Bendix

**Aerospace
Systems Division**

NO.	REV. NO.
EATM-17	

PAGE _____ OF _____

DATE   6 January 1969

PCU - SOLAR PANEL SIMULATOR
TEST REPORT

Prepared by: _____
R. Howell

Approved by: _____
D. Courtois

_____
K. Hsi

INTRODUCTION

A study was performed to determine if the ALSEP Power Conditioning Unit (PCU) is compatible with a solar panel array. The Solar Panel Simulator and the PCU Test Set were modified to permit a series of tests to verify the compatibility of the Qual-Backup ALSEP PCU with a solar panel array. The ALSEP PCU was not modified.

The test equipment modifications and test results are described; conclusions and recommendations are included.

SUMMARY

It has been determined that the ALSEP PCU is compatible with the simulated E-I characteristics of the PSEP solar panel array and that the regulation of the output voltages is within tolerance in the test temperature range of -22° (and lower) to +158°F for PSEP loads.

Further, it has been determined that the PCU probably will not switch from power conditioner #1 to #2 during the lunar sunset transient and that the PSEP PCU will probably start immediately and run properly at lunar sunrise providing the PCU temperature is above -75°F.

Solar Panel Simulation

The first task in this study was to determine the best means of simulating the I-V curves for the solar panel array designed for EASEP. Figure 1 shows these curves as a function of sun angles between 0° and 90°.

The curves of Figure 1 indicate a voltage controlled source for low currents and a current controlled source for high currents with a smooth transistion from one to the other.

There are two possible means for simulating these curves:

1) A standard power supply with a series resistor and a current limiter

2) The Solar Panel Simulator constructed for an earlier ALSEP solar power project.

