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SOLAR CELL RADIATION FLIGHT EXPERIMENT

FIRST QUARTERLY PROGRESS REPORT

JPL Contract 952351

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TECHNICAL CONTROL STATEMENT

This first Quarterly Progress Report for the Solar Cell Radiation Flight Experiment Project summarizes the work performed during the time period from 14 August to 2 December 1968, and is submitted to the Jet Propulsion Laboratory for approval This report contains information prepared by the Hughes Aircraft Company under JPL Contract No 952351. Its contents are not necessarily endorsed by the Jet Propulsion Laboratory, California Institute of Technology, or the National Aeronautics and Space Administration.

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ABSTRACT

The primary objective of the Solar Cell Radiation Flight Experiment, scheduled for launch on the ATS-E spacecraft, is to provide high accuracy data permitting a technical evaluation of the effects of the radiation environment in synchronous orbit on selected state-of-the-art solar cell configurations Data from the flight experiment and supplemental ground test program is a continuation of the work performed by other experimenters, and will provide design data required for extended spacecraft missions in synchronous orbit

The flight experiment consists of two small solar panels containing a total of 80 solar cells representing 16 solar cell configurations and two signal processors required to interface with the ATS-E telemetry system.

The Solar Cell Radiation Flight Experiment was initiated on 14 August 1968 under Jet Propulsion Laboratory Contract 952351 to the Hughes Aircraft Company. The detail design of the Flight Experiment, Project Status and results of tests conducted to date are presented in this report for review by the Jet Propulsion Laboratory

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1 INTRODUCTION

The primary objectives of the Solar Cell Radiation Flight Experiment, scheduled for launch on the fifth Applications Technology Satellite (ATS-E), are to isolate and identify the solar cell degradation mechanism(s) resulting from particulate radiation and to obtain specific design data applicable to extended synchronous spacecraft missions The program, which encompasses the design, qualification, and fabrication of the Flight Experiment and a supplemental ground test program, was initiated under JPL Contract No 952351 on 14 August 1968

The flight experiment consists of two small solar panels (a rigid panel tangentially mounted to the spacecraft midsection and a flexible panel radially mounted to the spacecraft midsection) and two signal processor units which interface with the ATS-E telemetry subsystem. A total of 80 solar cells representing 16 solar cell types will be mounted on the panels and periodically monitored during flight When activated by ground command, the flight experiment will provide 12 current voltage points for each solar cell and the temperature of each group of five identical solar cells. The periodic activation of the experiment and reduction of the solar cell data, in conjunction with data from the solar aspect sensors and radiation spectrometers, will permit a comprehensive evaluation of the radiation effects on solar cells

Solar cells representative of the current state of the art have been selected for the flight experiment for the following specific purposes:

1) Provision of five cells of each type for statistical analysis

2) Investigation of shunt loss effect noted on ATS-I solar cell experiment

3) Investigation of radiation effects on coverslide thicknesses

4) Investigation of coverslide or adhesive darkening effects due to radiation

5) Investigation of the shunt loss effect resulting from low energy proton damage to exposed solar cell areas and contacts

6) Investigation of radiation effects on the rear surface of three cell configurations

7) Correlation of the observed radiation degradation with the radiation environment as measured by the spacecraft-mounted radiation spectrometers

The supplemental ground test program includes proton, electron, and ultraviolet particulate radiation of state-of-the-art and advanced solar cell types The results of the ground test program will permit the final selection and optimization of the solar cell configurations for the flight experiment and the data required for correlation of the flight test results.

The detail design of the Solar Cell Radiation Flight Experiment, major milestones, and results of tests conducted to date are presented in this report for review and approval by the Jet Propulsion Laboratory

2 TECHNICAL DISCUSSION

FLIGHT EXPERIMENT CONFIGURATION

The Solar Cell Radiation Flight Experiment, shown in Figure 1, consists of the following components:

1) A rigid solar panel tangentially mounted to the spacecraft containing five solar cells of 13 types and 13 thermistors.

2) A flexible solar panel radially mounted to the spacecraft containing five solar cells of three types and three thermistors mounted to a flexible substrate.

3) A total of 80 solar cells of the 2 by 2 cm configuration.

4) Two signal processor units which sequentially select the solar cells and load resistors and process the signal into the format for telemetry via the ATS-E encoders.

5) A spacecraft payload regulator which provides the regulated power required to activate and operate the experiment and to protect the spacecraft bus from an experiment failure.

Solar cells for the flight experiment have been tentatively selected based on the data resulting from previous experiments, ground test results, and spacecraft flight data The selection of candidate cell configurations, shown in Table 1, has been heavily weighed toward obtaining design data on state-of-the-art solar cells and toward isolating the major degradation mechanism(s) observed on previous experiments and spacecraft Five solar cells of 16 types are planned to provide a meaningful statistical sample. The five cells and a temperature sensor or thermistor will be sequentially sampled to provide 12 current voltage measurements of the I-V characteristics. Five cells of three types have been assigned to the flexible panel to evaluate the effect of radiation on the back cell surface and the potential problems to be encountered on the design of large area flexible arrays. The three cell types on the flexible panel are identical to three of the 13 cell types on the rigid panel and will provide the comparative data for data evaluation Cells of the 2 by 2 cm configuration have been selected for the experiment.

