

Battery Discharge / Charge Controller (BD/CC)

The BD/CC is a small PC board based circuit designed to allow a user to limit the terminal voltage of various types of rechargeable battery systems to safe levels. The object of the BD/CC is automatically disconnect the charging current to the battery, or the load from the battery when a specified high or low voltage limit is reached, and in the case of a low voltage disconnect, to delay reconnection of the load until at least some amount of charge has been restored. The unit as originally designed is intended for use with "12 Volt" (6-cell) lead-acid batteries, which usually operate somewhere between 12.5 and 14.0 volts for a fully charged battery, depending on individual battery type, chemistry, configuration, condition, and how recently it was charged. The BD/CC can be adapted for other voltage ranges between 8 and 60 volts. In such a case, the user may need to procure a few different parts (resistors) than the ones called out in the schematic diagram.

Lead-acid, NiCad and other secondary (rechargeable) battery systems experience substantially reduced cycle life (number of charge-discharge cycles) or permanent damage if allowed to charge or discharge beyond safe limits. Unfortunately, in many installations, adequate battery monitoring instrumentation is not provided, and the user is left with little in the way of guidance as to what to do and when to do it. The BD/CC takes the guesswork out of using rechargeable batteries with portable equipment.

The BD/CC may be used in 2 different ways. Normally, the unit is used as a load controller, monitoring the battery voltage during discharge, and disconnecting the load (and/or optionally sounding a warning alarm) if the terminal voltage drops dangerously low. This prevents damage to batteries from cell reversal, which will permanently damage many types of batteries, and is not recommended in any case for any type of rechargeable system.

The second use of the unit is as an over-charge controller. In this application, the BD/CC monitors the battery terminal voltage and disconnects the battery at a specified upper limit, preventing battery damage from excessive charging. Over charging can result in excessive loss of electrolyte due to gassing, unsafe cell temperatures, and (in sealed systems) permanent damage to the cells. As in the discharge controller application, the unit can be made to control an alarm device to alert the operator if required. One BD/CC may be used for either application, but not both functions at the same time. To accommodate both functions, 2 separate BD/CC units are required.

The set points for each type of unit are designed to be adjustable within certain limits, but these limits may be expanded or altered with minimal effort. Information is included that will enable you to use the BD/CC with other than 12 volt systems. As originally designed, a BD/CC is designed to allow disconnection of the load between 11.0 and 10.0 VDC, and once cutoff occurs, delays reconnection of the load until the battery voltage has been raised to something between 11.0 and 12.0 VDC. Normal set points for lead-acid systems are 10.8 V for disconnect and 11.5 V for reconnect. A BD/CC used as an over-charge controller is normally set to allow charging to continue until terminal voltage reaches 14.0 volts for lead-acid cells, at which point the BD/CC will disconnect the charger from the battery. The range of charge cutoff is adjustable between approximate values of 13.8 and 15.2 volts. A chart (included) gives recommended charge and discharge voltage limits for various battery types.

The BD/CC is intended to control an external switching device and/or alarm unit. The external device can be a conventional relay or a power-FET, depending on the user's wishes and power budget. In battery-portable situations, with current draws in the under 2 ampere range, the use of a MOSFET as the external switch offers significant advantage in overall power consumption, although somewhat less flexible in application than electro-mechanical relays. This situation normally is only a consideration in discharge control applications, as it is assumed that adequate power to operate a cutoff relay would be available during charge cycles.

Part number codes (example: R1) apply to the parts as shown on the wiring diagram and the printed circuit board, although the unit can be point-to-point wired without using a PC board. Circuit layout is absolutely non-critical. All resistors are 5% tolerance, and can be either film or composition units. A limited amount of hookup wire is needed. Use 22 or 24 gauge wire for the connections to the BD/CC PCB, larger sizes for the actual charge and/or discharge path, as needed, sized to carry the required current. Parts are available from suppliers of small electronic parts, such as Digi-Key, Mouser Electronics, Newark Electronics, many Radio Shack stores, and other electronics parts vendors.

| ID Code | Description | Value | Color code or other info |
|------------------|--------------------|-----------|-----------------------------------|
| R1, R5, R6 | Resistor, fixed | 10K Ohms | brown - black – orange - gold |
| R1A * (see note) | Resistor, fixed | 13K Ohms | brown – orange – orange - gold |
| R2, R8 | Resistor, variable | 2000 Ohms | variable trimmer potentiometer |
| R3, R9 | Resistor, fixed | 6200 Ohms | blue – red – red - gold |
| R4 | Resistor, fixed | 1500 Ohms | brown – green – red – gold |
| R7 | Resistor, fixed | 9100 Ohms | white – brown – red – gold |
| D1, D3 | Diode, silicon | 1N4007 | Any silicon power diode > 100 PIV |
| D2 | Diode, Zener | 1N5230B | 4.7V ½ W 5% |
| Q1, Q2 | Transistor NPN | 2N3053 | (ECG / NTE 128 sub OK) |
| U1 | Comparator I/C | LM339 | Quad comparator, 14 Pin DIP |

In addition, 2 clip-on heat sinks and some mounting hardware will be required.

* For use as a charge controller, resistor R1 is substituted with resistor R1A, a 13K Ohm (brown – orange – orange – gold) unit.

The following additional parts are required if you want to use the output relay option:

| | | | |
|-----------|--------------------------------|----------|-----------------------------------|
| K1 (K3) * | Relay 12V DC (10 amp contacts) | | Omron LY2F-DC12 (DPDT) |
| LED1 | Diode, LED, Red | | “Disconnect” or “Charge Complete” |
| LED2 | Diode, LED, Green | | “Power On” or “Charging” |
| R10, R11 | Resistor, Fixed | 820 Ohms | gray – red – brown - gold |

* This relay is marked as K3 on the diagram, but there is only one relay required. The diagram was originally drawn to use the unit as part of a larger circuit.

Assembly:

Assembly of the unit is straight forward. The only considerations will be that some of the parts are a bit of a tight fit on the PC board, but this is easily handled. Resistors R5 and R6 are mounted with one end sticking up from the board (vertical mount), and diode D3 will be a tight fit between the case of Q1 and the row of external connection points.

Note that there is a step-by-step procedure following this text section. Read the text carefully before starting to mount parts, and follow each step in order until the unit is complete.

