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FINAL PROGRAM REPORT

DEVELOPMENT OF A BATTERY STATUS MONITOR

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SPACE DIVISION CHRYSLER CORPORATION

FINAL PROGRAM REPORT

FOR THE DEVELOPMENT OF A

BATTERY STATUS MONITOR

JULY 1974

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FOREWORD

This report documents the results of the work performed by Chrysler Corporation Space Division (CCSD) on the development of a Battery Status Monitor under contract NAS 9-13654. This unit has the capability of providing the energy status of the battery, measure and transmit basic parameters, process those measurements required to determine abnormal functioning of the battery, and transmit warning signals of the abnormal condition along with a Go/No Go signal.

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SECTION 1

INTRODUCTION

Chrysler Corporation Space Division has developed a prototype battery status monitor system for the Space Shuttle.

The Battery Status Monitor (BSM) functions to: 1) provide the energy status of the battery, 2) measure and transmit basic battery parameters, 3) process those measurements required to determine abnormal functioning by the battery, and 4) transmit warning signals of the abnormal condition along with a Go/No Go signal.

The objectives of the program were to design a system that would improve the design and operational characteristics of the Space Shuttle by:

- o Improving turnaround capabilities
- o Lowering telemetry measurement requirements
- o Adding redundancy and autonomy

To facilitate attainment of these objectives, the program was divided into the following phases:

- o Phase I - Technical Requirements Definition
- o Phase II - Modifications for Alternate Battery
- o Phase III - System Design
- o Phase IV - System Performance Demonstration

Section 2

EQUIPMENT REQUIREMENTS

2.1 General Requirements

Requirements for the BSM prototype unit were based on the following:

- Must be capable of operating with a 10 amp-hour, 26 vented cell nickel cadmium (Ni-Cad) battery.
- Must be capable of providing energy status (capacity) of the battery with proper compensation for charge efficiency, battery temperature and stand loss.
- Must be capable of measuring and transmitting basic parameters on parallel continuous analog outputs.
- Must be capable of processing various measured data to determine abnormal functioning of the battery.
- Must be capable of transmitting warning signals of the above abnormal conditions along with a Go/No Go signal.
- Must be capable of retaining memory of energy status during extended stand periods.
- Must be capable of accommodating silver cadmium or silver zinc batteries with minimum development cost and time.

2.2 Battery Status Monitor

To meet the overall requirements the BSM has the following characteristics:

- Power Input - 28 plus or minus 4 volts DC. The energy status memory is supplied directly from the battery so as to be energized at all times.
- Input Signals - Capable of accepting the following input signals:

Parameter	Range	Quantity
Battery Cell Voltages	0-1.75 VDC	26
Battery Temperature	32^oF-130^oF	3
Discharge Current	0-100 Amps	1
Charge Current	0-1 Amp	
Pressure	0-50 psia	1

- o Energy status circuitry capable of compensating for the effect of the following parameters:
  - o Charge efficiency
  - o Charge efficiency with temperature compensation
  - o Stand loss
  - o Capacity versus temperature
- o Data processed and the following signals transmitted:

Parameter	Range	Accuracy
Amp Hour	0-100%	± 2%
Capacity	0-100%	± 5%
Charge Current	0-1.0 Amp	Fig. 2.1
Discharge Current	0-100 Amp	Fig. 2.1
Total Battery Voltage	0-45 volts DC	± 1% over range of 20 to 45 volts
Median Temperature	32^oF-130^oF	$\pm 1^oF$
Pressure	0-50 psia	± 2% FS

- o Data processed to determine abnormal functioning of battery and following warning signals transmitted:

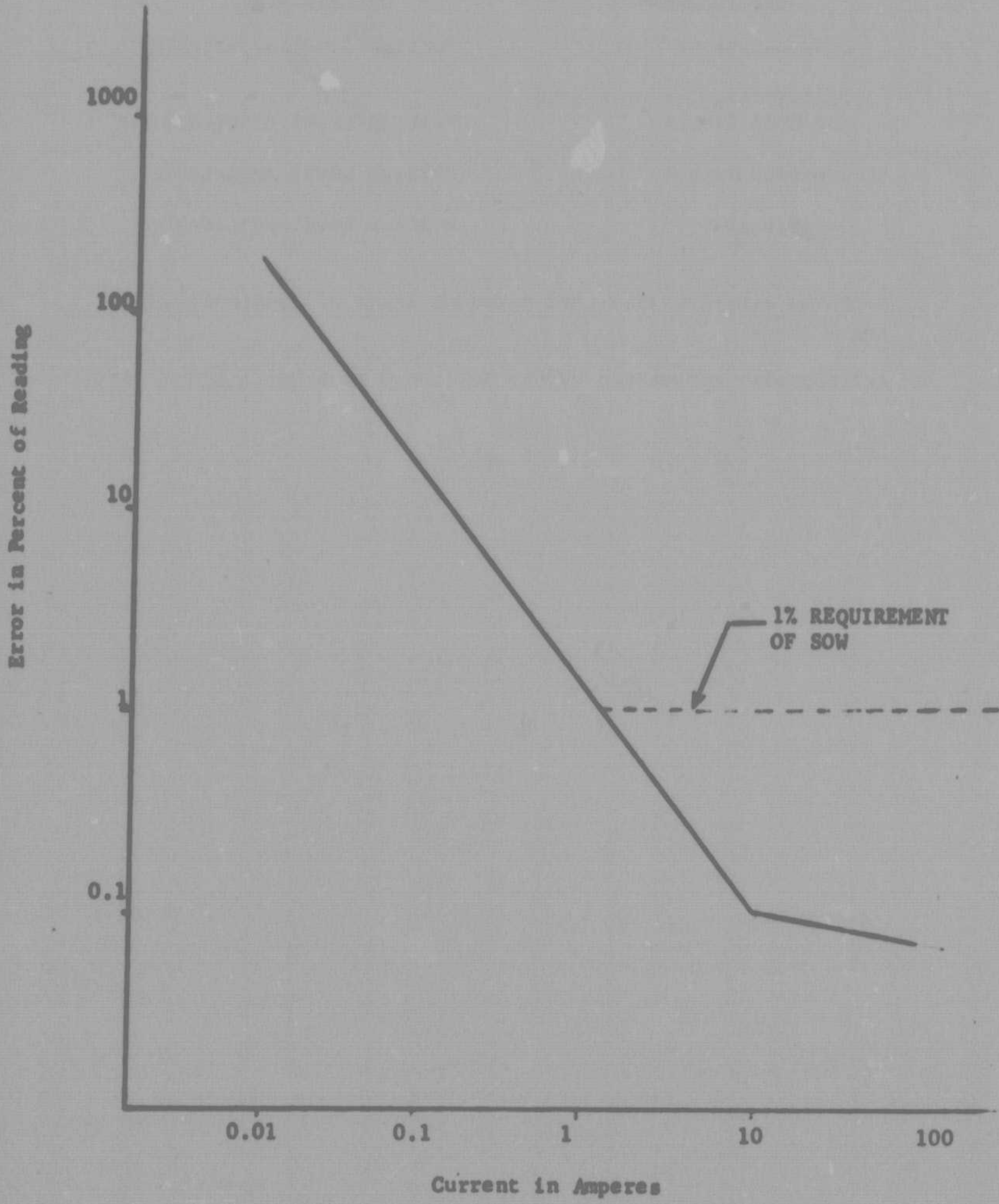

Figure 2-1 Accuracy of Charge and Discharge Current

Warning Signal	Warning Level
Overvoltage on Charge	Voltage Level Adjustable
Undervoltage on Discharge and Open Circuit	Voltage Level Adjustable
Overtemperature	Voltage Level Adjustable
Overpressure	Voltage Level Adjustable

- o Go/No Go signal transmitted based on state of combined warning signals.
- o All signals transmitted by the BSM are 0 to 5 volts DC.

Section 3

EQUIPMENT DESCRIPTION

3.1 Battery Status Monitor (BSM) System

The BSM system includes:

- o Battery Status Monitor Assembly (figure 3-1)
- o Modified Battery Assembly (figure 3-2)

The interconnection of the above system is shown in figure 3-3. The connector pin functions are identified in table 3-1.

3.2 Battery Status Monitor Assembly

The BSM assembly consists of a power supply board and five wire wrap type electronic circuit boards (WTB). The schematic for the assembly is SKEE B-6. The circuit boards are shown with the major components identified in figures 3-4 through 3-9. The board interconnection list is given by table 3-2. The adjustable functions are outlined in table 3-3.

The power board (PC1) converts the 28 ± 4 VDC input into the various voltages required by the BSM. It consists of two commercially available DC-DC converters which provide +15 VDC, -15 VDC, +12 VDC, -6 VDC and +5 VDC.

