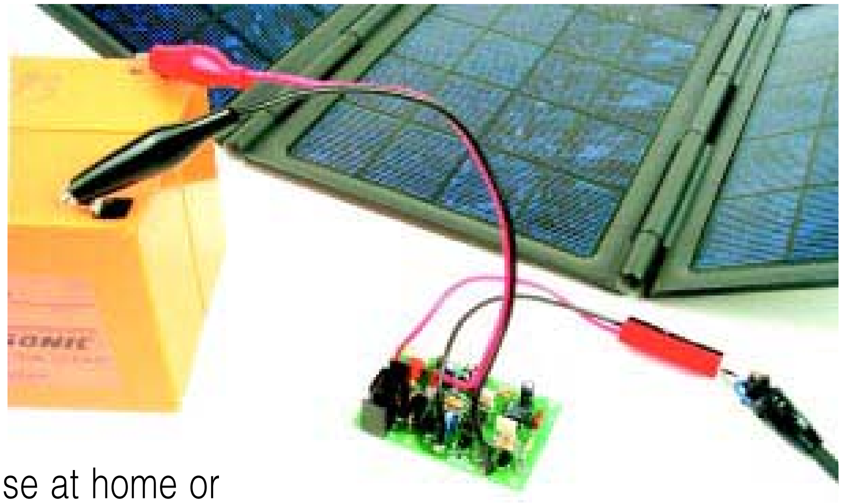
By Mike Bryce, WB8VGE

# The Micro M+ Charge Controller



Current capacity of up to 4 A, positive line switching so all grounds tie together, standby current of less than 1 mA and more features make the Micro M+ the ideal photovoltaic charge controller for use at home or in the field. It's an easy-to-build, one-evening project that just about anyone can master.

The Micro M proved a very popular project.[1] It seems hams really do like to operate their rigs from solar power while in the outback. Many hams find solar power to be very addictive. I had dozens of requests for information on how to increase the current capacity of the original Micro M controller. The original Micro M would handle up to 2 A of current. The PC board traces and blocking diode limited the design to this current capacity. I also wanted to improve the performance of the Micro M while I was at it. Because the Micro M switched the negative lead of the solar panel on and off, the negative lead of the solar panel had to be insulated from the system ground. While that's not a problem with portable use, it may cause trouble with a home station where all the grounds should be connected. Here's what I wanted to do:

- Reduce the standby current at night
- Increase current handling capacity to 4 A
- Change the charging scheme to high (positive) side switching
- Improve the charging algorithm
- Keep the size as small as possible, but large enough to build.

## The Micro M+

I called the end result the Micro M+. You can assemble one in about an hour. Everything mounts on one double-sided PC board. It's small enough to mount inside your rig yet large enough so you won't misplace it. You can stuff four of them in your shirt pocket! And, you need not worry about RFI being generated by the Micro M+. It's completely silent and makes absolutely zero RFI!

The Micro M+ will handle up to 4 A of current from a solar panel. That's equal to a 75-W solar panel.[2] I've reduced the standby current to less than 1 mA. I've also introduced a brand new charging algorithm to the Micro M+. All the current switching is done on the positive side. Now, you can connect the photovoltaic (PV) array, battery and load grounds together.

A complete kit of parts is available as well as just the PC board. The complete kit, including the PC board and all parts is $30.[3] The Micro M+ is easy to build, making it a perfect first-time project.

## Here's How it Works

Figure 1 shows the complete Micro M+, while Figure 2 shows the schematic diagram. Let's begin with the current handling part of the Micro M+. Current from the solar panel is controlled by a power MOSFET. Instead of using a common N-channel MOSFET, however, the Micro M+ uses an International Rectifier IRF4905 P-channel MOSFET. This P-channel FET has a current rating of 64 A with an $RDS_{on}$ of 0.02 Ω. It comes

[1]Notes appear on page 31.

