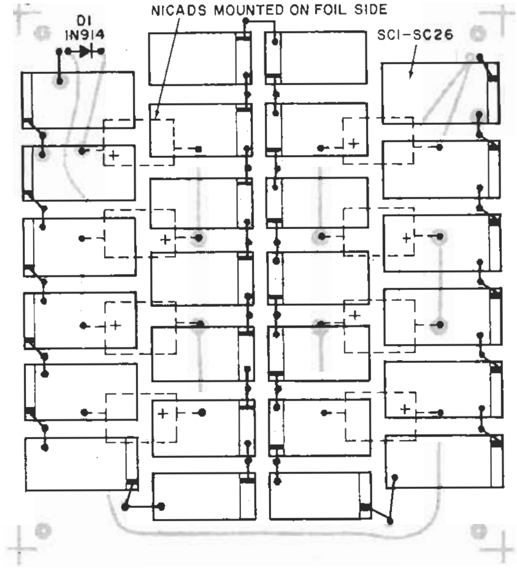
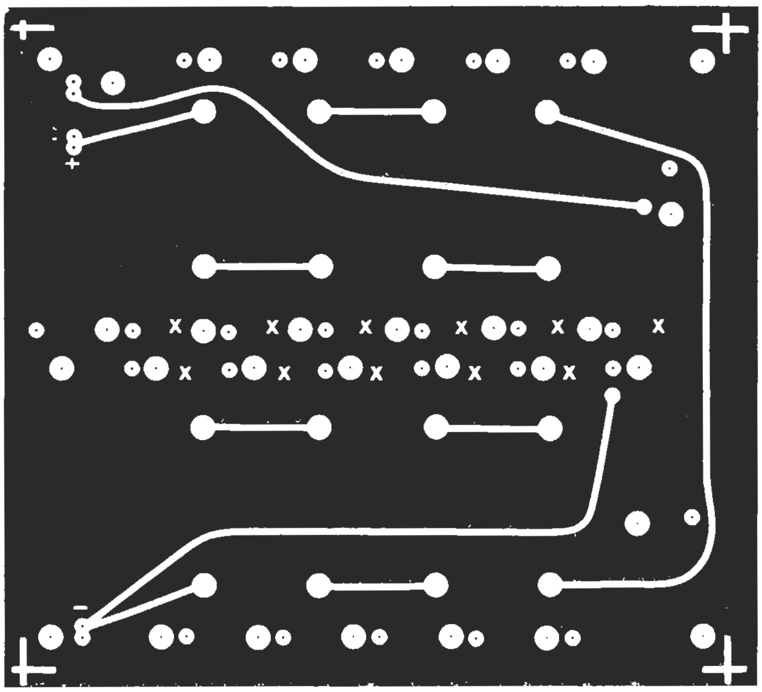


*Fig. 2. Basic solar power supply with solar cells on nonfoil side of board and nickel-cadmium cells on foil side.*



## SOLAR-CELL ARRAY PARTS LIST

B1 through B8—100-mAh nickel-cadmium cell
D1—1N914 diode
SC1 through SC26—Sc-50 silicon solar cell
Misc.—Printed circuit board; epoxy cement; hookup wire; solder; etc.

Place the pc board assembly solar cell side down on your work surface and pretin with solder the pads to which the NiCd cells connect. Then pretin the ter-

## CLOCK/CALENDAR PARTS LIST

B1,B2,B3—100-mAh nickel-cadmium cell (GE No. GCF100ST, rated at 1.2 V at 100 mAh, or similar)
C1—100-pF disc capacitor
C2—5-to-30-pF trimmer capacitor
C3—47-µF, 6-V electrolytic capacitor
D1,D2—1N 914 diode
DIS1—MLC200 liquid-crystal display (Motorola)
IC1—MC14440 LCD watch/clock (Motorola)
IC2—MC14584B hex Schmitt trigger (Motorola)
The following resistors are ¼-W, 10%:
R1—82,000 ohms
R2,R3,R4—1 megohm
R5,R8—100,000 ohms
R6,R11—470,000 ohms
R7—4700 ohms
R9—10 megohms
R10—560,000 ohms
S1,S2,S3—Normally open spst pubhbutton switch
S4—Normally closed spst pushbutton switch
SC1 through SC11—SC-50 silicon solar cell (0.4" × 0.4", rated at 40 mA at 0.4 volt)
XTAL—32,768-Hz crystal (miniature)
Misc.—Printed circuit boards (3); sockets for IC's and LCD; suitable enclosure; etc.

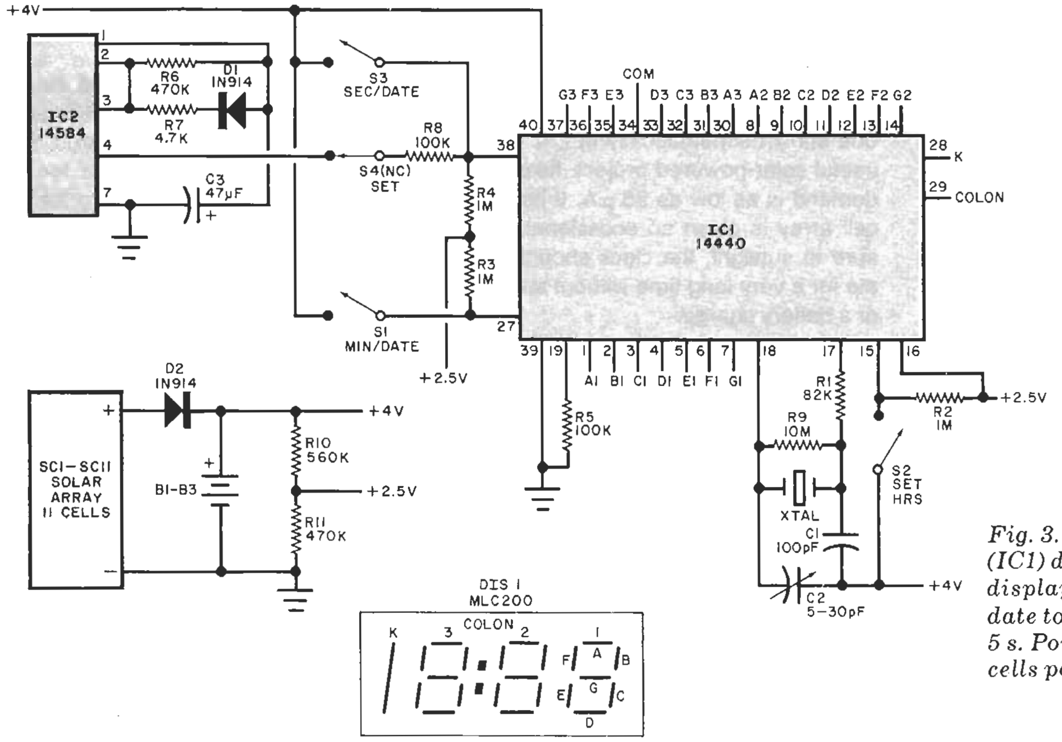
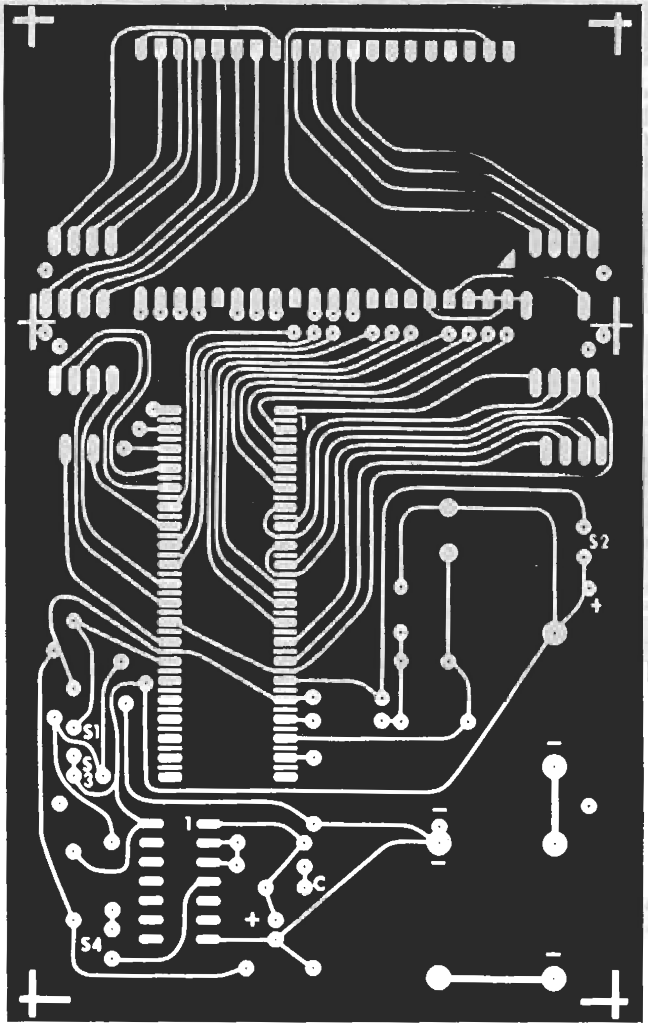


*Fig. 3. Clock/calendar chip (IC1) drives liquid-crystal display. Oscillator causes date to appear about every 5 s. Power is from 3 NiCd cells powered by solar array.*



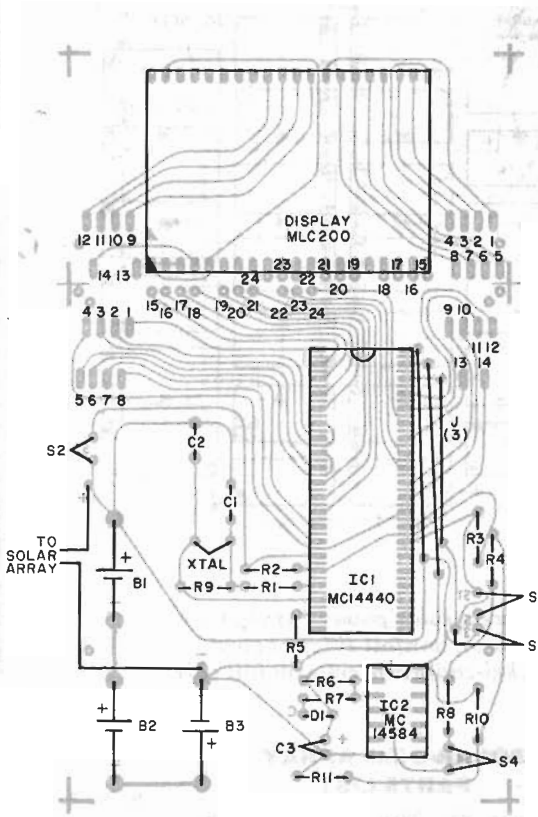


*Fig. 4. Actual-size foil pattern for the clock main and display board is at left. Component layout is shown above. After completing the board, carefully separate the two parts.*

minal tabs for all NiCd cells. Now, position the first cell on the pc board as shown in Fig. 2 and apply soldering heat to the top of one terminal tab to "reflow" the solder on tab and pc pad. Do not allow the cell to move until the solder sets. Then reflow solder the other cell tab to its pc pad. Continue this reflow soldering procedure until all NiCd cells are mounted on the pc board. When you are finished wiring in the NiCd cells, double check to make sure that they are properly polarized. Then install and solder into place diode *D1*, making sure that the cathode end goes to the pad labelled "C" on the board.

Finally, solder lengths of red and black insulated stranded 28-gauge hook-up wire to the positive and negative output pads on the board. These leads should be long enough to reach from the solar-cell power supply to the equipment the supply is to power. Twist the wires together to form a pair.

The power supply can be placed in a window or near bright indoor lighting and connected to the equipment it is to drive. It is important that you keep the supply in a location where it will receive enough light to keep the NiCd cells charged and provide enough current to make up for the power used by the equipment being powered by the supply.

**Solar-Powered Clock.** A CMOS/liquid-crystal-display clock, such as the one shown schematically in Fig. 3, is a useful solar-powered project. Its current demand is as low as 25 μA. If its solar-cell array is given an occasional exposure to sunlight, the clock should operate for a very long time without attention or a battery charge.

**How It Works.** Clock chip *IC1* contains all the electronics required to drive a liquid-crystal display and to count the time and date. The crystal (*XTAL*) sets the internal oscillator to a frequency of 32,768 Hz for accurate timekeeping. Trimmer capacitor *C2* permits slight adjustment of the oscillator's frequency to maximize precision.

Integrated circuit *IC2* forms a one-shot multivibrator that delivers a short pulse every five seconds or so to trigger the *IC1* date demand input so that the date will be automatically displayed. The network consisting of *R10* and *R11* divides the basic 4-volt dc line down to 2.5 volts as required by some elements within the clock chip.

**Construction.** The clock and its associated solar-cell array can be assembled on three separate pc boards, one for the solar-cell array, another for the basic clock circuit, and the third for the display. The solar-cell array can be assembled in a similar manner to that described for the basic array of Fig. 2 using only 11 solar cells and the series diode. Use the solar cell areas labelled with an X on Fig. 2 and do not install the NiCd cells on this board.

The etching and drilling and component-placement guides for the two clock boards are shown in Fig. 4. The liquid-crystal display mounts on a strip-type socket so that the small black wedge in the front of the display is positioned toward the small wedge on the conductor pattern of the board.

On the main board, install the resistors, capacitors, three jumper wires, and diode *D1*. Take care to observe the proper polarities of *D1* and *C3*. The cathode

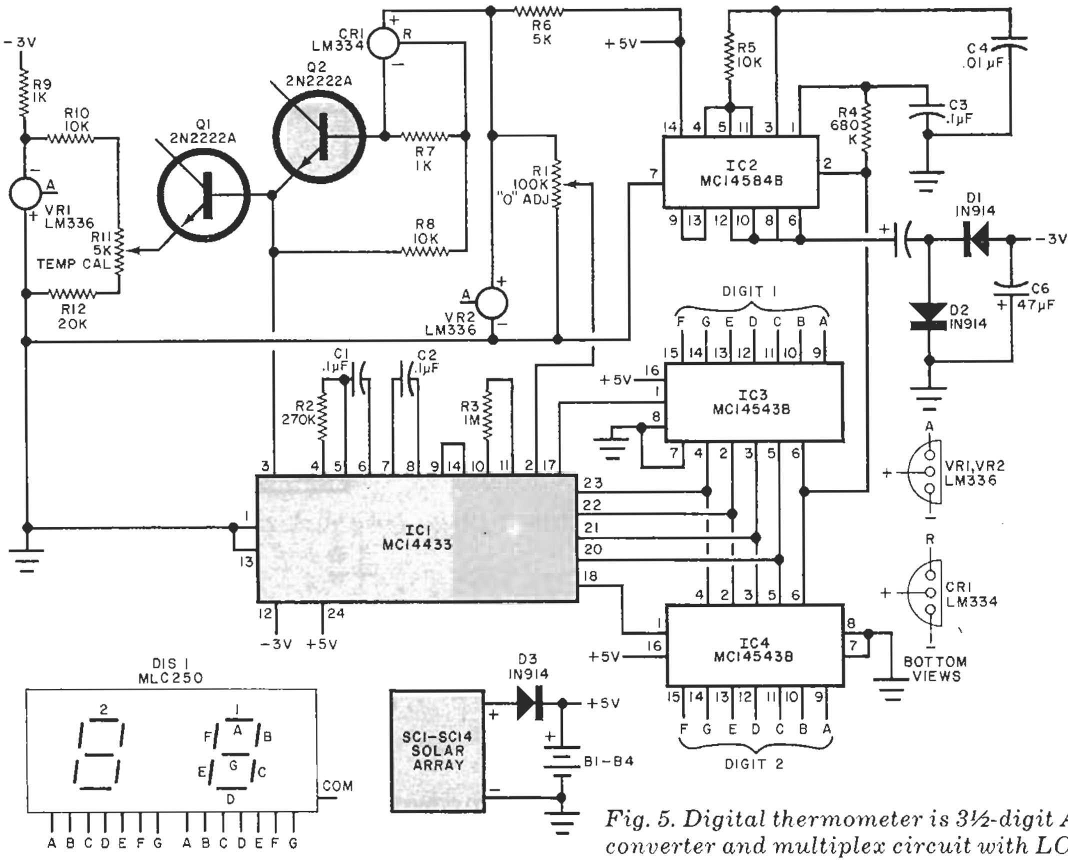


*Fig. 5. Digital thermometer is 3½-digit A/D converter and multiplex circuit with LCD.*

## THERMOMETER PARTS LIST

B1 through B4—100-mAh nickel-cadmium cells (GE No. GCF250ST or similar)
C1,C2,C3—0.1-µF, 6-V capacitor
C4—0.01-µF, 6-V capacitor
C5,C6—47-µF, 6-V electrolytic capacitor
CR1—LM334 current regulator (National)
D1,D2,D3—1N914 diode
DIS1—MLC250 liquid crystal display (Motorola)
IC1—MC14433 3½-digit A/D converter (Motorola)
IC2—MC14584 hex Schmitt trigger (Motorola)
IC3, IC4—MC14543B BCD-to-7-segment latch/decode/drive (Motorola)
Q1,Q2—2N2222A transistor
R1—100,000-ohm, 10-turn trimmer potentiometer
R2—270,000-ohm, ¼-W resistor
R3—1-megohm, ¼-W resistor
R4—680,000-ohm, ¼-W resistor
R5—10,000-ohm, ¼-W resistor
R6—5000-ohm, 1% metal-film resistor
R7,R9—1000-ohm, 1% metal-film resistor
R8,R10—10,000-ohm, 1% metal-film resistor
R11—5000-ohm, 10-turn trimmer potentiometer
R12—20,000-ohm, 1% metal-film resistor
VR1,VR2—LM336 voltage regulator (National Semiconductor)
SC1 through SC14—SC-100 silicon solar cell (0.8" × 0.8", rated at 80 mA at 0.4 volt)
Misc.—Printed circuit boards (3); suitable enclosure (Radio Shack No. 270-285 or similar); sockets for IC's and LCD; machine hardware; hookup wire; solder; etc.

end of *D1* goes to the pad labelled C on the foil. Then install the crystal. Connect suitable insulated hookup wire leads for the four switches and the solar-cell array. Sockets are recommended for *IC1* and *IC2*, although they are not necessary. Install the two IC's last, taking care to orient them properly and observing the accepted procedures for handling MOS devices.

