BUILD THE BATTERY TOOL

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NiCad Battery Analyzer
ENTER A NAME FOR THE BATTERY BEING TEST
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NiCad Battery Analyzer
!!!!!!!!!!! WARNING !!!!!!!!!!!
MAKE SURE POSITIVE (+) OF BATTERY IS CONNECTED TO RED TERMINAL...
MAKE SURE NEGATIVE (-) OF BATTERY IS CONNECTED TO BLACK TERMINAL...
CONNECT BATTERY TO BATTERY TOOL...
PRESS 'C' TO CONTINUE...
PRESS 'Q' TO QUIT...
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Get the most out of your rechargeable batteries with this microcontroller-based battery discharger.

FRED EADY

TIMES HAVE CHANGED-YOU'D PROBably be surprised at the number of devices containing some sort of rechargeable battery that you use on a regular basis. Cordless phones, mixers, radio-controlled gear, emergency flashlights, camcorders—and even vacuum cleaners—are just a few examples. The list goes on, but let's just say that rechargeable batteries are popular because of their convenience and reusability. Because you pay more for rechargeable cells, and depend on them for extensive use, it is imperative that you get maximum performance from them. But you can't do that unless you understand their physical nature.

The secret to rechargeable battery life and performance is proper conditioning and use. To condition a battery, you must discharge the internal cells to a predetermined voltage that is well below the operating level of most electronic equipment and that is beyond the "knee" of the discharge curve. Ni-Cd batteries exhibit a linear discharge rate over the majority of their discharge cycle. However, at some point just before full discharge, the voltage drops off sharply. That sharp downturn in voltage is called the "knee" (see Fig. 1).

Conditioning allows charged electrode material, that is not normally used, to be discharged or "exercised" to prevent premature battery-voltage droop, or kneeing. The premature voltage droop, or premature knee, is commonly mistaken for the battery malady known as "memory." Memory is virtually impossible to create during typical battery use. It takes laboratory-grade equipment and multiple precise charges and discharges to create the memory effect. The performance degradation you perceive as battery memory is actually due to the fact that not all of the charged electrode material in the cells of the battery is available for use by your equipment. That is, the battery has not been cycled, or discharged, sufficiently.

To properly facilitate the cycling process, the battery discharge current and end-point battery cutoff voltage must be carefully monitored to avoid damaging the cells. There are three ways to accomplish this: First, you purchase expensive laboratory-grade equipment specifically made for the purpose. Second, you can set aside a day and cycle the battery manually. But third, you can use the inexpensive, easy to build Battery Tool.

The Battery Tool is a microcontroller-based instrument that performs a controlled, user-determined, constant-current discharge on any type of rechargeable battery. Battery voltage can be as high as 18 volts, and the maximum discharge current can be set as high as 1.5 amperes..These maximums will accommodate most consumer batteries now in use. The Battery Tool monitors battery voltage and regulates the user-selected load current during the entire discharge cycle. Using the accompanying terminal program, you can determine such real-time parameters as 50% battery life voltage, 0% battery life voltage, battery capacity, knee voltage, and battery voltage under load. The Battery Tool also provides elapsed time and initial no-load battery voltage readings.

Since a history of battery performance is vital to determining when the battery is fully discharged or will not be able to provide useful service, the Battery Tool terminal program can save all of the above parameters to a disk file for retrieval and comparison later. The data collected during discharge can also be used to plot a typical battery discharge curve. If you're like most electronic experimenters, you have a gaggle of Ni-Cd's and chargers lying around. The Battery Tool can help determine if they are good or bad and, if they are good, what their capabilities are. Another plus for the Battery Tool is that you can build it for less than $100.