Soldering: Good solder connections are crucial to the proper functioning of any printed circuit board assembly. Use a correctly sized iron. A temperature controlled unit, such as the Weller WTCPT or the WCC-100 is ideal, using a 700 degree tip. If a temperature controlled soldering station is not available, use an iron rated at not more than 25 watts, and be careful! Use good quality solder. The best solder to use (and most expensive) is the special 2% silver bearing electronic solder, which also melts at the lowest temperature (354 degrees). This alloy consists of 62% Tin, 36% Lead, and 2% Silver. The next best is 63/37 “eutectic” mix solder, and finally 60/40, as the lowest acceptable grade. Each solder type is listed in order of decreasing cost and increasing flow temperature, respectively. The soldering tip must be clean, properly tinned itself, and not pitted. Do not use anything other than rosin core solder, and avoid at all costs acid core solder and the high-temperature “silver solder” used for sheet metal applications, which melts at a very high temperature indeed!

Some of the parts include specific markings that indicate polarity or other information about mounting. In such cases, take care to install each part so that it agrees with the corresponding marks on the circuit board (PCB) assembly. You can also look at the diagrams included as illustrations for assistance in identifying parts and their specific physical characteristics. Each semiconductor part (diodes, transistors, and the integrated circuit) is sensitive to polarity, and must be mounted in a particular manner. Check the placement of each semiconductor part carefully (twice) before soldering it to the board, as it is unlikely that you will be able to unsolder it without damage.

It does not matter if the lead from D3 closest to Q1 touches the case of Q1. You will note on the diagram that the anode of D3 connects to the collector of Q1, which is also connected to the metal can. If you prefer, and you have chosen to use the optional output relay option, diode D3 can be wired directly across the relay instead of being mounted on the PCB. If you choose this option, we recommend that you use different colors of wire to connect between the relay coil and connection points 3 and 4 on the PCB, taking care that the polarity of the diode is such that the cathode (with the mark on the case) is connected to connection point 3. If the diode is reversed, it will try to short the 12V source to ground when either Q1 or Q2 turn on, causing smoke and great excitement.

The mounting of variable potentiometers R2 and R8 should be examined, and the units mounted so as to have minimum interference with each other and resistor R9.

We suggest that you mount transistors Q1 and Q2 first, and integrated circuit U1 next, so that you will have a clear idea of the space requirements for the remaining components. U1 is mounted with the notch (or mark) at one end above the corresponding mark on the component side of the PCB, at position U1. The plastic package of the integrated circuit will have either a mark or a notch on the end between pins 1 and 14. Also, it may be necessary to gently bend the pins of the IC inward slightly until they fit easily into the holes on the circuit board.

Q1 and Q2 should be mounted so that their cases are flush with the circuit board, and no space exists between the transistor case and the PCB. Mount the transistors so that the tab on the transistor case lines up with the corresponding mark on the PCB (the tab is next to the emitter lead). Make sure the leads of the transistor go into the proper holes on the PCB, or to the proper connecting points if using point to point assembly. . You will note that the collector lead of the transistor comes directly out of the can without any surrounding insulation, and that the other two leads have tiny insulators encircling them. Also, the emitter lead of the transistors will be the lead closest to the small tab.

When mounting the diodes, you will note that there is a dark mark on the PCB showing how to mount the diode. This mark should correspond with the diode “cathode” terminal. On the diode itself, the cathode will be marked with either a color band (it may be black, white, or some other color), or there may be a small diode symbol engraved on the case, or some other method will be used to indicate the cathode. If a series of color bands is used, they will start from one end, which is the cathode.

Note particularly the relationship between transistor Q1 and resistor R6, and how the recommended clip-on heat sink fits onto Q1. Be sure that R6 is mounted so as not to interfere with the heat sink. Some kit constructors have found that the resistor can fit “inside” the heat sink. A little experimentation will show you how to accomplish this. Try various mounting positions of R6 (without soldering the resistor in place) and the heat sink you have to see what works best. Note that the heat sinks are not required if the output load is small, such as the suggested relay in the optional output module. This relay draws only 75 mA at 12 volts.

The completed board should be mounted with standoff spacers, or otherwise arranged so that none of the wiring on the board can come into contact with other circuitry or ground. There is an adequate safety area around each of the mounting points so that metal hardware may be used. It is not necessary to use all 4 mounting points. A 2-point, or even a single point mount will be satisfactory. We recommend using at least 2 mounting points.

If you are going to use the optional output relay add-on (K1 or K3), you can mount this relay in any convenient spot. The relay can safely handle up to 10 amperes of DC load. If your load requirements are greater than this amount, we suggest that you use a larger relay to switch the actual load current. The output transistors (Q1 and Q2) can safely handle relay coils that draw up to 500 mA when the included heat sinks are installed. A typical large relay, for example a P&B PRD series or equal, which uses a 70 Ohm 12V DC coil, draws 170 mA and can switch 25 to 30 ampere loads. If you are going to use a relay that requires substantially more coil power, we suggest that you use a small relay, such as the unit specified in the optional output relay kit, to control the larger relay. Please note that the output transistors can be used to switch the controlled device directly, for small loads (under 300 mA), but some additional circuitry will be required, and there are some other considerations involved. See the application note section for information concerning this choice. Finally, a MOSFET can be used in place of the output relay. Again, see the application note section for more information on using this option.

The unit as supplied can be used directly with power sources in the 8 to 16 volts DC range (with appropriate adjustments in resistors R1, and R7). If you are going to use this unit with a power system above this voltage, that is to say above 16 volts, up to a maximum of 60 volts, you will need to install some sort of “pre-regulator” to lower the input voltage to the controller module to approximately 12 volts DC. Standard “3-pin” regulators can be obtained for use in systems where the supply voltage runs no more than 35 or 40 volts (or so), and specialized units or additional circuitry can be used for higher voltage applications. It may be possible to use this unit at even higher voltages (above 60 volts), but such applications have not been tested. Again, refer to the application notes section for more information.

Also, if using the unit at voltages higher than 16 volts, or if using the BD/CC as a charge controller, you will need to make a minor modification to the circuit board itself. Instead of mounting resistor R1 flat against the board, as shown, mount this resistor vertically so that one end solders to the circuit at the hole nearest R9, and the other end of the resistor sticks up vertically. Form the free end of R1 into a small loop, so that a wire can be connected here. This change will allow the sense voltage connection point to be separated from the main PCB power source.

Once the transistors and integrated circuit are mounted, go ahead and mount all the resistors, and diodes, observing the markings on the component side of the board. Again, if you are using the BD/CC at

voltages other than in a nominal 12 volt system, you will likely be using some parts other than those supplied at positions R1 and R7. Remember that resistors R5 and R6 mount vertically, and that R6 must not interfere with the heat sink clipped onto Q1 (if used).