Note that the display and main boards have similar round copper pads near their edges. Insert a bare wire into each pad on the display board and solder into place. Then place the conductor side of the display board against the main board, the latter foil side down. Insert the two bare wires just installed in the display board through the mating holes in the main board. Firmly press the two boards together and solder the wires into place on the main board. (The row of pads on the display board should be slightly below the foil side of the main board.) Using thin wire and insulated tubing as necessary, interconnect the mating numbered pads between both printed circuit boards.

The three NiCd cells (*B1, B2, B3*) are installed on the main board using the solder reflow technique described above. Observe the polarities of each cell. Once installed, the cells can be initially charged using the solar-cell array or a dc power supply adjusted to deliver 100 mA for 1 hour and 20 minutes. In either case, the cells must be charged before attempting to calibrate and set the clock. Once the cells are charged, connect a frequency counter to the junction of the crystal and *R9* and the positive-voltage lead and then adjust trimmer capacitor *C2* for an indication of 32,768 Hz. If you do not have a frequency counter, use the timing intervals broadcast by WWV or CHU to adjust *C2*.

The clock can be mounted in any enclosure large enough to accommodate the circuit boards. Install the four switches on the rear panel of the enclosure. Mount the solar-cell array where its light-sensitive surface can be exposed to light through a cutout on the top of the enclosure.

Switch *S1* is used to set the minutes when the hours displays indicate 12 and the date when the hours indicate any figures other than 12. Switch *S2* is used for setting the hours. Switch *S3* is used for displaying the seconds and date on demand and, when held closed, allows the clock to display the seconds count-off. Releasing *S3* allows the clock to display the date for about 3 seconds. Switch *S4* is used to disconnect the timer from demand when setting the time. When the

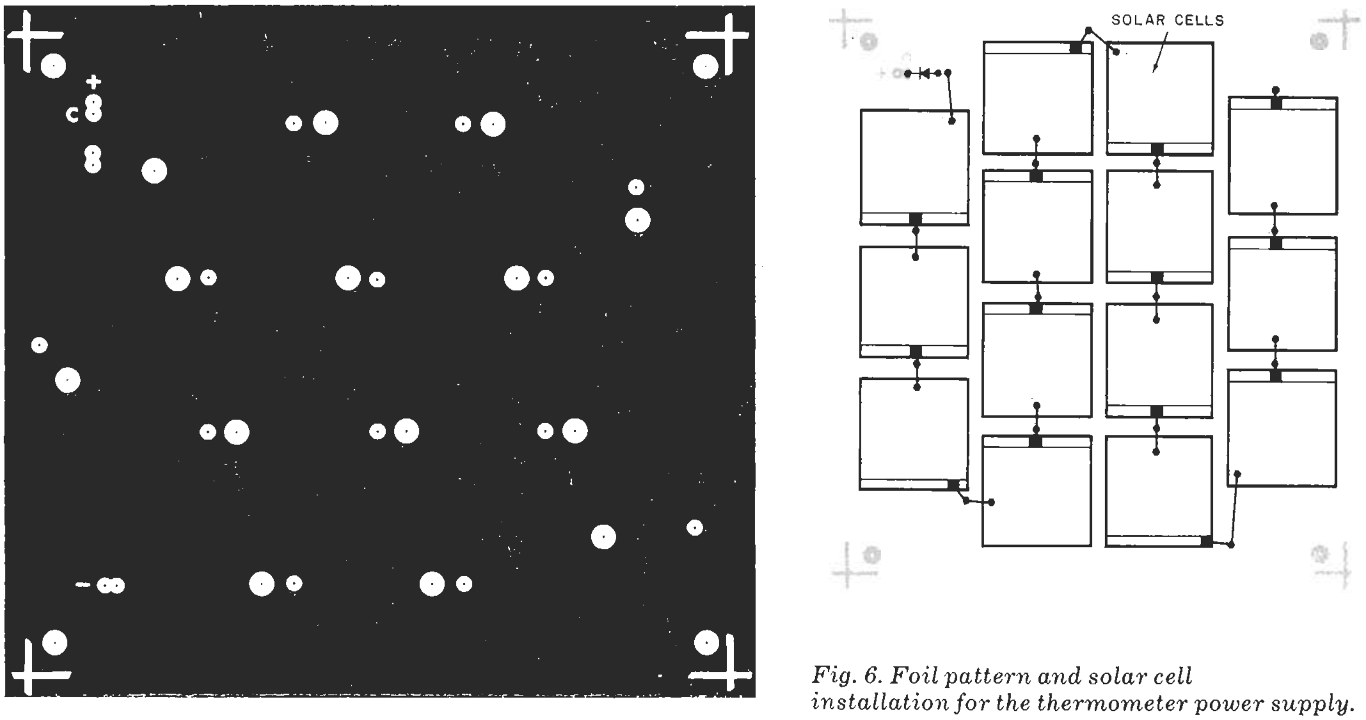


*Fig. 6. Foil pattern and solar cell installation for the thermometer power supply.*

clock is first turned on, the hours indicated are for AM, which must be kept in mind when setting the date.

To set the time, use *S2* to set the hours to any display but 12 and use *S1* to set the date. Operate *S3* to set the hours to 12 and *S1* to set the minutes. Use *S2* to set the hours and then depress *S3* to start timekeeping. Remember to keep *S4* depressed during the time setting and until *S3* is operated.

**A Solar-Powered Thermometer.** The liquid-crystal display thermometer shown schematically in Fig. 5 is essentially a digital voltmeter that has a temperature-to-voltage converter as its input. Two digits of °C or °F are displayed.

**How It Works.** Analog-to-digital converter integrated circuit *IC1* has multiplexed outputs, which require BCD-to-seven-segment latch/decoder/driver integrated circuits *IC3* and *IC4* to interface to the liquid-crystal display. Hex Schmitt-trigger *IC2* is designed as an oscillator that generates the clock signal required to drive the LCD and to simultaneously generate −3 volts dc (using *C5, D2, D1,* and *C6* as the RC timing elements) for the temperature converter and *IC1*.

Voltage dividers *VR1* and *VR2* provide a constant 2.5 volts to the temperature converter over varying battery-voltage levels. Current regulator *CR1* produces a constant current through *Q1*, whose base-emitter junction is used to sense the temperature. Temperature compensation for *CR1* (to provide stable current over a wide temperature range) is provided by *Q2, R7,* and *R8.* Note that 1% metal-film resistors are used in the converter to reduce drift over the temperature range of the system. Trimmer potentiometer *R1* is used to remove errors so that the system can produce accurate indications at 0° C and 32° F. The system is calibrated for accurate indications in either °C or °F by adjusting *R11*.

The thermometer uses CMOS IC's to keep its current drain to less than 3 mA. Since the system is powered from 200-mA NiCd cells, the thermometer can operate for about three days on fully charged cells. The solar cells used in this circuit can deliver about 80 mA in bright sunlight. About 5 hours and 20 minutes of bright sunlight or about 13 hours at a distance of 8" from a 100-watt incandescent lamp are required to fully recharge the NiCd cells.

**Construction.** Three circuit boards are required for the thermometer, as was the case with the clock/calendar. Shown in Fig. 6 are the etching and drilling and components-placement guides for the solar-cell array board, while Fig. 7 illustrates the guides for the main and display boards.

Install all passive components on the main circuit board, taking care to observe the proper polarities of *C5* and *C6*. Install *D1* and *D2,* again observing polarities, with the cathodes in each case going to the pads labelled C. Sockets are recommended for the IC's, but they are not necessary. Install *VR1, VR2* and *CR1,* observing the lead designations shown in Fig. 5. Install the IC's last, observing the proper orientations and using accepted procedures for handling MOS devices.

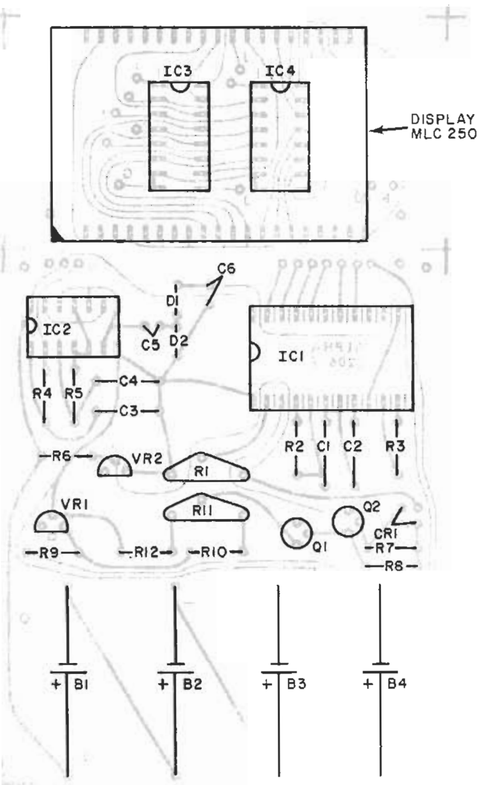
Transistor *Q2* can be installed directly on the board, while temperature-sensing transistor *Q1* can be mounted on the board, or it can be connected to the board via a twisted hookup wire pair if you wish to locate the sensor in a remote area.

Mount *IC3* and *IC4* on the display board as shown in Fig. 7. Install the LCD so that it straddles the two IC's, orienting it so that the small black wedge in the lower left aligns with the wedge on the board. Use a strip-type socket for the liquid crystal display.

Fasten together and interconnect the display and main board assemblies as described above for the clock/calendar.

Install the four NiCd cells as shown in Fig. 7, observing the proper polarities for the cells. Then charge the cells using the solar-cell array or a dc power supply adjusted to deliver 200 mA (about 1 hour and 20 minutes).

**Calibration.** Connect a voltmeter between pin 2 of *IC1* and circuit ground. Adjust *R1* for an indication of 0.46 volt for °C or 0.25 volt for °F. Use an accurate thermometer, positioned close to the main circuit board, to adjust *R11* so that both the thermometer and digital equivalent give the same indication. Allow the thermometer to stabilize be-



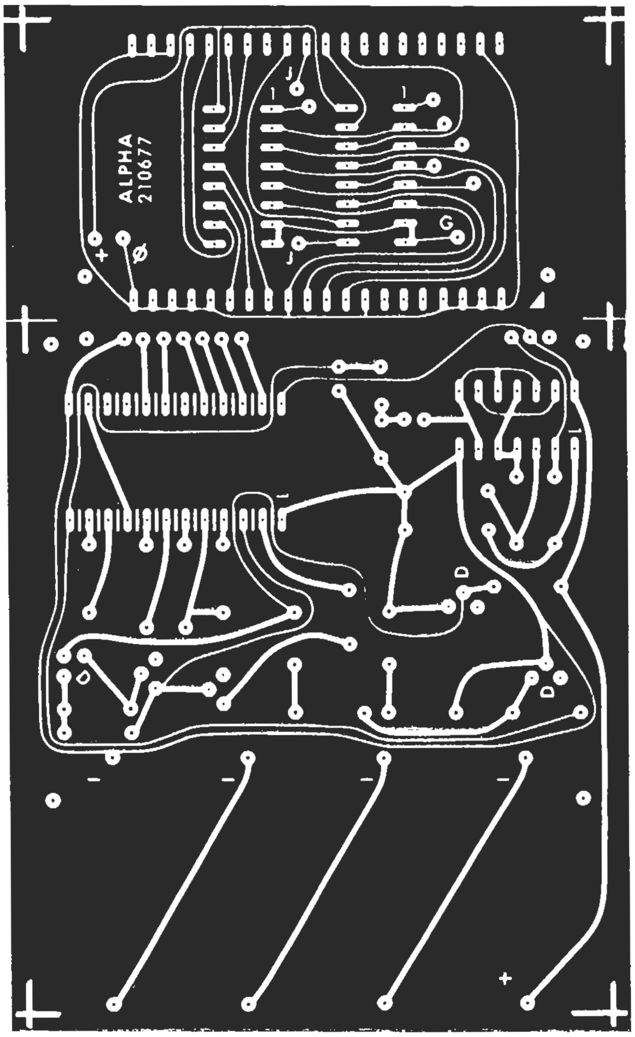


*Fig. 7. Thermometer foil pattern is at right. Component placement above. Note NiCd cells.*

fore performing this step. Note that potentiometer *R11* can be adjusted to obtain two "accurate" indications.

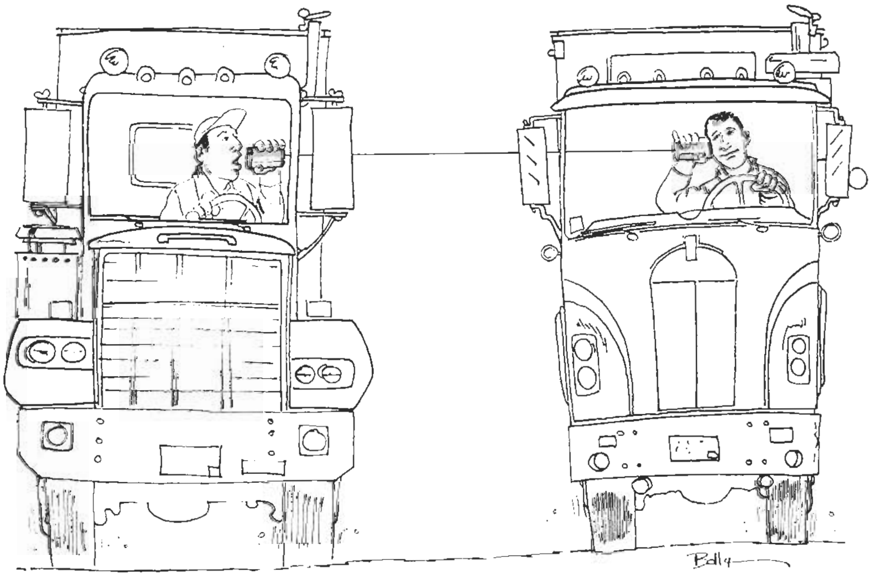
Once *R11* has been adjusted, warm up the case of *Q1* and observe the display. If the temperature indication goes up, *R11* is correctly adjusted. If the indicated temperature goes down as *Q1* is heated, change the adjustment of *R11* to the other "correct" position.

The solar-cell array can be mounted in a cutout in the upper surface of the enclosure selected to house the circuit. Alternatively, it can be located remotely and interconnected to the thermometer via a twisted-pair cable. The low temperature is determined by the liquid-crystal display and is approximately −5° C, while the upper limit is about 60° C.

Now you can let light charge the batteries of these and other projects to relieve you from dependence on electrical recharging or battery replacement. ◇

### KIT AVAILABILITY

The following are available from Alpha Electronics, P.O. Box 1005, Merritt Island, FL 32952 (Tel.: 305-632-5534): No. SPS-1 solar power supply kit at $45 plus $2 for postage and handling; No. SCK-1 solar clock/calendar kit at $79.95 plus $3.50 postage and handling; No. STK-1 solar thermometer kit at $89.95 plus $3.50 postage and handling. Also available separately: No. SC-50 solar cells at $1.25 each; No. SC-100 solar cells at $2.00 each; 110-mAh NiCd cells at $3.00 each; 200-mAh NiCd cells at $3.80 each; No. 290777 pc board for solar power supply and clock power supply for $5.00; No. 280777 main and display pc boards for clock/calendar for $8.00; No. 230677 pc board for thermometer power supply for $5.00; No. 220677 main and display pc boards for thermometer for $8.00.



*"Hey, big buddy. That's a big 10-4!"*

## SOLAR CONTROLLER

With the current interest in solar energy, the article entitled "Solar Controller" (December 1978, page 35) should be of interest to many readers. Further articles on this topic would also be appreciated.