Power decrease is 1.8 Watts/min

Figure 1 IV Curves for the EASEP/PSEP Solar Panel Array with Lunar Sun Angles from 0° to 90°
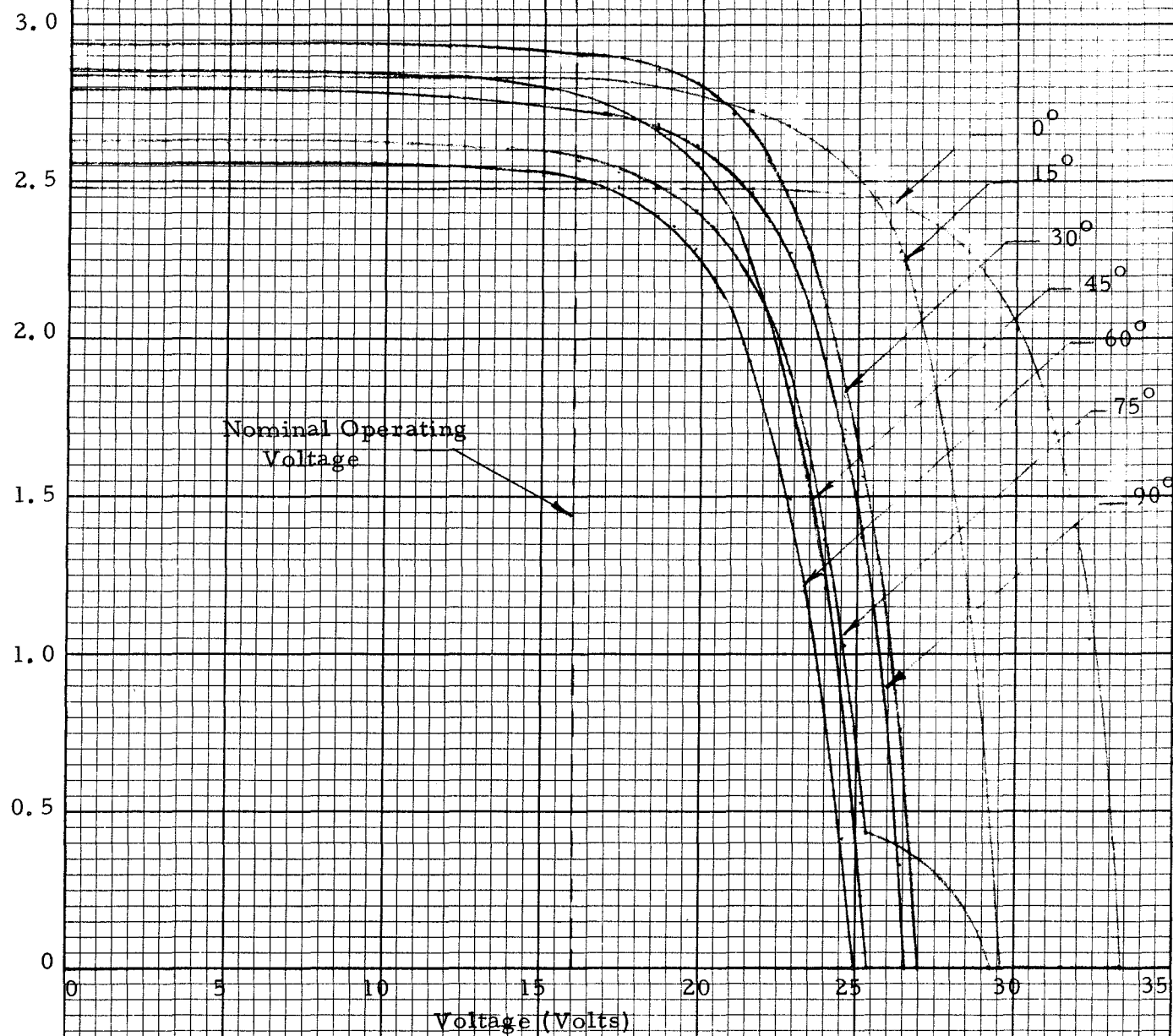
Figure 1 IV Curves for the EASEP/PSEP Solar Panel Array with Lunar Sun Angles from 0° to 90°
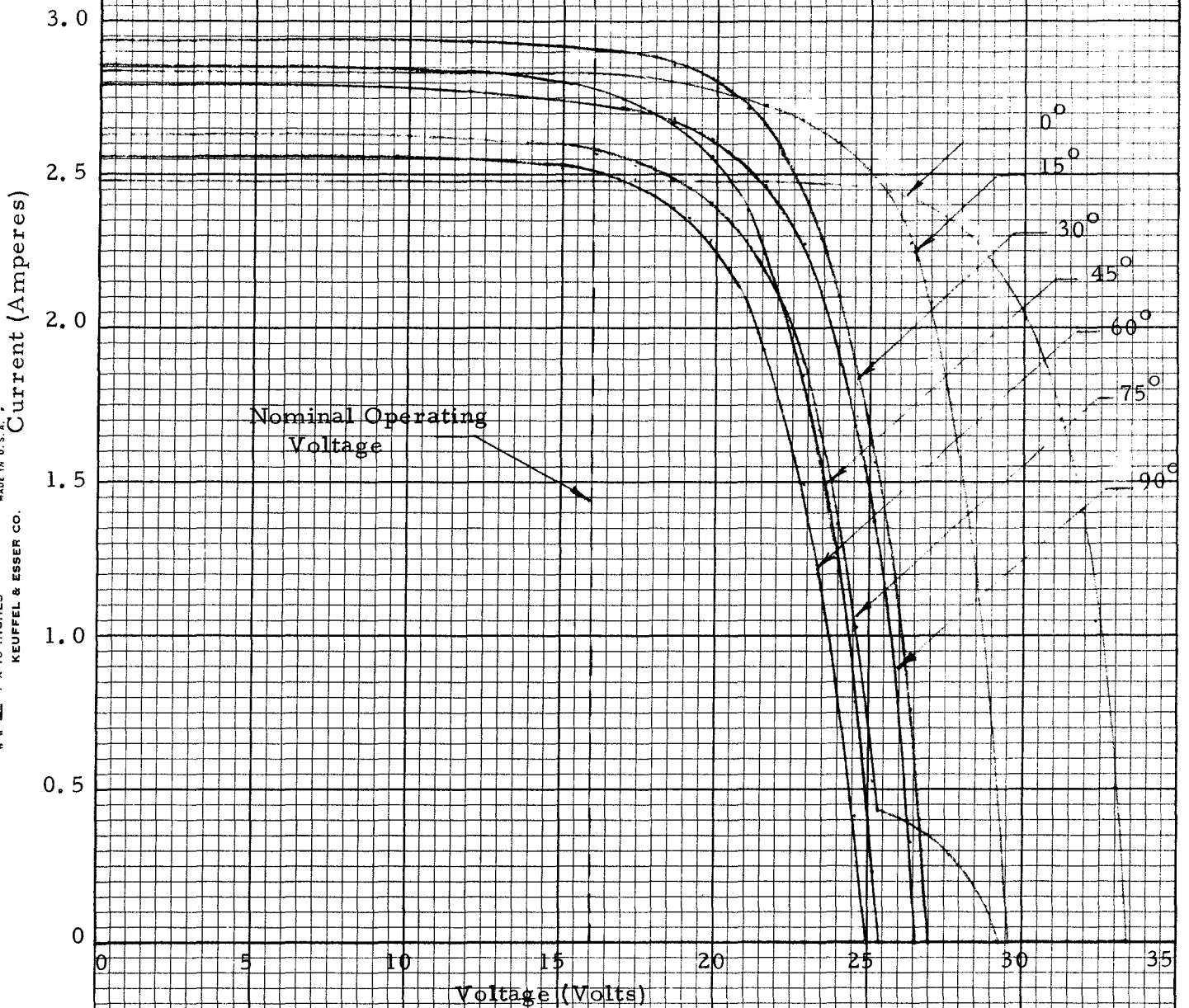
Power Supply with a Current Limiter

The power supply used for this test was the RTG power supply in the PCU test set. The I-V curve for that power supply is shown in Figure 2. These curves are not acceptable due to the negative slope in the current limiting region. The PCU regulator could not recover from this 180° phase shift. Thus, no further testing was performed with this means of simulating the solar panel.

Solar Panel Simulator

A Solar Panel Simulator (SPS) was designed and constructed for an earlier ALSEP Solar Power Project. The circuit was adapted from Patent No. 3,325,723 issued to J. H. Grayson. The SPS is described in ATM 727.