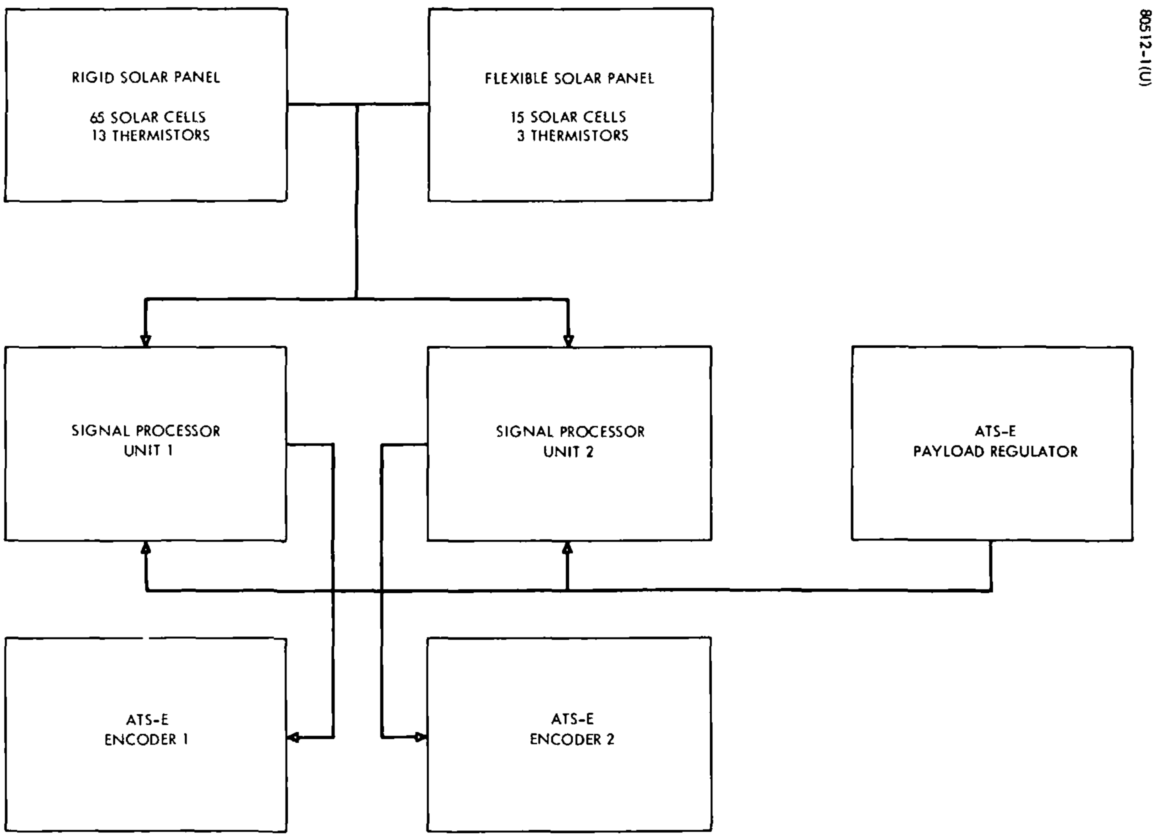

Figure 1. Solar Cell Radiation Flight Experiment Block Diagram

TABLE 1. LIST OF CELL CONFIGURATIONS*

Configuration Number	Cell Type	Resistivity (Ω-CM)	Cell Thickness (Mils)	7940 Coverglass Thickness (Mils)	Coverslide Gap (Mils)	Submodule Location
1	N/P	10	12	1	0	Main Panel
2	N/P	10	12	6	0	Main Panel
3	N/P	10	12	12	0	Main Panel
4	N/P	10	12	20	0	Main Panel
5	N/P	10	12	60	0	Main Panel
6	P/N (Li Float Zone	--	12	6	0	Main Panel
7	P/N (Li Crucible)	--	12	6	0	Main Panel
8	N/P	10	12	12	0	Main Panel (Solderless Bus Bar)
9	N/P	10	12	12	15	Main Panel
10	N/P	2	8	6	0	Main Panel
11	N/P	2	8	6	0	Flexible Panel
12	N/P Wrap-Around	--	12	6	0	Main Panel
13	N/P Wrap-Around	--	12	6	0	Flexible Panel
14	N/P	10	12	6	0	Flexible Panel
15	N/P	10	12	60	0	Main Panel (Solderless Grid Lines)
16	N/P (Pre-Irradiated)	10	12	12	0	Main Panel (No Filters A-R Coating Adhesives)

Notes.

1. One coverslide adhesive will be selected, based on ground test data, and will be used on all solar cells except No 16.
2. Five (5) solar cells of each configuration will be flight tested.
3. Final selection of candidate solar cells to be based on ground test results.

* This is the first preliminary configuration matrix which may be modified following further discussions with interested investigators in the solar cell field and/or initial results from the Ground Test Program

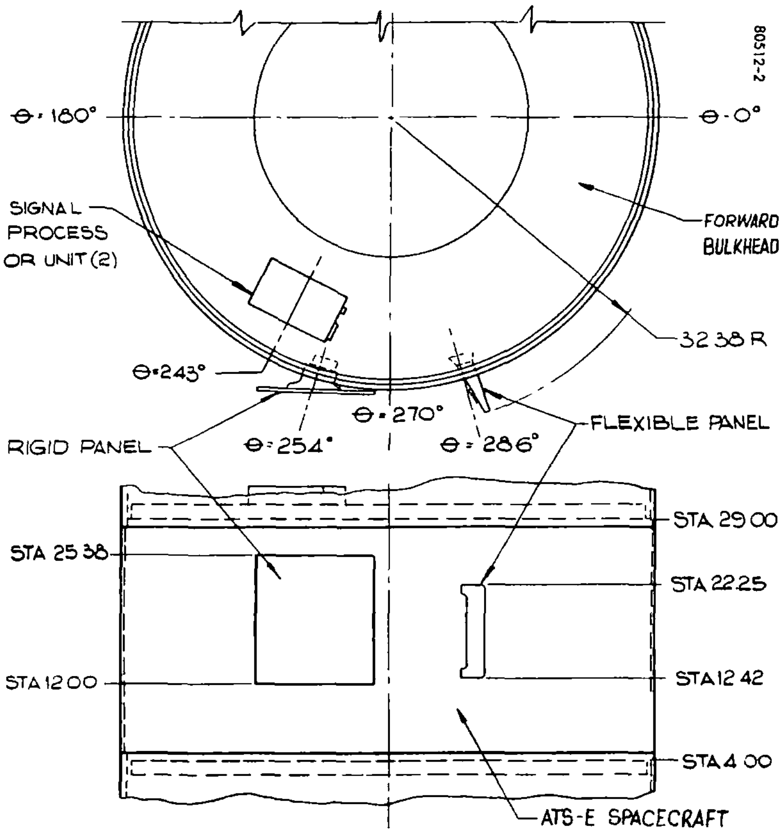

Figure 2. Solar Cell Radiation Flight Experiment Spacecraft Location

Individual lead wires are provided for voltage and current measurement of each solar cell by the signal processor units. The signal processors utilize four main-frame telemetry channels of the ATS-E encoders.

Two ground commands activate and control the experiment: (1) Payload Regulator On, and (2) Payload Regulator Off Due to the location of the solar panels on the spacecraft midsection, the experiment will be activated twice to obtain the full complement of data, once when each panel approaches the sun normal position. The elapsed time interval required for each activation is 45 minutes.

Each solar panel and signal processor unit will be subjected to qualification and acceptance testing at the unit level, and the flight experiment will be subjected to systems and spacecraft acceptance testing after installation

Spacecraft Interface

The location of the Solar Cell Radiation Flight Experiment on the ATS-E spacecraft is shown in Figure 2. The solar panels are externally mounted on the spacecraft midsection or "bellyband" at stations θ = 254 degrees and θ = 286 degrees. The two signal processors are mounted, one on top of the other, on the forward bulkhead at station θ = 243 degrees The locations have been selected to minimize spacecraft weight and to eliminate shadowing of the panels by the gravity gradient booms.

Each solar panel is thermally isolated from the spacrcraft to provide minimum impact on the spacecraft design Installation of the panels after spacecraft assembly requires the addition of nut plates on the spacecraft structure, and of holes in the bellybands for the harnesses and attaching bolts

Additional insets will be required on the forward shelf for installation of the signal processor units. Due to the low power levels, 4.8 watts per unit, operation of the experiment will not impact the spacecraft thermal design

The payload regulator will be mounted in the forward bulkhead at station θ = 22.5 degrees. The spacecraft wire harnesses will be redesigned to incorporate the payload regulators, signal processor units, and the two solar panels.

Design modification of the ATS-E spacecraft to incorporate the Solar Cell Radiation Flight Experiment has been initiated by Hughes Aircraft Company. Interface drawings and specifications defining the Flight Experiment are scheduled for release by 16 December 1968.

