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# U. S. NAVY

# MARINE ENGINEERING LABORATORY

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Automatic Battery Formation
Cycler and Controller

Assignment 61 501
MEL R&D Report 50/65
July 1965

By
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REFERENCE

(a) Li·wski, P.P.M., "Charge-Current Control Circuit for Nickel-Cadmium Cells with Control Electrodes," MEL Research and Development Report 25/65, May 1965

Distribution List

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## ABSTRACT

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An automatic cycler and controller has been designed to determine charge capacity and perform appropriate charge/discharge operations on electrochemical cells intended for use as satellite power sources. This device is capable of monitoring up to 20 series-connected cells at a time and characterizing each cell according to its terminal voltage and ampere-hour capacity.

Author

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# AUTOMATIC BATTERY FORMATION CYCLER AND CONTROLLER

## 1.0 INTRODUCTION

The U.S. Navy Marine Engineering Laboratory was requested by NASA (Goddard Space Flight Center) under Contract S-12730-G, Amendment 4 of 2 October 1964, to design a device that would automatically perform an electrochemical cell capacity check on each of 20 silver-cadmium cells connected in series by monitoring their terminal voltages. A description of the device designed to perform this task is presented in this report. Reference (a) describes earlier work on a different type of automatic controller for satellite battery power supplies.

1.1 Development Task. Before a group of electrochemical cells can be used in a satellite as a power source, the cells are characterized so that those of similar ampere-hour capacity at a common terminal voltage can be grouped as a power pack. This selection provides an optimum power pack with maximum effective utilization of all component cells and results in the most reliable and efficient satellite power source. The capacity check in the charge mode consists (starting from a common discharged state) of charging the cells at a constant current rate for the time needed for them to reach a predetermined terminal voltage level, called the "ampere-hour capacity." This voltage level is an indication that the cells are completely charged and are approaching the undesirable gaseous overcharged region. When any cell reaches this voltage level, it is taken out of the charge-flow path* and placed on open circuit; also, the ampere-hour capacity of that cell is recorded. This sequence of events is repeated until all 20 cells have been fully charged and have been placed on open circuit. The above procedure is repeated for the discharge mode using a preselected low terminal voltage to indicate end of discharge. By recording the ampere-hours necessary for a cell to reach a certain terminal voltage in the charge or discharge mode, the cells can be characterized. This process is commonly called "forming" the cells.

1.2 Problem Background. The forming and characterization of silver-cadmium cells for use in a satellite must be done according to the scheme described above. The present method, used by NASA Laboratory personnel, consists of charging and discharging a group of series connected cells and manually observing the terminal voltage of each cell with a voltmeter.

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*Charge flow path is the circuit used to charge and discharge the cells.

When a cell's terminal voltage reaches the desired value, it is manually switched from the charge-flow path, and the ampere-hour capacity of the cell is computed. In the discharge mode, in addition to switching a cell out of the charge-flow path, it is necessary to maintain a constant discharge current from all remaining cells as the total terminal voltage across the group of cells decreases when cells are removed. This task is accomplished by manually adjusting the load on the cells. This method of forming and characterizing cells requires careful observation by Laboratory personnel and extensive weekend work during the entire operation. The desire to find a more efficient method of preparing cells for satellite application and to eliminate human error led to the requirement for an automatic battery formation cycler and controller.

1.3 Technical Requirements. The following technical requirements controlled the design of the automatic battery formation cycler and controller: This device should have the capability of controlling the state of charge of at least 20 silver-cadmium cells in series. The end of a charge or a discharge cycle is determined by sensing individual cell voltage. When any individual cell reaches 1.65 volts (adjustable), the end of its charge cycle is reached. This device should then take the cell out of the series string (leaving it open circuited) and command a printer to record the ampere-hour capacity of the cell when this event takes place. A similar operation should also take place when any cell reaches 0.6 volt (adjustable) in the discharge cycle.

## 2.0 OPERATION

The following section will provide a general description of the operation of the automatic battery formation cycler and controller and the function performed by each circuit. A detailed description of each circuit may be found in Appendix A.

2.1 Functional Description. The automatic battery formation cycler and controller utilizes eight separate circuits to perform its designated function. The circuits are: (1) a voltage detector, (2) direct-current (d-c) amplifier, (3) gate pulse generator, (4) relay switching circuit, (5) square wave generator, (6) constant current discharge circuit, (7) stepping switch and drive circuit, and (8) drive circuit for cell-number indicator. The relay switching circuit includes the necessary circuitry to drive a 20-pen event recorder and to provide a signal to initiate a print-out of the ampere-hour printer and cell number indicator when a cell is switched from the charge-flow path. The ampere-hour integrator measures the charge-flow to or from the cells and provides an analog to digital readout (mechanical) of this information. The cell number indicator provides a digital readout of the cell being monitored by the detector. The block diagram shown in Figure 1 illustrates the functional operation of each circuit. Blocks shown with broken lines are external to the formation cycler and controller but are an integral part of the complete system required to form and characterize silver-cadmium cells automatically. As the stepping switch automatically connects the detector to each cell in sequence, the detector monitors its terminal voltage. The output of the detector is rectified to a d-c level that is a function of each cell's terminal voltage. The change in this d-c level is amplified by the d-c amplifier. When the output voltage of the amplifier is sufficiently high, the gate pulse generator provides a pulse to the relay switching circuit. This pulse results in the switching of the cell, whose voltage is being monitored, from the charge-flow path. Switching a cell out of the charge-flow path actuates a pen on the event-recorder and provides a signal to drive the ampere-hour and cell-number printer.

The square wave generator provides a signal to operate the detector. The constant current discharge circuit provides the cells with a voltage-varying impedance when in the discharge mode. The change in impedance maintains a constant discharge current from the cells. A drive circuit for the cell-number indicator and printer provides the signal to operate the mechanical readout which indicates the cell then being monitored by the detector.