Tests were performed on the SPS to determine if it could reproduce I-V curve of Figure 1.

Figure 3 is a comparison of the solar panel characteristics and the SPS with and without an additional stage of gain in the current limiter circuit. The additional stage of gain is an obvious improvement. This stage of gain was incorporated into the SPS.

Figures 4, 5, and 6 show the curves for the solar panel array and the modified SPS for sun angles of 0°, 30°, and 60° respectively. These angles were chosen because they result in minimum or maximum values for open circuit voltage and/or short circuit current.

PCU Test Set Modifications

The PCU test set was modified to permit testing the PCU with the Solar Panel Simulator.

Two test points were added to permit the output of the SPS to be connected to the PCU input terminals. A third test point was added to permit setting the SPS short circuit current. Also, a shunt was installed for measuring the SPS output current on the PCU test set DVM.

The PCU regulator range for EASEP will be modified by removing two of four parallel strings of resistors in the Power Dissipation Module on the Central Station. This will change the regulator range from 55 to 30.5 watts. This change was incorporated in the PCU test set by adjusting the regulator resistors from 33 watts (7.37 ohms) to 30.5 watts (7.85 ohms). This adjustment was performed by the Calibration Lab.

Figure 2. IV Curve for a Power Supply with Series Resistance and Current Limiting
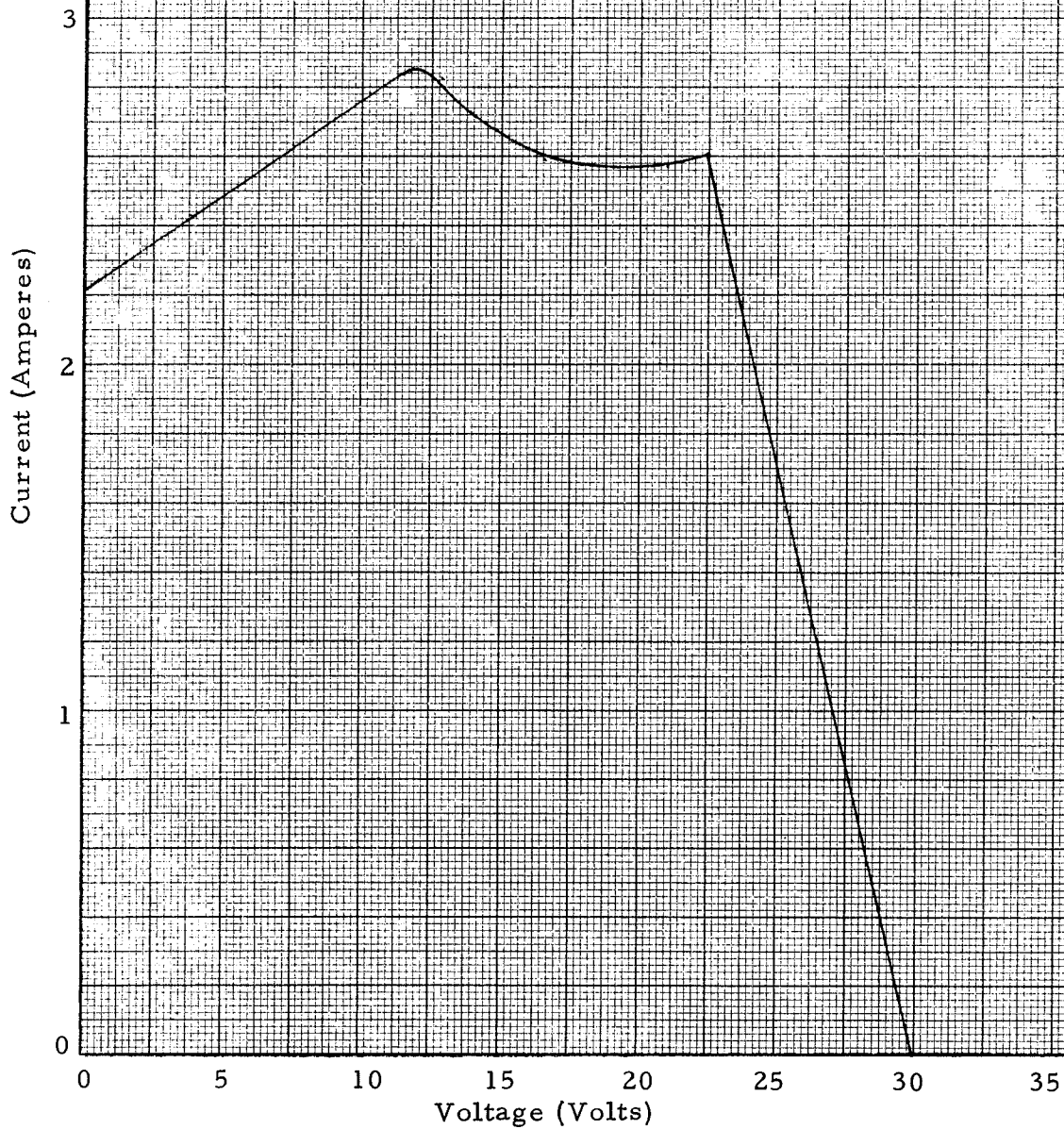
Figure 3 Comparison of IV Curves for the EASEP Solar Panel and Two Versions of the Solar Panel Simulator