The electronic circuit boards (PC2 through PC6) receive input power from PC1. Battery voltage, cell voltage, charge and discharge current, temperature and pressure signals are received from the modified battery assembly and converted to the following 0 to 5 volts output signals.

- o Energy Status
  - o Amp-Hour
  - o Capacity
- o Current
  - o Discharge Current
  - o Charge Current
- o Median Temperature
- o Total Battery Voltage

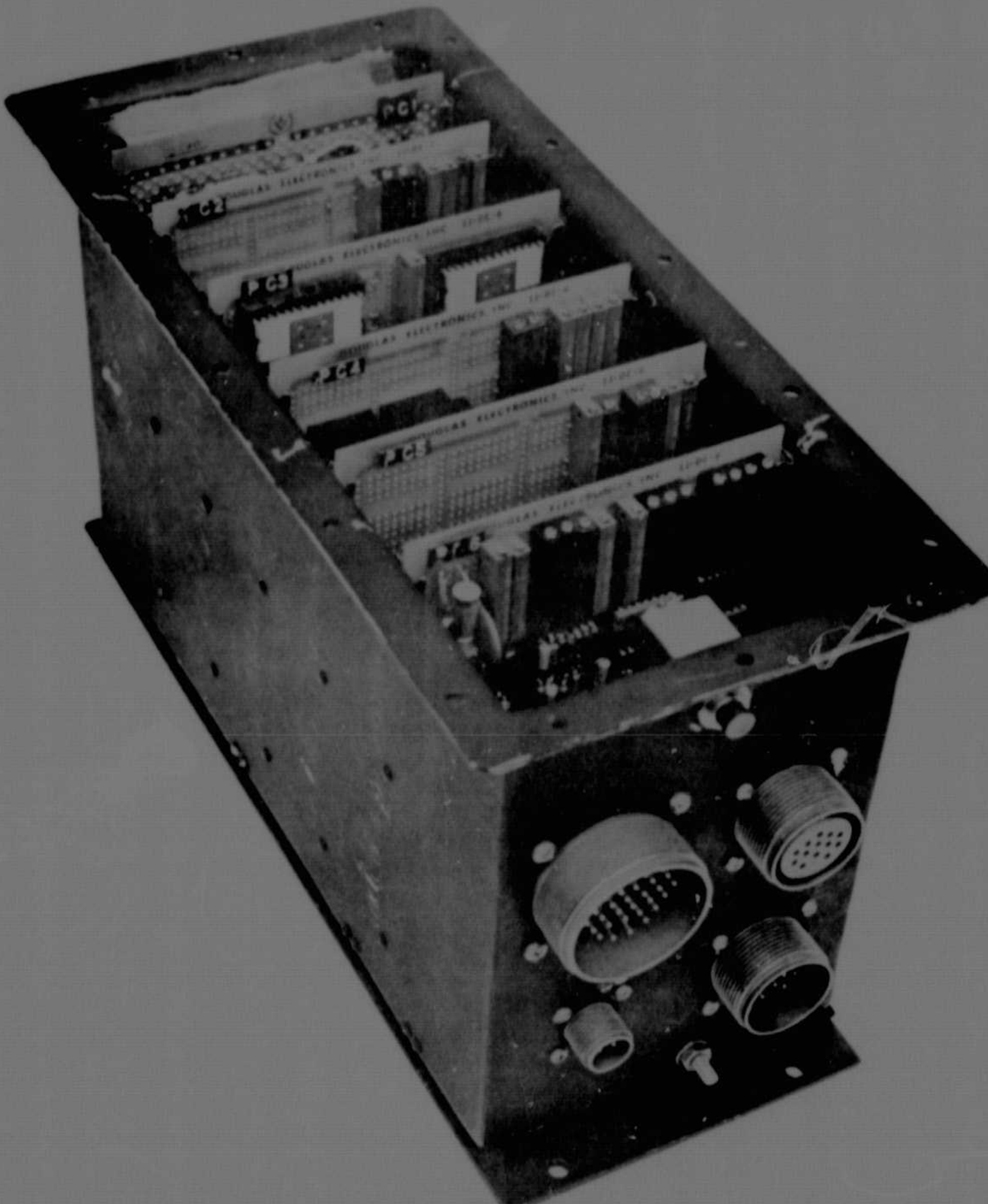

Figure 3-1. Battery Status Monitor Assembly

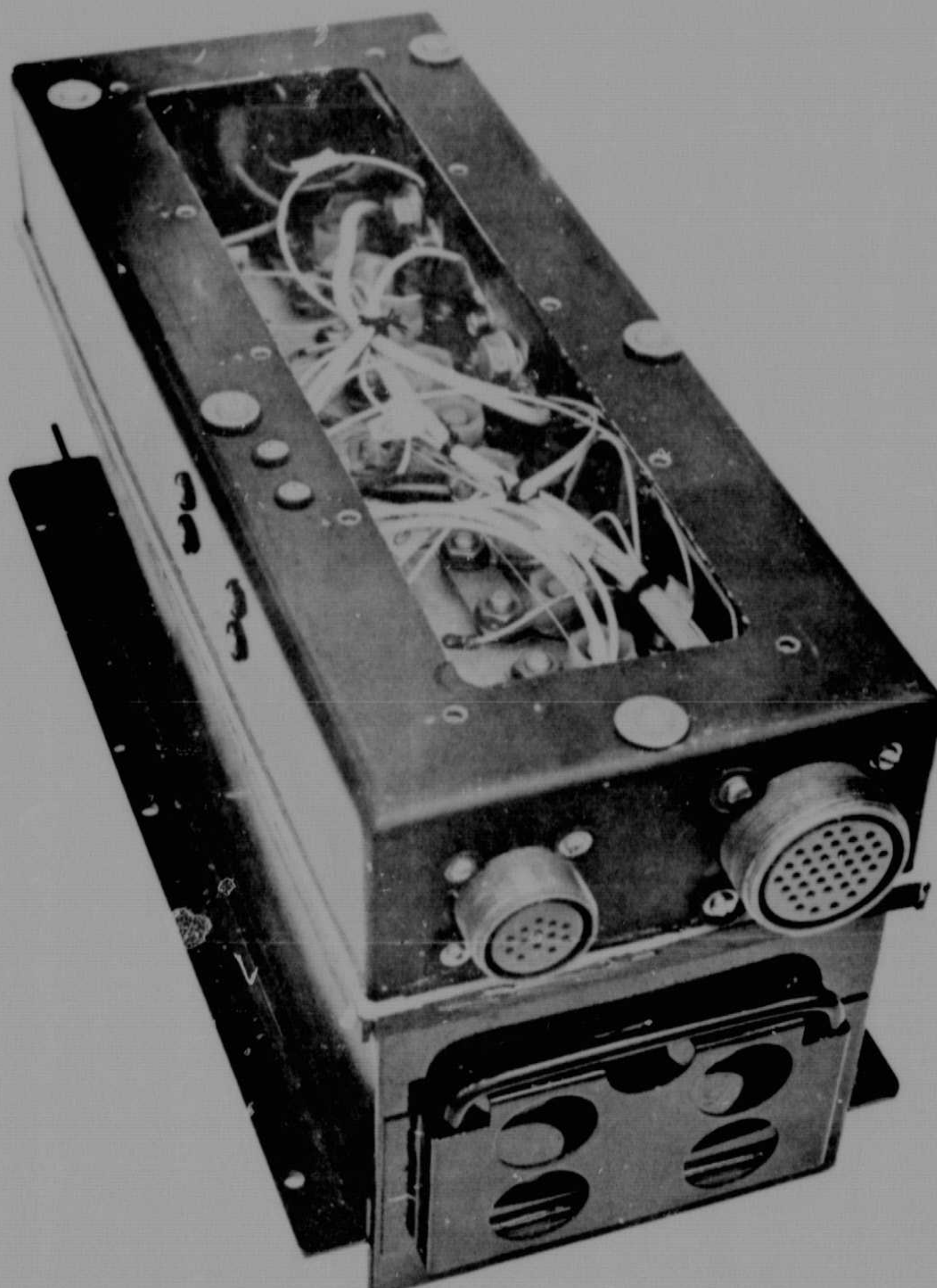

Figure 3-2. Modified Battery Assembly

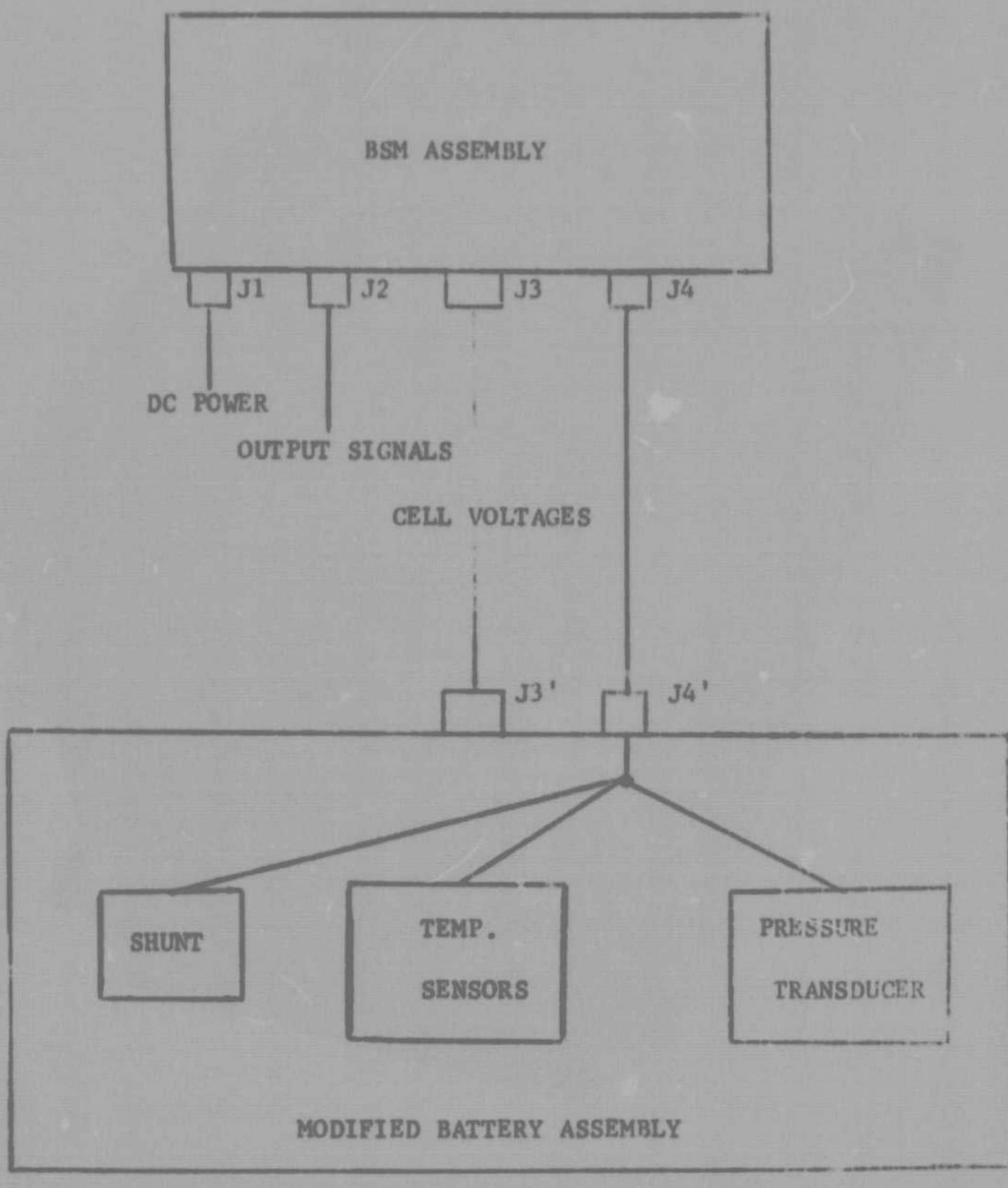

Figure 3-3 System Interconnection Block Diagram

TABLE 3.1 CONNECTOR PIN CONNECTIONS AND FUNCTIONS

SIGNAL DESCRIPTION	CONNECTOR - PIN		EXTERNAL CONNECTION
	BSM Assembly	Battery	
+ 28 V	J1-B	-	DC POWER
- 28 V	J1-A	-	DC POWER
OUTPUT - Amp-Hour	J2-A	-	-
Capacity	J2-B	-	-
Charge Current	J2-C	-	-
Discharge Current	J2-D	-	-
Total Voltage	J2-E	-	-
Median Temperature	J2-F	-	-
Pressure	J2-G	-	-
Cell Overvoltage Warning	J2-H	-	-
Cell Undervoltage Warning	J2-J	-	-
Over Press. Warning	J2-K	-	-
Over Temp. Warning	J2-L	-	-
Go/No Go Warning	J2-M	-	-
Ground	J2-N	-	-