2.2 Discussion. The terminal voltage at which a cell will be removed from the charge-flow path in the charge and discharge modes is adjustable over a relatively wide voltage range. These adjustments are: the high voltage detector, 1.00 to 1.85 volts; and the low voltage detector, 0.100 to 1.20 volts. Any cell will be switched from the charge-flow path within ±10 millivolts of the setting. The adjustment procedure is described in Appendix B.

The constant-current discharge circuit is designed to draw a constant current (continuously variable from 0.5 to 5.5 amperes) from a battery pack as the terminal voltage of the battery varies from 40 to 1.5 volts. There is only a 2-percent variation in the discharge current over this voltage range. Below 1.5 volts, the discharge current becomes a function of the terminal voltage. As charge is removed from the last cell, the terminal voltage of that cell is reduced to the switching level. The power dissipation of the transistors used in the circuit is the limiting factor in the maximum discharge current this circuit will control. Forced convection is utilized to cool these transistors while they are operating in the discharge mode.

The wide range of adjustments of the above parameters give the automatic battery formation cycler and controller an added versatility in that it can be used to form and characterize cells other than silver-cadmium, as long as they have similar voltage/charge characteristics.

When a cell is switched from the charge-flow path in the charge or discharge mode, the cell number and the ampere-hour capacity of the cell are automatically printed out on the same tape. At the completion of the forming cycles, the characteristic of each cell can be determined from this data. An alternate method of indicating which cell is switched from the charge-flow path is provided for in the circuitry to drive a 20-pen event recorder.

## 3.0 CONCLUSION

A prototype of the automatic battery formation cycler and controller has been built and delivered to NASA, Goddard Space Flight Center, Greenbelt, Maryland. Photographs of the instrument appear as Figures 2, 3, and 4. Several groups of electrochemical cells have already been formed using this formation cycler and controller.

Five- and ten-cell battery packs for satellite use have been formed with less than 2-percent variation of ampere-hour capacity of the individual cells that make up the pack. This compares to a 5-percent variation when cells were formed and characterized by the previous manual method.

The design of the automatic battery formation cycler and controller to form electrochemical cells has resulted in a more efficient and reliable battery pack for satellite applications while reducing the cost and manpower needed to form the cells.

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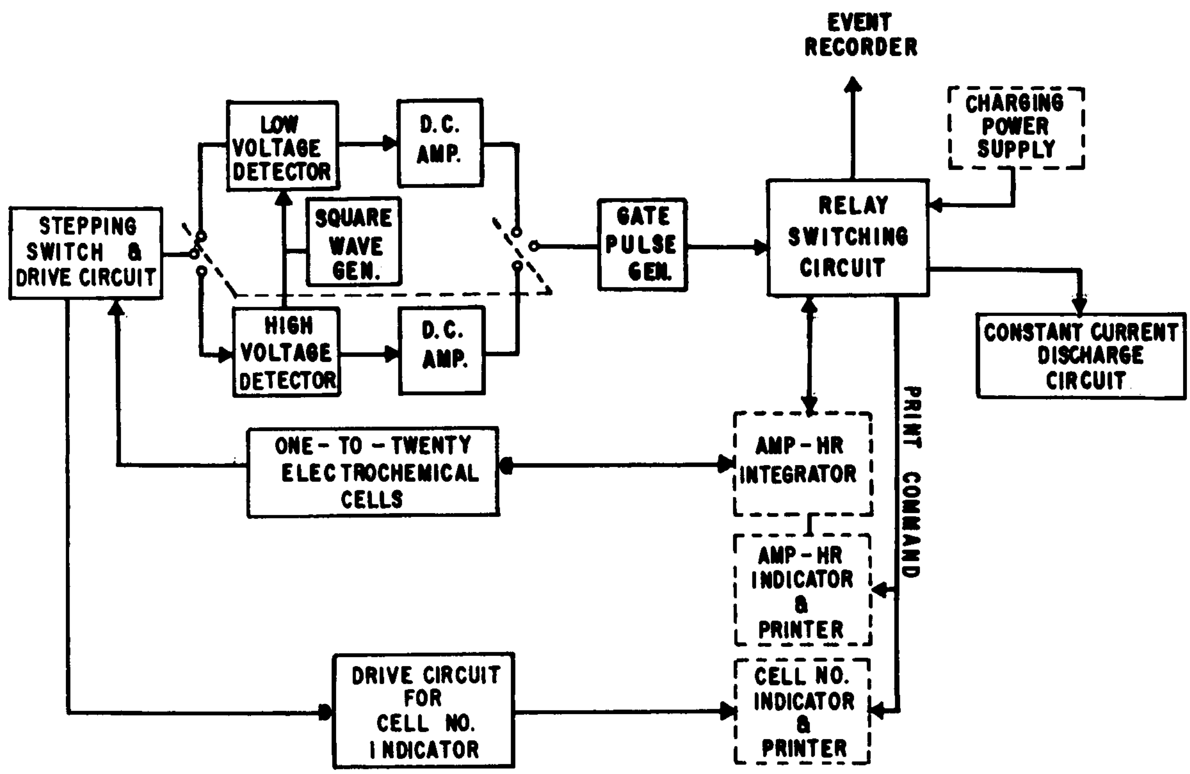