Step by step instructions (applicable if using the available PC board):

Once you have looked over the information, if you decide to get the PC board, just send me a check or MO for \$5.00 times the number of boards wanted (about 100 are still available). I had a batch fabricated by FAR circuits some months ago. They may also be available directly from FAR, you will have to contact them and ask.

My mailing address is:

Jim Wiley, KL7CC
PO Box 112573
Anchorage, AK, 99511-2573

[] (1) Mount transistors Q1 and Q2 (2N3053 / ECG 128) at the positions marked on the board. Mount them so that the leads come out on the side of the board that has the silver wiring (the printed circuit). Again, notice that the collector lead (the one attached to the transistor case) goes to the hole marked "C", the emitter lead (closest to the small metal tab on the can) goes to hole "E", and the remaining base lead goes to hole "B". Take care to see that the leads do not cross one another and short out. When you are satisfied that each transistor is oriented properly, carefully solder the leads to the PCB. Take care not to use excessive heat, but at the same time be sure to make a good connection.

[] (2) Mount integrated circuit U1 (LM339) at the position marked on the board. As with the transistors, make sure the leads come out the wiring side of the board, and that the actual IC package is on the side of the board with the component markings. Be sure the IC mounts to the board so that the notch (or other mark) at one end of the IC package is above the black mark between pins 1 and 14 of the IC outline diagram on the circuit board.

You will probably have to adjust the lead spacing of the IC until the pins fit easily into the holes in the PCB. The easiest way to do this is to grasp the IC gently in the jaws of a pair of long nose pliers, and carefully "roll" the IC slightly on a hard surface until the pin spacing decreases slightly. If you need to increase the spacing, gently grasp the entire row of pins in the pliers and carefully bend all of them at once (on one side, of course) outwards until the spacing is correct. The easiest way to hold the IC in place once the pins are all inserted is to bend just two of the opposite corner pins down against the circuit foil, which will hold the part in place while soldering.

Solder all of the pins to the PCB foil, taking care not to create solder "bridges" between the pins. If any shorts occur, carefully remove the excess solder using "solder-wick" or some other solder removal method before continuing. It is not necessary to clip off the remaining pins after soldering is complete, but you may do so if you wish.

As each following component is mounted, solder the leads as directed, and remove any excess wire. In some cases, you will be directed to leave a lead unsoldered. This is to allow connection of other parts or wires at a later time.

[] (3) Mount a 10 K Ohm resistor (brown – black – orange – gold) at position R1.

If you are using your unit as a charge controller, use the 13K Ohm resistor (brown – orange – orange – gold) resistor instead.

Also:

If using the BD/CC as a charge controller, or at voltages above 16V DC, see the paragraph (at the bottom of page 4) about modifying the mounting position of resistor R1. In this case, only one end of R1 is soldered to the board (the end closest to R9), and the other end is left free, to be connected later.

[] (4) Mount 2 more 10 K Ohm resistors (brown – black – orange – gold , one at each position R5 and R7. Solder both leads of each resistor.

[] (5) Mount a 6200 Ohm resistor (blue – red – red – gold) at position R3. Solder both leads.

[] (6) Mount a 1500 Ohm resistor (brown – green – red – gold) at position R4. Solder both leads.

[] (7) Mount a 6200 Ohm resistor (blue – red – red – gold) at position R9. Solder both leads

[] (8) Mount a 9100 Ohm resistor (white – brown – red – gold) at position R7. Solder both leads.

[] (9) Mount diode D1 (1N4007) at position D1. Make sure the cathode on the diode (marked with a line or other symbol – see text above) agrees with the corresponding mark on the component side of the PCB. Solder both leads.

[] (10) Mount Zener diode D2 (1N5230B) at position D2. Again, make sure the diode cathode lead goes into the PCB hole adjacent to the indicated line. Solder both leads

[] (11) Mount diode D3 (1N4007) at position D3. You might have to “fudge” a bit to get the diode to sit down against the board, or you can just let it “float” in the air a bit, bending the leads so as to increase the spacing between the diode and transistor Q1. As before, make sure the diode cathode terminal goes to the correct point on the circuit board (next to the mark on the outline drawing). Solder both leads when you are satisfied with the mounting arrangements.

[] (12) Mount variable resistors R2 and R8 (2000 Ohm trimmer potentiometers) at the positions indicated. Mount the trimmers so that there is no interference between the control wheel and other parts

previously attached to the PCB. Pre-set the trimmers so that the control is at its center position (not at one end). If proper instrumentation (a digital voltmeter) is not available for precise adjustment, this setting will at least get you by until better equipment is available. Solder all 3 leads of each control.

That's it – you're done. Carefully check the board for shorts between traces on the printed circuit, and make sure all applicable holes are soldered. There will be some unsoldered holes at this time, specifically the 5 holes numbered 2 – 3 – 1 – 4 – 5 along one side, and a series of holes numbered 8 thru 14 along one other side. All remaining holes should have a component lead sticking through them, and be soldered. EXCEPT – if you have mounted resistor R1 vertically for high voltage applications, the one hole where the “sense” end of this resistor would have been will likewise remain unsoldered and unfilled.

If you have decided to use the optional output relay, here are some hints on how to install it. Please refer to the circuit diagrams in the application notes section for additional information.

Output relay option:

The output relay option can be used in at least two ways. The most common use is to connect or disconnect the load from the power source (battery), depending on the state of charge in the battery, and to provide an auxiliary set of contacts that can be used to control the sensing circuit and operate some LED status lamps (or an alarm buzzer). The BD/CC can be used as a main power control for many systems, allowing it to simultaneously monitor the battery voltage and provide normal on-off switching for the device being controlled.

When used as a charge controller, the BD/CC can use the output relay option to disconnect the battery from the charging current once full charge is achieved, and hold it disconnected until the charger is powered down or unplugged.

The LED status lamps used with the output relay option can be used as follows: The lamps can be connected so that a green lamp is lit whenever the battery is connected to the load (“power on”), and a red lamp glows when a low-voltage condition has occurred (“disconnect”). These lamps each require a 820 Ohm (gray – red – red – gold) series resistor, and will only operate if connected with the correct polarity.

Normally, LED lamps are “keyed” in some manner to indicate the cathode side of the lamp. Such keys include a small flat spot on one side of the lamp, one lead longer than the other, or other means. The cathode side of the lamp should connect to “ground” or the more negative voltage. The anode of the lamp then connects to the more positive side of the source being indicated. Remember that LED lamps must use a resistor to limit the current through the lamp diode to a safe level (20 mA is recommended for most units). If you are unsure which side of the lamp connects to “positive” and which to “negative”, then temporarily hold the lamp and one of the 820 ohm resistors are pinched between your fingers, and touch the remaining leads to ground and positive battery. If the lamp lights, you have determined which way to connect it. If it does not light, then try reversing the leads.

