A versatile battery charger

IT'S EASY TO FIND BATTERY CHARGERS that are capable of handling one, two, or four cells at once. But when you have some device that requires some odd-ball number of batteries, or perhaps uses more cells than a single charging unit can handle at one time, what do you do? If you own one of the commercially available units, you must charge the maximum number of batteries. And then, after what seems like years, do the same for the remaining cells.

Because of that, I decided to build my own charger; one that would handle any number of AA cells, from one to six and charge at a rate of 50 mA as recommended by the cell's manufacturer. The result is shown in Fig. 1.

A look at the circuit

The operation of the circuit is pretty simple. The supply for the circuit is a conventional full-wave rectifier. An LM317 voltage regulator is configured as a constant-current source. It is used to supply the 50 mA charging current to SO1–SO6, an array of AA-cell battery holders Each of the battery holders is wired in series with an LED and its associated shunt resistor. When the battery holder contains a battery, the LED glows during charging.

Note that each of the battery holder/LED combinations is paralleled by a 5.1-volt Zener diode. If the battery holder is empty, the Zener conducts the current around the holder. An exception to that is SO1. A microswitch, S1, is inserted in that battery holder so that the switch is closed when a battery is in place. That switch is the power switch for the circuit.

The balance of the unit is a timing circuit that prevents overcharging. When power is applied to the circuit, timing is initiated by IC2, a CD4541 oscillator/programmable timer. The output of IC2 is fed to Q1, a VN67AF VMOS transistor. When that output is high, the transistor is on, and the charging circuit is completed. When the output is low, the transistor is off, and the path to ground is interrupted.

Note that resistors R1, R2, and R5

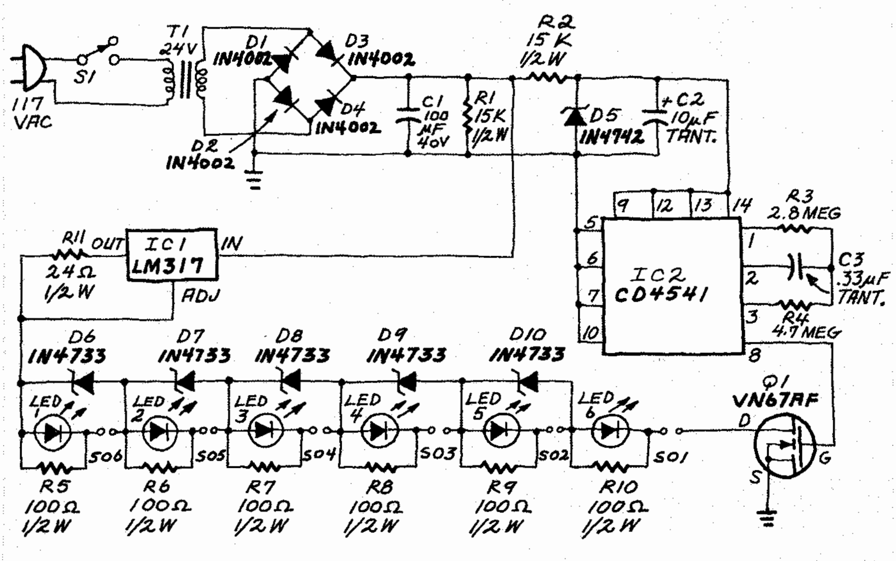


FIG. 1

1.7 Charging Methods

In brief, charging is the process of supplying direct current to the battery so as to convert it back into a chemical state at high energy level, capable of delivering electric power.

There are a variety of charging methods which can be used to charge sealed lead-acid batteries. From the view point of controlling the charging process, these methods can be classified into some basic categories: **constant-voltage, constant-current, tapered-current** and **combination charge systems.** (There are some other special methods used to control the charge by detecting internal pressure or battery temperature.)

The above types (with the exception of the special methods) are discussed here: [a summary chart appears in **section 1.6.1**]

1.7.1 Constant Current Charging

Constant current charging is one of the most well-known methods.

The advantage of constant current charging is the ease of determining the amount of capacity (amp hrs) supplied during charging; and there is no need for temperature compensation which is required in constant voltage systems.

On the other hand, the required charging time should be strictly adhered to, especially at high currents, which provides a full charge in a short period. On high-rate charge, the battery voltage rises excessively and the water decomposes, accompanying heat generation at the final stage of charge. This can damage a battery.

The constant current method, however, may be satisfactory when the charge rate can be kept at a relatively low rate and charging time is not critical.

Because of self-discharge, batteries require a refreshing charge from time to time during storage. A constant current charge may be used as a refreshing charge when many batteries are charged at one time, as this method will easily determine the amount of charge returned to the battery. **Batteries, which have been left on the shelf under the same known condition, shall be recharged approximately 120 percent of the lost capacity (Ah), as estimated from the data shown in Fig 7.**

If storage conditions such as temperature and time are known, but different for each battery, the charging amount shall be based on the worst storage condition or the largest lost capacity. For longest life, it is not recommended to repeatedly use constant current charging for refreshing the batteries.

It is also important to minimize the need to repeat the refreshing charge, by always keeping the batteries under a well-controlled stock rotation plan. ***Storing at lower temperature is the key to battery shelf life. If stored at a high temperature, batteries will require frequent refreshing charges.***

1.7.2 Constant Voltage Charging

It is very often necessary to restore batteries to a fully charged condition in as short a time period as practical. In doing this, much care must be exercised not to exceed specified charge rates or charge voltages as the battery is approaching a fully charged condition. A constant voltage charger can accomplish this type of charging. Ideally such a charger should have very stable output voltage and high current capacity, as extremely large currents are allowed to flow at the initial stage of charge, where the battery voltage is low. This type of charger, however, is not practical because the requirement of a high current capacity or a negligible small impedance for the power transformer, results in high cost and a large and heavy charger. Undesirable heat generation inside the battery cells, caused by initial high current, should also be taken into consideration.

In general, a commonly utilized constant voltage charger has a device to limit initial current. This current limitation can be accomplished by a constant-current regulator, a properly designed output voltage from the power transformer, or by designing the overall impedance of the circuit (for example by using a current regulating resistor). A constant voltage charger will perform effectively for charging in a short time, as during the final stage of charge the current automatically decreases, and the water decomposition will be minimized.

1.7.3 Tapered Current Charging

This is a simple and relatively inexpensive method. The circuit requires a power transformer, rectifiers and a suitable resistance for limiting current. In this system, the charging current drops gradually as the charging proceeds. If the impedance of the circuit is low, a step current slope can be obtained. This type for charge is generally considered to be unsuitable for charging sealed lead-acid batteries because the charging current will vary with fluctuation of line voltage as well as changes in battery voltage.

These effects, however, can be minimized by using a power transformer with a secondary voltage which is considerably higher than the battery voltage and a suitably high resistance in the circuit for current limiting. This type of charger will perform similar to a constant current charger, and can be utilized instead of a constant current charger for industrial uses; not only for recharging many batteries at one time, but also as a trickle charging system.

1.7.4 Combination Charging (Two-step)

A combination charging employs two types of charging. It's called a "Two-rate" or "Two-step" charging. A variety of couples can be made, such as constant-current/constant current, constant-voltage/constant-current and so on. In general the first step uses a quick or fast charge mode, and the second uses a low charge current. The switching from the first step to the second can be carried out by many different methods; battery voltage sensing, a time control, charge current sensing etc. **Some of these typical charging patterns are shown in Figure 12.**

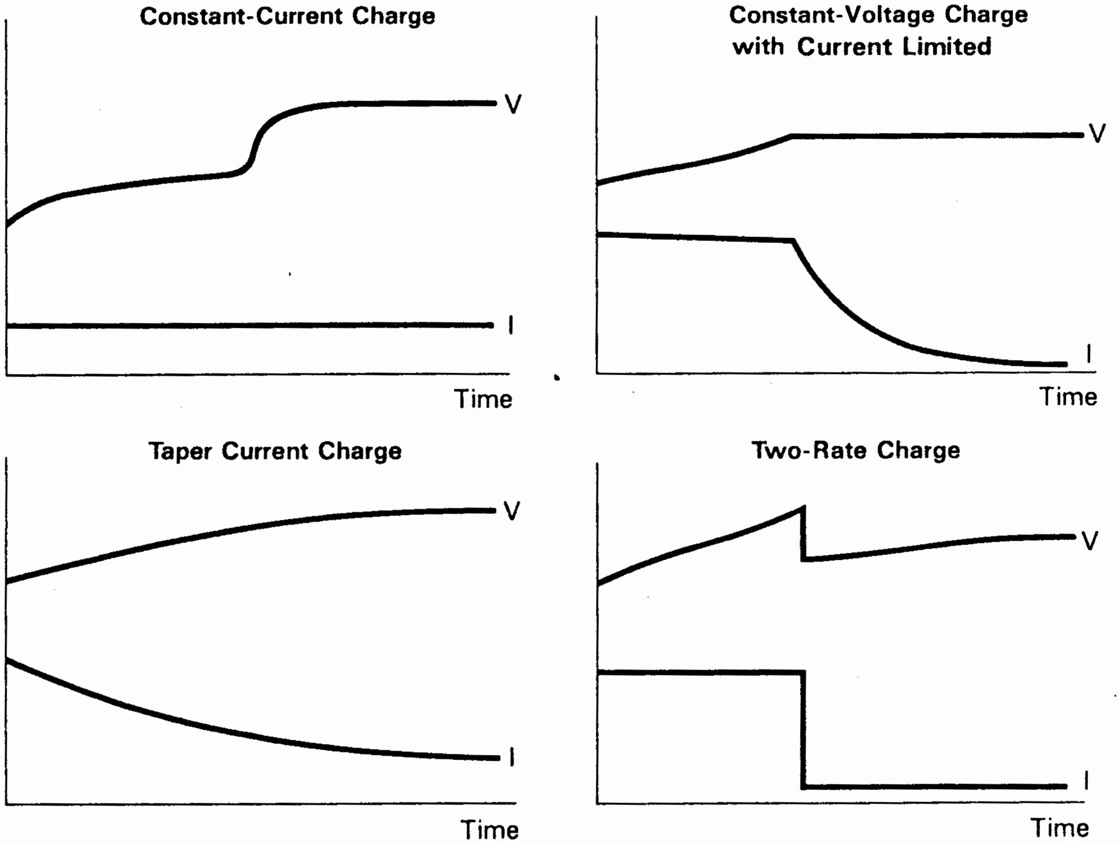


Figure 12
Typical Charging Patterns

1.7.5 Charging Application Notes

All of the charging methods discussed above are commonly used with satisfactory results. Applications of sealed lead-acid batteries can be classified roughly into two types; cyclic operation and standby service, and must be charged accordingly.

1.7.5.1 Cyclic Operation

Cyclic applications generally require a short time charge and protection against excessive charges and discharges, because the battery may be operated under unfavorable conditions by inexperienced users.
The most important requirements in a constant voltage charge technique are to hold the output voltage at the specified level at the final stage of charge, and to suppress the initial current below the designated maximum value as follows;

Constant Voltage Charge:
Initial current: 0.4 C* or less
Regulated voltage: 7.3 to 7.5V/per 6V battery
(Note) * C means the nominal capacity.
The regulated voltages are at a temperature of 68°F (20°C)

For a 12V- or a 24V-battery, the regulated voltage (above) shall be multiplied by 2 or respectively.
If the battery will be charged in a wide range of

ambients, **it is desirable for the charger to be temperature-compensated as shown in Figure 13.**

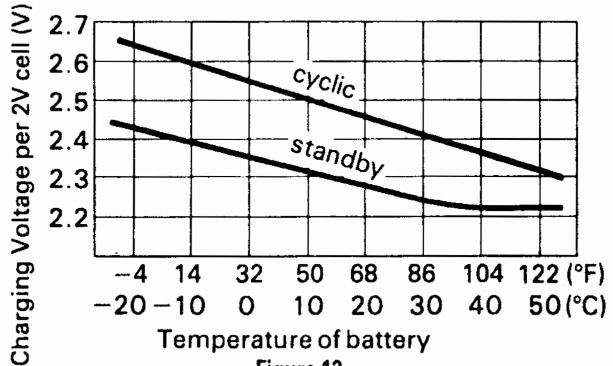


Figure 13
Recommended Temperature-Compensation for Voltage Regulation at the End of Charge

Without temperature compensation, the charge might be excessive in a high ambient area, insufficient in a low ambient area, resulting in cycle life patterns as illustrated in Figure 14.

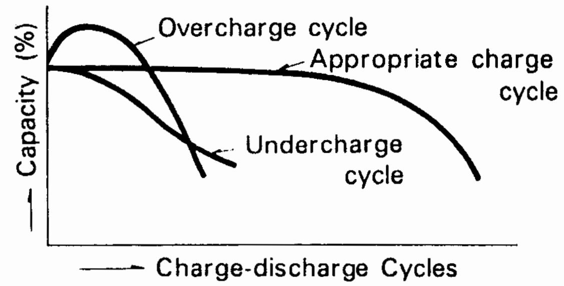


Figure 14
Cycle Life Patterns Resulting from Various Charging Conditions.

1.7.5.2 Standby/Backup Charging

LCR batteries (unless otherwise noted) can be utilized in standby applications, where they normally are kept in fully charged condition, and serve as a power supply to the load only when AC power fails. There are two modes of charging standby applications; trickle- and float-charge.

1.7.5.2.(a) Trickle Charge

This is a system in which AC power is normally supplied or operating the equipment, while charging the batteries which are not connected to the load. If AC power fails, a relay circuit connects the batteries to the load and battery power is supplied.

Trickle charging is generally considered to compensate for selfdischarge by continuously charging the battery at a low constant current to keep it fully charged. A constant voltage charge can accomplish this objective.

The appropriate current rate for trickle charge is **0.002C to 0.005C. (C/500 to C/200)**

In applications where AC power failure occurs infrequently, and the discharge is very small, the battery will be restored to a fully charged condition in short time, even at such a low current rate. In the case of deep discharges, this method will take an extremely long time to charge the battery. **A two-rate charger, or a constant voltage charger, is recommend for solving the problem, because of their initial quick charge modes. A two-rate charger has a distinct advantage, as there is no need for temperature-compensation.**

A constant voltage charger requires some precautions as follows:

(1) In these applications, the batteries are subjected to constant charging so long as a voltage difference exists between the battery and charger voltages. The charger voltage, therefore, must be stabilized in a narrow range during trickle charge.

(2) **When using the battery in a wide range of ambients, the charger should be temperature-compensated, as the charge characteristics will be greatly affected by the ambient temperature. (See Figure 13).**

Typical data for trickle charge application is shown in Figure 15.

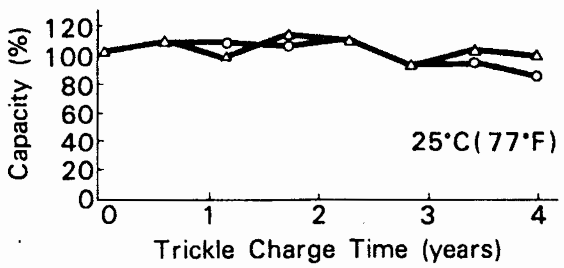


Figure 15 Trickle Charge Life

1.7.5.2.(b) Float Charge

This is a system in which the load and the battery are connected in parallel with the rectified power source.

This system requires only a constant voltage charger, in which the charge voltage is stabilized in a range of 6.8V to 6.9V per 6V battery, regardless of the power consumption by the load.

As the regulated voltage of a float charger is very close to the open circuit voltage of the battery, major fluctuations in the charge voltage may cause many small discharges of the battery while on float. In other words, the constant voltage charger should be designed for the maximum load, or the maximum load should be balanced within the stabilizing ability of the charger. Otherwise the life of the battery can not properly be estimated due to the irregular and complicated discharge patterns. In general, life in float service may be somewhat shorter than in trickle charge service.

1.7.5.3 Charger Design

1.7.5.3.(a) General Considerations

Battery life is affected not only by performance of the charger, but also by operating conditions. Charger, selection and design, therefore, must consider battery usage as well as charging characteristics. All charger designs use the same fundamental principles and require knowledge of the following basic parameters.

(1) the internal resistance of the batteries,
(2) the initial and final charge current and/or voltage value,
(3) the charges in battery voltage during the charging process,
(4) the required charging time,
(5) the effect of variable conditions such as ambient temperature and changes in voltage on the battery parameters,
(6) the maximum overall cost for the charger and batteries, and
(7) the expected battery life.

It should be noted that the resistances of lead wires and wire connections may be higher than the internal resistance of the battery.

1.7.5.3.(b) Unregulated Charger

This is one of the simplest chargers, and it is called a transformer type charger. This type of charger consists of a power transformer, diodes, and a resistive element for limiting current.

An elementary charging circuit is shown in **Figure 16** from which the following basic electrical relations are derived.

$$Edc = Eb + IR \qquad I = \frac{Edc - Eb}{R}$$

Where Edc is an impressed voltage from a direct current power source, Eb is battery voltage during charge, I is a charging current, and R is an overall impedance in the circuit (which consists of the internal battery resistance, rectifier dynamic resistance, current limiting resistance,and impedance of power transformer).

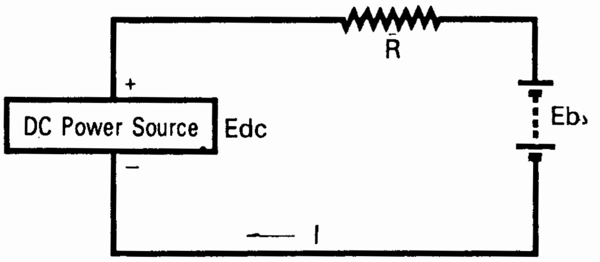


Figure 16
Elementary Charging Circuit

The DC voltage of the circuit decreases with increasing charge current due to the overall impedance. The V-I performance of the charger depends on the circuit resistance and the open the circuit voltage of the transformer. **Figure 17** shows three different V-I performances by chargers P-, Q- and R-. The circuits of P and Q have the same impedance, but different open circuit voltages. P- and R-circuits have the same open circuit voltage, but their impedances are different. The V-I relations of the battery at various states, from the discharged to the fully charged condition are also illustrated.

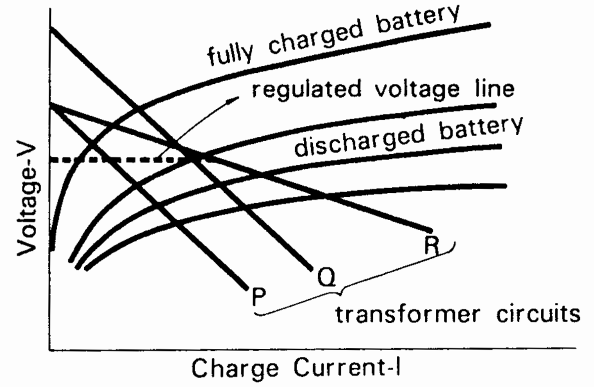


Figure 17
V-I Relations of Chargers and Battery at various states of charge

These three chargers having different V-I characteristics, will provide different charging performances as shown by solid lines in **Figure 18.**

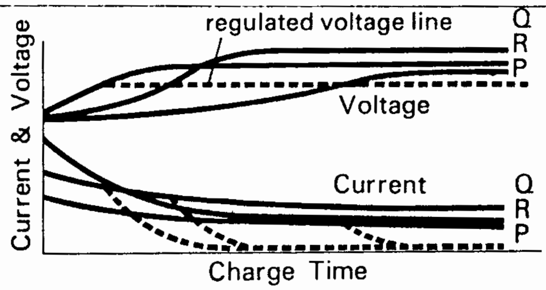
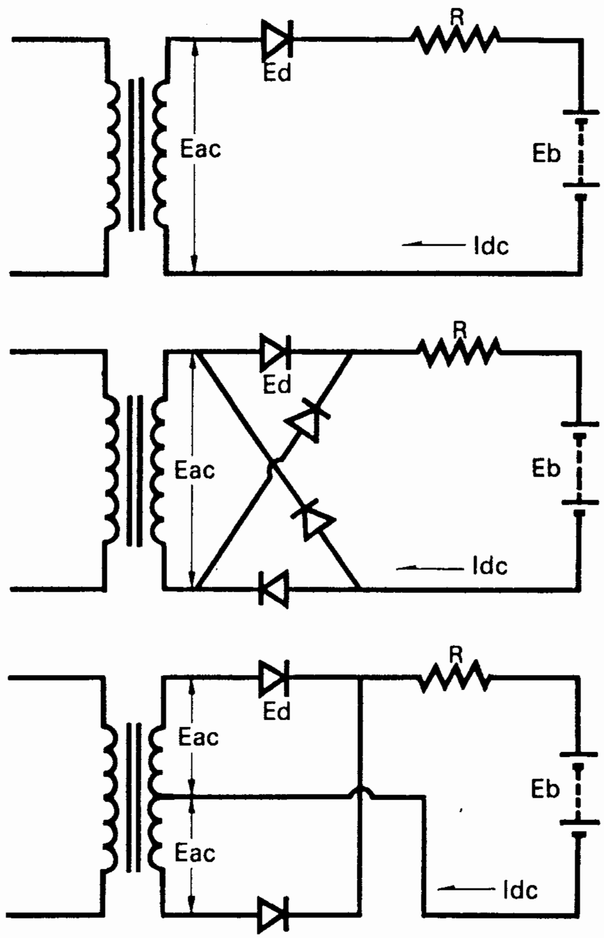


Figure 18
Charge Performances of P-, Q- and R- chargers having different V-I characteristics

The difference in V-I characteristics of the chargers results in different final steady state on charge voltages. However, if these circuits are connected to the batteries through a voltage regulating device, charge performance curves will reach the same final state. This constant voltage charger will be discussed in the next section. The single phase charging circuits and design equations are shown in **Figure 19.**



HALF-WAVE

$$Eac = K_1 (Eb + Ed) + K_2 Idc \cdot R$$

$$Irms = K_3 \ Idc \sqrt{2}$$

FULL-WAVE, BRIDGE

$$Eac = K_1 (Eb + Ed) + \frac{K_2}{2} Idc \cdot R$$

$$Irms = K_3 \ Idc$$

FULL-WAVE, CENTER TAP

$$Eac = K_1 (Eb + Ed) + \frac{K_2}{2} Idc \cdot R$$

$$Irms = K_3 \ Idc$$

Figure 19
Single Phase- Unregulated Charging Circuits and Design Equations

The symbols in **Figure 19** are as follows:

Eac = Open circuit rms source (secondary) voltage
Eb = Battery voltage during overcharge
Ed = Rectifier forward threshold voltage
Idc = Average overcharge current
R = Total circuit resistance
K_1 = DC voltage equation factor (taken from Figure 20)
K_2 = DC current equation factor (taken from Figure 20)
K_3 = Current form factor (taken from Figure 20)

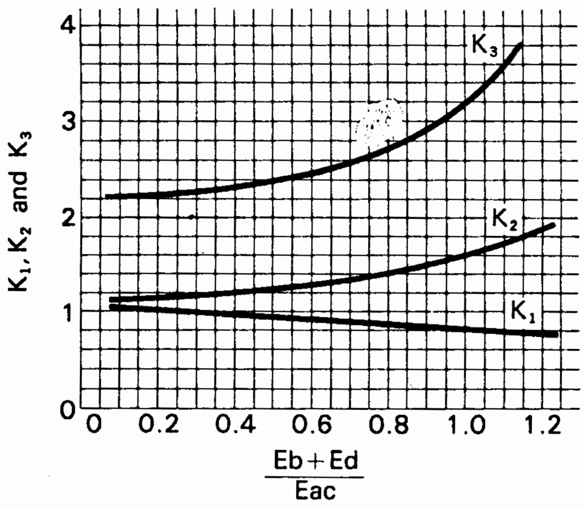


Figure 20
Design Equation Factors for Transformer Type Chargers

Charge currents at the 1-hour rate or less are commonly used in this type of charging system. Although the battery voltage during overcharge (Eb) varies with the charge rate and temperature, a value of 2.8 volts per cell is used with a satisfactory result for charger design calculations.

A smaller ratio of (Eb + Ed) to Eac requires higher resistance for current limiting, which results in higher power losses. However, this may minimize charge current changes with line voltage fluctuations. The ratio is commonly chosen to be between 0.4 and 0.7. The rectifier voltage drop (Ed) depends on diode materials and circuit types, as shown in the following Table 2.

Table 2 Rectifier voltage drops (Ed)

Type of circuit	Materials Silicon
Half-wave	0.8V
Full-wave, Center tap	0.8V
Full-wave, Bridge	1.6V

Peak inverse voltage (PIV) applied to the diode is the sum of the AC peak voltage ($\sqrt{2}$ Eac) and the battery voltage (Eb) for half-wave and, full-wave bridge type rectifications, or $2\sqrt{2}$ Eac for full-wave center tap.

Half-wave rectification is more economical than full-wave, if the product of Irms and Eac is small. Otherwise it is advisable to shift to full-wave rectification.

1.7.5.3.(c) Constant Voltage Charger

A constant votage charger is a system in which a voltage regulating device is put between the transformer circuit and the batteries, as shown in **Figure 21.**

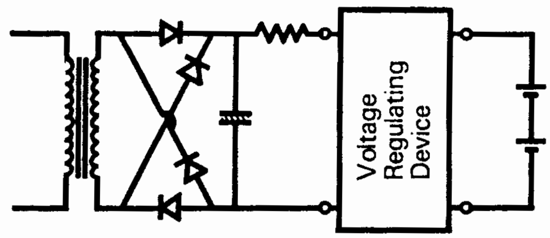


Figure 21
Charging Circuit with Voltage Regulation

The transformer circuit used in a constant voltage charger is generally required to have full-wave rectification, because of the relatively high DC current required.

The voltage regulating device includes a power transistor or thyristor to be connected in series with the batteries. Therefore, Ed in the design equations should include the voltage drop which a transistor or thyristor produces (0.8 or 1.1 volts, respectively).

Practical transformer design can be satisfied with the following rough calculation: the required rms secondary voltage of the transformer, supplying the desired initial current, is 3.5 to 4 volts in excess of the nominal voltage of the batteries. For example: to design a charger with an initial current of 1.0 ampere for a 12 volt battery, the transformer is required to have a secondary voltage of 15.5 (=12+3.5) volts when loaded at 1.0 ampere.

The voltage regulating device has a voltage detecting circuit which may allow a small current leakage from the batteries when AC line fails; and a diode for preventing reverse current flow may be put between the regulating device and the batteries, if necessary. In this case, however. the voltage drop caused by this diode should be included in the total diode voltage drop Ed. (It should be noted that the regulating device maintains a total potential equal to this diode plus the batteries, but does not apply a constant voltage to the batteries.)

In order to get a smooth current a filter capacitor is usually utilized. A big capacitance results in a large, well-smoothed current. But too big a capacitance may shorten life of the capacitor.

Characteristics of semi-conductors such as transistors diodes and Zener diodes, are all affected by temperature. Some have negative coefficients, and others positive ones. It is important to select semiconductors, and combine them, so that the voltage regulating device will have a temperature coefficient conforming to the battery characteristics.

SECTION V
METHODS OF CHARGING

FUNDAMENTAL PRINCIPLES

In order to recharge a storage battery after discharge, it is necessary to pass direct current through the cells in the proper direction (opposite to that of discharge) for a time sufficient to equal the ampere hours discharged, plus a small excess to make up for losses. This excess amount may vary from 5 to 20 per cent, depending upon the previous discharge, rate of discharge, age of battery, temperature, etc.

Proper charging simply means recharging sufficiently without excessive gassing, overcharging or overheating of the battery. In general, any charging rate is permissible which does not produce excessive gassing or a cell temperature exceeding 110°F (43°C).

CONDITIONS

The type of battery, service conditions, time available for charging, and the variation in battery voltages (number of cells) when charged in multiple, will determine which of the four following methods is best adapted to the solution of any particular problem. In charging lead acid batteries, the "finishing rate" of the charge is of the utmost importance and must not exceed the battery manufacturer's published values. Normally, lead acid batteries are recharged in eight hours based on normal discharged condition. However, batteries can be recharged over longer periods if time permits.

Before discussing various methods of charge, first review the volt-ampere characteristic of the lead acid battery during charge at various amounts of discharge. Figure 42 shows that a well discharged battery will absorb high charge rates at a relatively low battery voltage. It also shows that as the charge progresses, the voltage at end of charge is considerably greater than the voltage at the beginning of charge.

On this curve we have indicated ampere rates up to 40 per 100 ampere hour capacity. This means up to eight times finishing rate. This is a very high charge rate and is never used in normal charging but we have carried this curve to this high value to illustrate how much the voltage varies between rates at various percentages of charge. With modern charging equipment properly adjusted, the normal start charge rate to a completely discharged battery is in the area of 3-1/4 times finishing rate which usually is between 16.5 and 22.5 amperes on this curve.

Note the slight increase in voltage, even over this wide range of ampere rates between a 100% discharged battery and when 10% of the charge has been given to it.

An analysis of this curve will explain why, with modified constant voltage and taper charge, we have high charge

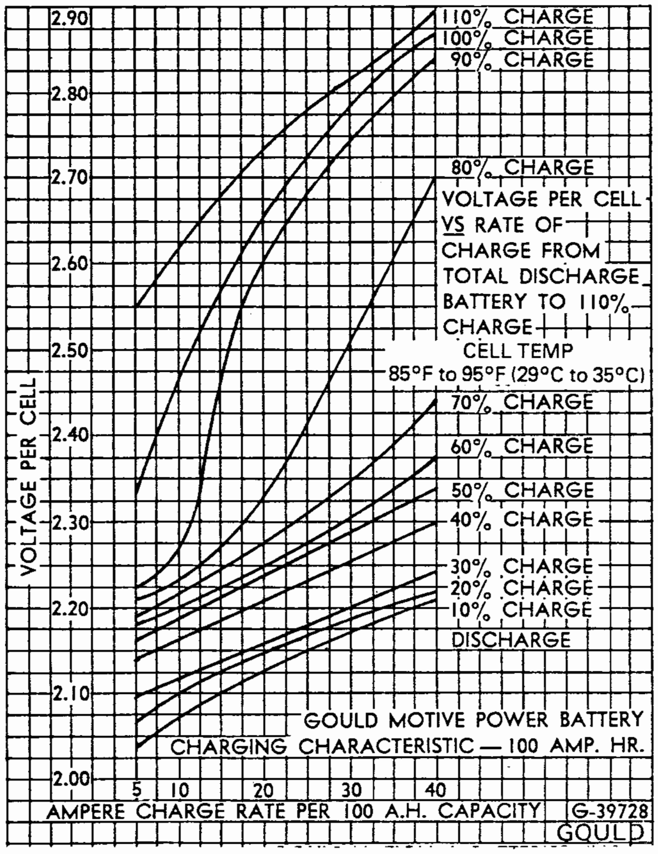


Figure 42. Charge Rate Characteristics

rates during the early part of a charge to a well-discharged battery and low end-of-charge rates when the battery is practically charged and yet no adjustment was made to the equipment during the charge.

This curve is not to be used for checking equipment. It is only for general information of battery volt-ampere characteristics.

METHODS OF CHARGING

MODIFIED CONSTANT POTENTIAL METHOD

In this method, the direct current voltage is maintained within a constant ± 3% of the rated voltage or 2.63 volts per each cell of the battery if an 8 hour recharge is required.

Figure 43 illustrates the relationship of volts per cell versus available time for recharge. Note for an 8 hour charge, 2.63 volts per cell is required of the power source; while for a 16 hour recharge, 3.27 volts per cell would be required. By the same comparison, on an 8 hour recharge 22-1/2 copy under figure 43 to be set smaller

(1) Hours Available for Recharge	(2) Bus Volts per Cell	(3) Resistance Values Per Cell: Normal "Tap"	(4) Resistance Values Per Cell: Max. to Provide	(5) Ampere Rates Per 100 A.H.: Start of Charge	(6) Ampere Rates Per 100 A.H.: Resistor Capacity
7.0	2.60	0.016	0.027	27.5	32.5
7.5	2.61	0.018	0.029	25.5	30.0
8.0	2.63	0.022	0.031	22.5	26.0
8.5	2.65	0.026	0.035	20.0	23.0
9.0	2.67	0.030	0.039	18.5	21.0
9.5	2.69	0.034	0.043	17.0	19.5
10.0	2.72	0.040	0.049	15.5	17.5
12.0	2.84	0.064	0.073	12.0	13.5
14.0	3.00	0.096	0.105	10.0	11.0
16.0	3.27	0.150	0.160	8.5	9.0

Design constants based on 100 ampere hour cell capacity. For cells of other capacity, external resistance per cell will be inversely proportional and ampere values directly proportional to the capacity. Cell resistance values correspond to electrolyte temperature 77°F (25°C).

Figure 43. Modified Constant Voltage Charging Design Constants

amperes per hundred ampere hours at start of charge is required; where the 16 hour recharge requires only 8.5 amperes per hundred ampere hours. The modified constant potential method of charge is illustrated in figure 44. Note in figure 43 that a charging resistor of sufficient current carrying capacity and resistive value may be selected to provide the proper start and finish rates of the battery.

The charging current, when using this method, will automatically be reduced as the charge progresses, to the ultimate finish rate of the battery.

When charging batteries in multiple from either a constant voltage source derived from a motor generator or rectifier, the modified constant potential method of charge is most acceptable, since the charge current inherently tapers during the charge, reducing the possibilities of severe overcharge.

The primary disadvantage of this method of charge is the loss in watts created by the necessity of ballast resistance. Furthermore, hot batteries will be charged excessively because the battery voltage will be depressed as the battery temperature increases which prevents the normal tapering of the charge current.

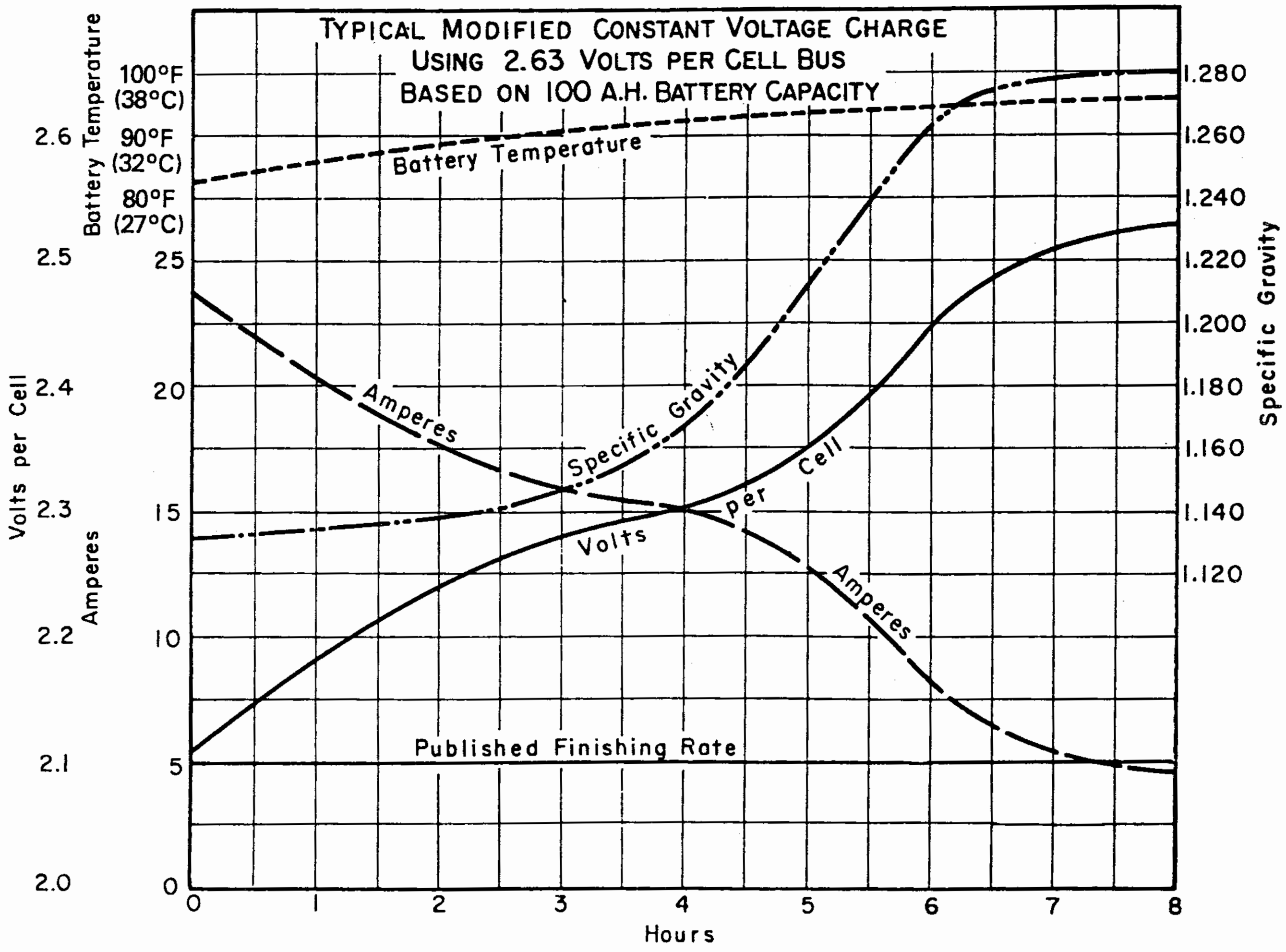


Figure 44. Typical Modified Constant Voltage Charge

To calculate the kilowatt requirements for motor generators to charge batteries in multiple from a fixed voltage bus in 8 hours would be as follows:

$$KW = \frac{A.H. \times 0.225 \times no.\ cells \times 2.63 \times 0.8 \times no.\ circuits}{1000}$$

Example: To charge four (4) 18 cell 500 ampere hour batteries:

$$\frac{500 \times 0.225 \times 18 \times 2.63 \times 0.8 \times 4}{1000} = 17\ KW$$

In figure 44 note the relationship of charge amperes to volts per cell. At the start of charge, we have approximately 22-1/2 amperes per hundred ampere hours at 2.135 volts per cell. At the end of charge, we have 5 amperes per hundred ampere hours and 2.52 volts per cell. These curves are typical of a modified constant potential method of charge.