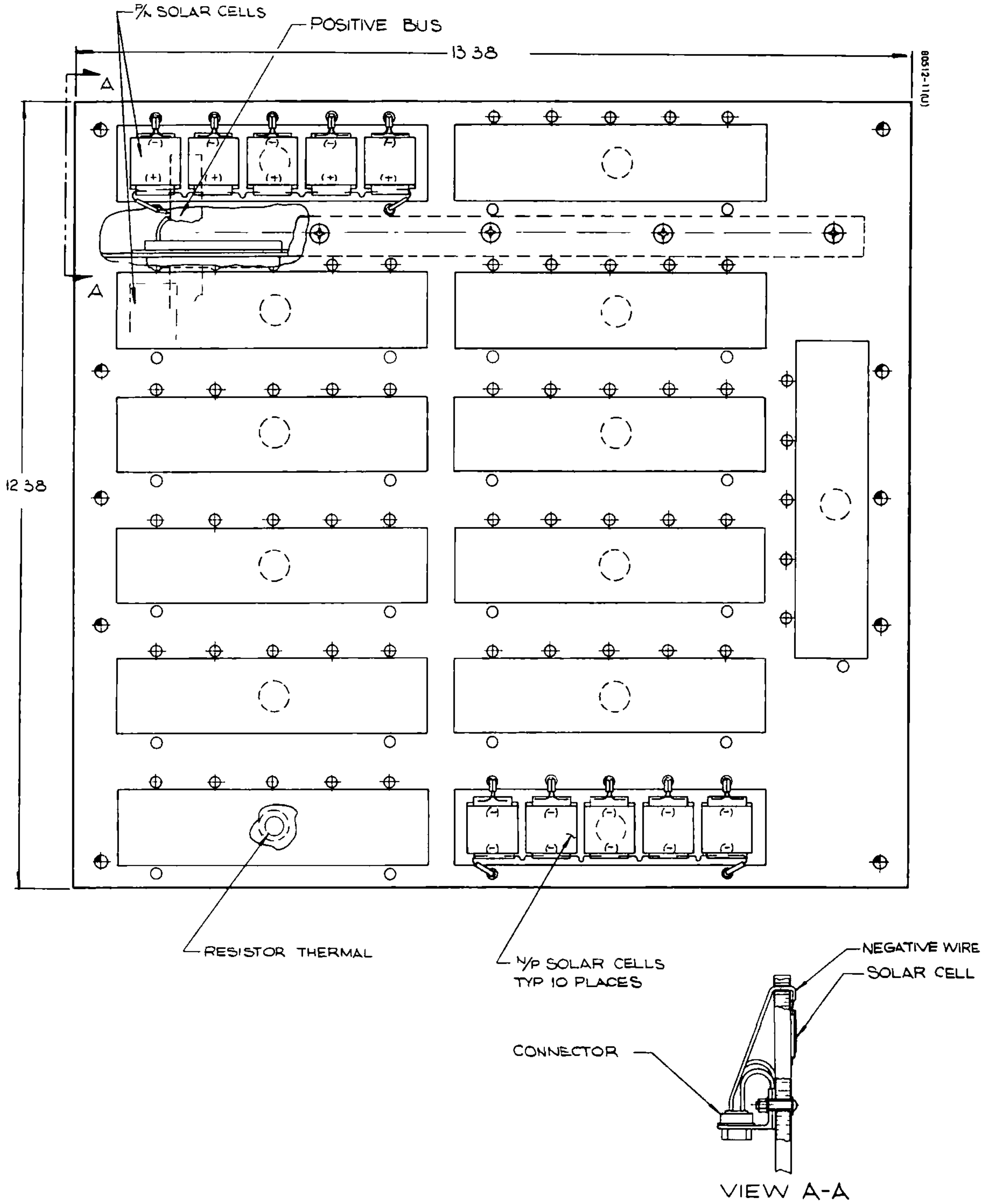

Figure 3. Rigid Panel

Solar Panels

The design of the two solar panels for the Solar Cell Radiation Flight Experiment has been completed, and fabrication of the substrates for the qualification and flight models has been initiated. Both solar panels have been redesigned for the revised spacecraft locations which were selected to eliminate shadowing by the spacecraft booms All of the solar cells and coverslides have been received, and fabrication of the qualification panels has started

Rigid Solar Panel Design

As shown in Figure 3, the rigid solar panel contains a total of 65 solar cells, five cells each of 13 selected configurations. Each group of five identical solar cells is individually bonded to an insulated aluminum strip to form a submodule. Each submodule is bonded to the substrate, which is of aluminum faced honeycomb construction. Individual voltage and current lead wires are routed from the solar cell through the substrate via insulated feedthrough to the panel electrical connectors. The solar cell ground is similarly routed through the substrate to a formed copper ground bus on the under surface of the substrate. The formed copper bus has been designed to minimize voltage differentials between the submodules

Thirteen temperature sensors, one for each solar cell submodule, are positioned under the center cell of the five cell group. The thermistors are bonded to the substrate face sheet for thermal conductance.

The design of the substrate, originally fiberglass faced, has been revised to incorporate 0 012-inch thick aluminum face sheets for thermal control purposes The face sheets will be bonded to the aluminum honeycomb core, nominally 0 25-inch thick, using the fabrication processes developed for the spacecraft structural bulkheads

After completion of solar cell bonding and wiring, the area surrounding the solar cells on the top surface of the solar panel will be covered with a vacuum deposited aluminum mylar thermal covering Based on the thermal analysis, the estimated panel temperatures will be within a range of 140°F (when sun normal) to -200°F during eclipse

After fabrication, each solar cell submodule will be subjected to thermal cycling testing, and each solar panel will be subjected to vibration and thermal cycling/thermal vacuum testing

The flight solar panels will be mounted to the ATS-E spacecraft structure using mounting brackets at each end of the panel The mounting brackets will be thermally isolated from the spacecraft to minimize the effect of the Solar Cell Radiation Flight Experiment on the spacecraft thermal balance. The estimated weight of the rigid panel is 1.70 pounds.

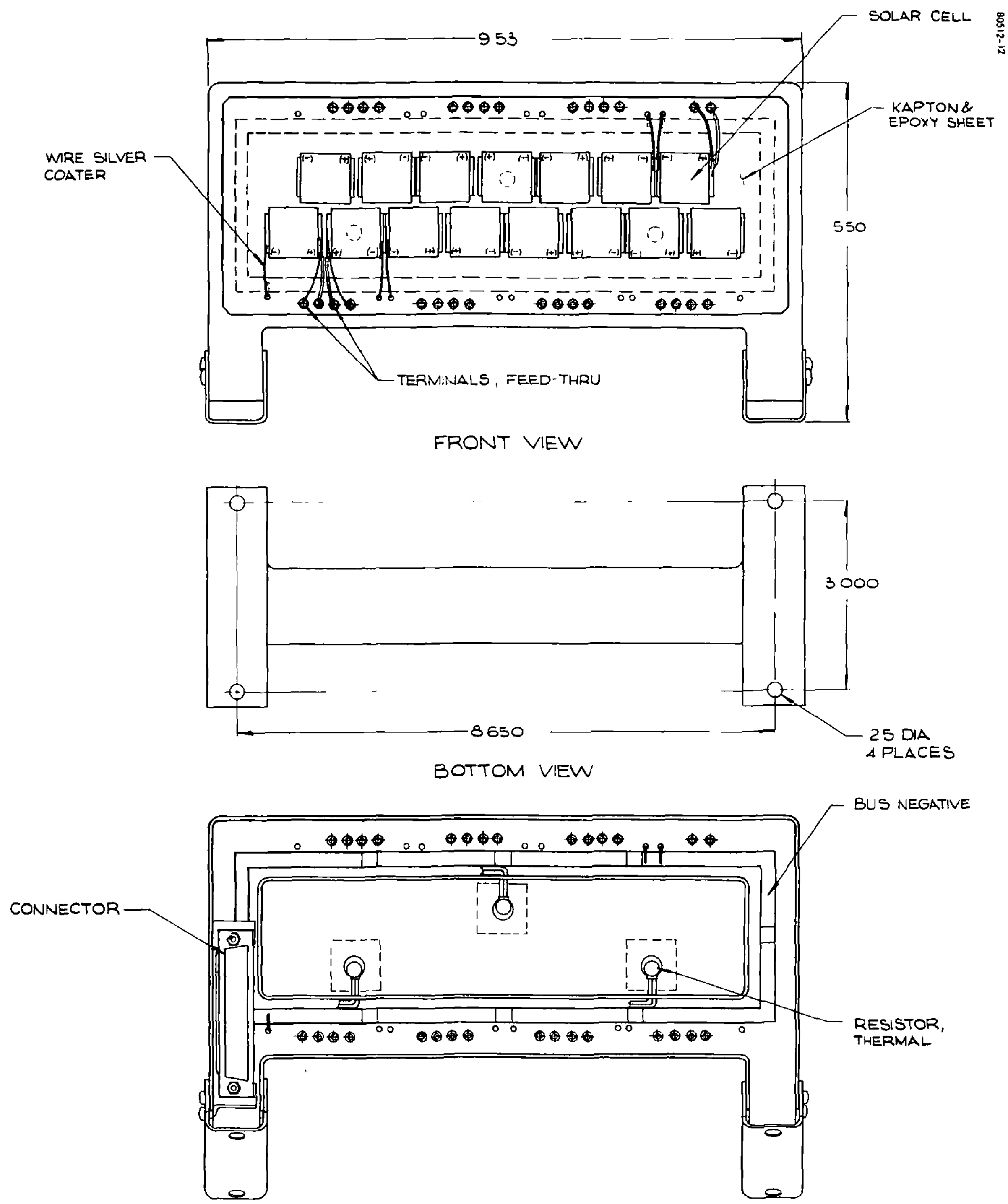

Figure 4. Flexible Panel

Flexible Solar Panel Design

The flexible solar panel, shown in Figure 4, contains a total of 15 solar cells (five cells each of three configurations) bonded to a thin flexible substrate member. The substrate will be bonded to a laminated fiberglass frame which will be bolted to the spacecraft structure. After bonding to the fiberglass frame, which will contain the copper ground bus and the terminals, each solar cell will be individually wired to the panel connector. Three temperature sensors will again be incorporated to monitor solar cell temperatures