+ CELL #1	J3-A	J3'-A	-
#2	J3-B	J3'-B	-
#3	J3-C	J3'-C	-
#4	J3-D	J3'-D	-
#5	J3-E	J3'-E	-
#6	J3-F	J3'-F	-
#7	J3-G	J3'-G	-
#8	J3-H	J3'-H	-
#9	J3-J	J3'-J	-

TABLE 3.1 CONNECTOR PIN CONNECTIONS AND FUNCTIONS

SIGNAL DESCRIPTION	CONNECTOR - PIN		EXTERNAL CONNECTION
	BSM Assembly	Battery	
#10	J3-K	J3'-K	-
#11	J3-L	J3'-L	-
#12	J3-M	J3'-M	-
#13	J3-N	J3'-N	-
#14	J3-P	J3'-P	-
#15	J3-R	J3'-R	-
#16	J3-V	J3'-V	-
#17	J3-W	J3'-W	-
#18	J3-X	J3'-X	-
#19	J3-Y	J3'-Y	-
#20	J3-b	J3'-b	-
#21	J3-c	J3'-c	-
#22	J3-d	J3'-d	-
#23	J3-e	J3'-e	-
#24	J3-f	J3'-f	-
SPARE	J3-h	J3'-h	-
SPARE	J3-j	J3'-j	-
- CELL #24	J3-k	J3'-k	-
SPARE	J3-l	J3'-l	-
SPARE	J3-m	J3'-m	-
SPARE	J3-g	J3'-g	-
+ Shunt	J4-A	J4'-A	-
- Shunt	J4-B	J4'-B	-
+ Thermistor #1	J4-C	J4'-C	-

TABLE 3.1 CONNECTOR FOR CONNECTIONS AND FUNCTIONS

SIGNAL DESCRIPTION	CONNECTOR - PIN		EXTERNAL CONNECTION
	BSM Assembly	Battery	
- Thermistor #1	J4-D	J4'-D	-
+ Thermistor #2	J4-E	J4'-E	-
- Thermistor #2	J4-F	J4'-F	-
+ Thermistor #3	J4-G	J4'-G	-
- Thermistor #3	J4-H	J4'-H	-
+ 2V Reference	J4-J	J4'-J	-
Pressure #1	J4-K	J4'-K	-
Pressure #2	J4-L	J4'-L	-
Pressure #3	J4-M	J4'-M	-
Pressure #4	J4-N	J4'-N	-
+ Charger/Load	-	J5-E	Charger/Load
- Charger/Load	-	J5-B	Charger/Load

