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QRZ Sunshine

—building solar-powered repeaters

Photo A. AARC repeater. Photovoltaic array is visible on the left side of the shack at the base of the tower.

A totally solar-powered repeater recently went on the air in Maryland. On March 15, 1980, the Anne Arundel Radio Club (AARC) switched from 110 V ac to sunshine to power a new 220-MHz repeater recently installed at the AARC site in Davidsonville, Maryland, near Annapolis. This unique microprocessor-controlled repeater will itself be the topic of a forthcoming article, as soon as its builders get around to writing it up.

The Site

The repeater is located at an abandoned Nike missile site which was provided to AARC by the local Davidsonville Family Recreation Center. A ready-made clubhouse and a 10m-high structure (former radar pedestal) at one of the highest points in the area offer an ideal location for this active and public-service-oriented amateur radio club. A 3m × 3m repeater shack was built atop the pedestal and a 40m antenna tower was added. At the present time, the club operates both a 2-meter repeater (147.105/147.705) and the 220-MHz repeater (223.88/222.28) and is planning to install a 430-MHz ATV repeater in the near future.

The repeaters offer reliable and convenient communications within the Washington, Baltimore, Annapolis, and central Chesapeake Bay area. Many of the club members are avid boaters, and during the boating season maintain a weekend weather net which also provides real-time information to the National Weather Service about the rapidly changing weather conditions on the Bay.

Photovoltaics

Photovoltaic (PV) panels, which convert sunlight into electricity, were provided by the Department of Energy in response to a request from the AARC in December, 1979. The panels were shipped to the club on loan from the Jet Propulsion Lab in Pasadena, California, in late February, 1980. (Who says government can't react quickly?) The PVs were part of a DoE research-and-development program to improve PV technology and reduce production costs.

he PV array consists of 14 ıdividual panels, made by ensor Technology Corp., ach about .3m × .6m ×)3m, attached to a 1.3m ‹ 2.3m frame made of ressure-treated lumber. he frame is fastened irectly to the south side of he repeater shack at a 53° ngle (from the horizontal) vhich will optimize electric eneration during the vinter. Each panel is rated bout 18 V at 0.55 A, and vith the panels connected n parallel, the array was exected to produce about 18 / at 8 A (at noon on a sunny lay).

Output voltage for this ›articular panel is somevhat temperature-sensitive, ›ut at a constant temperaure, it is fairly independent ›f current draw up to the ated current, whereafter it alls very rapidly to a maxmum short-circuit value of).62 A per panel. A check of ›ur 14-panel array showed ı maximum short-circuit :urrent of 8.7 A. Even on a very cloudy day, the array ›roduces about 0.5 A, which is more than adequate to provide the repeater's standby current draw of around 300 mA.

The 14-panel array is expected to produce almost 400 Watt-hours during an average December day, while in June it should be almost twice that amount. The array converts only about 6 percent of the sunlight falling on it into electric energy (actually the individual cells are about 10-percent efficient, but there is considerable open area between each cell in the panel). This should be sufficient power to run the repeater without auxiliary power, year-round, hopefully for the next 10 years, the panel service-life design goal.

Photo B. Photovoltaic array. Frank Troutman WB3CLF helped install the array on the side of the shack.

Power Conditioning and Storage

Since the repeater requires 12 V dc around-the-clock, and the array produces 18 to 25+ V dc for only part of the 24-hour cycle, some sort of power-conditioning and energy-storage system is needed. A simple system was designed to provide high reliability and efficiency at a low cost. It consists of a 16 V (13-cell, 20-Ah) primary nicad battery storage module, charged directly by the PV array through an overcharge protector. A 12-volt (60-Ah) secondary-storage auto battery is diode-isolated from, and trickle-charged by, the nicad battery.

A clock attached to the transmitter measured an average daily transmit time of about two hours. At a transmit current of 3 A, the average daily transmit power is 6 Ah, and at the .3 A standby level, another 7 Ah is consumed. Thus, the total average daily power consumption is around 13 Ah at 12 V dc (156 Wh/day). While the array output of 400 Wh would appear to be more than sufficient to power the repeater, there are major energy losses built into the system which must be taken into account.