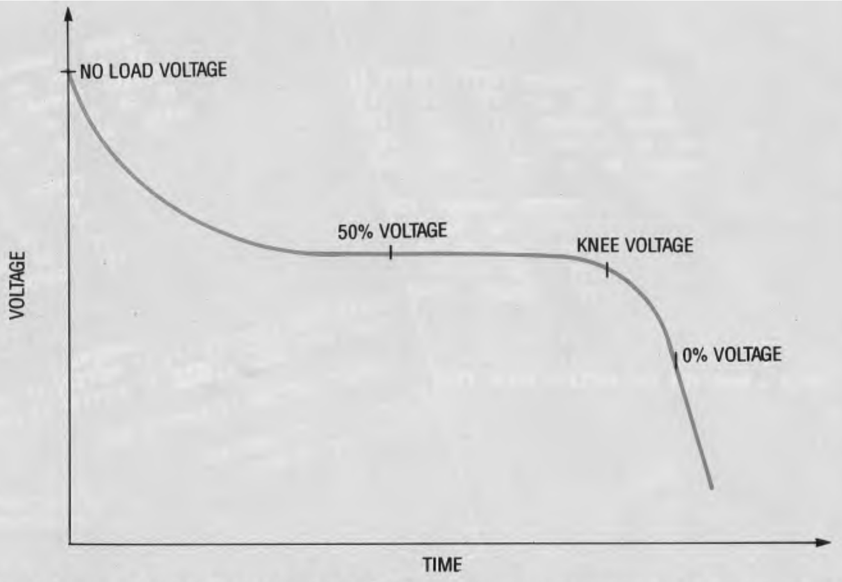
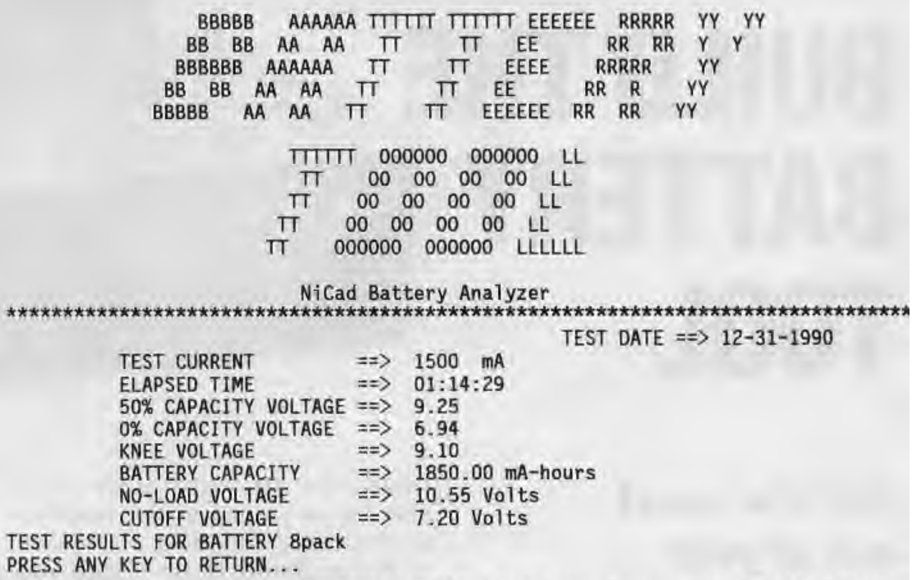


FIG. 1—TYPICAL RECHARGEABLE BATTERY CURVE. Proper conditioning entails controlled nondestructive discharging of the cells to a predetermined voltage that is well below the operating voltage of most electronic equipment.



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              BBBBB   AAAAAA TTTTTT TTTTTT EEEEEE  RRRRR  YY  YY
             BB  BB  AA  AA   TT     TT   EE      RR  RR  Y  Y
            BBBBBB  AAAAAA   TT     TT   EEEE    RRRRR    YY
           BB  BB  AA  AA   TT     TT   EE      RR  R    YY
          BBBBB   AA  AA   TT     TT   EEEEEE  RR  RR   YY

                      TTTTTT  000000  000000  LL
                       TT    00  00  00  00  LL
                      TT    00  00  00  00  LL
                     TT    00  00  00  00  LL
                    TT    000000  000000  LLLLLL

                      NiCad Battery Analyzer
********************************************************************************
                                                   TEST DATE ==> 12-31-1990
          TEST CURRENT          ==>  1500  mA
          ELAPSED TIME          ==>  01:14:29
          50% CAPACITY VOLTAGE ==>  9.25
          0% CAPACITY VOLTAGE  ==>  6.94
          KNEE VOLTAGE          ==>  9.10
          BATTERY CAPACITY      ==>  1850.00 mA-hours
          NO-LOAD VOLTAGE       ==>  10.55 Volts
          CUTOFF VOLTAGE        ==>  7.20 Volts
TEST RESULTS FOR BATTERY 8pack
PRESS ANY KEY TO RETURN...
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FIG. 2—A COMPLETED BATTERY TOOL TEST. All of the parameters are saved in a file to compile a history of battery performance.

What does it all mean?