Figure 1

System for Automatically Forming
and Characterizing Electrochemical Cells

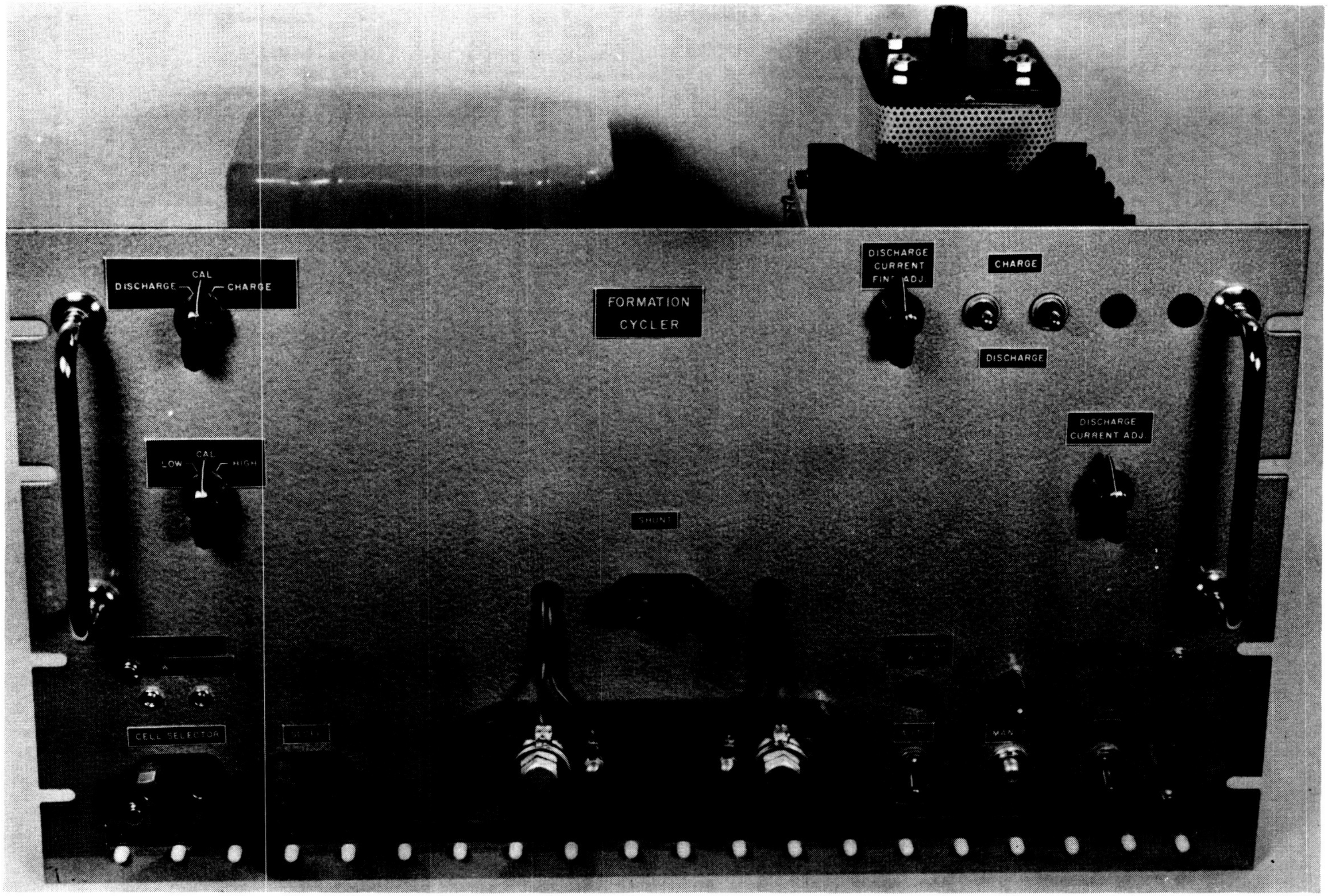


Figure 2 - Automatic Battery Formation Cycler and Controller (Front View)

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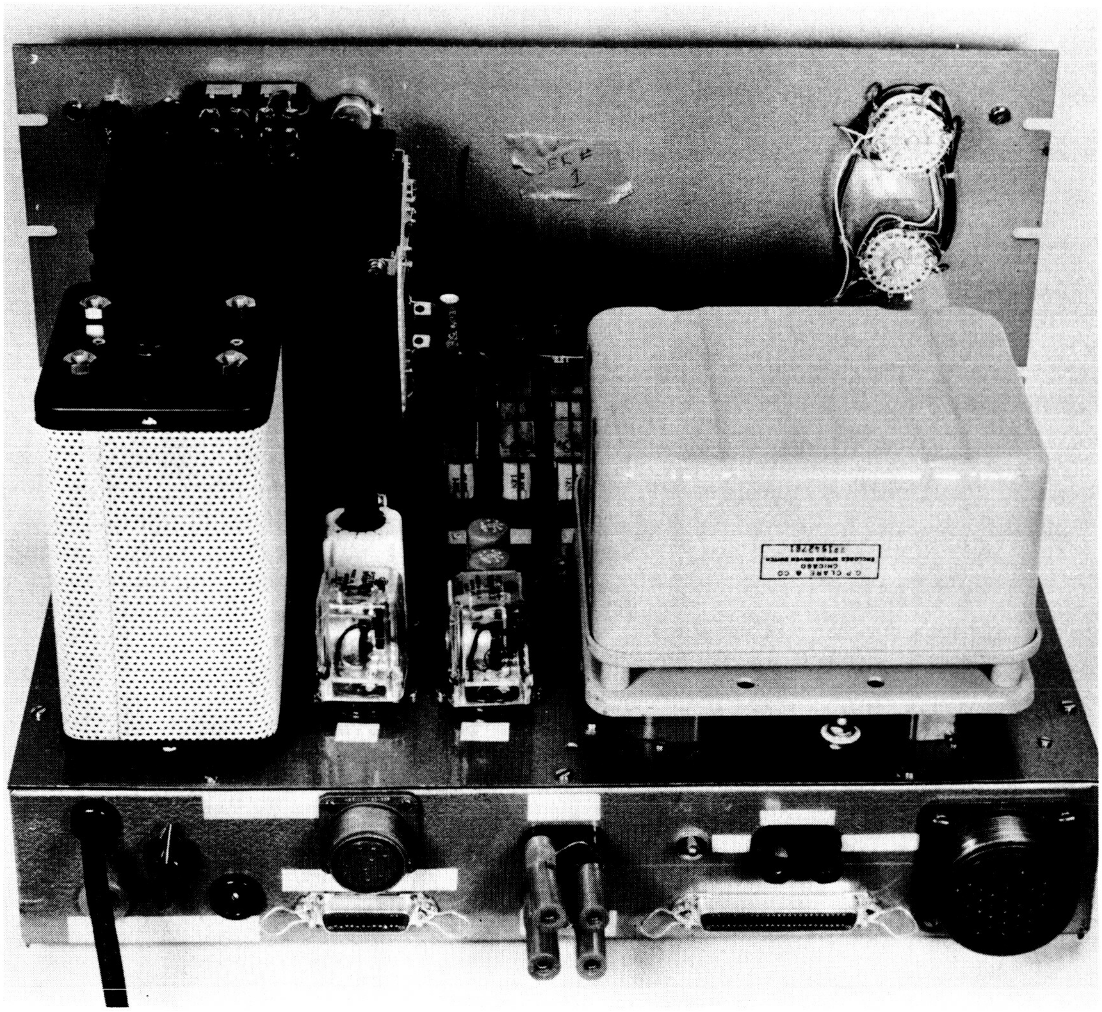