Probably many readers have noticed that the control, labeled "Hysteresis" in Figs. 5

*continued on page 24*

## LETTERS

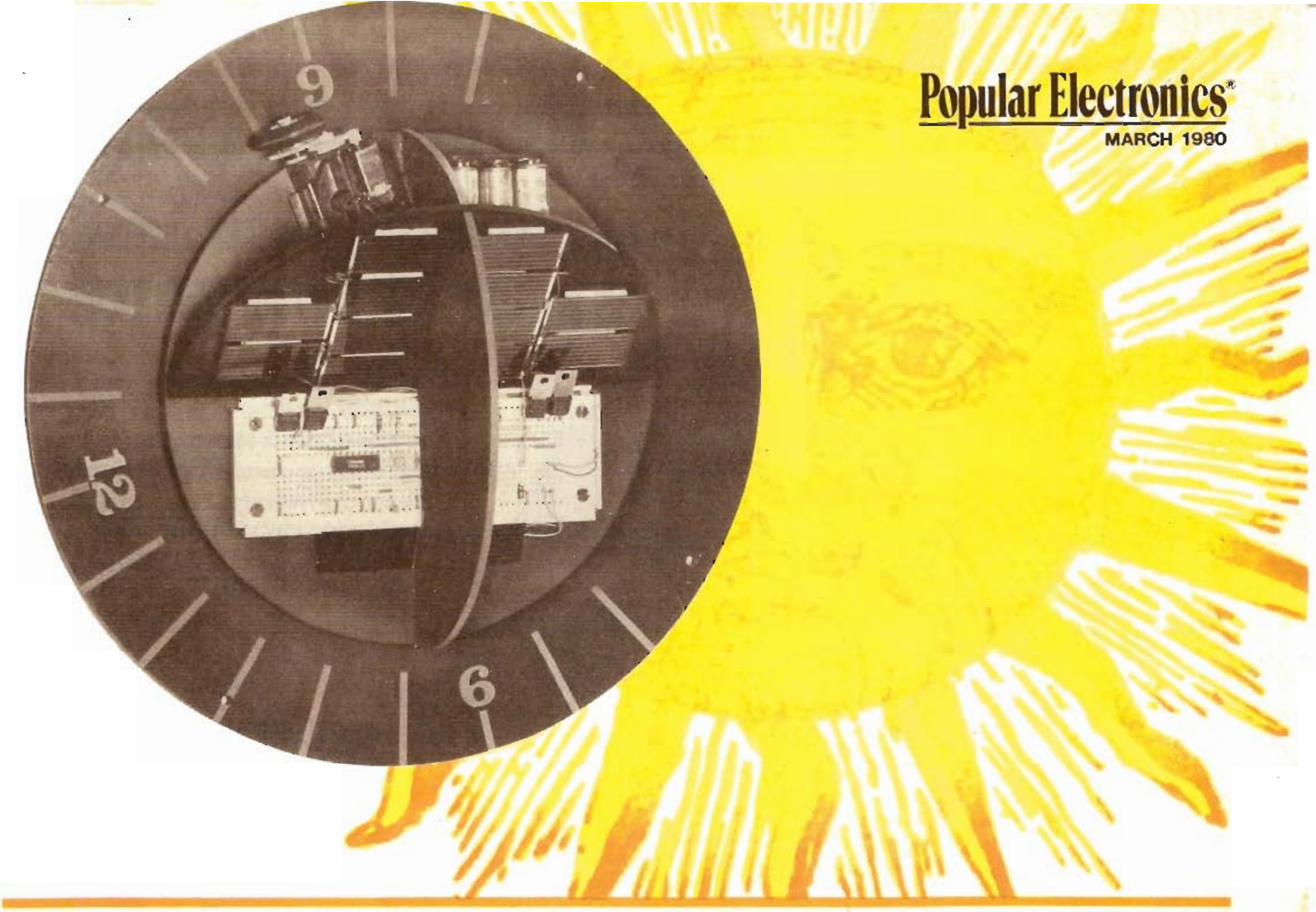
*continued from page 22*

and 7, is actually a "Trip Point" setting and that the circuit has no hysteresis. A suitable hysteresis effect can be achieved with the addition of two resistors (see diagram).

For a hysteresis of 5°F to 10°F, the resistance ratio would be on the order of $R_1 = 240\ R_2$. The exact values can be determined in the experiment Mr. Kreuter describes on page 37. The 47-ohm resistor should be increased somewhat to insure that minimum turn-on minus hysteresis is greater than zero. A change in the value of hysteresis will affect the calibration of the trip point.

CYRUS W. ROTON
*China Lake, CA*

Popular Electronics®
MARCH 1980



# BUILD A SOLAR POWERED SUNDIAL

BY WINN L. ROSCH & MARTIN BRADLEY WEINSTEIN

State-of-the-art sundial built around semiconductors follows the sun and indicates passing hours

LONG BEFORE the invention of the mechanical clock, man used a sundial to keep tabs on how much of his day was left, or approximately what time of day it was. Other than cosmetic changes, the main elements of a sundial have remained unchanged over the years.

Now, recent developments in techniques and devices—solar cell electricity generators, light-sensitive detectors and amplifiers, power semiconductors, rechargeable batteries and small dc motors—have made it possible to design a truly modern sundial. As described here, the sundial is a solar-powered, servo-controlled heliotropic (sun following) mechanism that not only indicates solar time, but also uses the sun as the source of its operating power.

Unlike the standard sundial, that has a fixed time scale and gnomon (shadow-casting element) to indicate the time, the solid-state sundial's gnomon is servo controlled to "follow" the sun, which it can do even under limited overcast conditions. The passing hours are indicated as the gnomon moves across a fixed time scale.

Besides being a conversation piece,

and a Science Fair project, the solar-powered sundial will teach you how servo systems operate, how light-sensitive circuits work, and the elements of solar-powered battery charging.

**How It Works.** As shown in Fig. 1, the opaque gnomon is placed between a pair of light-to-current converters so that if the gnomon is not pointing directly at the sun, one of the light detectors is shielded and the other receives more of the sun's light.

Since the outputs of the light-to-current converters used in this project reduce with increased illumination, they are cross-coupled, inverted and applied to a commutating bridge formed from four VMOS power FETs that simulate a double-pole, double-throw switch. This "switch," in turn, controls the operation of a small dc motor. When current flows one way through the dc motor, it rotates in one direction. When the current flow is reversed, so is the rotation. A small rubber wheel is attached to the dc motor shaft so as to rotate the bearing-mounted platform that carries the electronics and the gnomon.

Operation of the system shown in Fig. 1 is such that the motor-driven rotating platform is kept aligned and each light-to-current converter receives equal amounts of illumination. Thus, the gnomon will track the sun and can be used to indicate the passing hours on an arc scribed on the fixed baseplate.

Fourteen solar cells provide a charge for a set of nickel-cadmium cells that power the circuit and the dc motor. The solar array is tilted to face the sun at the local latitude angle so that the cells receive maximum light and thus generate maximum output.

**Circuit Operation.** The "heart" of the electronic sundial is the LM1890 Light-to-Current Converter shown in Fig. 2. This new IC is designed as a general-purpose building block for use in both visible light and infrared applications (its output peaks at 700 nm). The device includes a built-in light sensor, and provision is made to add fixed, light-independent comparator bias. The chip is monolithic, linear over several decades of light level, and can be operated with supply voltages down to 2.5 volts. The case is fabricated from clear plastic and has a recess for an optical filter. An internal zener diode regulator adds to the stability.

The outputs of both the light sensor and comparator can be converted into a voltage by using a resistor as the load and extracting the signal across this resistor.

As shown in Fig. 3, the light sensors are cross-coupled to the inputs of each comparator. Resistors *R1* and *R2* serve to convert the light-sensor output current to voltage. Since the comparator within the light sensor has an uncommitted collector output, resistors *R3* and *R4* are used to develop the output signal. Capacitors *C1* and *C2* combine to insert a pause (hysteresis) before allowing the circuit to change states. This prevents the rotating platform from moving in small erratic spurts.

The outputs of both light-sensing ICs are fed to inverters (in IC3) whose outputs are coupled to a motor control circuit formed by power FETs *Q1* through *Q4*. These FETs control the direction of current flow, hence rotation, of motor *M1*. This circuit then forms a basic light-sensitive servo system.

VMOS-type FETs are used because their very low gate current requirements, low voltage drop, and low "on" resistance make them directly compatible with CMOS inverter *IC3*. Assume that *IC3A* has a high output and *IC3B* a low output. In this case, both *Q1* and *Q4* will turn on and allow current to flow from the power supply through *Q1*, the motor and *Q4* to the return circuit. The motor then rotates.

When the output of *IC3B* is high, and that from *IC3A* is low, the current flow is through *Q2*, the motor and *Q3*. Since current flow through the motor is now reversed, it rotates the other way. When

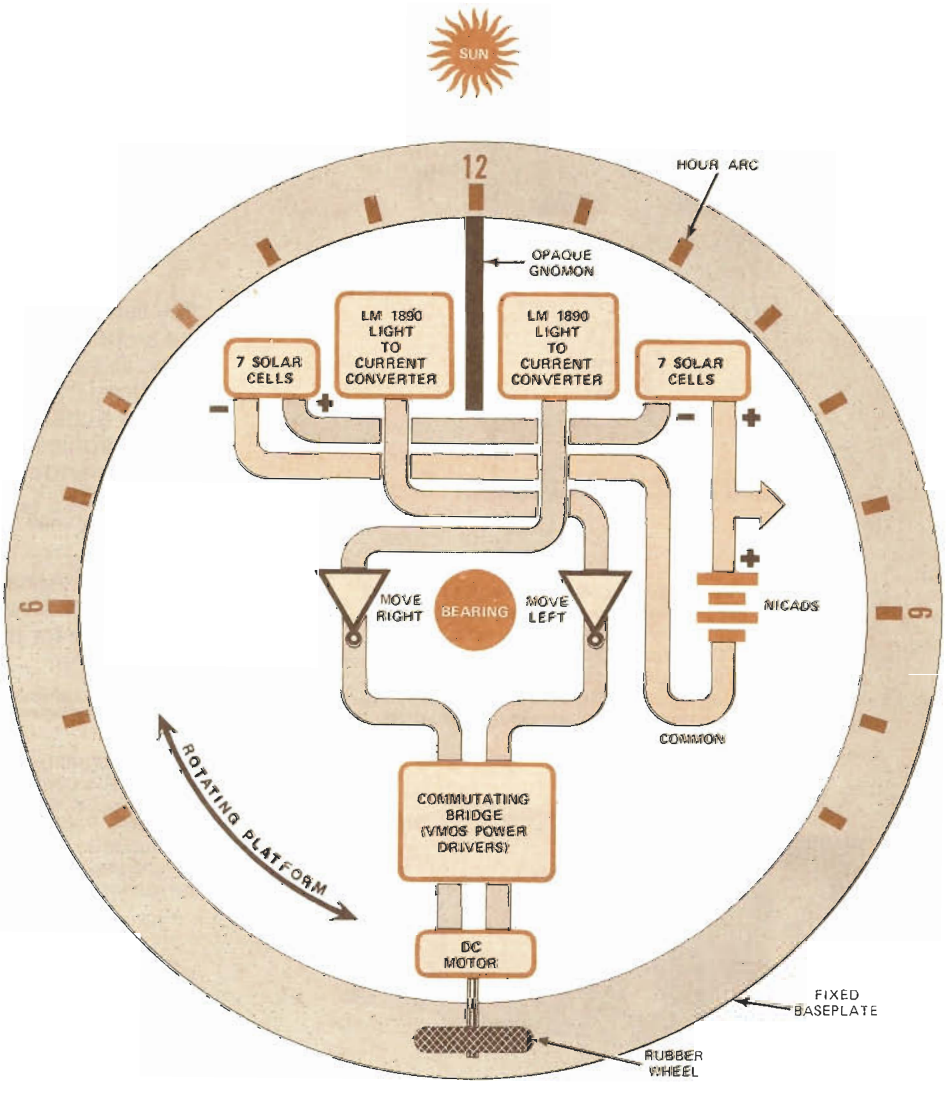


*Fig. 1. Diagram showing general operation of solid-state sundial. The servo loop keeps the gnomon (shadow caster) pointed at the sun.*

both light sensors receive equal illumination, the voltage generated across the FET "bridge" is equal and the motor remains stationary. When both light sensors are in the dark (nighttime), the voltage applied to the FETs is low, thus turning off the power semiconductors.

Power for the sundial comes from five AA-size NiCd cells that are recharged by 14 solar cells connected in series. Since each solar cell can generate 0.5 volt at 100 mA in bright sunshine, about 7 volts at 100 mA is available for the cells. If you live under a perpetual overcast, add an extra solar cell or two in series with the original 14. Diode *D1* is used to isolate the solar cells electrically from the battery.

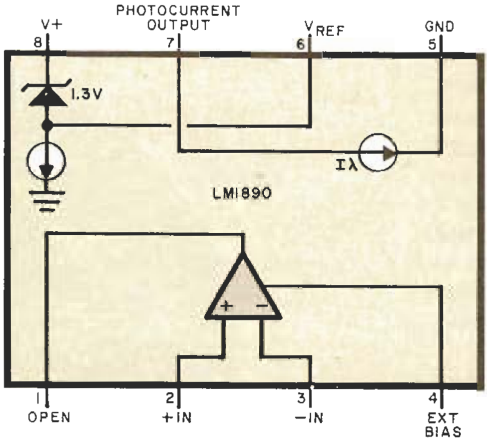


*Fig. 2. Pinout guide and internal schematic of the LM1890 light-to-current converter used in sundial.*

**Construction.** Other than the solar cells, battery and motor, all the electronic components can be mounted on a solderless breadboard. (This will be done later.) The physical placement of the two light-to-current converters *IC1* and *IC2*) is contingent on the particular design you select. However, two considerations should be observed: some form of shadow caster must be used between the two light sensors and the solar cells must be facing the sun at all times to generate their maximum output.

The sketches on succeeding pages show some ways that the sundial can be physically arranged. Final design is left up to the individual builder.

The following explanation covers the author's prototype and can provide some help in building your own version.

A photo of the prototype sundial is shown in Fig. 4. The 12" stationary baseplate and the 8" rotating platform were made of ⅛-inch plexiglass. In the prototype, a conventional bicycle ball-bearing race was used to mount the rotating platform in the center of the baseplate. A hole, large enough to form a press-fit over the bearing, was cut at the center of the moving platform. When fitted together, the moving platform rotated smoothly on the bearing.

In assembling the remainder of the sundial, use the following procedure: Before finally mounting the rotating platform to the baseplate, mount the solderless breadboard so that one long side is adjacent to, and just clearing, the bearing hole. Use four 4-40 screws and nuts to secure the breadboard in place.

Obtain another 8-inch diameter circle of plexiglass and cut it in half. One of these sections will form the solar-cell support while the other half will be used as the gnomon. Opaque the gnomon section with matte-black paint.

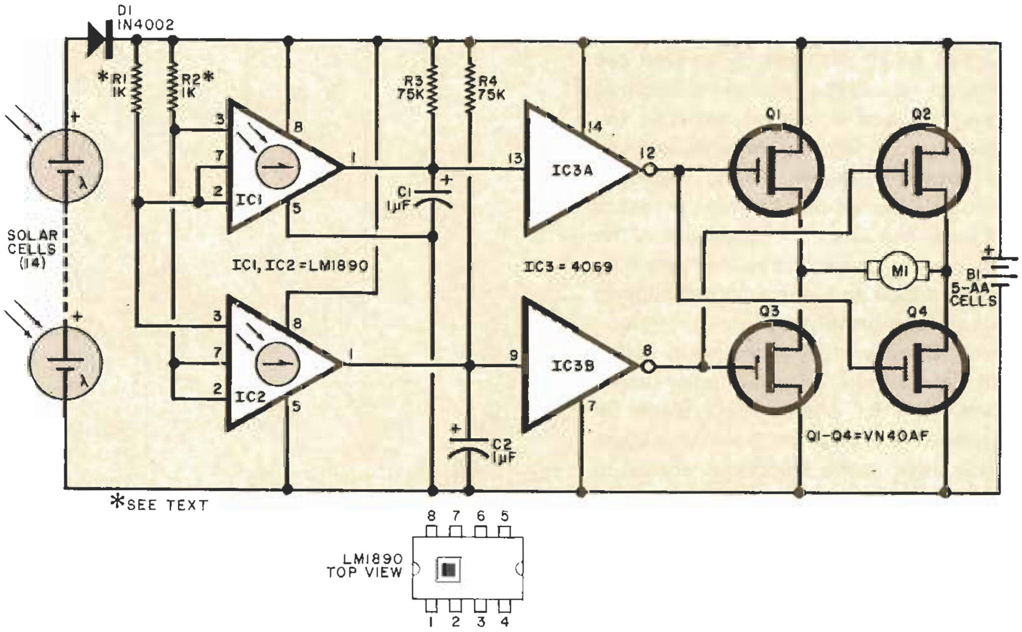


*Fig. 3. Light-sensitive circuits drive a commutation bridge formed from four VMOS devices. These act as a dpst switch to change the direction of current flow through the platform motor.*

**PARTS LIST**

B1—Five AA NiCd cells
C1,C2—1-µf, 25-V tantalum
D1—1N4002
IC1,IC2—LM1890 light-to-current converter (National)
IC3—CD4069 hex inverter
M1—1.5-to-3-V dc motor with reduction gear and rubber drive wheel
Q1 through Q4—VN40AF VMOS FET (Siliconix)
R1,R2—1000-ohm, ¼-watt resistor (see text)
R3,R4—75,000-ohm, ¼-watt resistor
Solar cells—0.5-volt, 100-mA (14) (Radio Shack 276-120 or similar)
Misc.—Solderless breadboard (CSC Experimentor 300), battery holder, silicone adhesive, double-sided pressure-sensitive tape, masking tape, transparent bubble dome, opaque plastic sheet or plexiglass sheet and black paint, bearing, interconnecting leads, mounting hardware, etc.