Figure 2 shows a completed Battery Tool test. Note that all of the parameters are included and saved in a file. The idea is to compile a history of battery performance. As the battery wears out, or if you accidentally abuse it, you can retrieve the history and determine just how much wear or damage has resulted. By using the Battery Tool, you'll never again have to guess about the condition of a particular rechargeable battery.

Let's talk about what all those real-time event readings tell you. The "test current" is the amperage drawn from the battery during the test. "Elapsed time" is the time it took to run the test. The "50% capacity voltage" represents both the average overall battery voltage during a test and the voltage at the point where half of the battery's useful charge is left. The 50% value is dependent upon the cutoff voltage you specify. Use your best judgment or, better yet, consult the manufacturer's recommendations when selecting your battery's cutoff voltage.

The "0% capacity voltage" is a calculated measurement that

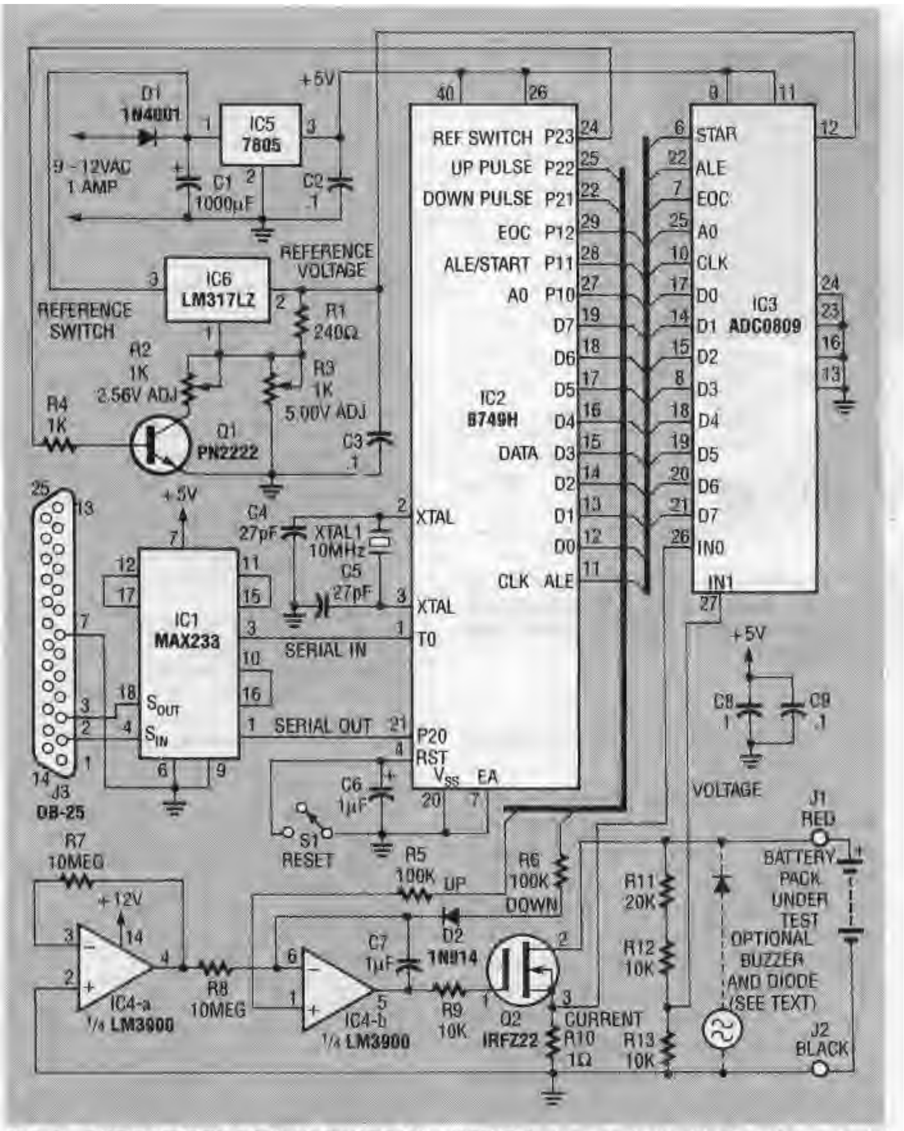


FIG. 3—THE BATTERY TOOL IS BASED ON AN 8749H microcontroller that performs serial I/O, analog-to-digital processing, and battery monitoring functions. A MAX233 converts TTL voltage levels to RS-232-C voltage levels and vice versa to simplify the serial interface between the Battery Tool and the terminal program.

projects the probable voltage under load that would be read when all usable battery energy is depleted. The projected reading is based on conventional Ni-Cd battery formulas involving the 50% calculation. The zero-capacity condition should occur after the knee has formed.