Connecting the BD/CC to your equipment:

We will first discuss the most common application, using the BD/CC with the output relay option as a discharge limit controller.

[] (13) To use the combined BD/CC and output relay option in the discharge control mode, wire the coil of the relay (terminals 7 and 8 on the relay - see included outline drawing) to connection points 3 and 4 of the BD/CC. You can use 20 to 24 gauge wire for these connections.

[] (14) Connect + 12V DC to connection point 1 of the BD/CC (through one side of a small DPST switch (not supplied) if you want to use the unit to serve as a main power control).

[] (15) Connect -12V DC (Ground) to connection point 5 of the BD/CC.

[] (16) Run a wire from +12V (switched via the small switch, above) to the relay common (moving) contact of the “A” side of the relay (terminal 5).

[] (17) Run another wire from the normally open contact of this same side of the relay (terminal 3) to connection BD/CC point 2. Solder all connections, if you have not already done so.

[] (18) Run a heavier wire from the 12V source (battery) to the common contact of the “B” side of the relay (terminal 6). Solder all connections.

[] (19) Run a heavier wire from the relay “B” side normally open contact (terminal 4) to the equipment to be controlled. Solder all connections.

At this point, the BD/CC is ready to use. Many users will prefer to install the LED status lamps, described below. If you do not wish to use the status lamps, proceed to the calibration instructions.

To use the LED lamps as status indicators, you will need to connect them to the BD/CC as follows:

[] (20) Connect the cathode lead of the green lamp to a grounded point.

[] (21) Connect the anode lead of this lamp to one end of one of the 820 Ohm resistors.

[] (22) Connect the other side of this same 820 Ohm resistor to the switched power lead coming from the relay (terminal 4).

The green lamp will light when the battery is supplying power to the load.

[] (23) Connect the cathode lead of the red lamp to a grounded point. If you want this lamp to be off when the main power is off, run the cathode lead through the unused side of the DPST switch mentioned in step 14, above, and then to a grounded point. Otherwise, the “disconnect” lamp will remain lit whenever the relay is de-energized.

[] (24) Connect the anode lead of this same lamp to one end of the other 820 Ohm resistor.

[] (25) Connect the other side of this 820 Ohm resistor to the normally closed contact of side “A” (relay terminal 1).

The red lamp will light when the BD/CC has sensed a low voltage condition and disconnected the battery from the load.

The BD/CC is ready to use. Proceed to the calibration and adjustment instructions.

Using the BD/CC as a charge controller:

Many modern battery chargers already include some type of circuit for limiting or halting the charging cycle once the battery has reached full charge. If the charging circuit or system you are using does not include such a limiting device, then the BD/CC can perform this task automatically, assuring you that battery damage from overcharge is unlikely to occur.

If you have not already assembled your BD/CC unit, or if you are going to use a second BD/CC as a charge controller in a dual control system (one BD/CC as a charge controller, the other as a discharge controller), then go back to step 1 and assemble your unit. Note that in step 3 you will install the optional 13 K Ohm resistor (brown – orange – orange – gold) at R1 in place of the 10 K Ohm unit.

Proceed through the assembly steps until you have reached step 12, then return here for additional instructions.

We will assume that you are going to use a control relay. The relay will need to be a DPDT relay, with a 12 V DC coil, that has a coil resistance of no less than 70 Ohms. If the relay you are using has a coil resistance of 150 Ohms or more, the use of heat sinks on the output transistors (Q1 and Q2) is not required. You should use the heat sinks if the relay you are using has a coil resistance of less than 150 Ohms, indicating that it will draw 100 mA or more when operating.

Refer to the drawing in the application notes section showing the wiring of the output relay when using the BD/CC as a charge limiting device. The basic wiring is similar to the hookups used in a discharge (load disconnect) control application, except that the relay does not pull in until it is time to halt the charging current.

Follow these steps to hook up the BD/CC as a charge controller:

[] (26) To use the combined BD/CC and output relay option in the charge control mode, wire the coil of the relay (terminals 7 and 8 on the included relay outline drawing) to connection points 3 and 4 of the BD/CC. You can use 20 to 24 gauge wire for these connections.

[] (27) Connect + 12V DC from the battery charger to connection point 1 of the BD/CC.

[] (28) Connect -12V DC (Ground) from the battery charger to connection point 5 of the BD/CC.

[] (29) Run a heavier wire from the 12V source (battery charger) to the common contact of the “A” side of the relay (terminal 5). Select the proper wire size to carry the expected load current.

[] (30) Run another heavy wire from relay terminal 1 (normally closed, side “A”) to the battery being charged. Select a wire as large as the one chosen in step 29.

A battery safety note: It is good practice to install a fuse in the hot lead of the battery to protect against fire or explosion in the event of an unexpected short across the battery leads. The fuse and holder should be able to handle the current of the battery at a “1C” discharge rate, or at whatever your maximum expected load will be. In other words, if you have a 20 AH battery, use a maximum of a 20 ampere fuse, but if your expected load will never exceed some smaller value, say 5 Amperes, then you can use a smaller fuse, for better protection. In this case, you would select a fuse rated at about 1 ½ times the maximum expected discharge rate, or 7.5 Amperes. Use of a “slow-blow” fuse will allow momentary high current excursions, but still provide adequate protection against shorts and faults.

A fuse wired directly at the battery will protect against both load shorts and charger failures.

[] (31) Run a small wire from relay terminal 1 (the same point that connects to the battery) to the end of resistor R1A, which will be the lead sticking up from the BD/CC board, and which hopefully will have a small loop formed in it to accept the wire you are connecting. Solder the lead from relay terminal 1 to resistor R1A, but do not wrap the wire so that it will be difficult to disconnect if needed. Simply stick the incoming wire through the loop formed by the lead of R1A, and fill the hole with solder. The solder will be strong enough to retain the wire, and the wire can be easily removed if the need arises by simply re-heating the joint.

This lead will sense the battery voltage, and cause the BD/CC relay to pull in (disconnecting the charger) when the desired maximum charge voltage has been reached.

[] (32) Connect a wire from the + 12V charging source to the common contact of side “B” of the relay, at terminal point 6. This can be a small gauge wire.