Figure 3
Automatic Battery Formation Cycler and Controller
(Top-Rear View)

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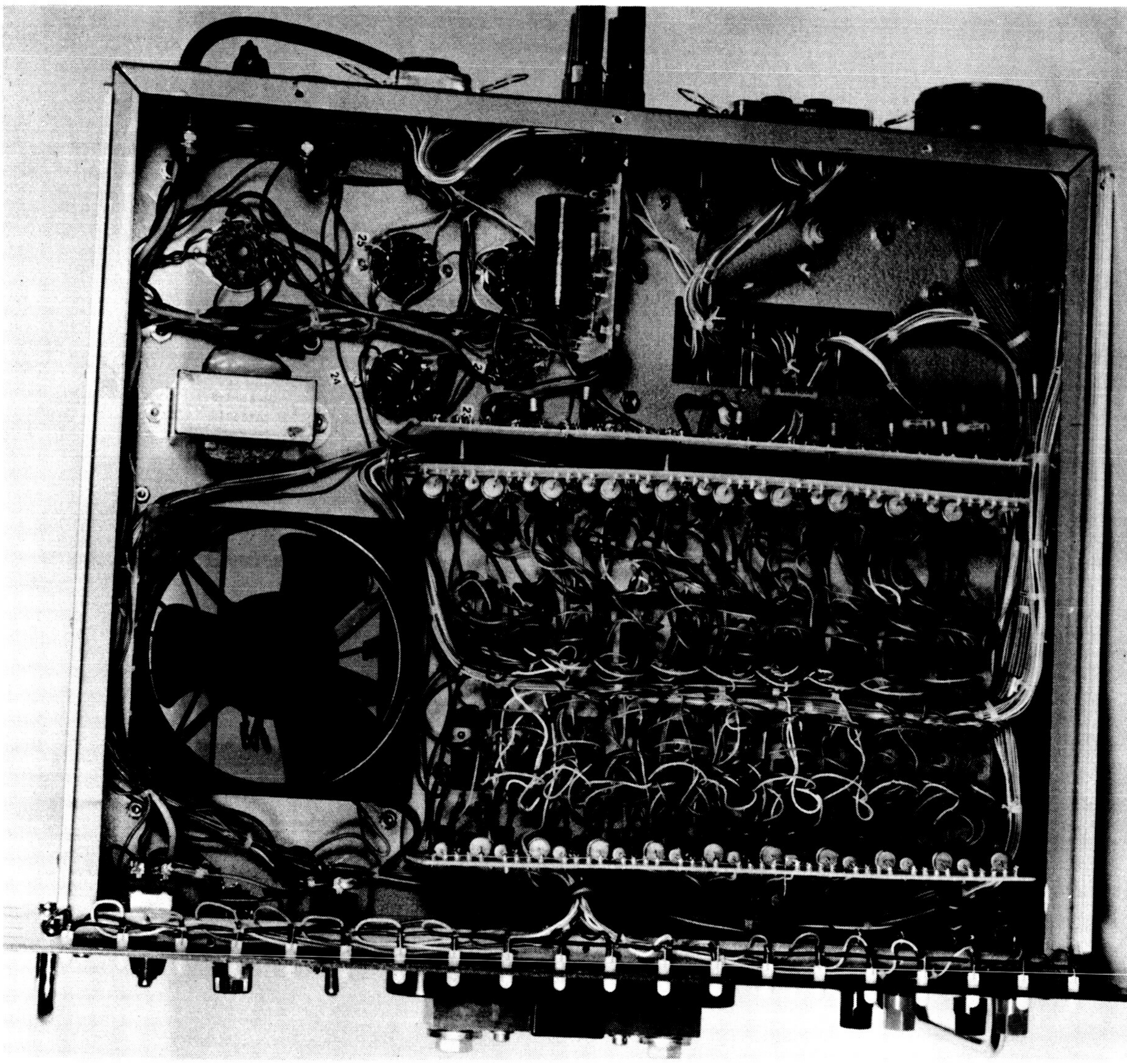


Figure 4
Automatic Battery Formation Cycler and Controller
(Bottom View, Connector Removed to Facilitate Viewing)

# Appendix A

## Detailed Description of Formation Cycler and Controller Operation

The appendix describes in detail the operation of the automatic battery formation cycler and controller. The description given below refers to components and designations given in Figure 1-A. A 28-volt, 3-ampere d-c supply and 115-volt 2-ampere, 60-cycle a-c supply are required to operate this device.

The square wave generator is the conventional-type circuit used to obtain a positive square wave with respect to ground. It consists of Transistors $Q_4$, $Q_5$; Capacitors $C_3$, $C_4$; and Resistors $R_{11}$ through $R_{14}$. The output taken across Resistor $R_{11}$ or $R_{14}$ is a 500 cycle per second, 5-volt square wave. Zener Diode $D_8$ reduces the supply voltage to the square wave generator.