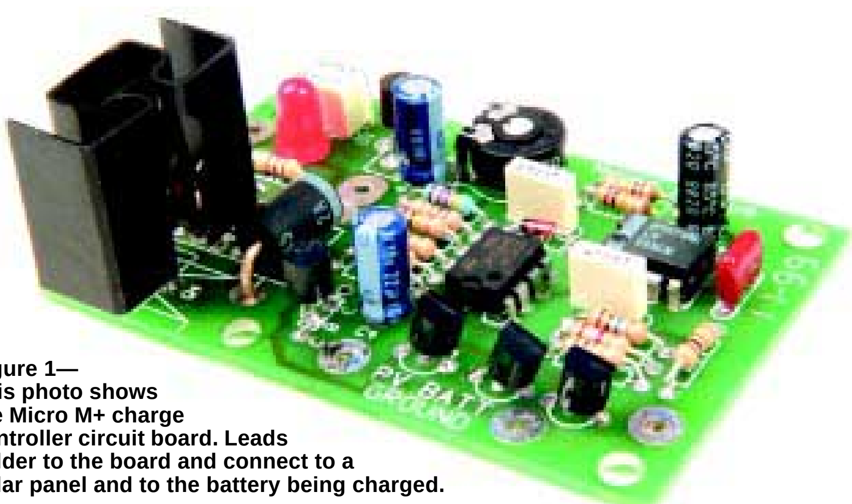


**Figure 1—This photo shows the Micro M+ charge controller circuit board. Leads solder to the board and connect to a solar panel and to the battery being charged.**