Figure 3-4. PC-1 BSM Assembly Board

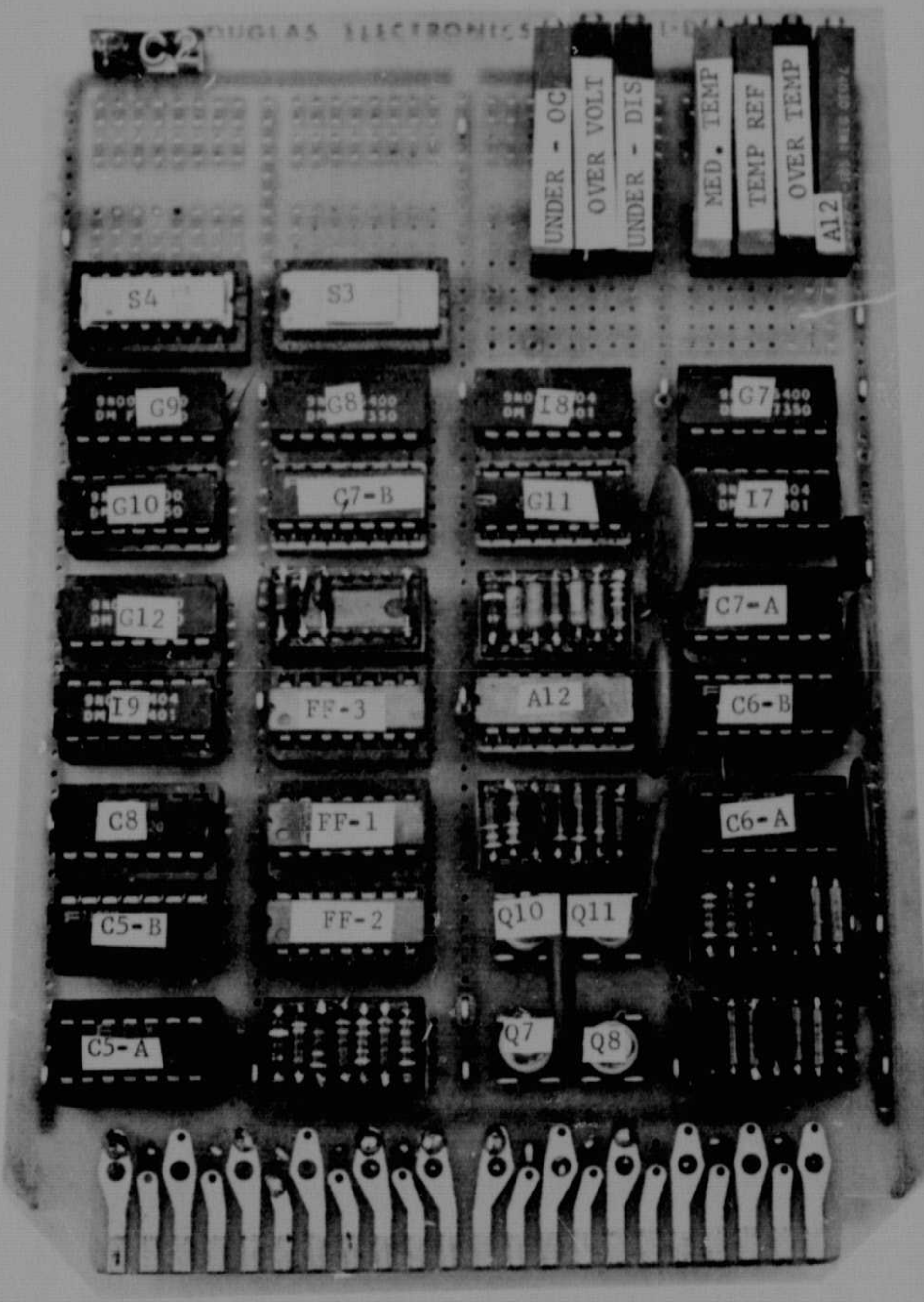

Figure 3-5. PC-2 BSM Assembly Board

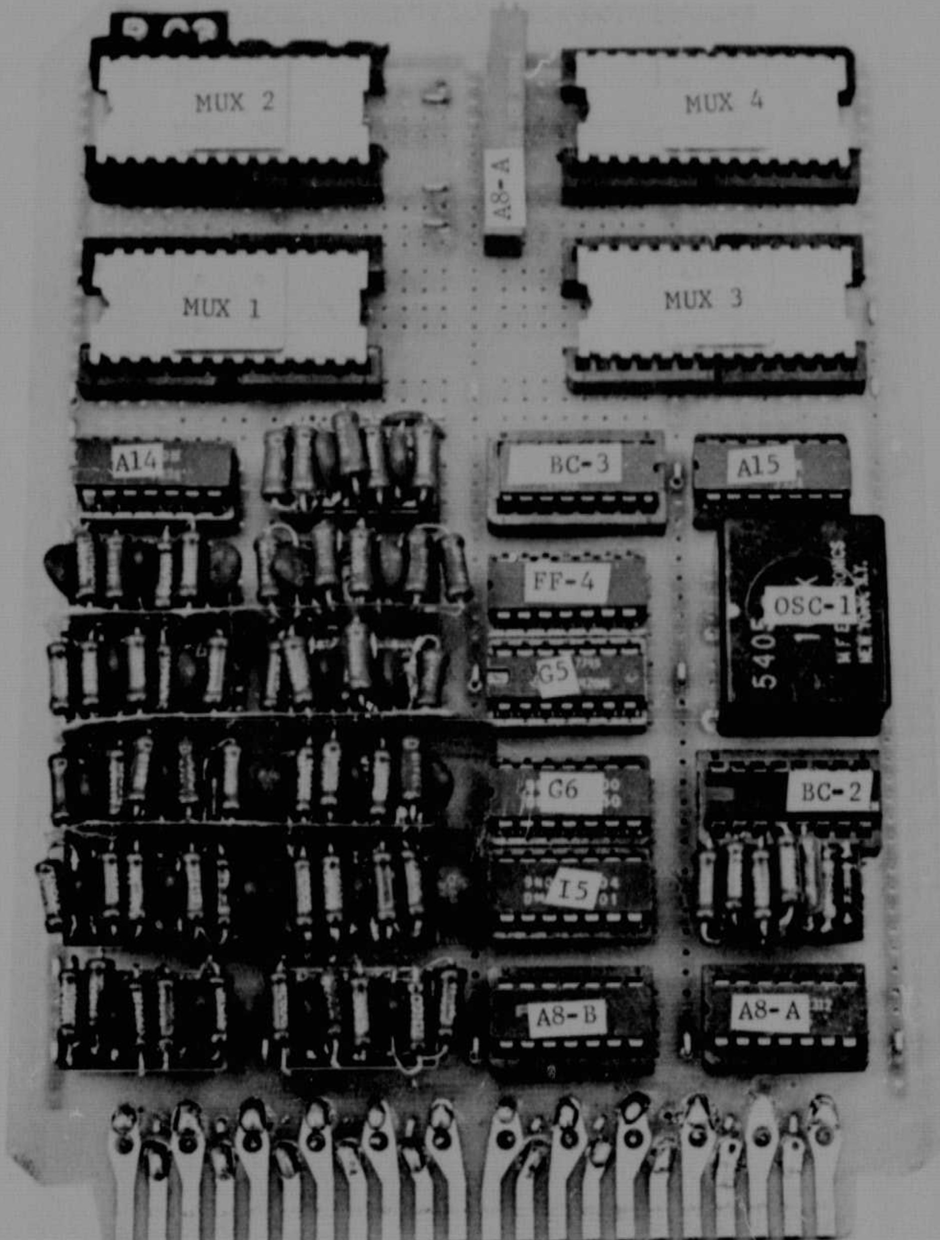

Figure 3-6. PC-3 BSM Assembly Board

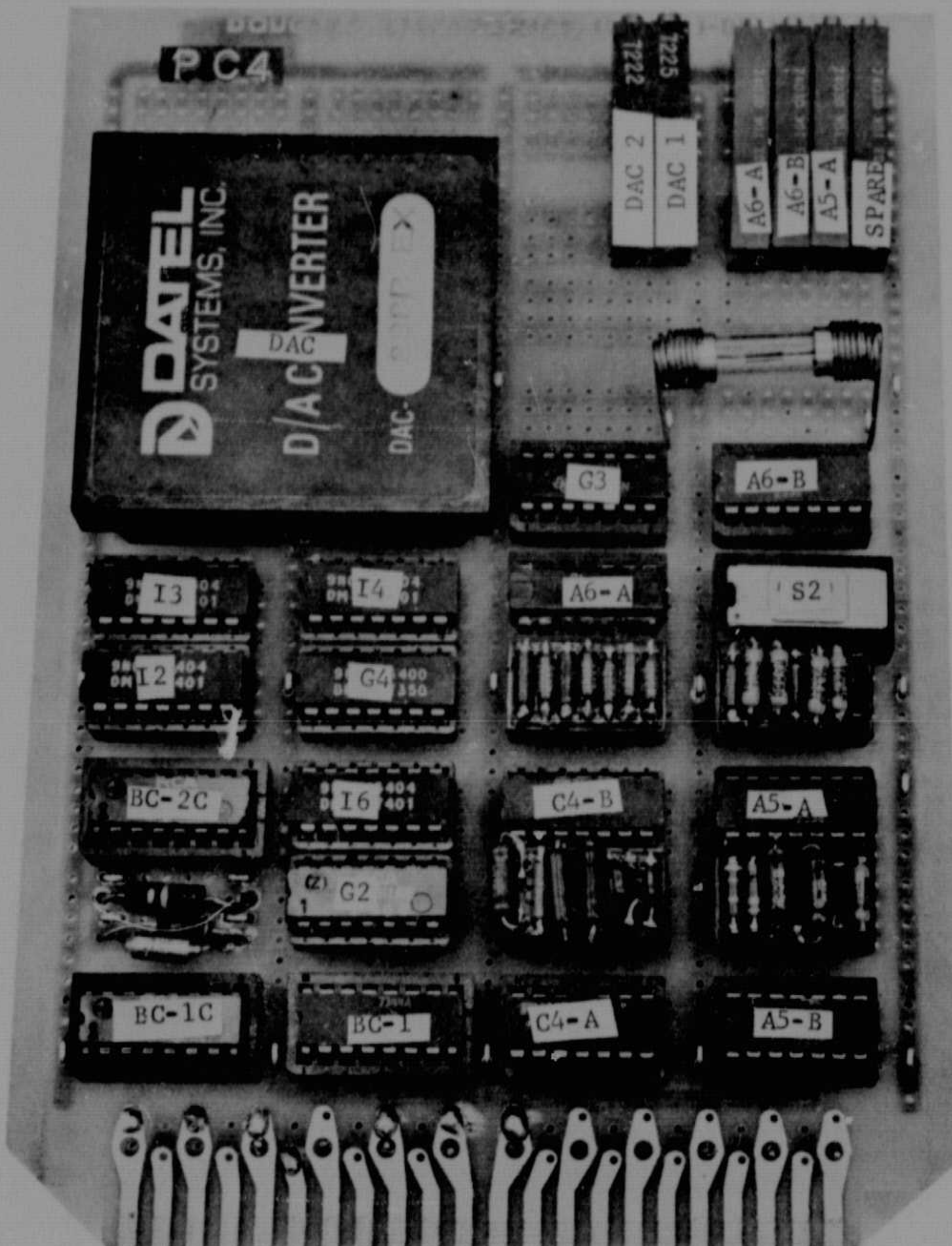

Figure 3-7. PC-4 BSM Assembly Board

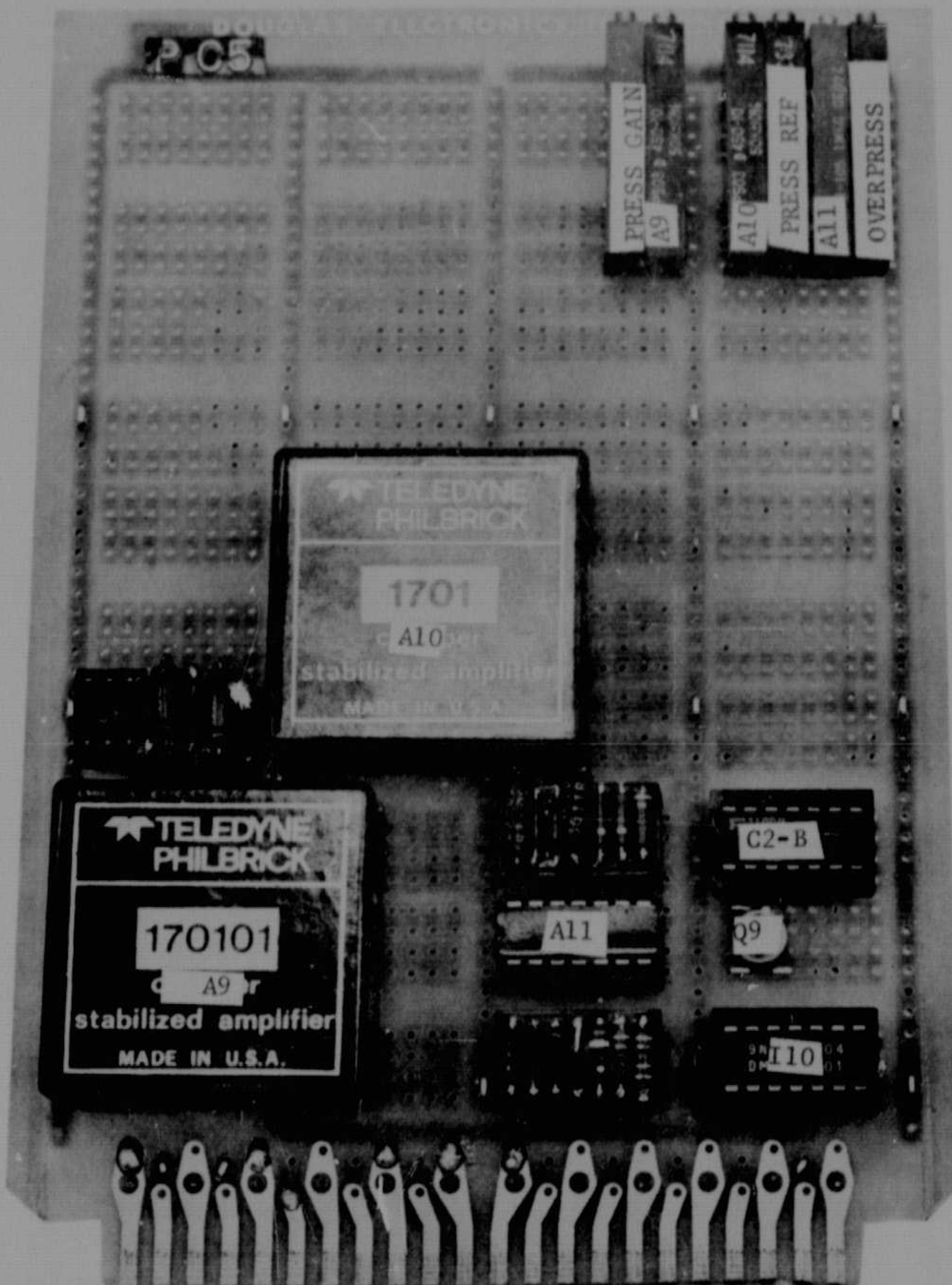

Figure 3-8. PC-5 BSM Assembly Board

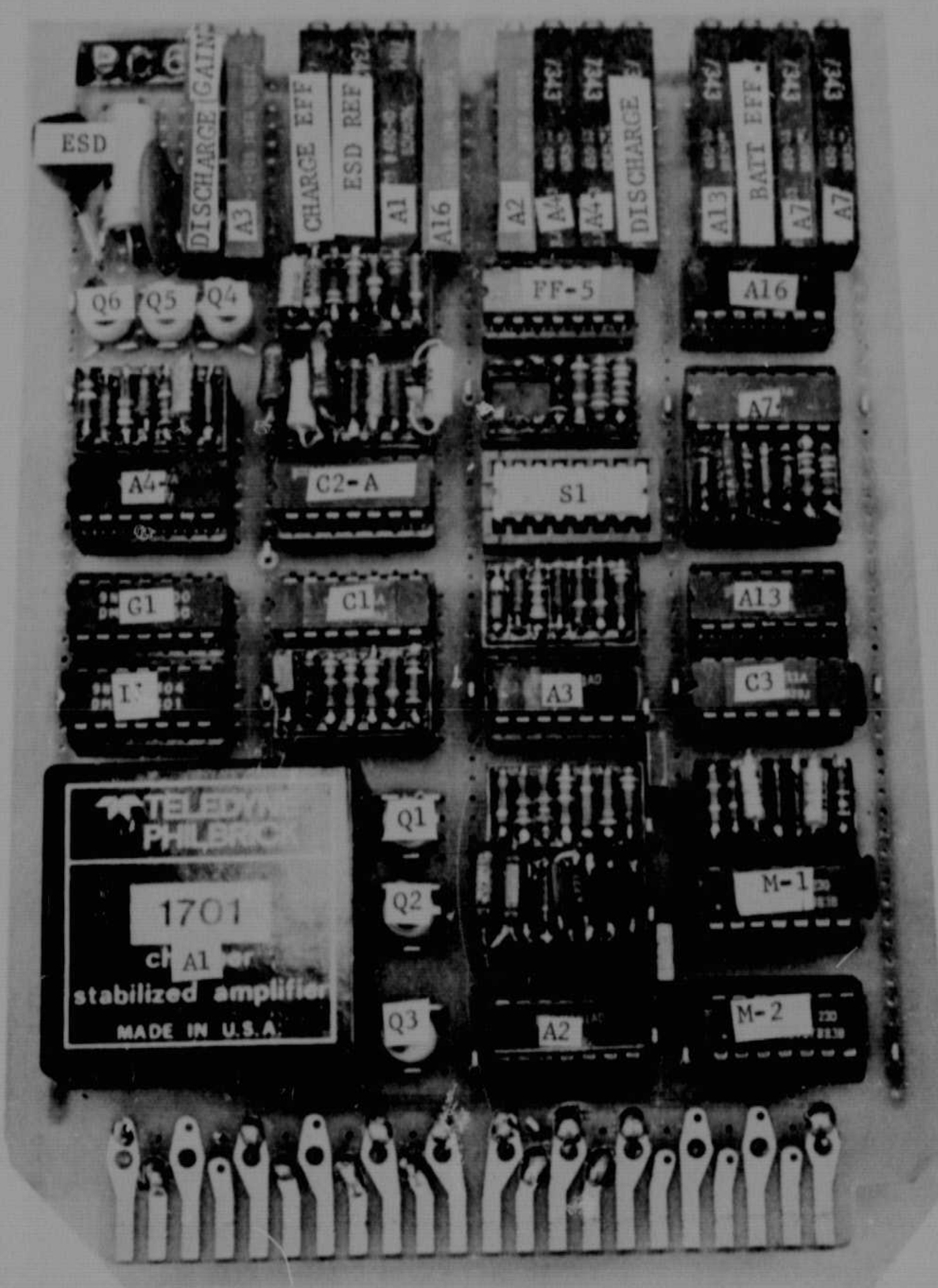

Figure 3-9. PC-6 BSM Assembly Board

TABLE 3.2 PC BOARD INTERCONNECTION LIST

SIGNAL DESCRIPTION	PC6	PC5	PC4	PC3	PC2	PC1	BSM Assembly CONN-PIN
Ground	1	1	1	1	1	X,Y	-
+ 28 Volt Batt.			3	2			-
+ 5 V	5	5	5	5	5	V	-
- 6 V	5	6	6	6	6	U	-
+ 15 V	9	9	9	9	9	R	-
- 15 V	11	11	11	11	11	N	-
+ 12 V	12	12	12	12	12	M	-
- 28 V Bus						J	J1-A
+ 28 V Bus						D	J1-B
+ 2 Volt Ref.					16		J4-J
+ Cell #1 (+28 Volt Batt.)				A			J3-A
#2				B			J3-B
#3				C			J3-C
#4				D			J3-D
#5				E			J3-E
#6				F			J3-F
#7				H			J3-G
#8				J			J3-H
#9				K			J3-J
#10				L			J3-K
#11				M			J3-L
#12				N			J3-M
#13				P			J3-N
#14				R			J3-P