The high voltage detector consists of Diodes $D_4$ through $D_7$; Resistors $R_7$, $R_8$, $R_{10}$; and Toroidal Transformer $T_2$. With Switch 3-c in the high voltage position, the cell voltage is applied to the d-c side of the detector and the 5-volt square wave is applied to the a-c side. As the cell voltage increases, the d-c current through the series-connected Diodes $D_4$, $D_5$ and $D_6$ increases, resulting in a decreasing a-c impedance of the diodes (reference (a)). This charging a-c impedance is reflected as a decreasing a-c impedance in the a-c side of Transformer $T_2$ (operation of the circuit is essentially the same as that in reference (a)). The voltage developed across the a-c side of Transformer $T_2$ decreases, allowing the bias voltage on Capacitor $C_2$ to decrease. Transistor $Q_3$, which is normally held in saturation by this bias voltage, comes out of saturation into the active region. Diode $D_7$ and Capacitor $C_2$ rectify and filter the voltage seen by the base of Transistor $Q_3$. Resistors $R_7$ and $R_8$ form a voltage divider with the a-c side of Transformer $T_2$. The adjustment of Resistor $R_7$ sets the d-c bias voltage on the base circuit of $Q_3$, thereby providing correlation between the terminal voltage of the cell being monitored and the voltage at the collector of Transistor $Q_3$.

The low voltage detector consists of Diodes $D_1$, $D_2$; Resistors $R_1$, $R_2$, $R_3$; and Transformer $T_1$. The operation of the low voltage detector with Diode $D_3$, Capacitor $C_1$, and Transistor $Q_1$, is as explained for the high voltage detector circuit. In this case, Transistor $Q_1$ is near saturation when the cell's terminal voltage reaches a value where it is to be switched out of the charge or discharge path. To make the output of the d-c amplifier for the low voltage detector circuit compatible with the output of the d-c amplifier for the high voltage detector circuit requires a phase inversion of the d-c level. Transistor $Q_2$, along with Resistors $R_5$, $R_6$, and $R_{49}$, provides this reversal.

When Transistor $Q_3$ or $Q_2$ (depending on mode of operation) comes out of saturation into the active region, the voltage at either collector increases as a function of the cell's terminal voltage. This voltage is connected to Resistor $R_{15}$ through Switch S-3A, Switch S-4B, relay contacts of Relay 1-20 (depending of position of stepping switch), and Section 3 of the stepping switch, S-8. Resistors $R_{15}$, $R_{16}$, $R_{17}$; Capacitor $C_5$; and the unijunction transistor (UJT), $Q_6$, form the gate pulse generator. This is a conventional UJT oscillator circuit with the exception that the timing of the oscillator is controlled by the voltage at the collector of Transistor $Q_2$ or $Q_3$, depending on the switch position.

When the UJT oscillator is triggered on by the voltage applied to Resistor $R_{15}$, a pulse appears across Resistor $R_{17}$. This pulse is applied to the relay switching circuit through Section 4 of the stepping switch, S-8.

The relay switching circuit consists of Capacitor $C_6$, Resistor $R_{18}$, silicon controlled rectifier $SCR_1$, and the solenoid coil of Relay 1. Similarly, a capacitor, resistor, SCR, and relay aré necessary for each cell to be switched. A pulse applied to the gate of $SCR_1$ triggers the SCR on and energizes Relay Coil 1 which opens the charge-flow path of the cell being monitored.

The stepping switch synchronizes the detector circuit with the relay switching circuit. When the stepping switch is across any cell's terminals and the terminal voltage of that cell is above (or below) the preselected voltage limit, that cell is immediately removed from the charge-flow path. Resistors $R_{39}$ through $R_{42}$ and Transistors $Q_7$, $Q_8$, and $Q_9$ provide the cells with an impedance that is a function of the total terminal voltage of the cells, thus keeping the discharge current constant. The circuit operation is as follows: Assume Switch S-6 in discharge position. The 28-volt supply voltage is applied through Switch S-7, causing Transistor $Q_7$ to turn on Transistor $Q_9$. The current through Resistors $R_{41}$ and $R_{42}$ in parallel with $R_{43}$ develops a voltage across the parallel combination. This voltage turns Transistor $Q_8$ on, causing the collector voltage of $Q_8$ to decrease, which decreases the current into the base of Transistor $Q_7$. Since Transistor $Q_7$ controls the current through Transistor $Q_9$, a point of equilibrium is obtained. Any change in the discharge current produces a corresponding change in the feedback loop (Resistors $R_{41}$, $R_{42}$, $R_{43}$ and Transistor $Q_8$), thereby holding the discharge current constant. Since the feedback is a function of the current through Transistor $Q_9$, and not the battery voltage, the current is held constant over a wide voltage change on the collector of Transistor $Q_9$. Resistor $R_{43}$ provides coarse adjustment of the discharge current, and Resistor $R_{42}$ provides a vernier adjustment.

