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# THE BATTERY CHARGER FOR THE ATMOSPHERE EXPLORER B SPACECRAFT

BY  
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**GODDARD SPACE FLIGHT CENTER  
GREENBELT, MARYLAND**

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EXPLORER B SPACECRAFT

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### ABSTRACT

Four related subcomponents combined in one package perform the necessary requirements imposed on the battery charger for the AE-B spacecraft. The charger selects the battery to be charged, supplies power to the battery, monitors the battery charge current and indicates the battery being charged. A description of each subcomponent and its circuit operation is presented.

11208

*Author*

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# THE BATTERY CHARGER FOR THE ATMOSPHERE EXPLORER B SPACECRAFT

By  
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## INTRODUCTION

The primary power system of the AEB spacecraft is powered by several battery packs ranging from three volts to twenty volts nominal. A solar cell source was added to charge these batteries in order to extend the life of the spacecraft. The solar cell source consisted of solar cells mounted on the satellite skin, for which the positive terminal was connected to the system common so as not to interfere with the experiments. As a result, some form of polarity reversal was required to charge the batteries at the various voltage levels. In addition, it was desired to monitor the battery charge current and to be able to select (by ground command) the battery to be charged. Consequently, the requirements imposed on the battery charger were to:

1. Select battery to be charged
2. Convert available power to charge the selected battery
3. Monitor battery charge current
4. Indicate which battery is under charge

These basic requirements are met in the battery charger package which consists of four subcomponents, and are designated:

1. Power converter
2. Battery selector switch
3. Current to voltage converter
4. Selector switch position indicator

## POWER CONVERTER

A. The power converter must invert the polarity of the solar cell source and also provide the correct charging voltage, which ranges from three volts to 25 volts. This is accomplished by utilizing storage elements in conjunction with a switching device. This switching device is pulse frequency modulated in order to regulate the input voltage to that corresponding to the peak power point of a typical solar cell source, Figure 1. Figure 1 illustrates the E vs I characteristics of a typical solar cell source and the peak power point. The power

represented by the product of the input voltage and current at this point is transferred to the battery, (less converter losses) and does not change as a function of battery voltage. Thus, the output voltage and current of the converter follows a  $P \cong K$  function, and is shown in Figure 2 as a family of curves for input power levels of approximately 1, 3, 5, and 7.5 watts. Also indicated is the efficiency of the converter at the various battery voltages anticipated.

A plot of the input voltage-current relationship of the power converter is illustrated in Figure 3. Figure 4 illustrates the initial and anticipated worst case E-I characteristics of the solar cell source. Curves A, B, and C represent the initial characteristics prior to space environmental irradiation whereas curves  $A_1$ ,  $B_1$ , and  $C_1$  represent the solar cells subjected to space environmental irradiation of  $5 \times 10^{15} \text{e/cm}^2$ . \* By superimposing the input characteristics of the charger (Figure 3) on the solar cell output characteristics (Figure 4) the power transferred to the battery can be determined by the intersection of the curves.

### B. Circuit Description

The power converter utilizes an inverted flyback technique as a means of transferring power to the battery. Energy is stored in an inductor during a portion of the cycle and is released to the battery during the remainder of the cycle. The frequency of operation and external voltage-current relationships determine the inductance required for the energy storage element, as well as the filter requirements.

The power converter is composed of a pi filter network for input and output filtering, the power converter driver, and the main storage and switching elements. The various elements are shown schematically in Figure 5. The input filter is made up of inductor L1 on the main board (mb) and capacitors C3, C4, C6, (mb), while the output filter is made up of C1, C2, L3, C7, L4, and C12 (mb). Inductor L2 (mb) is the main storage element, transistor Q1 (mb) and transformer T1 (mb) comprise the switching circuit. Transformer T1 (mb) provides the necessary current drive for the transistor Q1 (mb) and determines the time energy is stored in inductor L2 (mb). The unijunction transistor Q1 on the power converter driver module (pcd) supplies a pulse to Q1 (mb) at a repetition rate governed by the collector current of Q2b (pcd). Each time Q1 (pcd) supplies a pulse, Q1 (mb) turns on for a period (33 us) determined by the volt-seconds capacity of the transformer T1 (mb) thereby storing energy in L2 (mb). When Q1 (mb) turns off, this energy is discharged into capacitor C1 and C2 (mb) through diodes D2 and D3 (mb). Each pulse of energy increases the voltage on

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\*Brian T. Cunningham, Ernest Moss, NASA X-636-64-253

these capacitors. This stored energy in the capacitors is discharged to the selected battery through the inductors L3, L4, (mb), switch wafer A and B (mb) and coil winding T3 (mb).

The loading that the solar cells see is a function of the pulse rate. Since transistor Q2a (pcd) is normally in a full on condition by virtue of R6 (pcd), the voltage to which the input is regulated (approximately 15 volts) is mainly determined by zener diodes D1 and D4 (pcd). If the input voltage has a tendency to increase or decrease from 15 volts, collector current of transistor Q2b (pcd) will increase or decrease, thereby altering the pulse rate.

### C. Over-voltage Circuit

The purpose of the over-voltage circuit is to limit the maximum voltage at the output of the charger in the event that the load is removed. Should the load be removed from the charger, the capacitors on the output will charge up until the zener diode D4 (mb) conducts. Conduction of this diode turns off Q2a (pcd), thereby removing the current source to the pulse rate circuit and disabling it. The output capacitors will slowly discharge through the zener diode D4 (mb), resistor R2 (mb) and resistor R6 (pcd). The converter will operate at approximately one pulse per second in this standby condition, and the input voltage will rise to the open circuit voltage of the solar cell source.

### D. Circuit Waveforms

Waveforms at various parts of the power converter are illustrated in Figures 6 through 8. Figure 6 illustrates waveforms at the various points as indicated at 9.1 watts input, Figure 7 at 7.5 watts input, and Figure 8 at 2.8 watts input. A small change in the wave-shapes is noticed between Figure 6 and Figure 7, whereas a large change can be detected between Figure 7 and Figure 8. The difference in the wave shapes is the lower operating frequency corresponding to the lower available power from the source.

The ripple component at the input and output of the battery charger are indicated in Figure 9.

## BATTERY SELECTOR SWITCH

A. The battery selector switch performs the following functions:

1. Selects the battery to be charged.
2. Provides indication of the switch position.
3. Acts as an off-on switch to the power converter from the solar cell source.

The battery selector switch is a motor driven stepping switch with four, twelve position wafers. Wafers "A" and "B" are in parallel and are used to connect the output of the power converter to the various batteries through the current sensing windings of T3(mb). Four "off" positions are incorporated in the stepping sequence, as shown in Table 1. Resistors R13, R14, R15, and R16(mb) are connected between each "off" position and the following position in order that the output capacitors of the power converter will be at the same potential as that of the following position. This practically eliminates the surge of current which would occur as a result of any potential difference between the output of the converter and the next position.

Wafer "D" connects the output of the solar cells to the input of the power converter when any battery is to be charged.

The terminals of wafer "C" are connected to the diode logic necessary for conversion of the switch position to a four bit binary coded output. The position of the battery selector switch is indicated by four bits representing the 1 2 4 8 binary code, also shown in Table 1.

#### B. Stepping Motor Driver

The purpose of the stepping motor driver is to advance the battery selector switch upon ground command. Capacitor C8(mb) is charged to the supply voltage through R5 and diodes D7, D8 or D9, D10 (whichever is at the higher potential). An input pulse is applied through C10 and C11(mb) turning on SCRQ<sub>2</sub>. This discharges capacitor C8 through the relay (K1) which in turn closes the relay contacts to the stepping motor for a duration of approximately 40 milliseconds, advancing the stepping switch one position. A minimum delay of 15 seconds is required before the stepper may be advanced again. This permits the charging capacitor C8(mb) to charge sufficiently to advance the stepping motor. It also permits the output capacitors of the power converter to charge to the battery voltage in the off positions.

### CURRENT TO VOLTAGE CONVERTER

#### A. Purpose

The purpose of the current to voltage converter is to monitor the battery charge currents. It provides an output DC voltage to telemetry directly proportional to the battery charge current. The accuracy of the current to voltage converter is within  $\pm 1\%$  over the nominal temperature range of -10 degrees C to + 40 degrees C.