The "knee voltage" defines the voltage point at which the characteristic knee will occur. The value is calculated by taking into account the 50% battery voltage versus time.

The "battery capacity" is just that. That is, if you were to look at your particular cells closely you would find a manufacturer's capacity rating or rated cell capacity. On a AA Ni-Cd cell that's usually between 450 to 550 milliampere-hours. That says under normal temperature and load conditions, the cell should be able to deliver the rated current for 1 hour. That may be true for new cells, but wear and misuse can reduce the performance figure. The Battery Tool gives you the real-world performance figures so you can most effectively use the chemical energy supplied by the battery. The Battery Tool calculates battery capacity every 60 seconds using the user-defined load current versus time.

The "battery no-load voltage" is the voltage measured with the battery at rest with no resistive load applied. Its only purpose is to give the user an indication of what the battery voltage is before loading.

Theory of operation

As shown in Fig. 3, the Battery Tool is based on IC2, an 8749H microcontroller, running at a clock speed of 10 MHz. The 8749H performs serial I/O, analog-to-digital processing, and battery-monitoring functions, as well as supplying the clock source for the analog-to-digital converter by executing a program contained in its internal EPROM. The 8749H is reset via S1 and C6. Note that we ran a story on an 874X-series microcontroller programmer (see **Radio-Electronics,** November 1991).

A MAX233, IC1, converts TTL voltage levels to RS-232-C voltage levels and vice versa to simplify the serial interface between the Battery Tool and the terminal program. Note that no external charge-pump capacitors or power supplies are needed to generate the necessary negative RS-232 voltages as with other RS-232 devices.

An ADC0809 8-channel, 8-bit analog-to-digital (A/D) converter (IC3) monitors voltage levels from the battery under test. Microcontroller IC2 initiates a voltage or current measurement by selecting IC3's channel 0 (INo, pin 26) for current readings or channel 1 (IN1, pin 27) for voltage readings by applying a low or high respectively to pin 25 (Ao) of IC3. Depending upon whether current or voltage is to be measured, IC2 also selects the correct reference voltage for pin 12 of IC3 by turning reference-switch transistor Q1 on and off—Q1 is turned on for current measurements and off for voltage measurements. The reference voltage—either +5.00 volts for voltage measurements or +2.56 volts for current measurements—is generated by potentiometers R2 and R3, resistor R1, bypass capacitor C3, and variable voltage regulator IC6 (an LM317LZ).

To initiate a reading, IC2 simultaneously applies a high pulse to IC3's ALE and START pins 22 and 6. Once IC3 reads the appropriate voltage input at either pin 26 (current) or pin 27 (voltage), it performs an internal A/D conversion. When conversion is complete, IC3 signals IC2 that the 8 bits of converted analog data on its bus are valid by raising pin 7 (Eoc, or End Of Con-

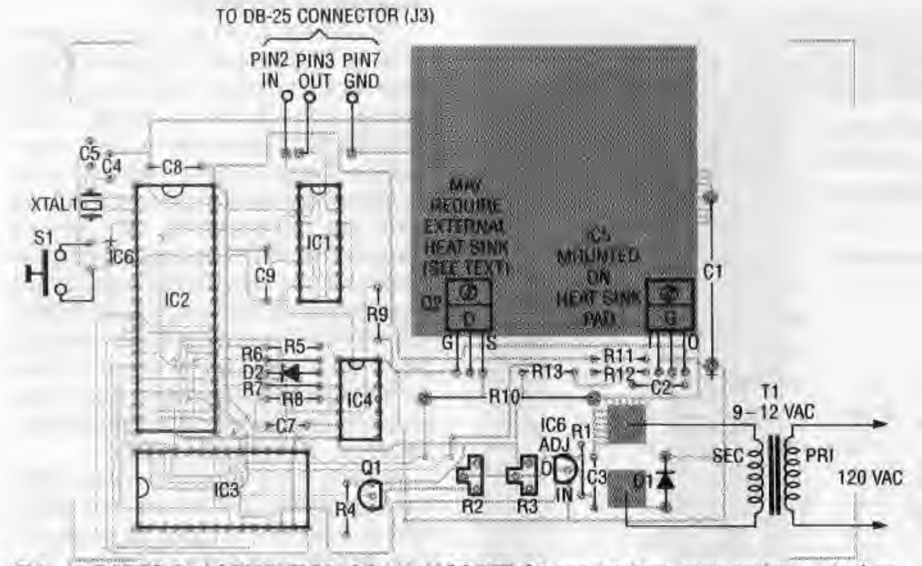


FIG. 4—PARTS-PLACEMENT DIAGRAM. MOSFET Q2 can be bent over and mounted on the heatsink pad along with IC5 if you intend to monitor batteries with four cells or less but must be insulated from the pad. If you will be monitoring battery packs with more than four cells, Q2 requires more substantial heatsinking (see text).