The solar cells selected for the flexible panel are identical to configurations mounted on the rigid panel, thereby permitting a comparative evaluation of back-side radiation effects. The cells will be bonded to a substrate fabricated using 1 mil Kaplon and 1 mil fiberglass cloth. The flexible substrate will be pretensioned when bonded to the laminated frame

The estimated temperature extremes of the flexible panel are +140°F under sun normal and -225°F when in eclipse. Use of the fiberglass frame provides thermal isolation from the spacecraft. The estimated weight of the flexible panel is 0.65 pound.

Solar Panel Fabrication

Materials and processes selected for solar panel fabrication are based on Hughes experience on the ATS program.

Based on the results of the ground test program, solar cell coverslides will be installed using the DOW-XR6-8489 coverslide adhesive system, except for the one group of five cells where the coverslide will be mechanically positioned. Solar cells will be bonded using the Hughes modified epoxy adhesive, and a fiberglass scrim cloth for insulation purposes.

Signal Processor Unit

The design of the signal processor unit has been completed, and the evaluation testing of a breadboard model has been successfully completed Fabrication of subassemblies for the qualification and flight units is in progress. Based on the successful completion of the breadboard evaluation tests, no major problems are anticipated other than receipt of some components.

Each of the two identical signal processor units has been specifically designed to interface between the solar panels and the ATS-E encoder. Each signal processor will provide voltage-current data for 40 solar cells under 12 load conditions and the temperature of each group of five cells Figure 5 depicts the signal processor unit interface, and Figure 6 depicts the unit detail block diagram. As shown in Figure 5, the two units are cross-strapped so that either encoder can be used to provide data for the complete flight experiment. Separate encoder inputs are used by each unit to provide the necessary isolation.

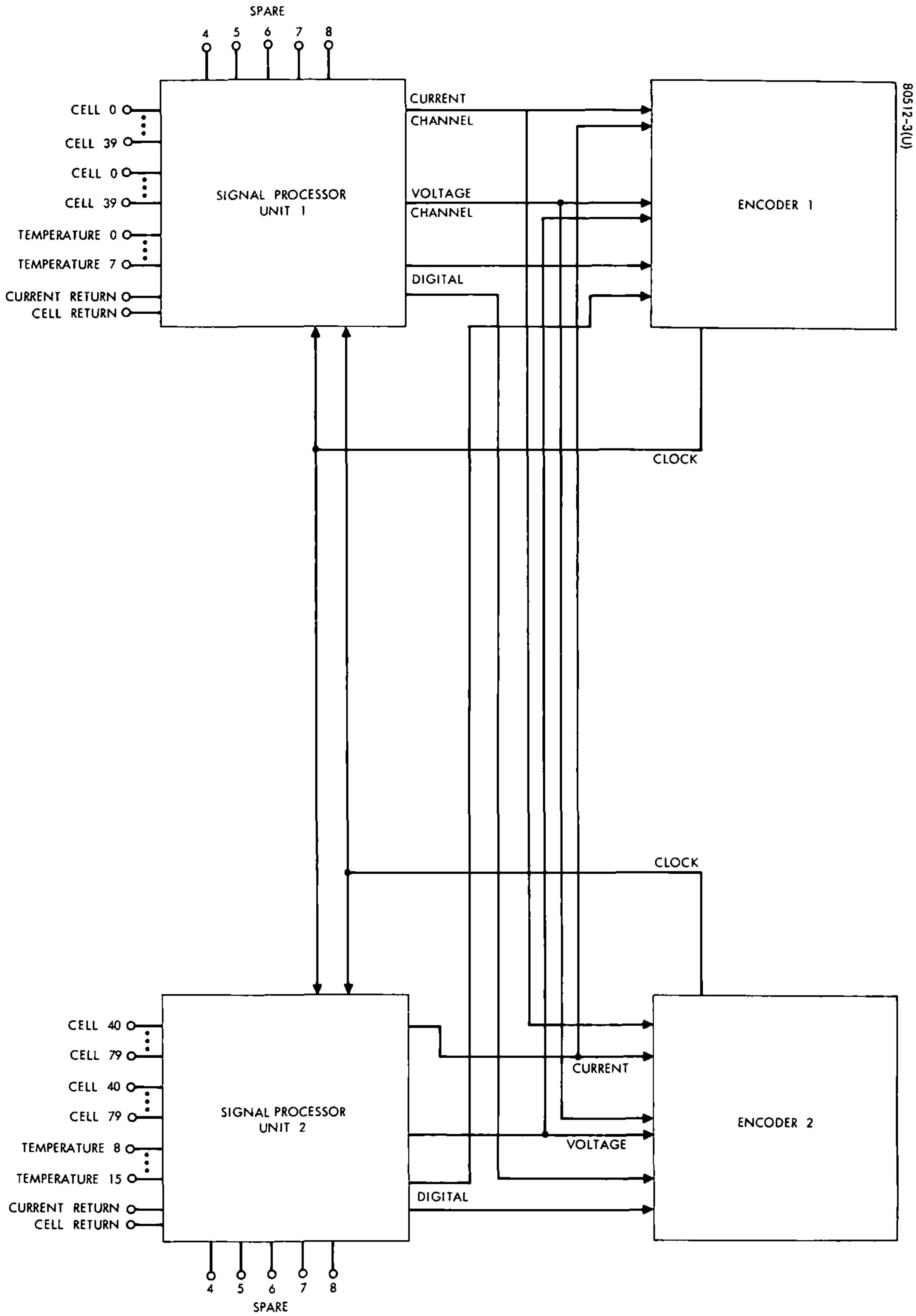

Figure 5. Signal Processor Unit/Encoder Interface

Figure 6. Signal Processor Unit Detail Block Diagram

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Solar cell selection and loading is controlled by relays One cell select relay is energized while the unit sequences through the load select relays which place one of the 12 precision resistors in series with the solar cell. Figure 7 presents the solar cell characteristics and load resistor selection. Current is measured by measuring the voltage across the load resistor This measured voltage is amplified to a level compatible with the -5. 12 volt encoder analog input capability. Cell voltage is measured differentially across the cell to eliminate line drop problems Each of the voltages is buffered and the difference between them is amplified to a 0 to -5. 12 volts level. The voltage common (cell RTN) line and the current common line are connected together at the solar panel bus to eliminate current flow in the voltage common line

Thermistors, located on the solar panels, are connected to a bias network to divide the -10. 24 volt reference voltage to an appropriate voltage level.