## B. Circuit Operation

Refer to Figure 5, current to voltage converter module. Assuming that transistor  $Q_{2a}$  is conducting during one half cycle of the square wave oscillator, (T2, Q2a and Q2b), the voltage at terminal 5 of T2 will be negative with respect to that of terminal 6. Diode D3 will be forward biased and transformer T3 will be "reset" to negative saturation through winding 1-2. Diodes D1 and D2 limit the reverse bias on transistor Q1 during "reset". Diode D4 and capacitor C1 establish collector supply voltage for Q1. After T3 saturates, its voltage collapses to zero and "reset" current is limited by resistor R1.

During the second half cycle when transistor Q2b is conducting, the voltage at terminal 5 will be positive with respect to that of terminal 6. Diodes D1, D2, D3, and D4 will be back biased and the only source of current to the current transformer T3 from the oscillator will be through resistors R1, R2, R3, and R4. These resistors are selected to give sufficient current to T3 to overcome the initial magnetizing current required by the core. These resistors also provide the necessary temperature compensation. The battery charge current through the sense winding adds to this magnetizing current and in order to maintain the equal ampere turns law, a current proportional to the magnitude of the battery charge current by the turns ratio, will flow through windings 1-2 of T3. The voltage developed across terminals 1-2 of T3 is clamped by the base emitter junction of Q1. The emitter current of Q1 will flow through resistor R7 in the collector circuit of Q1, establishing a voltage directly proportional to this current. Capacitor C2 averages the voltage across R7 for current variations caused by satellite spin. This voltage appears at the connector for telemetry and is shown in Figure 10 for the various current ranges. The nonlinearity at the extreme low end is caused by the initial magnetizing current bias required for T3. The current ranges incorporated in the sense windings, are as indicated in Table 1.

Voltage waveforms of the current to voltage converter are illustrated in Figure 11. The voltage developed across winding 1-2 of current transformer T3 is shown for current through the sensing winding ranging from full scale, 1 ampere to zero. The positive going portion of the top waveforms illustrates the time the transformer is acting as a current transformer, while the negative portion of the waveform represents the transformer being reset. As the current being sensed is reduced, the flux excursion of T3 also is reduced, as evidenced by the area of the negative portion of the waveform. Since the voltage across winding 1-2 is zero when T3 saturates, a reference on the waveform can be established. The bottom waveform of the four photographs represents the square wave voltage developed across winding 5-6 of transformer T2.

## POSITION INDICATOR

The position of the battery selector switch is indicated at the connector by four bits representing the 1248 binary code, as illustrated in Table 1. Diode logic connected to the terminals of wafer C is conventional. The voltage of each bit will be approximately plus 14 volts, indicating a zero state, or less than one volt, indicating a one state.

## REMARKS

An aluminum frame of rectangular configuration with three separate compartments was used to package the battery charger. The motor driven stepping switch occupies one compartment, the storage and switching elements of the power converter occupy another compartment, and the third compartment houses the electronic circuitry for the remainder of the package. Versatility to the package was added by using plug-in modules for the current to voltage converter and the power converter driver. Since the critical-valued components are mounted on these plug-in modules, the task of selecting these components is simplified. The input characteristics of the charger may be readily changed by inserting the desired plug-in module for the power converter driver.

Photographs of the complete package are shown in Figures 12, 13, and 14.

TABLE 1

Switch Position	Diode Logic	Battery Selected	Current Range Full Scale 0-5 Volt
1	0000	off	
2	0001	F <sub>1</sub>	0 to 1 ampere
3	0010	F <sub>2</sub>	0 to 1 ampere
4	0011	off	
5	0100	C	0 to 1 ampere
6	0101	D	0 to 1 ampere
7	0110	off	
8	0111	B	0 to 2 amperes
9	1000	A	0 to 2 amperes
10	1001	off	
11	1010	E <sub>1</sub>	0 to 4 amperes
12	1011	E <sub>2</sub>	0 to 4 amperes

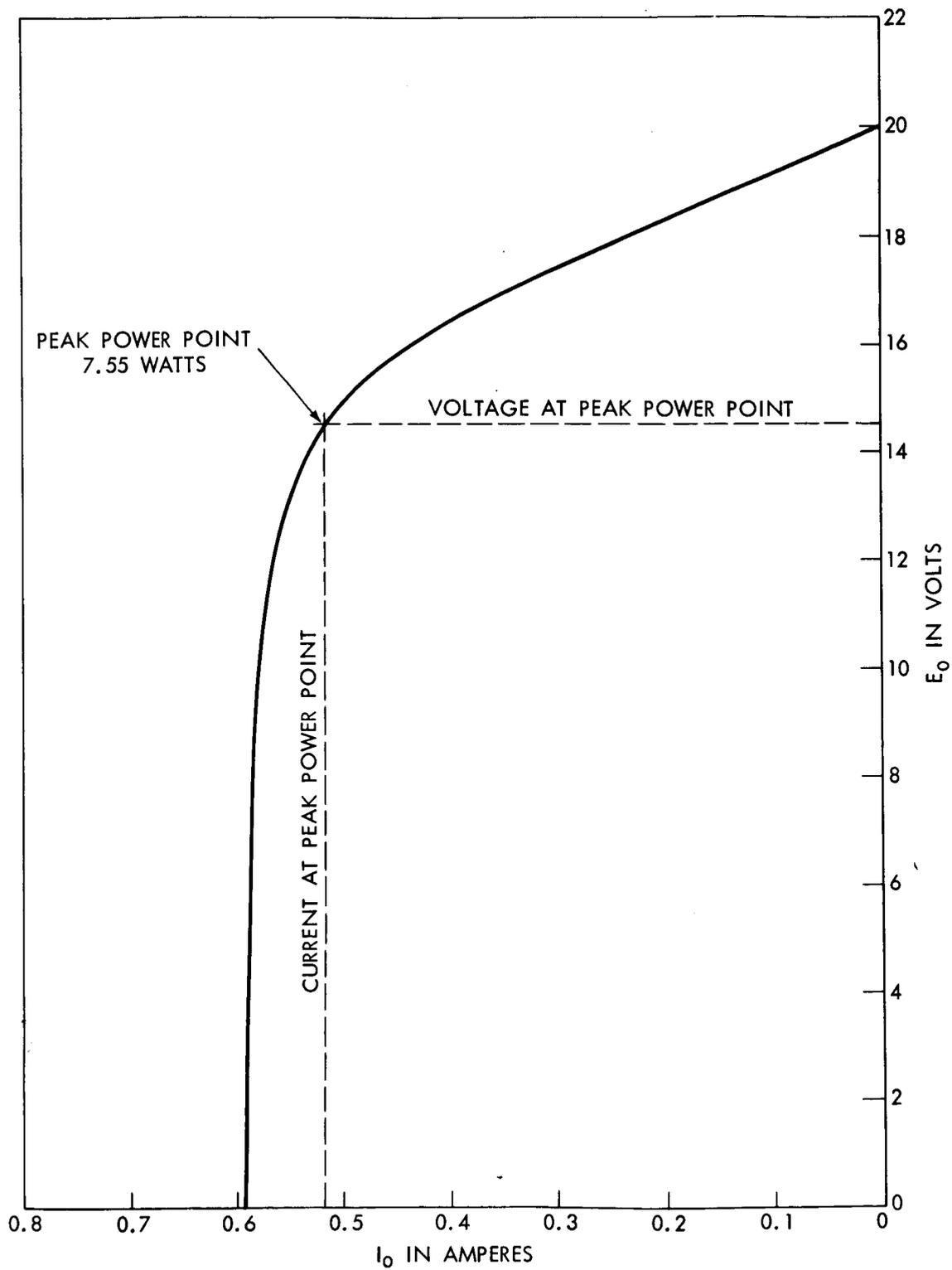


Figure 1.  $E_0$  vs  $I_0$  of a Typical Solar Cell Source.