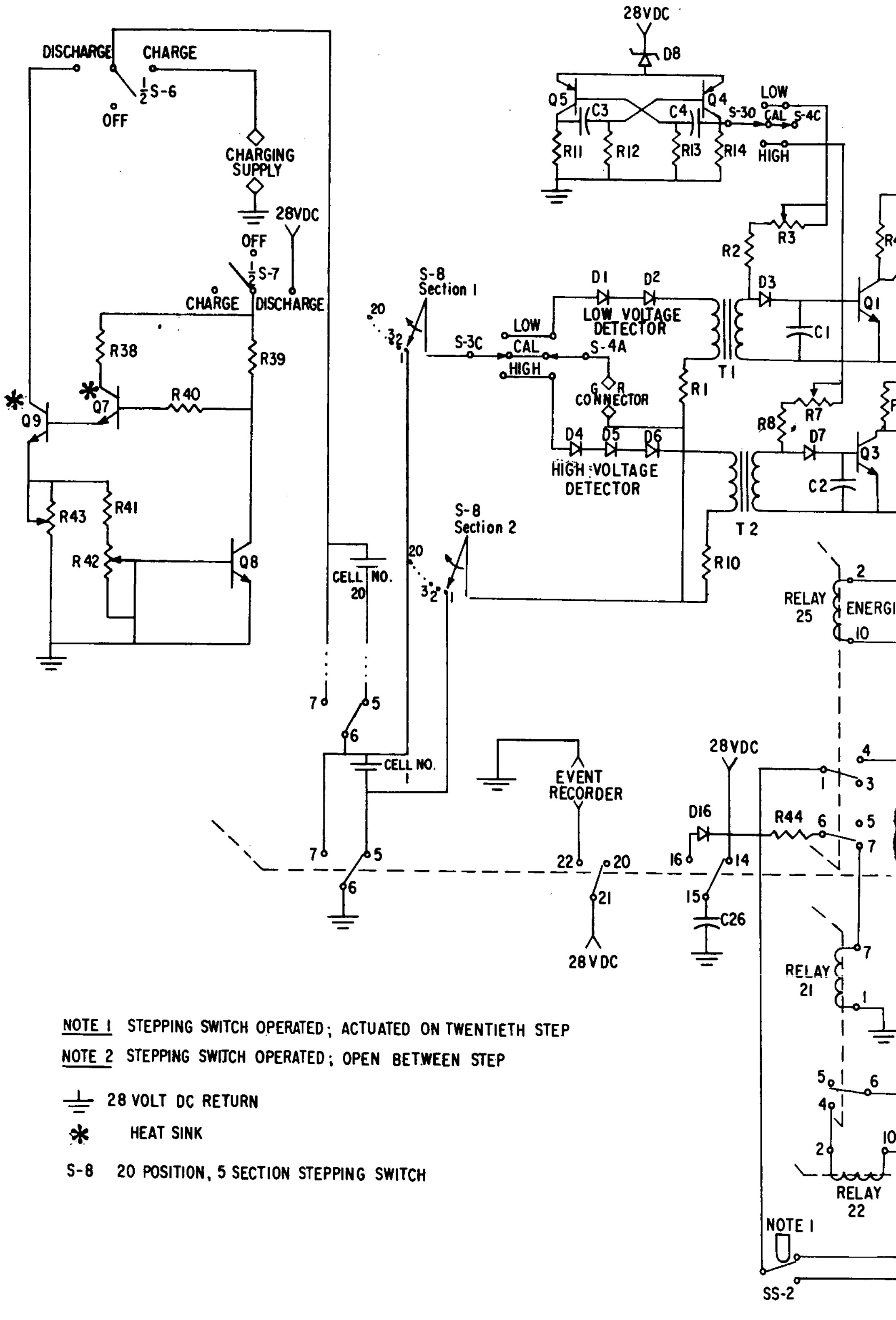
Diode $D_{10}$, Capacitor $C_{26}$ (one for each cell to be switched), Resistor $R_{44}$, and Relays 21 and 22 provide the signal to initiate the ampere-hour print-out when a cell is switched from the charge-flow path. The capacitor is charged from the 28-volt supply through the normally closed relay contacts. When a relay is switched (cell removed from charge-flow path), contact is made to Diode $D_{10}$, allowing Capacitor $C_{26}$ to discharge through the diode, Resistor $R_{44}$, and coil of Relay 21. Contact closure on this relay provides a-c voltage to energize Relay Coil 22, which provides the necessary contact closure to operate the ampere-hour and cell number printer.

The circuit to drive the automatic cell number indicator consists of Relay 24, Relay 25, and Contacts $SS_1$ and $SS_2$ located on the stepping switch S-8. The operation of this circuit is as follows: Assume Contacts $SS_1$ of stepping switch are closed, and Relays 24 and 25 are energized. When the stepping switch breaks contact with one set of cell terminals and makes contact to another, Contact $SS_1$ of the stepping switch is open for approximately 20 milliseconds. This allows the coil of Relay 25 to de-energize, opening the signal path to Relay Coil 21, and closing the contact to the count solenoid of the cell number indicator. As the stepping switch comes to rest, Contact $SS_1$ of the stepping switch is closed, energizing time-delay Relay 24. After a preset time delay, the coil of Relay 25 is energized by Relay 24, closing the signal path to Relay Coil 21 and opening the contact to the solenoid of the cell number indicator. This completes one count which corresponds to one step on the stepping switch. The action described above is repeated for each step of the stepping switch as it steps across each cell's terminals, from 1 to 20. On the 20th step, the cam actuated contacts, $SS_2$ on the stepping switch open the contacts to the cell count solenoid and close the reset contacts to the cell number indicator, resetting the cell number indicator to zero. The reset to zero occurs each time the stepping switch steps to the 20th cell. Thus, the cell number indicator counts from 0 to 19.

Adjustment of time-delay relay 24 allows for optimum counting rate of the cell number indicator by determining the closed time of the contact to the count, or reset, solenoid. The interruption of the signal path to the coil of Relay 21 prevents a print-out command from being initiated when counting is in process. When the coil of Relay 22 is energized (print-out command), the stepping switch drive circuit is open to prevent the stepping switch from moving to the next position until print-out is completed. These interlocks between the relays and the stepping switch are to ensure that only one of these functions (a count, reset, or print) will occur at any one time.

The stepping switch drive circuit consist of Transformer $T_3$, Diodes $D_{30}$ through $D_{33}$, Capacitors $C_{46}$ through $C_{48}$, Resistors $R_{45}$ through $R_{48}$, and Relay 23. The operation of this circuit is as follows: Transformer $T_3$, with Diodes D30 through $D_{33}$, converts the 115-volt a-c supply to a 28-volt unfiltered d-c voltage. This voltage, when applied to the stepping switch solenoid coil, causes it to step one step. During the transition period of the stepping switch, Switch $SS_1$ (which is cam actuated) closes Contacts 2 and 3. This brings the negative lead of Capacitor $C_{46}$ to the negative side of the full wave bridge, allowing C46 to charge up to the output voltage of the full wave bridge. When the voltage across Capacitor $C_{46}$ reaches the coil pull-in voltage of Relay Coil 23, Contacts 5 and 6 of the relay open and de-energize the stepping switch solenoid. The stepping switch by this time has completed the step (20-millisecond transition period), and Contacts 2 and 3 of Switch $SS_1$ are open, placing Capacitor $C_{48}$ in series with $C_{46}$. Capacitor $C_{48}$ charges up through Resistor $R_{48}$ and Capacitor $C_{46}$ discharges through the coil of Relay 23. As the capacitor discharges, the current through the relay coil drops below the holding current of the coil. Relay 23 de-energizes, closing Contacts 5 and 6, which energizes the stepping switch solenoid. This initiates another step and the cycle is repeated. The time between steps is controlled by Resistors $R_{45}$ and $R_{46}$ by determining the time required for Capacitor $C_{46}$ to discharge. Capacitor $C_{47}$ and Resistor $R_{47}$ form an arc suppressor across the relay contacts.