Batteries are less than 100-percent efficient, and the trickle-charge circuit dissipates an appreciable amount of energy. If we assume an average battery efficiency of 80 percent and a trickle-charge rate of 700 mA, we end up with only about 170 Wh being delivered to the repeater, which just slightly exceeds its anticipated demand of 156 Wh/day. It must be remembered that this was calculated for the worst part of the year (December), and in any event, the fully-charged 12-V battery should have enough capacity to run the repeater for at least four consecutive cloudy days.

During the design and testing of the power-conditioning and storage equipment, it was found that current and comprehensive technical information on lead-acid and nicad batteries was very difficult to obtain. Building a battery-charging circuit may appear at first to be a simple task. But to build one that does not damage the battery, seriously degrade its performance, or doom it to an early death is not really as straightforward as one might expect.

An excellent handbook has just become available on this topic entitled *Handbook for Battery Storage in Photovoltaic Power Systems*, February, 1980. The 120-page handbook was prepared for the Department of Energy by Bechtel National, Inc., and contains a wealth of engineering data on most types of rechargeable batteries. It includes a section on advanced batteries now under development primarily for electric vehicle applications. The handbook is well-referenced and includes an extensive listing of battery manufacturers, suppliers, and developers. A limited number of copies are available at $9.95 (including handling and postage) from: Moonraker East, Publications Department, Box 117, Riva MD 21140.