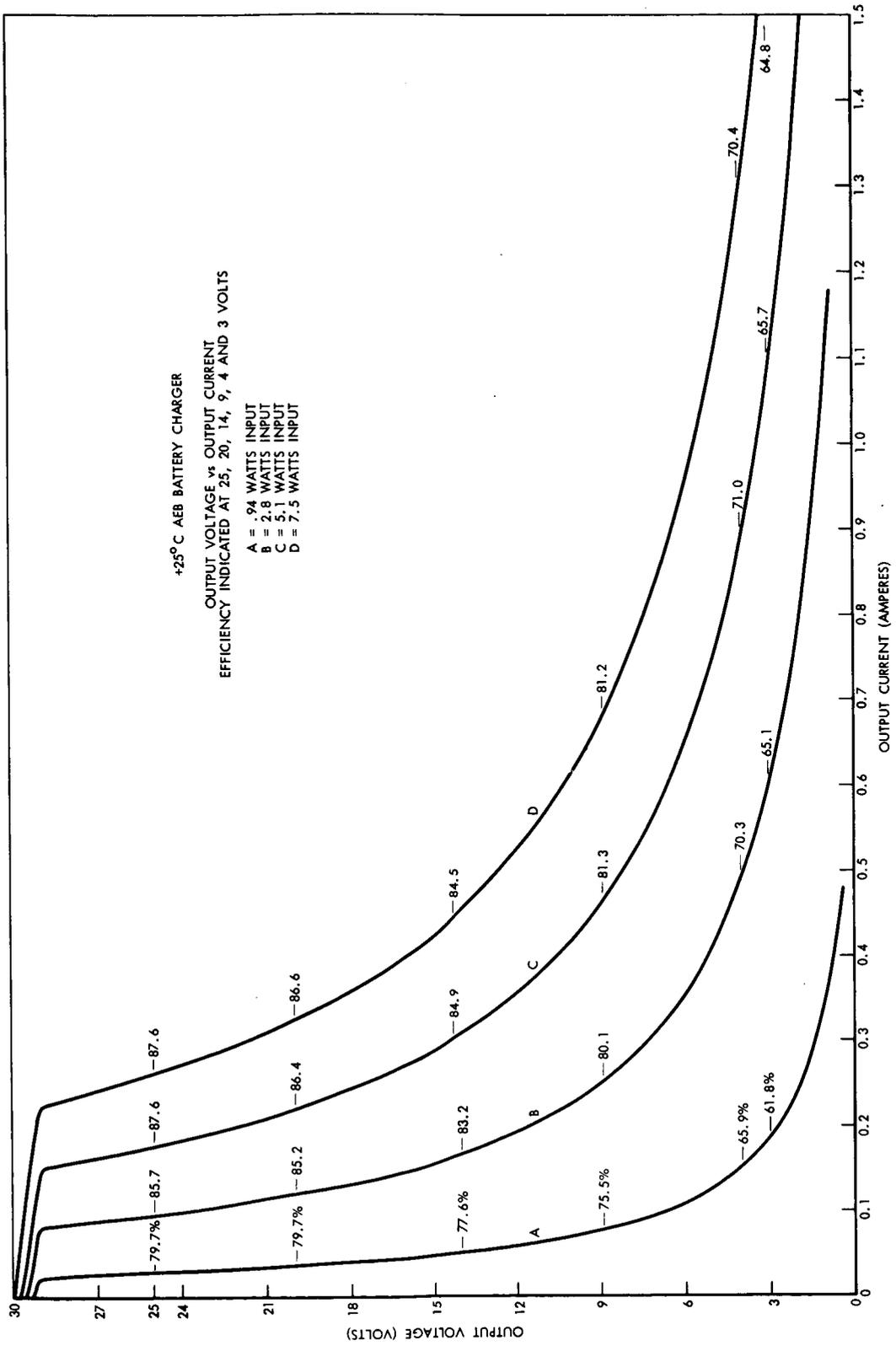


Figure 2. Output Characteristics of Power Converter .

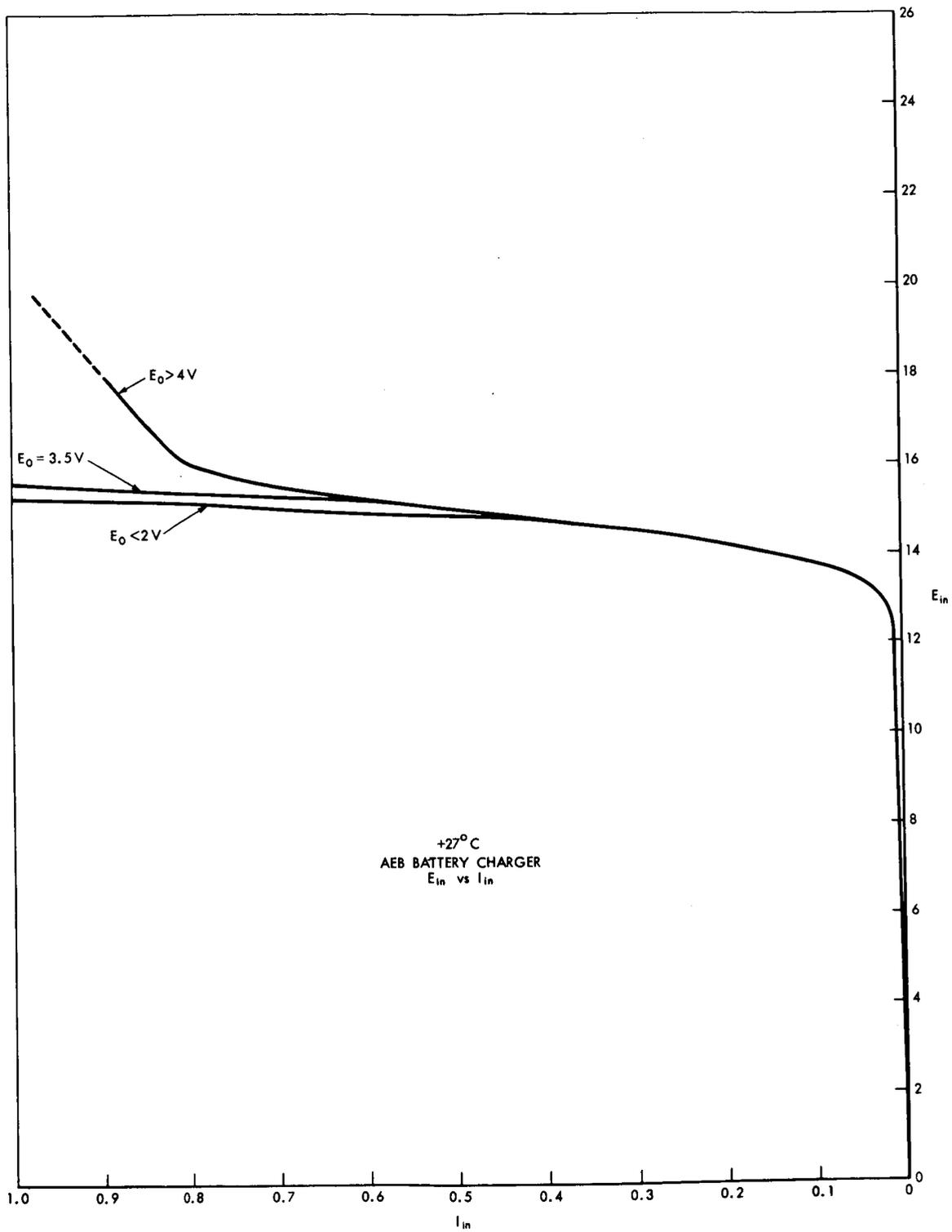


Figure 3. Input Characteristics of Power Converter .