Hold the solar-cell support section against the back of the solderless breadboard closest to the bearing hole. You may have to make a small cutout so that the solar-cell support will clear the bearing. Tilt the support to the approximate latitude of your location. Now, cut a wedge shape out of the gnomon half circle to hold the solar-cell support at the latitude angle. The latitude wedge should be at right angles to the solar-cell support.

Using epoxy or plastic cement, carefully affix the solar-cell support to the platform and to the latitude wedge, and the bottom of the latitude wedge to the platform. Allow the cement to dry.

The remaining section of the gnomon half circle will form a continuation of the latitude wedge and is mounted at right angles to the solar-cell support. After cutting a slot large enough to clear the solderless breadboard, and possibly a slot for the bearing, cement the opaque gnomon in place.

The mechanical construction is now complete. Allow all cement to dry. Make sure that the gnomon (and if desired, the remainder of the plastic) is opaque and that the platform rotates easily.

Six solar cells are mounted on one side of the support and another six on the other side of the gnomon. Double-sided tape, or silicone adhesive can be used to mount the cells. A seventh cell on each side of the gnomon is mounted (using silicone adhesive) between the front of the solderless breadboard and the rotating platform. These two cells must be at the same angle as the rest of the solar-cell array. (The locations of the two seventh cells are necessitated by lack of space on the regular cell support piece in the prototype.)

All 14 cells are connected in series and terminated in a pair of color-coded leads—red for positive and black for negative. The ends of these two leads are brought to the solderless socket to form the "plus" and "minus" lines.

As shown in Fig. 4, the battery holder is cemented to the platform "under" the solar-cell support. Leads to the battery are coded with the same colors as those to the solar cell array.

The platform positioning motor can be taken from a battery-operated toy car and will often have its own reduction gear and rubber wheel. Such 1.5-to-3-volt dc motors can be found in many discarded toys or can be purchased at most hobby stores.

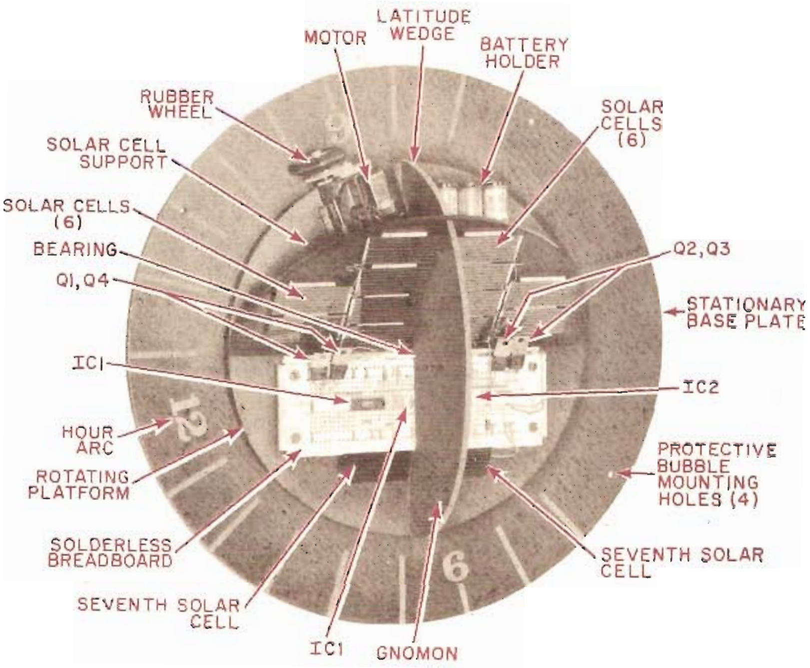
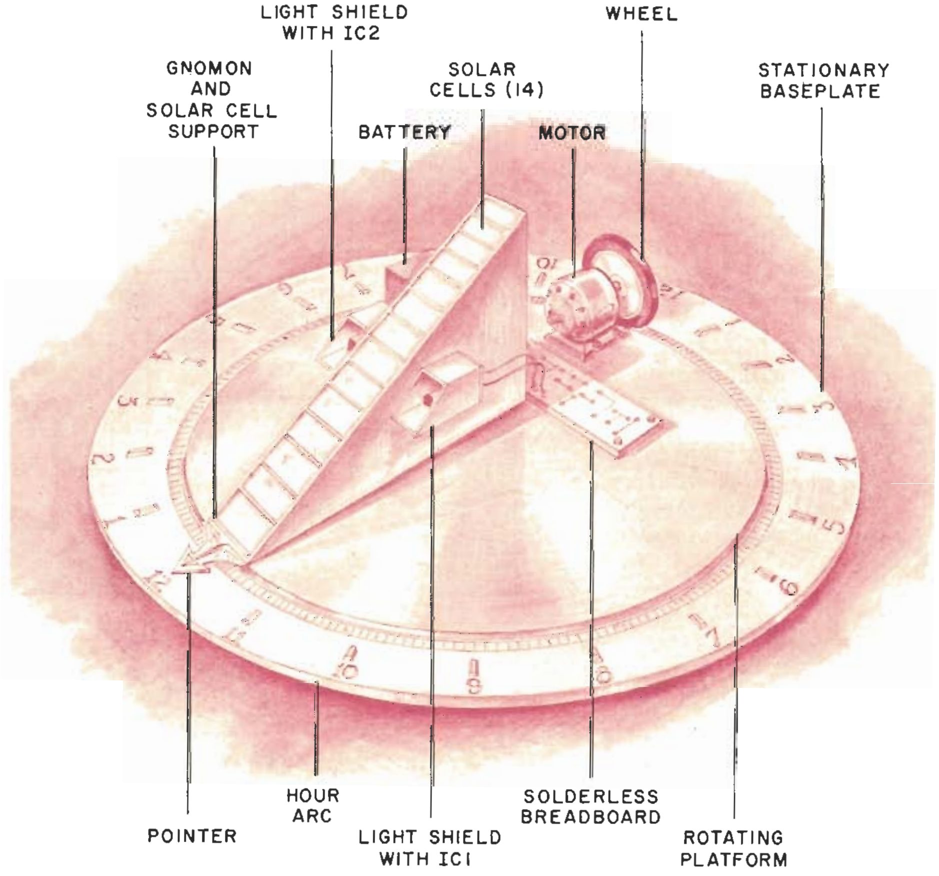


*Fig. 4. Photo of the author's prototype sundial showing construction details. Any configuration can be used as long as the two light-sensitive ICs have the gnomon between them.*

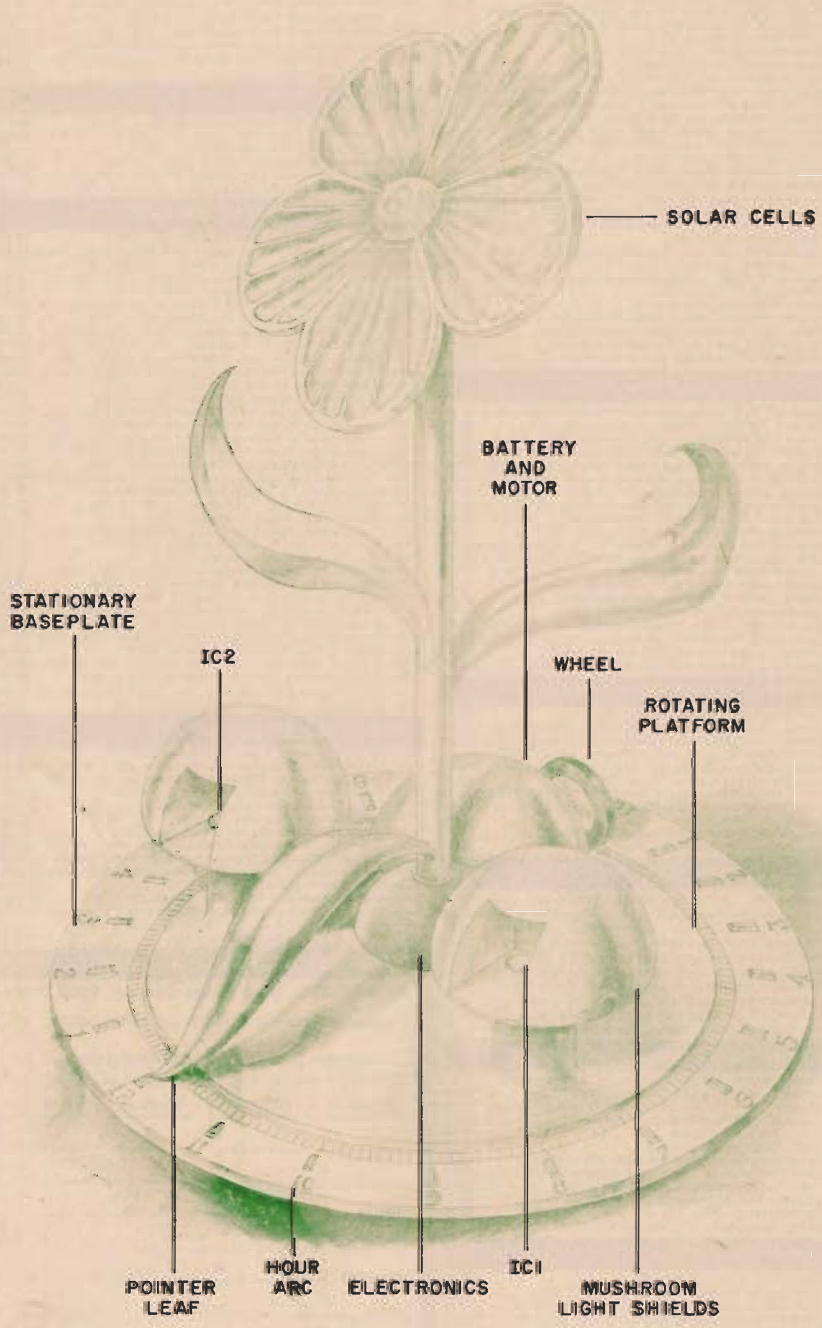


*This artist's conception of a possible sundial design shows the solar cells actually mounted on the gnomon.*

The motor is attached to the rotating platform so that the wheel makes contact with the fixed baseplate. If the wheel is large, the motor assembly can be mounted on a block. The two leads from the motor are also brought to the solderless breadboard.

**Final Assembly.** All that remains now is to build the circuit of Fig. 3 on the solderless breadboard and make the necessary connections between the circuit board, battery, solar-cell array and servo motor.

Install *IC1* and *IC2* on the solderless breadboard, one on each side and as close to the gnomon as possible. Refer to the top view of this IC shown in Fig. 3 to determine the correct pin-out. The IC has a cutout at each end, and only the location of the indentation on the upper surface of the chip correctly identifies the position.



*In this design, a flower and mushrooms made of plastic hold the solar cells and light sensors with a leaf for a pointer.*

None of the remainder of the circuitry is critical, so conventional solderless breadboard wiring practice can be used. In the prototype, FETs *Q1* and *Q4* were located on one side of the breadboard and *Q2* and *Q3* on the other side.

Because room illumination is not as bright as sunshine, increase system sensitivity by changing the values of *R1* and *R2* to approximately 33,000 ohms. For outdoor use, re-install the 1000-ohm resistors specified in the Parts List.

After all wiring is complete, and the circuit checked, insert the fully charged battery in the holder. The mechanism should go into immediate operation if a bright light is played across the gnomon so that the latter's shadow falls on one or the other light sensors (*IC1* or *IC2*). The mechanism should try to align itself with the gnomon pointing at the light source. If the system tries to orient itself *away* from the light source, reverse the two leads to the dc motor.

If the platform bearing is too smooth, inertia may cause the platform to overshoot and cause mechanical oscillation as the system "hunts" for the center of the light source. In this case, cement a small pad of cotton to the underside of the platform to act as a gentle friction brake between the moving and stationary parts.

A dc voltmeter can be used to check operation of the solar-cell array as a bright light is played across the solar cells. Make sure that the voltage change occurs on the circuit side of *D1*. If not, then *D1* should be reversed. Keep in mind that the solar cell output will greatly increase when the array is exposed to bright sunlight.

**Calibration.** The sundial is calibrated by placing it outdoors on a flat surface so that it is exposed to the sun all day. Don't forget to use the proper values of *R1* and *R2*. If the batteries are charged, the platform should rotate to point the gnomon at the sun.

Using a watch as the time reference, at each hour, mark the point on the hour arc that the gnomon points to at that time. If you are north of the equator, at 12 noon, the gnomon should be pointing south. This is the "12" mark, and on the opposite side of the baseplate place an arrow to indicate north. This arrow can be used to orient the sundial if it is

# SOLAR-POWERED SUNDIAL

### CORRECTION FACTORS FOR SOLAR TO SIDEREAL TIME

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Jan. | 1 | + 3.5 | Feb. | 1 | +13.4 | Mar. | 1 | +12.5 | Apr. | 1 | + 4.0 |
| | 6 | + 5.8 | | 6 | +14.1 | | 6 | +11.4 | | 6 | + 2.6 |
| | 11 | + 7.9 | | 11 | +14.3 | | 11 | +10.2 | | 11 | + 1.2 |
| | 16 | + 9.8 | | 16 | +14.2 | | 16 | + 8.8 | | 16 | − 0.1 |
| | 21 | +11.3 | | 21 | +13.7 | | 21 | + 7.4 | | 21 | − 1.2 |
| | 26 | +12.6 | | 26 | +13.0 | | 26 | + 5.8 | | 26 | − 2.1 |
| May | 1 | − 2.9 | June | 1 | − 2.3 | July | 1 | + 3.9 | Aug. | 1 | + 6.3 |
| | 6 | − 3.4 | | 6 | − 1.5 | | 6 | + 4.6 | | 6 | + 5.8 |
| | 11 | − 3.6 | | 11 | − 0.6 | | 11 | + 5.3 | | 11 | + 5.2 |
| | 16 | − 3.7 | | 16 | + 0.4 | | 16 | + 5.9 | | 16 | + 4.3 |
| | 21 | − 3.5 | | 21 | + 1.6 | | 21 | + 6.2 | | 21 | + 3.2 |
| | 26 | − 3.1 | | 26 | + 2.6 | | 26 | + 6.4 | | 26 | + 1.9 |
| Sept. | 1 | + 0.1 | Oct. | 1 | −10.2 | Nov. | 1 | −16.4 | Dec. | 1 | −11.0 |
| | 6 | − 1.5 | | 6 | −11.7 | | 6 | −16.3 | | 6 | − 9.0 |
| | 11 | − 3.2 | | 11 | −13.1 | | 11 | −16.0 | | 11 | − 6.9 |
| | 16 | − 5.0 | | 16 | −14.3 | | 16 | −15.2 | | 16 | − 4.5 |
| | 21 | − 6.8 | | 21 | −15.2 | | 21 | −14.2 | | 21 | − 2.0 |
| | 26 | − 8.5 | | 26 | −15.9 | | 26 | −12.8 | | 26 | + 0.4 |

*Source Sundials by Roy K Marshall, MacMillan Co., New York 1963*

moved to another location. Simply point the arrow north and the hour arc is correctly positioned.

A sundial keeps solar time, which may differ from "clock" time by as much as 16 minutes either way, depending on the date. The Table gives correction factors for sidereal time. For example, on March 1, the sundial will be 12.5 minutes "fast," while on April 16, the dial will be almost correct. On November 1, the sundial will be 16.4 minutes "slow."

The hour "tics" and numerals can be painted on the hour arc, or press-on type may be used. Weatherproof these indications for protection.

Once the hours have been marked, check that the dc voltage output of the solar-cell array is slightly higher than the battery voltage so that charging can take place.