TAPER METHOD

This method can apply to either generator or rectifier type equipment and can be considered a variation of the modified constant potential method of charge. It is employed only where one battery of a certain type and number of cells is to be charged. There are shunt wound motor generators so designed that their volt-ampere characteristics correspond to the modified constant potential type charge.

This is also true in the case of the controlled rectifier where the volt-ampere characteristic of the rectifier is designed to recharge the battery safely in a manner similar to the drooping voltage method of motor generators. In either case, no resistance is placed in series with the battery and the generator or rectifier is designed to provide the correct charge rate for the battery. Start of charge rates for lead acid batteries should be approximately four to five times the finish rate specified by the battery manufacturer. The rate in amperes will depend on the type of cell and the number of plates in the battery. The taper method of charge is not suitable for charging several batteries in parallel.

In order to meet the requirements of charging a single battery from a motor generator set, the following design perameters must be met:

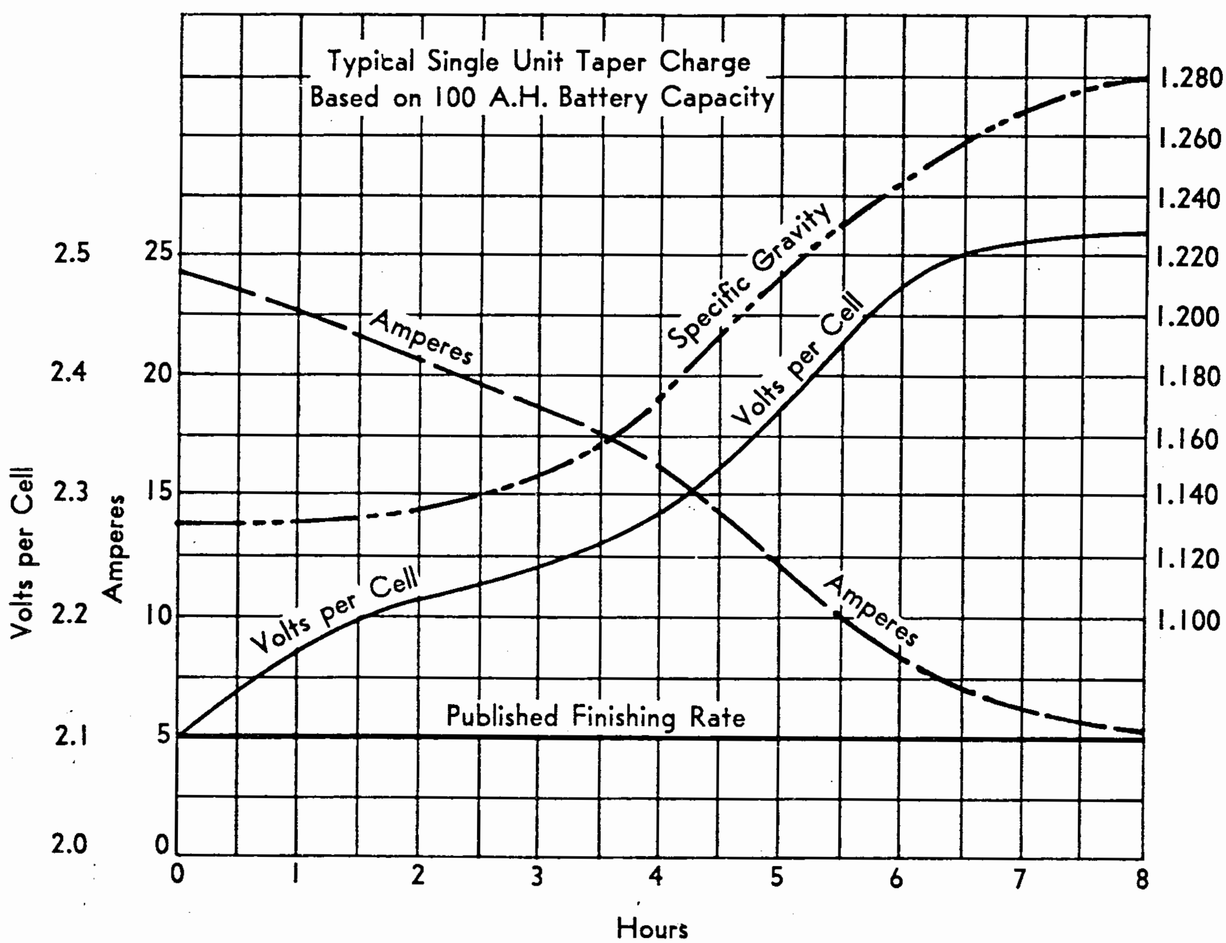


Figure 45. Typical Single Unit Taper Charge

The nominal voltage of the generator should be approximately 2.25 volts per cell. The generator should be so designed that at the start of charge, the generator voltage should droop to about 2.135 volts per cell. As the charge progresses, the voltage should rise in proportion to the increase of counter e. m. f. voltage of the battery being charged. At the end of 8 hours, the charging current should be approximately 5 amperes per hundred ampere hours and the voltage of the generator should rise to 2.52 volts per cell.

Figure 45 illustrates a charging curve produced by a single circuit motor generator having inherent taper characteristics.

TWO-RATE METHOD

Where the charging voltage available equals or exceeds 2.7 volts per cell, two-rate charging is necessary. Two definite resistor values are selected. One resistor is calculated, based on the output voltage of the power source, to provide the proper "start" of charge in amperes. The second resistor is selected with sufficient capacity in amperes and resistance, and is placed in series with the "start" resistor so that when it is switched into the circuit the two resistors will provide the proper "finish rate."

The "charge rate" (or when the charge rate resistor is incorporated into the circuit) will usually occur at the gassing point of the battery. Which is when the average cell voltage of the battery reaches 2.37 volts per cell.

Figure 46 illustrates the charge curve characteristic when utilizing the two-rate method of charge. Note that when the battery reaches the gassing point, there is a sharp decrease in charging current.

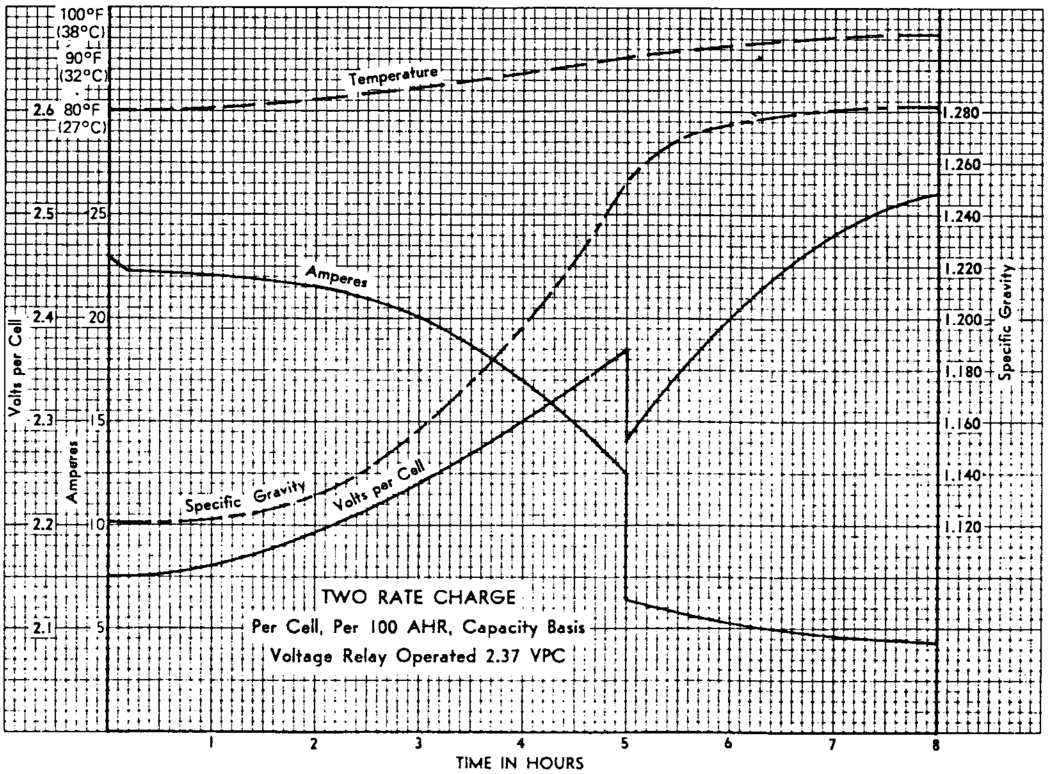


Figure 46. Two-Rate Charge

SOLID STATE CHARGE SYSTEM

"Solid State Charge System" implies a system which does not incorporate any mechanical means for the control of charger output current or voltage. Since the charging system depends on the battery back voltage which is sensed by the control unit (a solid state system), the sensing device is independent of any mechanical means. The mechanically operated chargers offer at best a two step function whereas the "Solid State Charge System" permits much finer regulation of the charger functions, as can be seen from figure 47.

Figure 47.

The solid state control provides a constant current for about 80% of the recharge and then changes to a constant voltage control mode so that only the necessary amount of charge is provided. A special feature of such system is the low trickle rate established when the battery has been fully charged. This does not only maintain the battery fully charged but also provides an equalizing charge for a battery over weekends without any extra effort of control necessary.

Since the solid state control provides for a constant current over 80% of the charge period required, it offers special savings in the peak power demand because a 36% lower charge rate for a given battery needs to be provided.

Typically a charge rate of 16.5A/100AH battery capacity is required for the solid state controlled charger, whereas most other systems require 22.5A/100AH starting rate.

A further benefit arises with the use of solid state controlled chargers; they are virtually maintenance free, since they contain no moving parts like fans, relays, mechanical timers, etc.

However, while all charge systems function well and prevent overcharging of batteries when the batteries being charged are healthy and at normal operating temperature, this is no longer true when defective cells occur, the battery ages, or operates at excessive temperatures.

For such reasons chargers are available, which incorporate a second completely independent control function, so that overcharging of other than perfect batteries is safely prevented. This independent control supervises the charge programme on a time basis and reduces the high charge rate at 80% of the charge period to the finish rate. At 100% of the charge, the rate is reduced to the trickle rate of approximately 1.5A/100AH which remains constant until the battery is disconnected.

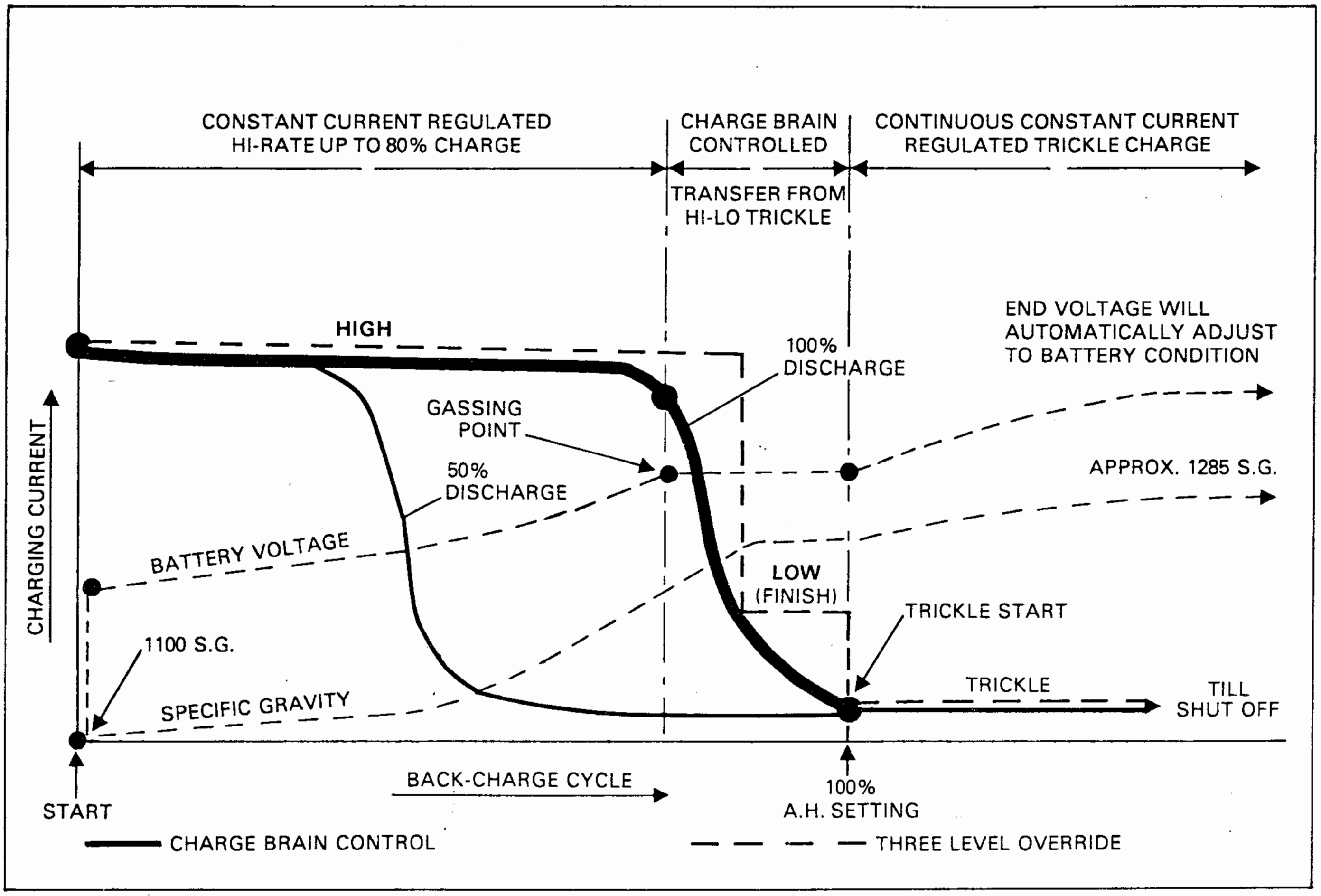


Figure 47. Solid State Charger Performance

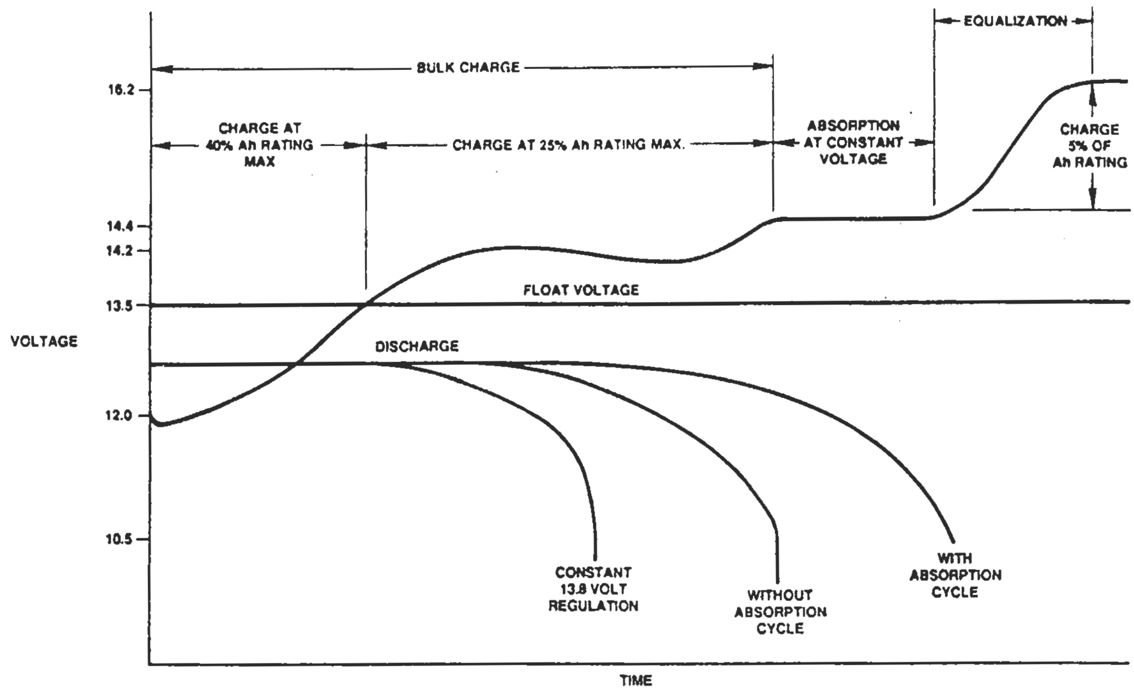


FIGURE 102. THE FOUR CHARGE CYCLES

Application Note 102: The Four Cycles required to Charge a Battery.

A performance charging system treats the battery to at least three distinct cycles. In technical parlance, the three are known as bulk charge, absorption, and float. For ultimate performance, a fourth, 'equalization' cycle should be applied periodically.

The four cycles are shown in Figure 102. As shown, bulk charge cycle covers initial charging until the battery voltage reaches the vigorous gassing point at about 14.4 Volts. The voltage should then be held constant at 14.4 until the charge current through the battery declines to about 5% of the Amp-Hour Rating of the battery. This portion of the cycle is called the absorption cycle.

Following the absorption cycle, the battery is usually placed on a maintenance 'float' voltage. This is a voltage high enough to keep the battery charged, but low enough to prevent continuous charge current. A typical float voltage falls in the range of 13.5 to 13.65 Volts.

Periodically, an equalization cycle should be applied to conventional liquid electrolyte batteries. The equalization process breaks up sulfate crystals which are a by-product of normal discharge. As shown in Figure 102, equalization starts where absorption leaves off. To properly equalize a battery, use a constant current equal to 5% of the Amp-Hour rating of the battery. Apply this current for 3 to 4 hours or until the battery voltage tops out at 16.2 Volts.

All the voltage values given are for liquid electrolyte, lead-acid batteries at 77 degrees Fahrenheit. Immobilized electrolyte batteries charge at different voltages, and do not require equalization. For a full description of proper charging and temperature correction, refer to our book 'Living on 12 Volts with Ample Power.'

Designing battery chargers

Difficult-to-find design curves and an inexpensive over-charging protection circuit

by Thomas Roddam

Have you ever seen a simple account of how to design a battery charger? It was with some surprise that I realised recently that I could not recall any description at all of the design characteristics of a transformer-rectifier system for pumping energy into a battery. Yet we are all using batteries nowadays. In my earliest days there was a simple procedure: you seized the leather strap, and headed for the local bicycle shop. Later there was the great array of cells in a battery room: two lots at 13 volts and two at 24 volts. Fred, in permanent attendance, living in a permanent sulphuric atmosphere, spent all his day charging and discharging 'his' batteries. Now we have float operation and if we are very rich, sensors for cell temperature, electrolyte specific gravity, the F.T. index, and a small computer to decide just what current to deliver.

I just want to charge my batteries, though I may add a cut-off device. How do I choose the transformer and the rectifier. The essential conditions really boil down to the following. If the mains voltage is high, and the battery voltage is low we must not overheat the transformer or overload the rectifiers. I assume we are not in a mad panic to get the battery charged again, so that we are well below the safe charging current of the battery. If the mains voltage is low and the battery is not particularly low we want to go on feeding energy into the battery.

There is a G.E. application report which can be used to guide the designer, although I found, when I tried to use the equations provided, that I fell rather quickly into confusion. The alternative method which I have now adopted involves some guess and try, but does provide a very simple approach. The starting point is a very useful set of curves for the design of rectifier circuits with capacitor input filter which are out of print in the original publication and which are reproduced in Fig. 1.

To use these curves we consider what happens when we charge a battery. The charging current is, or so the meter says, a direct current, while the terminal voltage remains nearly constant. This is very much the behaviour of a parallel capacitance and resistance. The only difference is that instead of thinking of a load current we must now think of a charging current. The battery capacitance is very large, so that we can replot the ratio curves as a single graph for ωCR large, with simply output voltage as a function of the ratio of source resistance to load resistance. This is what we have in Fig. 2.

Let us assume that we are dealing with a nominal 24-volt battery, with 12 cells. The float level of this battery will in practice be 2.25 volts per cell, giving 27 volts. The reason for operating at 2.25 volts per cell is that this is the point at which we have the maximum energy storage combined with the longest possible life. When a battery has been used it is not uncommon to boost it up

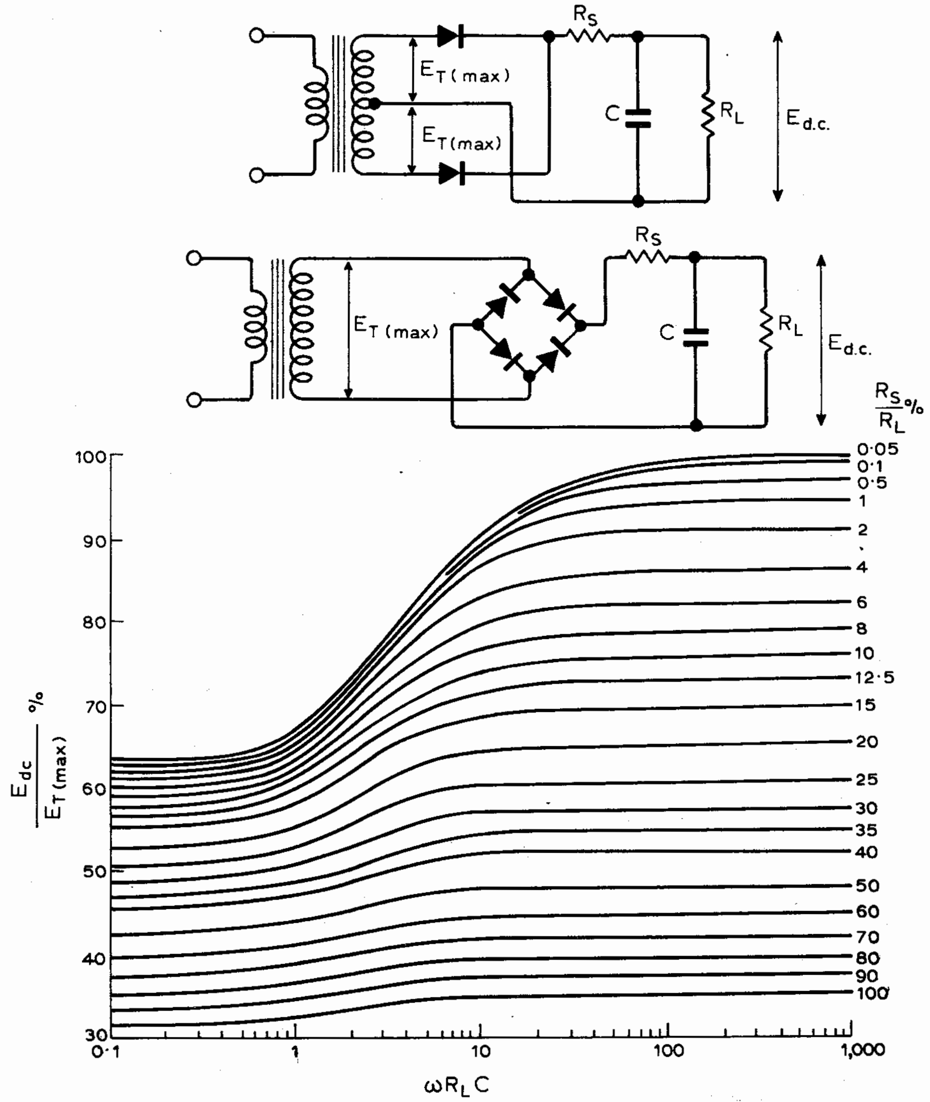


Fig. 1. $E_{dc}/E_{T(max)}$, % as a function of $\omega R_L C$ for full-wave circuits. C in farads and R_L in ohms, $\omega = 2\pi f$.

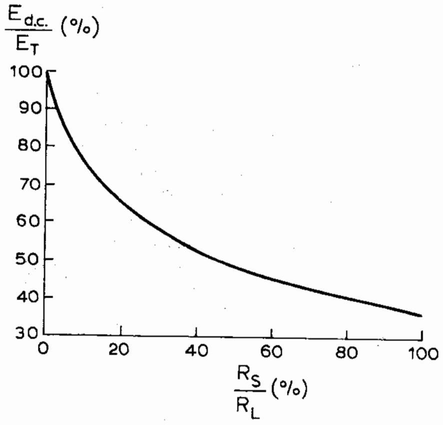


Fig. 2. Characteristics of full-wave rectifier for ωCR large, as is the case in battery charging.

to 2.6 to 2.7 volts per cell. I am not sure why, but it may be to make sure that all the cells are fully charged. This can bring us to a terrifying 32.4 volts, when lamps and transistors start to pop. Actually, the terminal voltage falls back once the charging current is cut.

Let us allow a meagre 1.2 volts drop in the rectifier bridge and our extreme condition corresponds to a direct voltage of 33.6. For the purpose of this analysis I shall assume that on a day when the mains input is 6% low it will take forever to reach 2.7V per cell. I shall therefore have $I_{load}=0$, so that $R_{load}\rightarrow\infty$ and $R_S/R_L=0$. For a peak voltage E_T of 33.6 we must have $E_{rms}=23.8$V. This, however, is for a low mains input, and the nominal value must be 6% higher, or 25.3V r.m.s. We have thus defined the turns ratio of the input transformer.

When the mains are 6% high we shall get $E_{rms}=26.8$V, and $E_T=37.8$V. Now we must subtract, say, 1.3V for the rectifiers, and we have an effective E_T of 36.5 volts.

It must be accepted that if you are sharing a battery, the other users will run it down to 1.8 volts per cell. When at last you can switch on the charger the terminal voltage will be only 21.6 volts. Sooner or later this condition coincides with the high mains input and we must consider the condition where $E_{dc}/E_T=21.6/36.5$, which is pretty close to 60%.

This max-min-max-min rate gives us our entry point to Fig. 2. We find that we must have a value of $R_S/R_L=27\%$. Let us say that to save money, not time, we have a nominal charge rate of 6 amps. For this current, and 24 volts, the value of R_L is 4 ohms. Immediately we see that we must make R_S 1 ohm. This includes the resistance of the transformer secondary and the primary resistance as seen at the secondary. Usually we can simply take twice the secondary winding resistance as a reasonable approximation. The transformer is, roughly, a 150W size, and will certainly not have 36 watts of copper loss: a physical resistor will be needed.

We do not know if this design is even roughly right, however. Let us go to design centre conditions. We shall then have a nominal 23.5V r.m.s., giving $E_T=33.2$, from which we take off 1.2V (the exact figure is chosen to get round numbers) to get E_T(max)=32V. The battery voltage is assumed to be at the 2.25 volts per cell level, or 27V so that $E_{dc}/E_T=85\%$. Returning to Fig. 2, we find $R_S/R_L=4\%$, to that R_L must be about 25 ohms. At the float level, then, the charging current is only a little more than 1 amp. We probably need to change something. What has happened is that we have been overcautious with our boost condition, but I shall stick with this transformer for a moment longer.

I do not work with a simple float system, because it is really too noisy and although it does not affect the way my equipment works, it gives a fuzzy trace on the oscilloscope. Now a battery which is roughly 20 to 80% fully charged is operating fairly close to 2 volts per cell. Under these conditions, when the battery is being topped up at lunchtime, for example, $E_{dc}/E_T=24/32=75\%$. This means that $R_S/R_L=10\%$. If we take a desirable charging current as 4 amps, this will make $R_L=6$ ohms, and so $R_S=0.6$ ohms. My guess for the effective copper loss resistance of the transformer is 0.2 to 0.3 ohms. We then have the possibility of putting in an external resistor to give the extra 0.3 to 0.4 ohms, with an additional 0.4 ohms which is switched into circuit to limit the current under flat battery conditions. We could have changed the resistance to suit 2.25 volts per cell, but then we should have needed to check the 2.0V condition. However, let us see what happens at 2.25 volts per cell with 0.6 ohms. We have $R_S/R_L=4\%$, so that R_L must be 15 ohms. The charging current has fallen from 4 to 1.8 amps. At a rough guess, I should say this was about the right size of float unit for a system in which the load varied from, say, 1 to 3 amps.

It is quite easy to work out the charging current at various values of E_{dc}, an invented regulation characteristic for the charger. If the current is found to be excessive, a new value of R_S must be used, and we can choose to switch this into circuit. There are advantages in putting this resistance on the primary side. In our example the transformer will be roughly 10:1 for 240 volts working. It is much easier to find a 33-ohm resistor than a 0.33-ohm unit. At 6 amps the dissipation will be about 12 watts. An inductor, in the a.c. part of the circuit, can be used. A 1mH inductor will give 0.3 ohms effective impedance at 50Hz, and will reduce the amount of heat generated – at a price.

Rectifier circuits

A figure for rectifiers in the ordinary power supply is shown as Fig. 3. Again we just use the right-hand edge of this set of curves. We had a condition of 6 amps average with $R_S/R_L=27\%$, and 4 amps average with $R_S/R_L=10\%$. For use in Fig. 3 we need to take $R_S/2R_L$, because the rectifier is full-wave, and so we have either $(2.1\times 6)/2$ or $(2.5\times 4)/2$ as our criterion. It boils down to a rectifier r.m.s. current of 6 amps as our design figure. The reverse peak voltage follows the usual rule of being either E_T or $2E_T$ but everyone is conservative

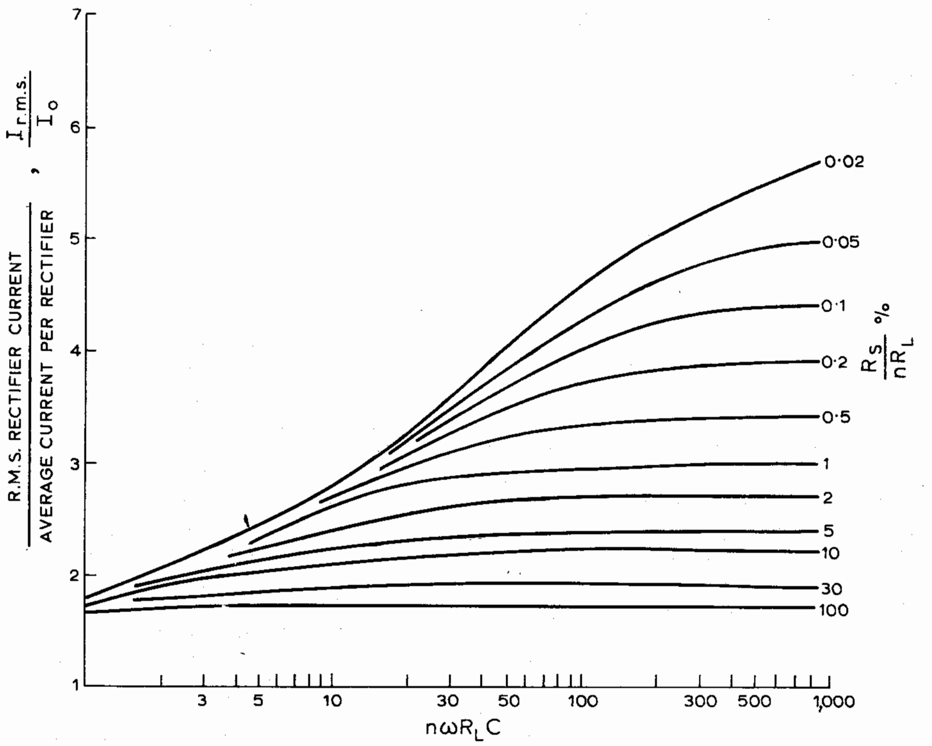
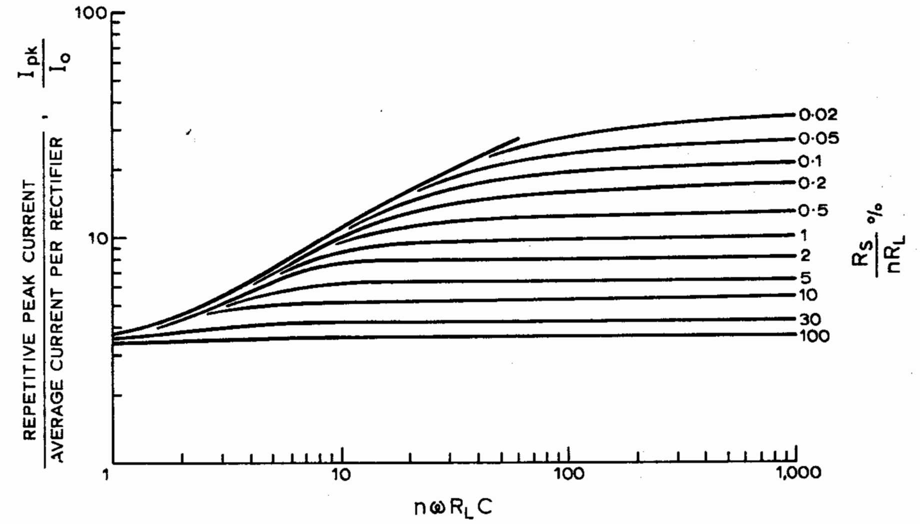


Fig. 3. The ratio r.m.s. rectifier current/average current per rectifier plotted against $n\omega R_LC$. C in farads, R_L in ohms. n = 1 for half-wave, n = 2 for full-wave and n = 0.5 for voltage doubler.

Fig. 4. The ratio repetitive peak current/average current per rectifier, plotted against $n\omega R_L C$. C in farads and R_L in ohms, $\omega = 2\pi f$ and f is line frequency. n = 1 for half-wave, n = 2 for full-wave and n = 0.5 for voltage-doubler.



when it comes to the choice of rectifier and step-down circuits are notoriously sensitive to mains spikes.

It is useful to check the rectifier peak circuit, using Fig. 4. There is no single inrush problem with a battery, as it is a charged capacitor when it starts. Under running conditions we shall get a ratio of I_{pk}/I_o of about 6.5 or a current of about 13A. The rectifier designer has usually taken this into account, but this figure enables us to guess an order of magnitude for the ripple voltage. A battery will have an internal resistance in the region of 10 milliohms, though it is not easy to get more than a rough number. But 10 milliohms will give 0.13 volts peak-to-peak ripple on the battery. It is a spiky ripple, as the peak-to-average current ratio indicates and is acoustically more of a nuisance than the numerical value indicates.

The use of half-wave rectification for battery charging was quite common at one time. Whether this was simply an economy measure in the days when copper was cheap and rectifiers were expensive, or whether it was the result of a mildly magical belief that the battery needed 15 milliseconds rest after a 5 millisecond current injection it is hard to know. Half-wave circuits have been used recently with thyristor controllers and it is useful to have on record the essential design curves, even if only to use them for their original purpose. Fig. 5 is the half-wave version of Fig. 1 and, as before, we can construct Fig. 6 to cover the very-large-capacitor or battery application. The regulation is seen to be even worse than the regulation of the full-wave system. The curves for the rectifier requirements are applicable to both modes of operation, so that we have a complete basis for the design of the half-wave system.