Light $L_1$ provides indication that power to the instrument is on, while Light $L_2$ indicates stepping switch operation. Lights $L_3$ (discharge) and $L_4$ (charge) indicate the state of operation of the instrument.




Page 1, Figure 1-A - Automatic Batter

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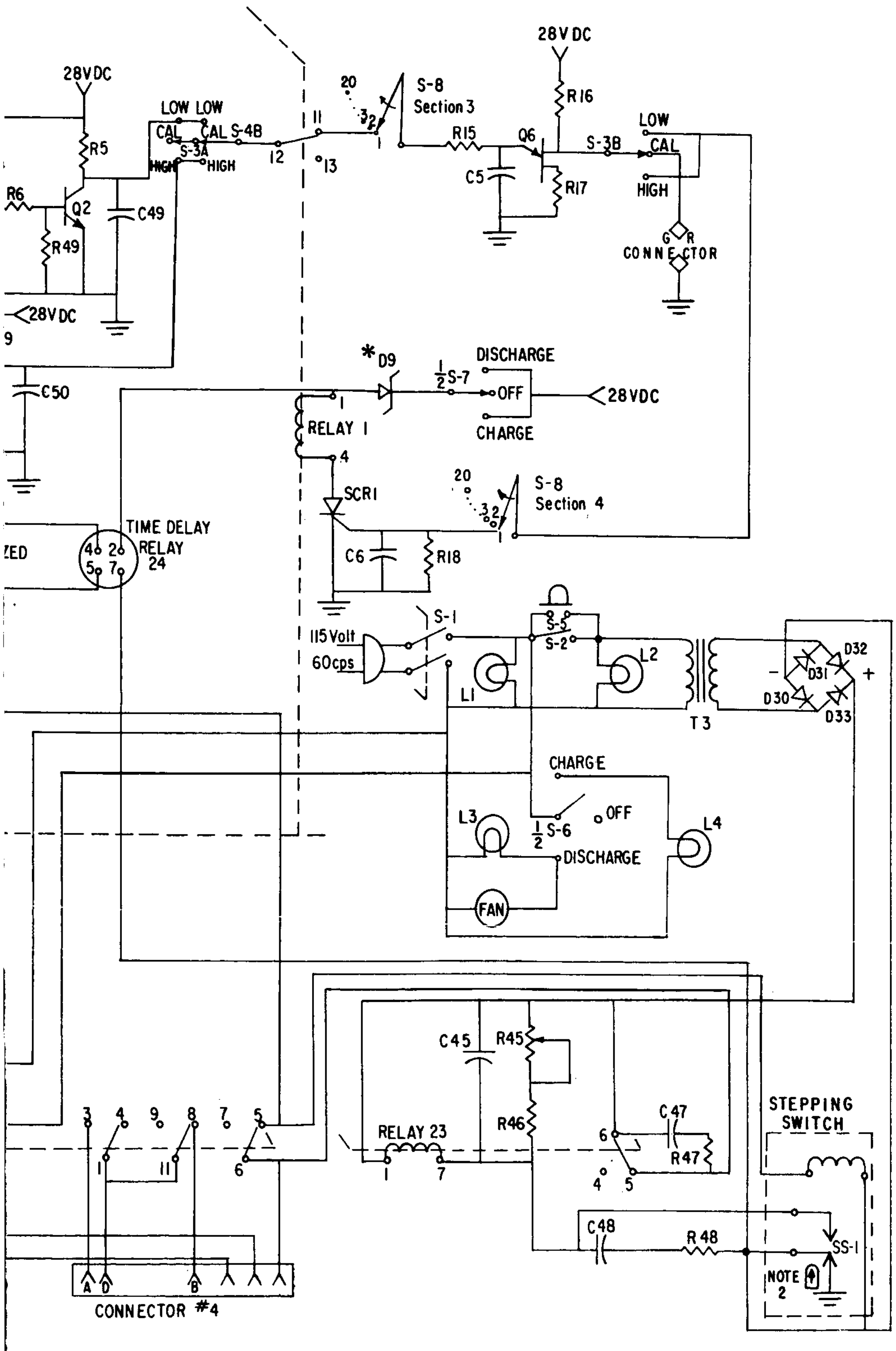


y Formation Cycler and Controller

## Parts List

### Automatic Battery Formation Cycler and Controller

| | | |
|---|---|---|
| $R_1$ | 470 Ω | |
| $R_2$ | 3K Ω | |
| $R_3$, $R_7$ | 20KΩ | Potentiometer |
| $R_4$ | 22KΩ | |
| $R_5$ | 10KΩ | |
| $R_6$ | 82KΩ | |
| $R_8$ | 5K Ω | |
| $R_9$ | 22KΩ | |
| $R_{10}$ | 470 Ω | |
| $R_{11}$ | 10KΩ | |
| $R_{12}$, $R_{13}$ | 47KΩ | |
| $R_{14}$ | 10KΩ | |
| $R_{15}$ | 33KΩ | |
| $R_{16}$ | 10KΩ | |
| $R_{17}$, $R_{37}$ | 470 Ω | |
| $R_{38}$ | 100 Ω,5 watts | |
| $R_{39}$ | 1KΩ | |
| $R_{40}$ | 4.7KΩ | |
| $R_{41}$ | 1 Ω | 2 watts |
| $R_{42}$ | 8 Ω | 5-watt Potentiometer |
| $R_{43}$ | 1 Ω | 75-watt (Ohmite 1101) |
| $R_{44}$ | 4.7KΩ | |
| $R_{45}$ | 2.5KΩ | Potentiometer |
| $R_{46}$ | 1.5KΩ | |
| $R_{47}$ | 100 Ω | |
| $R_{48}$ | 100 Ω | |
| $R_{49}$ | 5K Ω | |