A transparent bubble dome can be fitted over the moving platform, or the complete assembly, to provide weather protection and to create a greenhouse effect to maintain a reasonable internal temperature for the circuit. The bubble dome can be secured as desired. ◇

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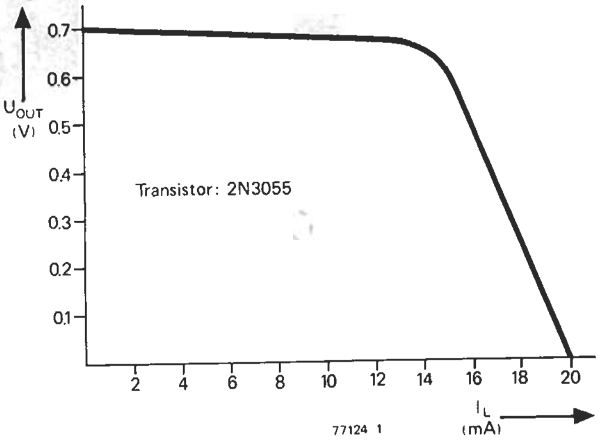
# transistor solar cell

**H. Januschkowetz**

1



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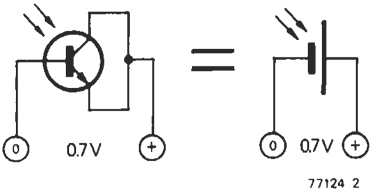


Most amateur constructors will have one or two burnt out power transistors lying about in their junk box. If at least one of the junctions is still intact, the transistor can be converted to a solar cell by filing or sawing off the top of the case to expose the chip.

In strong sunlight a 2N3055, for example, will generate about 0.7 V at currents of up to 20 mA. The graph shows output voltage plotted against load current. As the area of the silicon chip is small compared to a normal solar cell a magnifying glass may be used to focus light onto the junction and so increase the output current. However, this is not to be recommended in very strong sunlight or the junction may be destroyed!

If a good transistor is used then the output current may be doubled by connecting the collector-base and emitter-base junction in parallel, as shown in the diagram. This should not be done with faulty transistors, however, since if the faulty junction is short-circuit it would short the output of the solar cell.

**Warning:** It is not advisable to use old Germanium power transistors, since these may contain highly poisonous substances. However, a major semiconductor manufacturer has assured us that the more modern silicon devices, such as the 2N3055, are completely safe.

# Solar Controller

Build this unit to control your solar collection system. Developed jointly by the staffs of ETI and Markko Construction, this differential temperature controller is suitable for space, water or swimming pool heating control.

FOR THOSE PEOPLE who really are going to get into the sun, we present the ETI Differential Temperature Controller. Its main function is to monitor the temperatures of collector panel and storage tank, and turn on or off the pump which circulates the fluid.

Turn-on differential is switch selectable from 4 degrees C to 16 degrees C and turn off differential is preset to 2 degrees C.

Additionally the unit incorporates two limit circuits to detect when the system is above or below safe temperatures, activating the pump or separate valves for protection. Alternatively, one of the limit detectors may be used to switch other conventional heating systems in or out of action.

Conventional relay outputs (2.5A) and also solid state triac switch outputs (5A) are outlined. Heavier loads could be cattered to with external relay(s).

## DECIDE ON YOUR MODEL

A variety of different options is possible; what kind of outputs to use, what limits to detect and so on, see the separate box titled "Options". In addition, we have provided a switched selection of turn-on differentials, a variety which may not be neccesary in your application. Swimming pool heater builders will also want to read how to build the unit with lower on and off differentials, see "How It Works" and "Calibration" for details of selecting R8 and R9.

## CONSTRUCTION AND TESTING

Once the options have been decided upon, construction is quite straightforward. The mechanical details of the box should be settled first, all holes drilled etc., paying particular attention to the holes for mounting the board assembly, and the triac (more below). The board will be mounted in the box

*text continues on page 34 . . .*

# Solar Controller

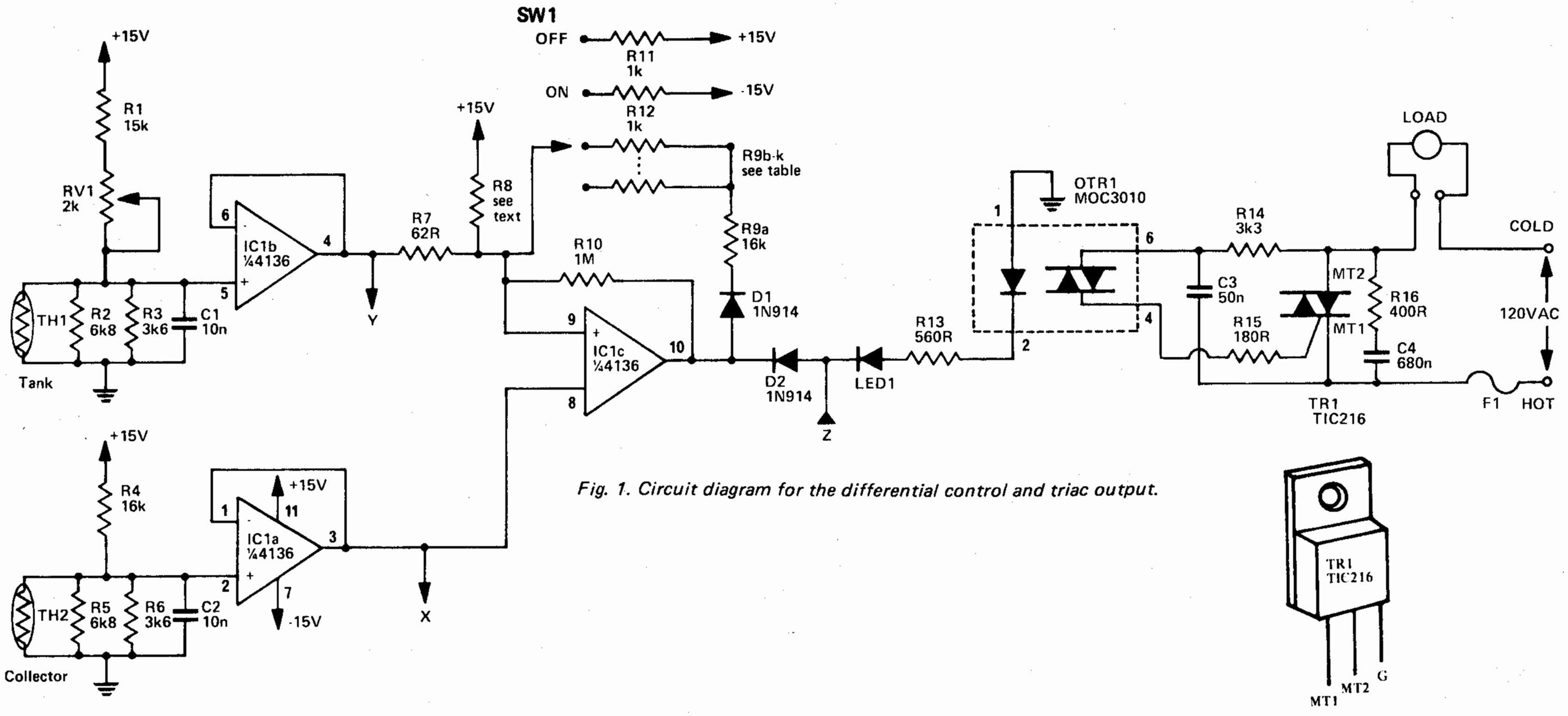
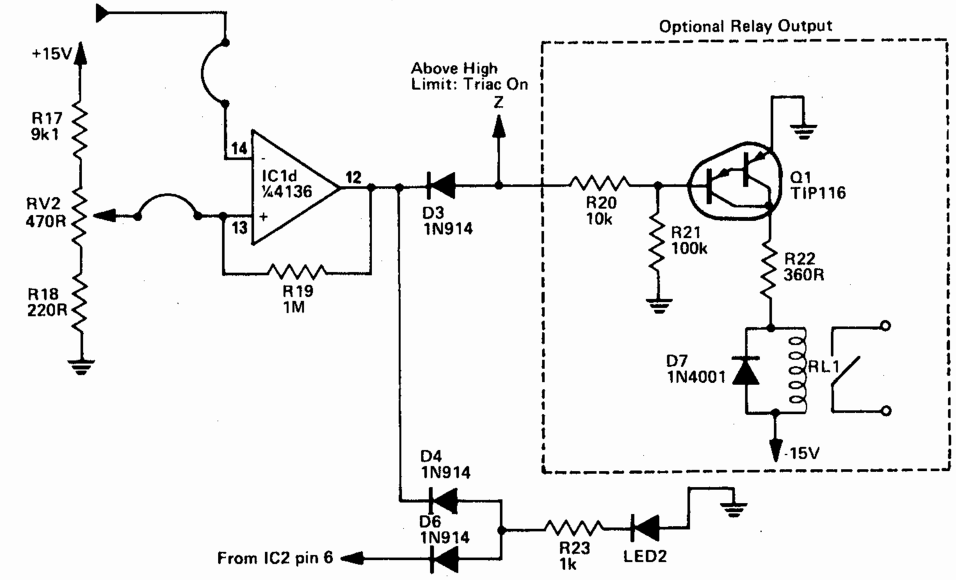


*Fig. 1. Circuit diagram for the differential control and triac output.*

*Fig. 2. High limit circuitry using IC1d.*



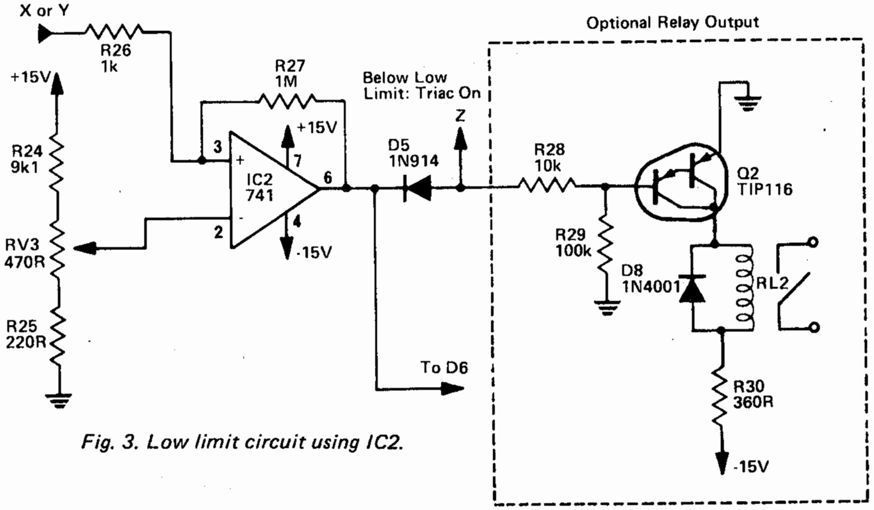


*Fig. 3. Low limit circuit using IC2.*

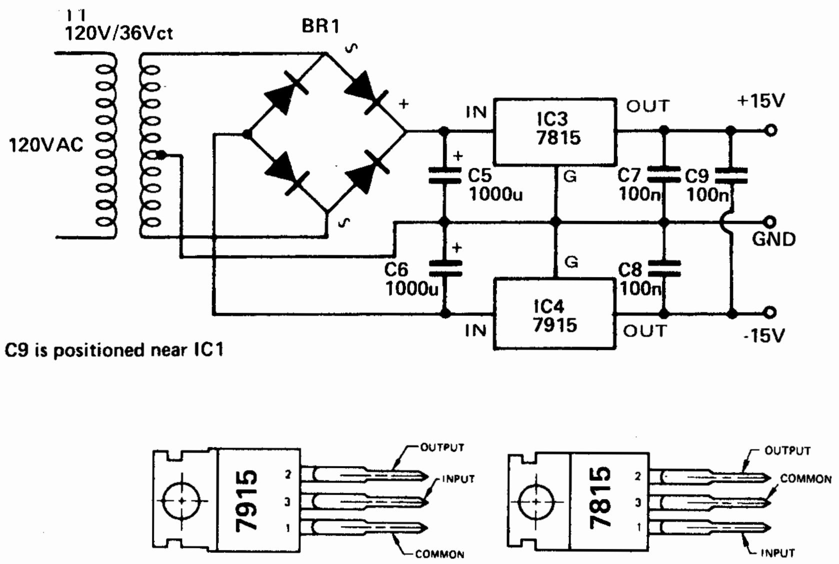


*Fig. 5. Circuit diagram of the power supply.*

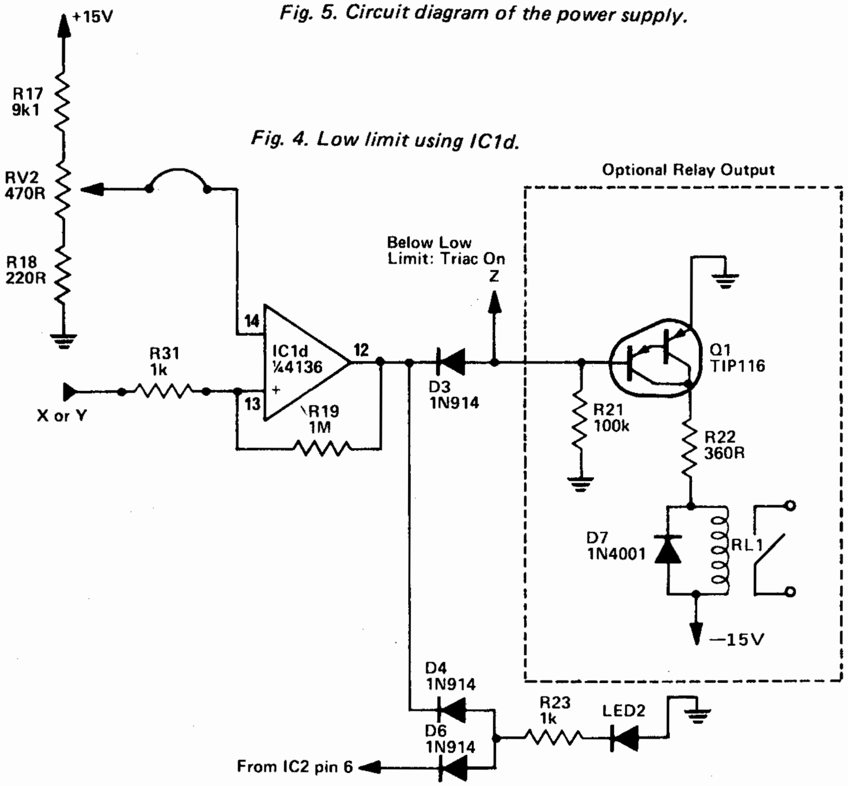


*Fig. 4. Low limit using IC1d.*

## HOW IT WORKS

A straightforward approach to understanding this circuit is to see how each part of the circuit forms a part of the overall system. For this purpose let us break down the system into "input" (thermistors and IC1a and b) "information processing" (IC1c, d and IC2) and "output drivers" (OTR1, TR1, and the sections marked "Optional Relay Output"). In this way the constructor can see how the various sections fit together, and also extract portions to use in other situations.

### INPUT

TH1 is a Texas Instruments TSP102, a sensor whose resistance varies as its temperature increases. When placed in parallel with a 2370 ohm resistor the combined resistance versus temperature curve is very linear. In fact it is approximately 614.3 ohms at 0 degrees (all temperatures in Celsius), rising by 3.578 ohms per degree. Over the range 0 to 100 degrees the deviation of an actual device is less than ½ degree. This linearity is important as we shall see.

The temperature sensing circuits consist of voltage dividers, in one case R1, RV1 and TH1 with R2 and 3 for the storage tank, and for the collector R4 with TH2, R5 and R6. Since the thermistors with parallel resistors are going to be in the range 600R to 1k, the voltages at IC1 pins 5 and 2 are going to be near .7V all the time. Thus R1 and RV1, or R4, may be regarded as supplying a constant current of 14.3V/16k (.894mA) to their respective thermistor circuits. This in turn simplifies the calculations because now the input voltages to IC1a and b are .614 x .894 = 594mV plus T(degrees C) x 3.578 x .894 (or 3.2mV per degree). If you're wondering why we chose these odd numbers, it's just to get convenient resistor sizes.

Manufacturing differences between thermistors are such as to multiply the whole value by some constant, so that a thermistor with a value say 5% below the specified value would measure 583 + 3.4 x T ohms. Adjustment of RV1 varies the current to one of the thermistors to compensate for this kind of error.

The rest of the input circuit is IC1a and b, connected as voltage followers, that is the output of each equals its input voltage. This is done so that the these voltages which carry the temperature information are not affected by later stages of the circuit.

### INFORMATION PROCESSING

The main information processing is done by IC1c and resistors R7 to 9. The idea is to compare the two input temperatures, and under certain conditions turn the power output (to pump) on or off. In this circuit, if IC1c output is "low" (−12V) the pump is turned on, if high (+12V) then it is off.

Let us start with the solar collector panel much hotter than the storage tank. The voltage at IC1 pin 9 will be lower than at pin 8 (initially imagine that R8 is not there). Thus the output of IC1c will be low — pump on. Gradually the heat is transfered to the tank, the tank warms while the collector cools. Voltage at pin 9 increases, and at pin 8 decreases.