0°

Figure 4 IV Curves for the EASEP
Solar Panel and the Solar Panel
Simulator at 0° Sun Angle

Solar Panel

Solar Panel Simulator

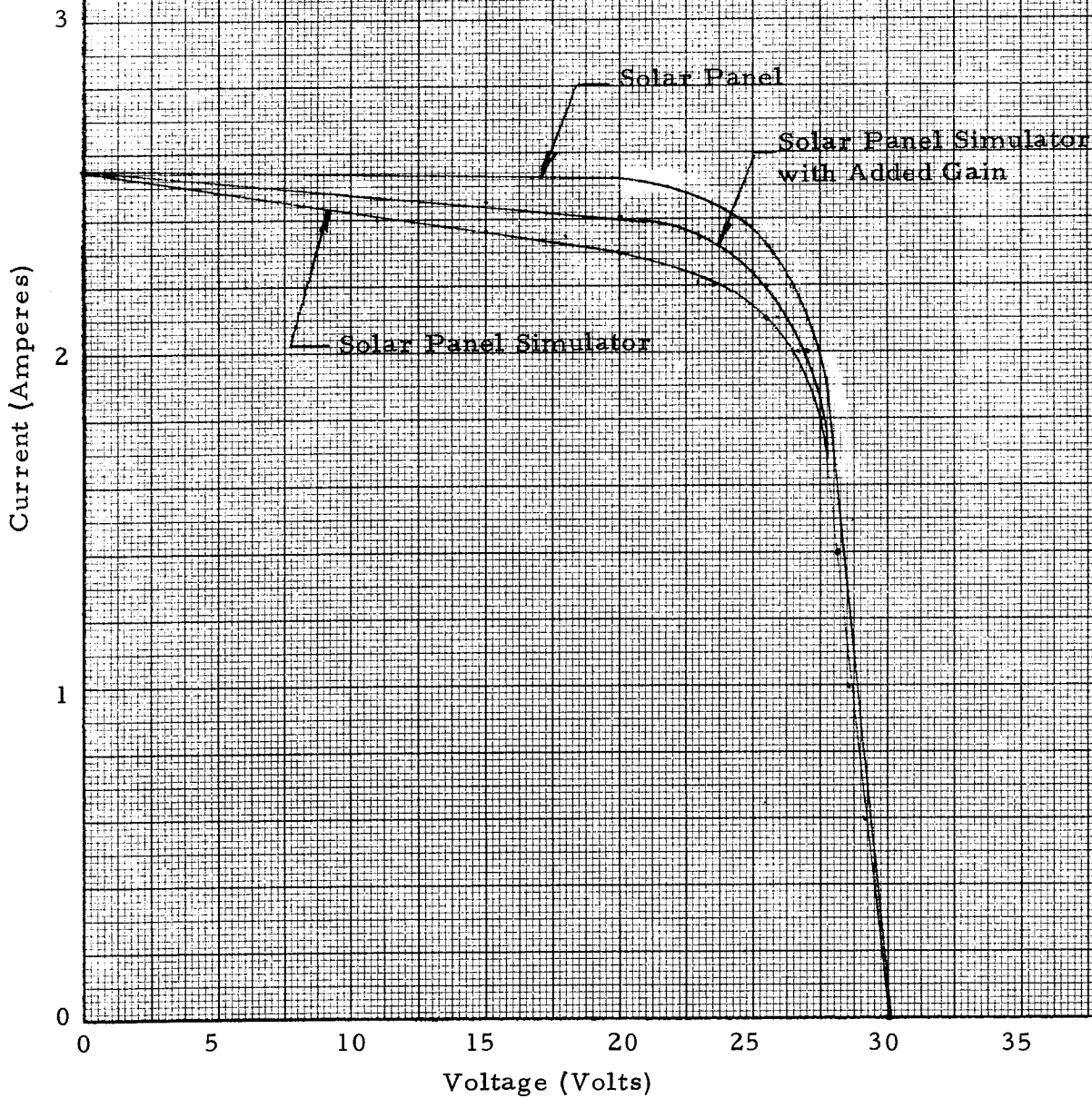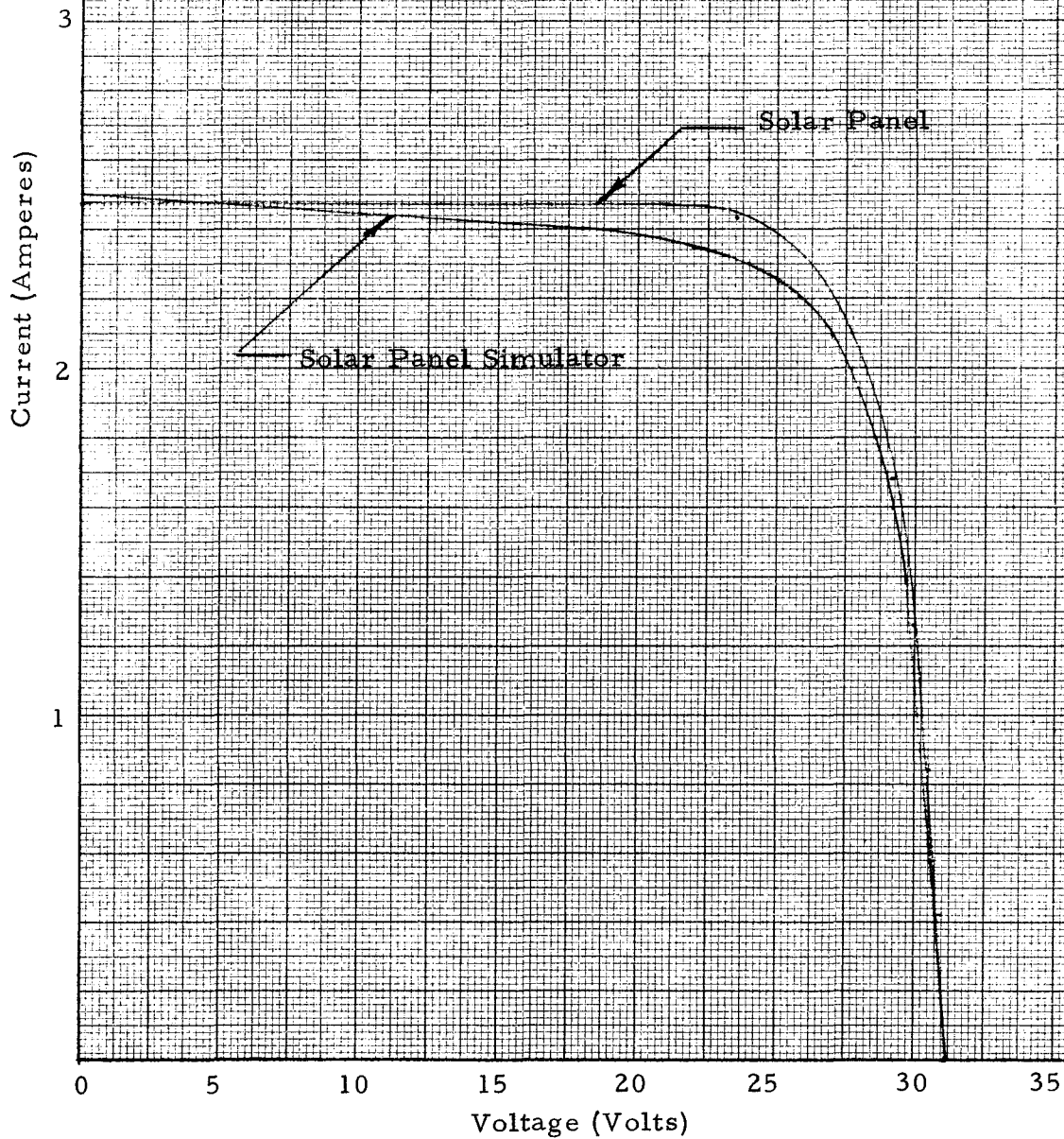Current (Amperes)