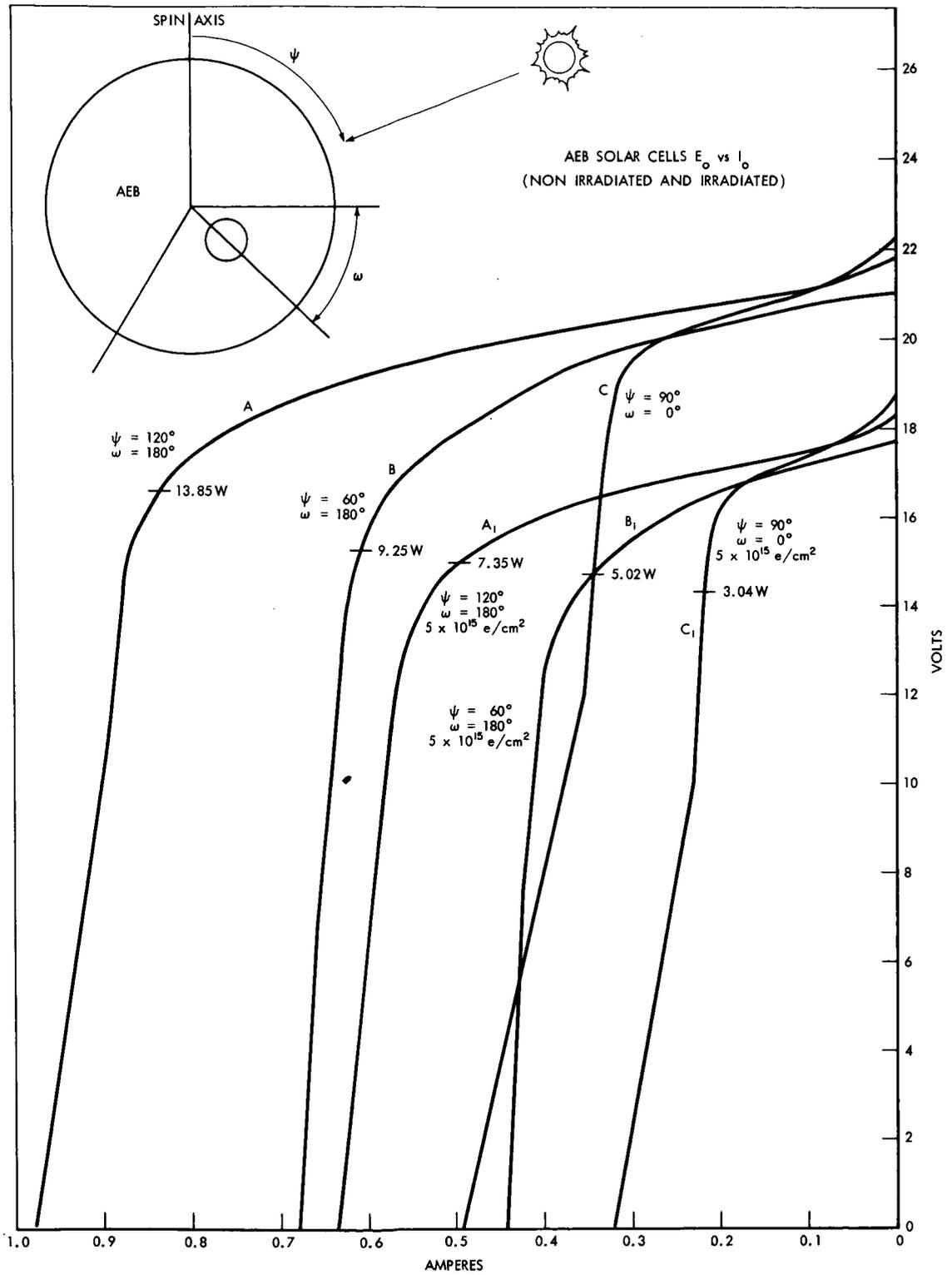


Figure 4. Output Characteristics of the Solar Cell Source, AE-B.

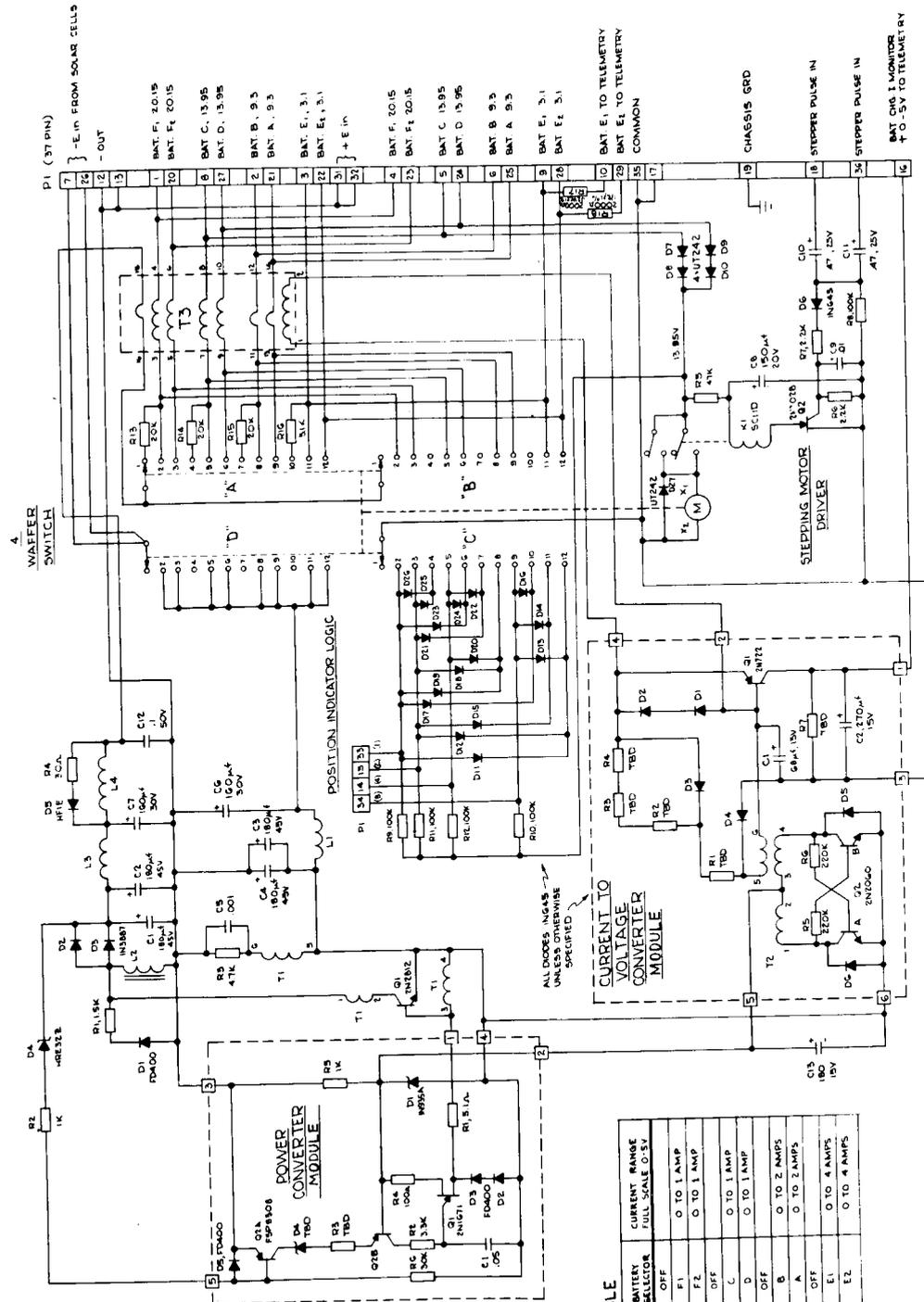
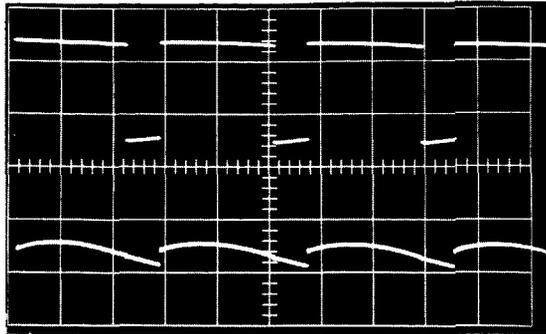
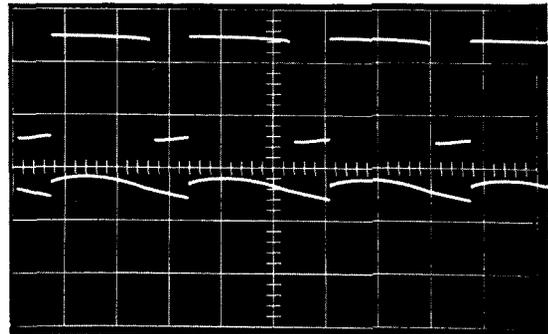


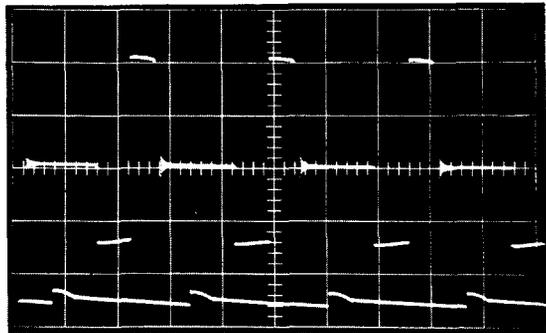
Figure 5. Schematic Diagram of Battery Charger.