If R7 and R8 had no effect then as pin 9 increased past pin 8 then the output of IC1c would switch from down to up, turning off the pump. However we wish this to occur not at the same temperature but when the collector is still 2 degrees hotter than the tank, so R7 and R8 are incorporated to "add" 2 degrees to the tank temperature signal, before the comparison is made. If R8 is 140k, about 0.1mA is supplied through R7, causing the required offset of about 6.4mV. R8 with R7 are also used to compensate for non-ideal op amps IC1a,b and c as outlined under "calibration".

supported on one edge by being soldered to a special barrier strip which has protruding tags, and on the other side by a bolt and spacer in the hole (between D7 and IC4). Thus either drill the holes in the box after soldering on the barrier strip, or vice versa paying extra attention to the position of the strip when attaching it to the board.

Next install the components in the board, using sockets for the IC1 and IC2. Before inserting IC1 and R8 read the section on calibration.

Note which components are not on the board, R9b-k and R11 and R12 are mounted on the switch, while LED1 and LED2 are later to be epoxied onto the box. Do not wire up the 120V AC connections yet (screw terminals 1-6). At this stage (board still out of box) you can hook up the transformer and check the operation of the power supply and most of the circuitry with a voltmeter. The relays can be seen and heard operating, and LED2 seen while twiddling RV1 and RV2, while LED1 will operate if the sensors are individually heated or cooled.

## TRIAC MOUNTING

To dissipate the heat from the triac it is mounted on the back of the box under the board. (see photo) When you are ready to test this circuitry, try out the positioning of the triac by inserting it into the board (do not solder), and gently bend it back and position the board in the box. Locate and drill the hole for the triac mounting screw. Again check the position of all pieces. You can now solder the triac and test the board out of the box. The triac will not need the heat sinking of the metal box unless driving a heavy load.

To actually test the operation of the triac wire up a load, say a 100W light bulb, plus fuse, and AC supply (120V!) as detailed in the component positioning diagram (Fig 7.) The bulb should operate as the sensors are heated and cooled appropriately.

If all is well proceed to the actual installation of the board into the box,

*HOW IT WORKS . . .continued.*

OK, continuing with the story, the collector temperature had sunk to the point where the pump turned off, IC1c output high. Now we don't want the pump to turn on again until the collector reaches a significantly higher temperature than the tank, perhaps 4 to 16 degrees. This is accomplished by R9a to k. When IC1c output is high, D1 conducts, feeding extra current through R9a and one of R9b - k selected by the switch SW1, finally through R7, again "adding" to the temperature signal from the tank. If the added temperature is called Ta, then the appropriate feedback loop resistor value is R9 = 232/Ta in kohms. Note that this includes R9a, and does not take into account the 2 degrees from R8. So for example, for a turn-on differential of 4 degrees, Ta = 2 degrees, the required value of R9 is 116k, thus R9b is 100k. See table 2.

It can now be seen that using linear sensors results in the capability to easily add on a desired amount of temperature to a particular signal.

If the selector switch is in the ON (or OFF) position, a relatively large current is provided to R7 via R12 (or R11) from −15V (+15V). This subtracts (or adds) a large voltage representing a large temperature, making the tank seem to IC1c very cold (or hot) thereby forcing the pump on (or off). R10 is incorporated to provide some small amount of hysteresis around IC1c to make sure that the transitions from high to low, or low to high, are sharp with no indecision when the two input voltages are very close.

### LIMITS

The other intelligence section or decision making is done by IC1d and IC2. Each compares an input voltage, one of the temperature signals, to a reference preset on trim pots RV2 or RV3. In the case of IC1d used as a high limit (temperature too hot), IC1d's output is caused to go low ("on" in our application) if say the signal at X (collector) exceeds a certain value, corresponding perhaps to near boiling.

Similarly, functioning as a low limit the collector temperature might be monitored (point X) and below a certain point near freezing the pump may be switched on to warm the collector up. Or set at a higher level, the low limit circuit may be used to sense point Y, tank temperature, to bring an electric heater into action if the solar system is not providing adequate heat. See discussion of options to find out how these connections are made.

Again the function of R19 and R27 is to provide hysteresis for IC1d and IC2 to ensure clean turn-on or off for these stages.

### OUTPUT STAGES

Two different sorts of output are used, both a triac "switch" and a relay style output.

As shown in the circuit diagram and pc board overlay, the main circuit output IC1c connects to the triac output, while the high or low limits may each be connected either to the same output (via point Z) or to their own separate relays ("Optional Relay Output"). Note that both styles of output are "on" when the input to them is low. Diodes D2, D3 and D5 are arranged so that if all are connected at Z, point Z will be pulled low if any of IC1c, d or IC2 outputs are low. This would be the case if these were all to activate the triac, and no relays were used for example. If three independent outputs were required then simply do not connect D2, 3 and 5 at Z, and each functions separately.

### TRIAC OUTPUT

The triac output operates if the cathode of the led (the "bar" end) is pulled low. This causes the led within optical triac isolator OTR1 to glow, (the led, LED1, will glow too, indicating output on.) turning on OTR1's output triac. This in turn feeds current to the gate of TR1 switching it on. Components R14 with C3 and R16 with C4 are to allow OTR1 and TR1 to operate with inductive loads, and are known as snubber networks.

If these are omitted and an inductive load (such as a pump) is connected, TR1 will be unable to turn off, even though no current may be arriving at the gate via R15. This is because the point of the AC cycle when TR1 is trying to turn off is when zero current is passing through, which with an inductive load will be a time when there is still voltage across the triac. In attempting to turn off, the voltage across TR1 suddenly rises. Due essentially to capacitive effects within the triac between MT2 and the gate, some current appears to flow at the gate keeping the triac on. This of course continues to occur and the triac never turns off. The solution is the snubber network to slow the rate of rise of voltage across MT1 – MT2. This is a compromise however, since now even with the triac off some current flows through the circuit via R16 and C4, and R14 and C3, but this is negligible in most applications. It is enough though to turn on very small loads, and thus if a noninductive load is to be attached these components may be omitted. (Just leave out C3, C4 and R16 replacing R14 by a wire.) Also the snubber components were chosen for worst case situations, and values allowing less "leakage" may be used with smaller inductive loads.

### RELAY OUTPUT

Both relay outputs are essentially identical. If the input to R20 is low, Q1 will turn on, feeding current through R22 and RL1 which of course turns RL1 on. D7 is placed across the relay coil to conduct when Q1 turns off and RL1 discharges its stored magnetic energy as a negative pulse, which could otherwise damage Q1.

D4 and D6 combine the signals from the high and low limits, turning on LED2 if either limit is passed.

### POWER SUPPLY

A very simple design, T1 feeds a full wave rectifier bridge, whose output is about plus and minus 24V. This is smoothed by C5 and C6, and regulated to plus and minus 15V by IC3 and IC4.

the triac onto the back, switch and leds onto the side and finally the wiring of the AC connections.

To mount the triac, insert and epoxy a nylon bolt to the triac so that the threaded end will poke through the hole in the box. Install a mica insulator, and coat with silicone heat sink compound between the triac and the box when finally installing board and triac into the box. Last, affix the nut on the other end of the nylon screw. NOTE: THE TRIAC MUST BE INSTALLED WITH THE MICA INSULATOR AND NYLON SCREW SINCE THE METAL BACK OF THE TRIAC WILL BE LIVE, AND MUST NOT TOUCH THE METAL BOX.

Also note that the connections to RL1's output are not made on the foil pattern to allow your own choice of hook-up, which should be done before installation in the box.

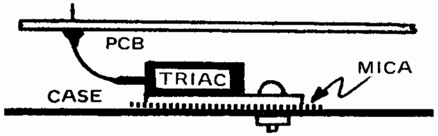
Next step . . . calibration.

## CALIBRATION

Three calibration operations are required. The first is a test on IC1, and must be done before the circuit is assembled.

CHECKING IC1: On a breadboard, or by other quick means, assemble the "Test Circuit" of Fig. 6., omitting Radd.

Ensure that no oscillation can occur by putting 100n capacitors from pins 7 and 11 to ground, close to the IC. (This can be checked on a scope if desired.) This circuit simulates the operation of IC1 in the controller, and is used to determine the overall effect of the offset voltages of each op-amp. The offset voltage is the amount by which the op-amp's input stage is off when it thinks that the two input voltages are the same, typically less than 5mV. We will worry about anything greater than say 1mV, since that represents about 1/3 degree.



Now, using a sensitive voltmeter, measure the voltage Vadd. Look at table 1, in the "2 degree" column and select the appropriate resistor for use as R8. If you put this in the test circuit as Radd the output to the meter should now read 6.4mV corresponding to the 2 degree offset for turn off (see How It Works). If zero differential is desired select R8 from the other column of table 1.

ADJUSTMENT OF RV1: This adjustment compensates for variations between TH1 and TH2 and associated circuitry. Bolt or attach the two sensors together and allow them to reach the same temperature, say 20 degrees C. Now adjust RV1 until the voltage between the two thermistors (screws 7 and 9, or IC1 pins 2 and 5) is less than 1mV.

ADJUSTMENT OF RV2 AND RV3: Two methods may be employed. Heat up the appropriate sensor to the desired limit temperature, then adjust RV2 or 3 to the point where the relay concerned just turns on. Or figure out the voltage which represents your desired temperature, and set the wiper of the trimmer to that voltage. This second method will not be as accurate as the first.

## OPTIONS

A number of sets of choices must be decided upon. First, how many, and what kind of limits are desired? Secondly, which output circuit is each signal (differential output, and one or two limit outputs) to be connected to? It would be a good idea to check off one from each group of:

a)First Limit

– IC1d as low limit – as shown on overlay Fig. 7.

OR IC1d as high limit. Remove R31 and jumper from RV2 to IC1 pin 14. Replace these with a jumper from RV2 to IC1 pin 13, and a jumper from pin 14 to X.

(b) Tank or Collector for above?

– IC1d monitors collector (point X) as shown in Fig. 7.

OR IC1d monitors tank, connect R31 (or jumper in the case of high limit) to Y instead of X.

(c) Second Limit

– Additional limit not required, omit all components of Fig 3 (IC2 etc).

OR: IC2 as low limit: as shown on overlay Fig. 7.

OR: IC2 as high limit: This is possible only by cutting the pc tracks to IC2 pins 2 and 3, and changing over the connections, ie: RV3 to pin 3, R26 (may be replaced by jumper as in Fig. 2 in this case) to pin 2. R27 still goes to pin 3.

(d) Tank or Collector for above?

– IC2 monitors collector, as shown on overlay Fig. 7.

OR IC2 monitors tank, connect R26 (or jumper, high limit) to Y instead of X.

(e) Output Connections

Differential circuit drives triac, while each limit drives relay, as shown on Fig. 7. "To point Z" location on each limit is not connected to point Z of Fig. 1.

Other Output Configurations:

(i) Triac driven by IC1c plus:
  IC1d: install jumper from D3/R20 to Z.
  OR IC2: install jumper A (Fig. 8) from D5/R28 to Z.
  OR both: install both.

(ii) RL1 driven by:
  IC1d plus:
  IC2: connect jumper from anode of D5 to anode of D3 (no connection to Z) (B on Fig. 8.).

(iii) RL2 driven by IC2 plus IC1d, install jumper from anode of D5 to anode of D3, (no connection to Z) (B on Fig. 8.)

(iv)If it is desired to have IC1c drive a relay instead of, or as well as the triac, connect the anode of D2 to the input end of R20, or R28, as appropriate. This may be independent of (or in addition to) operation of that relay by IC1d or IC2 according to whether D3 or D5 are disconnected (or connected) to the same point.

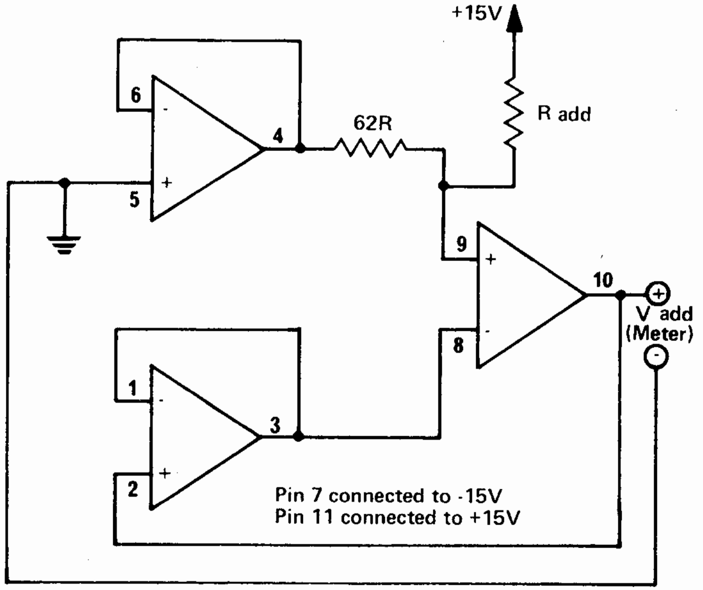


*Fig. 6. Circuit used to select R8 according to IC1.*

NOTE: It was intended that the limit circuits would operate the triac OR a relay. If however the two limit circuits are connected to Z, AND relays are installed, all output stages will of course turn on and off together. To make operation separate, (for example IC2 works as a limit to turn on triac plus relay, but IC1c only turns on triac) install D5 from IC2 to relay circuit as shown, and a separate diode from IC2 to point Z (anode to Z). Similarly for IC1d.

Table 1. Determination of R8.

| Vadd | 2 degree turn-off | 0 degree turn-off |
|---|---|---|
| +8mV | 62k | 110k |
| 7 | 66k | 126k |
| 6 | 72k | 147k |
| 5 | 78k | 180k |
| 4 | 85k | 220k |
| 3 | 94k | 300k |
| 2 | 106k | 440k |
| 1 | 120k | 890k |
| 0 | 140k | – |
| –1 | 165k | 970k* |
| –2 | 200k | 490k* |
| –3 | 260k | 320k* |
| –4 | 370k | 240k* |
| –5 | 640k | 200k* |
| –6 | 2.2M | 160k* |
| –7 | 1.6M* | 140k* |
| –8 | 600k* | 120k* |

* indicates R8 should be connected to –15V supply instead of +15V.

Table 2. Selection of R9.

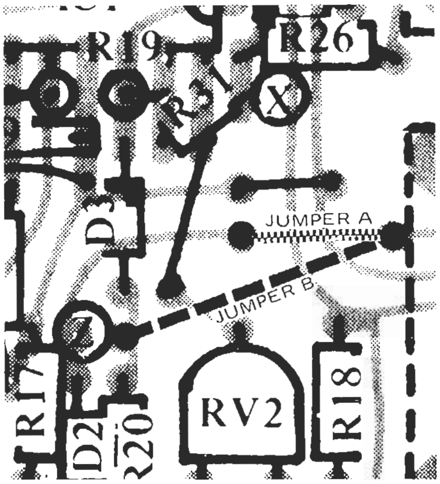
| T add | Turn-On Diff. | R9b-k (select) |
|---|---|---|
| 1 deg.C | 3 | 216k |
| 2 | 4 | 100k |
| 3 | 5 | 61k |
| 4 | 6 | 42k |
| 5 | 7 | 30k |
| 6 | 8 | 22k |
| 7 | 9 | 16k |
| 8 | 10 | 12k |
| 9 | 11 | 9k |
| 10 | 12 | 6.5k |
| 11 | 13 | 4.4k |
| 12 | 14 | 2.6k |
| 13 | 15 | 1.1k |
| 14 | 16 | 0 |

Note: Turn-on differential includes 2 degrees from R8. Also, total R9 is the series combination of R9b-k with R9a, a 16k resistor. Thus for Tadd = 2, R9 = 116k.