[] (33) Connect a wire from the normally open contact of the relay side “B” , terminal 4, to the BD/CC connection point 2. This connection will hold the relay closed (charger disconnected) once the battery is fully charged and as long as power continues to be available from the charging source. Once the charging source has been turned off or disconnected, the BD/CC will automatically reset to allow further charging.

To use the LED lamps as status indicators in a charge control application, you will need to connect them to the BD/CC as follows:

[] (34) Connect the cathode lead of the green lamp to a grounded point.

[] (35) Connect the anode lead of this lamp to one end of one of the 820 Ohm resistors.

[] (36) Connect the other side of this 820 Ohm resistor to the “B” side (NC) contact of the relay (terminal 5)

The green lamp will light when the battery is being charged.

[] (37) Connect the cathode lead of the red lamp to a grounded point.

[] (38) Connect the anode lead of this same lamp to one end of the other 820 Ohm resistor.

[] (39) Connect the other side of this 820 Ohm resistor to the charge control relay (NO) contact, (terminal 4).

The red lamp will light when the BD/CC has determined that the battery is fully charged and has disconnected the charger from the battery.

Proceed to the calibration instructions to adjust your BD/CC for proper operation.

Calibration and adjustments:

The BD/CC has two set points. In either mode of operation (charge or discharge control) potentiometer R2 sets the higher voltage limits and potentiometer R8 sets the lower voltage limits.

Calibration is best accomplished with a digital voltmeter, although a correctly reading analog meter is an acceptable substitute (just not as accurate). To calibrate the BD/CC, you will need an variable voltage DC power supply than can be adjusted between at least 10 and 16 volts. Power supplies having a wider adjustment range are also acceptable. The power source should be able to provide at least 500 mA of current. You will also need a load resistor, and to set up a BD/CC as a charge controller, (optionally) a suitable rechargeable battery (12 volts nominal, unless you are setting up the BD/CC for other voltages). A suggested value of load resistor is any small power resistor between 100 and 500 ohms, rated at 5 watts or more of power dissipation. The idea is to have a test load that will draw between 25 and 200 mA, which is appropriate for simulating the actual load of an electronic circuit.

Setting up the BD/CC for use as a discharge (load disconnect) controller:

To begin the setup process, first adjust the control R2 to its maximum voltage setting, which occurs when the wiper of the control is closest to the end of the control connected to R1.

Next, adjust the control R8 to its minimum voltage setting, which occurs when this control is adjusted so that the wiper is closest to the end connected to R9.

Connect the BD/CC to the power supply, with the positive lead going to BD/CC point 1, and the negative lead going to BD/CC point 5. Run a wire from the power source to relay terminal 6.

Run another wire from relay terminal 4 to the load resistor.

Turn on the power supply (and the BD/CC if you are using the optional control switch mentioned in step 13). Adjust the power supply to exactly 11.5 Volts DC. If you are using a different set point, adjust your power supply to that value instead. Use the digital voltmeter to confirm this value.

Adjust control R2 on the BD/CC very slowly downward until the relay just pulls in and connects power to the load. If you are using LED indicators, the green lamp should light, indicating power is being supplied to the load.

Now, carefully lower the power supply voltage to 10.8 Volts DC. Again, if you are using a different voltage, make the appropriate changes to allow for the values you have chosen. Do this slowly so any charged capacitors in the power supply have time to equalize.

Adjust control R8 on the BD/CC very slowly upward until the BD/CC relay drops out, and the red LED lights, indicating that the BD/CC has disconnected the load from the power source.

Carefully adjust the power supply slowly upward in voltage until the relay again activated, and the green LED lights once more. Measure the voltage, and it should be at or very near 11.5 Volts DC (or your preferred “high” set point).

Next, again lower the power supply voltage slowly until the relay drops out, and the red LED again lights. The voltage being delivered by the power supply should be at or very near 10.8 Volts DC (or your preferred “low” set point).

If the above conditions are not met, go back over the adjustments until you are satisfied with the results. You can of course use different set points, if you wish. The idea is to establish a low voltage cutoff point beyond which the battery will no longer supply power to the load, and another point to guarantee that the battery must receive at least some charge before being reconnected to the load.

Setting up the BD/CC for use as a charge controller:

If you are using the BD/CC as a charge controller, the adjustment process is very similar to the above procedure, but only the cutoff voltage (high voltage limit) needs to be set. The low voltage control is simply set to its minimum value and left at that point.

Connect the BD/CC to the power source. Connect the charger (power source) positive lead to both the free end of resistor R1 and relay terminal 5.

Connect the power supply negative lead to BD/CC connection point 5, and to one side of the load resistor.

Connect the other lead of the load resistor to the BD/CC relay, terminal 1.

Connect the digital voltmeter across the load resistor.

Turn control R8 to its minimum setting (wiper closest to resistor R9) and leave it at that point.

Set the power supply to its lowest voltage setting, and turn it on.

Slowly increase the voltage setting of the power supply / charger until the voltage across the load resistor indicates 14.0 volts, or whatever other charge cutoff voltage you wish to use. If the BD/CC disconnects the load resistor before 14.0 volts (or your preferred voltage) is reached, increase the setting of resistor R2 and try again.

Alternately, set R2 to its highest value, and once the power supply is adjusted for the desired cutoff voltage, slowly decrease R2 until the relay just activates.

The relay should remain activated as the voltage is lowered, at least until the point the relay drops out from not having enough voltage to hold the relay closed, which is typically less than 6 volts. Removing the power source (by turning off or disconnecting the power supply) and then re-applying power at a slightly lower voltage should again cause the load to receive power. As the voltage is again raised slowly, the BD/CC should cut off the load at 14.0 Volts DC (or your chosen set point).

If you wish, you can connect the BD/CC to a battery and observe the process with a digital voltmeter as the battery charges to the cutoff point and then is disconnected as the voltage rises to the preset value.

Once you are satisfied with the adjustment of the BD/CC unit, you can install it into whatever system you have in mind.

Theory of operation:

The BD/CC uses a comparator to determine whether or not certain user defined voltage limits for a battery powered system are above or below the desired value, and when one of these limits is exceeded, takes action to prevent damage to the battery involved.