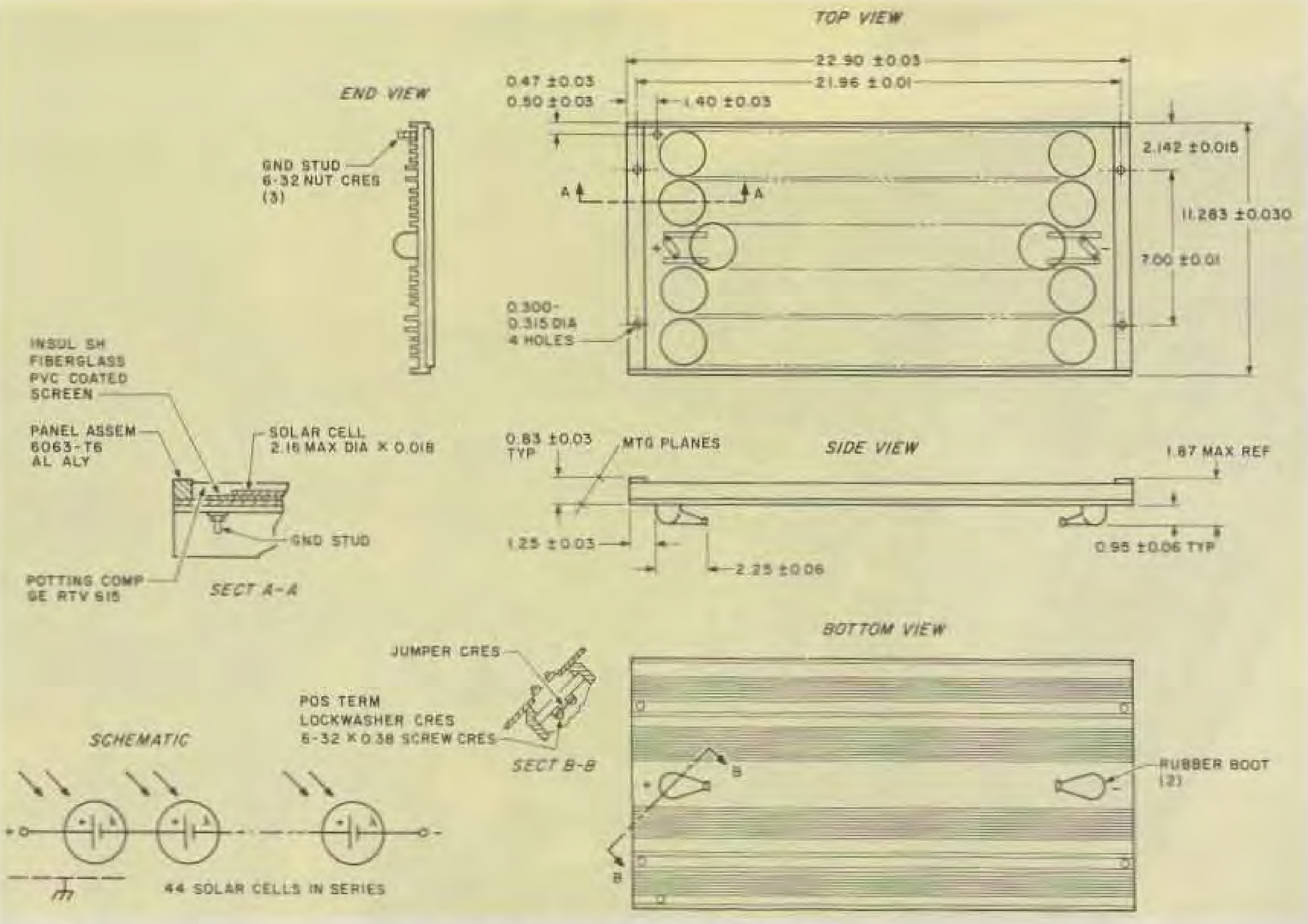

Fig. 1. Diagrams of PV module.

Design Considerations

A simple constant-voltage charging circuit was considered, which would have eliminated the need for the 16-V nicad battery by connecting the PV array directly to the 12-V auto battery through a regulator. While the overall efficiency might have been slightly better, the design was rejected for several reasons:

1) The lead-acid auto battery would discharge continuously at night due to the power demands of the repeater, with the terminal voltage falling to about 11.5 V by dawn. The PV array would then start to charge the battery with currents rapidly increasing to almost 9 Amps and, as the battery attained full charge, its terminal voltage would climb to about 15 V. This wide swing in supply voltage was not considered conducive to stable repeater operation, or to extended battery life.

2) Nicad batteries are much better suited for repeated charge/discharge cycling and are far more resistant to damage from overcharging.

3) The two-battery circuit provides an almost constant supply voltage to the repeater by continuously trickle-charging the lead-acid battery around the clock, not just when the sun is out.

4) The two-battery circuit design appears to be much more fail-safe in that a regulator failure would not cook the lead-acid battery, as it could in the simple circuit. Component failure in the two-battery circuit likely would result in a decrease in repeater performance noticeable over a period of days, allowing time to correct the problem rather than resulting in a sudden complete repeater failure.

This last consideration is an important factor in the operation of our repeaters, since routine inspection of the system is limited by the requirement that someone must climb the 10m structure, and thus periods of unattended operation of a month or more are expected. But this is all just theory and we should know much more about the reliability of our solar-powered repeater in a year or so.

PVs: Current Technology and Future Potential

The principle of the photovoltaic effect was discovered by Edmond Becquerel back in 1893, but useful energy conversion devices have been available only for the last 25 years. An early PV application was in photographic exposure meters. The first breakthrough in PV cell manufacture for electric power generation was made by researchers working at Bell Laboratories in 1954. Subsequently, high-reliability single-crystal silicon PVs were used as an energy source for U.S. and Russian space vehicles thoughout the 1960s. A few terrestrial PV devices were marketed on a trial basis as early as 1959 using silicon cells rejected by the space program as not meeting NASA's high-reliability requirements, but the first PVs designed specifically for terrestrial use were not produced until 1973. Thus, we are dealing with a very new product only recently available in the marketplace, and it is probable that PV applications will grow rapidly in the coming years, especially if anticipated tenfold PV cost reductions can be achieved.

Photovoltaic cells have much in common with transistors and utilize semiconductor technology to convert light into electricity. They consist of a junction of semiconducting material formed by one of three methods: (1) adding impurities (dopants) to one side of a pure material (homojunction); (2) joining two dissimilar semiconductor materials (heterojunction); (3) joining a semiconductor to a metal (Schottky junction).

The combination of materials creates a potential difference across the junction, with the materials on each side of the barrier having different electrical characteristics. One side has excess negative charges and is called n-material, while the other side has excess positive charges and is called p-material. Absorption of light in the semiconductor energizes the negative and positive charges and creates an electrical current when the absorbed energy is greater than the material's energy bandgap.