## SENSORS

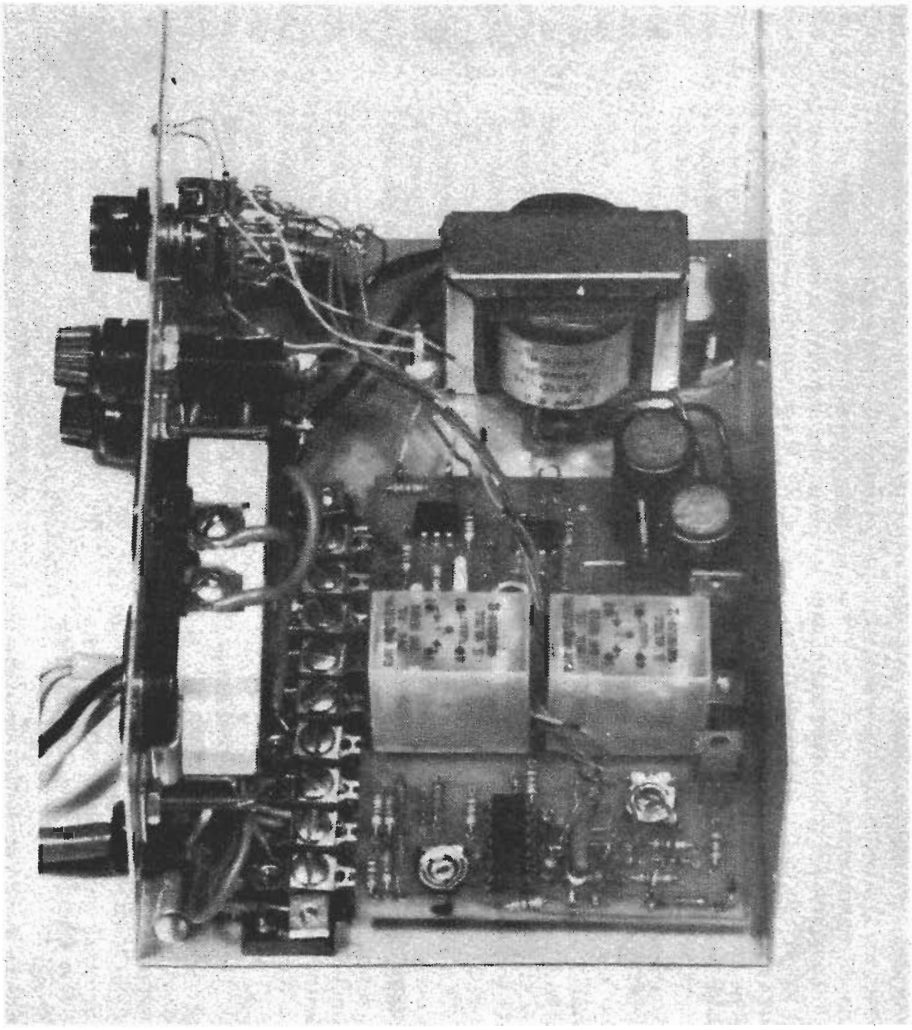
The temperature sensors are Texas Instruments TSP102s, and these are mounted in a special casing. Obtain some ¼ inch (outside diameter) brass tubing from a hobby shop and cut off a 2 inch length for each sensor. Carefully flatten about ½ inch at one end, and drill a hole ready for bolting the completed unit to the collector or tank. The flat part should be at an angle so that the round part of the tube will not interfere with the ability to mount the unit to a flat surface (see photo). Now take a thermistor and solder on the long leads (a 6 inch length of teflon coated wire may be used for the collector sensor which will get hot). Insulate the bare wire with tape or "spaghetti". Fill the prepared brass tube casing with epoxy and push the thermistor into it as far as possible, wiping away the excess epoxy. This completes the sensor unit ready for mounting.

*Fig. 8. Exploded view of overlay showing detail of jumpers.*



POSTSCIPT

Preliminary application has been made to CSA to have the production model of this unit approved. Markko Construction thus hopes to fill in for the present absence of Canadian made solar electronic products.



## PARTS LIST

RESISTORS all ¼W unless otherwise stated.

| | | | |
|---|---|---|---|
| R1 | 15k | R16 | 390R ½W |
| R2 | 6k8 | R17 | 9k1 |
| R3 | 3k6 | R18 | 220R |
| R4 | 16k | R19 | 1M |
| R5 | 6k8 | R20 | 10k |
| R6 | 3k6 | R21 | 100k |
| R7 | 62R | R22 | 360R |
| R8 | see text | R23 | 1k |
| R9a | 16k | R24 | 9k1 |
| R9b-k | see text | R25 | 220R |
| R10 | 1M | R26 | 1k |
| R11 | 1k | R27 | 1M |
| R12 | 1k | R28 | 10k |
| R13 | 560R | R29 | 100k |
| R14 | 3k3 | R30 | 360R |
| R15 | 180R | R31 | 1k |

VARIABLE RESISTORS

| | |
|---|---|
| RV1 | 2k |
| RV2 | 470R |
| RV3 | 470R |

CAPACITORS

| | |
|---|---|
| C1 | 10n |
| C2 | 10n |
| C3 | 50n |
| C4 | 680n |
| C5 | 1000u 25V |
| C6 | 1000u 25V |
| C7 | 100n |
| C8 | 100n |
| C9 | 100n |

DIODES

| | |
|---|---|
| D1—7 | 1N914 or sim. |
| D8,9 | 1N4001 |
| BR1 | 50V 1A or more |
| LED1, 2 | Any red 10mA |

TRANSISTORS

| | |
|---|---|
| Q1, Q2 | TIP116 |

INTEGRATED CIRCUITS

| | |
|---|---|
| IC1 | 4136 |
| IC2 | 741 |
| IC3 | 7815 |
| IC4 | 7915 |

TRIAC AND DRIVER

| | |
|---|---|
| TR1 | TIC216 |
| OTR1 | MOC3010 |

TRANSFORMER

| | |
|---|---|
| T1 | 120V—36Vct 150mA |

SENSORS

| | |
|---|---|
| TH1, 2 | Texas Instr. TSP102 |

RELAYS

GUARDIAN 1345-1C-12D

FUSE

| | |
|---|---|
| F1 | 6¼A |

SWITCH

| | |
|---|---|
| SW1 | Rotary, multi position to suit. |

HARDWARE

Barrier Strip CINCH JONES 9-140-¾-W

Appropriate sockets, fuses and holders, wire, nuts, bolts, case, pcb, line cord, etc.

THE Differential Controller is available in several forms from Markko Construction, 195 Kennedy Rd South, Suite 309, Brampton Ontario, L6W 3H2.

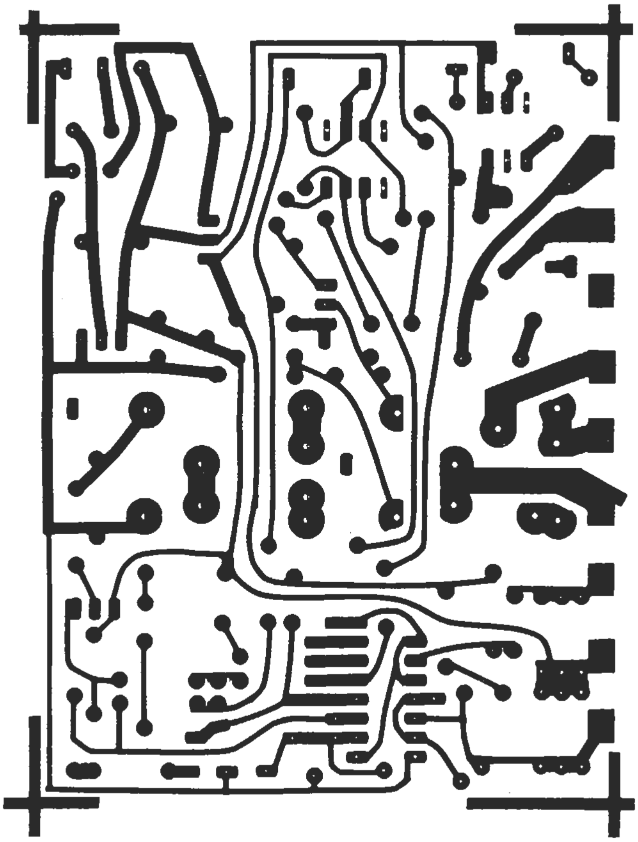
Differential Controller kit including drilled and punched case, complete hardware, pcb and components, two sensors and IC1 tested for R8 value: $70.

Same as above plus first additional limit including relay $82.

As above with first and second additional limits including relays: $94

Add $5 for mailing and handling, Ont res add 7% PST.

The printed circuit board is also available at $6 plus (7% PST for Ont res) plus $1 mail and handling.



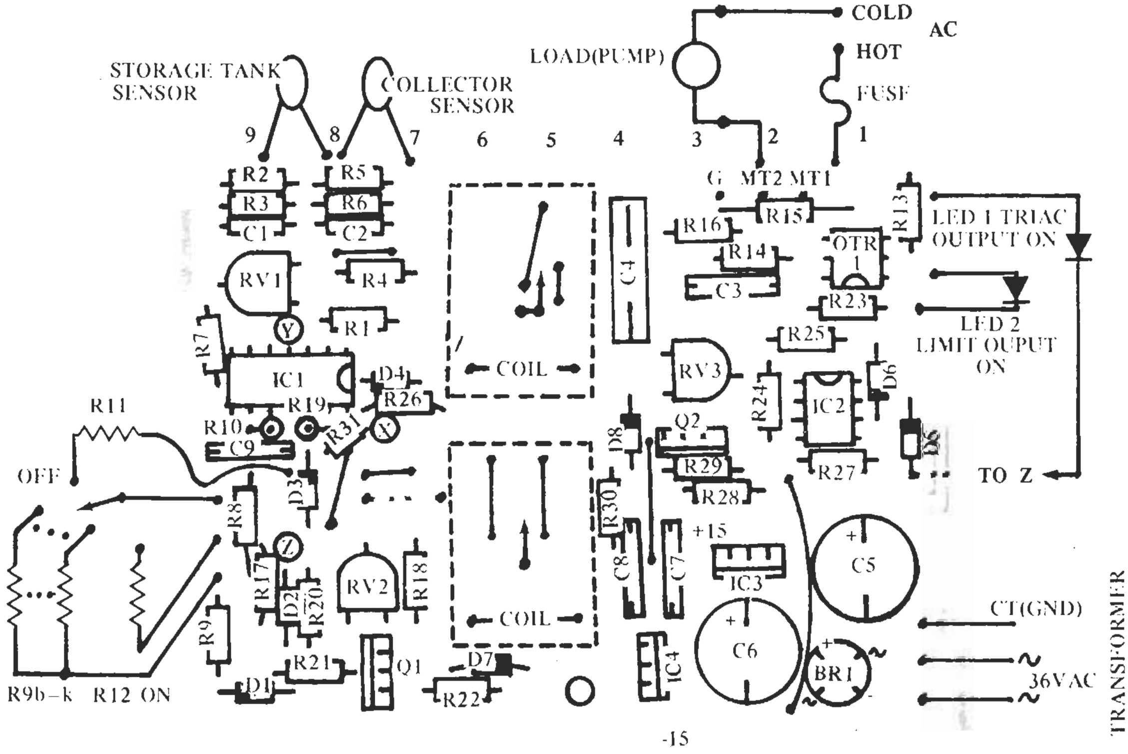


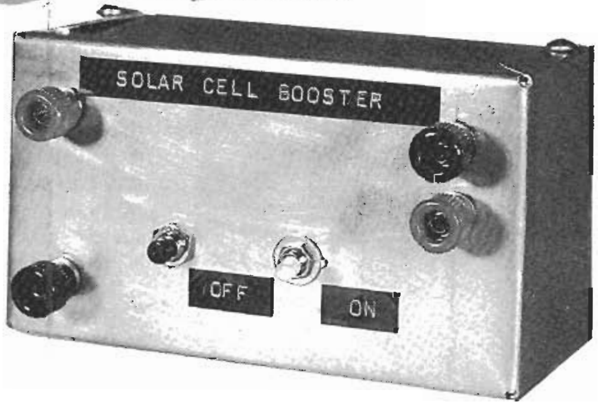
*Figure 7. Component positioning diagram showing IC1d as a low limit AND IC2 as a low limit. Each limit is independently connected to its own relay output. Connections inside relay outlines indicate the internal operation. The lower relay is not connected to the edge screws, so that it can be wired as the builder desires. If there is any ambiguity: X is IC1 pin 1, Y is IC1 pin 4 and Z is the anode of D2.*

BUILD THIS

# SOLAR POWER SUPPLY

*Here's a solar power supply that can be used even at night!*

**DAN BECKER**



SOLAR ENERGY IS ONE OF THE MOST ENvironmentally safe energy sources. Although solar power isn't going to compete with fossil fuel or nuclear power plants in the near future, researchers are striving to give solar energy a competitive edge. For example, scientists at Sandia National Laboratories, New Mexico, have developed a new photovoltaic solar cell that uses one gallium-arsenide and one silicon crystalline photovoltaic solar cell sandwiched together. The new device achieves a solar-to-electric conversion efficiency of 31%, and has the potential of reaching 40%. However, for the present, solar-to-electric conversion for the electronics hobbyist remains limited to low-power applications.

To bridge the gap between high-cost solar-cell projects and low-budget home or school versions, this article describes what we call a "solar-cell booster." That device can recharge a single Ni-Cd cell using solar power, and can also boost the Ni-Cd's output voltage enough so that you can power 5- or 9-volt devices from it, day or night.

## Solar power supply

Figure 1 is a block diagram showing the major parts of the solar/Ni-Cd power supply. Four solar cells, each rated at 0.49-volts at 1.9 amperes in bright sunlight, charge a single 1.25-volt, 1.1 Ah Ni-Cd battery. By connecting the solar cells in series, the output voltages add up to 1.96 volts, but the output current of all four cells remains equal to that of one cell. In bright sunlight, the arrangement can recharge a 1.1 Ah Ni-Cd battery in four to five hours. The Ni-Cd's charging current averages about 330 mA, so you'll need a solar-cell array with at least that capability.

The oscillator/driver section chops the Ni-Cd's DC output into a high-current 16-kHz square wave. The square wave is fed to a step-up transformer in the Ni-Cd converter section. The stepped-up output voltage from the transformer's secondary is then rectified and fed to the voltage-regulator section. Let's talk about the individual sections in more detail.

## Oscillator/driver

A schematic diagram of the oscillator/driver circuit is shown in Fig. 2. With S1 in the "off" position, and the solar-cell array exposed to sunlight, a charging current flows into D2 through J1, and into the Ni-Cd battery—J1 is either a wire jumper or a current-limiting resistor. A wire jumper (zero ohms) is used in the prototype, as the maximum current supplied by the solar array does not exceed the Ni-Cd's safe charging current. However, depending on the battery you use, you may need a current-limiting resistor instead. Diode D2 prevents the Ni-Cd from discharging through the solar array during periods of darkness (when the array's voltage is less than the Ni-Cd's). That takes care of charging the battery.

By momentarily pressing S2, C1 is connected across the Ni-Cd's termi-

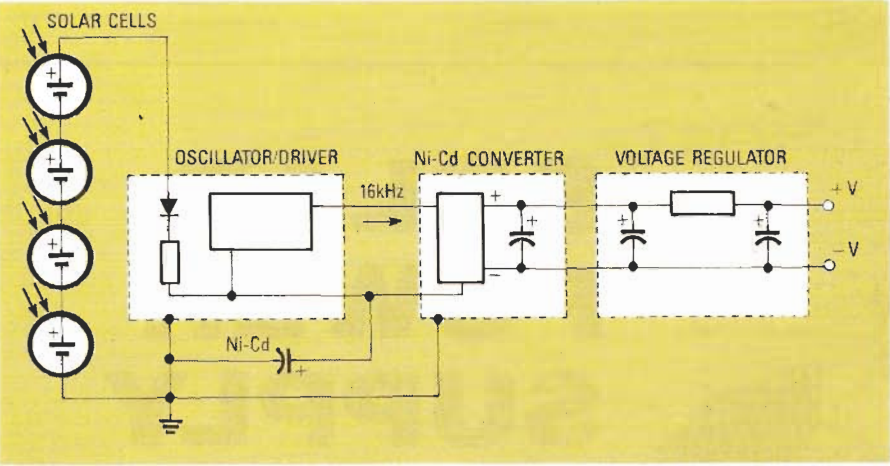


FIG. 1—THIS BLOCK DIAGRAM shows the major parts of the solar/Ni-Cd power supply. Four solar cells, each rated at 0.49-volts at 1.9 amperes in bright sunlight, charge a single 1.25-volt, 1.1-Ah nickel-cadmium battery.

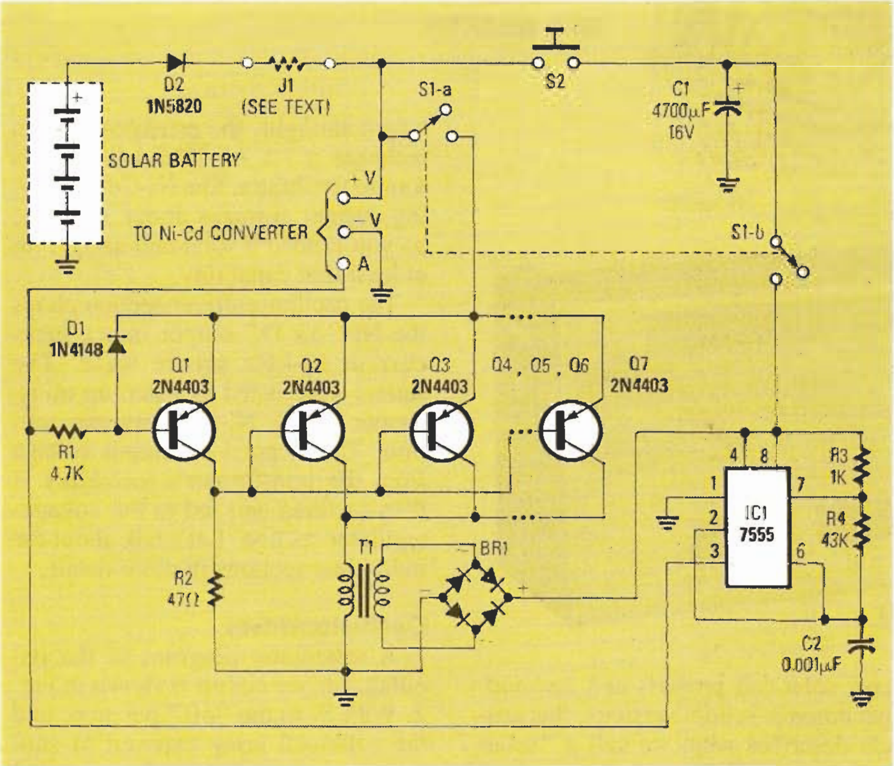


FIG. 2—SCHEMATIC DIAGRAM OF THE OSCILLATOR/DRIVER circuit. With S1 in the "off" position, and the solar-cell array exposed to sunlight, a charging current flows into D2 through J1, and into the Ni-Cd battery.

nals and is charged to the Ni-Cd's no-load terminal voltage of approximately 1.3 volts—the remainder of the circuit is inoperative. However, when S1 is placed in the "on" position, the emitters of transistors Q1–Q7 are connected to the Ni-Cd battery (a high), and C1 is connected to IC1, a CMOS 7555 timer. C1 holds enough charge to power IC1 for a few seconds. Components R3, R4, C2, and IC1 generate a 16-kHz square-wave, which is output at pin 3 of IC1. When that output is low, Q1 is turned on, forcing the bases of Q2–Q7 high; that turns Q2–Q7 off. When pin 3 of IC1 is high, Q1 is off, allowing the bases of Q2–Q7 to be at ground (low) through R2; that turns Q2–Q7 on. Diode D1 prevents Q1's emitter-base voltage from exceeding its breakdown value of 5 volts.