Information about the transformer, and all those odd factors which appear as utilisation factors, can be found in any reference book and in a good many rectifier catalogues. It is hardly necessary to repeat them here. One detail is worth mentioning, however, because it does sometimes get designers confused. If we use a half-wave rectifier we naturally have current flowing in the transformer secondary only for, say, the positive half-cycles. This means that a meter will show d.c. flowing through the winding. We all know that if you have d.c. in an iron-cored coil you will probably need to provide an air gap in the core. The unwary designer thinks of his transformer secondary as an inductor carrying d.c. and arrives at an unnecessarily large structure. The conditions in the core are set by the

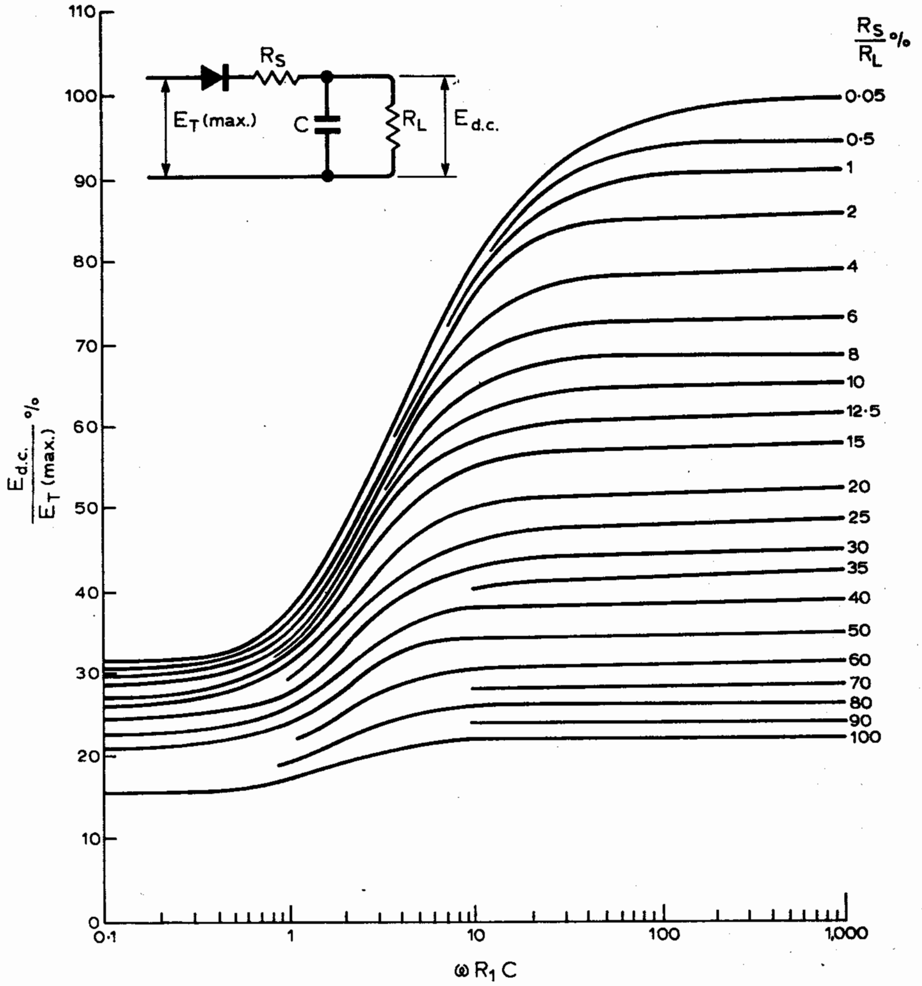


Fig. 5. $E_{dc}/E_{T(max)}$% as a function of $\omega R_L C$ for half-wave circuits. C in farads, and R_L in ohms, $\omega = 2\pi f$.

applied voltage: the flux density is the time integral of the voltage, with turns and area as factors, and the voltage is symmetrical. The use of half-wave rectification does not produce any flux offset under any normal operating conditions. The high I_{rms}/I_{dc} ratio makes the transformer pretty inefficient anyway, but there is no advantage in making it even worse.

The full-wave rectifier circuit was designed as an example to show the use of the design curves and with the criterion that it should just haul the battery up to the 'boost' voltage, combined with a maximum current at the start of charge, we found that the charging current fell smartly as charging progressed. We should call this 'taper charging' if we wanted to sell a cheap charger with this performance, and would point out the essential safety of the drooping current characteristic. Some users, however, do not want to wait forever, to get a really full charge into the battery.

Examination of Fig. 2 shows that the curve is pretty close to

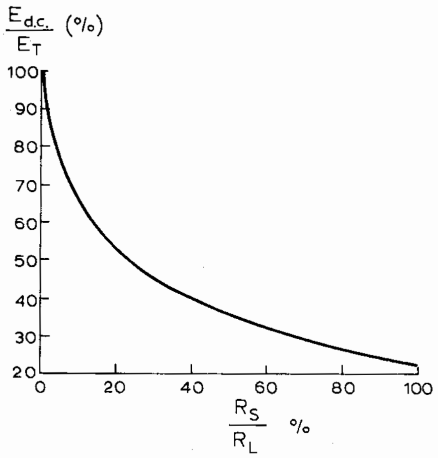


Fig. 6. Characteristics of half-wave rectifier for ωCR large.

$$\frac{E_{dc}}{E_T} = \frac{R_L}{R_L + 2R_S}.$$

Let us choose to have 6 amps charging at 21.6 volts, which makes R_L 3.6, and 4 amps charging at 27 volts, the normal float level, which makes R_L 6.7. We can then write

$$\frac{E_T}{21.6} = \frac{3.6 + 2R_S}{3.6}$$

and

$$\frac{E_T}{27} = \frac{6.7 + 2R_S}{6.7}.$$

It is a quick step to get $E_T = 37.2$ volts and $R_S = 1.3$ ohms.

We can, if we wish, construct a full regulation characteristic, but the resistor is now going to be rated at, in practical terms, 48 watts. This charger, left on indefinitely, will try to bring the battery up to just over 3 volts per cell.

Over-charging protection

It is not expensive to provide some protection against over-charging. The cost starts to rise if we write a very tight specification. At one time the method was to use a voltage-sensitive trip circuit, but it is probably cheaper to use solid-state switching, and we can make the system fully automatic. This means that it will be permanently connected to the battery. The disadvantage is battery noise, but in many applications the equipment must be designed to put up with this, anyway.

The circuit is shown in Fig. 7. Ignore D_2 and R_4, which are simply there to provide 50 to 100 mA trickle into a charged, idle battery, and possibly some lamps. The main charging path is through the thyristor Th_1. If Th_2 is not conducting, Th_1 will start to conduct as soon as point P rises enough above the battery voltage to get triggering current through R_1 and D_1. For a BTY79, which can be obtained easily, and which will carry the 6 amps of d.c., we might make R_1 100 ohms, and D_1 a small half-amp rectifier diode.

As soon as the voltage at P reaches about 3 to 4 volts above the battery voltage the thyristor triggers and current flows into the battery.

Now let us operate Th_2. The cathode of Th_1 is at not less than 21.6 volts, while P will peak up to 37.2 + 6%, say 40 volts under worst mains conditions. We can make $R_2 = R_1$, and the gate of Th_1 will only be 20 volts above the negative line, so that Th_1 will not trigger. The current through $R_1 + R_2$ will be, at its peak, 40/200, or 200 mA, which makes Th_2 a small device and R_1 and R_2 conveniently 3-watt resistors. A suitable cheap device (£0.50) for Th_2 is the BTX18, which needs up to 5mA to trigger it, and which may trigger at anything from 0.5 to 2 volts. The trigger current is provided by the capacitor, C, which is only needed to be, say, a 5-volt unit and can be 10 to 100μF. Resistor R_3 is needed to let C leak away, and 1000 ohms is as good a value as any.

The choice of P_1, the resistor in series with it, and the zener diode are pretty arbitrary. For a 24-volt battery it seems reasonable to choose a 10 or 12V zener diode. Value of P_1 is conveniently 1000 ohms, and the series resistor should be worked out so that the slider of the potentiometer is fairly near the top. Indeed, it is probably better to use a 500 or 200-ohm potentiometer and put resistors both above and below it, to limit the range of adjustment.

There are three phases of the control operation. If the battery is low, Th_1 fires but Th_2 does not. As the critical region is approached, after Th_1 has fired, the ripple voltage across the battery will be enough to tip Th_2 on, although as Th_1 has already fired this does not matter. When the battery voltage is high enough for the necessary few milliamps to be flowing through the zener diode, Th_2 will fire as soon as its anode volts permit. This is before Th_1 has reached the trigger point, and the firing of Th_2 cuts off the trigger supply to the gate of Th_1. Charging, except through D_2 and R_4, stops.

The circuit can be set up fairly quickly if a large capacitor and, say, a 6-ohm resistor are used in place of the battery. The low current through the zener diode and the range of values for the trigger conditions of Th_2 make it impossible to calculate the exact setting. In practice a unit of this kind will have a transition region of about half a volt, which is good enough for general applications. The use of an operational amplifier or comparator, in a control section of the style shown in Fig. 8, will give a very high precision, but such precision is meaningless when the ripple voltage is greater than the setting accuracy.

Perhaps the only justifiable improvement is to go the whole hog. The equipment is supplied from a stabilised power supply and the battery is merely a stand-by system. The problem we have considered is basically different from, and simpler than, this. The design curves are the necessary aids to its construction.

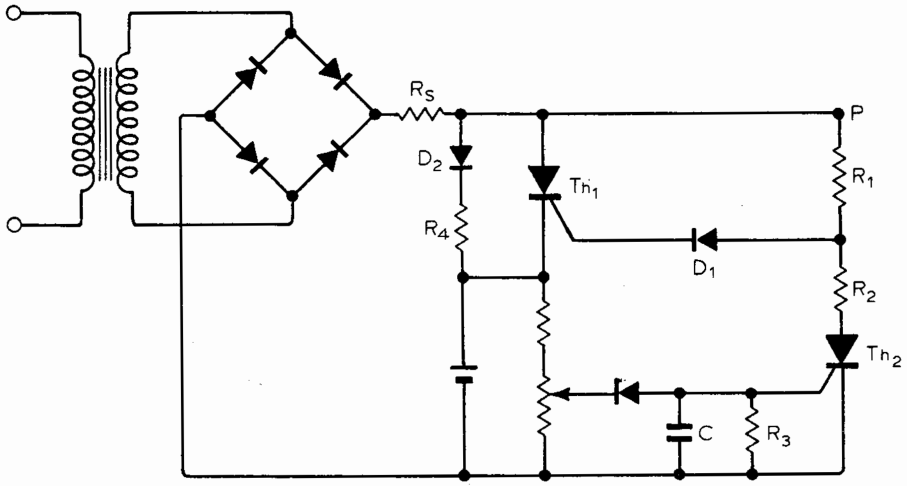


Fig. 7. Automatic charger control. Circuit can be simply set up by using a large capacitor and suitable resistor in place of battery.

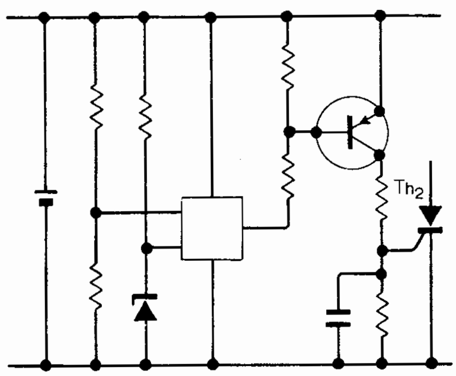
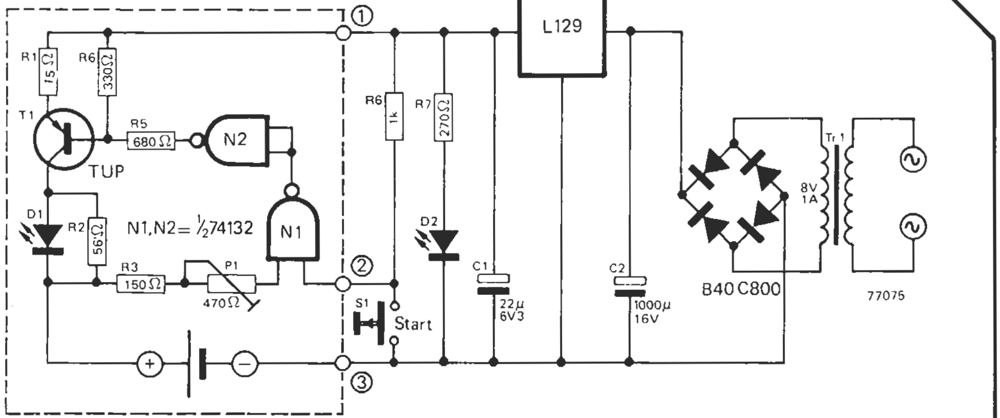


Fig. 8. Use of precision control section is only meaningful if ripple voltage is less than required setting accuracy.

13

automatic NiCad charger

H. Knote



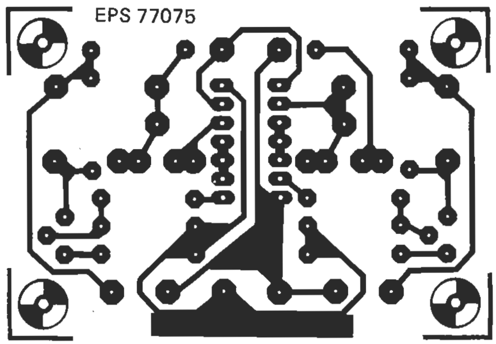
It is not generally appreciated that, if Nickel-Cadmium batteries are subjected to prolonged overcharging from chargers of the constant current type, their life may be considerably reduced. The charger described here overcomes this problem by charging at a constant current but switching off the charger when the terminal voltage of the battery rises, which indicates a fully-charged condition. The basic circuit described is intended to charge a single 500 mAh 'AA' cell at the recommended charge rate of around 50 mA, but it can easily be extended at little cost to charge more than one cell.

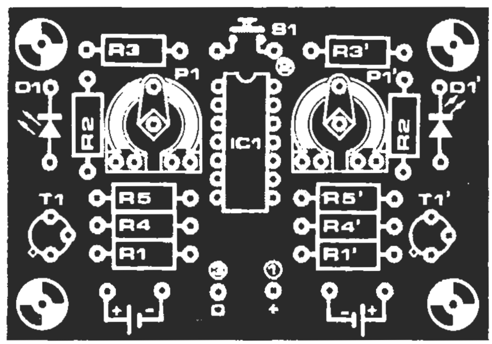
Power for the circuit is provided by a transformer, bridge rectifier and 5 V IC regulator. The cell is charged by a constant current source T1 which is controlled by a voltage comparator based on a TTL Schmitt trigger N1. While the cell is charging the terminal voltage remains at around 1.25 V, which is below the positive trigger threshold of N1. The output of N1 is thus high, the output of N2 is low and T1 receives a base bias voltage from the potential divider R4/R5. While the cell is being charged D1 is lit.

When the cell approaches the fully-charged state the terminal voltage rises to about 1.45 V, the positive trigger threshold of N1 is exceeded and the output of N2 goes high, turning off T1. The cell ceases to charge and D1 is extinguished.

As the positive trigger threshold of N1 is about 1.7 V and is subject to a certain tolerance, R3 and P1 are included to adjust it to 1.45 V. The negative trigger threshold of the Schmitt trigger is about 0.9 V, which is below the terminal voltage of even a fully-discharged cell, so connecting a discharged cell in circuit will not cause charging to begin automatically. For this reason a start button S1 is included which, when pressed, takes the input of N1 low.

To charge a number of cells the portion of the circuit enclosed in the dotted box must be duplicated. This has the advantage that, unlike chargers in which cells are connected in series, cells in any state of discharge may be placed on the charger and each will be individually charged to the correct level. The disadvantage is that batteries of cells cannot be charged. However, up to ten AA cells may be charged if the circuit is duplicated the appropriate number of times.





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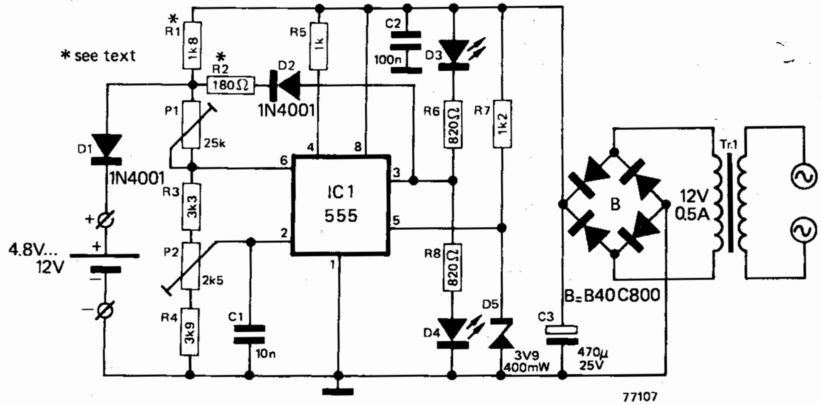
automatic charger

elektor july/august 1977

The recent reduction in the price of nickel cadmium batteries has led to increasingly widespread use of these energy sources. The following circuit, which uses a 555 IC, is a simple but effective automatic charger for these popular batteries.
Although originally designed for normal batteries, the circuit can be adapted to charge batteries with sintered electrodes by suiting the values of R1 and R2 to the manufacturer's specifications.
To determine whether the battery is fully charged, the battery voltage is monitored. This method will only function satisfactorily if the temperature of the battery is always the same when fully charged. For this reason D5 is placed next to the battery to provide a certain amount of automatic temperature compensation. However, if the ambient temperature varies over a wider range, then P1 should be adjusted accordingly. The IC 555 has two voltage-sensitive inputs. The input at pin 6 will switch the output to zero as soon as this input voltage exceeds the zener voltage at pin 5; the other input at pin 2 will switch the output back in as soon as this input voltage drops below half the zener voltage. Thus the voltage at which the



charger will be switched on and off can be set by means of P1 and P2 respectively. In addition, the battery is trickle-charged continuously to compensate for self-discharging.
D3 and D4 are LEDs which indicate whether the charger is on or off. The procedure for adjusting the circuit for different types of battery is as follows: the correct cut-off voltage is set by means of P1 (normally P2 will need only a single initial adjustment); the charging current is determined by R2 and the correct value for this resistor can be calculated as:

$$R2 = \frac{16 - V_{batt}}{I_{charging}}.$$

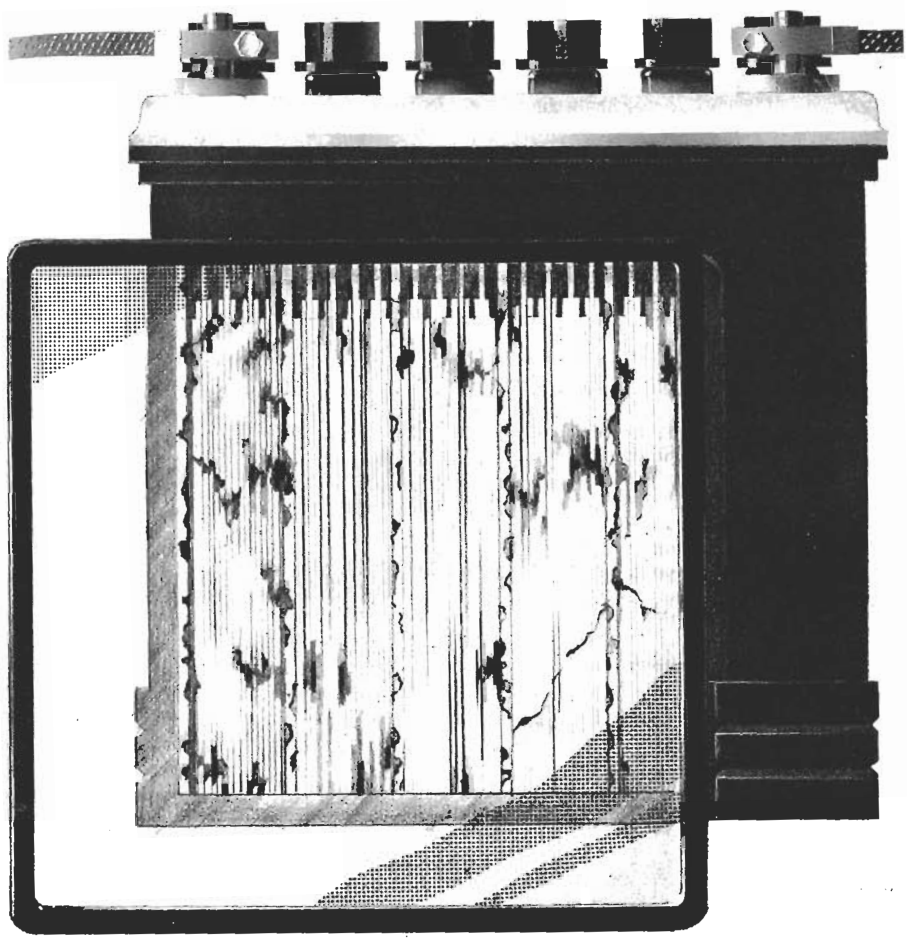
Care should be taken to ensure that the current does not exceed 200 mA, lest the IC be damaged.
The current used to continuously trickle-charge the battery is set in a similar fashion by means of R1.
The simplest way to set P1 and P2 is to use an additional variable supply. The battery is replaced by a variable supply in series with a high wattage resistor. The voltage at the cathode of D1 is then measured using a universal meter, the variable supply is set to the voltage level at which the 555 should cut off (corresponding to 'battery fully charged'), and P1 is adjusted until D3 just lights up. The variable voltage is then set at the level at which the charger should switch on, and P2 is adjusted until D4 just lights. If P2 is set incorrectly, then it is possible that the circuit will begin to oscillate.

INEXPENSIVE

AUTO BATTERY TESTER

BY HANK OLSON

Simulates 200-ampere starter-motor load



AN AUTOMOTIVE battery works very hard, especially when cranking the engine, and if you have a plethora of electrically operated accessories that often draw more power than the unaided alternator can deliver, it may not have a full charge to work with. Even a battery that loafs most of the time may age to the point where it can no longer start the engine on a cold day, so it's a good idea to check your battery's health now and then.

Numerous tests can be made on a battery, and all of them give some indication of its condition. But none is as conclusive as checking its performance under load. To do that you need a professional battery tester, an inexpensive version of which you can build, as described in this article.

The Circuit. The battery tester, shown schematically in Fig. 1, assumes the test current to be 200 amperes at 12 volts. (To determine appropriate load current, refer to the box.) Using Ohm's Law and assuming a 12-volt battery, you can readily see that load resistor *R2*'s value would have to be a very low 0.06 ohm ($R = E/I$ = 12 volts/200 amperes = 0.06 ohm). Furthermore, its power rating would have to be a whopping 2400 watts ($P = IE$ = 200 amperes × 12 volts = 2400 watts). Clearly, you're not going to find a resistor with these ratings in your local electronics parts store. Fortunately, however, you can fabricate your own power resistor from available inexpensive materials.

Continuing with our example of 12 volts and 200 amperes, you'll need about 12 feet of ½-inch wide, 0.025-inch thick steel banding strap (used to cinch wooden packing cases) to fabricate *R2*. Connect the strap in series with an ammeter that can handle at least 2.5 amperes across a variable power supply capable of delivering up to 1 volt at more than 2 amperes. Adjust the power supply for a 2-A output and measure the voltage across the load. If it is over 0.12 volt, trim the strap until it equals 0.12 V.

Turn off the power supply and disconnect the test setup. You've now determined the length of steel strap to use for a 0.06-ohm load resistor. (You can use the same test setup to determine the length needed for any other battery voltage/power ratings simply by changing the voltage or/and current to the appropriate values in the formulas that are provided in the box.)

You're not likely to find a switch that can handle 200 amperes in an electronic parts store, but a conventional 12-volt automotive starter solenoid (*K1* in Fig. 1) will fill your need. Operating current for the solenoid is controlled by normally open pushbutton switch *S1*.

Meter *M1*, resistors *R3* through *R6*,

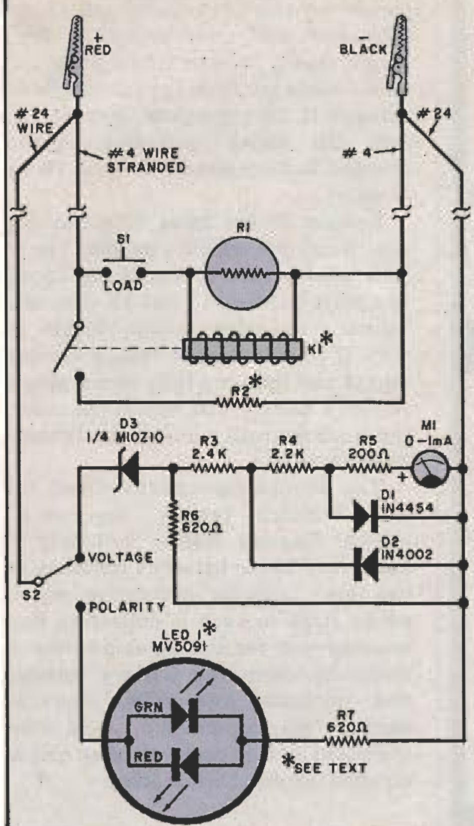


Fig. 1. In the circuit, a standard starter solenoid and contact are used instead of a switch.

PARTS LIST

D1—1N4454 diode
D2—1N4002 diode
D3—10-volt zener (Motorola ¼ M10Z10 or similar)
K1—12-volt automotive starter solenoid
LED1—Two-color LED (Monsanto MV5091 or similar; see text)
M1—0-1-mA meter movement
R1—Thyrite varistor for solenoid
R2—See text
R3—2.4-kΩ, ½-W, 5% resistor
R4—2.2-kΩ, ½-W, 5% resistor
R5—200-Ω, ½-W, 5% resistor
R6, R7—620-Ω, ½-W, 10% resistor
S1—Normally open pushbutton switch
S2—Spdt switch
Misc.—#4 wire cables; suitable Mueller clips or jumper-cable clamps (2); 12 feet steel banding (for R2); ½" steel or aluminum spacers (13); 1" × ½" metal L brackets; ¾" plywood board; 16-gauge sheet aluminum; 6-32 machine screws (1" and ¼" long); large flat No. 6 washers; No. 6 × ½" metal spacers; ¼" machine hardware; assorted terminal strips (see text); ¾"-long round-head wood screws; #24 hookup wire; etc.

and diodes *D1* and *D2* make up a 0-to-6-volt dc voltmeter. When connected in series with 10-volt zener diode *D3*, this meter circuit becomes an expanded-scale 10-to-16-volt dc voltmeter. Diode *D2* protects the meter against reverse polarity, while diode *D1* protects against overvoltage when the meter is connected in proper polarity.

When selector switch *S2* is set to POLARITY, *LED1* glows green if the tester is connected to the battery in proper polarity, red when the connection's polarity is incorrect. Note that Fig. 1 shows and the Parts List specifies an integrated red/green LED assembly for *LED1*. If you wish, you can replace this with discrete red and green LEDs, connecting them into the circuit as shown for the integrated unit.

Construction Hints. As shown in Fig. 2, the best way to mount the steel strapping that makes up the load resistor, *R2*, is on a ¾-inch plywood board, using No. 6 metal—*not* plastic—spacers and machine hardware. Start by drilling a ¼-inch hole spaced ¼-inch in from each end of the strapping.

Next, drill two rows of ⅛-inch holes through the board, spacing the rows about 8 inches apart and the holes within each row about 1 inch apart. Then mount a metal spacer at each hole location with a 6-32 × 1" machine screw, placing a large flat No. 6 washer under the head of each screw. Mount another large flat washer on top of each spacer with a 6-32 × ¼" machine screw.

Mount the starter solenoid at the right rear of the plywood board and fasten one end of the steel strapping to one of its terminals. Then route the strapping back and forth from spacer to spacer. (The washers prevent the strapping from slipping off the spacers.)

Fasten a large L bracket to the free end of the strapping with ¼-inch hardware. Then secure the L bracket and one- and two-lug terminal strips to the wood base with ¾-inch round-head wood screws.

For the front panel, you will need a sheet of 16-gauge aluminum. Trim it to the width of the plywood base. Then, if possible, bend a 90° lip, about 1 inch wide, along the panel's bottom edge (alternatively, use three large L brackets) and drill three or four ⅛-inch holes along the length of the lip to permit mounting the panel to the plywood base.

Machine the panel and mount on it the meter movement, integrated LED assembly (or discrete LEDs), switches, and two three-lug terminal strips. This done, mount the panel to the top front of the plywood base with ¾-inch-long roundhead wood screws.

Wire the circuit as shown in Fig. 1. Note that separate #24 wires are used as voltage sensors and are run in parallel with the large #4 cables that carry the actual current. The #24 wires are used to measure the voltage at the battery before any voltage drops in the cable resulting from the high-current flow through *R3*. When installing the #24 wires, route them along the #4 cables and use either lacing cord or tape to bind wire and cable together. Finish the assembly by attaching large Mueller clips or jumper-cable clamps to the free ends of the #4 cables.

Use. To use the tester, connect the two Mueller clips (or clamps) to the battery/charger system (at the battery's terminals) in the vehicle you wish to test and set *S2* to POLARITY. If the LED glows green, the tester is properly connected, but if the LED glows red, reverse the connections to the battery.

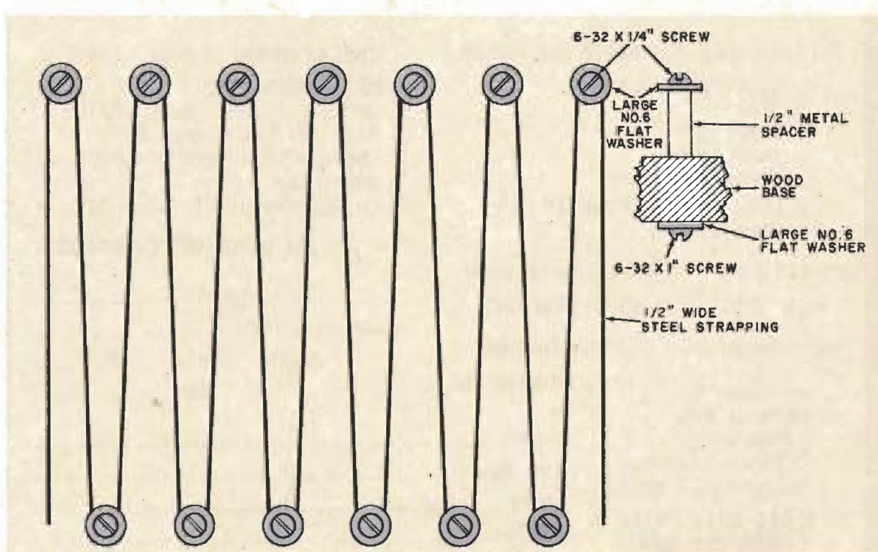


Fig. 2. Using this diagram as a guide and following instructions in the text, you can make up your own load resistor from ½-inch steel banding strap.

Now set *S2* to VOLTAGE; the meter should indicate between 10 and 13 volts. Press and hold LOAD switch *S1* for no longer than 5 seconds (the limit because as *R2* heats up, from the current flowing through it, its resistance increases) and note the meter indication. A fully charged battery should indicate 10 volts or more.

Release *S1* but leave *S2* set to VOLTAGE. Start the vehicle's engine. The meter's pointer should now swing up-scale to a point between 13 and 15 volts as the vehicle's charging system comes into play. If you obtain abnormally low readings at any time, try fully recharging the vehicle's battery and repeat the tests. If the condition still persists, the battery is most likely bad.

You should periodically "load test" your vehicle's battery, say, once a month. Regular testing will help you keep track of the battery's condition and can also indicate preventive maintenance steps to keep it delivering maximum current for as long as possible. Periodically clean the battery terminals and connectors and, unless yours is a sealed, "no-maintenance" type, check the liquid level in each cell often and add distilled water where necessary. ◇

SELECTING A LOAD

Battery testers used by professionals have built-in load resistors specifically selected for testing a range of typical automotive battery power-delivery capabilities. As a general rule, load-resistance values are calculated from a simple formula that states that the load resistor should draw half of the battery's maximum current during a voltage measurement. Since automotive batteries are usually rated in watts, rather than current-delivery capability, it is necessary to first convert to current before you can calculate the load resistance.

Using the standard power formula $P = IE$ (P is rated battery power, I is unknown battery current, and E is battery voltage), we obtain $I = E/P$. Now, let's assume the battery is rated at 12 volts and 4800 watts. First, we divide the power rating by 2, obtaining 2400 watts. Plugging these values into the formula, we get $I = P/E$ = 2400 watts/12 volts = 200 amperes.

Now, use Ohm's Law to calculate the resistance of the load: $R = E/I$, where R is load resistance, E is battery voltage, and I is test current (calculated above). Continuing our example, we obtain R = 12 volts/200 amperes, or 0.06 ohm. Therefore, for a typical 12-volt, 4800-watt automotive battery, the load resistance should be 0.06 ohm at 2400 watts.

Using the procedure described above, you can calculate the required load resistor's parameters for any battery voltage/power ratings.

ARE YOU COMMITTING "BATTERYCIDE?"

Winter is the time of the year that many people are committing "batterycide." Fortunately, in most cases, it is not premeditated and the guilty verdict only results in a fine that empties the wallet.

Most of these cases are actually accidental and can be prevented. There are two ways that batteries are commonly murdered. In the following paragraphs we will talk about these and other ways to keep our batteries alive and healthy.

Probably the most common way that a battery is killed is to leave it out in the cold to starve to death. We button up our boats for the winter and go home to the fireplace. When spring comes we find dead batteries and no amount of charge resuscitation will bring them back to life.

What happens is that batteries slowly lose their charge when left unused. When a battery discharges, sulphur is deposited on the plates (remember this). The sulphur comes from the sulfuric acid that is in the battery. (Please don't stop reading now as this is as technical as we are going to get.) If the battery is left discharged for any length of time the sulphur will crystalize permanently. Then we have a battery that is "sulphated." The battery will no longer take a charge. May it rest in peace; and please don't bury it in the river.

The next most common way to murder a battery is to cook it. Here our perpetrator wants to look less obvious. He puts his charger on and then leaves for Baha for the winter. When he returns the batteries have died of thirst. Now he can claim that the charger directions said it was automatic or that it would never damage batteries. Baloney! No $29.95 battery charger is "automatic". And, if you read the small print of the more expensive so called "automatic" battery chargers, you will find a statement like this: "Check and refill the water in your batteries regularly." What they don't say is that you will ruin them if the water gets below the plates inside.

Now most of us are good, honest people and have no desire to commit "batterycide." So how do we prevent it? Figure I shows a few important voltage levels and what they mean to your battery.

Most inexpensive battery chargers are not automatic and will push the voltage up to 14.2 volts and higher. This includes many trickle chargers. Smaller versions of these (10 amps and under) can be left unattended for 10 hours or so. Larger versions should be checked much more frequently. When 14.2 volts is reached, turn it off until the next charge.

If you have a charger that is really automatic and has a finish voltage of 13.8, check the water level on at least two week intervals.

Now, for those of us who have a charging system that finishes at 13.2 volts, hang this sign on our boats: "Batterycide prevention boat." If your system charges to 14.2v and then returns to 13.2v, use flashing neon lights.

To summarize: Keep your batteries charged (at least monthly). A discharged battery will become sulphated and die. Do not overcharge. Overcharging will cause excessive water loss and, if the plates are exposed, damage will occur.

P.S. Use distilled water or "Bull Run" water to top off your battery.

Charging Voltage	Effect to Electrolyte	What this means to your battery
14.2V	Hard gassing	Needed to fully charge a battery, i.e. remove sulphur from the plates. (Remember?) Also it quickly "boils" the water out. Many alternators/ regulators are set at this level.
13.8V	Light gassing Correct voltage for unfiltered charger (BC911)	A poor compromise used by many charger manufacturers. It never fully charges the battery, often leading to early sulphation. It also slowly "boils" out the water leading to damage if the batteries are not kept full.
13.2V	No gassing Correct voltage for filtered charger (BC928)	A good maintenance voltage. The batteries can be left on "charge" indefinitely without damage. Great for live-aboard use or leaving the batteries unattended.

Figure I

GAUGES, DIALS, POINTERS, AND OTHER SEEMINGLY MEANINGLESS GADGETS!

Previously we talked about the crime of "batterycide" and its prevention. Now let's talk about the meters that are on our boats, and how they can help us prevent "batterycide."

There are two kinds of meters that will help. The first is a voltmeter. It measures the electrical "pressure" of the battery. A good analogy for voltage is the amount of water pressure in a hose. The higher the water pressure, the farther the water will squirt. The higher the voltage the higher the electrical pressure.

The ammeter is the other kind of meter that is useful to us. It measures the amount of electrical current in amps. It too can be compared to water. Here we are concerned about the amount of water (or electricity) flowing. We could compare a large flow of water like the Columbia River to say Johnson Creek which has a relatively small current (I'm sure some Johnson Creek residents would argue the point at times). Relate this to the amount of current your engine starter uses compared to your running lights.

The voltmeter is the most useful of the two meters. There are two basic types: analog and digital. Either type is fine, but they must be accurate and be readable within 0.1 volts. An examination of the following chart will quickly reveal why:

BATTERY VOLTAGE				BATTERY CONDITION
6V	12V	24V	32V	
7.1	14.2	28.4	37.9	-- High gassing level, needed for full charge. Typical alternator regulator setting.
6.9	13.8	27.6	36.8	-- Light gassing level. Typical "automatic" battery charger setting.
6.6	13.2	26.4	35.2	-- No gassing. A good maintenance voltage.
6.4	12.8	25.6	34.1	-- 100% charge on battery*
6.3	12.5	25.0	33.3	-- 75% charge on battery*
6.1	12.2	24.4	32.5	-- 50% charge on battery*
5.9	11.8	23.6	31.5	-- 25% charge on battery*
5.6	11.2	22.4	30.0	-- Completely discharged battery*
≤5	≤10	≤20	≤26	-- Battery damaged with one or more shorted cells*

*These voltages are measured when the battery is at rest. In other words, turn off your charger, alternator (engine), or anything hooked up to the battery.

When reading the voltage on a battery, be aware that a surface charge will remain on the battery for several hours after charging. This will cause a falsely high reading. It may be removed by discharging the battery for about a minute at 10 amps. Just turn on a few things for about one minute, then turn everything off, leaving on one small light or the Loran will make little difference in the accuracy of your reading.

The ammeter will tell us how much current is going out or coming into our battery. When we turn things on we can see how much current is going out. If we are only drawing 5 amps, our battery will last a long time, but if we are drawing 50 amps, our battery will be dead soon.

When charging with a conventional charging system, our ammeter will show a high rate of charge at first. This current will reduce quickly as the battery takes a charge. This is why conventional charging systems take longer to charge than the new "intelligent" charging systems. The new systems will continue to charge your battery at a high rate until 14.2 volts is reached. It will then step back to a maintenance voltage and show a low charge current.