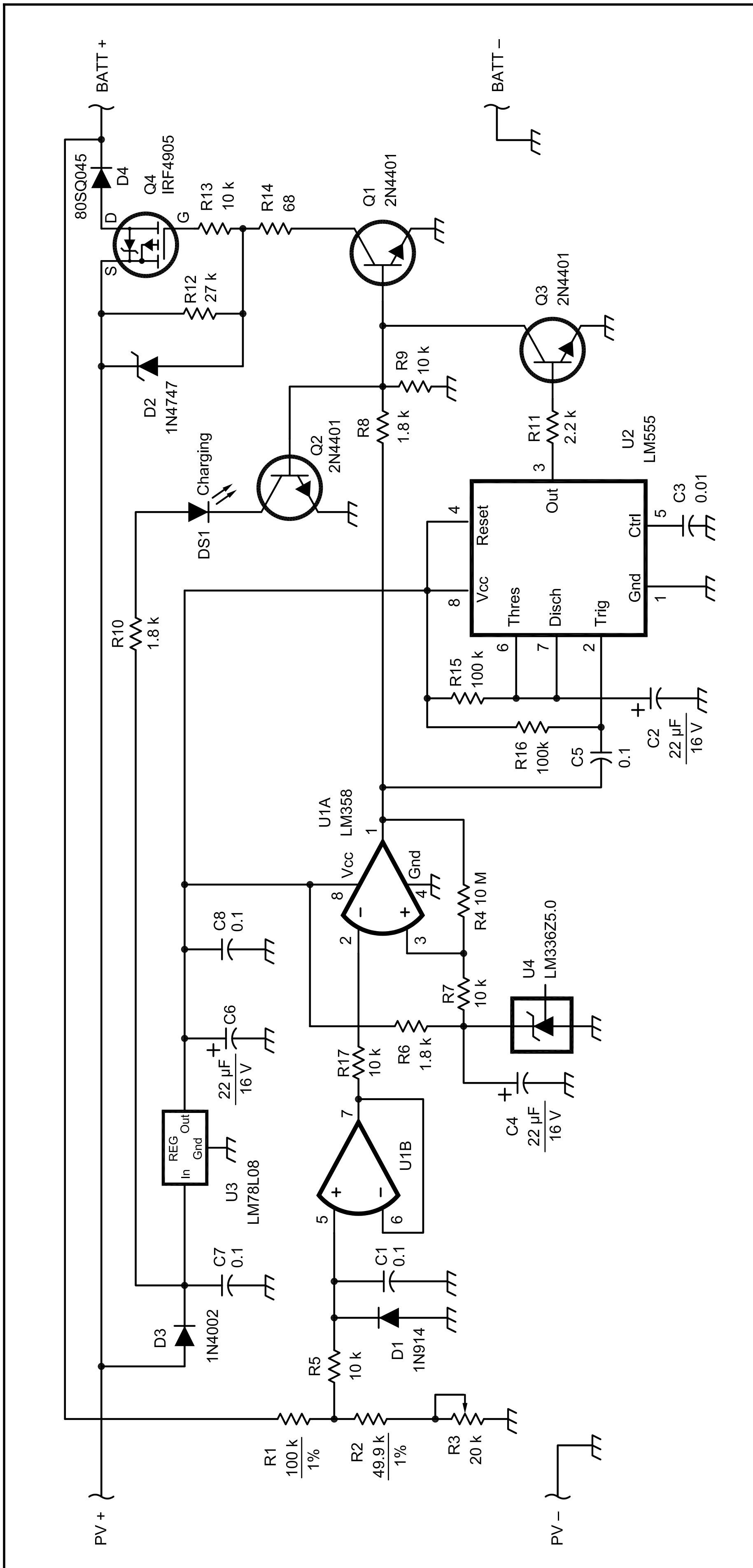



**Figure 2—The schematic diagram of the Micro M+ charge controller.**

**C1, C5, C7, C8—0.1 µF.**
**C2, C4, C6—22-µF, 16-V electrolytic.**
**C3—0.01 µF.**
**D1—1N914, small signal silicon switching diode.**
**D2—1N4747, 20-V, 1-W Zener.**
**D3—1N4002, silicon rectifier diode.**
**D4—80SQ045, 45-V, 8-A Schottky diode.**
**DS1—LED, junkbox variety.**
**Q1, Q2, Q3—2N4401 NPN small-signal transistor (2N2222 or 2N3904 will also work).**
**Q4—IRF4905 P-channel MOSFET in TO-220 case. You will also need a small clip-on heat sink for this case.**
**R1—100 kΩ, 1%.**
**R2—49.9 kΩ, 1%.**
**R3—20-kΩ trimmer.**
**U1—LM358AN, dual op-amp.**
**U2—LM555AN timer.**
**U3—LM78L08, 8-V regulator.**
**U4—LM336Z-5.0, 5.0-V Zener diode in TO-92 case. The adjust terminal allows control of the temperature coefficient and voltage over a range. The adjust terminal is not used for the Micro M+.**

in a TO-220 case. Current from the solar panel is routed directly to the MOSFET source lead.

N-channel power MOSFETs have very low $RDS_{on}$ and even lower prices. To switch current on and off in a high side application, the gate of an N-channel MOSFET must be at least 10 volts higher than the rail it is switching. In a typical 12-volt system, the gate voltage must be at least 22 volts to ensure the MOSFET is turned completely on. If the gate voltage is less than that required to fully enhance the MOSFET, it will be almost on and somewhat off (the MOSFET is operating in its linear region). The device will be destroyed at high current.

To produce this higher gate voltage, some sort of oscillator typically is used to charge up a capacitor via a voltage doubler. This charge pump generates harmonics that may ride on the dc flowing into the battery under charge. Normally, this would not cause any problem, and in most cases, a filter or two on the dc bus will eliminate most of the harmonics generated. Even the best filter won't get rid of all the harmonics, however. To compound the problem, long wire runs to and from the solar panels and batteries act like antennas.

The P-channel MOSFET eliminates the need for a charge pump altogether. To turn on a P-channel MOSFET, all we have to do is pull the gate lead to ground! Since the Micro M+ does not have a charge pump, it generates *no RFI*!

Now, you may be wondering, if the

### Using the Micro M+ with the Yaesu FT-817

With the introduction of the new Yaesu FT-817 all mode, all band QRP transceiver, more and more of us will be using solar power in the field. The Micro M+ was designed to use a 12-V solar panel to charge a 12-V battery. The Yaesu FT-817 can operate from 12 V supplied externally or from an internal 9.6-V NiCd battery. The NiCd battery may be charged when the battery is installed in the radio. Or, if you want, it can be charged separately from the 817 via a solar panel and the Micro M+ controller.

To use the Micro M+ to charge this NiCd pack, you'll have to change the value of resistor R2 from 49.9 kW 1% to 82.5 kW 1%. This will allow the logic to switch correctly at 11.6 V, the voltage of a fully charged 9.6-V NiCd battery. This assumes you use the standard of 1.45 V per NiCd cell. With the new value for R2, there's plenty of adjustment in the state-of-charge trimmer to allow you to fine-tune the state-of-charge.

Since the NiCd battery is rated at only 9.6 V, this throws the power point of the solar panel in the trash. A typical 5-W solar panel is rated at 290 mA at 17.1 V. Because of the lower battery voltage, there will be more than the 290 mA of current flowing. However, if the panel is designed to produce 5 W, that's all it will do. As the voltage goes down, the current will increase, up to the Isc (current short circuit) of the panel. The panel will not produce any more current than it was designed for.