TABLE 3.2 PC BOARD INTERCONNECTION LIST

SIGNAL DESCRIPTION	PC6	PC5	PC4	PC3	PC2	PC1	BSM Assembly CONN-PIN
+ CELL #15				S			J3-R
#16				T			J3-V
#17				17			J3-W
#18				3			J3-X
#19				4			J3-Y
#20				7			J3-b
#21				8			J3-c
#22				10			J3-d
#23				13			J3-e
#24				14			J3-f
SPARE #25				15			J3-h
SPARE #26				16			J3-j
- CELL #24				V			J3-k
+ Shunt	D						J4-A
- Shunt	C						J4-B
Median Temp.	N				N		-
$\overline{\text{Discharge}}$	P				B		-
Charge	R	M					-
Output - Dischg. Cur.	T						J2-D
Output - Charge Cur.	V						J2-C
$\overline{\text{Down Count}}$	X		H				-
$\overline{\text{Up Count}}$	Z		K				-
Pressure #1		D					J4-K

TABLE 3.2 PC BOARD INTERCONNECTION LIST

SIGNAL DESCRIPTION	PC6	PC5	PC4	PC3	PC2	PC1	BSM Assembly CONN-PIN
Pressure #2		C					J4-L
Pressure #3		B					J4-M
Pressure #4		A					J4-N
Output Press.		X					J2-G
Over Press. Warning		Y					J2-K
Over Press.		Z			F		-
Med. Temp.			V		R		-
Output Capacity			X				J2-B
Output Amp-Hr.			Z				J2-A
Output Med. Temp.					P		J2-F
Output - Total Voltage				W			J2-E
Cell Voltage				X	A		-
Clock 1				Y	C		-
End of Scan				Z	D		-
Go/No Go Warning					J		J2-M
Cell Undervolt. Warning					K		J2-J
Cell Overvolt. Warning					L		J2-H
Overtemp. Warning					M		J2-L
- Thermistor #3					S		J4-H
+ Thermistor #3					T		J4-G
- Thermistor #2					V		J4-F

TABLE 3.2 PC BOARD INTERCONNECTION LIST

SIGNAL DESCRIPTION	PC6	PC5	PC4	PC3	PC2	PC1	BSM Assembly CONN-PIN
+ Thermistor #2					W		J4-E
- Thermistor #1					Y		J4-D
+ Thermistor #1					Z		J4-C
Amplifier 1 Ground	2					W	-
Output Ground						K	J2-N
Switch *	8						-
Switch *	10						-
Switch *	13						-
Switch *	14						-
Switch *	15						-
Clock 2	22			22			-
Relay **	16						-
Relay **	18						-
+ 28 V **						C	-
- 28 V **						F	-

* These pins are connected to the energy reset switch (ERS)

** These pins are connected to the relay used in stand loss circuit.

TABLE 3-3 PC CARD ADJUSTMENTS

PC CARD NO.	ADJ. NAME*	ADJ. FUNCTION	REMARKS
PC-2	Temp Ref.	Thermistor network voltage reference	
	Overtemp.	Overtemperature reference	
	Med. Temp.	Used in median temp. signal conditioning	Set for .27 V
	Overvolt.	Overvoltage in charge reference	
	Under-OC	Undervoltage on open circuit reference	
	Under-Dis.	Undervoltage on discharge reference	
PC-3	None		
PC-4	DAC1	Adjustment on D/A converter	
	DAC2	Adjustment on D/A converter	
PC-5	Press. Ref.	Pressure transducer voltage reference	
	Overpress.	Overpressure reference	
	Press. Gain	Gain adjustment on pressure signal conditioning	
PC-6	Batt. Eff.	Energy status circuit battery efficiency adjustment	
	Discharge	Energy status discharge rate adjustment	

TABLE 3-3 PC CARD ADJUSTMENTS

PC CARD NO.	ADJ. NAME*	ADJ. FUNCTION	REMARKS
PC-6	ESD Ref.	ESD circuit reference voltage	
	Charge Eff.	Charge efficiency vs. temp. adjustment	
	Discharge Gain	Gain adjustment of discharge current output	

NOTE* All "A" type potentiometers are for zero adjustment of the amplifiers with the corresponding number of the potentiometer.

- Pressure
- Warning Signals
  - Overvoltage on charge
  - Undervoltage on discharge and on open circuit
  - Overtemperature
  - Overpressure
  - Go/No Go

The charge and discharge current signals are converted to an amp-hour signal by applying the current input signals through a chopper stabilized amplifier to an integrator/pulse generator which emit pulses equivalent to a predetermined number of ampere-hours. The pulses are applied to an eight-bit up/down binary counter which also acts as a memory device during long stand periods to retain the output reading. The outputs of the counter are applied through inverters to a digital-to-analog (D/A) converter. The output of the D/A converter is signal conditioned and transmitted as the amp-hour output. Compensation for efficiency and stand loss is made at the integrator/pulse generator.

The amp-hour output signal is applied to amplifiers where it is temperature compensated to reflect battery capacity reduction due to temperature. The modified signal is transmitted as the capacity output.

Charge and discharge current signals from the battery are signal conditioned and transmitted as charge and discharge current outputs.

Three temperature signals are received from the battery. The high and median temperatures are determined by logic circuitry. The median temperature signal is conditioned and transmitted as the median temperature output. The high temperature signal is compared to an overtemperature reference voltage and a five volt overtemperature warning signal is transmitted if the temperature signal exceeds the reference.

Battery voltage is measured, signal conditioned and transmitted as the total voltage output.

The cell voltages are received from the battery and applied through a resistance voltage divider network to the multiplexers. They scan the cell voltages and convert them to two single output cell voltage wave trains. The wave trains are applied through a differential amplifier to comparator circuits which monitor the cell voltages for under voltage during open circuit or discharge and overvoltage during charge. The output of the comparators are conditioned to provide undervoltage and overvoltage warning signals.

Battery case pressure is measured, signal conditioned and transmitted as the pressure output. The pressure output is also compared to a pressure reference voltage and a five volt overpressure warning signal transmitted when the signal exceeds the reference.

If any of the warning signals indicate an abnormal condition, a five volt No Go signal is transmitted. When all warning signals are in a zero state, a zero volt Go signal is transmitted.

3.3 Modified Battery Assembly

The test battery has been modified to provide the following information to the BSM assembly:

- Charge/Discharge Current
- Battery Voltage
- Temperatures
- Pressure

The modifications are as follows:

- Wiring to provide cell output voltages
- Three linear thermistor networks mounted on three of the battery cell interconnection strips
- A 100 amp shunt
- A strain gage type pressure transducer mounted on the battery case.
- Connectors to provide the necessary interconnection between the battery and BSM.

3.4 Initial System Operation

The BSM is initially mated with the modified battery as follows:

- Charge the battery to 100% and connect to BSM.
- Apply power to the BSM.
- Adjust the output of the BSM to 100% by depressing the energy reset switch (ERS) on the BSM assembly until the voltage across J2 pin A and J2 pin N reads 5 $\pm$ .04 VDC.
- The BSM will now monitor battery status.

Section 4

ACCEPTANCE TEST PERFORMANCE DATA

4.1 General

Results of the Acceptance Test are described in the following paragraphs. The test was run in accordance with the Acceptance Test Plan PL-EE-74-14.

4.2 Current Measurement

The charge current output signal was measured when the battery was being charged at 0.25 ampere, 0.50 ampere, 0.75 ampere and 1.0 amperes. A comparison of the test results with the expected results is given in table 4-1. All results were within the specified measurement test tolerance.

Current	Expected Value	Test Result
0.25A	1.25 VDC	1.21 VDC
0.50A	2.50 VDC	2.49 VDC
0.75A	3.75 VDC	3.76 VDC
1.00A	5.00 VDC	5.02 VDC

Table 4-1 Charge Current Test Results

The discharge current output signal was measured when the battery was discharging at 10 milliamps, 100 milliamps, 1 ampere, 10 amperes and a simulated input signal of 100 amperes. A comparison of test results with the expected results is given in table 4-2.