Power for the signal processor is derived from the -24 volts generated in the payload regulator. From this voltage, an electronic conversion unit (ECU) generates all of the supply voltages required for operation by the signal processor The primary purpose of the ECU is to provide isolation between the power return (transformer primary) and signal ground (transformer secondary), thus minimizing circulating ground currents

The signal processor is activated by ground command to the payload regulator. Operation is controlled by three timing circuits The load timing circuit controls which load select relay is to be energized and is incremented once each minor frame by a clock reference generated from the encoder channel 0 pulse. The cell timing circuit controls which of the four cells is analyzed during a major frame and is incremented after the load counter has completed its 16 states. The major frame timing circuit controls which of the 10 major frames required for the 40 solar cells is the current one

As shown in Figure 5, spare data channels are provided within the signal processor and are utilized for telemetry of other spacecraft data Data transmittal will use four main frame channels of the ATS-E telemetry system

Figure 8 depicts the construction of one circuit board including the method used for protective foaming

The signal processor unit operates on the following time cycle

1) Time for single V-I point — 3 seconds

2) Time for one cell — 48 seconds

3) Time for 40 cells — 32 minutes

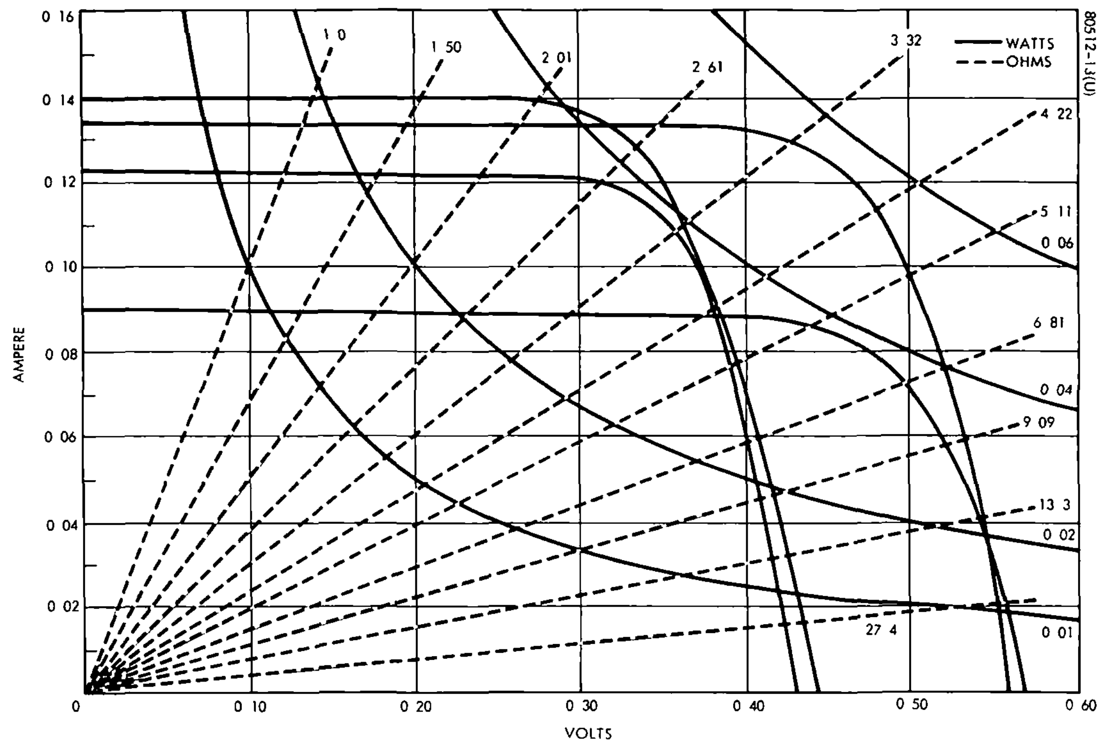


Figure 7. Load Resistors and Power Dissipations

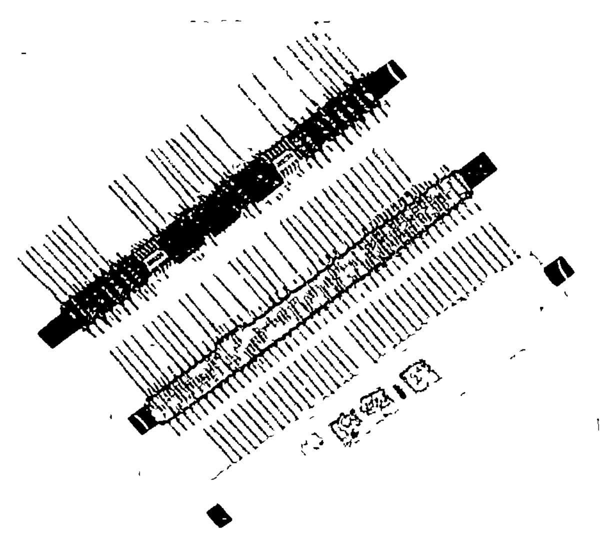


Figure 8. Signal Processor Stick Fabrication
(Photo 4R06666)

Temperature data will be transmitted once every four cells. Based on the selection of five cells of each single type, the temperature data will not be fully sequenced with the cell under test. A maximum time interval between the measurement of one cell of the five cell group and the temperature of the group will not exceed 6 minutes

Voltage calibration data is also telemetered for every fourth solar cell This calibration data will provide a reference source for the reduction of cell data.

Each signal processor unit occupies a volume of 5.18 inches by 9.50 inches by 1.40 inches and weighs 3.0 pounds. The estimated heat dissipation for each unit is 3 3 watts.

<u>TM Format</u>

The format of the telemetry output for one unit is shown in Figure 9. It is seen that two analog channels and one digital channel are used. A minor frame is 3 seconds in length and during this time the signal processing unit is in a dwell mode. It takes 16 of these minor frames to obtain complete information about a cell, so that four cells can be analyzed in one major frame (64 minor frames). The telemetry format is such that during the first 12 minor frames of a cell, the voltage and current information is telemetered on the voltage channel and current channel, respectively. At the 13th minor frame of a cell, one of four types of information is telemetered on the voltage channel. For the case of the first cell of a major frame, temperature information is telemetered. The two voltages required for major frame definition are telemetered at the second and third cells, respectively, of a major frame. For the case of the fourth cell of a major frame, a spare is telemetered. On the current channel, the temperature of the internal load resistors is telemetered at the 13th minor frame of a cell.

At the 14th minor frame of a cell, one of four calibration voltages is telemetered on both analog channels. Figure 9 shows this format. Spares are telemetered at the 15th and 16th minor frames of each cell on the voltage channel, while signal ground is telemetered on the current channel.

The digital channel is used for continuous telemetry of a bit which, by changing state from a logical 1 to a logical 0, indicates that a new major frame has begun.

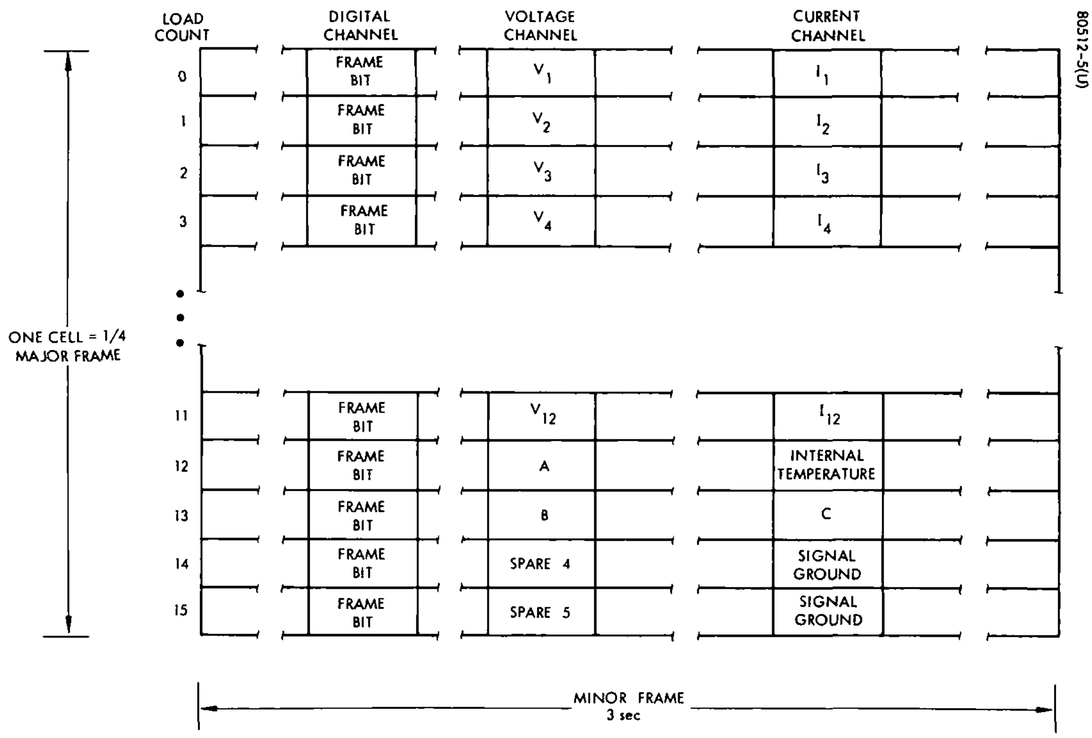
<u>Breadboard Evaluation Tests</u>

Fabrication and evaluation testing of one breadboard signal processor has been completed. Evaluation testing consisted of the following tests