Assume the following conditions for the circuit: A fully charged 12V battery is connected to the BD/CC (via connection point 1) and also to a load via relay K1/K3 (the load relay). Assuming the battery is fully charged, it's voltage should be somewhere in the area of 12.6 volts. When the circuit is turned on, the following sequence of events occurs:

+12V is passed through diode D1, resistor R4 and Zener diode D2. This establishes a reference voltage of + 4.7V on comparator (U1) pins 4 and 6. At the same time, voltage divider R1, R2, R3 takes the same +12V and supplies a signal to comparator U1A pin 7. If the circuit is adjusted properly, and the battery (or source) voltage is at least 11.5 VDC, U1 pin 7 will have a higher voltage than U1 pin 6 (the 4.7V reference) and comparator U1A will switch "off". If U1A is in the off state, current will flow through resistor R6 to the base of transistor Q1, turning on the transistor and causing the load relay to activate. As soon as the relay activates, +12V is also sent through R7, R8, R9, which causes comparator U1B to switch to the off state as well, and transistor Q2 turns on, duplicating the efforts of Q1. The voltage divider consisting of R7, R8, and R9 is, however, set to a lower "trigger" value than the R1, R2, R3 divider.

As the voltage presented to the comparator input varies above or below the reference, which in this case is 4.7 volts, the comparator switches rapidly from "high" to "low" at it's output terminal. In the case of the LM-339, the output is simply a NPN transistor, so the resistance of the output goes from a very high resistance state (off) to a low resistance state (on).

As the battery voltage falls slowly, a point is eventually reached where the terminal voltage is less than 11.5 volts. At this point, the voltage on U1A pin 7 falls below the 4.7V reference voltage, and comparator U1A turns on, which grounds the base of transistor Q1, turning it off. Transistor Q2, however, is still turned on (via R6), and thus the load relay remains closed, and power continues to flow to the load.

As the battery voltage declines further, eventually it reaches the lower set point, nominally 10.8 V DC, and the voltage at pin 5 of comparator U1B also falls below the 4.7V reference. At this time, comparator U1B changes state, grounding the base of transistor Q2, and because Q1 is already off, the load relay no longer has a way for current to flow through its coil, and it releases, interrupting the path to the load. The battery voltage will almost certainly rise slightly at this point as almost all of the load has been removed. But, since opening the load relay also removes the “drive” voltage to R7, R8 and R9, and thus comparator U1B, it cannot immediately re-activate the relay.

At this point, the normal procedure would be to connect the battery to a suitable charger. If the BD/CC is still connected, and the load is still ready to use, the following will occur: As the battery is charged again, its terminal voltage will slowly rise. Once the battery voltage exceeds 11.5 V DC, comparator U1A will change state, turning off, allowing base current to again flow to Q1, and the load relay will energize. Assuming the charger can supply more current than drawn by the load, the battery will continue to charge. If, however, the load takes more than the charger can supply, the declining battery voltage will again be sensed at the 10.8 V DC point, and the load will again disconnect. In normal use, the fact that the BD/CC has disconnected the load would serve as a signal to the user that it is time to recharge the battery, and the powered device (the load) should not be activated until the battery was once again fully charged.

Resistors R1 and R3, combined with variable control R2 establish the “high” set point. In a similar manner, resistors R7 and R9, combined with variable control R8 establish the “low” set point. The combination of Zener diode D2 (4.7V) and R4 establish a reference which is used by the comparator (LM339) to control output transistors Q1 and Q2.

The comparator is a specialized type of operational amplifier. You can think of it as an OP-AMP with infinite loop gain. In fact, an OP-AMP can be used as a comparator if the feedback resistors are eliminated. As such, the comparator has a very high input impedance, and draws virtually no current from the voltage divider used to “drive” the comparator.

When the BD/CC is used as a charge controller, it is wired so that when the maximum charge voltage is reached (14.0 volts, for the 12 volt example) the load relay activates. Since the battery is connected to the charger through the normally closed contacts of the relay, as soon as it pulls in, the charging current is interrupted. At this point, the relay (via another set of contacts) connects the BD/CC low voltage set point to the battery, which will cause the BD/CC relay to remain activated. If the power from the charger is removed, the output relay will release, and if the charger is then connected and/or turned on, charging current will be supplied to the battery. The BD/CC circuit requires that power from the charger be interrupted to reset the unit so charging can be resumed.

Note: Charging sealed lead acid cells above 14.0 V (for a “12 volt” battery) may result in excessive gassing and damage to the cell if the charge is continued for an extended time. Some publications recommend charging to around 14.5 volts, then reducing the charge so the battery “floats” at about 13.6 volts. We prefer to simply limit the charging to about 14 volts (for sealed batteries), stopping the charge as soon as this point is reached. While a cutoff at this voltage may result in some underutilization of the full capacity of the battery, it also helps to insure long life. For long-term use in float charged systems, a nominal 12 volt plant should “float” at about 13.5 to 13.6 volts (2.25 to 2.27 volts/cell). The 14.0 volt example used above assumes that the batteries are charged more or less in “batch” mode, and the charger is then disconnected (or turned off) until the batteries are run down and need another recharge. A good quality lead-acid unit can be recharged 200 (or more) times using this procedure. Float charged units will last a long time (10 to 20 years) when set to 13.5 volts “float” and any rapid charge or discharge cycles are of limited duration and relatively few in number.

Options:

The following paragraphs give some ideas for using the BD/CC with different battery voltages, different output switching devices, and possible modifications.

Using the BD/CC with different voltages:

To use the BD/CC with battery systems having different terminal voltages, it will be necessary to change the values of the resistors in the adjustable voltage dividers so that the appropriate levels are presented to the comparator. Since the comparator uses a 4.7V reference, the voltage dividers providing a comparison to U1A or U1B should be set up accordingly.

Assume for the moment that we are working with a 12V system, and we are trying to choose the value or resistance required for R1, for a “high” set point voltage of 11.5 Volts.

Also, to make things easier, we need to remember that the voltage at the “high” end of variable resistors R2 and R8 should be about 5.2 volts. By using Ohm’s law ($I = E / R$) we can calculate that the current flow through the divider chains should be about 0.6 mA (.0006 Ampere). For the problem shown, add the value of the “bottom” resistor (6200 ohms) and the variable control (2000 ohms) which gives a total resistance of 8200 ohms. Divide 5.2 volts by 8200, and the answer is (roughly) 0.6 mA. The actual result is a bit higher, (0.634 mA), but rounding the answer to 0.6 mA is good enough.

Subtracting the “high side” voltage of 5.2V from the desired set point voltage of 11.5V leaves us with a required “drop” of 6.3 volts across R1. Again using Ohm’ law, solving for R ($R = E / I$), we come up with the following answer: $R = 6.3 / .0006$, which calculates to 10.500 Ohms. Since 10.5 K ohm resistors are not commonly available, we will use instead 10,000 ohms (10K) which is the closest standard value.