Current	Expected Value	Test Result
10mA	0.0005 VDC	-0.0005 VDC
100mA	0.0050 VDC	0.0045 VDC
1A	0.050 VDC	0.044 VDC
10A	0.500 VDC	0.501 VDC
100A	5.000 VDC	5.056 VDC

Table 4-2 Discharge Current Test Results

Charge and discharge current percent errors are plotted for comparison with the test tolerances in figure 4-1.

The discharge current error is slightly greater than the specified tolerance because the tolerance represents the error at the output of the chopper stabilized amplifier and does not take into account the output buffer amplifier circuitry used to provide the 0 to 5 VDC telemetry output signal. The discharge current signal errors were adjusted to insure that the actual capacity of the battery will be always slightly greater than the readout value of capacity. The increase in the error at the 100 ampere test point is due to the use of simulation circuitry to provide an input signal rather than actually discharging the battery at 100 amperes.

4.3 Total Battery Voltage Measurement

The output was measured with battery input voltage at 0 volts, 19.97 volts, 30.05 volts and 43.73 volts. A comparison of results is given in table 4-3. All results were within the test tolerance of ±1% between 20 and 45 VDC.

Voltage	Expected Value	Test Result	Error %
0.00 VDC	0.000 VDC	0.006 VDC	-
19.97 VDC	2.219 VDC	2.203 VDC	-.79%
30.05 VDC	3.339 VDC	3.313 VDC	-.77%
43.73 VDC	4.859 VDC	4.819 VDC	-.82%

Table 4-3 Total Voltage Test Results

4.4 Temperature Measurement

The three thermistor networks were checked and found to work properly. The high and median temperature logic was checked for all combinations of high, median and low input temperature signals and worked properly. The median temperature output was checked at a simulated 32°F, 80°F and 130°F. Results are given in table 4-4.

Median Temperature	Expected Value	Test Result	Error °F
32°F	0.000 VDC	-0.048 VDC	-0.94°F
80°F	2.427 VDC	2.353 VDC	+1.45°F
130°F	5.000 VDC	5.049 VDC	+0.96°F

Table 4-4 Temperature Test Results

The error at 80 F is slightly above the test tolerance of ±1°F. This is attributed to the imbalance between the circuitry used to simulate the three-thermistor input voltage network and slightly unmatched condition between the three temperature channel circuits used for median temperature selection. In actual operation the thermistors are matched within ±0.3°F.

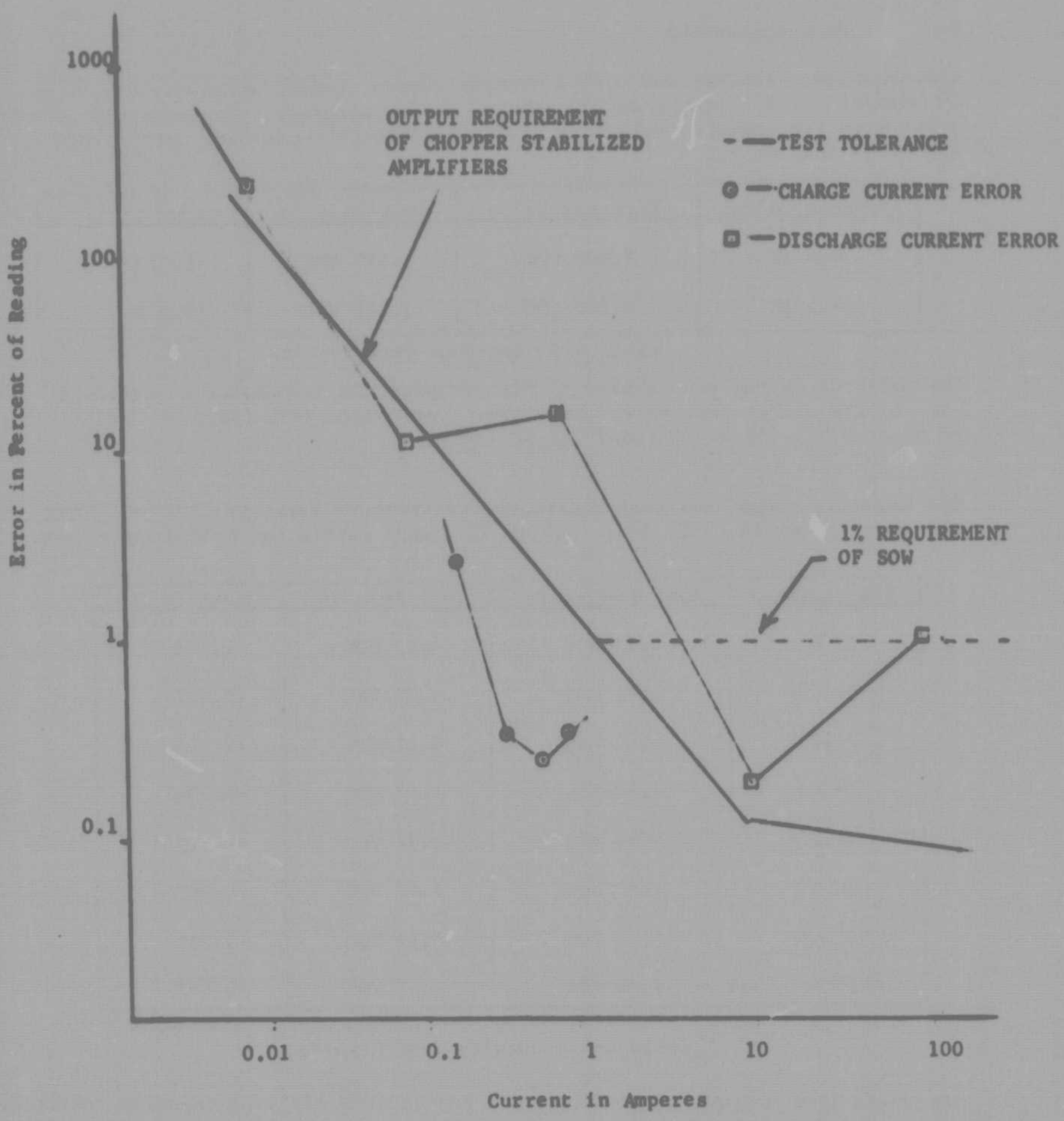

Figure 4-1 Error Versus Current on BSM

4.5 Amp Hour Accounting

The amp-hour circuitry was tested without current compensation for discharges of 10 amperes for 27 minutes and 20 amperes for 12 minutes. Comparison of test results with the expected values is given in table 4-5. Results were within the test tolerance of ±2%.

Amp-Hour Charge	Expected Value	Test Results	Error in %
4.0 AH	2.000 VDC	1.993 VDC	-0.35%
4.5 AH	2.250 VDC	2.268 VDC	+0.80%

Table 4-5 Amp-Hour Test Results

The amp-hour output was calibrated with temperature compensation adjustments made to the charge accounting circuitry. The charge efficiency was set for 98.8% at 32°F, 89% at 78°F and 79% at 130°F.

The capacity output was tested over the temperature range of 32°F to 130°F. Results are given in table 4-6. All results were within the tolerance of ±5%.

Temperature	Expected Value	Test Results	Error in %
32°F	4.53 VDC	4.53 VDC	0.00%
51.6°F	4.74 VDC	4.72 VDC	-0.42%
71.2°F	4.95 VDC	4.91 VDC	-0.81%
79°F	4.98 VDC	4.97 VDC	-0.20%
92.2°F	4.98 VDC	4.97 VDC	-0.20%
98.6°F	4.96 VDC	4.96 VDC	0.00%
110.4°F	4.64 VDC	4.78 VDC	+3.02%
130°F	4.42 VDC	4.45 VDC	+0.68%

Table 4-6 Capacity Test Results

The stand loss circuitry was tested and indicated a 12 ±1.5% capacity correction over a ten day stand period.

4.6 Pressure Measurement

The pressure transducer was tested at atmospheric pressure and functioned properly. The pressure measurement circuitry was tested at atmospheric pressure and a pressure of 31 psia. Test results were within the tolerance of ±1 psia and are given in table 4-7.

Pressure	Expected Value	Test Results	Error PSIA
14.7psia	1.47 VDC	1.44 VDC	-.3 psia
31 psia	3.10 VDC	3.09 VDC	-.1 psia

Table 4-7 Pressure Test Results

4.7 Action Signals (Warning Signals)

All warning signals were tested using simulated signals and functioned properly. The Go/No Go signal was monitored during the test of the warning signals and it met the specified requirements.

4.8 Impedance

Output impedance, insulation resistance and isolation resistance were measured and meet the tolerances given in the design/performance specification.

4.9 Supply Voltage

All outputs were measured with an input supply voltage of 24 volts and 32 volts with a noise level of 1.0 voltspeak to peak from zero to 20 KHz. All outputs operated properly at the above supply voltages.