1) Straight line generation

2) Calibration voltage stability

3) Calibration voltage repeatability — different cells



CELLS	A	B	C
0,4,8, 36	TEMPERATURE *	CALIBRATION 1	CALIBRATION 1
1,5,9, 37	MEDIUM FREQUENCY 1	CALIBRATION 2	CALIBRATION 2
2,6 10, 38	MEDIUM FREQUENCY 2	CALIBRATION 3	CALIBRATION 3
3,7,11, 39	SPARE 6	CALIBRATION 4	CALIBRATION 4

* SPARES 7 AND 8 AT CELLS 8 AND 28

Figure 9. Telemetry Format

4) Output voltage levels

5) Effects of input voltage change

6) Effect of temperature change

7) Internal thermistor operation

8) Alternate encoder mode

9) Solar cell measurement

The results of the tests are discussed in the following paragraphs.

Straight Line Generation. Figure 10 depicts the results of the straight line generation test where the unit was calibrated using a constant voltage source and known load resistor. The resultant curves were obtained from the output telemetry data.

Calibration Voltage Stability. The -50 mv calibration voltage was measured every 15 minutes for a period of 1 hour to verify that the voltage remained constant within 1 mv.

Time	Calibration Voltage, mv
11:15 a.m.	48.47
11·30 a.m.	48.42
11·45 a.m.	48.45
12:00 p.m.	48.45
12 15 p.m.	48.44

Calibration Voltage Repeatability. The output calibration voltage was measured for each of the two channels, and was repeatable within 5 mv.

Calibration 1, mv		Calibration 2, mv		Calibration 3, mv		Calibration 4, mv	
V	I	V	I	V	I	V	I
-433	-406	-1642	-1612	-3208	-3176	-4816	-4783
-434	-406	-1641	-1612	-3207	-3176	-4815	-4783
-432	-406	-1641	-1612	-3206	-3176	-4816	-4783
-433	-406	-1642	-1612	-3208	-3176	-4817	-4783

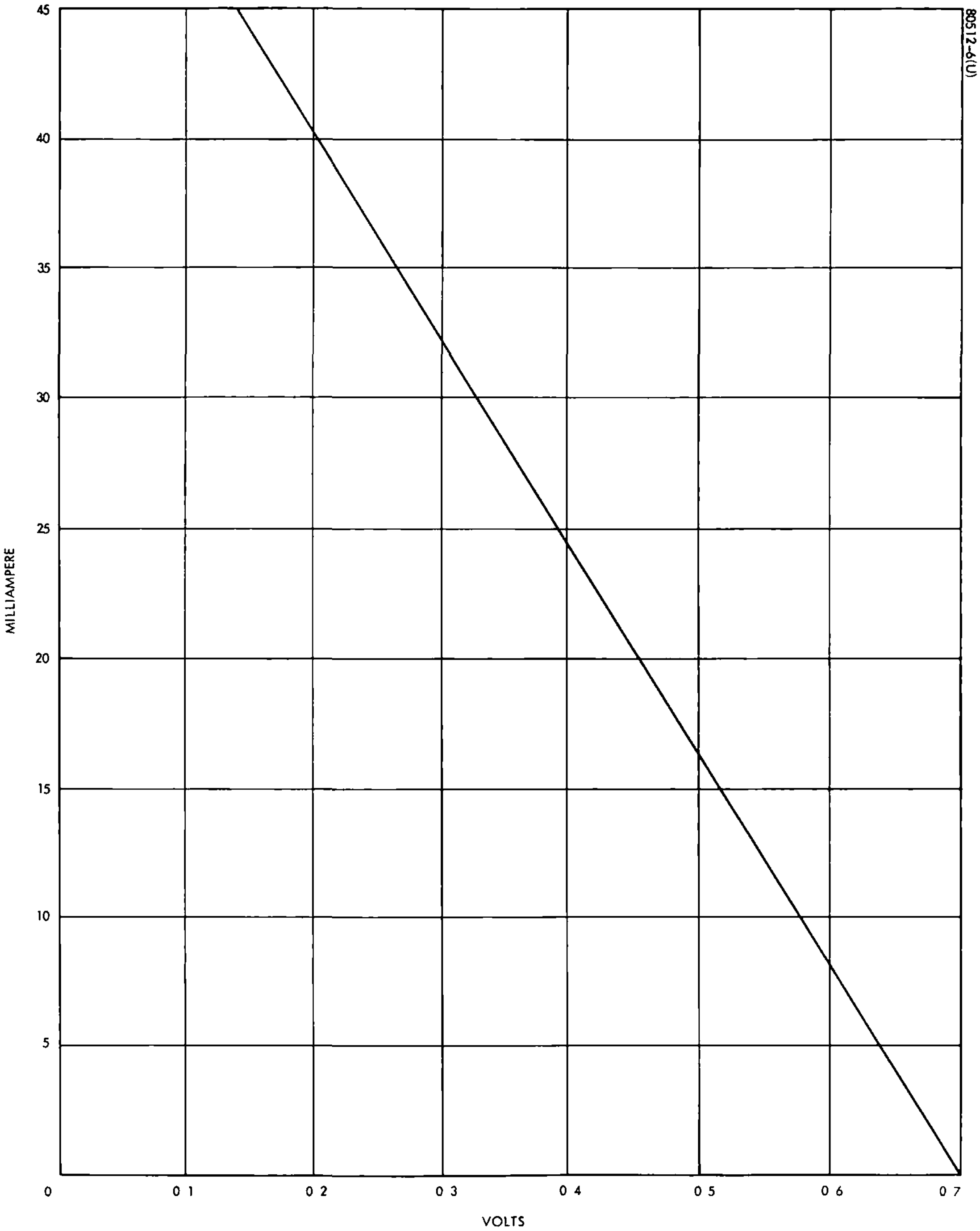


Figure 10. Straight Line Generation Test Results

Output Voltage Levels. The output levels of both stages of the digital channel output were measured at 25°C to the following specifications:

High	+0.5 volt	-2.0 volts	into a load of 52K to -7.5 watts
Low		-5.5 volts	

MF 1, volts	MF 2, volts
0.0 ± 0.3	-2.94 ± 0.3
-1.60 ± 0.3	-4.17 ± 0.3
-4.17 ± 0.3	0.0 ± 0.3
-2.94 ± 0.3	-1.60 ± 0.3

Results:

High	-0.722 volt
Low	-7.748 volts

MF 1, volts	MF 2, volts
0.0000	-2.923
-1.573	-4.133
-4.116	-0.0001
-2.898	-1.575

Effects of Input Voltage Change. Measure all ECU output voltages, all calibration voltages, the -10 volt reference supply output, and the unit input current for input voltage = -24.51 ± 1 volt. Verify that the measured voltages do not change by more than those limits listed. Perform this test at +25°C.