version). The data that is sampled by IC2 is either used by IC2 or sent in raw 8-bit form to the terminal program via IC1 for further processing.

Because IC3 can measure only voltages, it is necessary to derive current readings from known voltages and resistances. Since we are looking for a resultant current, voltage and resistance must be constants. Ohm's Law says that current is equal to voltage divided by resistance, or I = E/R. So, if we are measuring current, and IC3 measures 1 volt across R10, which in our case is 1 ohm, Ohm's Law says that I = 1/1, resulting in 1 amp flowing through R10. The 8-bit representation of 1 volt generated by IC3 causes IC2 to vary the resistance of MOSFET Q2 and regulate the load current.

Because, as mentioned before, IC3 is a voltage-measuring device, voltage measurements—as opposed to current measurements—are more straightforward. Resistors R11–R13 make up a low-power precision voltage divider that is placed across the battery's positive and negative terminals. The voltage-divider resistances were selected with two design points in mind: First, to draw insignificant current from the battery under test, and second, to divide the battery voltage by 4. In this application IC3 has a voltage-measurement range of 0 to + 5 volts DC. That restriction would severely hamper the usefulness of the Battery Tool, so the R11–R13 voltage divider is used to prescale the output data provided by IC3.

Note that IC3 can resolve to 256 discrete steps including step 0 (0 volts DC). When the reference voltage at pin 12 of IC3 is +5 volts, each voltage step resolved by IC3 is + 5 volts divided by 256 steps, or 0.0195 volts per step. The prescaling enables IC3 to effectively read a minimum of 0 volts DC and a maximum of + 20 volts DC. The terminal program processes the 8 bits of sampled data and computes the corresponding battery voltage which is displayed to you in real time. The maximum allowed battery voltage is also controlled by the terminal program. Also, IC2 uses the voltage data to determine if the preset cutoff voltage has been reached. If the battery under test exceeds 18 volts, the terminal program immediately removes the resistive load from the battery and halts the test.

With respect to current readings, each digital step is 0.01 volts, because of the 2.56-volt reference, so a maximum current of 2.56 amperes can be sensed. The limiting factor as to how much load current can be applied is dependent upon the power dissipation capacity of power resistor R10. The terminal program limits the operating test current to 1.5 amperes, which falls safely within the 5-watt dissipation rating of R10.

It would be impossible to get any accurate voltage or current measurements from any battery if the load current was not maintained at a constant value. Remember that if any of the three values used in Ohm's Law change, all others are affected. So, to get maximum measurement accuracy, IC2, IC4, and Q2, along with resistors R5–R9, blocking diode D2, and capacitor C7, form a low-drift ramp-and-hold circuit.

Here's how that circuit works. The first gate of IC4 (IC4-a) provides a very low input bias current to the input of the second gate, IC4-b. The bias gate elimi-

PARTS LISTS

All resistors are ¼ watt, 5%, unless otherwise noted

R1—240 ohms
R2, R3—1000 ohms, potentiometer
R4—1000 ohms
R5, R6—100,000 ohms
R7, R8—10 megohms
R9—10, 000 ohms
R10—1 ohm, 5 watts, 1%
R11—20,000 ohms, 1%
R12, R13—10,000 ohms, 1%

Capacitors

C1—1000 µF, 16 volts, electrolytic
C2, C3, C8, C9—0.1 µF, ceramic
C4, C5—27 pF, ceramic disk
C6—1 µF, 16 volts, tantalum electrolytic
C7—1 µF, metal film

Semiconductors

IC1—MAX233 RS-232 driver
IC2—8749H microcontroller
IC3—ADC0809 8-channel 8-bit A/D converter
IC4—LM3900 quad op-amp
IC5—7805 5-volt regulator
IC6—LM317LZ adjustable regulator
D1—1N4001 diode
D2—1N914 diode
Q1—PN2222A NPN transistor
Q2—IRFZ22 MOSFET

Other components

S1—SPST momentary pushbutton switch
XTAL1—10 MHz crystal
J1, J2—red and black banana jacks (or whatever best suits your needs)
J3—female DB-25 connector

Miscellaneous: PC board, case, 18-gauge wire, heatsink (see text), 9–12 VAC 1-amp transformer, ribbon cable, hardware, IC sockets, solder, etc.