Much more could be said, but space here won't permit it. All of the voltages shown are approximate and depend on the battery and temperature, but the above table will suffice in most circumstances. If you want to know more, the best book that I have found is Living on Twelve Volts with Ample Power, by David Smead and Ruth Ishihara, available at most boating book outlets or I have a few copies at our shop now.

ALARM SYSTEM BACKUP

I've designed an alarm circuit for my house that's powered by line voltage but I want it to switch over to backup batteries if and when the power fails. The control part of the circuit is the only section that has to be constantly powered. I'm not worried about lights and other high current devices since I have a commercial unit for that part of the system. Do you have a simple circuit that can provide the battery backup? I only need 100 milliamps or so.—G. Benjamin Indianapolis, IN

Having a fail-safe power-supply for a home alarm system is a good idea and, if you think of it, is probably the most important part of the alarm system. Fortunately, it's also one of the easiest things to add to the circuit. In your case, it's even easier, since you designed the alarm-control circuit yourself.

There are several ways to add a battery backup to a circuit, but since you're only looking for 100 milliamps, you can keep it simple and the back-up circuit can be made so small you'll be able to easily find room for it in your existing enclosure.

The circuit shown in Fig. 1 is a simple design that can do the job. When the line voltage is available and operating, D2 is reverse-biased and current flows into the batteries through R1, the current limiter for the nickel-cadmium (Ni-Cd) batteries, or whatever type of rechargeable battery you want to use. If the main power is disconnected (inadvertently by you or intentionally by a burglar), D2 is forward-biased and battery power is available for the alarm circuit. By adding D1 to the circuit, you can keep the battery from powering other circuitry that's not essential to keeping the alarm system active.

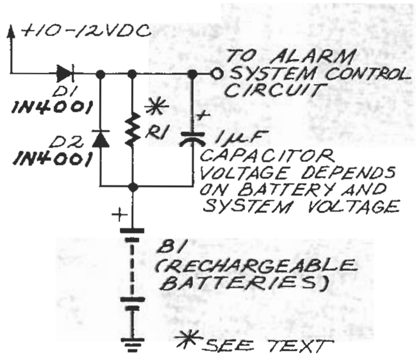


FIG. 1—THIS SIMPLE BATTERY backup circuit can be used to power a control circuit for an alarm system.

The particular diode you should use for D2 depends on the amount of power you want to draw from the battery when the main power is disconnected. If you're sure that you'll never need more than 100 milliamps, you can probably get by with a small 1N914 diode but, if there's a chance you might draw more current, or you just want to play it safe, you're better off with something like a 1N4001.

If you use Ni-Cd batteries, you'll need a constant trickle-charging current. You should select R1 to limit the charging current to the battery's C/10 rating, which is 10% of the capacity of the battery. In a C/10 rating, "C" is the charge capacity in amp-hours, and "10" is the number of hours the battery can supply useful power. Therefore, the capacity divided by that operating interval equals the maximum current safely drawn from or supplied to the battery. The trickle current charge, I_c, must be less than or equal to the maximum safe current drawn through the battery.

The value of R1 can easily be calculated using

$$R1 = [(V_c - (0.6 \text{ volts} + V_b)]/I_c$$

where V_c is the circuit voltage, V_b is the battery voltage, and I_c is the charging current.

This is just a straight application of Ohm's Law. The reason it seems more complex is that you have to subtract the 0.6 volt-diode drop and battery voltage from the supply voltage.

The capacitor in the circuit is used to filter any voltage glitches and also to provide a few seconds of power if you want to change batteries.

through R11 are half-watt units. That's because of the power that each may have to dissipate. Also, the VN67AF may be replaced with a VN10KM. The circuit may be built using the construction method of your choice.

There is, however, one precaution to keep in mind; since IC2 is a VMOS device, it is static sensitive and we all know what that means. So be careful when handling the device. The LM317 regulator should be heat sinked to avoid thermal damage to the unit during operation.—*Joseph A. Scannell*

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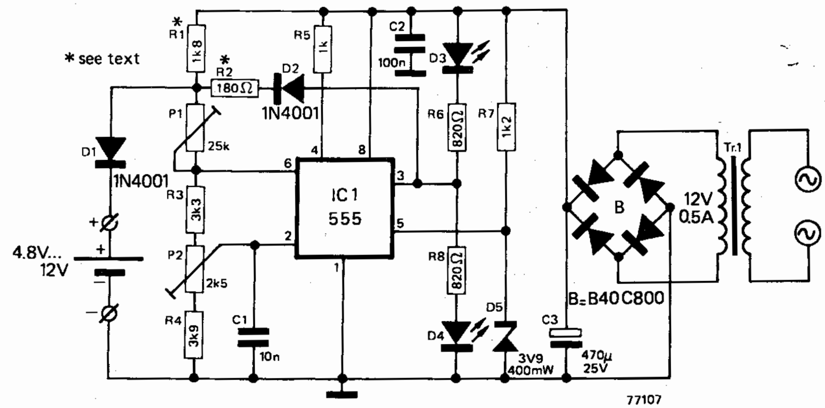
automatic charger

elektor july/august 1977

The recent reduction in the price of nickel cadmium batteries has led to increasingly widespread use of these energy sources. The following circuit, which uses a 555 IC, is a simple but effective automatic charger for these popular batteries.
Although originally designed for normal batteries, the circuit can be adapted to charge batteries with sintered electrodes by suiting the values of R1 and R2 to the manufacturer's specifications.
To determine whether the battery is fully charged, the battery voltage is monitored. This method will only function satisfactorily if the temperature of the battery is always the same when fully charged. For this reason D5 is placed next to the battery to provide a certain amount of automatic temperature compensation. However, if the ambient temperature varies over a wider range, then P1 should be adjusted accordingly. The IC 555 has two voltage-sensitive inputs. The input at pin 6 will switch the output to zero as soon as this input voltage exceeds the zener voltage at pin 5; the other input at pin 2 will switch the output back in as soon as this input voltage drops below half the zener voltage. Thus the voltage at which the



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charger will be switched on and off can be set by means of P1 and P2 respectively. In addition, the battery is trickle-charged continuously to compensate for self-discharging.
D3 and D4 are LEDs which indicate whether the charger is on or off. The procedure for adjusting the circuit for different types of battery is as follows: the correct cut-off voltage is set by means of P1 (normally P2 will need only a single initial adjustment); the charging current is determined by R2 and the correct value for this resistor can be calculated as:

$$R2 = \frac{16 - V_{batt}}{I_{charging}}.$$

Care should be taken to ensure that the current does not exceed 200 mA, lest the IC be damaged.
The current used to continuously trickle-charge the battery is set in a similar fashion by means of R1.
The simplest way to set P1 and P2 is to use an additional variable supply. The battery is replaced by a variable supply in series with a high wattage resistor. The voltage at the cathode of D1 is then measured using a universal meter, the variable supply is set to the voltage level at which the 555 should cut off (corresponding to 'battery fully charged'), and P1 is adjusted until D3 just lights up. The variable voltage is then set at the level at which the charger should switch on, and P2 is adjusted until D4 just lights. If P2 is set incorrectly, then it is possible that the circuit will begin to oscillate.

DESIGNER'S NOTEBOOK

A battery backup for CMOS-based circuits

ROBERT GROSSBLATT
CIRCUITS EDITOR

ONE OF THE BIGGEST ADVANTAGES OF CMOS-based circuit design is the ability to run everything off batteries. Not only does that make the circuit completely portable, but it simplifies the overall design process as well. Powering a device from a wall socket means that you have to use transformers and rectifiers. It also means that you have to deal with ripple, regulation, and a lot of other stuff that has nothing to do with the circuit you're trying to build.

Of course, there are two sides to every story. Batteries simplify a lot of problems, but they also have one big one of their own: They go dead. And if power is drawn by a circuit to retain memory, those batteries will fail a lot sooner.

Memories like the 5101, 6116, 6264, and the other members of the CMOS low-power series require only about 10 μA at 2 volts to retain their contents. That makes it possible to use a battery backup with those devices.

Battery backup circuit

If a battery backup is to be of any use, you need a circuit that will automatically switch from the main supply to the battery backup with an absolute minimum of glitching. That's the purpose of the circuit shown in Fig. 1. Designed for use with rechargable Ni-Cd units, it charges the batteries whenever power is applied to the +V terminal, and supplies power from B1 when power is absent from that terminal. The circuit is easily modified for use with non-rechargeable batteries.

The first thing you should notice about the circuit is its simplicity.

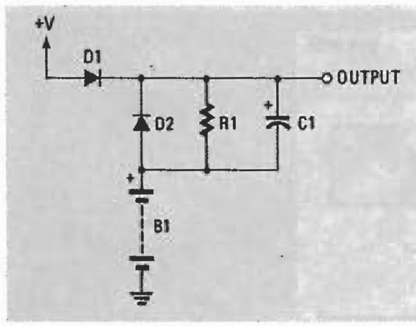

FIG. 1

The circuit's operation is straightforward. When power is supplied to +V, D1 conducts and, since D2 is reverse-biased, current flows into the batteries through current limiter R1. When the power is removed from +V, D2 is forward-biased and current flows from the battery to the output and on to the low-power voltage input of the CMOS device. Since D1 is reverse-biased at that time, no current can leak out via the +V terminal to the main part of the circuit. Capacitor C1 is included to filter out any glitches that may pop up during the change over from main power to battery backup, or when you replace the battery.

Component selection

Diode D2 can be a 1N914 unit since only small amounts of current will ever flow through it. Choosing a unit for D2 presents more of a problem; its selection depends on how much current is expected to flow through that diode. Chances are, if you're powering a CMOS IC, that the operating current is so low that you can use a 1N914 there as well. It is a simple matter to measure the current needs of the device to be powered; that should be done before making a decision about which diode to use for D2.

Resistor R1 is the current limiter for the battery. Its value will depend on the battery's charging current and the voltage that's available from +V. The value can be found from:

$$R1 = (+V - 0.6 - V_B)/I_C$$

where +V is the voltage available at the +V terminal, 0.6 is the voltage drop across diode D1, V_B is the nominal voltage of the battery, and I_C is the charge current required by the battery. For I_C use the battery's 14-hour charge rate. The value of I_C might be different for batteries from different manufacturers. The value for the battery you will use may be marked on the battery itself. Otherwise it can be obtained from the battery's data sheet or from the manufacturer. You can modify the circuit for use with lithium or other non-rechargeable units by deleting R1.

Stabilizing control lines

One precaution you should take when using the circuit is to make sure that the memory control lines are stable before switching from main power to backup. If the control lines are enabled during the switch over, you stand a good chance of generating a write pulse and scrambling the data. In most cases, it's possible to three-state the appropriate inputs on the IC, which will take care of the problem. Otherwise, extra circuitry can be added that will perform the same function. If there's enough interest in that topic, we'll talk about it in more depth in a future column. **R-E**

BATTERY "AEROBICS"

We have talked about how to keep your battery out of the morgue. We talked about how "batterycide" is committed. That can easily be done by not charging them for months at a time or overcharging them for a long period. Then we talked about a few important voltages that can mean life or death to our batteries. To top it off there was a lesson on how to interpret all those meters on our boats.

I'm afraid by now that fear has struck deep into the hearts of those who sincerely don't want to commit "batterycide." The meters are being read and compared to the charts. Batteries are being charged. Some chargers are being turned on and some off. But the question is, "are we treating our batteries right?"

I think the best way to answer that question is to describe a little device that puts our batteries through an "aerobic exercise program." It is an alternator regulator designed by Dave Smead of Ample Power Company. By studying what it does we will know what has to happen to our batteries for their best health.

The first thing it does when turned on is sense the voltage and temperature of our battery with a sensor at the battery. Let's say it is March 24, 1989 and it is a cold, rainy, miserable day. It doesn't know that; but it does know that the temperature of the battery is 47 degrees and has a voltage of 12.3. It's reaction is simple -- CHARGE!

Our regulator tells our alternator to put out all it can to charge the battery. The alternator will continue to put out its maximum current until 14.6 volts is reached. (At normal room temperature it would stop at about 14.2 volts.) This would give our battery what is called the "bulk" charge and hard gassing will have started.

Now our regulator goes through what is called an "absorption cycle." It reduces the current of the alternator to maintain the hard gassing level of 14.6 volts. This level is held for a time (25 to 45 minutes) relative to how long it took the battery to reach 14.6 volts.

Satisfied that the battery is fully charged, our smart little device reduces the alternator output to 13.5 volts (13.2 at 70 degrees). This is called the float voltage. Our batteries may be left at this level for months at a time without worry of damage.

As you can see, there are three steps to charging our batteries. First there is the bulk charge which gives us about an 80 percent cycle. Then we have the absorption cycle. The hard gassing that occurs here completes the charge and helps reduce sulphation, prolonging battery life. Lastly we reduce the charge to a float voltage for maintaining the batteries without danger of harming them.

"THE BIG COMPROMISE"

To get the best possible life out of your batteries they need to be on a good exercise program. Just like our bodies, poorly taken care of batteries will have a poorer, shorter life.

I told you previously about the Ample Power three step regulators that did everything right. Now I will tell you when and why the old system is an acceptable compromise. We will discuss reasons for improving the system that you have.

We first need a short history on batteries to understand why the stock regulators on our alternators are not necessarily the best. When lead acid batteries were first discovered, they were simply built, used, and then rebuilt. It was a long time before Edison provided electricity to everyone's door and battery chargers were available. "Batterycide" abounded.

The best research on good battery care was done during the beginning of this century. Researchers then knew how to get the best life from lead acid batteries, but the technology was not available to do the job automatically. The first regulators were electromechanical (how's that for a six bit word?) devices that used a vibrating relay to regulate the alternator at one fixed voltage. These regulators were used for more than half a century.

Recently the old regulators were replaced with newer solid state devices. Unfortunately they were no smarter than the old ones. They were set at a fixed voltage around 14.4 volts. This would do little to properly charge a battery setting at 30 degrees which needs about 14.8 volts for a complete charge. The engineers had to assume that you were sitting on an L.A. freeway in August. They hoped that the commute wouldn't take more than a couple of hours and that the water level would be checked sometime. If not, it would just mean that many more millions for the battery manufacturers.

So what do we do? Batteries in your car will usually last three to five years treated this way. Not bad. Some cold morning you go out and the lizzy won't start. You lose a couple hours work, buy a $39.95 special and off you go again. But what about the boat? All but the tiniest boats should have two good batteries. (It is hard to pull over to the side of the channel and hold out jumper cables when needed!) That's at least a $120 investment. Some larger boats have over $2,000 in batteries.

Marine service is also much harder on batteries. I have replaced many batteries after only one year of service. It is very common to see only two years of life. Beyond that it can be assumed that the batteries have seen fairly good care.

Now we get down to where the rubber meets the road. What is our best cost to benefit trade off? If we have a boat with a couple of good small batteries, a VHF radio, running lights and a couple of cabin lights, we should not worry about making any big changes to our charging system. Just do the minimum to prevent gross "batterycide." (Please see previous articles.) Have your batteries checked at the beginning of each season and replace when needed.

If, on the other hand, we have refrigeration (the #1 big one), an inverter, lighted companion ways, and a 12 volt toaster (don't laugh), we need a battery system that will last through at least three cold beers. We also need a charging system that recharges our batteries without running the engines 4 to 5 hours daily. this system should have the capability to give our batteries regular aerobic exercise.

What you invest in your batteries and charging system depends on many factors. These include: all the electrical equipment on your boat, your cruising habits, how reliable you want your system to be, and of course, your pocket book. All this and other factors need to be considered in properly engineering a battery system.

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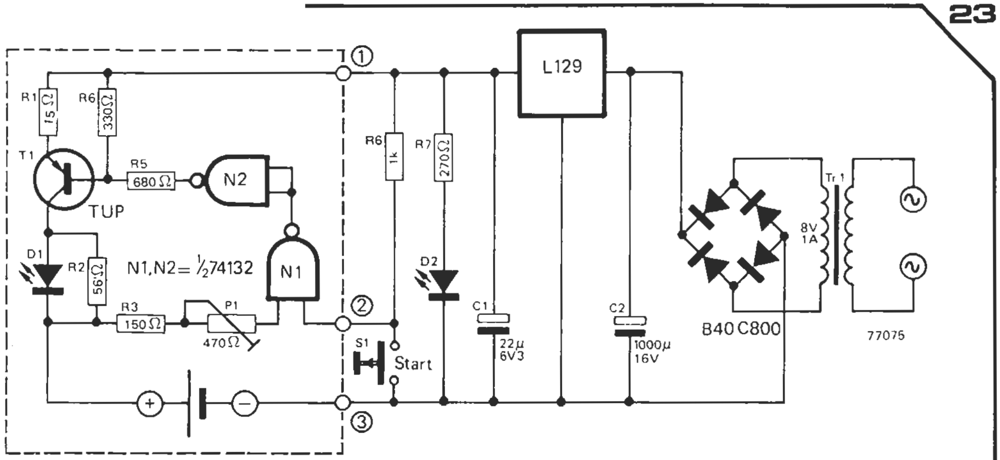
automatic NiCad charger

H. Knote



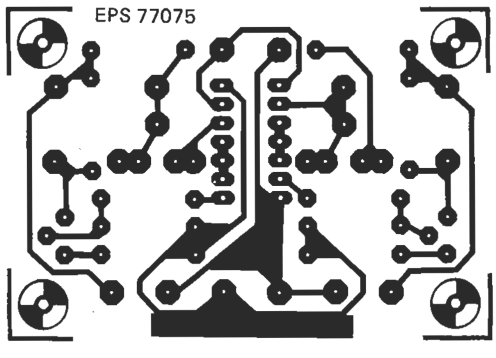
It is not generally appreciated that, if Nickel-Cadmium batteries are subjected to prolonged overcharging from chargers of the constant current type, their life may be considerably reduced. The charger described here overcomes this problem by charging at a constant current but switching off the charger when the terminal voltage of the battery rises, which indicates a fully-charged condition. The basic circuit described is intended to charge a single 500 mAh 'AA' cell at the recommended charge rate of around 50 mA, but it can easily be extended at little cost to charge more than one cell.

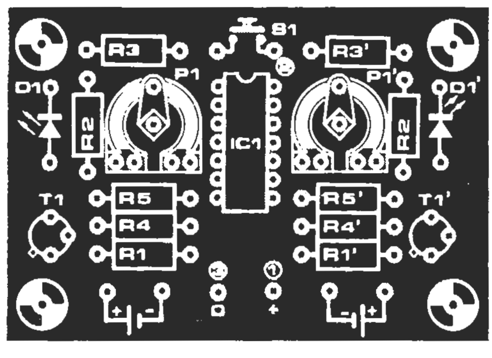
Power for the circuit is provided by a transformer, bridge rectifier and 5 V IC regulator. The cell is charged by a constant current source T1 which is controlled by a voltage comparator based on a TTL Schmitt trigger N1. While the cell is charging the terminal voltage remains at around 1.25 V, which is below the positive trigger threshold of N1. The output of N1 is thus high, the output of N2 is low and T1 receives a base bias voltage from the potential divider R4/R5. While the cell is being charged D1 is lit.

When the cell approaches the fully-charged state the terminal voltage rises to about 1.45 V, the positive trigger threshold of N1 is exceeded and the output of N2 goes high, turning off T1. The cell ceases to charge and D1 is extinguished.

As the positive trigger threshold of N1 is about 1.7 V and is subject to a certain tolerance, R3 and P1 are included to adjust it to 1.45 V. The negative trigger threshold of the Schmitt trigger is about 0.9 V, which is below the terminal voltage of even a fully-discharged cell, so connecting a discharged cell in circuit will not cause charging to begin automatically. For this reason a start button S1 is included which, when pressed, takes the input of N1 low.

To charge a number of cells the portion of the circuit enclosed in the dotted box must be duplicated. This has the advantage that, unlike chargers in which cells are connected in series, cells in any state of discharge may be placed on the charger and each will be individually charged to the correct level. The disadvantage is that batteries of cells cannot be charged. However, up to ten AA cells may be charged if the circuit is duplicated the appropriate number of times.

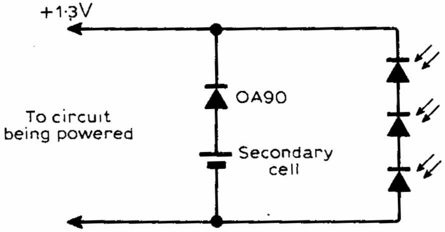




Automatic micropower battery charger

In micropower equipment it is sometimes necessary to switch between an intermittent power source, such as a solar cell, and a storage battery which must be kept charged. The circuit shown offers this facility with very few components. When the solar cell voltage is 0.2V below the battery voltage, the circuit is powered through the forward biased diode. When the cell voltage is greater than the battery voltage, the battery is charged by an approximately constant reverse leakage current from the diode. The diode, which may be a Germanium point contact or junction type such as an OA90 or OA73, should be selected for a suitable reverse leakage current. The battery can be a manganese-alkaline type or a Zn-AgO watch type cell.

M. Hadley,
University of Southampton.



DESIGNER'S NOTEBOOK

A battery backup for CMOS-based circuits

ROBERT GROSSBLATT
CIRCUITS EDITOR

ONE OF THE BIGGEST ADVANTAGES OF CMOS-based circuit design is the ability to run everything off batteries. Not only does that make the circuit completely portable, but it simplifies the overall design process as well. Powering a device from a wall socket means that you have to use transformers and rectifiers. It also means that you have to deal with ripple, regulation, and a lot of other stuff that has nothing to do with the circuit you're trying to build.

Of course, there are two sides to every story. Batteries simplify a lot of problems, but they also have one big one of their own: They go dead. And if power is drawn by a circuit to retain memory, those batteries will fail a lot sooner.

Memories like the 5101, 6116, 6264, and the other members of the CMOS low-power series require only about 10 μA at 2 volts to retain their contents. That makes it possible to use a battery backup with those devices.

Battery backup circuit

If a battery backup is to be of any use, you need a circuit that will automatically switch from the main supply to the battery backup with an absolute minimum of glitching. That's the purpose of the circuit shown in Fig. 1. Designed for use with rechargable Ni-Cd units, it charges the batteries whenever power is applied to the +V terminal, and supplies power from B1 when power is absent from that terminal. The circuit is easily modified for use with non-rechargeable batteries.

The first thing you should notice about the circuit is its simplicity.

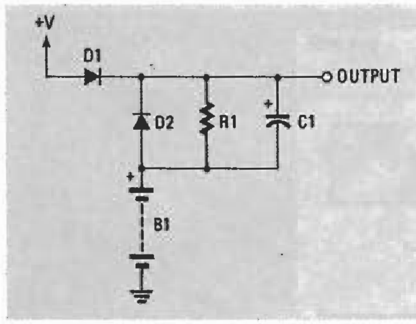


FIG. 1

The circuit's operation is straightforward. When power is supplied to +V, D1 conducts and, since D2 is reverse-biased, current flows into the batteries through current limiter R1. When the power is removed from +V, D2 is forward-biased and current flows from the battery to the output and on to the low-power voltage input of the CMOS device. Since D1 is reverse-biased at that time, no current can leak out via the +V terminal to the main part of the circuit. Capacitor C1 is included to filter out any glitches that may pop up during the change over from main power to battery backup, or when you replace the battery.

Component selection

Diode D2 can be a 1N914 unit since only small amounts of current will ever flow through it. Choosing a unit for D2 presents more of a problem; its selection depends on how much current is expected to flow through that diode. Chances are, if you're powering a CMOS IC, that the operating current is so low that you can use a 1N914 there as well. It is a simple matter to measure the current needs of the device to be powered; that should be done before making a decision about which diode to use for D2.

Resistor R1 is the current limiter for the battery. Its value will depend on the battery's charging current and the voltage that's available from +V. The value can be found from:

$$R1 = (+V - 0.6 - V_B)/I_C$$

where +V is the voltage available at the +V terminal, 0.6 is the voltage drop across diode D1, V_B is the nominal voltage of the battery, and I_C is the charge current required by the battery. For I_C use the battery's 14-hour charge rate. The value of I_C might be different for batteries from different manufacturers. The value for the battery you will use may be marked on the battery itself. Otherwise it can be obtained from the battery's data sheet or from the manufacturer. You can modify the circuit for use with lithium or other non-rechargeable units by deleting R1.

Stabilizing control lines

One precaution you should take when using the circuit is to make sure that the memory control lines are stable before switching from main power to backup. If the control lines are enabled during the switch over, you stand a good chance of generating a write pulse and scrambling the data. In most cases, it's possible to three-state the appropriate inputs on the IC, which will take care of the problem. Otherwise, extra circuitry can be added that will perform the same function. If there's enough interest in that topic, we'll talk about it in more depth in a future column. **R-E**

BUILD A STATE-OF-THE-ART BATTERY CHARGE MONITOR

Prevents early failure of Ni-Cd batteries by determining proper time to recharge.

BY W. J. PRUDHOMME

THE PRIMARY cause of early cell failure in nickel-cadmium batteries is internal shorting that results from allowing the battery to become too deeply discharged in service. Therefore, any electronic device that uses Ni-Cd cells should contain a low-battery indicator that trips and warns you to recharge long before the battery's "critical" voltage is reached. Though there are a number of different types of charge monitors you can incorporate into your battery-powered equipment, the lambda-diode monitor described here is more advanced than other monitors in use.

Most low-battery indicators use a transistor to switch on the drive current for a LED or meter movement. The disadvantage here is that the monitor circuit places a constant drain on the battery, even when the LED is extinguished. In low-power applications, this drain can drastically reduce the available operating time of the battery. The ideal solution is to use a circuit that draws no current from the battery as long as the supply voltage is greater than the critical potential of the battery. This is what the lambda-diode monitor does. In addition, the trip potential is adjustable over an 8-to-20-volt range, and cost is low.

Technical Details. The output potential of most batteries varies in relation to the state of charge. This relation is different for each type of battery. Lead-acid batteries, for example, exhibit an almost linear dropoff in output voltage as the cells become discharged. The same is generally true for dry cells. For Ni-Cd batteries, however, the dropoff is not quite linear.

A fully charged Ni-Cd cell has an output potential of typically 1.25 volts. The cell maintains an almost constant output potential until it is almost completely discharged, at which point, the potential drops rapidly to about 1.0 to 1.1 volts, or 1.05 volts average. A precise voltage monitor set to trip at this "critical" voltage level (or at a multiple of this potential if more than one cell is in series) can be very useful in determining the charge level of the battery.

An eight-cell Ni-Cd battery pack, for example, would have a fully charged output potential of 10.0 volts. When nearly completely discharged, the battery would have an output of 8.4 volts. If the lambda-diode monitor circuit shown in Fig. 1 were set to trip at 8.4 volts, we have a useful state-of-charge monitor for a Ni-Cd battery system.

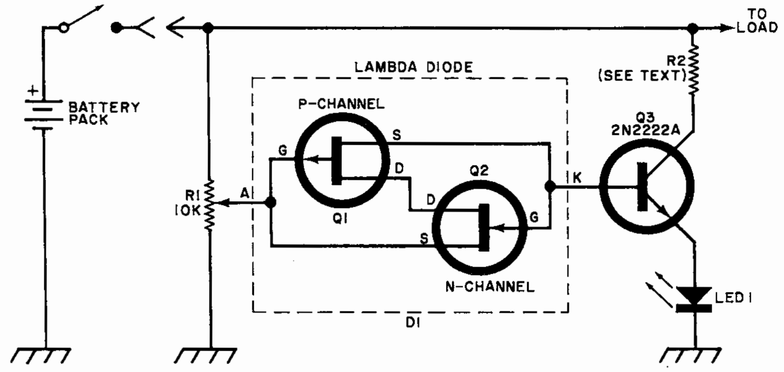


Fig. 1. Battery charger uses a lambda diode made of 2 FET's.

PARTS LIST

- LED1—Any discrete light-emitting diode
- Q1—P-channel junction field-effect transistor (2N4360 or similar)
- Q2—N-channel junction field-effect transistor (2N3819 or similar)
- Q3—Silicon switching transistor (2N2222A or similar)
- R1—10,000-ohm, 1/5-watt miniature pc potentiometer
- R2—Current-limiting resistor (see text for details on how to calculate value; typically about 150 ohms, ½-watt)
- Misc.—Printed circuit board or perforated board and solder clips; relay (substitutes for LED1; see text); hookup wire; solder; etc.

The two-terminal, negative-resistance lambda diode shown inside the dashed box in Fig. 1 consists of one each n- and p-channel FET's. (There is no "lambda" diode available commercially.) Note that in this configuration there are only two terminals, which can be labelled "anode" (A) and "cathode" (K).

If the lambda diode is biased into cutoff, transistor *Q3* is also cut off and *LED1* is off. As battery voltage drops, a point is reached where the lambda diode abruptly conducts. This biases *Q3* into conduction and turns on *LED1* to indicate a low-battery condition. (The operating characteristic of the lambda diode is shown in Fig. 2.)

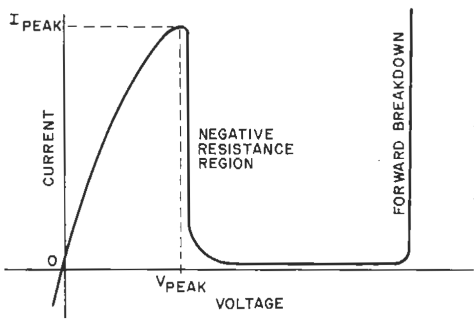


Fig. 2. Operating characteristics of the lambda-diode portion of circuit.

The potential at which the lambda diode conducts can be adjusted by potentiometer *R1*. Resistor *R2* is a current limiter for *LED1*. Its value is determined by Ohm's Law (*R2* = E/I, where *R2* is in ohms, E is the potential of the battery at the point *LED1* turns on, and I is the operating current of the LED used.

Construction Details. The lambda-diode battery-charge monitor is small enough to be built into the equipment in which a Ni-Cd battery pack is used for power. Alternatively, it can be assembled as an external low-battery indicator accessory and housed in a small utility box. In either case, printed-circuit (Fig. 3) or perforated board construction can be used.

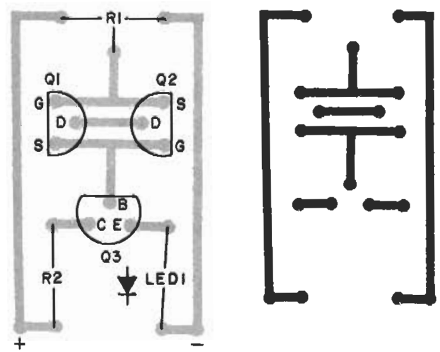


Fig. 3. Etching and drilling guide (right) with component layout (left) can be used or a perforated board will do.

The choice of JFET's for making up the lambda diode is not critical. Almost any combination of n- and p-channel devices will work as well as those specified in the Parts List.

You may want to consider substituting a small relay for *LED1* to disconnect the battery pack from the load when the potential falls low enough to trigger the system. This setup will automatically protect the battery pack from polarity reversal during discharge. ◇

OPENING STATEMENT CONTRADICTED

The opening statement of "Battery Charge Monitor" by W.J. Prudhomme (June 1977) is contradicted by information contained in "Characteristics and Uses of Nickel-Cadmium Batteries," third edition, by the International Nickel Co., Inc. I have, however, seen a number of examples of the failure with shorting described in the article. On the other hand, it is sometimes recommended that the "memory" phenomenon sometimes observed in NiCd cells that are repeatedly charged after only partial discharge can be overcome by complete discharge, then recharging.—*Milford S. Brown, Albany, CA.*

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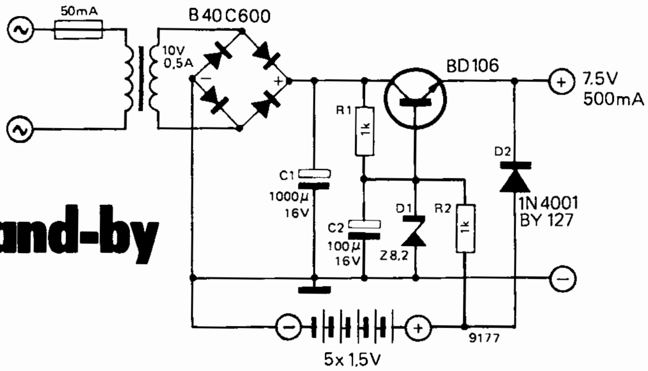
J. Skubic

battery stand-by circuit



This simple circuit will find many applications as a battery eliminator for low power requirements. It consists of a transformer, a bridge rectifier and an electrolytic capacitor followed by a zener controlled series pass transistor. The output is stabilised at 7.5 volts. The stand-by battery, 7.5 volts, in series with D2, floats across the output terminals, ready to take over in case of mains failure. The voltage drop across D2 will then reduce the power supply to about 7 volts.

Resistor R2 has an additional function: when working off the mains it will trickle charge the dry cells or storage battery. Since not many accumulators, and very few dry batteries, will stand prolonged overcharging, R2 must not allow for more than just the self-leakage. Its correct resistance can be found by dividing the voltage potential difference between the zener and the battery by the safe trickle current, which may amount to some 0.7 milliamps.

"ZAP" NEW LIFE INTO DEAD Ni-Cd BATTERIES

That dead cell may not be completely gone. A properly applied high current can often clear a fault, making the cell useful again.

BY DOUGLAS C. MYERS

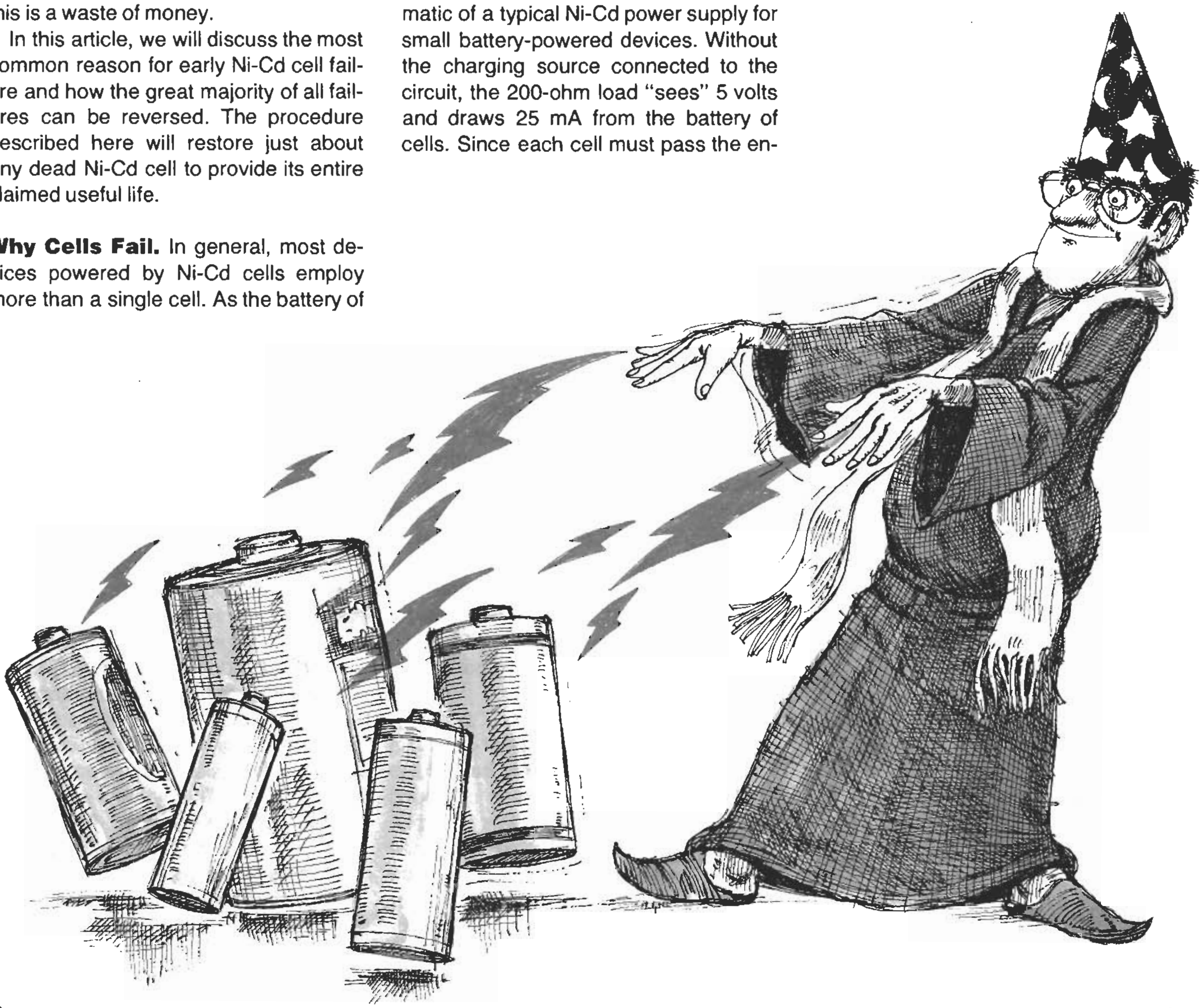
THE NICKEL-CADMIUM cell is a paradox. Capable of being charged many hundreds to many thousands of times, it occasionally fails long before its claimed life cycle comes to an end. Most people simply replace a cell that has failed with a new cell. Considering that most Ni-Cd cell failures are reversible, this is a waste of money.