P-channel MOSFET is so great, why have you not seen them in applications like this before? The answer is twofold. First, the $RDS_{on}$ of a P-channel MOSFET has always been much higher than its N-channel cousin. Several years ago, a P-channel MOSFET with an $RDS_{on}$ of 0.12 ohms was considered very low. At that time an N-channel MOSFET had an $RDS_{on}$ of 0.009 ohms. Suppose you want to control 10 A of current from your solar panel. Using the N-channel MOSFET above we find the MOSFET will dissipate less than a watt of power. On the other hand, the P-channel MOSFET will dissipate 12 W of power! Current generated by our solar panels is way too expensive to have 12 W of it go up as heat from the charge controller.

The second factor was price. The P-channel MOSFET I described above would have sold for $19 each. The N-channel would have been a few dollars.

***The Micro M+ never draws current from the battery. The solar panel provides all the power the Micro M+ needs.***

In the last year or so the $RDS_{on}$ of the P-channel MOSFET has fallen to 0.028 ohms. The price, while still a bit on the steep side, has dropped to about $8 each.

With the P-channel MOSFET controlling the current, diode D4—an 80SQ045 Schottky—prevents current from the battery from flowing into the solar panel at night. This diode also provides reverse polarity protection to the battery in the event you connect the solar panel backwards. This protects the expensive P-channel MOSFET.

Zener diode D2, a 1N4747, protects the gate from damage due to spikes on the PV line. Resistor R12 pulls the gate up, ensuring the power MOSFET is off when it is supposed to be.

### The Micro M+ Likes to Sleep

The Micro M+ never draws current from the battery. The solar panel provides all the power the Micro M+ needs. At night, the Micro M+ goes to sleep. When the sun rises, the Micro M+ will start up again. As soon as the solar panel is producing enough current and voltage to start charging the battery, the Micro M+ will pass current into the battery.

To reduce the amount of standby current, diode D3 passes current from the solar panel to U3, the voltage regulator. U3, an LM78L08 regulator, provides a steady + 8 V to the Micro M+ controller. Bypass capacitors C6, C7 and C8 are used to keep everything happy. As long as the solar panel is producing power, the Micro M+ will be awake. At sundown, the Micro M+ will go to sleep. Sleep current is on the order of less than 1 mA.

### Battery Sensing

The battery terminal voltage is divided down to a more usable level by resistors R1, R2 and R3. Resistor R3, a 20-kΩ trimmer, sets the state-of-charge for the Micro M+. A filter consisting of R5 and C1 helps keep the input clean from noise picked up by the wires to and from the solar panel. Diode D1 protects the input of the op-amp in the event the battery sense line were connected backward.

An LM358 dual op-amp is used in the Micro M+. One section, U1B, buffers the divided battery voltage before passing it along to the voltage comparator, U1A. Here the battery sense voltage is compared to the reference voltage supplied by U4. U4 is an LM336Z-5.0 precision diode. To prevent U1A from oscillating, a 10-MΩ resistor is used to eliminate any hysteresis.

As long as the battery under charge is below the reference point, the output of U1A will be high. This saturates transistors Q1 and Q2. Transistor Q2 conducts and lights LED DS1, our CHARGING LED. Q1, also fully saturated, pulls the gate of the P-channel MOSFET to ground. This effectively turns on the FET and current flows from the solar panel into the battery via D4.

As the battery begins to take up the charge, its terminal voltage will increase. When the battery reaches the state-of-charge set point, the output of U1A goes low. With Q1 and Q2 now off, the P-channel MOSFET is turned off, stopping all current into the battery. With Q2 off, the CHARGING LED goes dark.

Since we have basically eliminated any hysteresis in U1A, as soon as the current stops, the output of U1A pops back up high again. Why? Because the battery terminal voltage will fall back down as the charging current is removed. If left like this, the Micro M+ would sit and oscillate at the state-of-charge set point.

To prevent that from happening, an LM555 timer chip, U2, monitors the output of U1A. As soon as the output of U1A goes low, this low trips U2. The output of U2 goes high, fully saturating transistor Q3. With Q3 turned on, it pulls the base of Q1 and Q2 low. Since both Q2 and Q1 are now deprived of base current, they remain off.