Note: The following items are available from Fred Eady, 1320 Anchor Lane, Merritt Island, FL 32952:

- **Kit of parts with a programmed microcontroller and PC board (not including connectors, heatsink, and case)—$89.00 + $2.50 S&H**
- **Programmed microcontroller only—$20.00 + $2.50 S&H**
- **PC board only—$25.00 + $2.50 S&H**
- **Software on a 5¼-inch disk—$5 postpaid**

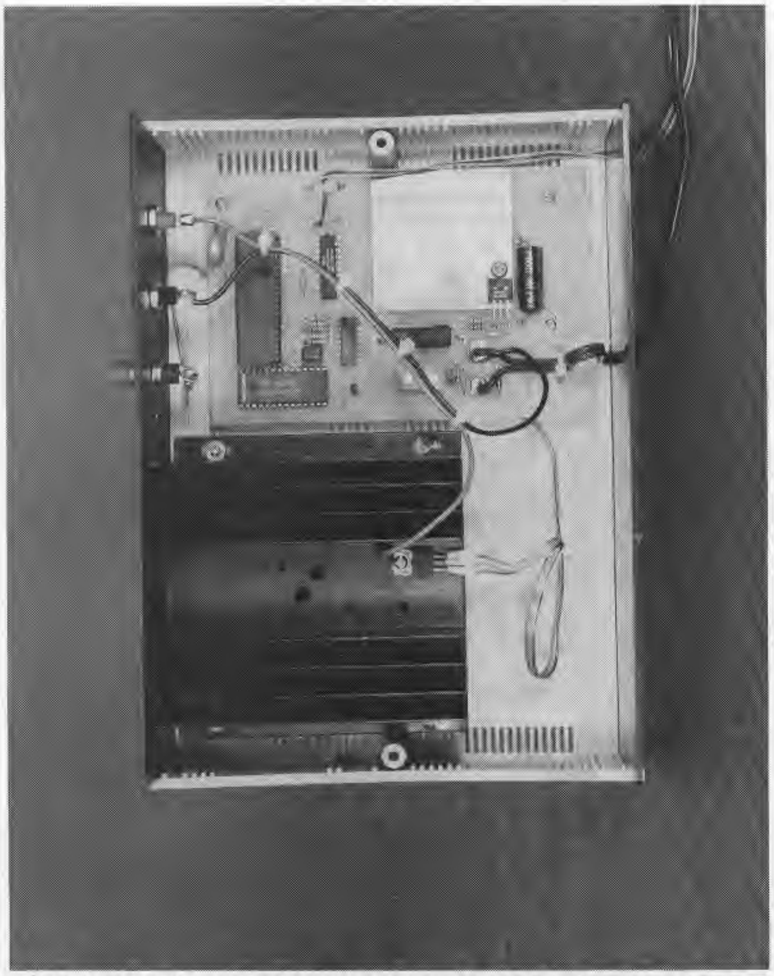


FIG. 5—THE AUTHOR'S PROTOTYPE. Notice how MOSFET Q2 is mounted on a separate heatsink. (You certainly don't need such a big heatsink; use whatever you have on hand, which is what the author did.)

nates the need for FET transistors and special-purpose integrated circuits normally needed for sensitive ramp-and-hold applications. The matched amplifiers found in the LM3900 op-amp are also helpful in this area.

Microcontroller IC2 supplies either a high or low TTL voltage level to resistors R5 and R6 via output port pins 22 and 23. (Note that, in Fig. 3, R5 is marked "up" and R6 is marked "down.") When a low TTL level is applied to both R5 and R6, the ramp and hold circuit is in the hold state. Thus the voltage at IC4 output pin 5 is stable. The higher the quality of capacitor C7, the less voltage drift at pin 5. Applying a TTL high to R5 while holding R6 low causes the voltage at pin 5 of IC4 to rise. Conversely, applying a TTL high to R6 while holding R5 low decreases the voltage at pin 5 of 1C4.