In this article, we will discuss the most common reason for early Ni-Cd cell failure and how the great majority of all failures can be reversed. The procedure described here will restore just about any dead Ni-Cd cell to provide its entire claimed useful life.

Why Cells Fail. In general, most devices powered by Ni-Cd cells employ more than a single cell. As the battery of cells is discharged and recharged, the time available between recharges reduces. Almost invariably, this is due to the weakening of a single cell in the battery.

To understand the cause of such a failure—one cell "dead" while the others are still good—refer to Fig. 1, a schematic of a typical Ni-Cd power supply for small battery-powered devices. Without the charging source connected to the circuit, the 200-ohm load "sees" 5 volts and draws 25 mA from the battery of cells. Since each cell must pass the entire 25 mA and each cell's potential is 1.25 volts, Ohm's Law tells us that each cell sees the equivalent load of 50 ohms. Ideally, the four cells deliver identical performance and, hence, share the load equally.

In practice, no four cells in a battery



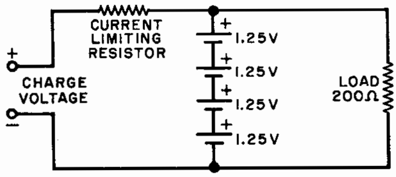


Fig. 1. Schematic of a typical NiCd supply for a small load.

ever exhibit exactly the same output voltage. Assume that one cell is delivering only 1.20 volts, while the other cells are delivering their rated 1.25 volts. Now, the 200-ohm load sees 4.95 volts and draws 24.75 mA. Since all four cells must pass the entire 24.75 mA, each of the strong cells at 1.25 volts sees an equivalent load of 50.5 ohms. This means that the weak cell sees only 48.5 ohms. While this does not seem to be too unequal a distribution, note that the weak cell is working into the heaviest load and, as a result, will discharge more rapidly than the other cells in the battery. Similarly, when the cells are recharged for only a short period of time, the weak cell, which has been working the hardest, is also the one that receives the least charging power.

This unequal loading and recharging is of little consequence in normal operation. The inequality is small for any given charge or discharge cycle, due to the relatively flat output voltage Ni-Cd cells exhibit over most of their range. And a good charge tends to equalize any energy differences between cells. However, during heavy usage, one is tempted to "quick charge" the battery just enough to restore service. A combination of shallow charges and deeper-than-normal discharges tends to exaggerate the energy difference between a weak cell and the other cells in the battery system. Operated continually in this manner, the weak cell inevitably reaches its "knee," the point at which its voltage decreases sharply, long before the other cells reach the same point.

At the knee, the picture changes dramatically. Suddenly, the weakest cell sees an increasingly heavy load, which causes its voltage to drop even faster. This avalanche continues until the cell is completely discharged, even as the other cells continue to force current to flow. The inevitable result is that the weak cell begins to charge in reverse, which eventually causes an internal short.

Once an internal short develops, recharging the cell at the normal rate is futile. The short simply bypasses current around the cell's active materials. (Even though the cell is apparently dead, most of its plate material is still intact.) If the small amount of material that forms the short could be removed, the cell would be restored to virtually its original capacity once again.

Clearing the Short. Using the circuit shown in Fig. 2, the internal short can be burned away in a few seconds. In operation, energy stored in the capacitor is rapidly discharged through the dead cell to produce the high current necessary to clear the short. Current is then limited by the resistor to a safe charge rate for a small A cell.

Several applications of discharge current are usually necessary to clear a cell. During the "zapping" (restoration) process, it is a good idea to connect a voltmeter across the cell to monitor results. Momentarily close the normally open pushbutton switch several times to successively zap the cell, allowing sufficient time for the capacitor to charge up between zaps, until the voltage begins to rise. Then, with the toggle switch closed, watch as the potential across the cell climbs to 1.25 volts. If the potential

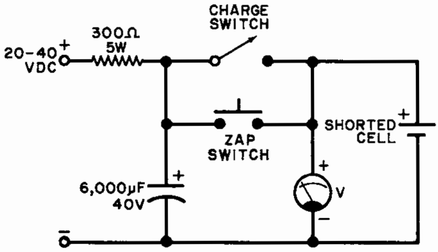


Fig. 2. Shorted cell is cleared by energy stored in capacitor.

stops before full voltage is reached, some residual short still remains and another series of zaps is in order. If you observe no effect whatsoever after several zaps and shorting out the cell and taking an ohmmeter measurement indicates a dead short, the cell is beyond redemption and should be replaced.

Once full cell potential is achieved, remove the charging current and monitor battery voltage. If the cell retains its charge, it can be returned to charge and eventually restored to service. But if the cell slowly discharges with no appreciable load, the residual slight short should be cleared. To do this, short circuit the cell for a few minutes to discharge it, zap again, and recharge it to full capacity.

Not all Ni-Cd cells can be restored by the method described here, but most can. After restoration, a cell's life expectancy will be roughly the same as that of the other cells taken from the same service application. ◇

Out of Tune

In "Build a Versatile Nickel-Cadmium Battery Charger" (October 194), the schematic should be modified as follows: The bottom of the secondary of *T1* should be connected to the *B1-BP1*-negative node, rather than *R1-S2A*.

Timed NICAD Charger

Extend the capacity and life of your nicad batteries by optimizing the charge.

By Robert Card

NICAD batteries are an increasingly popular replacement for dry cell batteries. Their one disadvantage is that you have to have a special charging unit, and although relatively cheap units are available, they have the drawback that they don't have any facility for timing. Timing the length of charge is important; overcharging can actually reduce the capacity of the battery.

The unit described here avoids this problem by providing a timed charging interval after which it switches off the current and flashes a ready light.

The way the circuit works is shown in the block diagram. It is quite difficult to generate a low frequency accurately, so the first section generates a relatively high frequency, 5KHz or higher, and then uses a binary counter to divide this down by 16384 to give a frequency of about 0.3Hz. This section is the clock generator, and its frequency is set by the value of Rx.

The next section, divide and stop, is another binary counter but one which turns itself off when it reaches its maximum count. The output from this stage goes to the control logic, which turns off the constant current generator and flashes the indicator light.

The final section is the constant current generator; this provides a constant current to the battery regardless of the voltage across the battery's terminals. This is the usual way of charging nicads, and has the advantage that several batteries can be put in series and charged at the same time. The magnitude of the charging current is set by selecting one of the resistors using the switch shown. This is necessary because different battery sizes require different charging currents.

Other sections are: the power supply, which converts the 115VAC to 15VDC, the GO switch, which, when off, resets the divide and stop function and holds off the charging current and indicator light, and the indicator lights with drivers Q1 and Q2.

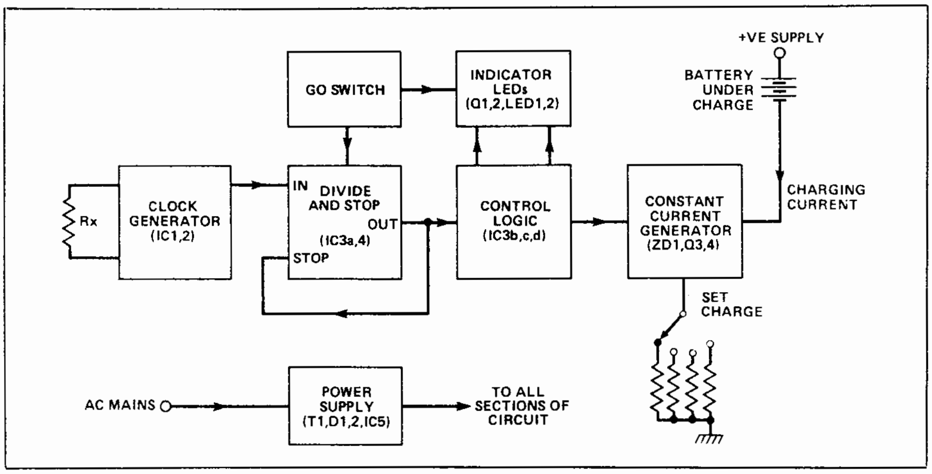


Fig. 1 The block diagram. Several batteries can be charged in series. There are limitations.

Choosing and Setting

Nicads have capacities usually measured in milliamp-hours (mAH) or amp-hours (AH). In theory, a battery with a capacity of 1AH could deliver a current of one amp for one hour, but in practice it doesn't work this way; the battery's voltage tails off as it runs down. There is also some energy dissipated in the battery's internal resistance. Nonetheless, the capacity is a guide to how much charging is necessary.

Generally, nicads prefer reasonably long charging periods, say ten hours, and for this Rx should be 33K. Other periods are possible: Rx is equal to 3456T - 1350 where T is the required charge time in hours. Table 1 shows some charge times if you don't trust your math.

Actually, choosing ten hours makes the choice of charging current much easier, so we recommend sticking to this. Note that some batteries can be charged at a very high rate, requiring a much shorter period.

The next step is to work out the charging current: this is the battery's capacity divided by the charging time. A 1AH battery for ten hours would be a 100 mA charge.

The value of Ry sets the charging current, and unless you only use one type of battery you'll find it useful to use a switch, SW3, to select different values of Ry according to **Table 2**. If none of these values suit you, you can work out the value of Ry from the equation Ry = 2.5/I, where I is the required current in amps, and Ry is in ohms.

To prevent overcharging, be sure that the batteries are discharged before charging them. A fully charged nicad has a lower voltage than standard cells, about 1.2V compared to about 1.5V. This may make them unsuitable for certain applications.

One final point on this section is that a switch, S1, can be used to select the full divide chain, or miss off the final divider stage by taking the output from pin 2 rather than pin 3. This latter option halves the timing period.

The output from this section is passed to IC3d, and this gates the output from the divide and stop section and gates it with the GO switch. As long as both these signals are low, the output of IC3d is high, which keeps the constant current

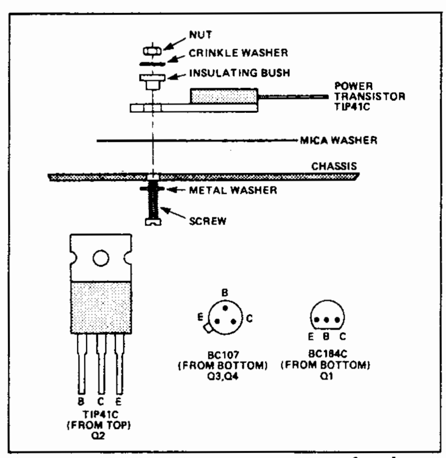


Fig. 2 The heatsinking arrangement for the power transistor, plus connection details for the other transistor types.

Table 1 Charging Times And Resistor Values

Time (hours)	Rx
1	2k1 (or 2k2)
2	5k6
5	16k (or 15k)
10	33k
14	47k
20	68k

Table 2 Battery Capacities And Charging Currents

Battery capacity (mAH)	Charging Current for 10hr charge (mA)	Ry value (ohms)	Ry power (watts)
110	11	230 (or 220)	¼
200	20	125 (or 120)	¼
500	50	50 (or 47)	¼
1AH	200	25 (or 24)	½
4AH	400	6.25 (or 4.7 + 1.8)	2

generator on. If either the counter output or the output from the circuit around SW2a goes high, the output from IC3d goes high. SW2a also controls the input to the rest of the divide and stop section, pin 11 of IC4; opening SW2a takes this input high and resets all the stages of the divider IC.

The CCG

The output of IC3d goes to the constant current generator (CCG). This uses the fact that transistors have a relatively constant voltage between base and emitter. If we hold the base voltage constant by means of a Zener regulator diode, the emitter will also be held at this voltage (less the B-E drop). Now any resistor from the emitter to ground will have a constant current through it (because of the constant voltage), and this current flows through the collector circuit. If we place the load (in this case, the battery) from the collector to the power supply, it has a constant current through it. This current can be changed by varying the emitter resistor.

In this circuit, Q3 and Q4 form a Darlington amplifier; Q3 is used to reduce the control current into the base of Q4 and prevent loading of IC3d, a CMOS gate.

A limitation of the circuit is that since there has to be a volt or two between Q3's collector and its base, plus 3V9 for the Zener diode, the maximum output voltage is limited to about 10 volts. This means that a maximum of about six cells can be charged in series, less for some types of cells.

The indicator drivers are formed from IC3. IC3c keeps IC3b off while the input to IC3c from the divide and stop is low. This means that the output for IC3c will be high, holding IC3b off, until the divide and stop output goes high. From then on, when the other input to to IC3b from the clock generator goes low, IC3b can turn on and illuminate LED 2 via Q1. When the clock generator goes high, IC3b is turned off, switching off the LED. As the line oscillates between high and low, LED 2 will flash.

The overall effect of this circuit is as follows: while charging is taking place,

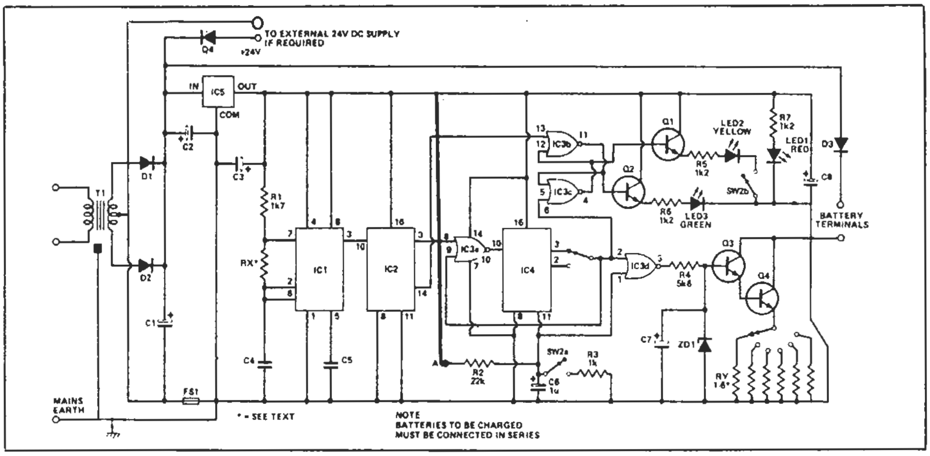
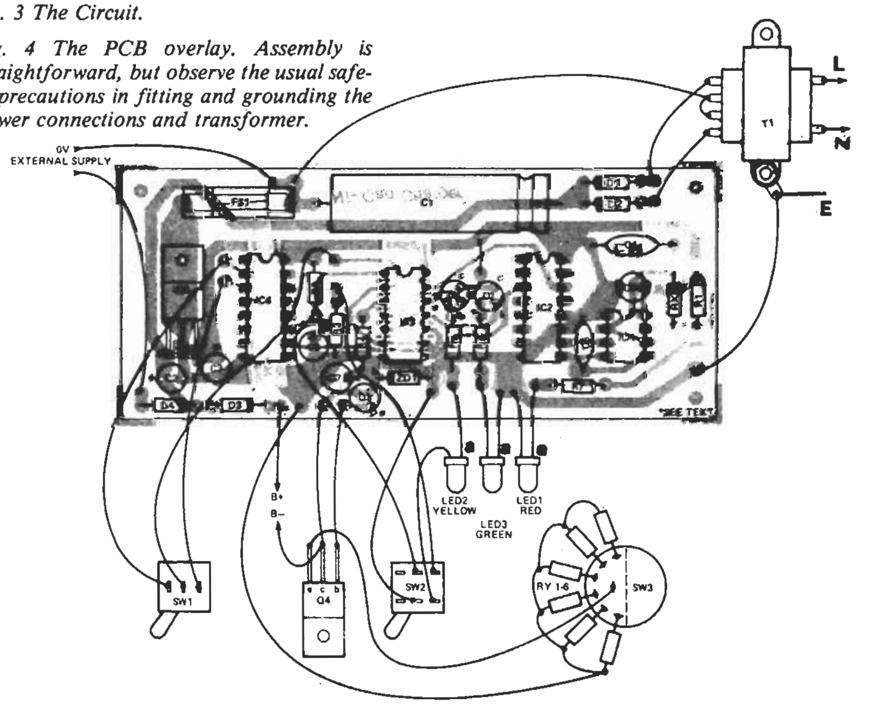


Fig. 3 The Circuit.

Fig. 4 The PCB overlay. Assembly is straightforward, but observe the usual safety precautions in fitting and grounding the power connections and transformer.



LED 3 will be on, driven by Q2 from the output of IC3c. When the charging period is finished, this turns off and LED 2 will flash. Moving the GO switch to OFF turns off LED 2 via SW2b. LED 1 is on all the time as a pilot light.

More Workings

IC1, a 555 timer, is configured as a continuous oscillator with the frequency set by C4 and Rx. The output at pin 3 is sent to IC2, a 14-stage binary counter which divides by 16384. This divided output at pin 3 comprises the output of the clock generator section. The output from IC2 pin 14 is taken from part way along the divider chain; it's the 555 signal divided by 1024, and this is used to pulse the "charge finished" LED.

The divide and stop section is based

continued on page 28

continued from page 24

on IC4, another 14-stage counter. To reach the counter, the clock pulses have to pass through a NOR gate, IC3a. While the other input to this gate, from the output of the binary counter, is low, pulses from the clock generator can pass, although they are inverted by the gate. Once the other input to the gate goes high, the output of the gate will go low whatever the clock generator output is doing, so no further pulses pass to IC4. Otherwise, IC4 would carry on counting and eventually turn on the CCG via the control logic.

Construction

The prototype was built in a metal box with the PCB mounted on plastic pillars. The power transistor, Q4, becomes quite hot when fully loaded. This has to dissipate up to 20 watts, so it will require a heatsink. This can be achieved by bolting Q4 to the bottom of the box, using a suitable insulator and heatsink compound on both sides of the insulator.

Testing

The voltage across C1 should be 18 to 25 volts and the red LED should be illuminated. The voltage across ZD1 should be zero when SW2 is OFF, and about 3.9V in the ON position. The yellow LED should illuminate in the ON position. Check that the calculated values of current are flowing through the battery terminals by placing an ammeter across them.

To ensure that the timing circuit is working without having to wait for the full charge time, calculate a value for Rx so that the time is one hour, for example (try 47K and 2K2 in parallel). The switch S1 to the half charge position and start the charge using SW2. The yellow LED should light and charging current flow for thirty minutes and then stop; the yellow LED goes off and the green one flashes to indicate a charge. Now replace Rx with the proper value.

PARTS LIST

Resistors
(All carbon film ¼W 5% unless noted)

R1	2k7, 2%
R2	22k
R3	1k
R4	5.6k
R5, 6, 7	1.2k

Capacitors

C1	2200u, 25V electro
C2, 3, 6	1u, 35V tantalum
C4	5n6, 2% polyestyrene
C5	22n polyester
C7	47u, 6V3 tantalum
C8	10u, 25V tantalum

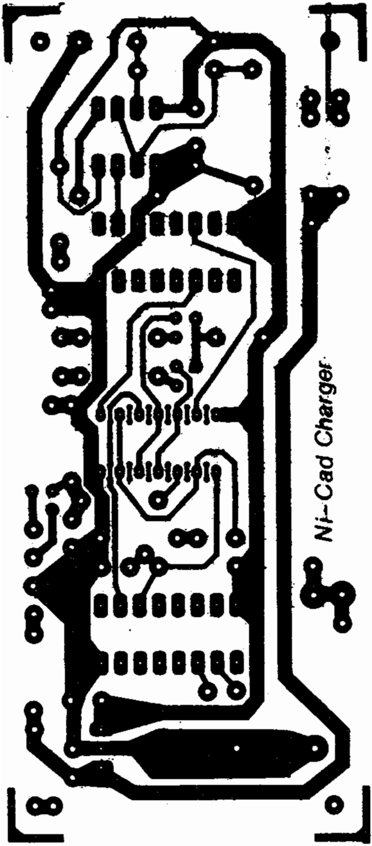
Semiconductors

Q1, 2	BC107
Q3	BC184C
Q4	TIP41C
IC1	555 timer
IC2, 3	4020
IC4	4001
IC5	7815
D1-4	IN4001
ZD1	3.9V, 400mW Zener diode
LED 1-4	0.2in red, green and yellow

Miscellaneous

T1	18-0-18V, 1A mains transformer
F1	800mA quick blow fuse
SW1	SPDT
SW2	DPDT
SW3	single pole, six way rotary (See text)

Metal case to fit; 4mm wander plugs and sockets; heat sink for Q4; PCB pillars, nuts and bolts; cable gland for mains cable; PCB, wire, solder etc.


Ni-Cad Charger

Solar-powered regulator charges batteries efficiently

by G. J. Millard
Volcanological Observatory, Rabaul, Papua New Guinea

For use with solar panels, this simple and efficient regulator circuit provides an energy-saving solution to charging batteries of the lead-acid type commonly found in automobiles. Not considering the cost of the solar cells, assumed to be at hand for use in other projects, the regulator alone is under $10.

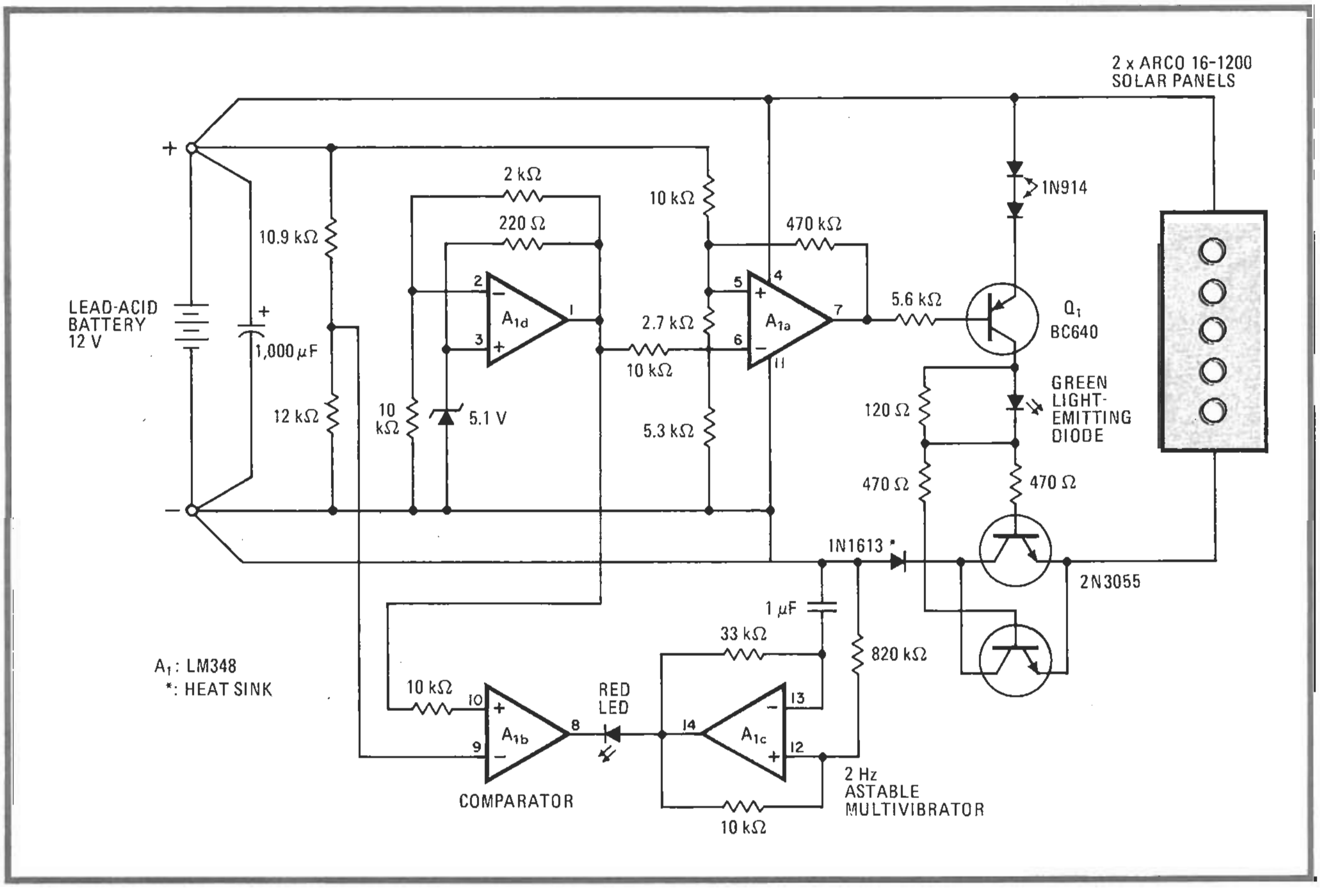
Unlike many other shunt regulators that divert current into a resistor when the battery is fully charged, this circuit opens the charging path so that the resistors can be eliminated. This method is extremely advantageous when solar panels are used, for large resistors would otherwise be required to dissipate the high power levels typically encountered.

When the battery voltage, e_o, is below 13.5 volts (normally the open-circuit potential of a 12-V battery), transistors Q_1, Q_2, and Q_3 turn on and charging current flows from the solar panels as required. The active green light-emitting diode indicates the battery is taking charge.

As e_o approaches the open-circuit voltage, op amp A_{1a} switches Q_1–Q_3 off. This condition is maintained until such time as the battery voltage drops to 13.2 V, whereupon the charge cycle repeats.

If the battery voltage should continue to fall from 13.2 to approximately 11.4 V, indicating a flat battery, A_{1b} switches low, causing a red LED to flash at a rate determined by the astable multivibrator A_{1c}, in this case oscillating at a frequency of 2 hertz. A_{1d} provides a reference of 6 V to maintain the switching points at the 11.4- and the 13.2-V levels.

The circuit will handle currents to 3 amperes. To draw larger currents, it is necessary to increase the base currents of Q_2 and Q_3 so that these transistors will remain in saturation during the charging periods. □



Light charge. Regulator for handling currents produced by solar panels charges lead-acid batteries without wasting excessive power. Circuit cuts off current to battery when its open-circuit voltage is greater than 13.5 V, eliminating need for dissipating power in resistors. Green LED indicates battery is charging. Flashing red LED indicates battery is flat (battery voltage below 11.4 V) and refuses to take charge.

Shunt regulator monitors battery voltage

Vladimir Rentyuk, Modul-98 Ltd, Zaporozhye, Ukraine

A TL431 shunt regulator is a perfect choice for many applications. You can use it as a comparator with hysteresis by taking advantage of its inner voltage reference along with few additional components. You can use this comparator with hysteresis, like a Schmitt trigger, as a simple battery monitor (**Figure 1**). You calculate the threshold voltage, V_{T+}, of this comparator as $V_{T+}=V_{REF}\times(1+R_1/R_3)$, where V_{REF} the internal reference voltage of shunt-regulator TL431, is 2.5V.

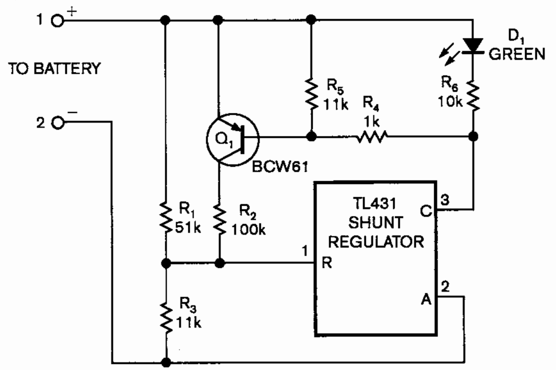


Figure 1 A shunt regulator and associated circuitry function as a Schmitt trigger, lighting LED_1 when the battery is fully charged.

When the battery voltage is higher than the threshold voltage, the cathode voltage of the TL431 is at its low level of approximately 2V, and transistor Q_1 turns on, lighting LED_1. You calculate the release voltage, V_{T-}, of the trigger as $V_{T-}=V_{REF}\times(1+R_1\times R_2/(R_1+R_2)\times 1/R_3)$.

When the battery voltage is less than the release voltage, the cathode voltage of the TL431 goes to its high level—to the battery voltage. Transistor Q_1 turns off, and LED_1 does not shine. LED_1 turns on again when the battery voltage, after recharging, exceeds the threshold voltage.EDN

Comparator circuit regulates battery's charging current

by Ajit Pal
Indian Statistical Institute, Calcutta, India

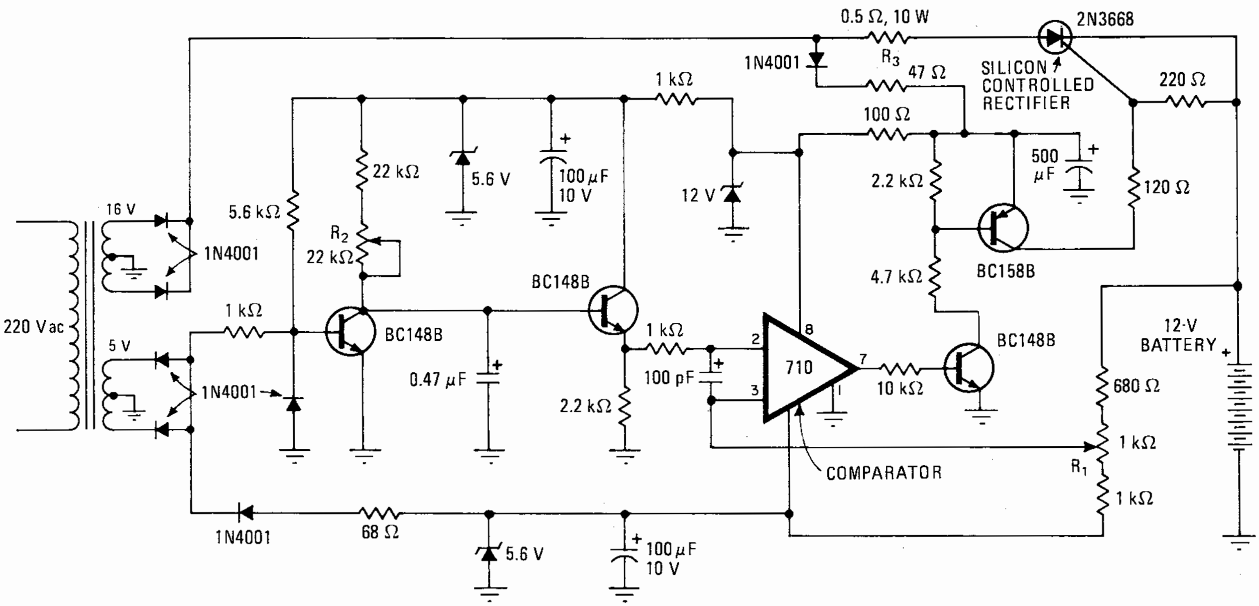
As charge builds up in a battery, its effective plate-charging area gradually decreases. To prevent damage, a good battery charger should continuously limit the charging current from the power line as a function of time. This completely solid-state charger performs the required regulation for a 12-volt automobile battery using a simple circuit built around the μA710 comparator. Although designed for 220-V operation, the charger is easily adapted for 110-V service, making it suitable for application in the U.S.

The comparator automatically adjusts the charging current by sensing the battery voltage, which increases as charge accumulates. The 710 also regulates the current by controlling the on-off switching times of a thyristor that is placed in series with the battery.

As shown in the figure, a dc voltage proportional to the battery voltage is applied to pin 3 of the comparator, with potentiometer R_1 determining the actual value. Simultaneously, a ramp signal that is derived from the power line is fed to pin 2 of the 710, with R_2 setting the slope of the ramp.

When the battery is being discharged, the voltage at pin 3 of the 710 is nearly equal to the lowest instantaneous ramp voltage, and so the output of the 710 is virtually always high. Thus, the thyristor is on for almost the entire 180° switching cycle.

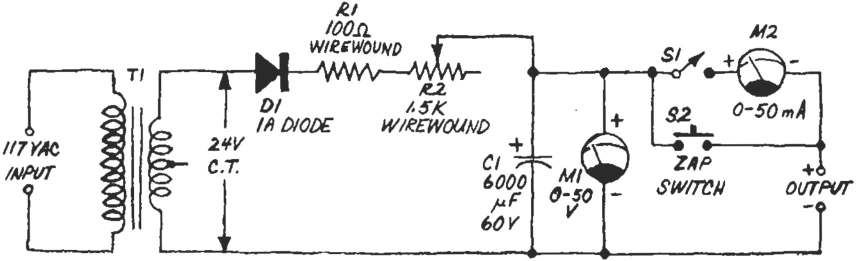
At the other extreme, when the battery is almost fully charged, the voltage at pin 3 is practically equal to the highest instantaneous ramp voltage, and so the thyristor is on for only a small portion of the cycle. For intermediate conditions, the thyristor will be on from between 0° and 180° of the cycle. The maximum charging current is limited by the resistor R_3. □



Cutting down. This circuit progressively limits the amount of charging current through a standard 12-V automobile battery as it attains its nominal terminal voltage from its discharged condition, thus avoiding cell damage. The single 710 comparator performs comparison regulation functions. Other circuitry sets conditions where the thyristor can be fired over a 0° to 180° cycle.

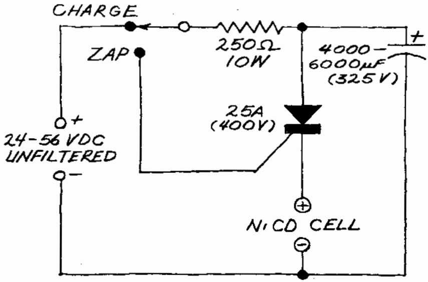
MODIFIED NI-CD CELL ZAPPER

"'Zap' New Life Into Dead Ni-Cd Batteries" (July 1977) was of great interest to me. After building the project, I decided to modify it as shown in the schematic diagram to add what I feel is an extremely desirable feature. My battery "zapper" both zaps and charges Ni-Cd cells. The 1500-ohm wirewound potentiometer (*R2*) is in the circuit to accommodate the charging current required and to allow the charge rate to be varied for different size cells. The milliammeter is required to provide a means for monitoring the charge current. —*Clifford D. Dorman, La Habra, CA.*



NiCd ZAPPER WORKS

When I first read the article on the NiCd "Zapper" in your July 1977 issue, I didn't think it would work so I didn't build it. Then I saw a reader's recent comments on the device in your "Letters" column so I decided to give it a try after all. Surprise! It works great! So far, I've run into only two cells that haven't responded to the treatment. The secret seems to be to catch the cells before they've been shorted too long. However, the heavy current through the cell burns the switch contacts. Therefore, I've modified the circuit slightly



with good results. Perhaps your readers might like to try the modification as shown here.—*Zack T. Hinckley, Melbourne, FL.*

NiCad Charger/Regenerator

PROJECT

To accompany our battery article, here is a NiCad charger which extends battery life my minimizing "memory" and metallic deposits.

by Mike Punnett

NICKEL-CADMIUM BATTERIES (NiCads) are becoming increasingly popular as replacements for conventional dry batteries in a wide range of equipment. Properly used, they can give an enormous cost saving over the life of the equipment, but if misused, tend to fail early.

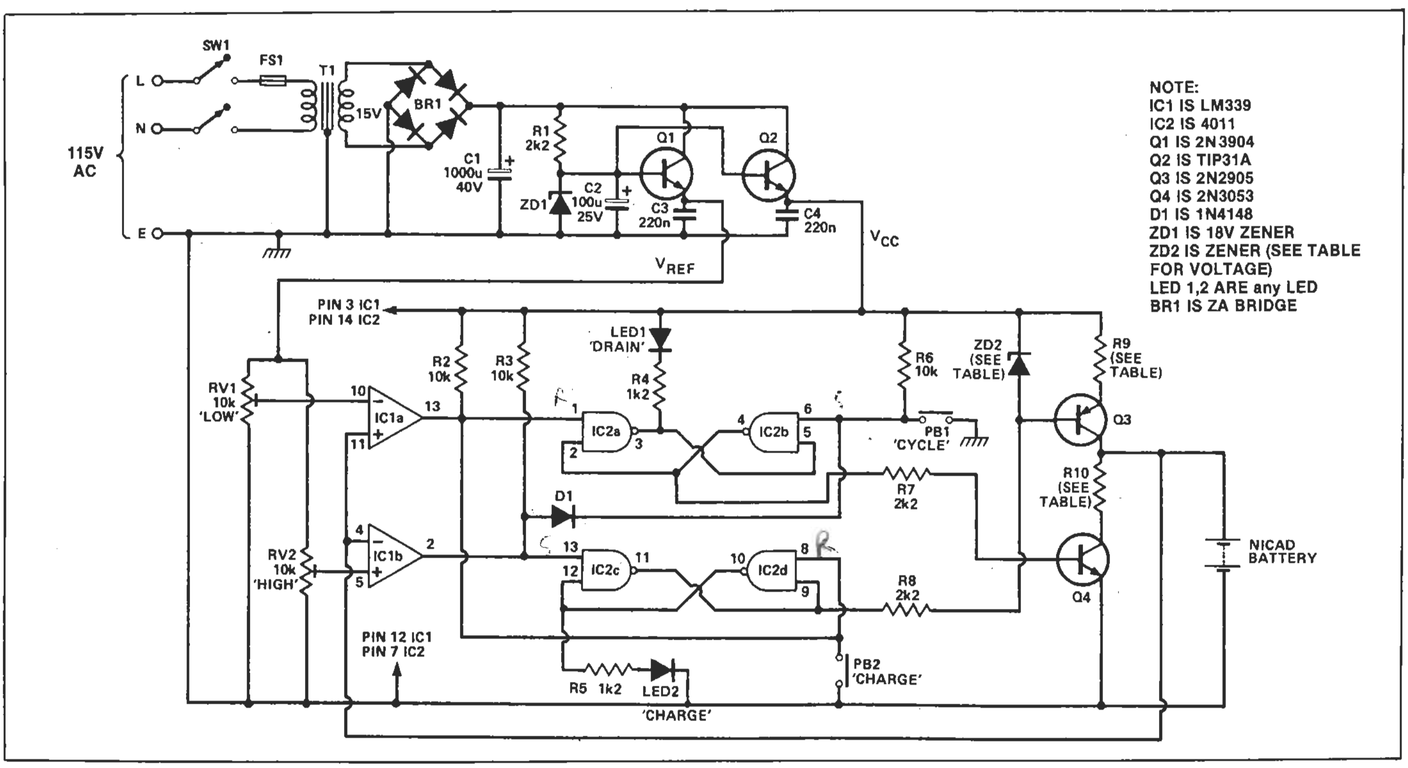
Since NiCads have a tendency to self-discharge over a few months, they have to be charged regularly. Furthermore, to avoid the inconvenience of a flat battery, they are often "topped up" with charge even when far from discharged. This leads to an effect known as whiskering, where fine deposits of cadmium build up, which can partially short-circuit the cell, as well as reducing the active electrode size. This leads to a loss of capacity; a 500mAh cell may be reduced to 300mAh after a year of light service and frequent charges.