	-23.51 volts	-24.51 volts	-25.51 volts
ECU Voltages, volts	-11.04	-11.55	-12.07
	-17.73	-18.50	-19.27
Should not change by more than	+ 6.846	+ 6.859	+ 6.881
2 volts from lowest to	-22.36	-23.36	-24.36
highest	+11.11	+11.61	+12.12

	-23.51 volts	-24.51 volts	-25.51 volts
Calibration Voltages, millivolts	- 52.1	- 52.2	- 52.4
	-203.1	-203.2	-203.3
Should not change by more than 1 mv from lowest to highest	-398.7	-398.9	-399.0
	-599.8	-599.9	-600.1
-10 Volt Reference, volts			
Should not change by more than 10 mv	- 10.24	- 10.24	- 10.25
Current, milliamperes	140	148	156

Effects of Temperature Change. Measure all ECU output voltages, all calibration voltages, and the -10 volt reference supply output for temperature = 20°C, +25°C, +85°C. Verify that the measured voltages do not change by more than those limits listed. Perform this test with -24.51 volts input.

	-20°C	+25°C	+85°C
ECU Voltages, volts			
Should not change by more than 2 volts from lowest to highest	+ 6 75	+ 6.89	+ 7.056
	+ 11.65	+ 11.68	+ 11.79
	- 18.70	- 18.63	- 18.99
	- 11.62	- 11.64	- 10.65
	- 23.58	- 23.53	- 23.94
Calibration Voltages, millivolts			
Should not change by more than 4 mv from lowest to highest	- 48.35	- 49.55	- 48.65
	-200.7	-200.5	-199.0
	-397.1	-396.1	-394.2
	-595.8	-597.3	-595.8

	-20°C	+25°C	+85°C
-10.24 Volt Reference Supply			
Should not change by more than 10 mv	- 10.23	- 10.24	- 10.23

Internal Thermistor Operation. From the output tape, measure the internal temperature value for -20°C, +25°C, +85°C. Verify the operation of the internal thermistor. Perform this test with -24.51 volts input.

Temperature, °C	Output, volts
-20	-4.414
+25	-1.850
+85	-0.320

Alternate Encoder Mode.

1) Dwell on the Digital Channel. Switch the Digital Output from Encoder 1 to Encoder 2 by means of the switch on the tester panel. Verify that the output does not change by more than 1 volt.

	Digital Output, volts	
Encoder	High	Low
1	-0.715	-7.538
2	-0.721	-7.538

2) Verify clocking of the solar panel unit with the CH. 0 switch in both the CH. 0-1 and CH. 0-2.

Solar Cell Measurement. A 2 by 2 cm solar cell was illuminated using a tungsten light source and the performance was measured both with the signal processor unit and a sweep load and X-Y plotter. Figure 11 shows the results of the test and the capability of the unit to accurately measure solar cell performance characteristics.

Flight Experiment/Spacecraft Test Plans

Preparation of the System Test Plans has been started defining the tests to be performed on the Solar Cell Radiation Flight Experiment prior to and after installation on the ATS-E spacecraft. As planned, the Flight

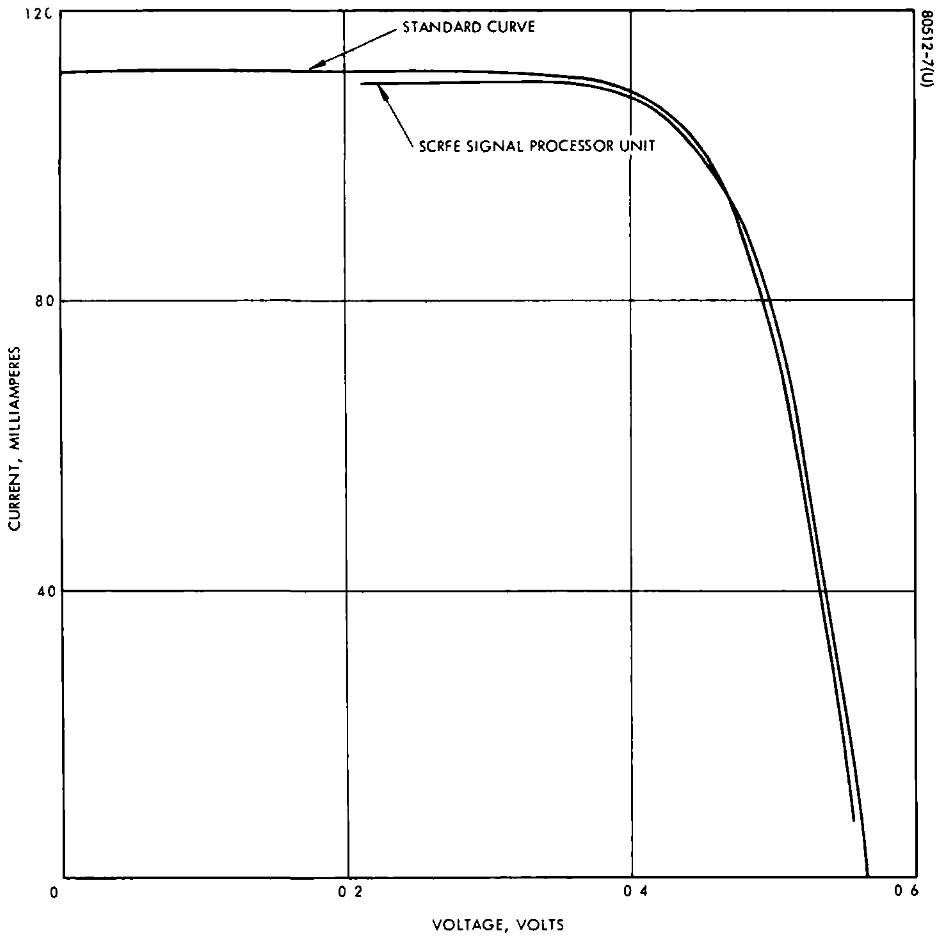


Figure 11. Signal Processor Performance With Tungsten Light Source (2 by 2 cm Cell)

Experiment will be subjected to a functional test after delivery to the experiment integrator and will be subjected to vibration and thermal vacuum testing with the ATS-E spacecraft.

After review with the ATS-E systems engineers at Hughes, the completed test plans will be submitted to JPL and NASA for approval.

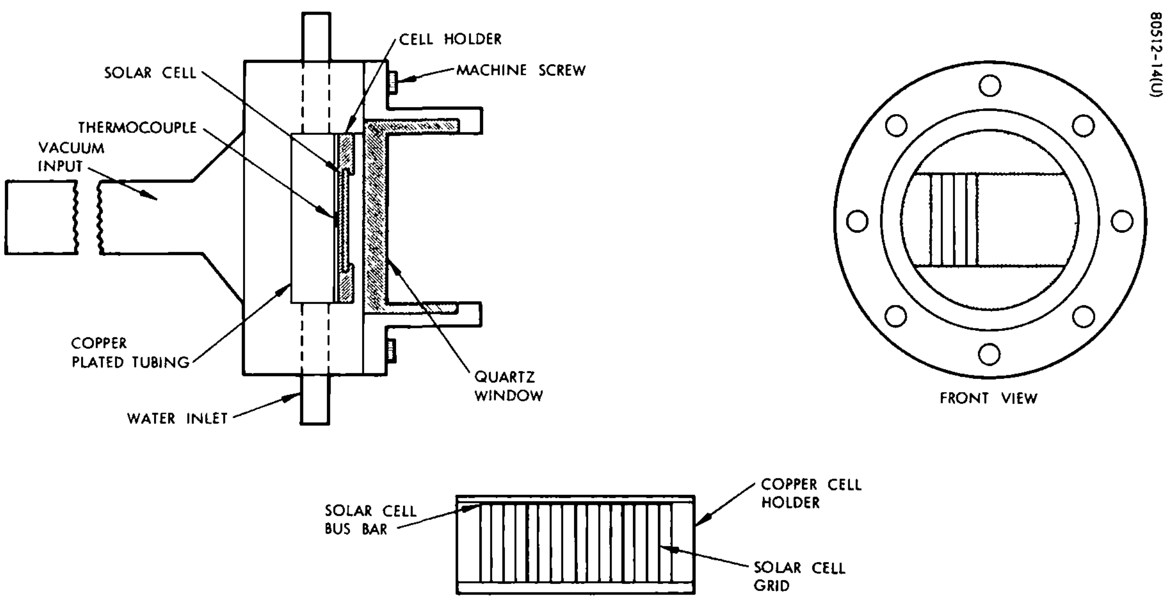


Figure 12. Vacuum Chamber Used in Ultraviolet Irradiations – Side and Front Views and Inset of Copper Cell Holder

GROUND TEST PROGRAM

A ground test program has been initiated to supplement the Flight Experiment, and will provide data required to finalize the selection of solar cell configurations for the Flight Experiment Table 2 presents a summary of the planned tests to be conducted in the ground test phase, and the status of each test

A detailed description of tests completed to date and the test data is presented in the following sections.