If we wished to make some additional calculations, we would find that the adjustment range of R2 would allow the voltage applied to U1A pin 7 to vary between about 3.9 volts and 5.2 volts.

A little observation will show that the reference voltage is (very roughly) about 1/2 way between the values of 3.9 and 5.2 volts provided by adjusting control R2. Therefore, the adjustment range is enough to allow the comparator trip point to be set properly.

In a similar manner, again for a 12V system with a 10.8 V “low” set point, Ohm’s law tells us that the resistance value required for R7 should be 9333 ohms. As before, the closest standard value, which is 9100 ohms, is used. Again, the desired trip point is approximately 1/2 way around the rotation of the variable control, and the adjustment range is correct.

24 Volt operation:

Now suppose you wanted to use the BD/CC with a 24 volt system, and you calculated that the “high”, or “reconnect” trip point should be 23 Volts, and the low, or “disconnect” trip point should be 21.6 volts. You would change the values of R1 and R7 until similar adjustment ranges were available. Remember that we want to have a voltage presented to the comparator that is approximately 4.7 V when the adjustable control is at or close to the center of it’s adjustment range.

If we use the example above, and do not change the value of R3, we need to find what value of resistance at R1 will create the same current flow (and thus the same voltages) across R2 and R3. In the example above, there was approximately 5.2 volts at the top end of R2. If we subtract 5.2 from 23 Volts (our new “high” trip point) we get 17.8 volts. Ohm’s law ($R = E / I$) tells us that using the same 0.6 mA of current as in the 12V example, we will need a resistance of 29,666 Ohms. This is not a standard value. The closest standard values are 27K and 30K. If we choose a 30K resistor (orange – black – orange – gold), the values, after calculation, indicate that the range of adjustment at R2 will be satisfactory.

In a similar manner, we find that the resistance of R7 for a “low” set point of 21.6 volts can be found by using the same methods. Remembering that the current through R8 and R9 was about 0.6 mA (.0006 Ampere), which resulted in a voltage of about 5.2 volts at the high end of R8, and we need to find out what value of resistance is needed to “drop” 16.4 volts (21.6 – 5.2) when a current of 0.6 mA is flowing. Ohms law ($R = E / I$) tells us that the resistance needed is 27,333 Ohms. Again, the closest standard value is 27,000 Ohms (red – violet – orange - gold). Substituting that value, and rerunning the calculations shows that the voltage available across control R8 will still be within acceptable limits.

Remember, the “high” end of R1 must be disconnected from the PC Board if you are intending to use the BD/CC at voltages higher than 16 volts, or as a charge controller.

Voltages other than 12 or 24 volts:

The steps to determine the approximate values of R1 and R7 for other voltages are as follows:

(a) Determine the required set points. You can use battery technical manuals or manufacturers data sheets to determine the correct voltages to use. Or, you can “scale” the voltages using the 11.5 volt and 10.8 volt points of the standard unit. You should probably have the “reconnect” set point a minimum of 5% higher than the “disconnect” point, although you can use whatever values you are comfortable with.

(b) Assume that the voltage at the high end of either R2 or R8 needs to be about 5.2 volts, and that the current flow through the divider will be about 0.6 ma (.0006 Ampere). Then just subtract 5.2 from whatever set point voltage you want, and calculate accordingly ($R = E / I$). For example, for a 36 volt set point, the drop across R1 (or R8) would need to be about 30.8 volts, and 30.8 divided by .0006 is 51,333. A 51K ohm resistor (the closest standard value) would work properly.

(c) The closest standard resistance will generally work just fine. If you want to figure out what the new adjustment range would be, simply add all the resistance values in the divider, use Ohm’s law ($I = E / R$) to determine the current flow, and using that value, find the various voltage drops across each resistor. This will tell you the voltages present at each end of the adjustment potentiometer. As long as the voltages are such as to allow you to easily reach 4.7V somewhere within the center 50% of the control’s range, your circuit will work properly.

Note: If you want to be “fussy”, the current through the divider chains in the 12V standard unit was actually a bit higher, about 0.634 mA (.000634 Ampere), in our engineering test model. Recalculating the resistance values at that slightly larger current will change the numbers a bit, but in real terms will not affect the operation of the BD/CC. The bottom line is that as long as the voltages available at either end of adjustable resistors R2 and R8 are such that the “sensed” voltage applied to the comparator can be brought to the same value as the reference voltage whenever a set point is reached, the circuit will operate properly.

Also, if the voltage you are monitoring is higher than 16 volts, you will need to reduce the overall voltage supplied to the BD/CC to a safe value. A “3-pin” regulator (type 7812) will work for voltages between 16 and about 36 volts. This regulator will reduce the higher supply voltage to 12 volts, allowing normal operation of the BD/CC. Remember the note about modification of the mounting and connection for R1 with higher voltages.

If you are monitoring a higher voltage (than 36 volts) , you will need to come up with your own pre-regulator to reduce the supplied voltage to within safe limits.

Using the BD/CC with a transistor output controller:

It is very possible to use the BD/CC with a transistor output switch instead of a electro-mechanical relay.

The best type of transistor to use as a switch is a P-channel enhancement mode MOSFET. These devices allow control with minimal voltage loss across the control device, and therefore minimum wasted power.

Because a transistor switch does not offer the option of “normally closed” contacts, status indicators (if used) that are controlled by this type of relay contact will need to be re-engineered or not used. It is left to the individual user to determine what approach to use in solving this minor problem.

The application note section shows an example of how to wire the BD/CC to a P-channel MOSFET for “high side” control of the external load. Be sure the MOSFET transistor you choose has a low turn-on resistance (R_{ds}) and has adequate current carrying capacity. Some suggested HEXFET (IRC trademark) types are the IRF-4905 ($R_{ds} = 0.02 \Omega$), good for switching up to 48 Volts and, in practical applications, perhaps 20 or at most 25 Amperes, and which sells for approximately \$ 8.00 per unit. Also available are the IRF-5210 ($R_{ds} = 0.06 \Omega$), which is good for loads upwards of 60 Volts at 10 or 15 Amperes (\$4.00). The IRF-5305 ($R_{ds} = 0.06 \Omega$) can switch 24V / 15 to 20 A loads, and is only \$1.75. You may find other units with suitable characteristics at surplus sales or from other sources. Note that these units have published ratings that are much higher (higher voltage, higher current, or both), but because of other considerations these values can seldom be used safely, a characteristic shared with almost all semiconductor products.