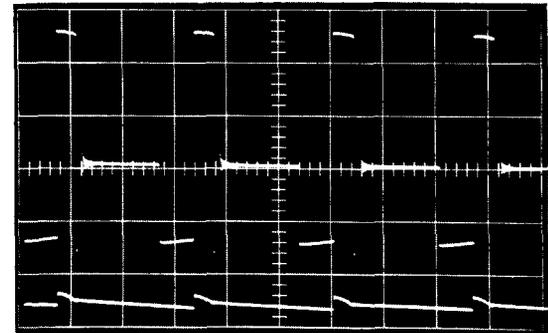
A



B



C



D

TOP TRACE Vertical deflection is 10 v/cm  
Horizontal deflection is 50  $\mu$ s/cm

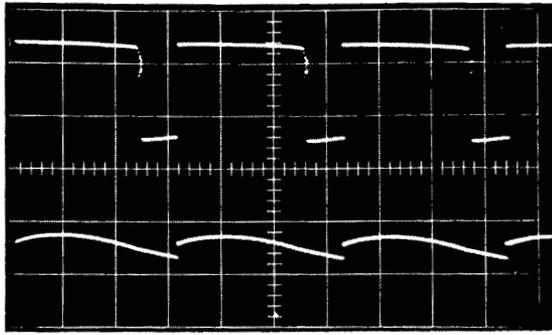
BOTTOM TRACE Vertical deflection is 1 v/cm  
Horizontal deflection is 50  $\mu$ s/cm

For A, B, C & D, top trace represents voltage at anodes of  $D_2$  &  $D_3$  with respect to common and bottom trace represents voltage at cathode of  $D_2$  &  $D_3$  with respect to common, where:

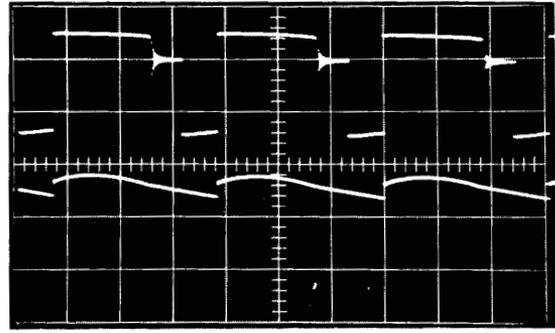
- A.  $E_o$  of charger is equal to 3.0 volts
- B.  $E_o$  of charger is equal to 4.0 volts
- C.  $E_o$  of charger is equal to 20 volts
- D.  $E_o$  of charger is equal to 25 volts

Power input is equal to 9.1 watts

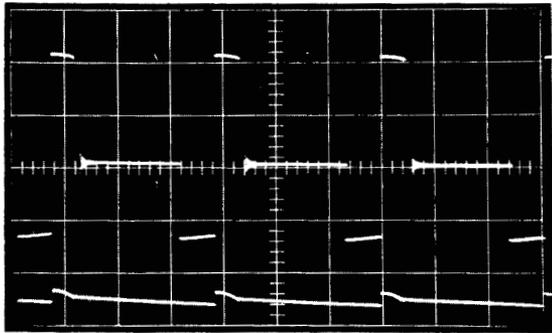
Figure 6. Power Converter Waveforms @  $P_{in} = 9.1$  watts .



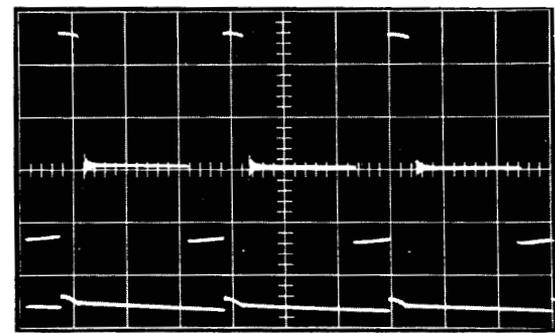
A



B



C



D

TOP TRACE

Vertical deflection is 10 v/cm  
Horizontal deflection is 50  $\mu$ s/cm

BOTTOM TRACE

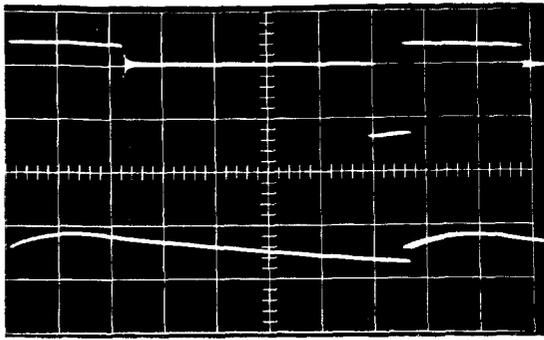
Vertical deflection is 1 v/cm  
Horizontal deflection is 50  $\mu$ s/cm

For A, B, C & D, top trace represents voltage at anodes of  $D_2$  &  $D_3$  with respect to common and bottom trace represents voltage at cathode of  $D_2$  &  $D_3$  with respect to common, where:

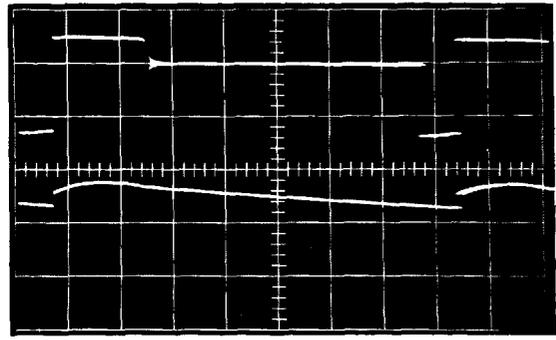
- A.  $E_o$  of charger is equal to 3.0 volts
- B.  $E_o$  of charger is equal to 4.0 volts
- C.  $E_o$  of charger is equal to 20 volts
- D.  $E_o$  of charger is equal to 25 volts

Power input is equal to 7.5 watts

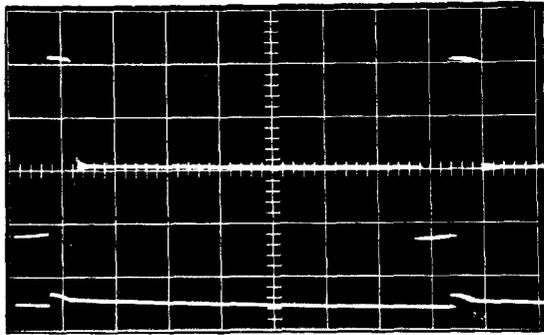
Figure 7. Power Converter Waveforms @  $P_{in} = 7.5$  watts .



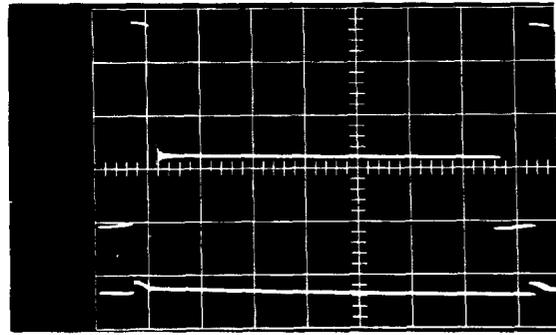
A



B



C



D

TOP TRACE

Vertical deflection is 10 v/cm  
Horizontal deflection is 50  $\mu$ s/cm

BOTTOM TRACE

Vertical deflection is 1 v/cm  
Horizontal deflection is 50  $\mu$ s/cm

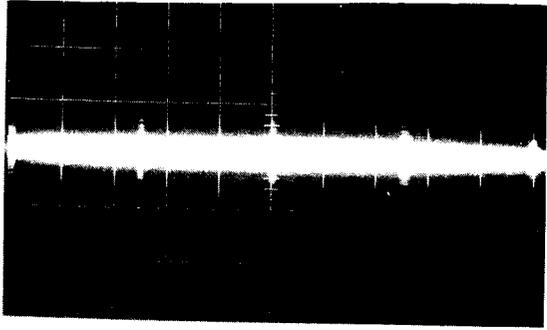
For A, B, C & D,

top trace represents voltage at anodes of  $D_2$  &  $D_3$  with respect to voltage at cathode of  $D_2$  &  $D_3$  with respect to common, where:

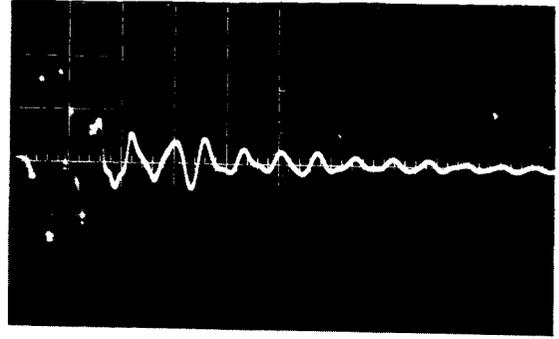
- A.  $E_o$  of charger is equal to 3.0 volts
- B.  $E_o$  of charger is equal to 4.0 volts
- C.  $E_o$  of charger is equal to 20 volts
- D.  $E_o$  of charger is equal to 25 volts

Power input is equal to 2.8 watts

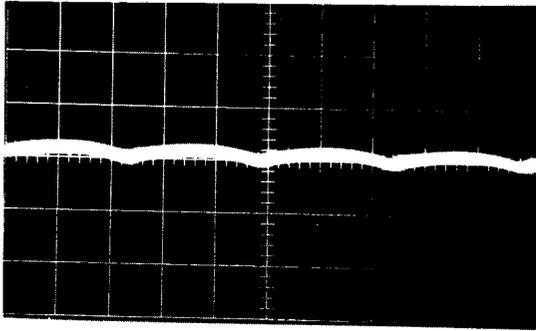
Figure 8. Power Converter Waveforms @  $P_{in} = 2.8$  watts .



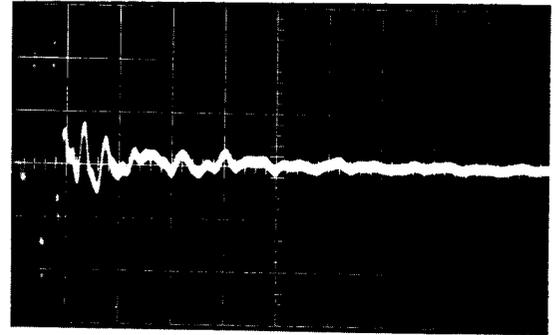
A



B



C



D

Vertical deflection is 0.05 volts/cm for pictures A & C and 0.1 volts/cm for B & D.  
Horizontal deflection is 0.1 ms/cm for pictures A & C, and 0.2  $\mu$ s/cm for B & D.

Where A & B represents ripple voltage at battery and C & D represents ripple voltage at output of solar cell source simulator.

Figure 9. Ripple Voltage of Battery Charger .

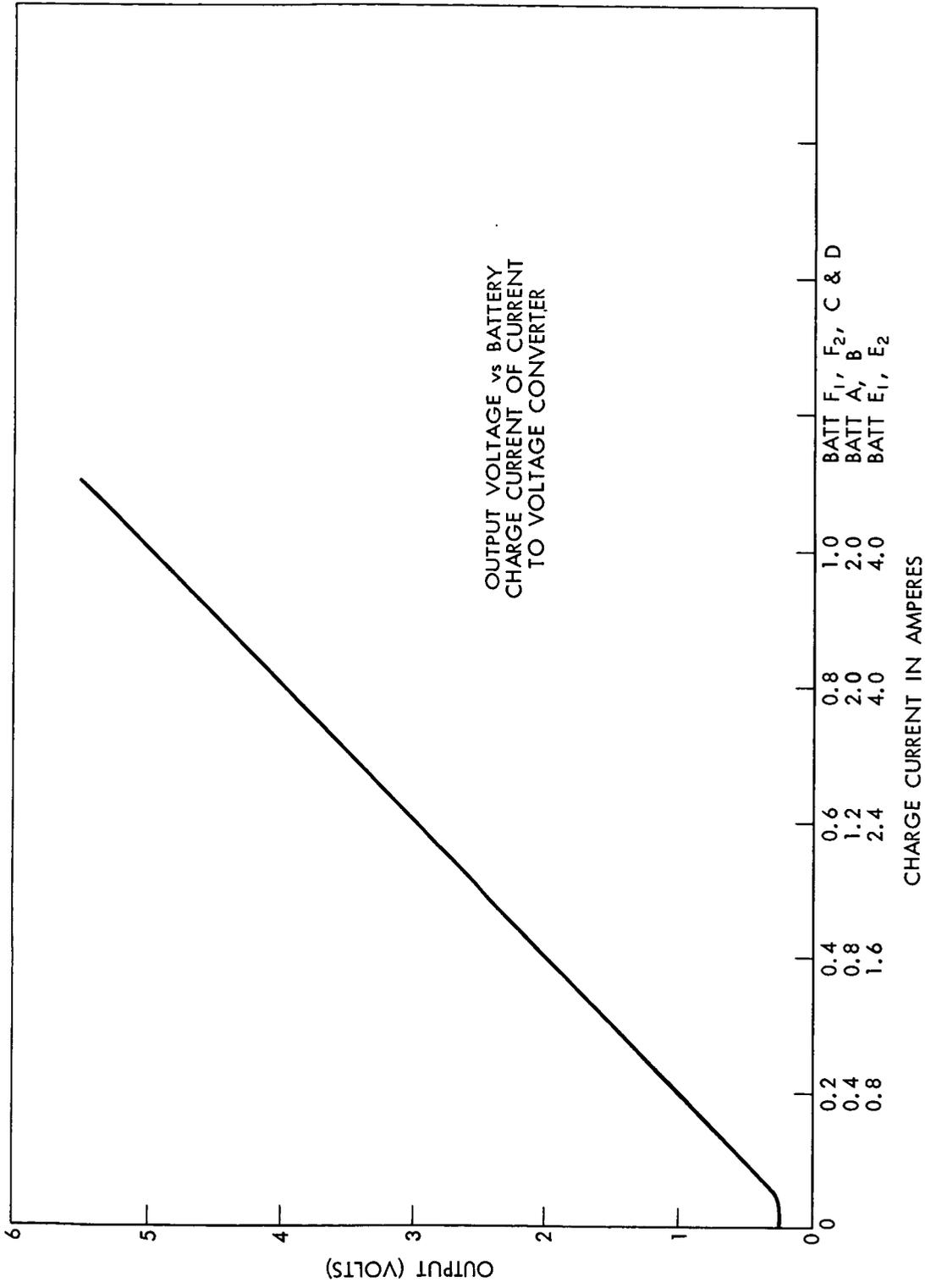
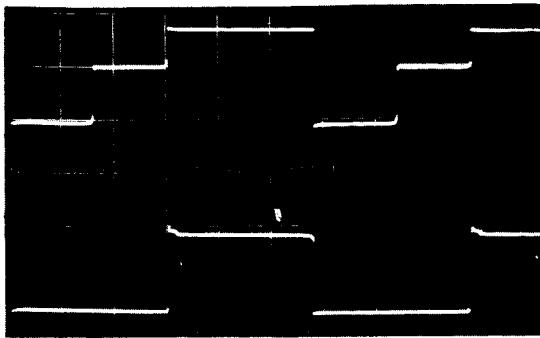
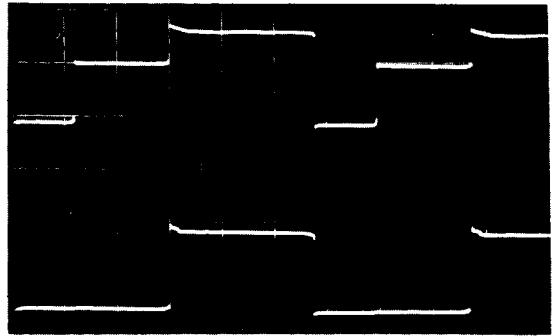


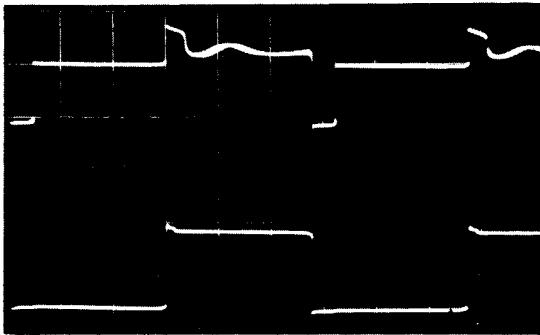
Figure 10. Output Characteristics of Current to Voltage Converter.