Fundamental restrictions of quantum physics limit the portion of the sun's spectrum which can be utilized by solar cells and the efficiencies which are achievable. Thus, each different cell design has a unique performance characteristic across the spectrum of sunlight from ultraviolet to infrared. Light with energy below the material's bandgap is insufficient to generate a current; light with energy above the bandgap produces energy equal to the bandgap, with excess energy resulting in heat which must be dissipated. The direct-current electricity that is produced is collected by a contact grid imprinted on the surface of the cell.

The capability to control the energy bandgap and the electrical characteristics of the materials on each side of the barrier is fundamental to the science and art of photovoltaic cell design. Particularly for terrestrial photovoltaics, the technical problem is to construct and control these sophisticated material characteristics in a mass-production process.

Manufacturing of the cell, or a module (panel) of cells, is complete when anti-reflection coatings and protective encapsulants are applied. Single-layer antireflection coatings can reduce average reflective losses from 40 percent to as little as 10 percent, and double-layer coatings can further reduce reflective losses to about three percent. Glass, plastic, or silicone encapsulants seal the panel of cells against environmental elements and are a key factor in determining the useful life of the cells. The output of a terrestrial solar cell in peak Watts (Wp) depends on the daily insolation in each location.

On a clear day, the sun's energy reaches the Earth at a rate of about one kilowatt per square meter. This is equivalent to the energy contained in a gallon of gasoline for every 10 minutes the sun shines on an area the size of a tennis court. Even with the low efficiency of today's solar cells (say, 10%), 60 square meters of cells with adequate storage under optimum conditions can provide the needs of an average single-family residence 6 kWp, 700 kWh per month). Unfortunately, such an installation would be far too expensive for an average homeowner. For example, at a PV module price of $10/Wp, the cost would amount to $60,000 just for the PVs, and the installation, energy storage, and power conditioning equipment would be extra.

That is precisely why the Department of Energy is spending over a billion dollars on a 10-year program to develop the technology and production techniques needed to reduce the cost of PVs to $.50-$1.00/Wp by 1986. By then, utility electric rates will be considerably higher and PVs should be able to compete on a sound economic basis. But what are DoE's chances of pulling this off, you might ask? Of course, no one really knows, but DoE is fairly confident that the price goal can be achieved. So much is happening in the PV field (advances in competing cell materials such as silicon, cadmium sulfide, gallium arsenide, encapsulation improvements, better and lower-cost manufacturing techniques being developed) that it is just too early to attempt to select the best technology/manufacturing mix. The next few years may bring several major breakthroughs in PV material technology providing lower-cost cells and in developing cells with much higher efficiencies.

One particularly promising avenue of PV research involves the use of lenses or reflectors to concentrate the light striking the PVs. Concentrations equivalent to many thousands of suns have been tried with very encouraging results. A recent breakthrough was achieved with one type which is called a thermophotovoltaic cell, which reached an efficiency of 26 percent. This particular device utilizes concentrating mirrors to focus the light on a spectral converter which absorbs the full spectrum of sunlight, then reradiates the energy at specific wavelengths which match the optimum operating bandgap of the cell. Ultimately, 30- to 50-percent efficiencies are expected.