Note: All resistors 1/2 watt, 10 percent unless otherwise stated.

| | | |
|---|---|---|
| $C_1$, $C_2$ | 10 μf | 20 WVDC (Sprague 150D 106X9020 B2) |
| $C_3$, $C_4$ | 0.003 μf | 35 WVDC |
| $C_5$ | 1 μf | 35 WVDC |
| $C_6$, $C_{25}$ | 10 μf | 6 WVDC |
| $C_{26}$, $C_{45}$ | 50 μf | 50 WVDC |
| $C_{47}$, $C_{48}$ | 1 μf | 50 WVDC |
| $C_{49}$, $C_{50}$ | 1 μf | 35 WVDC |
| $C_{46}$ | 500 μf | |

| | | |
|---|---|---|
| $D_1$, $D_6$ | 1N646 | |
| $D_2$, $D_5$ | 1N457 | |
| $D_7$ | 1N457 | |
| $D_8$ | SV144 Transitron (20-volt Zener) | |
| $D_9$ | Z-1300 International Rectifier (3.9-volt Zener 10 watts) | |
| $D_{10}$, $D_{29}$ | 1N457 | |
| $D_{30}$, $D_{33}$ | 1N4005 | |
| $Q_1$, $Q_3$ | 2N338 | |
| $Q_2$ | 2N1613 | |
| $Q_4$, $Q_5$ | 2N1303 | |
| $Q_6$ | 2N491 | |
| $Q_7$ | 2N1720 (Mounted on Wakefield Heat Sink NC301M) | |
| $Q_8$ | 2N1613 | |
| $Q_9$ | 164-04 Westinghouse (Mounted on Wakefield Heat Sink NC441K) | |
| $SCR_1$, $SCR_{20}$ | 2N2323 (General Electric C5F) | |
| Relays 1-20 | TF-154-6C, Allied Control (24-volt coil, 5-ampere contacts) | |
| Relay 21 | PW-5047, Potter and Brumfield | |
| Relays 22 and 25 | KRP14AG, Potter and Brumfield | |
| Relay 23 | PW5LS, Potter and Brumfield | |
| Relay 24 | CDD-21-30003 (24-volt coil) Potter and Brumfield | |
| Relay Sockets | 30055-2C Allied Control, plug in | |
| Connector 1 | AN-3102A-36-8S | Amphenol |
| Connector 2 | 57-40500 | Amphenol |
| Connector 3 | 57-40240 | Amphenol |
| Connector 4 | MS3102A-20-33S | Amphenol |
| $S_1$ | DPST bat-handle switch | |
| $S_2$ | SPST bat-handle switch | |
| $S_3$ | Four Poles - three positions | |
| $S_4$ | Three Poles - three positions | |
| $S_5$ | SP push button (NO) | |
| $S_6$, $S_7$ | DPDT three positions - center off, bat-handle switch | |
| $S_8$ | Stepping switch, CLARE Type 20 (complete specifications by NASA) | |
| $S_9$ | SPST bat-handle switch | |

| | |
|---|---|
| $T_1$, $T_2$ | Sprague R-1111 (1:1) toroid |
| $T_3$ | Filament transformer, Knight 6-K-48 HF |
| Relay Rack, Slide Drawer | Bud Type SD-1717 |
| Plate | Bud Type TP-1718 |
| Rack Panel (Hammertone Gray) | Bud Type PA-1106 |
| $K_1$, $L_2$, $L_3$ | Dialco Datalites NO249-7841 1431 (red) |
| $L_4$ | Dialco Datalites NO249-7841 1433 (amber) |
| Fan, Rotran Gold Seal | (100 cfm air delivery) |
| Shunt, Current | 5 amperes, 50 millivolts |
| Connectors | Three banana type |

## Appendix B

## Calibration of Detectors

The terminal voltage at which a cell will be switched from the charge-flow path can be set by either of two methods. These methods are described in this appendix.

Method I

Set Switch S-3 in CAL-position and Switch S-4 in high (or low) position. Connect an adjustable voltage source to the connection so provided and set its voltage to the level at which the cells are to be switched. With an oscilloscope connected to the connection so marked, adjust Potentiometer $R_7$ ($R_3$ if S-4 is in low position) until a pulse (approximately 2 volts) appears on the scope. This method of calibration can be completed with the cells connected to the instrument. The accuracy of this setting is $\pm 10$ millivolts.

Method II

Set Switch S-3 in high (or low) position and S-4 in charge (or discharge) position. Connect an adjustable voltage source to the connection provided and set its voltage to the voltage at which the cells are to be switched from the charge-flow path. Place Switch S-7 in charge or discharge position. Adjust Potentiometer $R_7$ ($R_3$ if Switch S-3 in discharge position and S-4 in low position) until an audible click is heard from one of the relays, 1-20. This indicates the cell was switched from the charge-flow path. Switch S-7 must be returned to OFF position momentarily to reset the relay before starting a charge or discharge cycle. This method of calibrating the detectors is equivalent to Method I; however, in Method II the cells must be disconnected from the instrument while calibrating.

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13. ABSTRACT

An automatic cycler and controller has been designed to determine charge capacity and perform appropriate charge/discharge operations on electrochemical cells intended for use as satellite power sources. This device is capable of monitoring up to 20 series-connected cells at a time and characterizing each cell according to its terminal voltage and ampere-hour capacity.

(Author)

Security Classification Unclassified

| 14. KEY WORDS | LINK A | | LINK B | | LINK C | |
|---|---|---|---|---|---|---|
| | ROLE | WT | ROLE | WT | ROLE | WT. |
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