Because the circuit must operate from the low 1.2 volts supplied by the single Ni-Cd cell, six 2N4403 transistors (Q2–Q7) are connected in parallel; that minimizes the total on-state resistance, thereby maximizing the total current. Transistors Q2–Q7 switch on and off at 16 kHz, driving the primary winding of step-up transformer T1. The secondary winding drives bridge-rectifier BR1. While filtering the ripple voltage from BR1, C1 gradually reaches a terminal voltage of 10 to 16 volts. With that voltage supplied to IC1, the amplitude of the square-wave output at pin 3 reaches 10 to 16 volts. That square wave then feeds the Ni-Cd converter circuit from terminal A.

## Ni-Cd converter

The schematic of the Ni-Cd converter is shown in Fig. 3. The 16-kHz square wave from the oscillator/driver

### Ni-Cd MAINTENANCE TIPS

- A Ni-Cd's capacity is given in ampere-hours (Ah). For a 1.1 Ah battery, a 3.3-hour quick-charging rate is equal to 1.1 ampere-hours divided by 3.3 hours; that equals a recommended quick-charging current of 0.330 amperes, or 330 mA.
- Ni-Cd's require constant-current charging (as opposed to constant-voltage charging). A charging current less than a 30-hour rate will not give the cell a full-capacity charge.
- Once fully charged, a Ni-Cd battery can be trickle-charged at a 30- to 50-hour charging rate to maintain a full charge.
- Ni-Cd's can be fast-charged at a 3.3- to 10-hour rate.
- They can be slow-charged at a 10- to 30-hour rate.
- A Ni-Cd will self-discharge at a rate of 2% per day at 68 degrees Fahrenheit (20 degrees Celsius).
- Temperature limits:
  Storage... −40 to +122°F (−40 to +50°C)
  Discharge... −4 to +122°F (−20 to +50°C)
  Charge... +32 to +122°F (0 to +50°C)
- A Ni-Cd's terminal voltage should not exceed 1.5 volts during charging.
- Adhere to a battery's charging-time-versus-current schedule. Do not overcharge a Ni-Cd for long periods of time.
- Immediately after charging, a fully charged Ni-Cd has a terminal voltage of about 1.4-volts.
- Completely discharge a Ni-Cd before recharging it. That will prevent a premature reduction in cell capacity—that is known as "memory."
- Do not leave a load connected to a discharged Ni-Cd.

drives the gate of MOSFET Q8. R5 prevents static charges from accumulating on Q8's gate by shorting them to ground. Switching on and off at 16 kHz, Q8 allows the Ni-Cd battery, B1, to drive high-amplitude current pulses through the primary winding of T2. The secondary of T2 feeds the Ni-Cd's stepped-up voltage to bridge-rectifier BR2, whose DC output is filtered by C3. Under no-load conditions, C3 charges to approximately 17 volts. After connecting a resistive load to the output, the Ni-Cd converter can provide unregulated voltages from about 3 to 15 volts, depending on the resistance of the load. The maximum load current is approximately 150 mA, when the output is about 6 volts.

### The voltage regulator

The schematic of the voltage regulator is shown in Fig. 4. Capacitor C4 provides additional filtering of the DC voltage from the Ni-Cd converter. C5 filters the regulator's output; the output can be either 5 or 9 volts depending on whether you use a 7805 or a 7809 for IC2. Using the 9-volt regulator, the circuit can supply a maximum of 100 mA, and can power a 50-mA load for about one hour.

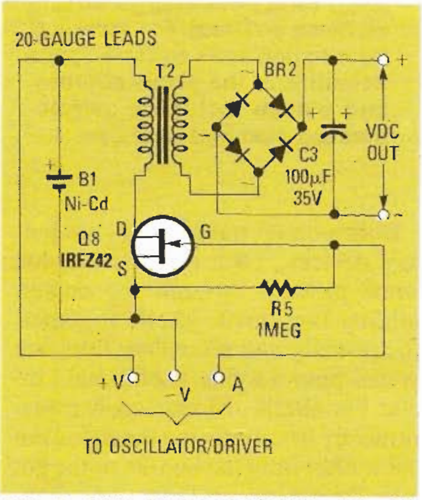


FIG. 3—SCHEMATIC DIAGRAM of the Ni-Cd converter. 16-kHz square wave from oscillator/driver drives MOSFET Q8.

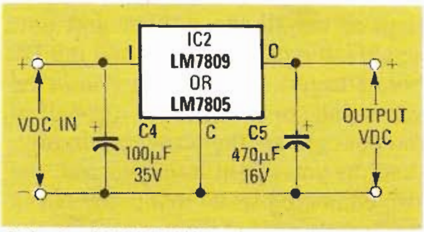


FIG. 4—SCHEMATIC of the voltage regulator. C4 filters the DC voltage from the Ni-Cd converter.

### PARTS LIST—OSCILLATOR/DRIVER

**All resistors ¼-watt 5%**
R1—10,000 ohms
R2—47 ohms
R3—1000 ohms
R4—43,000 ohms
**Capacitors**
C1—4700 µF, 16 volts, electrolytic
C2—0.001 µF, metallized film
**Semiconductors**
IC1—7555, CMOS timer IC
D1—1N4148 switching diode
D2—1N5820 Schottky diode
Q1, Q2–Q7—2N4403 PNP transistor
BR1—DB104 bridge rectifier
**Other components**
T1—step-up transformer, TS408-10-160 (see text)
S1—DPST toggle switch, 6- to 10-amp contacts.
J1—0-ohm jumper or current-limiting resistor (see text)
**Miscellaneous:** PC board (TS8.2), 8-pin dip socket, project case, 4 binding posts, solar-cell array.

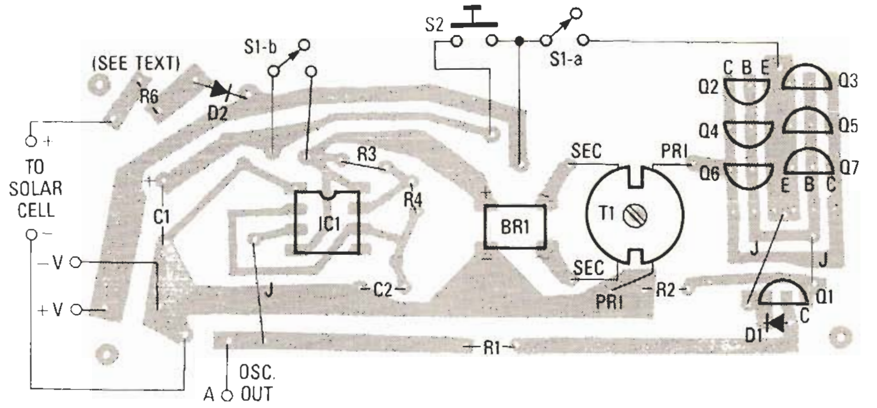


FIG. 5—PARTS PLACEMENT for the oscillator/driver. The six transistors (Q2–Q7) all work together as one low-resistance transistor.

### Construction

Any solar array capable of charging a single Ni-Cd cell can be used. A minimum of four 0.49-volt, 1.9-ampere, or six 0.45-volt, 400-mA cells are required. Because there are a wide variety of solar cells and panels available, further details about constructing a solar array are not given here.

Each of the three circuits that make up the solar-cell booster (the oscillator/driver, the Ni-Cd converter, and the voltage regulator) is assembled on its own PC board. Templates for the boards are provided in PC Service. Alternatively, etched and drilled boards can be purchased from the source given in the Parts List. Be sure to select an enclosure that is large enough to house the three PC boards and a Ni-Cd battery. If you use an aluminum enclosure, you can fasten the metal tabs of MOSFET Q8 and voltage-regulator IC2 to the enclosure. Otherwise, a separate heat sink is recommended for those two components. Using the PC boards as templates, mark and drill mounting holes for each board. In addition, mark and drill six holes in the enclosure's lid to mount S1, S2, and four binding posts; two binding posts for the DC output, and two are for the leads from the solar-cell array.

Because MOS devices are used in the circuit, we suggest that you wear a grounding strap and use a grounded soldering iron when assembling the boards. Refer to Figs. 5–7 for parts placement. Observe the polarity of diodes, electrolytic capacitors, and the orientation of IC's, transistors and transformer windings. Leave about ⅛-inch of bare wire on each of the leads

### PARTS LIST—Ni-Cd CONVERTER

**Resistors**
R5—one megohm, ¼-watt
**Capacitors**
C3—100 µF, 35-volts, electrolytic
**Semiconductors**
Q8—IRFZ42, N-channel power MOSFET transistor
BR2—DB104, bridge rectifier
**Other components**
T2—step-up transformer, TS811-5-75 (see text)
B1—Ni-Cd cell, rapid charge, size C or D
**Miscellaneous:** PC board (TS9.2), Ni-Cd battery

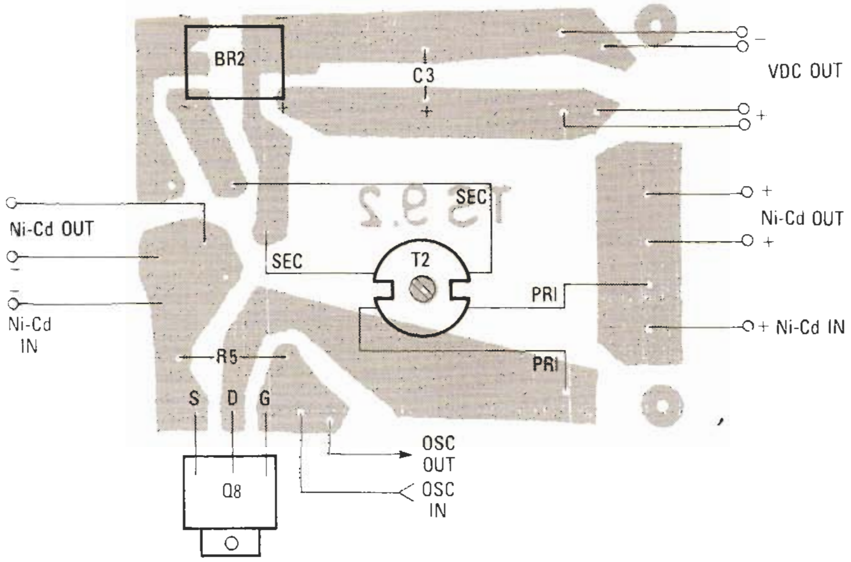


FIG. 6—THE Ni-Cd CONVERTER Parts-Placement diagram. Q8's metal tab should be heat sinked by mounting it to the metal project case.

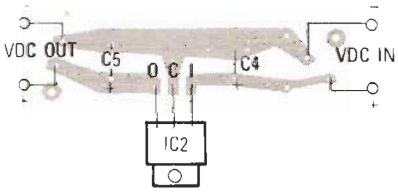


FIG. 7—THE VOLTAGE-REGULATOR circuit only contains three parts, and it is assembled on a small PC board.

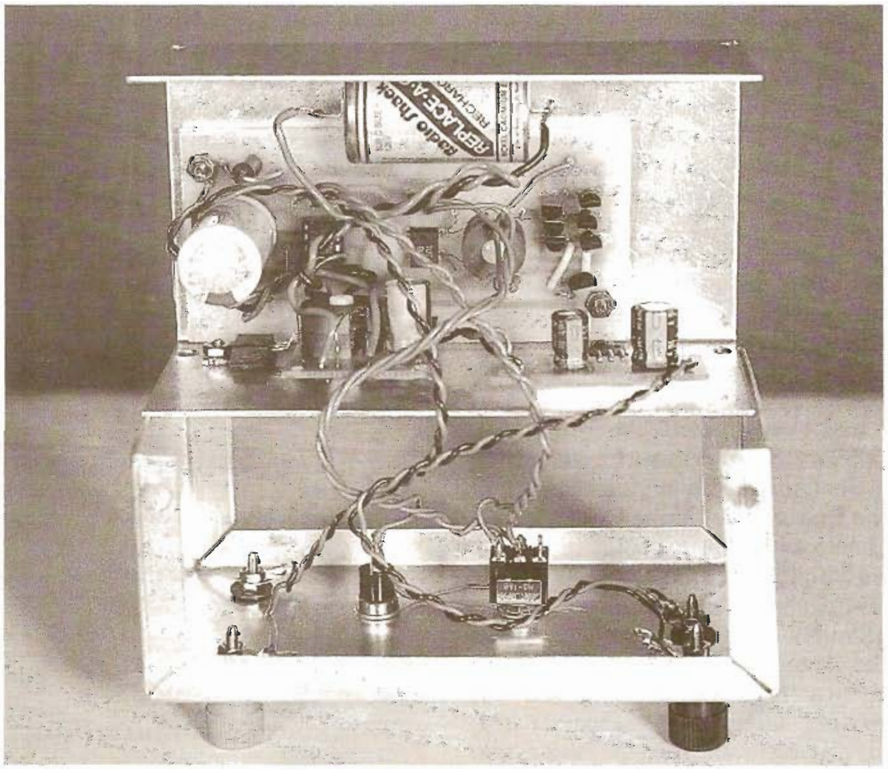


FIG. 8—HERE ARE THE COMPLETED PC boards after they are mounted inside the case. Notice how Q8 and IC2 are mounted to the project case.

feeding the regulator circuit to allow connection of voltmeter probes.

As for transformers T1 and T2, they are available preassembled from the Sources Box, or they can be made by hand. T1 is 10 turns of #34 magnet wire for the primary, 160 turns of #34 magnet wire for the secondary, both wound on a 14 × 8 linear ferrite pot core (Fair-rite #5677140821). T2 is 5 turns of #28 magnet wire for the primary, 75 turns of #30 magnet wire for the secondary, both wound on an 18 × 11 linear ferrite pot core (Fair-rite #5677181121).

## PARTS LIST—VOLTAGE REGULATOR

**Capacitors**

C4—100 µF, 35 volts, radial electrolytic

C5—470 µF, 16 volts, radial electrolytic

**Semiconductors**

IC2—LM7809, 1-amp voltage regulator

**Miscellaneous:** PC board (TS10.1)

**Note: The following items are available from Time Space Scientific, 101 Highland Dr., Chapel Hill, NC 27514: Step-up transformer (T1) TS408-10-160; $8.95. Step-up transformer (T2) TS811-5-75; $9.95. Oscillator/driver PC board (TS8.2); $9.95. Ni-Cd converter PC board (TS9.2); $4.95. Voltage-regulator PC board (TS10.1); $2.95.**

**The following kits include all semiconductors, resistors, and capacitors, but none of the parts listed as miscellaneous items: Oscillator/driver kit (SCB-8.2); $19.95. Ni-Cd converter kit (SCB-9.2); $16.95. Voltage-regulator kit (9-volt) (SCB-10.1); $5.95.**

**Add $4.50 for shipping and handling (one-time charge covers all items ordered). For technical information write to Time Space Scientific at the above address, and please include a self-addressed stamped envelope.**

Both step-up transformers are pot-core devices. Each one has a nylon screw passing through the center, holding two ferrite shells together. The primary and secondary turns are wound onto a nylon bobbin held inside the shells. Mount each transformer by first removing the nylon nut and washer from the bottom of the pot core. Do not remove the screw or separate the ferrite shells. Pass the bottom end of the screw through the mounting hole in the PC board and then re-install the washer and nut, sandwiching the pot core and the PC board together. The two enameled wires that come out of the top-half of the pot core are the primary winding. And, as you might have guessed, the two enameled wires that come out of the bottom-half of the pot core are the secondary winding.

Use short lengths of 20-gauge