It has been found that "cycling" NiCads can return them to an almost-new condition. This process involves discharging the battery hard (at the 1 hour rate, e.g. 500mA for a 500mAh battery), until it reaches the minimum safe voltage — NiCads can be easily damaged by over-discharging. A full charge at the 10 hour rate follows. This rather rough treatment disintegrates the whiskers of cadmium, and the full charge redeposits the metal on the electrodes. However, cycling NiCads "by hand" is a risky business, since they can easily be damaged.

The ETI NiCaddy was designed to cycle NiCads correctly and easily. It uses a minimum of components, and has two "programs": *cycle* and *charge*. Operating the unit is very straightforward: the NicCad is connected to it, and the appropriate button for the required program pressed. Cycle mode discharges the battery to its minimum safe voltage, and then switches to charge mode, in which the unit functions as a constant-current charger, automatically turning off when the battery reaches full charge. If the NiCad is already below its minimum safe voltage when connected up, the unit will automatically enter charge mode, overriding the switches, which are re-enabled when the battery rises above minimum safe voltage.

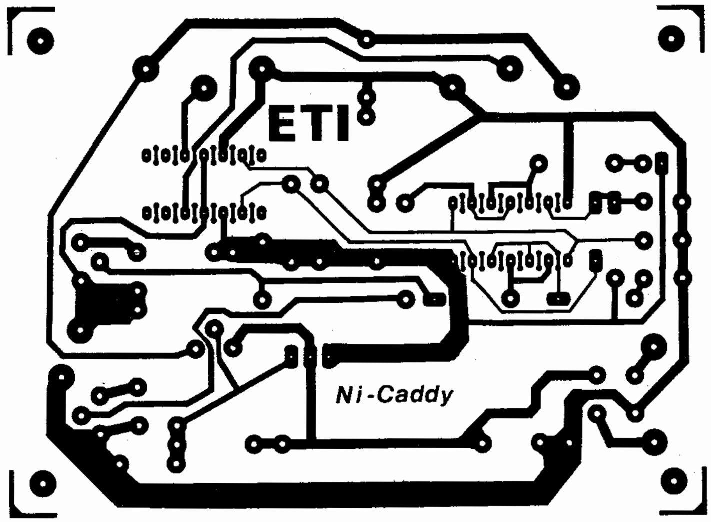
Construction

Construction of the unit is quite straightforward, either on the PCB or stripboard. Sockets are recommended for the ICs particularly IC2 which is a CMOS device. Do not forget the three wire links on the PCB.



Modifications

The circuit was originally designed for AA size (500mAh) NiCads, since these are the most widely used, but it can easily be adapted for other sizes by changing R9 and R10. These are calculated from the quoted values simply by reducing the resistance and increasing the wattage in proportion to the capacity; so for a 1 Ah six-cell battery, R9 would be 50R 1W and R10, 6R 15W. (The values do not have to be absolutely exact, of course). For cells over 1 Ah capacity, it is best to uprate Q3 and Q4; since the circuit will be on for long periods, it is advisable to rate components generously, especially heatsinks. Replacing Q3/Q4 with TIP32/TIP31 respectively, mounted off the PCB on a suitable heatsink, will enable the unit to cope with cells up to about 4 Ah. As a rough guide, allow 1 Watt dissipation per Ah cell capacity when choosing heatsinks. Remember that the heatsink on Q1 may need uprating also. Allow a dissipation of 1.2 W per AH cell capacity.



HOW IT WORKS

The power supply section is quite straightforward, using a very simple voltage regulator. V_{cc} is not critical, but the reference voltage, V_{ref}, must be stable, even though the precise voltage is not important. With a separate regulating transistor (Q1) the circuit shown is quite adequate. The two reference levels (the points at which discharge and charge respectively terminate) are derived by RV1 and RV2.

IC1 is a dual comparator which has a number of advantages over similar units, including single-rail operation, the ability to accept inputs at near-ground potential, very low offset, and open-collector outputs. In the circuit, the output of IC1a goes low to indicate that the battery has reached minimum voltage, and that of IC1b goes low when maximum voltage is reached.

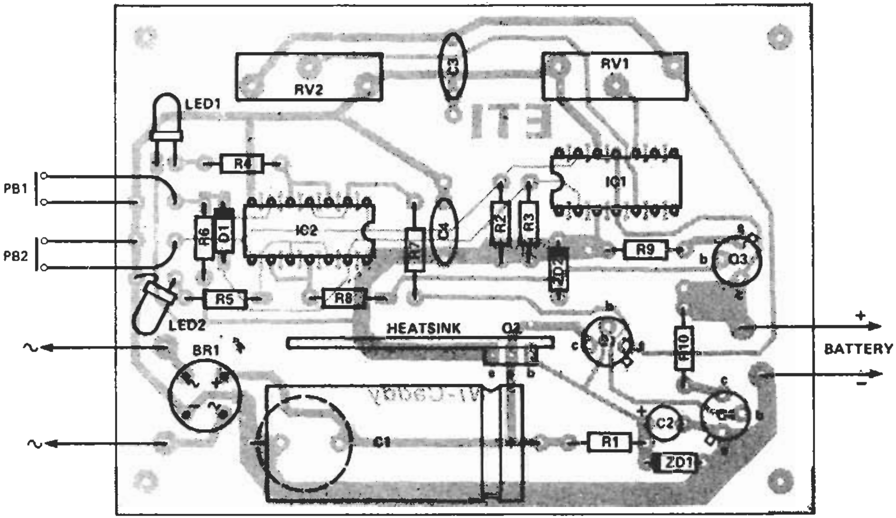
IC2 is wired as two flip-flops, one for discharging (IC2a,b) and one for charging (IC2c,d). Pressing "Cycle" sets the dicharge flip-flop and clears the charge flip-flop (via D2). When the battery reaches minimum voltage, or "Charge" is pressed, the discharge flip-flop is cleared and the charge flip-flop is set. The battery reaching full charge clears the charge flip-flop but does not set the discharge flip-flop. The status LEDs are driven directly by the two flip-flops, which also drive the output stage. The latter consists of a discharge circuit — when Q4 is turned on, the battery dicharges through R11 — and a constant current circuit consisting of Q3 and its ancilliary components, which is turned on by an active-low signal (when IC2 pin 11 is high, Q3 is driven fully off and passes no current).

PARTS LIST

Resistors (all ¼W 5% unless stated)	
R1,7,8	2k2
R2,3,6	10k
R4,5	1k2
R9,10	See text
RV1,2	10k multi-turn preset pot
Capacitors	
C1	1000u 40V PCB mounting electrolytic
C2	100u 25V PCB mounting electrolytic
C3,4	220n polyester
Semiconductors	
IC1	LM339
IC2	4011B
Q1	2N3904
Q2	TIP31A
Q3	2N2905 (but see text)
Q4	2N3053 (but see text)
D1	18V 400mW Zener
D2	1N4148 or similar
D3	400mW Zener (see Table 1)
LED1,2	Any 0.125" LED
BR1	2A bridge rectifier
Miscellaneous	
PB1,2	Min push-to-make switches
SW1	Two-pole power switch
FS1	1A power fuse and holder
T1	Power transformer, 15V 1A secondary (but see text)

Two 14-pin DIL sockets, case to suit, battery connectors, heatsinks as required (see text).

Table 1 gives component values for AA size (500mAh) cells (see later for details of use with other battery sizes). The circuit will work with batteries of up to eight cells. Remember that R11 will get hot, since the battery is discharged through this. For power ratings over 4 W, this component should be mounted off the board, preferably outside the box, to aid heat dissipation. Some of the transistors are fitted with heatsinks; Q1 has an aluminum heatsink (see overlay), Q3 and Q4 have push-fit TO5 heatsinks.



Testing and Calibration

Check the voltages across C3 and C4. Both should be in the range 16.5-17.4 V. If not, the power supply section should be investigated. The precise values do not matter, since the calibration will allow for some variability.

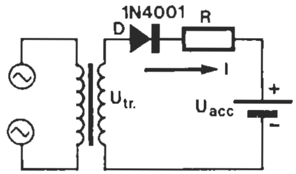
If the power supply is working properly, the unit can be calibrated. RV1 is set to the minimum safe voltage for the battery; this is 1.1 V per cell (i.e., 4.4. V for a four cell battery). An accurate, high resistance voltmeter connected to pin 8 of IC1 will enable the voltage to be checked. RV2 (full charge voltage) must be set rather more accurately, since the step in voltage which a NiCad exhibits as it reaches full charge is quite small. The best method is to set the voltage too high at first; about 1.7 V per cell on IC1 pin 11 is adequate. The operation of the unit is then checked with a battery which is known to be in full working order; at this stage the circuit should perform as described above, except that it will not turn off after charging. The charging current can be checked; it should be 0.1 of the cell capacity (i.e., about 50mA for 500mAh (AA) bateries). The test battery is then left on charge for a long period — 20 hours if flat. This guarantees that it stabilizes at full charge voltage. Since the charging is constant-current, there is no risk of damaging the battery by charging for too long. At this point, RV2 can be slowly turned down until the circuit just switches off, and the setting re-checked. The unit is now completed.

Table 1

No of cells	D3 voltage V	R9 ohms/watts	R10 ohms/watts
2	10	210/1	4.7/2
4	8.2	160/0.5	10/4
6	5.1	100/0.5	13/7
8	3.6	68/0.25	18/10

2 super cheapo NiCad charger

1



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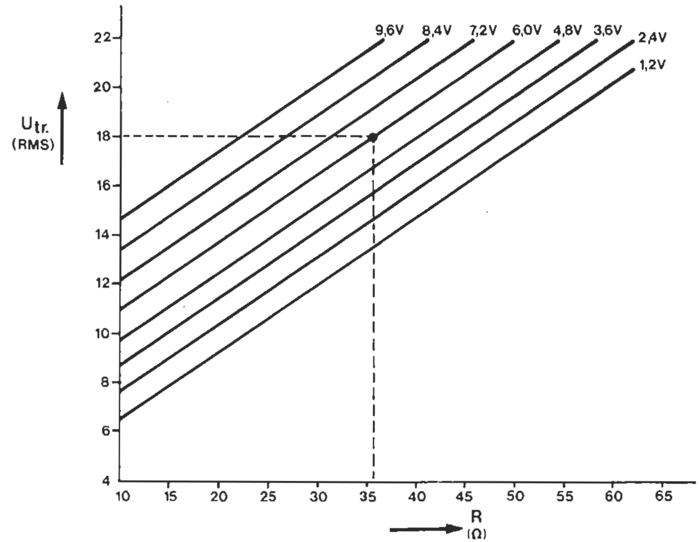
Nickel-Cadmium rechargeable batteries are gaining popularity in many applications, as they offer (in the long term) significant savings over dry (primary) batteries. Of course, the initial outlay involved is increased because a charger unit is required; however, this simple charger can be built using components that may be found in almost any constructor's junk box.

For maximum life (number of charging cycles) NiCad batteries should be charged at a fairly constant current. This can be achieved quite simply by charging through a resistor from a supply voltage several times greater than the battery voltage. Variation in the battery voltage as it charges will then have little effect upon the charge current.

The circuit consists simply of a transformer, diode rectifier and series resistor as shown in figure 1. The accompanying nomogram allows the required series resistor value to be calculated. A horizontal line is drawn from the transformer voltage on the vertical axis until it intersects the required battery voltage line. A line dropped vertically from this point to intersect the horizontal axis then gives the required resistor value in ohms. As an example, the dotted line in figure 2 shows that if the transformer voltage is 18 V and a 6 V battery is to be charged then the required resistance value is 36 ohms. This resistance value is for a charging current of 120 mA and if other values of charging current are required the resistor value must be scaled accordingly, e.g. 18 ohms for 240 mA, 72 ohms for 60 mA etc. D1 may also be replaced by a bridge rectifier, in which case the resistance value for a given current must be doubled. The power rating (watts) of the resistor should be greater than I^2R, where I is the charge current in amps and R the resistance in ohms. As the circuit does not incorporate any form of charge cutoff the charge rate must not be too great or the life of the battery may be reduced. As a general rule it is permissible to charge most NiCads at a current of 0.1C or less for several days, where C is the capacity of the battery in ampere-hours.

2



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BRIAN CHU | MICROCHIP TECHNOLOGY INC. brian.chu@microchip.com ED ONLINE 21113

Design A Linear Li-ion Battery Charger For Portable Systems

Lithium-ion batteries help designers meet their goals of getting greener, whether used for storage or backup power purposes, or in highly integrated solutions to develop low-power solutions.

Energy-storage devices such as batteries continue to change how people live. Every year sees greater daily usage of battery-powered personal electronic devices. Moreover, demands for longer run times and smaller sizes are driving continuous growth in both the battery and semiconductor industries.

When the time to develop next-generation batteries takes longer than Moore's Law, the need arises for highly integrated, feature-rich ICs that deliver better performance. It's important to learn how to design with these types of ICs to simplify the development of new systems.

A battery converts chemical energy into electric potential, or voltage. If the energy can be restored, the battery is considered a secondary or rechargeable battery. Nickel-metal-hydride (NiMH) and lithium-ion (Li-ion) batteries are common in portable applications. Compared to NiMH batteries, Li-ion batteries offer a higher nominal voltage per cell, lower self-discharge rate, and energy density in mass and volume that make them attractive for powering lightweight and space-sensitive applications *(Table 1)*.

WHY USE SINGLE-CELL LI-ION?

Li-ion batteries are relatively safe when designers use caution working with them. Table 2 shows some typical applications of Li-ion battery-powered systems. Single- and dual-cell applications comprise approximately 70% of the Li-ion battery market. Recent trends in space, cost, and weight reduction when designing small tools, digital camcorders, and similar devices are driving some dual-cell applications to become single-cell.

A single Li-ion cell can replace three NiMH battery cells in devices *(Table 1, again)*. One advantage of reducing the number of battery cells in a system is to avoid extra design work for balancing multiple cells.

With the widely used Universal Series Bus (USB), Li-ion batteries are able to be charged from USB ports on a majority of computers. A nominal voltage of 5 V makes the USB protocol attractive for single Li-ion cell applications. The USB specification defines the voltage drop budget in the range of 4.75 to 5.25 V for both host and/or hub, and no less than 4.45 V is allowed at the connector of host and/or hub.

Li-ion batteries typically use the constant-current constant-voltage (CCCV) algorithm for charging. When a charge voltage of 4.2 V per cell is met, the charger maintains a constant voltage until the termination condition is satisfied. A battery's voltage should be carefully designed with tolerance to avoid premature termination and hazard. The USB voltage range is well suited for simple step-down charger designs with a typical Li-ion voltage-regulation value of 4.2 V.

Two common step-down topologies are linear (low dropout, or LDO) converters and switching (buck) converters. Ideally, a switching topology offers 100% efficiency. After considering areas of power loss, efficiency may fall between 85% and 95%. Equation 1 calculates LDO efficiency:

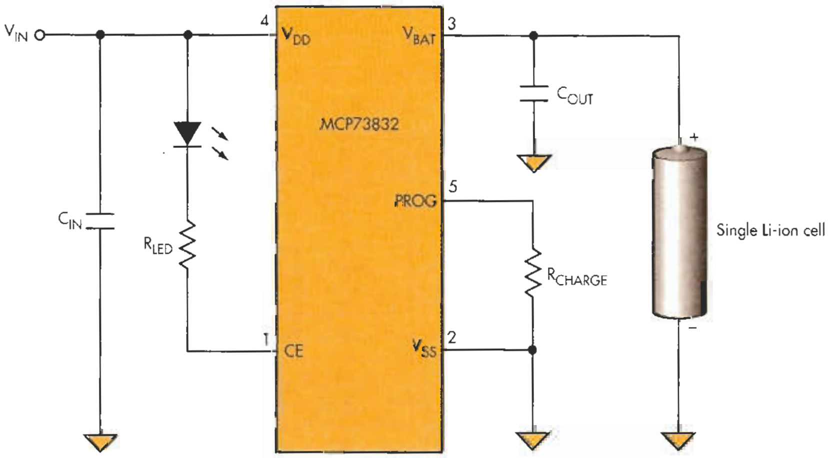
$$\eta = \frac{V_{OUT} \times I_{OUT}}{V_{IN} \times I_{OUT} + V_{IN} \times I_{GND}}$$

When I_{GND} is much smaller than I_{OUT}, it can be ignored. Thus, the efficiency of an LDO-based Li-ion battery charger can be simplified to the ratio of V_{OUT} to V_{IN}:

$$\eta_{CV} = \frac{4.2\ V}{5.0\ V} = 84\%$$

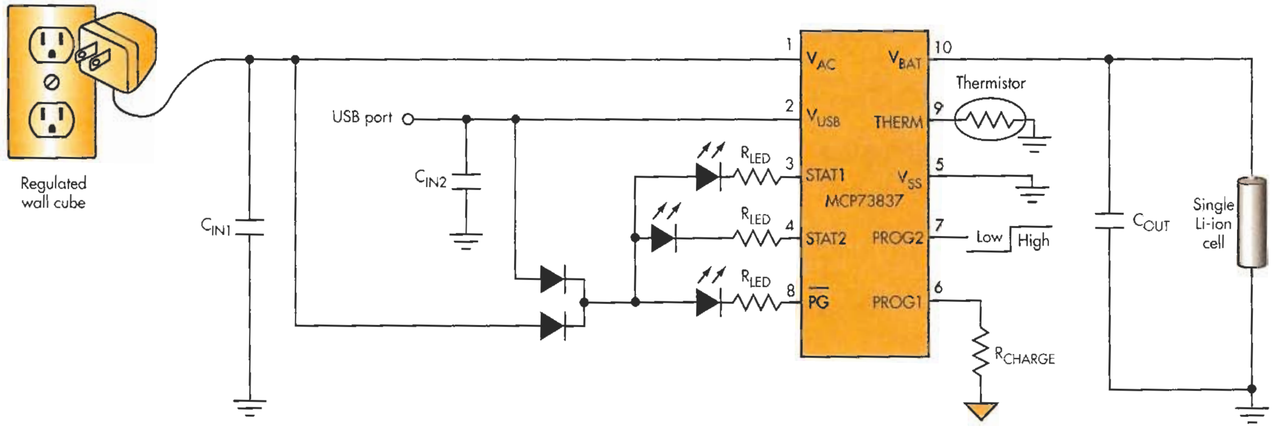
$$\eta_{BAT=3.0\ V} = \frac{3.0\ V}{5.0\ V} = 60\%$$

During a typical constant-current (CC) charging mode, the efficiency moves from



1. To operate, a typical baseline Li-ion battery charger typically needs an input capacitor, output capacitor, and programming resistor.

BRIAN CHU, senior applications engineer, Analog and Interface Products Division, received a BSEE and MSEE from the University at Buffalo, the State University of New York.



2. This dual-input Li-ion battery charger, which offers three different charge-current settings, can seamlessly switch between a wall wart (ac-dc adapter) and a USB port.

60% to 84%. The efficiency will stay at 84% for the constant-voltage (CV) charging mode. Thus, an LDO topology works well in single-cell Li-ion battery-charger designs when the input voltage is about 5 V.

An LDO topology also reduces cost by omitting inductors, and it avoids electromagnetic interference (EMI) challenges associated with switching topologies. But, if a fast-charging current above 1 A is required, a switching topology should be considered. Equation 4 presents a power-dissipation calculation that illustrates this:

$$P_{DISSIPATION} = I_{CHARGE} \times (V_{IN} - V_{OUT}) = 2\ A(5\ V - 3\ V) = 4\ Watts$$

In this example, a battery-charging current of 2 A and a battery voltage of 3 V are selected to show the worst condition in CC mode. An input voltage of 5 V is selected to simplify the calculation. When designing a system, the worst condition that's based on a given tolerance should be considered.

Even for a 35°C/W thermal-rated 4- by 4-mm quad flat no-lead (QFN) package, it's difficult to dissipate 4 W:

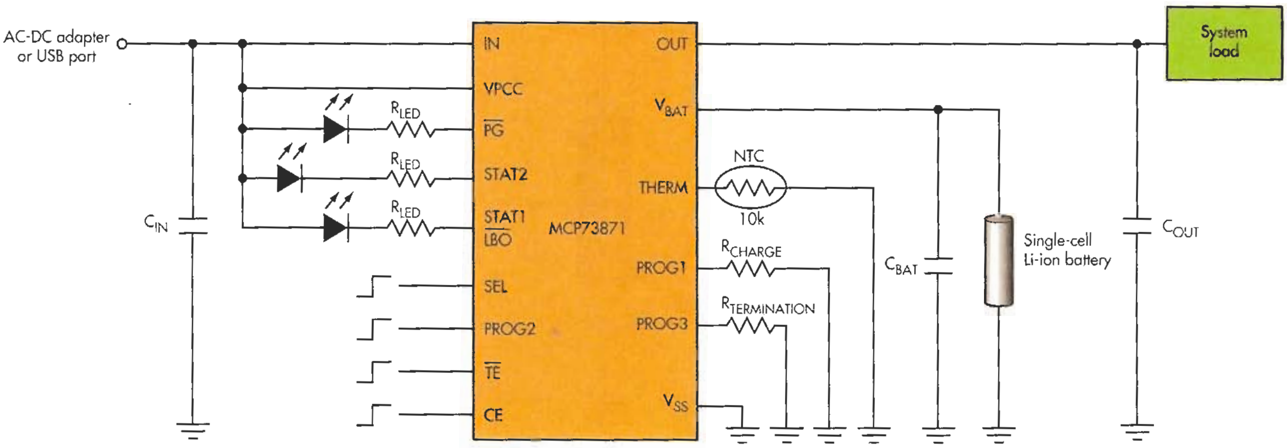
$$35°C/Watt \times 4\ Watts = 144°C$$

A room temperature of 25°C with an additional 144°C introduces a temperature of 169°C in a system. A junction temperature of 169°C is over the thermal-shutdown threshold of a typical die temperature. Well-designed Li-ion charging-management ICs should include thermal feedback that reduces the charge current when temperature begins to rise to threshold levels.

BASELINE LINEAR LI-ION BATTERY CHARGERS

Baseline linear Li-ion battery chargers are usually low-cost and have a low pin count and low passive-component requirements. They're often available in packages such as SOT-23, MSOP, and DFN. With the maturation of semiconductor technology, most baseline linear battery chargers are fully integrated. The typical pin count ranges from five to 10 pins.

Charging a Li-ion battery safely is usually the primary and only goal for baseline chargers. No fancy features are required. Figure 1 depicts a simple five-pin battery charger that requires a minimum of three components to operate—an input



3. Power-path management features can switch between power sources in this system load-sharing Li-ion battery charger.

Table 1: NiMH Vs. Li-ion Battery Characteristics

Cell type	Nominal voltage (V)	Energy density (Wh/L)	Energy density (Wh/kg)	Self-discharge (%/month)	Cycle life (charge/discharge)
Li-ion	3.6	500	160	10	500
NiMH	1.2	250	80	30	1000

Note: These values are for reference only. Actual battery parameters may vary depending on the choice of materials, the manufacturer, and testing conditions. Advanced NiMH and Li-ion batteries are not discussed here.

capacitor, an output capacitor, and a programming resistor. Additional pins may be available for functions such as extra status indicators, power-good indicators, battery temperature monitoring, timer, and logic current control.

USB-BASED LINEAR LI-ION BATTERY CHARGERS

In addition to linking peripherals and computers, the USB protocol also delivers high speed at an economic cost. Connecting devices and peripherals through USB ports to a computer has become the most popular method. With a voltage range of 4.75 to 5.25 V, USB is an excellent candidate for restoring energy back to single-cell Li-ion battery cells or packs as previously discussed. There are many methods for charging single-cell Li-ion batteries.

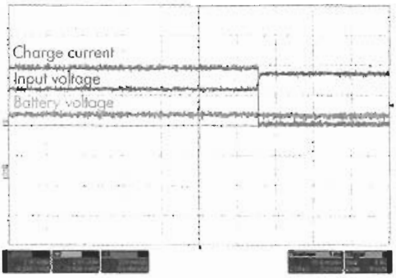
Table 3 lists a few basic methods for designing a single-cell Li-ion battery charger from USB ports. The first method utilizes a low-power USB port for a fixed charging current. This method usually ends up below the absolute maximum current of a low-speed USB port, which is 100 mA. Due to the resistor's tolerance, charge current, and supply current, this charge current is typically under 90 mA. This simply treats a USB port as a 5-V, 100-mA-rated power supply.

To take advantage of high-speed USB ports, an external MOSFET can be used to set two different charging currents when driving the gate low or high. A high-speed USB port allows an absolute maximum current of 500 mA, but a port should always start at low speed until verification is complete.

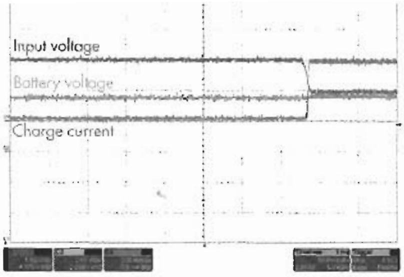
An integrated MOSFET for setting two different charging currents simplifies this design and offers either a preset or resistor-programmable charge current. Figure 2 shows an example that offers three different charge-current settings and can seamlessly switch between a wall wart (ac-dc adapter) and a USB port.

When a wall wart is present, the maximum charging current can easily be higher than 500 mA from a high-speed USB port. When just a USB cable is applied, the charge current will be based on the logic level high or low. Some designs require only one input-power rail, but a different input type can be set by communication between interfaces.

Typically, the preset USB charging current is below 450 mA for a high-speed USB port for the same reason as it is in a low-speed USB port. Proper design methods should also limit the amount of input current drawn from the USB port for safety, as well as to meet USB specifications.



4. Charge current terminates when input overvoltage protection is activated.



5. Charge current resumes once the input voltage falls back to the designed range.

Table 2: Typical Li-ion Battery Applications

Number of Li-ion cells in series	Typical applications
1	Mobile phones, digital still cameras, media players, toys, Bluetooth headsets, global positioning systems, digital picture frames, home entertainment remotes with touchscreen
2	Netbooks, digital camcorders, communication devices, power tools, medical devices
3	Netbooks, ultra-mobile computing devices, laptop computers, power tools
4 and above	Laptop computers, power tools, electric bikes, electric wheelchairs, hybrid electrical vehicles, military equipment, medical devices

Table 3: Methods For Charging From USB Ports*

Method	Description
1	Fixed charge current (typically < 90 mA)
2	External MOSFET charge-current control
3	Integrated MOSFET for multiple charge-current controls
4	Logic dual-input charge control (typically 450 mA/90 mA)
5	Input current-limit control with maximum charge-current setting

**system load-sharing and power-path management-type Li-ion battery charger*

As today's portable devices become more feature-rich, requirements for proper battery management increase. In space-constrained applications, highly integrated power-rail controls advance a designer's experience. Each power rail must be well managed for seamless switching among the input power path, system load, and battery cell.

Figure 3 demonstrates a typical application circuit of a Li-ion battery charger with system load-sharing and power-path management features that can switch between power sources. One advantage to using this design instead of a traditional method is that each power rail is managed and the battery is in support mode when the input voltage is insufficient to keep the output voltage steady. Sometimes, additional features such as low-power indicators or controls, as well as power-source selection, offer functionality beyond just restoring energy back to batteries.

ADDITIONAL BATTERY-CHARGER FEATURES

Increased use of Li-ion batteries leads to a broader range of safety and functionality requirements. These requirements may come from internal organizations that promote hazard-free design guidance; local governmental regulations or policies; regional product-manufacturer preference; battery-manufacturer specifications; a designer's level of experience; or an end-user's habits. Common functions include timers for each charging stage, input overvoltage protection, communication protocols, multiple channels of regulated outputs, and battery authentication.

Figure 4 shows an input overvoltage protection feature of a single-cell Li-ion battery charger. The output-charge current terminates when the input voltage passes the protection threshold, and it resumes once the input voltage falls back to the designed range *(Fig. 5)*. Since December 2006, this technique has been recommended for mobile devices as a technical requirement and test method of charger interfaces for mobile telecommunication terminal equipment.

Limiting the input voltage for a linear battery charger keeps end users from incorrectly using wall-wart or ac-dc adapters. It also prevents voltage spikes. Recall Equation 4:

$$P_{DISSIPATION} = I_{CHARGE} \times (V_{IN} - V_{OUT})$$

$$P_{DISSIPATION} = 1\ A \times (7\ V - 3\ V) = 4\ Watts$$

Assuming the charge current is 1 A, if the input and output voltages (battery voltage) increase, power dissipation grows. Therefore, when the differences between input and battery voltages jump to 4 V, the power dissipation is 4 W.

CONCLUSION

Green technology is always a hot topic. Engineers and scientists constantly work to improve existing designs and offer better solutions for society. Li-ion batteries can be designed with fuel cells, photovoltaic solar cells, hydro power, and wind power as storage, backup, or supportive power.

Highly integrated linear solutions may overcome hurdles in low-power designs, such as compactness and simplicity.

When intelligence, efficiency, or power dissipation are concerns, designers should survey their solutions thoroughly and understand the tradeoffs between platforms that are available. When designing with batteries or any power systems, safety is always the first priority.

For more information, visit *www.microchip.com/battery*. Also, visit *www.analogtalk.com* to view Microchip's analog technology blog.

Here is the design information you requested.

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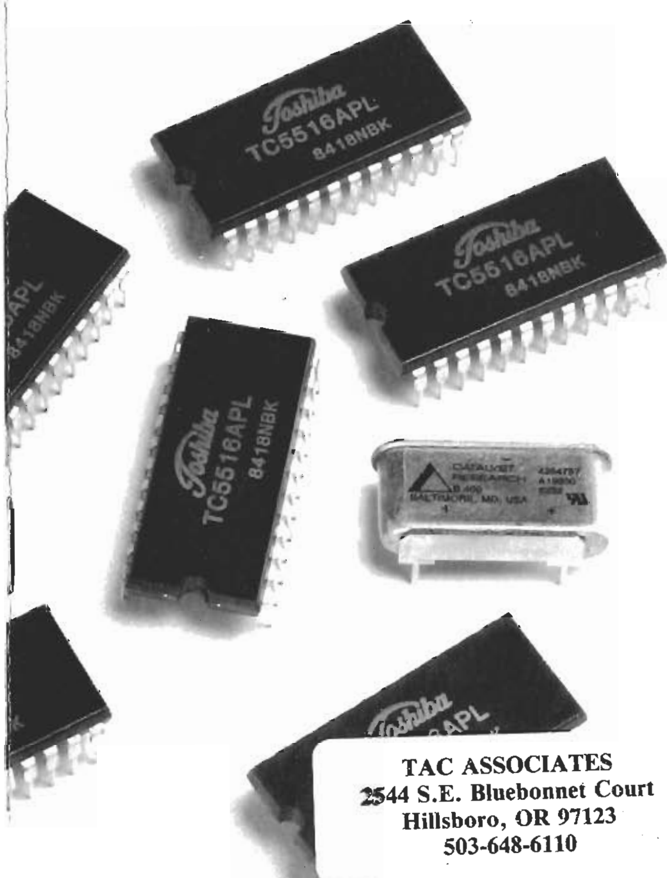
How To Use the μ PowerCell™ to Make CMOS Non-volatile



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Introduction

By far the most common reason for batteries on a PC board is to make Random Access Memory non-volatile, to avoid loss of data during power outage. Another application for batteries is to keep clock/calendar circuitry functioning when power is down. However, as more current efficient integrated circuits are found, a wider range of circuit function non-volatility will become practical.

CMOS is the semiconductor technology of choice for non-volatility by battery backup because of its low leakage current for data retention ($< 10\ \mu A$ typical). CMOS also has the ability to retain data with V_{DR}[1] at 2 VDC, compared to 5 VDC for normal operation.

With today's CMOS RAM it is possible to use Catalyst Research µPowerCell™ batteries to provide decades of reliable non-volatile memory. As CMOS circuitry has evolved to lower power, it has become possible to make an entire microprocessor system non-volatile for the life of the product.

Why CMOS with Battery Backup?

There are many alternatives for obtaining non-volatility in the event of power loss (see table 1). Magnetic media answer the most basic issue of volatility. However, it requires transfer of volatile memory data to a separate device, so it can not protect active RAM. ROMs, PROMs and EPROMs can be used where there is no need to alter data, such as in the storage of constants.

Another alternative is electrically alterable non-volatile memory such as EEPROM and EAPROM. However, these memory types impose their own severe limitations:

- They have a limited life in terms of write cycles.
- They have relatively slow write cycles.

For continuous protection of data without sacrificing the advantages of RAM, the best choice is to use µPowerCell™ battery backup. µPowerCell's™ long life and proven reliability mean that you can count on effective data protection for the practical life of the circuit and product.

[1] V_{DR}-rated data retention supply voltage.

Table 1. Characteristics of solid state non-volatile memory.

MEMORY	WRITE	ERASE	FAST WRITE	FAST READ	MAXIMUM VULNERABILITY PERIOD WHEN WRITING AT POWER OUTAGE	UNLIMITED STORE WRITES	NEVER LOSES STORED DATA	AUTOMATICALLY STORES
RAM	✓	✓	✓	✓	Always			
ROM	✓			✓	None		✓	✓
PROM	✓			✓	None		✓	✓
EPROM	✓	✓		✓	None		✓	✓
EEPROM	✓	✓	100ms	✓	100ms	★	★	✓
EAROM	✓	✓	100ms	✓	100ms	★	★	✓
SHADOW RAM OR RAM + EEPROM	✓	✓	✓	✓	10ms	★	★	?
RAM + BATTERY	✓	✓	✓	✓	10ms	✓	?	?
µPowerCell™ + this book	✓	✓	✓	✓	None	✓	★•	✓
IDEAL NON-VOLATILE RAM	✓	✓	✓	✓	None	✓	✓	✓

✓ has feature
★ approximate feature
? user supplied feature
• Data retention time may be limited above +55°C. See CRC spec sheets. Below +55°C data retention times over 10 years are no problem.

Why Lithium?

When choosing a battery for CMOS RAM backup, there are several alternatives (see table 2).

Secondary (rechargeable) batteries would seem to be a good choice for RAM backup. However, both Sealed Lead Acid and Nickel-Cadmium (NiCad) rechargeable batteries have low energy density due to low voltage per cell and short life between charges due to high self discharge. Their operational life is much shorter than lithium cells, typically 3-5 years. Therefore, they must be replaced if the equipment they are used in is to last more than 3-5 years. Whereas a properly designed backup system using μPowerCells™ can last 20 years or longer without replacement when *all* design considerations are solved correctly. Don't make the mistake of trying to use high voltage, high capacity or rechargeability to overcome problems of high energy requirements or inefficient energy use. End of life is a function of energy required and operational life only. Higher voltage, capacity and rechargeability cannot make a 3-year battery a 20-year battery.

Energy requirements can be dramatically lowered by proper selection of hardware and circuit design (RAMS, Diodes, switches, etc.). Sealed Lead Acid batteries are also large and heavy. NiCad batteries suffer particularly high discharge when the circuitry is subjected to high temperatures. Similar problems and limitations apply to "super caps" capacitors. Power must be on intermittently to recharge the "super cap" or data is lost.

Table 2. Comparison of μ PowerCell™ Lithium batteries with other chemistries.

CHARACTERISTIC	IDEAL POWER CELL	SEALED LEAD ACID	NICAD	MERCURY	ALKALINE	SILVER	LITHIUM
MAX ENERGY DENSITY	High	Low	Low	Med	Med	Med	High
SHELF LIFE	High	Low To Med	Low	Low	Med	Med	High
RECHARGEABLE	Yes	Yes	Yes	No	No	No	Partial*
LIGHT WEIGHT	Yes	No	No	No	No	Yes	Yes
SAFETY	High	Med	High	Low	High	High	High*
COST	Low	Med	Med	High	Low	Med	Med

*Depends upon particular system

Primary batteries hold their charge and do not require recharging, giving a better result in CMOS backup because they have much lower self discharge and therefore much longer data retention without recharging (ten years instead of several weeks). Of the primary battery chemistries available, Lithium offers the best combination of energy density and shelf life. The μPowerCell™ has secondary characteristics, see Float Charging μPowerCell™, page 3.