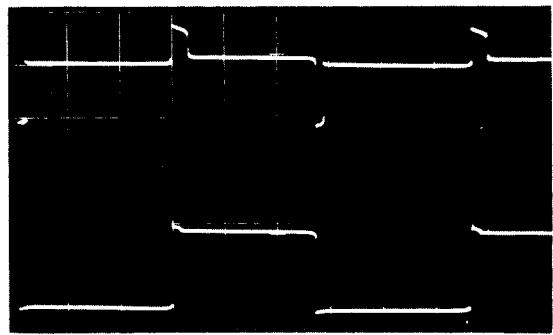
A



B



C



D

TOP TRACE      Vertical deflection is 1 v/cm  
Horizontal deflection is 1 ms/cm

BOTTOM TRACE      Vertical deflection is 10 v/cm  
Horizontal deflection is 1 ms/cm

For A, B, C, & D, top trace represents voltage across winding 1-2 of T3

bottom trace represents voltage across winding 5-6 of T3, where:

- A. Charge current is 500 ma (0-500 range)
- B. Charge current is 30 ma (0-500 range)
- C. Charge current is 14 ma (0-500 range)
- D. Charge current is 0 ma (0-500 range)

Figure 11. Current to Voltage Converter Waveforms .

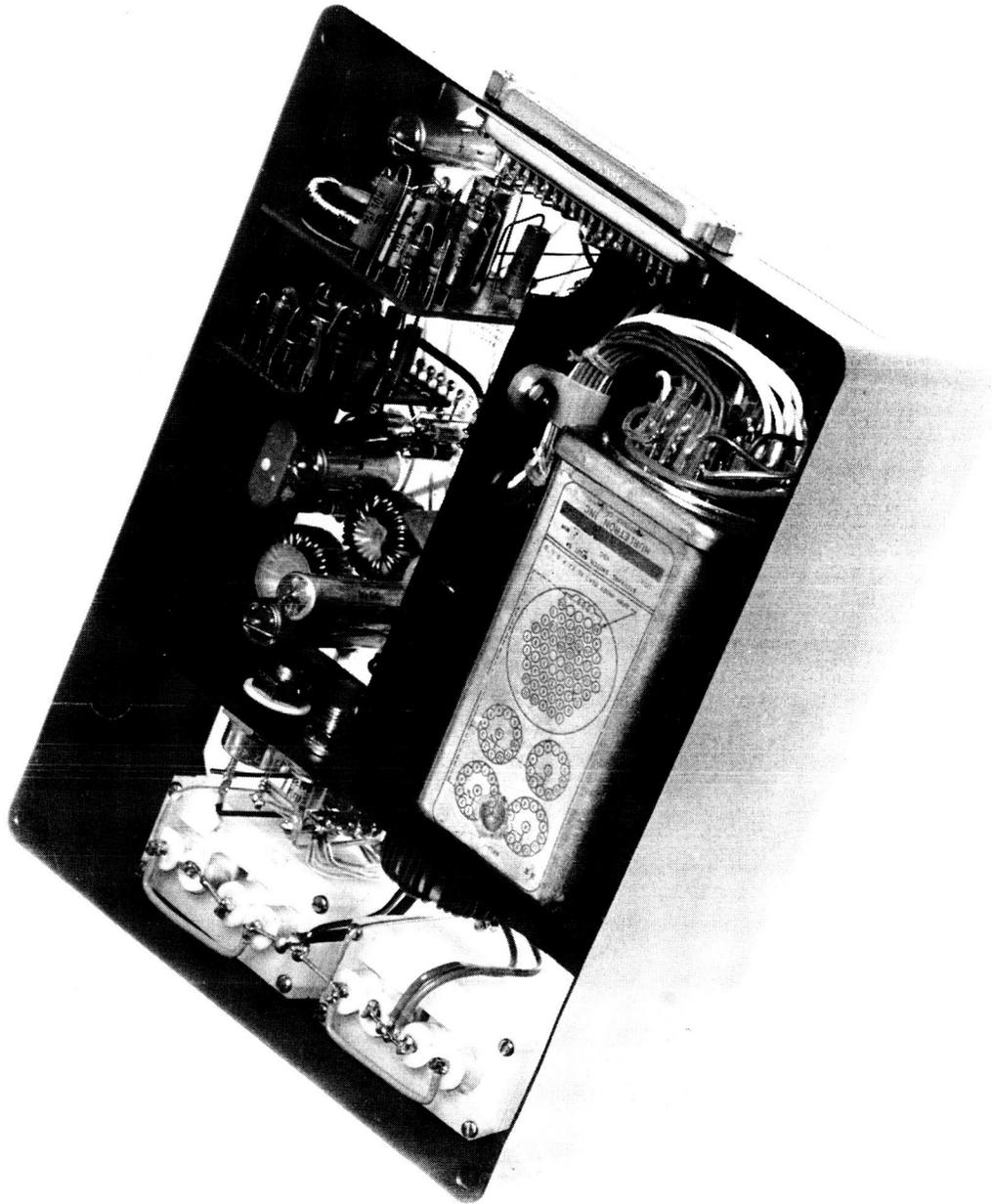


Figure 12. A.E.B. Battery Charger .

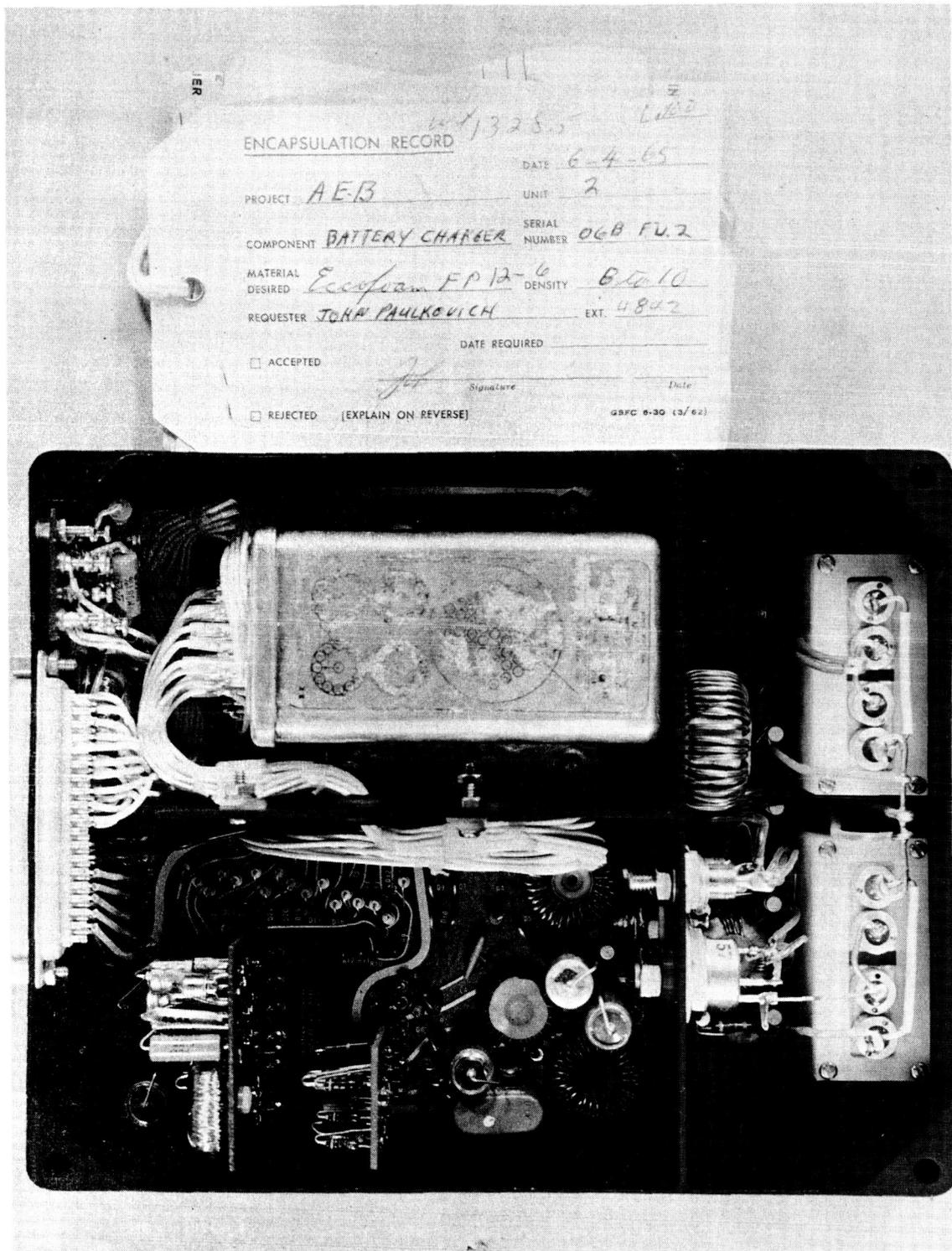


Figure 13. Top View of Battery Charger.