It still remains as a consideration that at high current levels, a transistor switch may still lose more power to $I^2 R$ losses than it takes to operate a conventional relay capable of handling the same amperage. For example, even with a R_{ds} of only 0.06 Ohms, if a current flow of 15 amperes is being controlled, there will be losses on the order of 13.5 watts in the switching transistor. A relay handling this same current uses approximately 2 watts of power to activate it’s coil. At lower current draws, however, the transistor switch makes sense. For example, at a current draw of 0.5 Amperes (typical in QRP equipment) the losses through the switching transistor (using an IRF-5305 as the switch) would be a much more acceptable 15 milliwatts!

You can also use the two 2N3053 transistors (Q1 and Q2) to switch small loads directly. In this application, simply connect the positive lead of the device being controlled to the battery, and the negative lead to BD/CC connection point 4. When either transistor turns on, the load will receive power. A word of caution here, however. When Q1 and Q2 are in the off state, there will still be approximately 12 volts standing between the negative lead of the controlled device and actual ground. While this mode of operation is OK for certain types of loads, such as lamps and devices that have no other connections to the

outside world, other equipment may not function properly under these conditions. It may be better to use a relay or a MOSFET switch to perform more conventional “high side” switching. In any case, if using the on-board transistors to directly control an external device, use heat sinks on the transistor cases, and do not exceed 500 mA of load current. You may also need to lower the values of R5 and R6 (increasing the available base current) if the collector voltage standing on Q1 and/or Q2 is above about 0.8 volts when the transistors are conducting.

Potential Problems and some solutions:

Unnecessary Dropouts:

It is possible that momentary load fluctuations could cause the BD/CC to decide that the desired dropout voltage had been reached, when in fact as soon as the momentary heavy load is released, the battery voltage would return to a higher value, and thus not require disconnection. One reason this may happen is if you are using a battery that is too small for the load being drawn (discharge rate is too high). Another reason might be a requirement to start a device (such as a motor) that has a high starting drain but a lower running demand. If these transients are fairly short in duration, you could attach a capacitor to the junction of resistors R7 and R8. This capacitor would slow down the voltage change to the disconnect circuit, and if the overload was of short duration, allow the battery to remain connected. You would need to experiment with just how much capacitance to use, but we suggest you start with at least 470 μFd (16 Volts). You can use a larger capacitor if you wish. Connect the positive (+) terminal of the capacitor to the junction of R7 and R8, and the negative (-) lead to ground (power source negative terminal). Our experiments indicate that a capacitor of this size will allow for a temporary load voltage dip down to about 9 volts for at least 1/2 second without causing U1B to change state (and disconnect the load).

If the BD/CC does not properly disconnect the charger when used as a charge controller, or if the relay “buzzes” when trying to disconnect, the same symptom maybe the cause. Again, try adding a 470 μFd 16V capacitor, as in the above paragraph, but this time connect it at the junction of R1 and R2.

Inadequate adjustment range:

If your application results in a situation where either or both of the controls of the BD/CC are operating too close to one end of their range for comfort (or completely out of range), simply change R1 (or R7) up or down to the next standard value. This should correct the situation and bring the set point control closer to the center of the control’s adjustment range. Remember, all that is required is that the BD/CC be capable of being adjusted so that the set point can be reached. It does not matter (other than making adjustment easier) if the set point (change of state) occurs when the variable control is in the center or its range or near to one end.

Low voltage operation:

The input supply voltage should be reasonably well regulated, and should not dip below about 10 volts, if possible. A properly charged and maintained battery of adequate capacity will satisfy this requirement. The output relay will require at least this much voltage (10V) to energize properly, although once activated it will remain closed down to much lower voltages. If the input voltage falls below about 6 volts, the 4.7 V reference circuit (D2 and R4) may lose control, and the comparator itself may cease to function correctly (it could change state unpredictably).

If you have a requirement to operate the BD/CC at lower nominal voltages, for example from an 8 Volt source, you will need to select an output relay that will function properly at this lower potential, or use a different type of output switching device. For 8 volt operation, we suggest changing resistor R4 from the supplied 1500 ohm unit to a 1000 Ohm unit (brown - black – red – gold), as well as recalculating the resistances required for R1 and R7. (see page 16)

For operation at even lower voltages, you will probably have to change the reference to a lower voltage, for example 3 volts. You will need to recalculate all of the resistances, and the values at either end of the set point controls will also need to be adjusted. In any case, you should operate the circuit so that the set point controls fall near the center of their range when the correct sample voltage has been found. It is up to the experimenter to figure out where to go and what to do in these situations. We do not offer technical assistance for using the BD/CC at voltages outside the 8 to 36 volt range.

Battery voltages:

There are any number of references that claim to have the last word on battery terminal voltages, state of charge, damage values, and so on. We have found that these references frequently fail to agree between themselves, to a greater or lesser degree, depending on which one is cited. If you prefer to operate your batteries at different set points than those discussed here, by all means do so. Your choice may very well be better than ours. You will find that the set point range of a BD/CC is adjustable over a fairly wide range without modification. If the set point range you want is too near the limits on a control, simply change the value of either resistor R1 or R7 up or down one step (next standard value) until you are satisfied with the operation of the unit.

The limits we used when designing the BD/CC were based on 3 sets of references for operating lead-acid cells. These references are: Lucent Technologies (Bell Labs) publication number 157-622-025 (December 1999) concerning care and maintenance of type 121R125 (series II) 12 volt batteries (125 A/H); C & D Technologies publication RS-1672, which describes the operation and maintenance requirements for their FA series 12 volt sealed lead-acid batteries rated at 25 to 150 A/H; and IEEE standards 485-1983, 1187-1996, 1188-1996, and 1189-1996, all of which refer to the installation, maintenance, operation, and other considerations involving the use of sealed lead-acid storage batteries. We also consulted an older publication that primarily deals with “wet” type lead-acid cells. This publication (C & D publication 12-800, dated 1981) gave substantially the same information, with additional data for cells running at different specific gravities of the electrolyte mix.

In each case, we interpreted the information given in a very conservative manner. For example, all of these publications (listed above) suggested that batteries could be discharged to 1.75 volts per cell (10.5 volts total) and a 5th publication by another manufacturer of gelled electrolyte cells indicated that cell voltages as low as 1.5 volts per cell could be tolerated, together with higher charging voltages, up to 15 volts (2.5 volts / cell) for short periods. Our selection of cutoff points at 10.8 Volts (1.8 volts / cell) (low) and 14.0 volts (2.33 volts / cell) (high) was chosen to provide the longest battery life instead of absolute maximum storage capacity.