4.10 Temperature

With the BSM in a temperature chamber, operational checks were performed after a soak period of 30 minutes with the chamber set at $0^{o}F$, $130^{o}F$ and $175^{o}F$. The operational checks included the following:

- o Median temperature output at ambient.
- o Total battery voltage output.
- o Discharge current output with a discharge current of 10 amperes.
- o Charge current output with a charge current of 1 ampere.
- o Amp-hour and capacity circuitry.
- o Pressure output at atmospheric pressure.
- o Overvoltage, undervoltage and go/no go outputs with simulated abnormal conditions.
- o Overtemperature and overpressure outputs.

All outputs operated properly at the three temperatures except the pressure output. The pressure readout circuitry exhibited an output change with wide temperature variations (approximately 9.7 mv/ F) which exceeds the specification requirement for thepressure circuit. Recommended improvement of this circuit is discussed in Section 5.

4.11 Other Environmental Requirements Analysis

This analysis includes the operational capability and general modifications required on the BSM to meet the vibration, altitude and humidity environmental requirements.

4.11.1 Vibration

All the components used in the BSM have the capability to more than withstand the specified vibration requirement. However, the components would be repackaged on P.C. cards using solder rather than the wire wrap technique used in the prototype. In addition the integrated circuits would be soldered directly instead of using plug-in sockets. The PC boards are mounted such that all four (4) sides of the cards are supported resulting in prevention of high level mechanical resonances that would result in overstressing.

4.11.2 Altitude

The unit should encounter no difficulties or present any operational hazard in operation under the required altitude environment. All voltages within the system are small (approximately 46 VDC max.).

4.11.3 Humidity

The BSM is a sealed unit. Therefore, no problem should be encountered during operation at the specified humidity environment. In addition the PC boards shall be coated in accordance with the material specification for the airborne equipment.

Section 5

RECOMMENDED IMPROVEMENTS

5.1 General

Although the system performs well, some desirable improvements were identified during the test program. Consideration should be given to incorporation of these improvements in equipment covered by follow-on programs. The following are recommended for consideration:

- o Circuit Simplification and Component Reduction
- o Amp-Hour Memory
- o Discharge Current Range
- o Pressure Circuit
- o Total Power Reduction

5.2 Circuit Simplification and Component Reduction

Circuit simplification can be achieved both by review of present designed circuitry and use of IC components with improved circuit density (Quad Op Amps, Quad Comparators, etc.).

5.3 Amp Hour Circuitry Memory

The amp hour counter circuitry should be improved such that the counter will retain the battery status readout when input power is removed and reapplied. Reliable operation of the present system requires that 28 VDC input power be applied to the system continuously. This improvement can be accomplished by either using a separate isolated power supply or by applying battery power to the amp-hour circuitry continuously.

5.4 Discharge Current Ranges

Two five volt ranges of discharge current output can be used to improve the accuracy of this measurement. One range would correspond to discharges of 100 amperes to 1 ampere and the other range from 1 ampere to 10 milliamperes.

5.5 Pressure Circuit

The pressure measuring circuit should be redesigned to eliminate the variation of the pressure readout signal with large changes in temperature.

5.6 Power Dissipation

The amount of power being drawn from the battery should be reduced by increasing the impedance of the cell voltage divider circuitry, total battery voltage divider, and various other circuitry requiring battery power.

Section 6

OTHER REPORTS

6.1 Reliability and Safety

The results of the reliability study are as follows:

The reliability on the originally defined mission (5 components operating continuously for the 7 day mission - 168 hrs., and the remaining components operate for 1 hour) yields a system reliability of .99966. This valve exceeds the goal of .999.

If the mission time was defined as all components having to operate for the entire 7 day mission (168 hrs) the total BSM system reliability would be only .98. In order to obtain the reliability goal of .999 for a mission of this length two entire BSM systems would have to be made redundant.

There are no single point failures in the BSM which could lead directly to damage of equipment or personnel.

6.2 Alternate Battery Development Study

A study was made to determine the design changes and development cost in adapting the present BSM design to accommodate silver-cadmium or silver-zinc batteries. The characteristics considered in establishing the requirements included:

- o Cell and battery voltage
- o Charge efficiency
- o Temperature effect
- o Charging methods
- o Capacity loss characteristics

1) Cell and total battery voltage

   To accommodate the difference in number of cells and the per cell voltage, the following circuits require revisions:

   - o The logic circuitry for the multiplexer to accommodate the increase or decrease in number of cells to be multiplexed.

- o The gain of the differential output amplifier for the cell voltage output circuitry.
- o Readjustment of the reference voltages for the "undervoltage" and "overvoltage" alarm circuitry.

2) Charge Efficiency

The charge efficiency circuitry would require readjustment.

3) Temperature Effects

The temperature compensation circuitry would require rescaling the various gains to accommodate silver-cadmium or silver-zinc batteries.

4) Charging

The charging method would require no change. However, the reference voltage levels for reducing the charger current levels would require rescaling to accommodate the voltage level characteristics of the silver-cadmium or silver-zinc battery.

5) Capacity loss characteristics

The capacity loss in temperature circuitry requires changes in gain and comparator reference voltages to provide for the output capacity profile for silver-cadmium or silver-zinc batteries.

The result of the study shows that the development of a universal type BSM that can accommodate nickel-cadmium and silver-cadmium or silver-zinc batteries will result in a per unit cost of approximately 12-15 per cent above the cost of the Ni-cad type BSM. The per unit cost of a silver-cadmium or silver-zinc unit would be the same as the Ni-cad units except for a small non-recurring cost for the design revision and documentation.

Appendix I

RELIABILITY/SAFETY STUDY ON BATTERY STATUS MONITOR (BSM)

FOR CONTRACT NAS9-13654

The results of a preliminary analysis of the Battery Status Monitor (BSM) are as follows:

Assessed board reliability on the originally defined mission (5 components operating continuously for the 7 day mission - 168 hrs., and the remaining components operate for 1 hour) yields a system reliability of .99966. This value exceeds the goal of .999.

The reliability of each of the six boards is relatively close to one another. This is good in that there is no one or two "bad" boards i.e., boards with significantly higher failure rates which would result in repeated failures and high system down time.

The components with the highest failure rates are the D/A converter, and the three modular amplifiers A1, A9 and A10. The failure rates are not excessively high, however, and in fact are quite acceptable.

If the mission time was defined as all components having to operate for the entire 7 day mission (168 hrs) the total BSM system reliability would be only .98. In order to obtain the reliability goal of .999 for a mission of this length two entire BSM systems would have to be made redundant.

There are no single point failures in the BSM which could lead directly to damage to equipment or personnel.

Some background data are included in the attached tables and diagram.

SYSTEM RELIABILITY BASED ON 2 DIFFERENT "ON" TIMES

BOARD	$\lambda \times 10^6$	"ON" TIME
Board #1	27.05	t_1
Board #2	23.62 1.32*	t_1 t_2
Board #3	17.95	t_1
Board #4	19.53	t_1
Board #5	21.11	t_1
Power Board	8.53	t_1

*1.32 is the failure rate of 5 components on board #2 which are supposed to be on for the entire 7 day mission (t_2=168 hr). These components are BC-1C, BC-2C, R202, C_7, D_3.

Assuming all other components operate for t_1=1 hr., then the system reliability is:

$$R = e^{-\left[(117.79)\, t_1 + (1.32)\, t_2\right]}$$

$$R = .99966$$

MEASUREMENT AND TOTAL SYSTEM RELIABILITY

BASED ON CONSTANT "ON" TIME

OUTPUT MEASUREMENT	FAILURE RATE $\lambda \times 10^6$	RELIABILITY 1 Hr.	1 Day (24 Hr.)	1 WK. (168 Hr.)
Amp. Hr.	40.89	$.9_4\ 69$	$.9_3\ 02$	.9931
Capacity	66.79	$.9_4\ 33$	$.9_2\ 840$	.9888
Median Temp.	18.64	$.9_4\ 81$	$.9_3\ 55$	.9969
Total Voltage	10.22	$.9_5\ 0$	$.9_3\ 75$	.9983
Pressure	27.26	$.9_4\ 73$	$.9_3\ 35$	.9954
Current	19.72	$.9_4\ 80$	$.9_3\ 53$	.9967
Warning - Over/Under Voltage	31.07	$.9_4\ 69$	$.9_3\ 25$	.9948
Warning - Over Temp.	21.02	$.9_4\ 79$	$.9_3\ 50$	.9965
Warning - Over Pressure	29.64	$.9_4\ 70$	$.9_3\ 29$	.9950
Warning - Go/No Go	65.43	$.9_4\ 35$	$.9_2\ 843$	.9890
TOTAL SYSTEM	119.11	$.9_3\ 881$	$.9_2\ 714$	.980

MEASUREMENT FLOW DIAGRAM