With the values shown for R15 and C2, charging current is stopped for about four seconds after the state-of-charge has been reached.

After the four second delay, Q1 and Q2 are allowed to have base drive from U1A. This lights up the charging LED and allows Q4 to pass current once more to the battery.

As soon as the battery hits the state-of-charge once more, the process is repeated. As the battery becomes fully charged, the "on" time will shorten up while the "off" time will always remain the same four seconds. In effect, a pulse of current will be sent to the battery that will shorten over time. I call this charging algorithm "Pulse Time Modulation."

As a side benefit of the pulse time modulation, the Micro M+ won't go nuts if you put a large solar panel onto a small battery. The charging algorithm will always keep the off time at four seconds allowing the battery time to rest before being hit by higher current than normal for its capacity.

### Building Your Own Micro M+

There's nothing special about the circuit. The use of a PC board makes the assembly of the Micro M+ quick and easy. It also makes it much easier if you need to troubleshoot the circuit. You can build the entire circuit on a piece of perfboard if you want.

The power MOSFET must be protected against static discharges. A dash of common sense and standard MOSFET handling procedures will work best. Don't handle the MOSFET until you need to install it in the circuit. A wrist strap would be a good idea to prevent static damage. Once installed in the PC board, the device is quite robust.

A small clip-on heat sink is used for the power MOSFET. If you desired, the MOSFET could be mounted to a metal chassis. If you do this, make sure you insulate the MOSFET tab from the chassis.

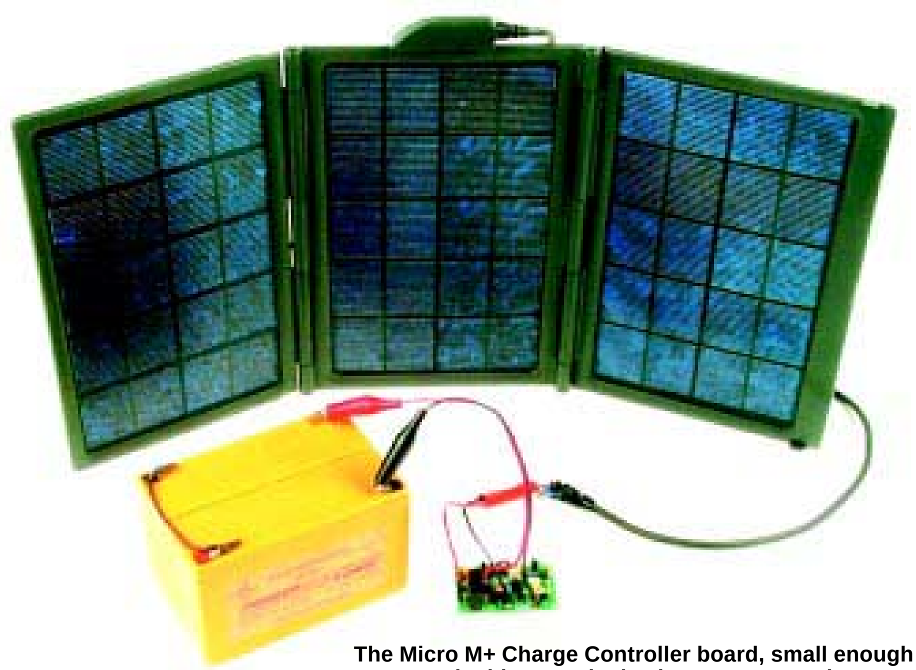
If you plan on using the Micro M+ outside, then consider soldering the IC directly onto the board. I've found that cheap solder-plated IC sockets corrode. If you want to use an IC socket, use one with gold-plated contacts.

Feel free to substitute part values. There's nothing really critical. I do suggest you stick with 1% resistors for both R1 and R2. This isn't so much for the close tolerance, but for the 50-PPM temperature compensation they have. You can use standard off-the-shelf parts for either or both R1 and R2, but the entire circuit should then be located in an environment with a stable temperature.

### Adjustments

You'll need a good digital voltmeter and a variable power supply. Set the power supply to 14.3 V. Connect the battery negative and power supply negative leads together at a circuit-board ground point. Connect the PV positive and battery positive lead, and the power supply positive leads together. The charging LED should be on. If not, adjust trimmer R3 until it comes on. Check for +8 V at the $V_{cc}$ pins of the LM358 and the LM555. You should also see + 5 V from the LM336Z5.0 diode.