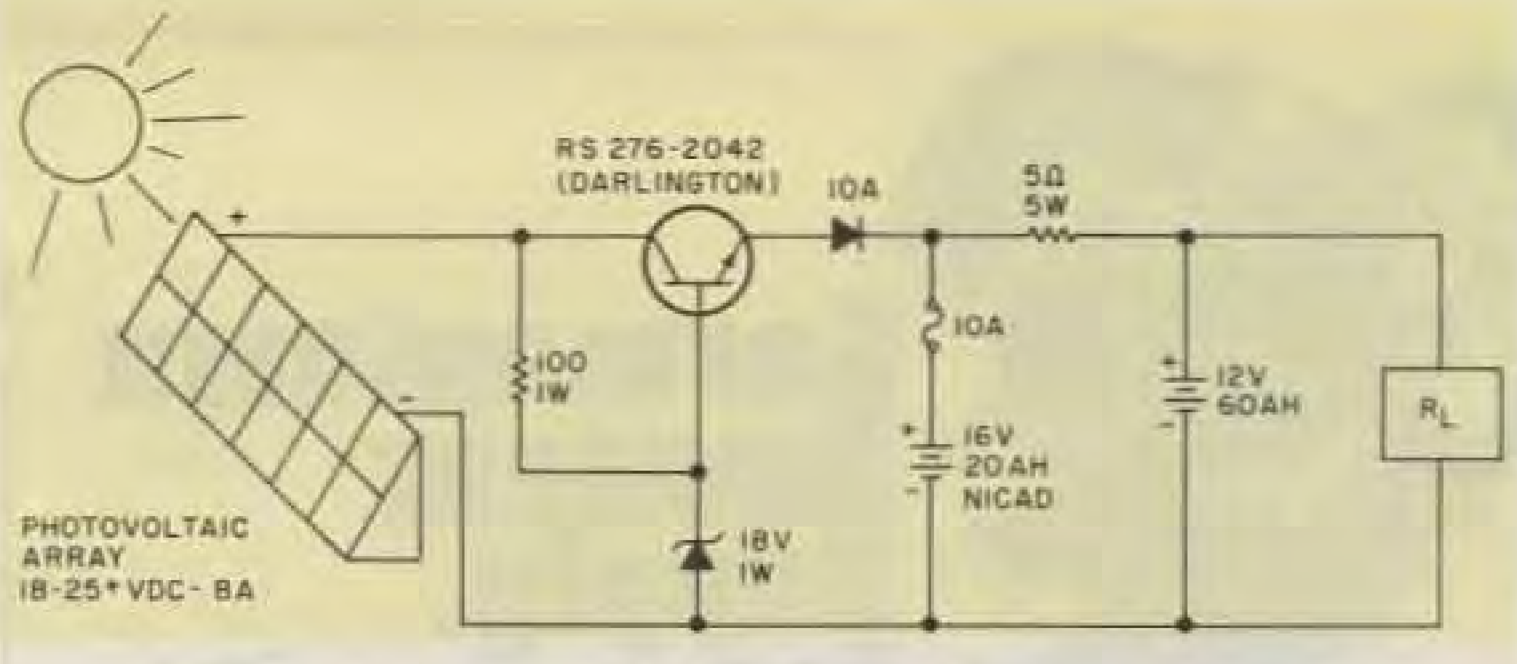

Fig. 2. Power conditioning and storage circuit.