Voltage (Volts)

Figure 5 IV Curves for the EASEP Solar Panel and the Solar Panel Simulator at 30° Sun Angle

Figure 6 IV Curves for the EASEP Solar Panel and the Solar Panel Simulator at 60° Sun Angle
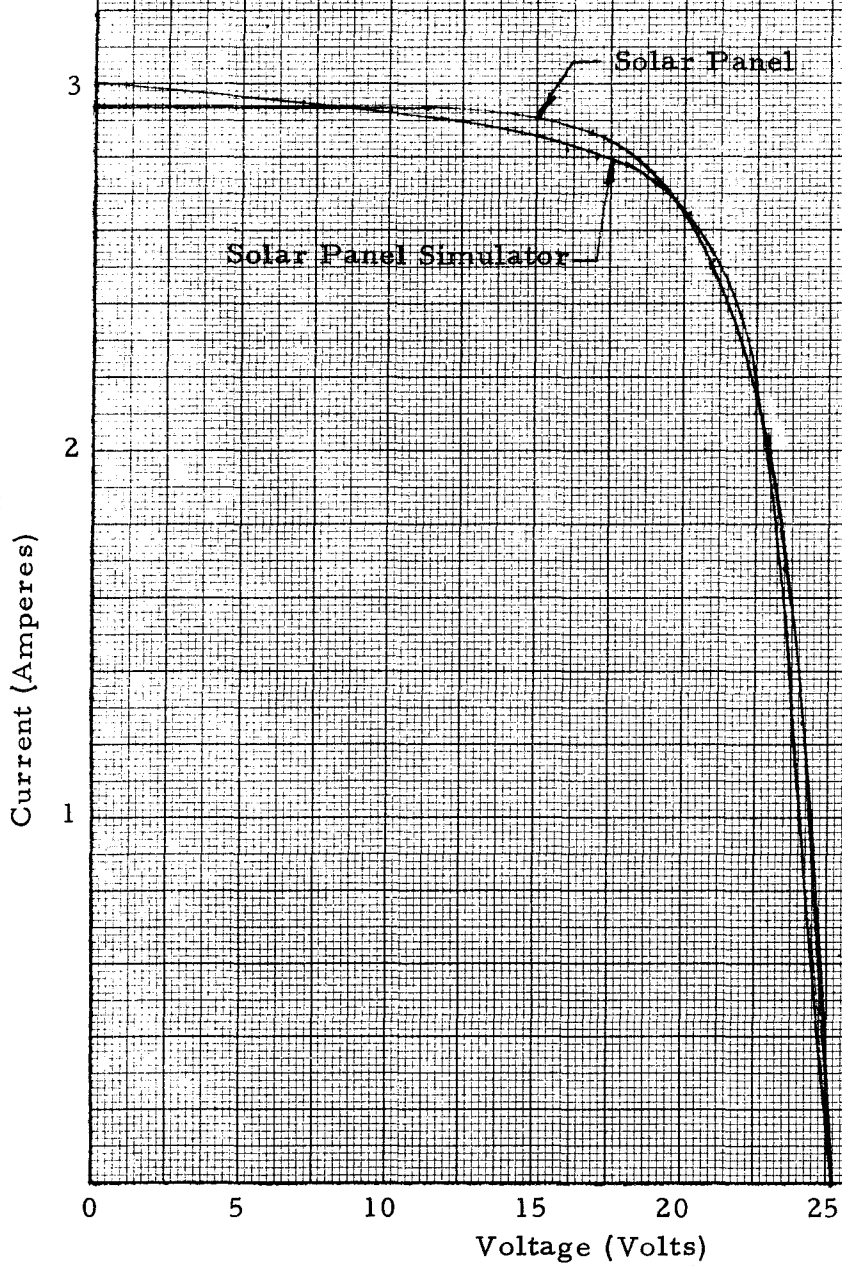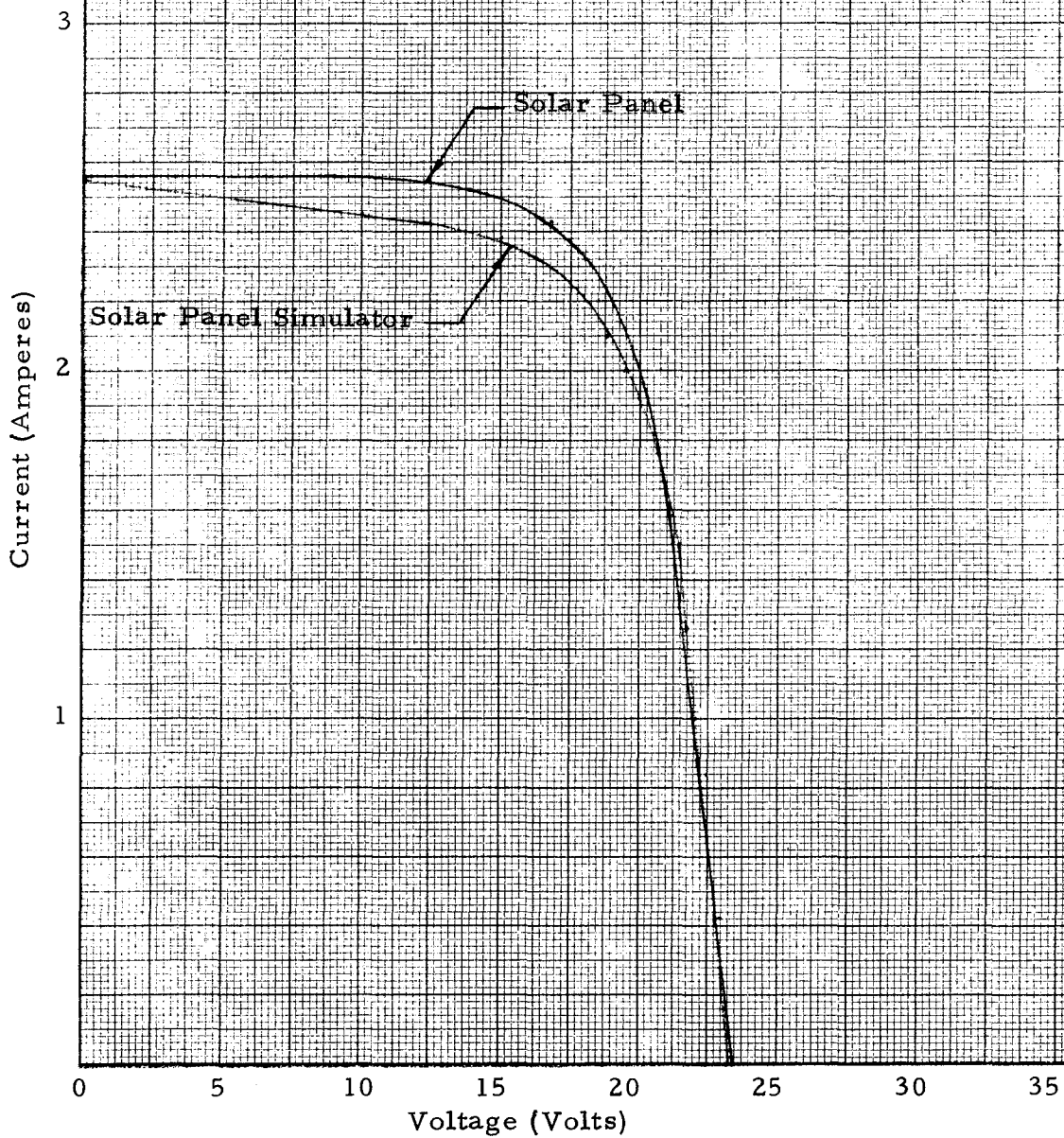
Bendix