Mercury batteries offer high energy density but do not provide long shelf life. They are also quite heavy and have demonstrated reliability and disposal problems. Alkaline batteries do not have a very high energy density and have short shelf life compared to Lithium. Elevated temperatures limit shelf life even further. Silver oxide batteries combine high energy density with moderate shelf life, but still exhibit unacceptable self discharge rates at high temperatures and have a lower energy density than Lithium. And the cost of silver batteries fluctuates with the market price of silver.

Why Catalyst Research uPowerCell™?

Within the group of Lithium battery chemistries, there are again several alternatives. Since Lithium is a highly reactive material, care must be taken to avoid batteries that could explode due to reverse current, short circuit or puncture. The higher the impedance of a Lithium cell, the less likely these occurrences are.

The sealing of Lithium batteries is very important. The ingredients of the cell must not leak and no outside air or moisture should get in. Some cells have plastic seals which limit their ability to withstand harsh environments (temperature, shock, vibration, etc.). μPowerCells™ have glass to metal insulator seals and metal to metal weld joints. They can withstand harsh environments as well as any battery made and better than most.

Catalyst Research's proprietary Lithium-Iodine chemistry is truly solid state. A solid Lithium anode and solid Iodine cathode form a Lithium-Iodide electrolyte layer at their interface. This electrolyte separator is self healing. If a break should occur, more Lithium-Iodide is automatically formed to heal the break. Therefore the separator is self healing and can not fail. The cell also has high impedance properties which make a current limited system that *can not* explode due to reverse current, short circuit or puncture. There is no gas generation or appreciable volumetric change. And the solid state Lithium-Iodine cell will not freeze or rupture at very low temperatures.

Hundreds of thousands of Catalyst Research Lithium-Iodine (Lithiode™) cells have been used for cardiac pacemakers. Their long life and high reliability are field proven. Over a million Lithiode™ cells have been used for CMOS RAM backup.

µ PowerCells™ from Catalyst Research use the same proven chemistry as the Lithiode™ but have a higher energy density and are in packaging that is better suited for electronic production. Within the µ PowerCell™ line are rectilinear shapes and very small axial lead packages.

µ PowerCells™ can be handled just like other components such as resistors and capacitors. They accept wave soldering, cleaning cycles and drying ovens as long as temperatures do not exceed 250°C for 5 minutes, 500°C for 2 minutes or 700°C for 10 seconds. And axial lead µ PowerCells™ can be machine inserted directly on the PC board just like other components.

Care and Handling of Backup Batteries

High impedance and, therefore, low current requirements for data retention make CMOS ideal for µPowerCell™ backup. µPowerCells™ will retain their energy while in the circuit, but switched off (open circuit) for 20 years. It is absolutely necessary to avoid parasitic leakage paths in this open circuit mode because over the life of product such leakage can use up the battery's energy. They must truly be on "open circuit". That means circuit elements (diodes, capacitors or transistors) that are connected across the battery must be very low leakage. It also means that care must taken in handling backup batteries to avoid finger oil, conductive flux or corrosive material bridging the battery and discharging it. Parasitic leakage of a few µamps will shorten the battery's life 35 mA hours or more per year.

The recommended procedure is to keep µPowerCells™ in their Catalyst Research shipping containers until they are to be mounted on the PC board. Handle with gloves to avoid contaminating the terminals. Insure thorough cleaning after soldering to eliminate all flux residue on the glass seal. If the operating environment is expected to include high humidity or corrosive atmospheres, it is recommended that the batteries and PC board be encapsulated or conformally coated to avoid unexpected leakage paths from developing. Catalyst Research engineers have used many encapsulating materials successfully, but each designer must evaluate his specific application.

Backup Design Considerations

The circuit for RAM backup is not as simple as it might appear. And there are several pitfalls to avoid.

The following suggestions have come from Catalyst Research engineers and are based on their analysis and testing. However, each system's configuration is likely to have unique characteristics to be considered, so Catalyst Research offers these only as examples of some solutions that do work. Contact us about your particular requirements.

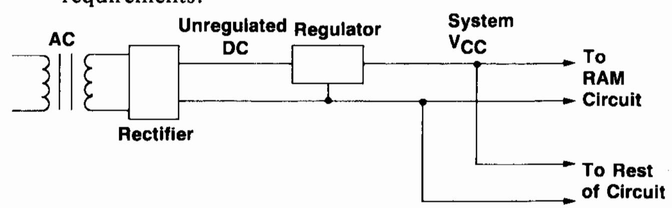


Figure 1. Basic power supply elements.

Look Ahead Power Fail Detection

The backup issue should be considered as part of overall system design. A typical power supply will have the elements shown in figure 1. In the event of total power failure, the AC will disappear immediately, but the regulated DC will decay slowly due to system capacitance. In a typical system there may be as much as 20 milliseconds or more between loss of power and DC decay to the point of losing data in RAM. In microprocessor based systems, that time can be used by the processor to save registers and provide for an orderly shut down.

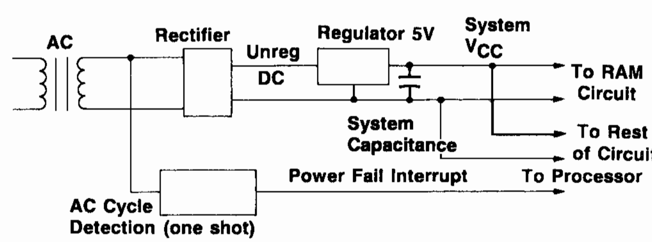


Figure 2. AC line look ahead power fail detection.

To provide notification to the processor, the designer could sense the unfiltered AC line to detect absence of power cycles and use that absence to generate a Power Fail Interrupt (PFI) signal (see figure 2). Another alternative is sensing the unregulated DC. Since most regulators require 1 to 2 volts compliance, and system capacitance can maintain the system long enough to save important data, detection of the failing unregulated DC supply can provide advance warning (see figure 3).

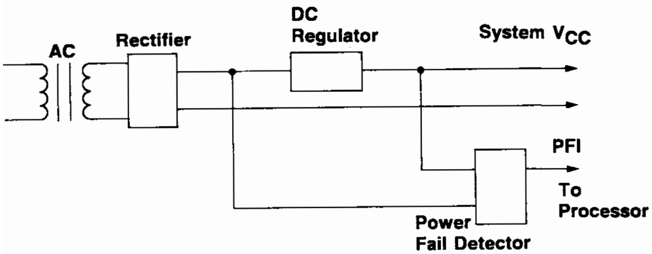


Figure 3. Unregulated DC look ahead power fail detection.

RAM Switchover

To switch from line power to battery backup requires control of the sequence of events to insure data integrity. Normal circuit power V_{CC} should be 5.0V ±10%. In normal operation, a Chip Enable (CE) logic signal must be provided to the RAM chip for proper read/write functioning. When switching to backup, CE must be deselected before the supply voltage falls below 4.5 VDC, placing the chip in backup mode where 2.0 VDC is sufficient for memory retention, and Data Retention Current (I_{DR}) is at minimum. Logic level of CE must be maintained within 200mV of either supply rail (V_{CC} or ground) to guarantee minimum Data Retention Current. CE must remain deselected in the absence of the power supply.

Once CE has been deselected, the RAM power source can be switched from the power supply to the battery. The switchover must occur before the supply reaches 2 VDC (preferably it should be when supply equals battery voltage or 2.8 VDC). A diagram of the switchover sequence is shown in figure 4. Ideally PFI would be generated at T_1, CE deselect at T_2 and battery switchover would occur at T_3.

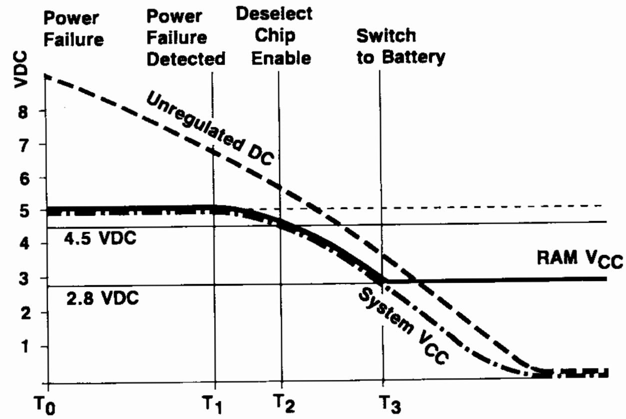


Figure 4. Power switchover sequence.

Recommended Circuits

A system configuration for power switchover is suggested in the block diagram (see figure 5).

Circuits that have been designed and tested by Catalyst Research engineers for each of the block functions are shown in figures 6 and 7.

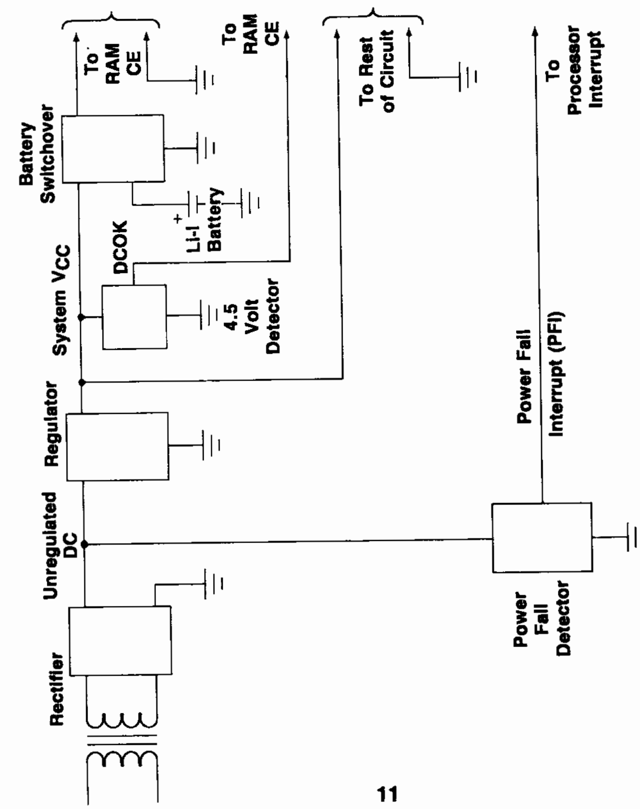
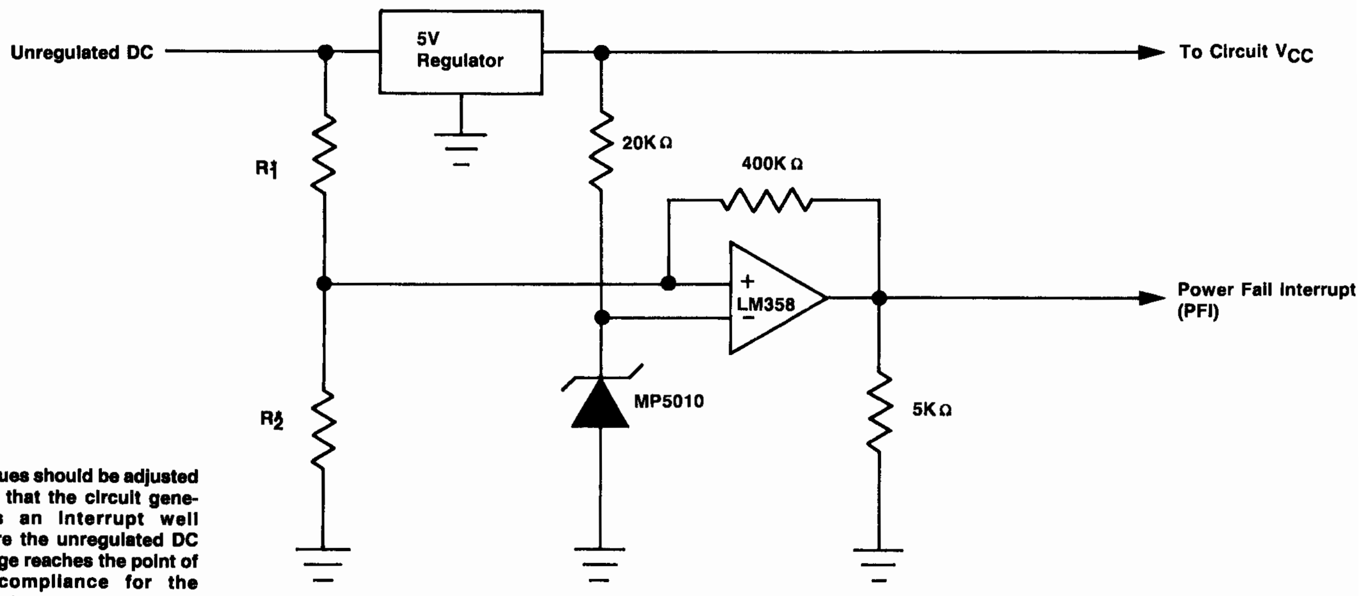


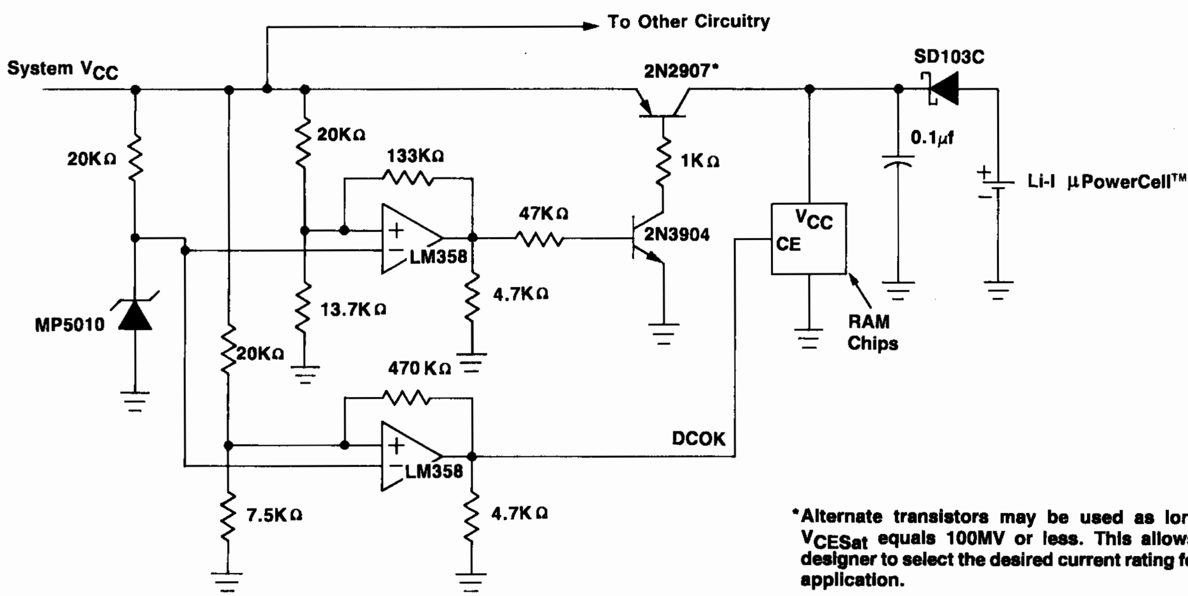
Figure 5. Battery backup system block diagram.

Figure 6. Suggested circuit for power fail detection.



*R values should be adjusted such that the circuit generates an interrupt well before the unregulated DC voltage reaches the point of non-compliance for the regulator.

Figure 7. Recommended circuit for battery switchover.



*Alternate transistors may be used as long as V_{CESat} equals 100MV or less. This allows the designer to select the desired current rating for the application.

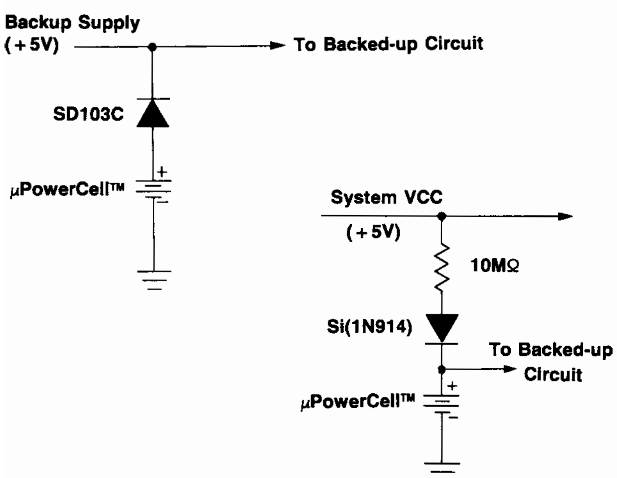
Float Charging uPowerCell™

The μPowerCell™'s Lithiode™ lithium iodine chemistry has secondary characteristics. We do not recommend using it as a true secondary cell but we do recommend setting up the battery backup circuit to allow a "float" charge while the 5V power supply is on. This is particularly useful and beneficial when the μPowerCell™ will be exposed to high temperatures (above 55°C) while the 5V power supply is on. The backcurrent will reduce the higher self discharge rate which occurs at high temperatures (over 50°C).

There is no potential safety hazard associated with backcurrent on a μPowerCell™. If done incorrectly (too much backcurrent at too low a temperature) it is virtually impossible for venting, overheating or outgassing to occur. It is possible to damage the electrical function of a μPowerCell™ if it receives more than 10-20 microamps of backcurrent at room temperature (25°C). Therefore, we strongly recommend using the ITT part number SD103C or equivalent diode in the battery backup circuit (see figure 8).

We suggest the following two float charge circuits:

Figure 8. Recommended Float Charge Circuits.



Generally speaking, charge current should be two (2) times discharge current at a given temperature. See current *vs.* temperature curves on each individual cell model's specification sheets.

Design Pitfalls to Avoid

Simpler circuits have been used for battery switchover. They may work in some applications, but beware of problems like those described below.

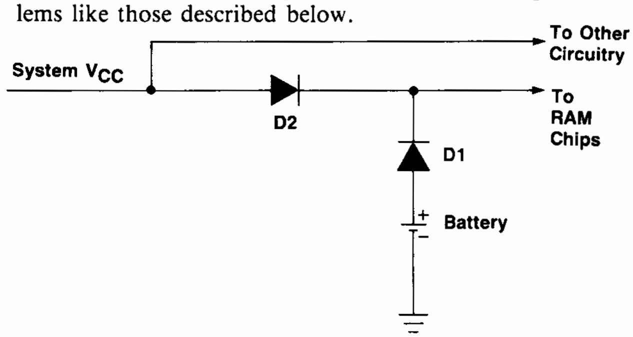


Figure 9. Simple diode Or.

This circuit seems to provide the minimum requirements of isolation between the primary supply and the battery. However, the typical 0.7V voltage drop across D2 allows an illegal condition to occur in normal operation. The RAM chip's V_{CC} is 0.7V less than the potential voltage of a logic signal from a device not in the backed up system. That can cause the RAM to latch up, destroying data. Typical CMOS RAM specifications require that logic input signals not exceed V_{CC} by more than 0.3 VDC. The most obvious answer is to add D3 (see figure 10).

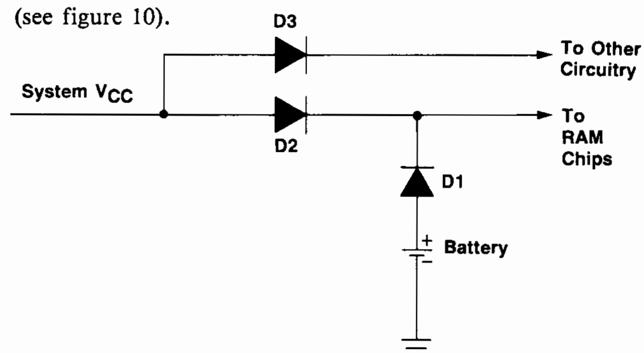


Figure 10. Modified diode Or.

D3 takes care of the illegal condition described above, but requires the system power supply to be increased to a non-standard level of about 5.6 VDC to maintain 5.0 VDC on the circuits. Another problem with this circuit is the drop across D1 in the backup mode. The lower voltage available reduces backup life. This problem can be partially solved by using a low voltage drop schottkey diode.

The next logical design step is to consider a "pass transistor" in place of D2 (see figure 11). Its saturation voltage (V_{SAT}) is less than 100mV, avoiding the illegal V_{CC} to logic signal condition described above. That allows D3 to be removed and system V_{CC} to be set at the standard 5.0 VDC.

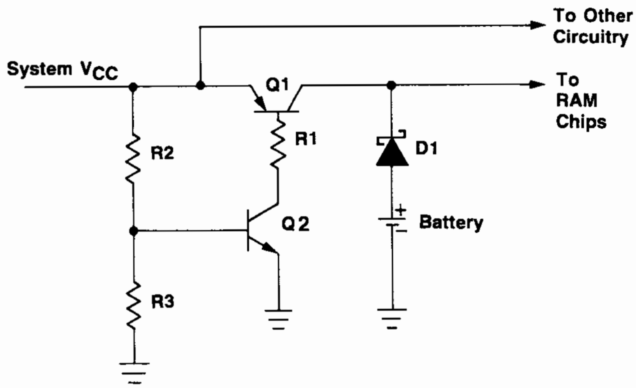


Figure 11. Use pass transistor.

The basic pass transistor approach is acceptable for some applications, but has a poorly defined switchover point. It is sensitive to the gain of Q2 and the threshold established by R2 and R3. This approach produces a soft transition between on and off conditions of the pass transistor, Q1.

A more reliable switch point is achieved by using a Zener diode (Z1) in the divider circuit (see figure 12). However, the switch point is still sensitive to Q2 gain.

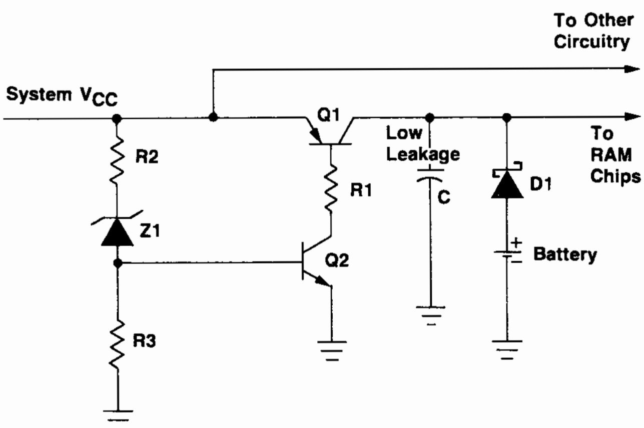


Figure 12. Use Zener diode.

The most effective way to switch to backup is with the use of a precision comparator (see figure 13).

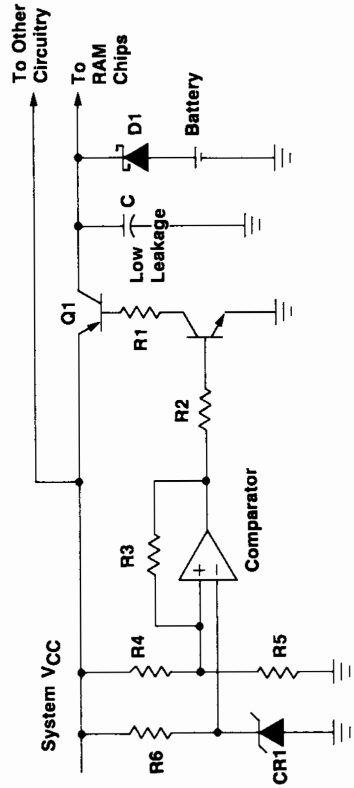


Figure 13. Use precision comparator.

Figure 13 includes provision for introducing hysteresis in the switchover point to avoid oscillation around the threshold point. R3 determines amount of hysteresis. Care should be taken to choose a comparator or 0P AMP that behaves in a known or acceptable fashion during the power supply transition from 5V to 0V and 0V to 5V.

CMOS Static RAMS

There are many manufacturers of CMOS static RAMS. Most of them produce parts that are ideal for µ PowerCell™ battery backup. To save space we do not list all the parts that each manufacturer makes. We show the number of parts, range of organization, speed and data retention currents and give one example of a particular part for each manufacturer.

Please note speeds as fast as 25 nanoseconds, densities up to 256K bits and maximum data retention currents as low as 3 µ amps at 70°C in some cases. Over ten years of non-volatility at 70°C with a B-400 means battery backup for the life of the product.

*Consult with RAM, clock/calendar and switching circuit manufacturers directly for accurate specifications and availability.

Table 3. CMOS static RAMs.

Manufacturer	Parts	Density (bits)	Number of Pins	Access Time (ns)	Minimum V_{DR} (Volts)	Typical I_{DR} (μA)	Maximum I_{DR} (μA)	Temperature Range (°C) 0 to 70	 −40 to 85	 −55 to 125
Advanced Micro Devices (Sunnyvale, CA)	(7)	4K to 256K		70 to 200 70 100 120 150	2			X	X	X
Example	AM 99C88L	8192 x 8	28	200	2		50		X	X
DENSE-PAC Microsystems, Inc. (Garden Grove, CA) Note: These are hybrid modules.	(19)	16K to 1152K		25 to 200	2	4	1000	X	X	X
Example	DPS41288	128K x 8	32	100	2	1	300	X	X	X
Electronic Designs Inc. (EDI) (Hopkinton, MA)	(30)	32K to 384K		45 to 200 120 150	2		100	X	X	X
Example	EDH 88162C-12	16K x 8	28	200	2		100			X
Electronic Research and Service Organization (ERSO) (Taipei, Taiwan)	(1)									
Example	CIC 2428	2K x 8	24	55	2		2	X		
Fairchild Semiconductor Corporation (Payallup, WA)	(4)	65K		45 to 70	2	3	50	X	X	X
Example	F1601-55	65K x 1	22	55	2	8	50	X		
Fujitsu Microelectronics Inc. (Tokyo, Japan)	(23)	16K to 256K		50 to 200	2		30	X	X	
Example	MB84256L	32K x 8	28	100 150	2		50		X	

Table 3, continued. CMOS static RAMs.

Manufacturer	Parts	Density (bits)	Number of Pins	Access Time (ns)	Minimum V_{DR} (Volts)	Typical I_{DR} (μA)	Maximum I_{DR} (μA)	Temperature Range (°C) 0 to 70	 −40 to 85	 −55 to 125
Gould AMI (2 parts	56514	1K x 4	18	300	2		15	X	X	X
(Santa Clara, CA) described)	56516	2K x 8	24	120	2		15		X	X
Harris Semiconductor (Palm Bay, FL)	(15)	1K to 256K		55 to 200	2		5 to 400	X	X	X
Example	HM6516259	2K x 8	24	55	2		40	X		
Hitachi American Ltd. (San Jose, CA)	(28)	16K to 256K		35 to 200	2		50	X		
Example	HM6264	8K x 8	28	120 150	2		50	X		
Hughes Semiconductor Div. (Newport Beach, CA)	(3)	256 to 2048		250 to 500	1.5 to 2		50 to 100		X	X
Example	H1822C	256 x 8			1.5		100			X
Hyundai (Santa Clara, CA)	(11)	16K to 64K		35 to 150	2		100	X		
Example	HY61C16/L	2K x 8	24	45	2		2	X		
INMOS Corporation (Colorado Springs, CO)	(8)	16K to 64K		25 to 100	2	5	250 @ 70°C 600 @ 125°C	X	X	X
Example	IMS1403LM	16K x 1	20	35	2	5	600			X
Integrated Circuits Inc. (ICI) (2 parts	CMOS 64	8K x 8	28	100	2	10	20	X		X
(Bellevue, WA) described)	CMOS 256	32K x 8	28	120	2	1	15	X		X
Integrated Devices Technology Inc. (IDT) (Santa Clara, CA)	(11)	8K to 256K		35 to 100	2	10	20 to 400	X	X	X
Example	IDT7188L45	16K x 4	22	45	2	15	500	X	X	X

Table 3, continued. CMOS static RAMs.

Manufacturer	Parts	Density (bits)	Number of Pins	Access Time (ns)	Minimum V_{DR} (Volts)	Typical I_{DR} (μA)	Maximum I_{DR} (μA)	Temperature Range (°C) 0 to 70	−40 to 85	−55 to 125
Micro Power Systems (MPS) (Santa Clara, CA) (3 parts described)	MP2114C	1K x 4	18	250	2		25		X	
	MP6504	4K x 1	18	250	2		25		X	
	MP6514	1K x 4	18	250	2		25		X	
Mitsubishi Semiconductors (Tokyo, Japan)	(15)	16K to 64K		35 to 150	2		50	X		
Example	M5M5165P70L	8K x 8	28	70	2		50	X		
Mostek (Thomson Mostek) (Carrollton, TX)	(8)	8K to 16K		55 to 250	2					
*Battery backup circuit on board this product only. Example	MK48C02L15*	2K x 8	28	150	1.8		1	X		
Motorola Semiconductor (Austin, TX)	(30)	4K to 64K		25 to 450	2		50	X	X	
Example	MCM61L64C45	8K x 8	28	45	2	5	50	X		
National Semiconductor Corporation (Santa Clara, CA)	MM54C929	1K x 1	18	250	2	.01	10	X		
NEC Electronics Inc. (Mountainview, CA)	(3)	16K to 64K		150 to 450						
Example	MPD4464	8K x 8	28	150	2	.01	10		X	
OKI Semiconductor (Sunnyvale, CA)	(5)	4K to 16K		120 to 200	2			X		
Example	MSM5128-12	2K x 8	24	120	2	1	3	X		

Table 3, continued. CMOS static RAMs.

Manufacturer	Parts	Density (bits)	Number of Pins	Access Time (ns)	Minimum V_{DR} (Volts)	Typical I_{DR} (μA)	Maximum I_{DR} (μA)	Temperature Range (°C) 0 to 70	−40 to 85	−55 to 125
RCA Solid State (Somerville, NJ)	(5)	16K to 256K		100 to 200						
Example	CDM62256	32K x 8	28	100	2		100	X		
Sanyo (Tokyo, Japan) (2 parts described)	LC3516N	2K x 8	24	150	2		20		X	
	LC3517N	2K x 8	24	200 250	2		20		X	
Sharp Electronics Corporation (Mahwah, NJ)	(7)	1K to 256K		55 to 100	2		6	X		
Example	LH51256	32K x 8		70	2		3	X		
SMOS Systems (San Jose, CA)	(9)	4K to 256K		35 to 250	2		50	X		
Example	SRM2064	8K x 8		120	2		50	X		
Sprague Solid State (Willow Grove, PA)	(4)	16K		25 to 70	2		10	X		X
Example	20C16	2K x 8	24	45	2		50	X		X
Toshiba America Inc. (Tustin, CA)	(12)	16K to 256K		45 to 250	2		50	X		
Example	TC55257P-10	32K x 8	28	100	2		50	X		
United Microelectronics Corporation (UMC) (Santa Clara, CA)	(5)	4K to 16K		45 to 200	2	1	30	X		
Example	UM6116	2K x 8		150	2	2	20	X		
Vitelic Corporation (San Jose, CA)	(6)	8K to 64K		35 to 150	2		50	X		
Example	V62C64	8K x 8	28	120	2	2	50	X		

Table 4. CMOS clock/calendar parts. (Table format compliments of OKI Semiconductor.)

Manufacturer Part Number	Device Resolution	Comments	Read Access tRA-Addr To Data tRR-Read To Data	Maximum Oper I_{CC} Stby. I_{CC}	Oper. V (range) Stby. V (min)	Maximum Operating Temperature Range	Pins/ Package	Interrupts	Crystal
CALMOS CA 01C50 (Kanata, Canada)	1 sec to 99 yrs (auto leap year)	On board oscillator.	350 ns	2 mA @ 5V 100 µ A @ 3V	5V ±10% 2.5V	0°C to 70°C	24/DIP (8 bits parallel	1 sec variable to 1 day	32.768 kHz
DALLAS SEMICONDUCTOR DS1215 (Dallas, TX)	1/100 sec to 99 yrs (auto leap yr)	Battery backup circuit internal. Can be used to back up external RAM.	250 ns 50 ns	5 mA @ 5.5 10 µ A @ 3.7	5V ±10% 2.5V	0°C to 70°C	16/DIP (serial 64 bit)	None	32.768 kHz
EPSON RTC58321	1 sec to 99 yrs (auto leap yr)	Internal crystal. Low V_{DD} detection provided by CS. (V_{DD} − 0.5V min)	6.6µ s 5.0 µ s	500 µ A @ 5V 30µ A @ 3V	5V ±10% 2.2V	−10°C to +60°C	16/DIP (4 bit muxed addr/data)	976 µ s 1 sec 1 min 1 hr	32.768 kHz (internal)
HITACHI HD146818 (San Jose, CA)	1 sec to 99 yrs (auto leap yr)	Internal 50 byte RAM. (Note: I_{CC} Interrupts @ 32 kHz	380 ns 220 ns	50 mA @ 5V 100 µ A @ 3V	4.5V to 5.25V 2.7V	0°C to 70°C	24/DIP 24/FP (8 bit muxed addr/data	Periodic: 122 µ sec to 500 ms Alarm: 1/sec to 24 hr	4 MHz 1 MHz 32.768 kHz
INTERSIL ICM 7170 (Cupertino, CA)	1 sec to 99 yrs (auto leap yr)	Battery backup circuit internal. On chip 51 bit RAM.	300 ns 250 ns	300 to 1200 @ 5V 20µ A @ 5V	2.6V to 5.5V 2.0V	−40°C to +85°C	24/DIP (8 bit muxed or direct)	100 Hz 10 Hz 1 sec 1 min 1 hr 1 day Also from alarm.	4 MHz 2 MHz 1 MHz 32.768 kHz
MICROELECTRONIC MARIN µCM, µ 3003 (Other types 3000 & 3002) (Marin, Switzerland)	1 sec to 99 yrs (auto leap yr)	alarm 16 x 8 RAM	180 ns	20 µ A 8 µ A	5V ±10% 2.0V	−40°C to +85°C	16/DIP (4 bit muxed)	variable 1 sec to 1 day	32.768 kHz
MOTOROLA MC146818 (Phoenix, AZ)	1 sec to 99 yrs (auto leap yr)	Internal 50 byte RAM. (Note I_{CC} interrupts @ 32 kHz)	380 ns 220 ns	50 mA @ 5V 100 µ A @ 3V	4.5V to 5.25 V 2.7 V	0°C to 70°C	24/DIP 24/FP (8 bit muxed addr/data)	Periodic: 122 µ sec to 500 ms alarm: 1/sec to 24 hrs	4 MHz 1 MHz 32.768 kHz

Table 4, continued. CMOS clock/calendar parts. (Table format compliments of OKI Semiconductor.)

Manufacturer Part Number	Device Resolution	Comments	Read Access tRA-Addr To Data tRR-Read To Data	Maximum Oper I_{CC} Stby. I_{CC}	Oper. V (range) Stby. V (min)	Maximum Operating Temperature Range	Pins/ Package	Interrupts	Crystal
NATIONAL SEMICONDUCTOR MM58274 (Santa Clara, CA)	1/10 sec to 99 yrs (auto leap yr)		700 ns 375 ns	1.0 mA @ 5V 10 mA @ 2.2V	5V ±10% 2.2V	−40°C to +85°C	16/DIP (4 bit addr 4 bit data)	100 m sec 500 m sec 1 sec 5 sec 10 sec 30 sec 1 min	32.768 kHz
NEC µ P1990 (Mountainview, CA)	1 sec to 99 yrs		4 µ s	50 µ A @ 3.6V (I_{CC} & I_{STB})	2.0V to 5.5V 2.0V	−40°C to +85°C	14/DIP (Serial I/O)		32.768 kHz
OKI MSM 6242B (Sunnyvale, CA)	1 sec to 99 yrs (auto leap yr)	Low V_{DD} detection provided by CS. (4/5 V_{DD} min.) Bus compatible.	140 ns 120 ns	30 µ A @ 5V 12 µ A @ 2V	5V ±10% 2.0V	−30°C to +88°C	18/DIP 24/FP (4 bit addr 4 bit data)	1/64 sec 1 sec 1 min 1 hr	32.768 kHz
OKI MSM 5832	1 sec to 99 yrs	Leap year register software control. CS (4/5 V_{DD} min.)	6.0 µ s 600 ns	500 µ A @ 5V 30 µ A @ 3V	5V ±10% 2.2V	−30°C to +85°C	18/DIP (4 bit addr 4 bit data)	976 µ s 1 sec 1 min 1hr	32.768 kHz
OKI MSM 58321	1 sec to 99 yrs (auto leap yr)	Low V_{DD} detection provided by CS. (V_{DD} − 0.5V min.)	6.6 µ s 6.0 ns	500 µ A @ 5V 30 µ A @ 3V	5V ±10% 2.2V	−30°C to +85°C	16/DIP (4 bit muxed addr/data)	976 µ s 1 sec 1 min 1 hr	32.768 kHz
RCA CDP1879C (−1) (Somerville, NJ)	1 sec to months (auto leap yr)	Alarm: sec, min, hrs	400 ns	150 µ A	4.0V to 10V 2.5V (32 kHz)	−40°C to +125°C	24/DIP	Variable clock out alarm out	4.19 MHz 2.09 MHz 1.04 MHz 32.768 kHz
STATEK RTC58321 (Orange, CA)	1 sec to 99 yrs (auto leap yr)	Internal crystal. Low V_{DD} detection provided by CS. (V_{DD} − 0.5V min)	6.6 µ s 6.0 µ s	500 µ A @ 5V 30 µ A @ 3V	5V ±10% 2.2V	−10°C to +60°C	16/DIP (4 bit muxed addr/data)	976µ s 1 sec 1 min 1 hr	32.768 kHz (internal)

These manufacturers have one or more CMOS clock/calendar parts that can be made non-volatile (keep time in power down) for periods as long as 10 years or more.