The output voltage at pin 5 of IC4 is fed through R9 to the gate of Q2, an insulated-gate MOSFET power transistor; think of Q2 as simply a high-wattage potentiometer whose wiper is the voltage supplied by IC4. As the voltage on the gate of 92 increases, the resistance between 92's drain and source decreases, and vice versa. A high-wattage precision voltage divider is formed by Q2 and precision power resistor R10. By Ohm's Law, we know that current is constant in a series of resistances while voltage differs at each resistance node. Now comes the good part: if we measure the voltage across the 1-ohm precision resistor and control the voltage drop across it using Q2, we can produce a constant load across a battery independent of the battery's voltage and operating temperature.

In summary, the user tells IC2 via the terminal program what load current to place on the battery under test. Microcontroller IC2 ramps the battery up to the selected current by reading the voltage drop across R10 that is monitored by IC3. The sampled voltage drop is compared to the user-selected load-current value (actually a converted voltage drop value) sent to it by the terminal program. If the sampled voltage drop (current) reading is too high, a "down" command is sent to the ramp and hold circuit thus increasing the resistance across the drain and source of Q2, thereby reducing the voltage drop across R10. That of course has the effect of lowering the current across the precision voltage divider formed by Q2 and R10. The opposite is true if the comparison is too low. The process takes place hundreds of times per second providing a varying resistance able to track a varying voltage, resulting in a constant current independent of the battery voltage.

Construction

Using the supplied foil patterns, you can make your own PC board. If you would prefer not to make your own, a professionally prepared PC board is available—see the parts list. Following Fig 4 as a guide, begin assembly by installing voltage regulator IC5, rectifier diode DI, filter capacitor Cl, and decoupling capacitor C2. Note that IC5 should be bolted down to lie flat against the heatsink pad on the PC board. Temporarily connect a 9-12 VAC, **l-amp** source to the pads indicated in Fig. 4 and apply power; there should be + 5 volts DC at the output (pin 3) of regulator IC5. Remove power and install IC6, R1–R4, 91, and C3, observing proper orientation of 91 and IC6.

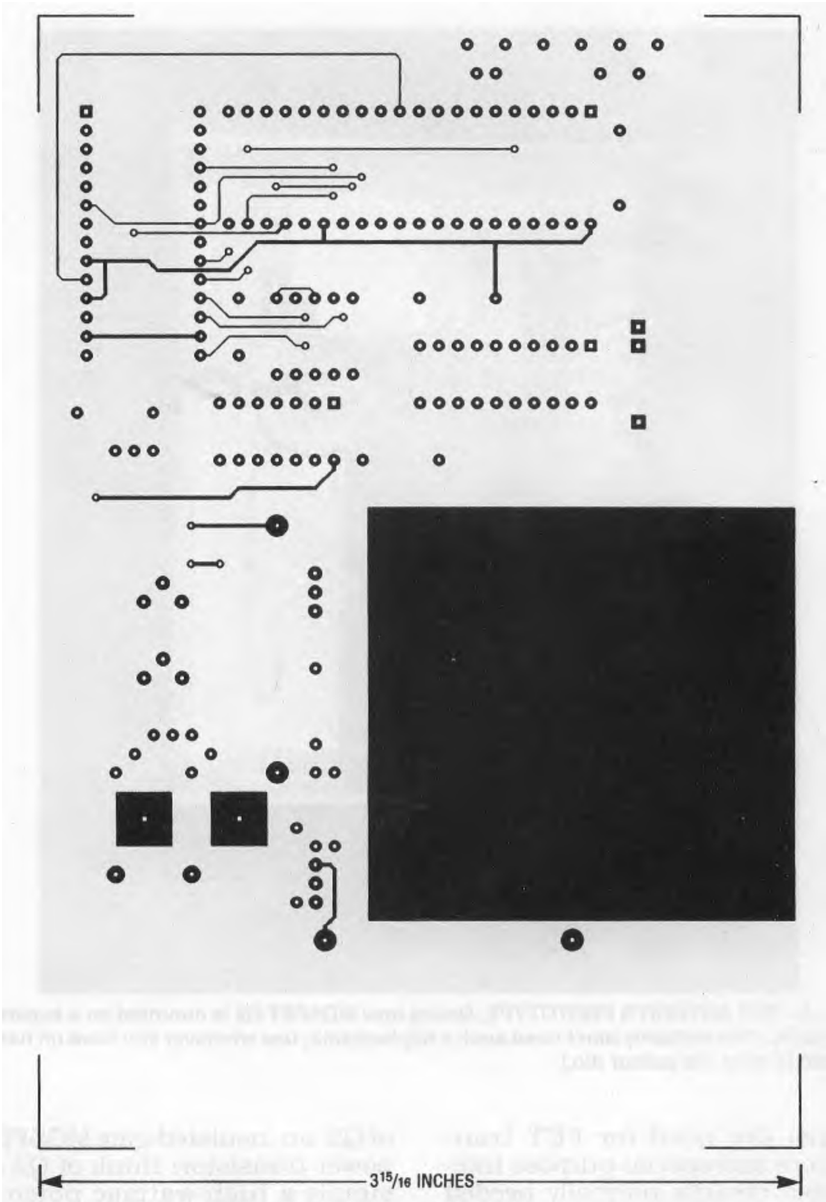
To perform reference-voltage calibration, connect a jumper between the end of R4 that is *not* connected to the base of 91 and ground. Grounding R4 will assure that 91 is off and allows the adjustment of R3 for + 5.00 volts at the output of IC6; apply power and make the adjustment. After adjusting R3, disconnect the grounded end of the jumper and connect it to the + 5-volt output of IC5; that turns 91 on and places potentiometers R2 and R3 in parallel. Adjust R2 for a reading of + 2.56 volts DC at the output (pin 2) of IC6. Recheck both the + 5.00- and the + 2.56-volt adjustments until you can alternate between them by moving the jumper without further adjustments to either R2 or R3. Remove power and the jumper before proceeding any further.