Aerospace Systems Division

PCU - Solar Panel Simulator
Test Report

NO.	REV. NO.
EATM-17	

PAGE __9__ OF __15__

DATE 6 January 1969

PCU - SPS Compatibility Tests

A series of tests were performed to verify the compatibility of the ALSEP Power Conditioning Unit with the Solar Panel Simulator. The Qual Back-up PCU (P/N 2330000-3, SN 2) was used for these tests.

The following is an outline of the test. The as-run test procedures are available but have not been included as part of this report.

Test Procedure Outline

6.2	PCU TS set up
6.3	SPS TS set up
6.4	Initial test set up
6.5	PCU performance at 0° sun angle (Max E_{oc}, Min I_{sc})
6.5.1	PC #1 with 11.5 watts load
6.5.2	PC #2 with 11.5 watts load
6.5.3	PC #1 with 22.5 watts load
6.5.4	PC #2 with 22.5 watts load
6.6	PCU performance at 30° sun angle (Max I_{sc})
6.6.0.1	Adjust for 30° sun angle
6.6.1	PC #1 with 11.5 watts load
6.6.2	PC #2 with 11.5 watts load
6.6.3	PC #1 with 22.5 watts load
6.6.4	PC #2 with 22.5 watts load
6.7	PCU performance at 60° sun angle (Min E_{oc})
6.7.0.1	Adjust for 60° sun angle
6.7.1	PC #1 with 11.5 watts load
6.7.2	PC #2 with 11.5 watts load

Bendix

Aerospace Systems Division

PCU - Solar Panel Simulator
Test Report

| NO. | REV. NO. |
| EATM-17 | |

PAGE 10 OF 15

DATE 6 January 1969

Test Procedure Outline (continued)

6.7.3   PC #1 with 22.5 watts load

6.7.4   PC #2 with 22.5 watts load

6.8   Low voltage auto switch

6.9   Lunar morning start

Paragraphs 6.2 thru 6.7.4 were performed at three temperatures;
-22 + 5°F, Room Ambient, and +158 + 5°F. Paragraph 6.8 was performed
at room temperature and paragraph 6.9 was performed at -55 + 5°F and
-75 + 5°F. It should be noted the hold-off circuit was shorted out throughout
these tests.

PCU Performance with Temperature, Load, and Sun Angle

Paragraphs 6.5 thru 6.7.4 were performed to obtain voltage regulation
characteristics over the expected temperature, load, and input power ranges.
The actual current in the voltage regulator and the actual input current were
measured in order to permit calculating the reserve power at each condition.
Other data taken included telemetry outputs for input voltage, input current,
regulator and inverter temperatures, and regulator current.

The output voltage regulation as a function of load, temperature and sun angle
is shown in Table I. The input voltage variation is shown also.

Switching Problem

The performance of the PCU with the SPS was very good in all respects
except one. The exception occurred whenever the PCU was switched from
Power Conditioner 2 (PC2) to Power Conditioner 1 (PC1) with the 22.5 watt
load on the unit. The problem occurred at all three temperatures.

Troubleshooting at the end of the test revealed the problem was caused by the
slow response of the SPS to load changes. The PCU has a 300 millisecond delay
incorporated in its undervoltage trip circuit. If the voltage on the +12 volt line
remains below 10.8 volts for 300 milliseconds or longer, the undervoltage
circuit will trip the relay to put PC2 in operation. The SPS has a time constant
greater than 300 milliseconds. Thus, whenever the SET 1 command is sent,
the relay switches to PC1 but the voltage build-up is slow enough to cause the
undervoltage circuit to trip. This was verified by returning the test set-up
to the RTG mode of operation. The switching problem did not exist in the RTG
mode.

Bendix

Aerospace Systems Division

NO.	REV. NO.
EATM-17	

PCU – Solar Panel Simulator
Test Report

PAGE 11 OF 15

DATE 6 January 1969

TABLE I

VOLTAGE REGULATION OVER EXPECTED LOAD, TEMPERATURE AND INPUT POWER CONDITIONS

Power Conditioner 1

$-22^{\circ}F$		Ambient		$+158^{\circ}F$		Overall	
Min	Max	Min	Max	Min	Max	Min	Max
28.76v	28.80v	28.86v	28.89 v	28.91v	28.94v	28.76v	28.94v
15.08	15.11	15.16	15.19	15.21	15.24	15.08	15.24
11.98	11.99	12.00	12.01	12.00	12.01	11.98	12.01
-12.22	-12.22	-12.26	-12.27	-12.28	-12.28	-12.22	-12.28
- 5.93	- 5.936	- 5.99	- 6.00	- 6.0	- 6.03	- 5.93	- 6.03
5.057	5.073	5.14	5.16	5.2	5.2	5.057	5.2
15.67	15.82	15.73	15.89	15.76	15.94	15.67	15.94