Table 5. Manufacturers of battery backup switchover circuits.

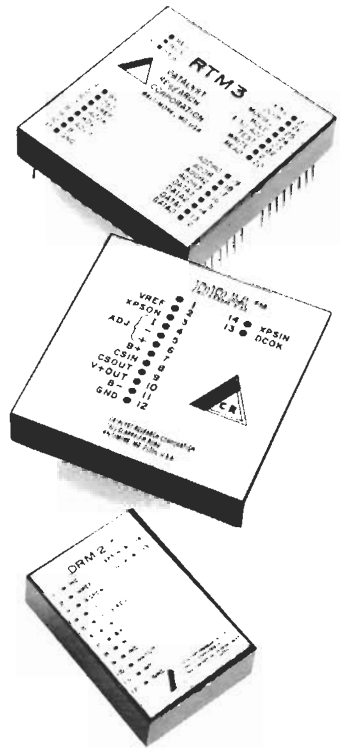
Manufacturer	Part #	Size (inches)	Pins	Maximum Parasitic Drain (nA)	Internal Battery Test	Maximum V_{CC} Forward Voltage Drop (volts)	Maximum Output Current Pass (mA)	Maximum Supply Voltage (volts)	Minimum/ Maximum Battery Voltage (volts)	Maximum Battery Current (μA)	Operating Temperature (°C)	Number Chips It Can Back Up
Catalyst Research	DRM[1]	2 x 2	14	1	No	0.01	100	12	—	—	−40 to +85	50
(Baltimore, MD)	DRM2	1 x 1.5	14	1	No	0.01	100	12	2/3	—	−40 to +85	50
Dallas	DS1210	.36 x .24	8	100	Yes	0.2	80	5.5	2/4	5	0 to 70	1
Semiconductor	DS1221	.74 x .24	16	100	Yes	0.2	80	5.5	2/4	40	0 to 70	2 to 4
	DS1211	.96 x .24	20	100	Yes	0.2	80	5.5	2/4	100	0 to 70	3 to 8
	DS1212	1.4 x .54	28	100	Yes	0.2	80	5.5	2/4	100	0 to 70	4 to 16
	DS1234	.74 x .24	14	100	No	0.2	80	5.5	2.5/3.7	100	0 to 70	1
	DS1259	.75 x .24	16	100	Yes	0.2	250	5.5	2.5/3.7	100	0 to 70	1
(Dallas, TX)	DS1215[2]	.74 x .24	16	100[3]	No	0.2[3]	80	5.5	2.5/3.7	10	0 to 70	1
INTERSIL (Cupertino, CA)	ICL7673	.325 x .38	8	5000	No	0.2	38	2.5/15	2.5/15	30,000	0 to 70 or −40 to 85	Multiple
Maxim	MAX690	.34 x .3	8	1000	Yes	0.2	100	5.5	2/4.3	200	0 to 70	
(Sunnyvale, CA)	MAX691	.74 x .3	16	1000	Yes	0.2	100	5.5	2/4.3	200	−40 to 85 or −55 to 125	Multiple

[1]Contains internal battery: 450 mAhr capacity, 20 μA maximum drain at 25°C.
[2]Contains internal clock function.
[3]Without clock running.

Several circuits are available from four manufacturers at this time. With a μPowerCell™ Lithium battery and CMOS RAMs or clock/calendars, these circuits will give trouble free non-volatility.

Catalyst Research Backup Modules

A complete battery switch module can be purchased from Catalyst Research. It is called the Data Retention Module (DRM™/DRM2™). The DRM contains the Lithiode™ battery packaged with power switchover circuitry similar to that shown in figure 7. The DRM also provides logic signals for external processor use. DRM2 is the same as DRM but allows the battery to be mounted separately to provide flexibility in battery selection.



The Catalyst Research Non-volatile RAM Module (NVRM™) performs the switching and backup features of the DRM and also contains RAM internally. It includes 2K bytes of Toshiba RAM.

The Real Time Module (RTM3™) incorporates an OKI 5832 clock/calendar with a Lithium-Iodine backup battery and full automatic switchover circuitry.

™DRM, DRM2, NVRM and RTM3 are trademarks of Catalyst Research.

Catalyst Research Lithium-Iodine Battery Performance Data

There are over 1,000,000 Catalyst Research industrial Lithiode™ Lithium-Iodine batteries in use for CMOS backup and watch operation. They collectively represent over 5,000,000 battery-years operation. Based on all known mechanical, electrical and chemical failures, they have demonstrated MTBF between 600 years and 1100 years, depending on model types.

The μPowerCell™ line has been designed to remove the few known failure mechanisms that existed in the Lithiode™ line. Therefore, we expect the reliability numbers to be higher and comparable to standard electronic component reliability.

Projected voltage performance for μPowerCells™ in battery backup mode is shown for low currents in figure 14.

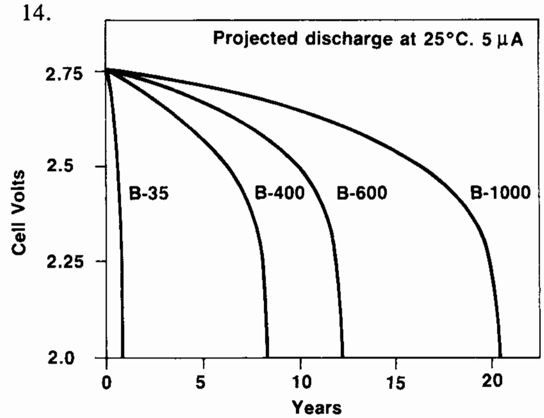


Figure 14. Voltage as a function of time.

The effect of temperature on shelf life to 20% capacity is shown in figure 15.

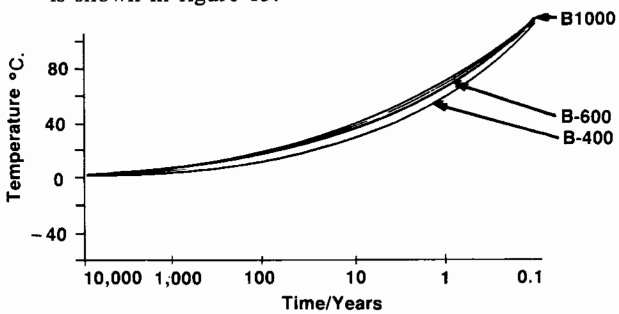


Figure 15. Shelf life vs. temperature.

CHARGE TWO CAR BATTERIES AT ONCE

Speed charging time of batteries by doubling up on the circuit

BY CHARLES COHN

CHARGING two or more lead-acid batteries with one battery charger, while keeping them isolated from each other, can be a snap with the simple circuit modification described here. One of its uses is for recreational vehicles that have a main battery for starting and ignition and an auxiliary battery for accessories. These batteries are isolated from each other so that overuse of accessories while the engine is off will not run down the starting battery and immobilize the vehicle.

Circuit Operation. Figure 1 shows a simplified schematic of a commercially available "automatic" battery charger (the type that can be left permanently connected to a battery without danger of overcharging). A transformer and rectifier feed rectified ac to the battery through a silicon controlled rectifier (SCR). A recreational vehicle usually has a power converter that charges the auxiliary battery when line power is available. The converter works in much the same way as the battery charger. However, in some converters, the SCR anode is connected directly to one side of the power transformer.

In the battery charger, the control circuit senses the battery voltage. If that voltage is below a preset point (*e.g.* 13.4 volts), the circuit turns on the SCR. The SCR, in turn, passes current to the battery. When the battery is fully charged, its voltage rises above the preset point and the SCR is *not* gated on. Recall that the gate of an SCR can turn it on but cannot turn it off. However, SCR turnoff is guaranteed in this circuit because of the absence of a filter capacitor following the rectifier. Without filtering, the rectifier output drops to zero every half cycle, turning off the SCR. When self-discharge, electrolyte diffusion, or loading pulls the battery voltage below the preset point, the charger turns on again—just long enough to bring the voltage back up. Thus, the battery floats at full charge.

Construction. Figure 2 shows how to modify the battery charger to charge two batteries at once. Break the connections between the SCR cathode, the output, and the voltage sensing lead. Connect a diode between the SCR cathode and each battery, with the diode cathode going to the battery. You can use a lug terminal strip to make connections. Select diodes that have a current rating at least equal to the maximum output of the charger.

Connect the voltage sensing lead to one of the batteries. It's best to connect it to the battery that is most likely to need charging, for example, the auxiliary battery on a recreational vehicle. The other battery will follow. If the second battery has a higher state of charge than the controlled battery, the diodes will steer the charging current away from it. If it is lower than the controlled battery, the diodes will steer the current into it. The charger will not shut off until the controlled battery comes to full charge. That won't happen until the other battery comes up enough to allow current to be steered to the controlled battery. Self-discharge will always bring the controlled battery down enough to turn on the charger.

If your recreational vehicle has a solid-state battery isolator, you don't need the diodes. Simply connect the SCR cathode to the center terminal of the isolator, the one to which the alternator connects.

If you don't want to use individual diodes, you can use a bridge rectifier assembly with the appropriate current rating, as shown in Fig. 3. Here, two of the diodes are active, while the other two are in series opposing and do nothing. This circuit has been used with a Heathkit GP-21 10-A battery charger installed in a camper van and it works very well. ◇

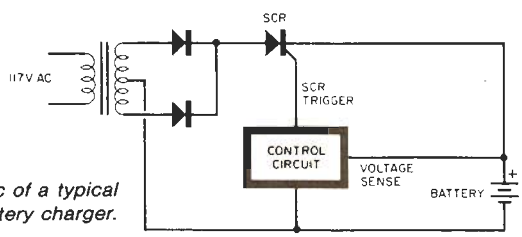
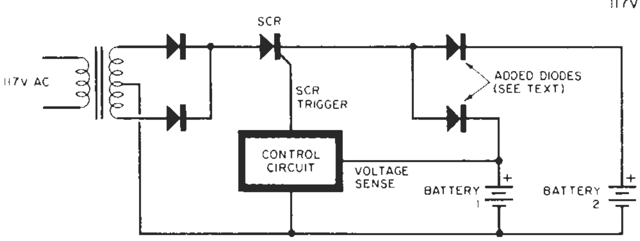


Fig. 1. Simplified schematic of a typical commercial "automatic" battery charger.

Fig. 2. Modification of the battery charger to charge two batteries using individual diodes.



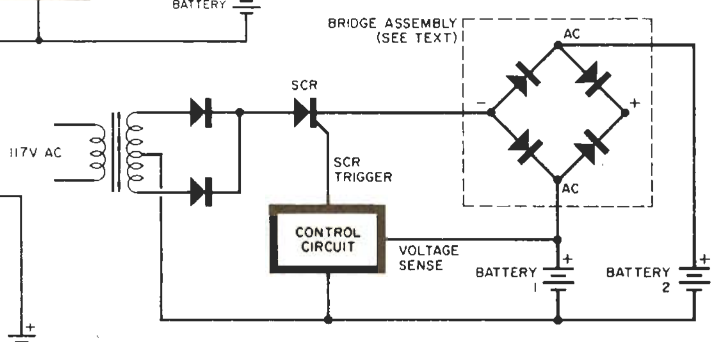


Fig. 3. The charger circuit can also be modified by adding a bridge rectifier assembly.

EMERGENCY LIGHTING UNIT

PROJECT

If the power fails, you needn't be left completely in the dark. This unit automatically switches on a battery operated lamp as soon as the power goes off and keeps the battery always fully charged and ready for action.

IF YOU'VE ever lived in a large city like Toronto on a hot July day when everyone has their air conditioners going, then you probably know what it's like to be suddenly and completely without power.

Being deprived of the TV and hi-fi for a while could well be good for the imagination and improve your conversational skills no end, but trying to find the toothpaste in a pitch black bathroom is simply infuriating!

In these circumstances, even a low intensity light is infinitely better than none at all. With this in mind we've designed this project, which switches on a 12 volt lamp of up to 24 watts as soon as the main power fails. It could also be used of course to power any other 12 volt appliance with the same power rating.

The emergency lamp runs on current supplied by a 12 volt battery, which is kept fully charged when not in use by a trickle of current. We used a NiCad battery for our prototype, but there is no reason why you shouldn't use a lead/acid accumulator instead because the charging current is kept so low there is no risk of overcharging and damaging the cells. The charging current is determined by a current limiting resistor, which must be chosen to suit the capacity and charge characteristics of the battery you are using. We have provided a table which lists the necessary values of this resistor for different batteries.

We've also included a red LED on the front panel of the unit, to show when it is operating (i.e. when the battery is discharging). This may seem superfluous, because after all you can see for yourself whether a lamp is lit or not, but if you are using the unit to run a fish tank heater or suchlike, then an indication that the unit is operating will be reassuring.

Construction

All the components are housed in a plastic case with an aluminum front panel that has terminals for the battery and lamp connections. The LED which indicates power failure is set in the panel above the lamp terminals.

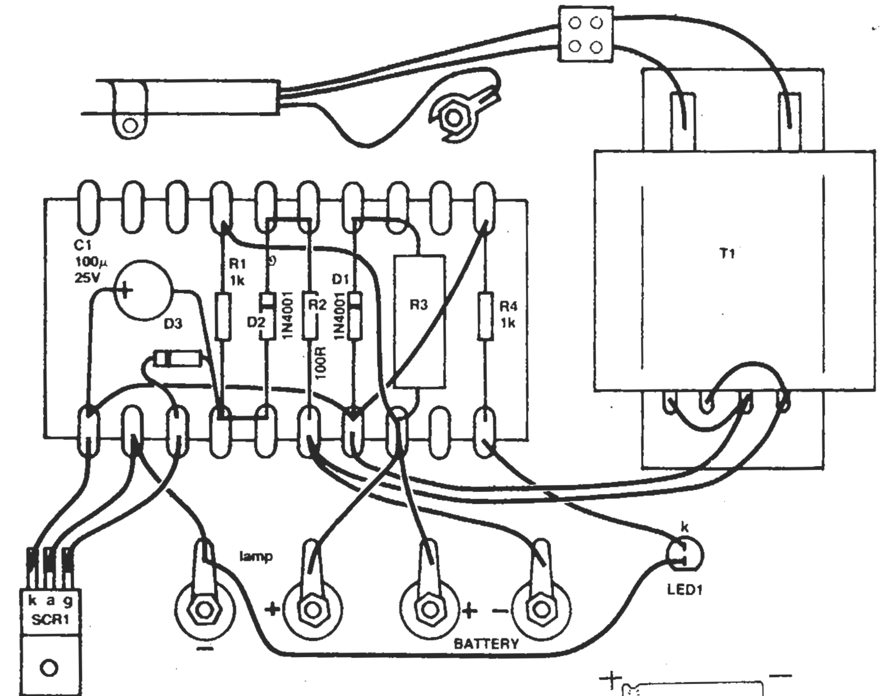
As the circuit is very simple, we decided to mount the electronics on a length of twin tag strip. Mount the components as shown in the diagram on this page, being careful with the orientation of the diodes and the electrolytic capacitor.

The current limiting resistor R3 sets the charging current to the batteries and must be selected to suit the voltage and capacity of the battery. Consult the table for the correct value. This resistor may run quite warm, so it should be mounted so that it is spaced about 5mm above the tag board for adequate ventilation.

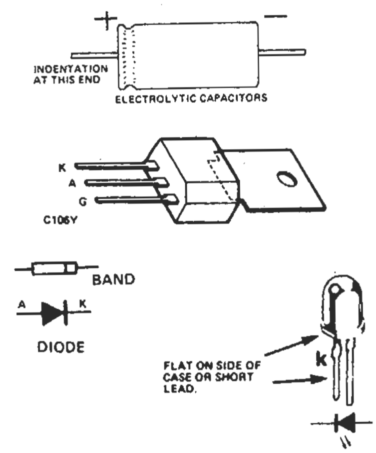
If the emergency lamp draws 1 A or less, the SCR does not need a heatsink; if the lamp draws between 1 A and 2 A, the SCR can be mounted on the aluminium front panel with an insulating mica strip between it and the metal. For load currents over 2 A a heavier SCR with its own heatsink would have to be used, but we do not recommend drawing this much current because this is an emergency lamp and you won't want to discharge the battery too quickly.

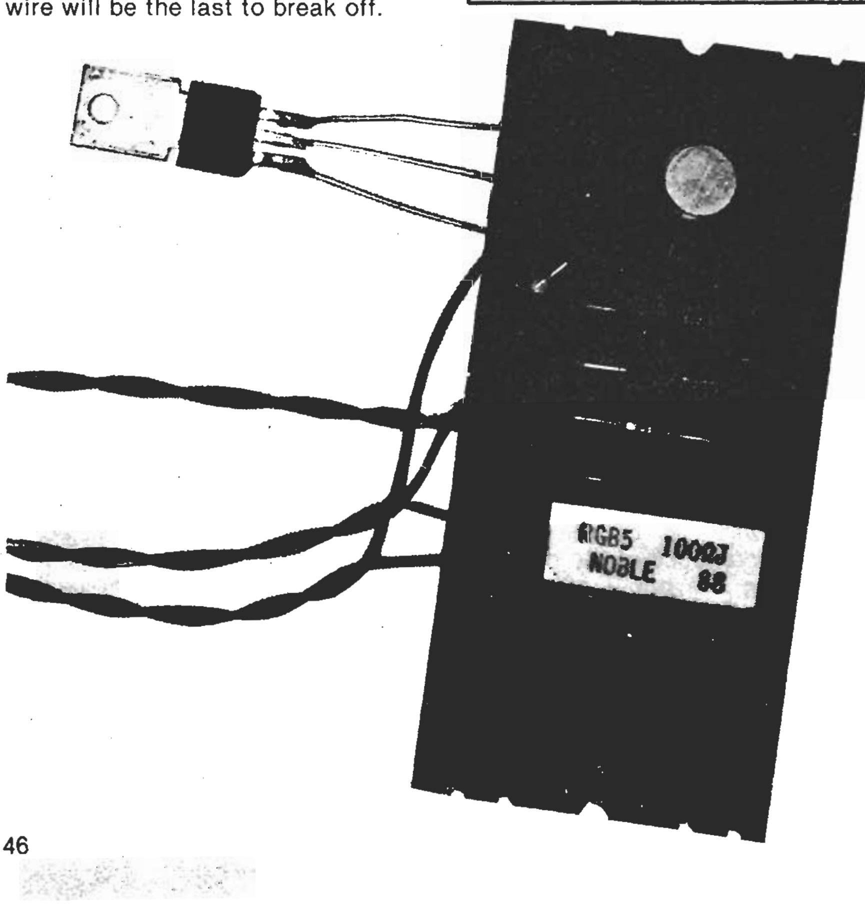
Next wire the connections from the tag board to the LED, the terminals and the transformer. Be extra careful with all of these connections and use insulated hookup wire for all wiring, including connections across the tags on the tag board. The transformer is mounted in the top right corner of the box, leaving enough room for the terminals and the tag board.

Secure the power lead by passing it into the box through a clamping type grommet. Connect the ground wire of the line cord to the solder lugs on the transformer case and to the the front panel. Make sure that these connections are well made and that there is slack left on the power ground wire, so that if the cable is pulled out of the grommet the ground wire will be the last to break off.



BATTERY CAPACITY	VALUE OF R3 (5W, 5%)
500 mAh	82R
1.2 Ah	33R
2 Ah	22R
4 Ah	10R
6 Ah	6R8





PARTS LIST

Resistors ½ W, 5% unless otherwise specified

R1	1K
R2	100R
R3	Current limiting resistor, See table
R4	1K

Capacitor

C1	100*u* electrolytic, 25V

Semiconductors

D1,D2	1N4001 or similar silicon diode
D3	1N34 or similar germanium diode
LED1	TIL220R or similar red LED
SCR1	C106Y or similar

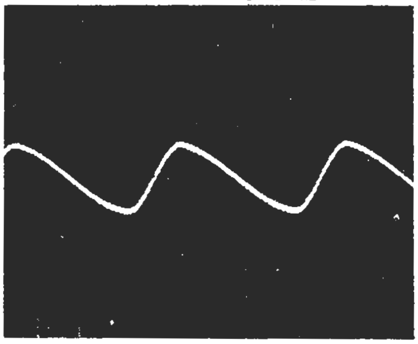
Miscellaneous

Transformer with 120V primary and 12V secondary rated at 1.5A; 12V NiCad battery; plastic box to suit (155mm x 95mm x 50mm); four screw terminals, two red, two black; 12V light bulb and socket.

HOW IT WORKS

When the power is on, the circuit float charges a NiCad battery from a transformer and rectifier. When the power fails, a control circuit switches the battery through to the emergency light and the LED on the front panel.

When power is on the NiCad battery is trickle charged through a rectifier diode D1, which supplies half wave rectified current pulses to the battery. Capacitor C1 smooths out these pulses by charging to the peak voltage from the transformer secondary through D2 and R2 and discharging through R1 and the battery when the output from the transformer falls. the discharge time constant of C1 is much longer than its charge time constant, so that it does not have time to discharge fully during the transformer negative half cycle. So C1 stays at a high positive voltage, with some ripple, as can be seen from the oscilloscope photograph.



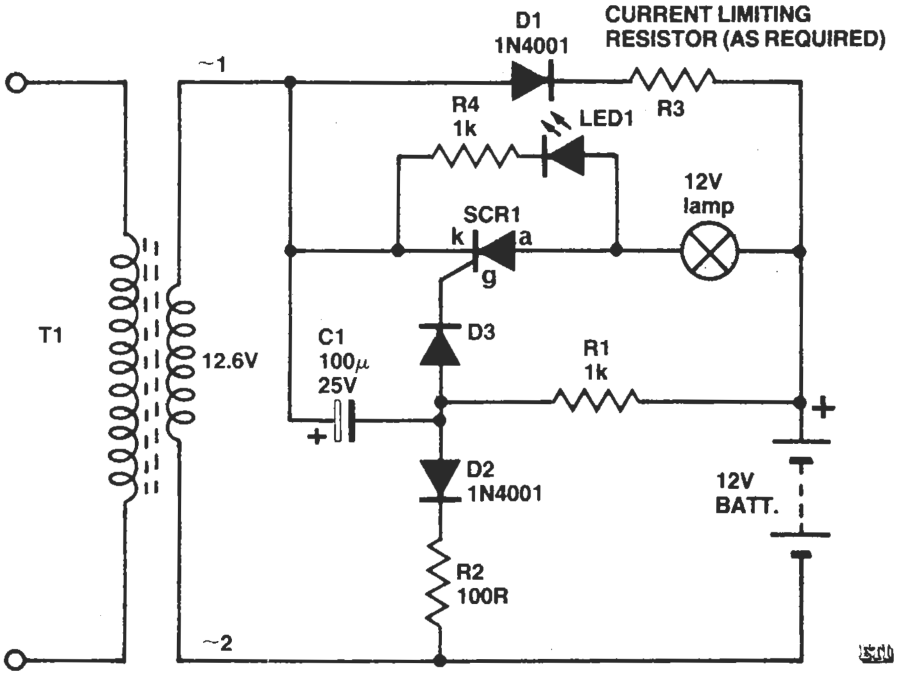
Waveform at the positive lead of C1.

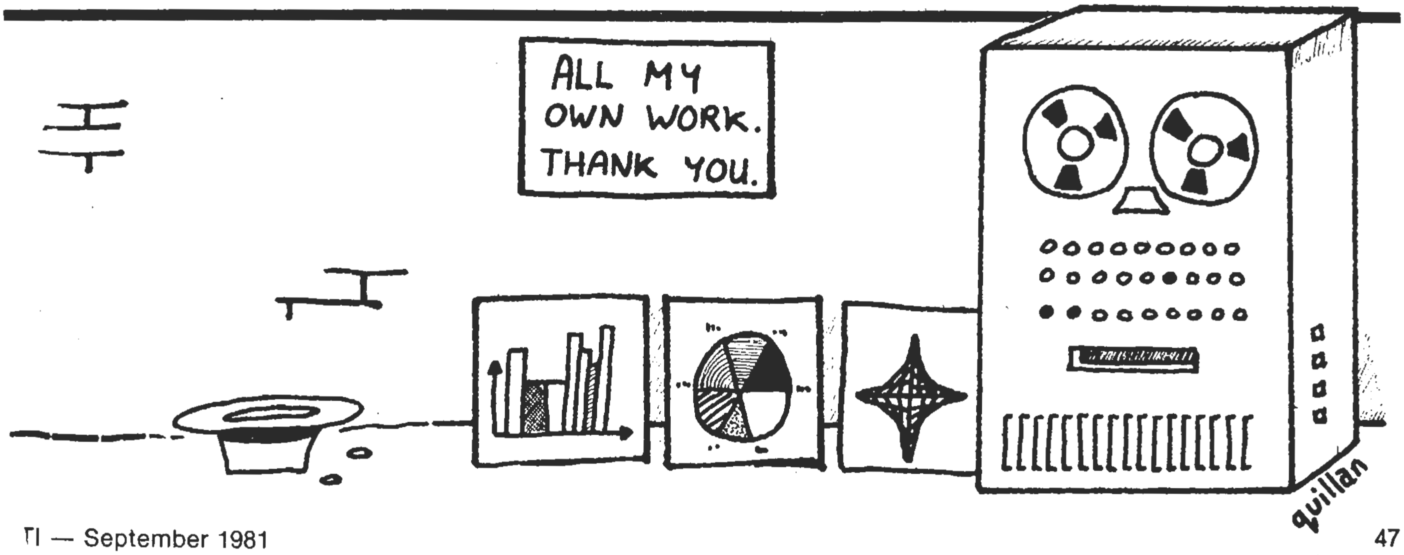
As C1 remains charged, the voltage on the gate of SCR1 is always lower than the voltage on its cathode and SCR1 is therefore reverse biased, so that the emergency lamp is switched off. LED1 is also reverse biased and not illuminated.

When the power fails the output from the transformer falls to zero and C1 starts to discharge through R1 and the battery. Once C1 is fully discharged it begins to charge in the reverse direction from the battery until the voltage on the gate of SCR1 is about 0.6 volts higher than the voltage on its cathode. SCR1 then switches on, lighting the emergency lamp. LED1 is now forward biased and illuminated. The voltage on C1 does not rise any further and the capacitor is not damaged by the reverse polarity because the voltage across it is less than the forming voltage of the electrolyte.

When the power returns, C1 charges again through D2 and R2, turning off SCR1 and resetting the circuit.

NiCad batteries may be used with this project and they can be obtained in ratings from 500 mAh up to 2 Ah capacity. Sealed lead-acid batteries can be obtained in higher capacities





attery charger

simple circuit shown is for charging ı. size D nickel cadmium cells in series a: constant current and with automatic voltage limiting. The BC301 acts as a current source, its base voltage being stabilized at about 3V by two l.e.ds, which may also be used to indicate the charge condition. The 2N3638 provides voltage limiting by cutting off the BC301 when V_c approaches the voltage across the 1kΩ branch of the voltage divider. For the component values shown, charge current is 260mA at low V_c, 200mA at V_c of 5V, and decreases to virtually zero at V_c of 6.5V.

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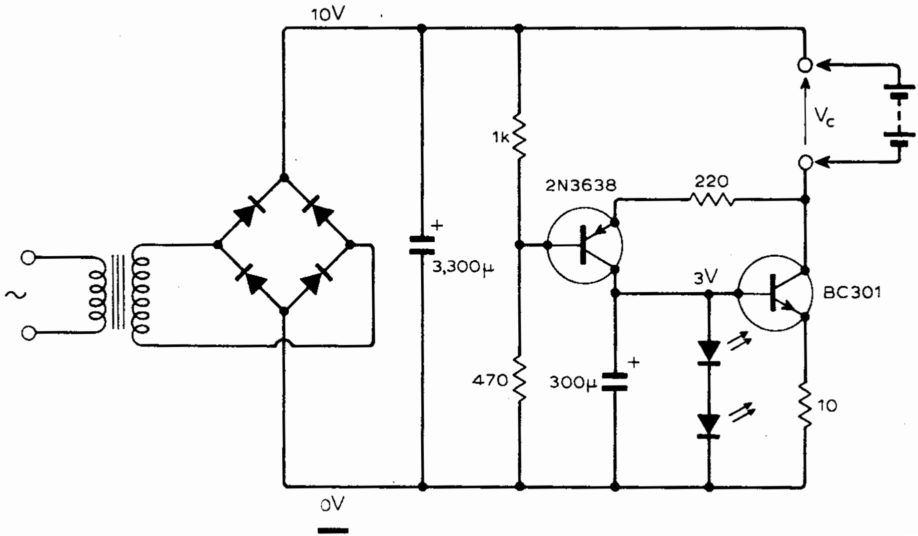

TEXAS INSTRUMENTS

POWER MANAGEMENT

Analog Applications Journal

BRIEF

Enhanced-Safety, Linear Li-Ion Battery Charger with Thermal Regulation and Input Overvoltage Protection

By Jinrong Qian

Applications Manager, Battery Management Applications

The lithium-ion (Li-ion) battery is widely adopted in portable devices because of its high energy density on both a gravimetric and volumetric basis. Due to their simplicity, low cost, and small size, highly integrated linear battery chargers are widely used to charge single-cell Li-ion batteries. However, when unregulated adapters are used to power portable systems, it can be a challenge to remove or minimize the heat generated from the linear chargers and to maintain their operation within a safe thermal range. This article describes a newly developed battery charger with thermal regulation. This charger has input overvoltage protection (OVP), which alleviates thermal concerns while maximizing the charge rate and minimizing the charging time, allowing use of an unregulated adapter.

Battery-Charging Requirements

The charge profile widely used for charging Li-ion batteries consists of three charging phases: precharge; fast-charge constant current (CC); and constant voltage (CV). In the precharge phase, the battery is charged at a low rate when the cell voltage is below 3.0 V. Typically, when the cell voltage reaches 3.0 V, the charger enters the CC phase. The faster-charge CC is usually limited to stay below the cell's 1C rating. The cell cycle life decreases with charge rates above 1C because metallic lithium deposited on the node easily reacts with the electrolyte and is permanently lost. Finally, the charger enters the CV phase, where it maintains the peak cell voltage and then terminates charging when the charge current drops to a predefined level.

The cell capacity is a function of the cell voltage—the higher the voltage, the higher the capacity. However, higher cell voltage results in shorter cycle life. For example, charging a cell at 4.3 V can provide 10% more capacity, but cell cycle life may be 50% shorter. On the other hand, if the cell is undercharged at just 40 mV under the optimum voltage, it can have about 8% lower capacity. Therefore, a very accurate battery charge voltage is extremely important.

Thermal-Regulated Battery Charger with Input OVP

Figure 1 shows a low-cost, stand-alone linear battery charger circuit with thermal regulation and input OVP. The charger simply drops the adapter's DC voltage down to the battery voltage. The power dissipation in the linear charger is given by

$$P_{CHGR} = (V_{IN} - V_{BAT}) \times I_{CHG}.$$

There is a large difference between the input and battery voltages when the charger transitions from precharge to fast-charge mode, where the power dissipation reaches the maximum. For example, if a 5-V adapter is used to charge a 1200-mAh Li-ion battery, it has a maximum power dissipation of 1.8 W with a 1-A charge current and a 3.2-V battery voltage. This power dissipation results in an 85°C temperature rise for a 3 x 3-mm QFN package with 47°C/W thermal impedance. The junction temperature exceeds the maximum allowed operating temperature of 125°C at 45°C

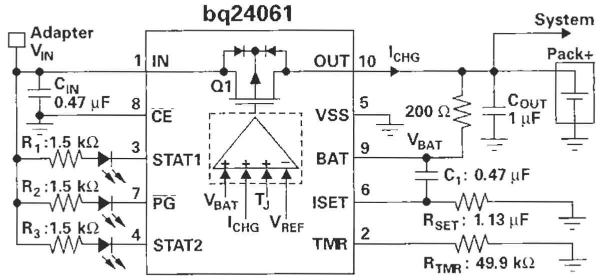

Figure 1: Charger with thermal regulation and input OVP

ambient temperature. It is hard to maintain the junction temperature within a safe thermal range at the beginning of the charging. As the battery voltage rises during the charging, the power dissipation drops. After charging enters the CV mode, the power dissipation drops further as the charge current starts to taper down.

How do we improve the design to keep the charger operating in a safe thermal range? The more advanced battery chargers such as bq2406x and bq2403x have introduced a thermal regulation loop to prevent overheating of the charger. When the internal chip temperature reaches a predefined temperature threshold—for example, 110°C—any further increase of the IC temperature results in reduction of the charge current. This limits the power dissipation and provides thermal protection to the charger. The maximum power dissipation causing the IC junction temperature to reach thermal regulation depends upon the PCB layout, the number of thermal vias, and the ambient temperature. Figure 2 shows that after 1.2 seconds the thermal loop reduces the effective charging current from 1.2 A to 600 mA within 2 seconds.

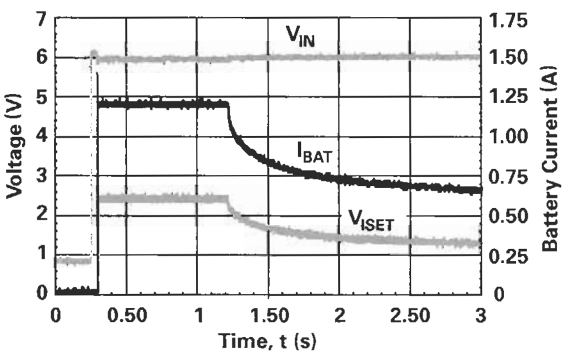

Figure 2. Charge-current with thermal regulation

Thermal regulation usually happens at the early stage of the fast charge, but if it is active during the CV mode, the charging current could prematurely reach the charge termination threshold. To prevent this false charge termination, the battery charge-termination function is disabled whenever the thermal regulation loop is active. In addition, the effective charge current is reduced, which increases the battery charging time and which, if the charge safety timer had a fixed setting, could terminate charging early. The bq2406x employs a dynamic safety-timer control circuit that effectively extends the safety time during thermal regulation and minimizes the chance of a safety-timer fault. Figure 3 shows that the safety-timer response is inversely proportional to the effective charge current in thermal-regulation mode.

When the battery-charging function is enabled, the internal circuit generates a current proportional to the real charging current set by the ISET pin. The voltage generated across resistor R_{SET} reflects the charge current. This voltage can be monitored by the host for charge-current information.

There are several types of adapters used to charge Li-ion batteries. Less expensive adapters may not have well regulated output and have higher output voltages under no load than at the normal load. In addition, during the battery hot plug-in, the input voltage to the charger could reach as high as two times that of the adapter voltage due to resonance between the cable inductance and the input capacitor of the battery charger. To increase safety when the input voltage is above the predefined threshold, the input OVP implemented in bq2406x chargers does not allow charging.

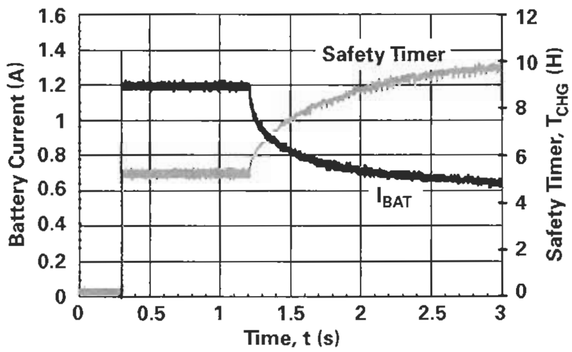

Figure 3. Dynamic safety timer in thermal regulation

Many applications require powering the system while charging the battery simultaneously. When the system is directly connected to the battery-charge output as shown in Figure 1, interaction between the system and charger may result in a false charge termination caused by the safety timer. Figure 4 shows a typical application circuit that eliminates such issues. There are two independent power paths, one to charge the battery and one to power the system. When the AC adapter is not available, the battery discharge MOSFET is turned on after a time delay set by R_4 and C_2 so that the battery will provide power to the system.

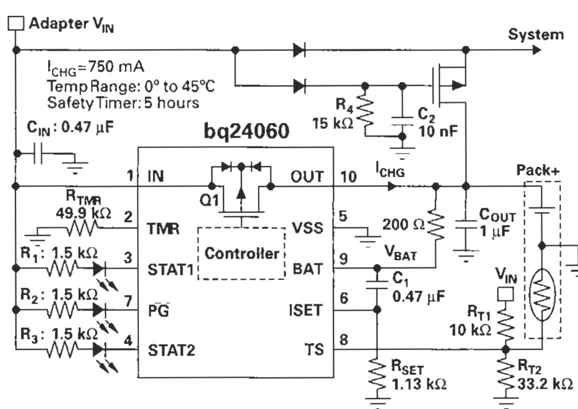

Figure 4. Power-path-management battery charger

Summary

The linear battery charger with thermal regulation can significantly improve the thermal design and safety. With input OVP, it allows only authorized adapters to charge the battery, improving system safety.

References:

1. bq2406x Datasheet (SLUS689A)
2. *power.ti.com*