ENCAPSULATION RECORD

PROJECT AEB DATE 6-4-63

COMPONENT BATTERY CHARGER SERIAL NUMBER 008 FU2

MATERIAL DESIRED Eccoflam FDP-4 DENSITY 6.0-10

REQUESTER JOHN PAULKOVICH EXT. 2812

DATE REQUIRED \_\_\_\_\_

ACCEPTED \_\_\_\_\_

REJECTED [EXPLAIN ON REVERSE] \_\_\_\_\_

NSFC 8-30 (9/62)

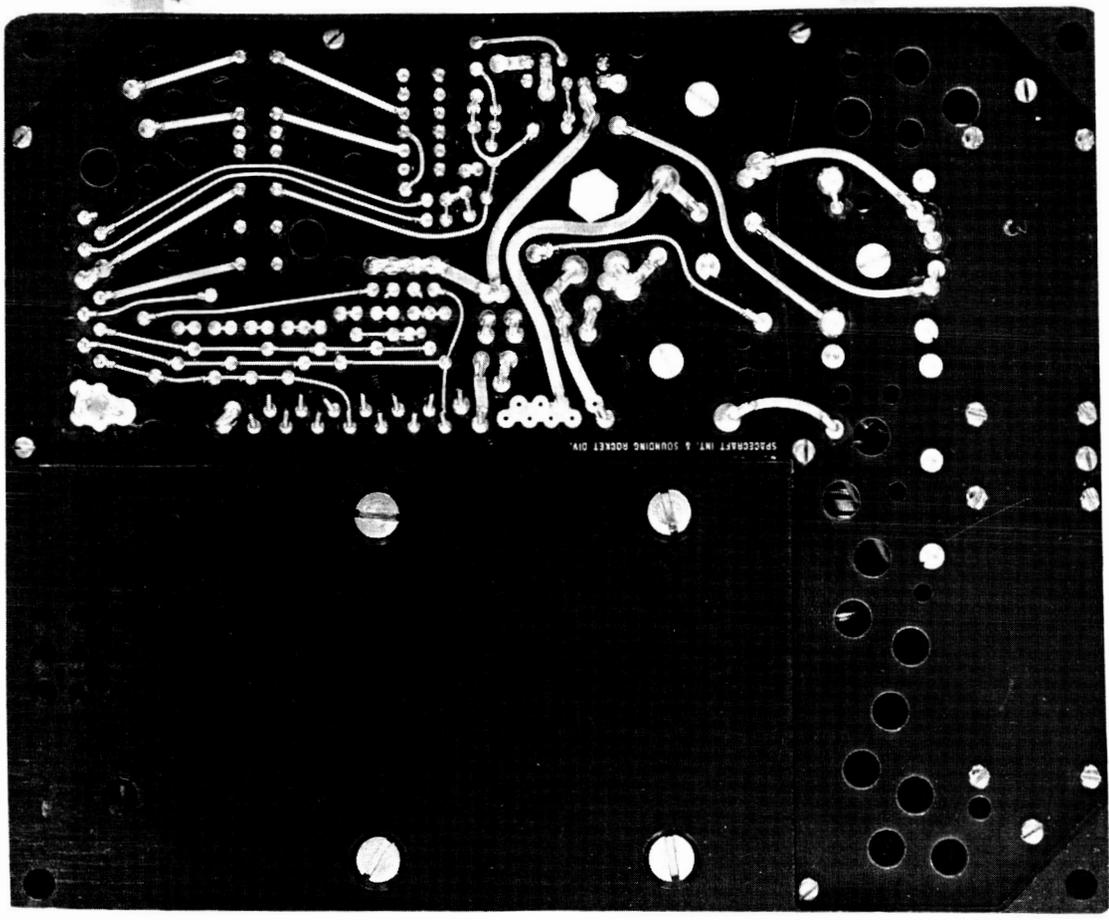


Figure 14. Bottom View of Battery Charger.

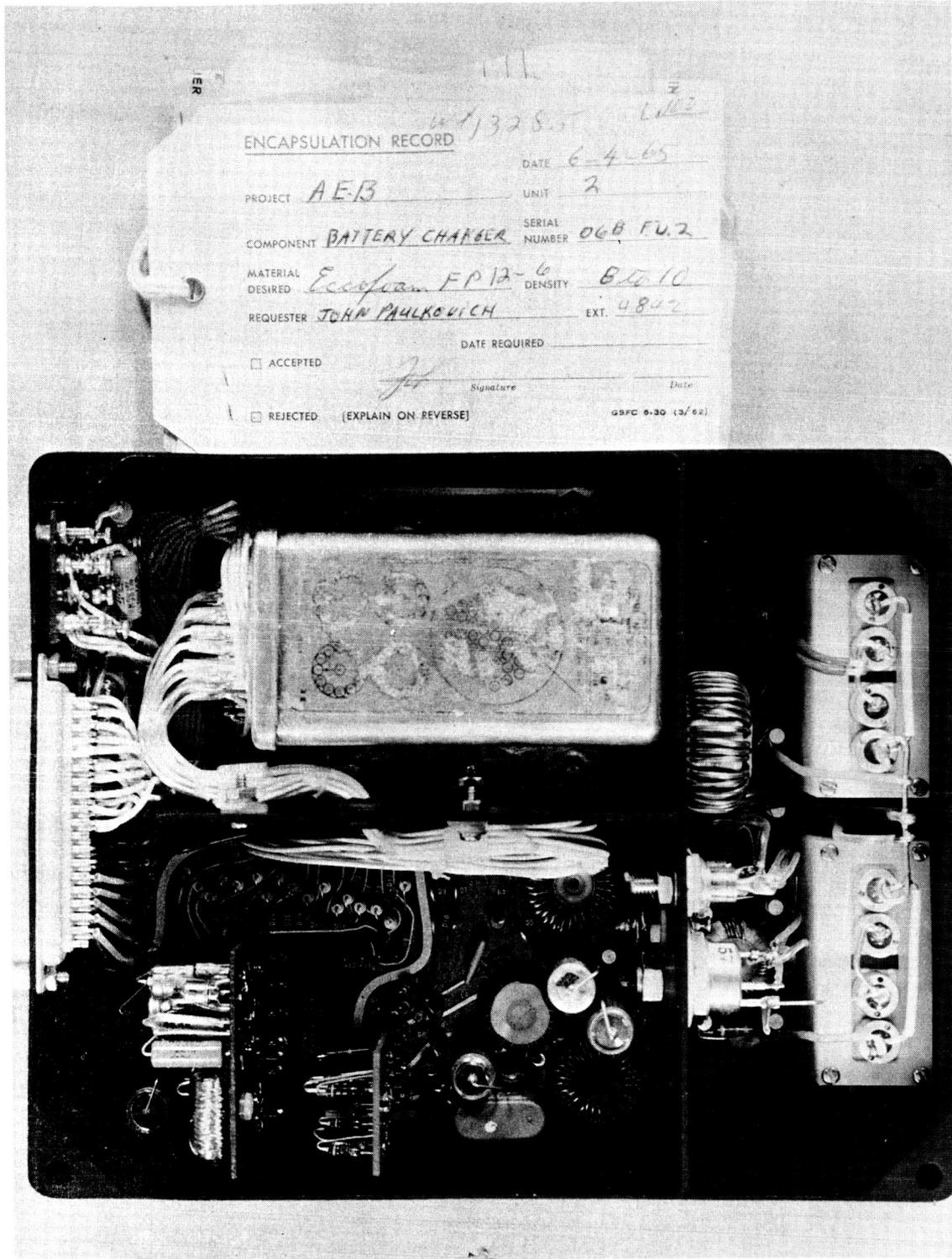


Figure 13. Top View of Battery Charger.