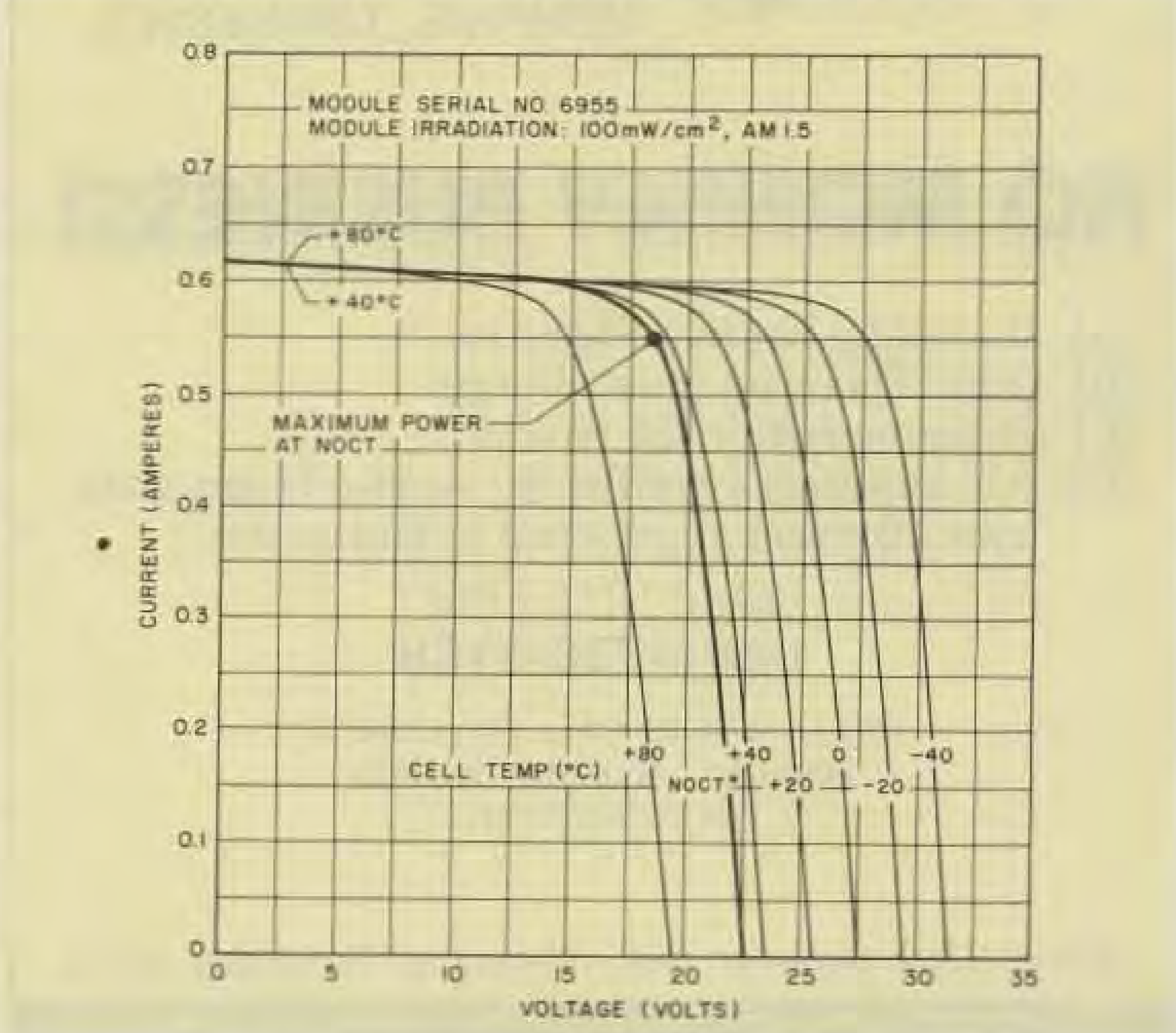

Fig. 3. Specifications of photovoltaic array.

Much of the R-&-D effort on concentrating PVs has been privately supported, and it is still too early to tell just how much of a competitor they will be to flat-plate non-concentrating options. But the overall trend is plain; the immense potential of PVs is no longer just theoretical, and the question now appears to be one more appropriately stated in terms of how long will it take PVs to capture a significant market share.

Photovoltaics and Repeaters

The use of PVs to power amateur repeaters provides us with new opportunities to locate our repeaters at sites which offer better coverage, but which otherwise may not be usable because of a lack of electricity. PVs with battery storage also provide a much greater degree of communications reliability during local emergencies accompanied by commercial power outages (as is often the case). Although many repeater clubs are equipped with auxiliary generators, it is often not easy to find a member who is willing (or able) to hurry over to the repeater site in the middle of a flood or blizzard, start up the generator, and keep it running during an extended power outage.

At the present time, high cost is one of the major problems hindering use of PVs by amateurs. Eventually, prices will come down, but it will take a number of years, and in the meantime our repeaters will remain dependent on external power. This is a situation where a little creative groundwork could be of great service to amateur radio. Here's how: The Congress is very anxious to accelerate the commercialization of PVs and for the past few years has appropriated millions of dollars over and above agency requests with the intent of stimulating PV manufacture and use. But it is not always easy for the administration to effectively utilize all of the funds; hence, most deserving PV projects have been welcomed with open arms.

Amateur radio spokesmen could approach the newly-created Federal Emergency Management Administration with a proposal to solar-power a number of repeaters throughout the country, to strengthen the nation's emergency preparedness. The Federal Emergency Management Administration, in cooperation with the Department of Energy, might provide the PVs at no cost to repeater clubs as part of the PV accelerated commercialization program. The whole program could be coordinated at the user end by the ARRL.

The federal cost of a program to solar-power 1000 repeaters based on today's PV prices and a collector system similar to ours would be less than $5 million. This is a pretty small part of a billion-dollar PV program budget, and not only that, the real benefit the nation would gain from such a program would far outweigh its very modest cost. So how about it, ARRL, is anybody there in Newington listening? ■