Power Conditioner 2

Min	Max	Min	Max	Min	Max	Min	Max
28.63	28.67	28.76	28.80	28.84	28.88	28.63	28.88
15.02	15.06	15.13	15.16	15.2	15.2	15.02	15.2
11.96	11.97	11.99	12.00	11.99	12.0	11.96	12.0
-12.19	-12.20	-12.26	-12.27	-12.3	-12.3	-12.19	-12.3
- 5.921	- 5.93	- 6.00	- 6.01	- 6.0	- 6.0	- 5.921	- 6.01
5.04	5.056	5.13	5.14	5.1	5.2	5.04	5.2
15.55	15.66	15.61	15.71	15.64	15.79	15.55	15.79

Bendix

**Aerospace
Systems Division**

NO.	REV. NO.
EATM-17	

PCU - Solar Panel Simulator
Test Report

PAGE 12 OF 15

DATE 6 January 1969

Lunar Sunset Auto Switch

The preferred mode of PCU operation is in PC1. This permits automatic switch-over to PC2 if, as described above, the +12 volt line drops below and remains below 10.8 volts for 300 milliseconds. This is desirable in the event of a failure in PC1. This implies an automatic switch-over at lunar sunset and PC2 would be in operation at the next sunrise. However, if the switching point is passed at a slow rate, the switch-over will not occur. The purpose of this test (para. 6.8) was to determine the rate of change at which switch-over will not occur.

The rate of solar panel voltage change at lunar sunset is estimated to be approximately 0.5 volt per minute. Thus, in order to assure no switch-over, the PCU sensitivity must be greater than 0.5 volt per minute.

The results of the test show the highest rate of change at which switch-over would not occur was 1.88 volts per minute. This means that the lower limit of PCU sensitivity to voltage changes is about 3.7 times that expected from the solar panel.

Thus, the PCU will not switch to PC2 at sunset provided the estimate of 0.5 volt per minute for the solar panel is valid.

Lunar Morning Start

The solar panel characteristics are such that it can supply an open circuit voltage of approximately 50 volts and a short circuit current of 2.1 amperes under lunar sunrise conditions. Unfortunately, the central station thermal plate will be at its lowest possible temperature under the same condition. The temperature of the PCU will be -60 ± 10°F.

One of the critical characteristics of interest during the PCU development was the ability to start and run properly under load at low temperatures. Some of the early PCU models were weaker in this respect than the flight units. The unit used for this test (Qual Backup) exhibited some problems at running in the proper mode -22°F with a 46 watt load on PC1, however it had no problem starting or running with a 23 watt load at -22°F. The Qual, Flight 1, and Flight 2 (EASEP) units did not exhibit any problem starting or running at low temperatures. A design change incorporating high gain transistors eliminated the problem for Flights 3 and up.

Bendix

Aerospace Systems Division

PCU – Solar Panel Simulator
Test Report

NO.	REV. NO.
EATM-17	

PAGE 13 OF 15

DATE 6 January 1969

The purpose of this test (Paragraph 6.9) was to determine the cold starting characteristics of the PCU at -55°F and -75°F with the 22.5 watt load.

The results of the test showed that both sides of the PCU would start at -55°F with a 22.5 watt load. The data for PC2 are shown in Table II. The test at -75°F showed PC2 ran properly but PC1 did not. The +12 volt line voltage was approximately 10.5 volts. This is characteristic of the mode of running on the early models as described above.

As a result of these tests it appears unlikely that the Flight 2 unit will have any problem starting or running properly as long as the PCU temperature is above -75°F.

CONCLUSIONS

The following conclusions have been drawn from the results of this test:

1. A standard power supply with current limiting can not simulate a solar panel array.

2. The Solar Panel Simulator provided a satisfactory solar panel simulation with an additional stage of gain in the current limiter.

3. The Solar Panel Simulator has a fairly long time constant and prevents switching from PC2 to PC1 by normal means.

4. The PCU will not switch from PC1 to PC2 at sunset provided the estimate of 0.5 volt per minute rate of change is valid.

5. The Flight 2 PCU should start and run properly provided the PCU is above -75°F.

RECOMMENDATIONS

The following recommendations are made:

1. The Solar Panel Simulator should not be used in subsequent testing due to the switching problem encountered.

2. The RTG Simulators will not require any modifications for subsequent tests. However, the 33 watt regulator resistors must be recalibrated to 30.5 watt regulator resistors if the central station PDM is not used for all tests.

3. A better estimate of the solar panel array performance during lunar sunset is needed to determine if switch-over from PC1 to PC2 will or will not occur.

4. Study and modify the SPS to reduce its time constant if it is needed on subsequent tests.

Bendix

Aerospace Systems Division

PCU - Solar Panel Simulator
Test Report

NO.	REV. NO.
EATM-17	

PAGE 15 OF 15

DATE 6 January 1969

TABLE II

POWER CONDITIONER 2 OUTPUT VOLTAGES AT
-55°F with a 22.5 Watt Load

+29	28.61
+15	15.01
+12	11.94
-12	-12.16
- 6	- 5.891
+ 5	5.008