Install components IC2, XTAL1, and C4—C6. You may also temporarily connect reset switch S1 at this time. Once again apply power and, using a logic probe, check for oscillation at pin 11 of IC2; if it doesn't oscillate, check power connections, the clock circuit (consisting of XTAL1, C4, and C5), and make sure Si is not closed. If pin 11 is oscillating, check to see that the oscillation stops when S1 is closed. Oscillation at pin 11 of IC2 indicates that the IC is operating properly.

Complete the board by mounting IC3, IC4, R5—R13, C7, and D2. Recheck the reference voltages at pin 12 of IC3. Mount ICI and assemble the serial cable according to your needs. Most of you will use a DB-25 IDC (Insulation Displacement Connector) connector and 3 strands of ribbon cable connected between the points indicated in Fig. 4 and pins 2 (serial in), 3 (serial out), and 7 (signal ground) of DB-25 connector J1.

Note that MOSFET Q2 must be heatsinked. If you intend to monitor batteries with four cells or less, Q2 can be bent over and mounted on the heatsink pad along with IC5. BUT, if you do that, Q2 *must* be insulated from the pad because its metal tab gets connected directly to the positive terminal of the battery under test, while the 7805's tab is at ground potential. If you will be monitoring battery packs with more than four cells, Q2 requires more substantial heatsinking than just the foil pad. In that case, you can either mount Q2 on the board, along with a suitable heatsink, or mount it off the board on a heatsink and wire it to the appropriate PC pads as was done with the prototype shown in Fig. 5. Keep in mind that the larger the heatsink, the cooler the MOSFET runs, and the more stable the MOSFET's operation will be.

Install a solder lug on the heatsink tab of Q2 and solder a length of 18-gauge wire from the lug to a connector of your choice; the connector is for the positive terminal of the battery under test. The prototype uses standard red and black banana jacks for the battery receptacles, although you can use whatever you like. Solder a second piece of 18-gauge wire from the ground pad on the printed circuit board to the other battery connector.



COMPONENT SIDE of the Battery Tool PC board.

You can install the Battery Tool in a suitable case if desired. The prototype is housed in a 10" x 8" x 3" 2-piece plastic case. The banana jacks and the reset switch are mounted on the top panel, although the layout is not critical. The serial cable and AC power cable can enter the rear of the case. As shown in the schematic, you can install the optional diode and buzzer across the input jacks to indicate that the battery under test is connected with the wrong polarity.

Using the Battery Tool

Use of the Battery Tool is simple. The terminal program called TOOL.EXE, which is available on the RE-BBS (516 293-2283, 1200/2400, 8N1) as part of a self-extracting ZIP file called BATTOOL.EXE, prompts you through the entire process. (After downloading the file, simply type "BATTOOL. EXE , " and the file will unzip itself.) The ZIP file also contains the code for the microcontroller (TOOL.ASM), in case you want to program your own, although a programmed microcontroller is included in the parts kit. All of the software is also available on a 51/4-inch floppy