Quickly move the trimmer from one end of its travel to the other. At one point the LED will go dark. This is the switch point. To verify that the "off pulse" is working, as soon as the LED goes dark quickly reverse the direction of the trimmer. The LED should remain off for several seconds and then come back on. If everything seems to be working, it's time to set the state-of-charge trimmer.



**The Micro M+ Charge Controller board, small enough to mount inside your rig, is shown connected to a solar panel and a rechargeable battery.**

Now, slowly adjust the trimmer until the LED goes dark. You might want to try this adjustment more than once as the closer you get the comparator to switch at exactly 14.3 V, the more accurate the Micro M+ will be. Here's a hint I've learned after adjusting hundreds of Micro M+ controllers. Set the power supply to slightly above the cutoff voltage you want. If you want 14.3 V, then set the supply to 14.5 V. I've found that in the time it takes to react to the LED going dark, you overshoot the cutoff point. Setting the supply higher takes this into account and usually you can get the trimmer set to exactly what you need in one try. That's all you need to do. Disconnect the supply from the Micro M+ and you're ready for the solar panel.

### Odds and Ends

The 14.3-V terminal voltage will be correct for just about all sealed and flooded cell lead-acid batteries. You can change the state-of-charge set point if you want to recharge NiCds or captive sealed lead-acid batteries.

Keep the current from the solar panel within reason for the size of the battery you're going to be using. If you have a 7-amp hour battery, then don't use a 75-W solar panel. You'll get much better results and smoother operation.

The tab of the power MOSFET is electrically hot. If you plan on using the Micro M+ without a protective case, make sure you insulate the tab from the heat sink. A misplaced wire touching the heat sink could cause real damage to both the Micro M+ and your equipment. A small plastic box from RadioShack works great.

### More Current?

Well yes, you can get the Micro M+ to handle more current. You must increase the capacity of the blocking diode and mount the power MOSFET on a larger heat sink. I've used an MBR2025 diode and a large heat sink for the MOSFET and can easily control 12 A of current.

### Battery Charging Without a Solar Panel?

Yes, that's possible, too. The trick is to use a power supply for which you can limit the output current. A discharged lead acid battery will draw all the current it can from the charging source. In a solar panel setup, if the panel produces 3 A, that's all it will do. With an ac powered supply, the current can be excessive. To use the Micro M+ with an ac powered supply, set the voltage to 15.5 V. Then limit the current to 2 or 3 A.

No matter if you're camping in the outback, or storing photons just in case of an emergency, the Micro M+ will provide your battery with the fullest charge. The Micro M+ is simple to use and completely silent. Just like the sun!

**Notes**

[1]"The Micro M," Sep 1996 *QST*, p 41.

[2]A 75-W module produces 4.4 A at 17 V. The Micro M+ can easily handle the extra 400 mA.

[3]A complete kit of parts is available from SunLight Energy Systems, 955 Manchester Ave SW, North Lawrence, OH 44666. A complete kit including all parts and PC board is $30 plus $4 US Priority mail. Visa, MasterCard accepted. Tel 330-832-3114; **www.seslogic.com/**.

# FEEDBACK

◊ In “The Micro-M Charge Controller” (Oct 2001 *QST*, page 30), the reference to R2 in the shaded sidebar should read, “from 49.9 kΩ 1% to 82.5 kΩ 1%.”

◊ Press Jones, N8EUG, of The Wireman, has called our attention to the fact that some information was left out of the New Products announcement for the CQ113PE coaxial cable (New Products, October 2001, page 100). The description should have read: The center conductor, solid polyethylene dielectric and 97% copper braid follow the specification for Mil SpecRG-213/U and its predecessor RG-8A/U, but CQ113PE then includes a moisture blocking material and adds a tough, UV resistant, abrasion fighting, moisture impermeable, black polyethylene jacket.

◊ Georg, DJ1YJ, points out an error in Figure 2 of “Uncle Albert’s Touch Pad Keyer,” by Sam Ulbing, N4UAU (Oct 2001 *QST*, page 33). The connecting dots at the wire intersections for Q4 through Q7 are not shown, making it appear that the sources are not connected to ground.