Ultraviolet Irradiation of Special Solar Cell/Coverslide Assemblies – Test T-1

The object of this test was to investigate the effect of ultraviolet irradiation solar cell assemblies representative of those cells previously flown having a history of anomalous transmission losses The samples included representive solar cells from the Intelsat II, F-4 main panel, ATS, F-3 main panel, and LES-5 solar cell experiment, LES-5 and -6 main panels

Test Sample Description

The test sample description is summarized in Table 3. These solar cells are representive of those cells currently flying aboard the indicated spacecraft and flight experiment The samples include three coverslide adhesive systems: RTV-602, Sylgard 182, and XR6-3489 Three thicknesses of solar cell 7940 fuzed quartz coverslides are included· 6, 12, and 30 mil The coverslides have the antireflective coating and the ultraviolet filter

Test Apparatus

The source of the ultraviolet energy was a 5000 watt, Engelhard Hanovia, xenon compact arc lamp, Model 966C-39. The output of the lamp was maintained so that the ultraviolet energy striking the samples was 38 1 mw/cm^2 or three times the solar ultraviolet constant. (In the wavelength region from 1500 to 4000 Å, the total solar intensity at the earth's orbit is called the "solar ultraviolet constant" and has the value of 12 7 mw/cm^2)

The vacuum chamber which was used to house the samples during the ultraviolet irradiation is shown in Figure 12 A Suprasil II synthetic fuzed quartz window, which is ultraviolet transparent, was placed in front of the samples The solar cell samples were mounted in the copper cell holder which was attached to the heat sink The copper cell holder is capable of holding four 1 by 2 cm or two 2 by 2 cm samples. The heat sink consisted of a stainless steel tube through which water was allowed to flow, with a copper plate An iron-constantan thermocouple was attached between

TABLE 2 GROUND TEST PROGRAM SUMMARY

Test No.	Description	Status
T-1	UV radiation of special cell/coverslide assemblies	Completed
T-2	UV qualification of coverslide adhesive	Completed
T-3	Thermal cycle and thermal soak effects on cell performance as a function of coverglass thickness, coverslide adhesive type and thickness and cell grid design	Completed
T-4	Electron irradiation effects on cell performance as a function of coverslide thickness	Preradiation calibration completed
T-5	Electron irradiation of coverglass assemblies	Calibration completed. UV portion completed
T-6	Low energy proton irradiation of exposed bus bar areas	Preradiation calibration completed
T-7	Low energy proton irradiation of exposed bar gap areas	Masks in fabrication. Cells calibrated
T-8	Low energy proton irradiation of exposed B' gap areas	Cells calibrated
T-9	Low energy proton irradiation of unshielded cells	Cells calibrated
T-10	Low energy proton irradiation of cell rear contact surface	Cells calibrated
T-11	Low energy proton irradiation of "zero-gap" cells	Cells calibrated
T-12	Electron irradiation of "zero-gap" cells	Cells calibrated
T-13	Temperature coefficient as a function of angle of incidence for irradiated cells	Preradiation calibration completed

TABLE 3 TEST SAMPLE DESCRIPTION FOR TEST T-1

Sample Description	Quantity Tested	Coverslide Adhesive System	Coverslide Thickness, mils
Intelsat II-F4, main panel	2	RTV-602	12
ATS-F3, main panel	2	XR6-3489	30
LES-5, solar cell experiment	2	Sylgard 182	6
	2	Sylgard 182	12
	2	Sylgard 182	30
LES-5, main panel	2	RTV-602	6
LES-6, main panel	2	XR6-3489	6

the copper plate and the copper cell holder. The temperature was to be maintained at approximately room temperature.

The vacuum chamber was first evacuated using an absorption pump, and the final evacuation was made with an 8 liter per second Varian Ion pump, Model No. 911-500 The vacuum during the irradiations was maintained at less than 10^{-6} torr.

The solar cell's voltage-current characteristics were measured using the X-25 solar simulator which was furnished by JPL The X-25 simulator was calibrated and maintained at an intensity of 140 mw/cm^2, AMO using Balloon Flight Standard Cell No. 408. Also, three Hughes control cells were used throughout the V-I measurements as controls.

The temperature of the solar cells during measurements was maintained at 25° C using a water-cooled brass cell holder.

Test Procedure

The solar cells were cleaned with MEK. Each of the solar cell's voltage-current characteristics were measured at an intensity of a 140 mw/cm^2, AMO equivalent and 25° C temperature. The samples were again cleaned with MEK

The solar cells were carefully loaded into the copper cell holder and mechanically held in place The copper cell holder was then placed

TABLE 4. RESULTS OF TEST T-1

Cell No	Spacecraft	Adhesive	Coverslide Thickness, mils	I_{sc} Before, ma	I'_{sc} After, ma	I'_{sc}/I_{sc}	Comments
1	ATS-F3	XR6-3489	30	67 09	64 90	0 967	High temperature, solder melted
2	ATS-F3	XR6-3489	30	65 50	62 98	0 962	High temperature, solder melted
18	Intelsat II F-4	RTV-602	12	142 0	83 60	0 589	High temperature, solder melted
19	Intelsat II F-4	RTV-602	12	143 1	103 2	0 721	High temperature solder melted
5	LES 5-MP	RTV-602	6	66 50	64 60	0 971	Temperature ~ 235°F
6	LES 5-MP	RTV-602	6	67 90	59 59	0 878	High temperature ~ 450°F
12	LES 5-SCE	Sylgard 182	6	69 89	68 70	0 983	Temperature ~ 235°F
26	LES 5-SCE	Sylgard 182	6	70 89	60 16	0 849	High temperature ~ 450°F
33	LES 5-SCE	Sylgard 182	30	71 31	70 29	0 986	Temperature ~ 235°F
56	LES 5-SCE	Sylgard 182	30	72 20	70 49	0 976	High temperature ~ 450°F
16	LES 5-SCE	Sylgard 182	12	71 70	64 79	0 904	High temperature ~ 450°F
47	LES 5-SCE	Sylgard 182	12	70 20	66 79	0 951	Temperature ~ 235°F
21	LES 6-MP	XR6-3489	6	68 70	43 29	0 630	High temperature ~ 450°F
22	LES 6-MP	XR6-3489	6	66 60	64 40	0 967	Temperature 235 F

in the vacuum chamber and attached to the copper heat sink by six screws The quartz window was mounted to the test chamber, making a vacuum-tight fit. The vacuum chamber was pumped down and maintained at a pressure of less than 10^{-6} torr. Four such chambers were available, making possible the simultaneous irradiation of two 2 by 2 cm and 12 1 by 2 cm samples.

The vacuum chambers were placed in front of the xenon ultraviolet source at the three sun position. The cells were left at the three sun position for 80 hours, giving an equivalent of 240 sun hour irradiation After 80 hours the samples were removed from the vacuum chamber and cleaned with MEK. The cells' voltage-current characteristics were again measured using the X-25 solar simulator.

Results

The results of ultraviolet irradiation for 80 hours at the three sun level, equivalent to 240 sun hours, are summarized in Table 4. It was observed that some of the samples degraded quite severely. It was noticed upon close observation of the cells that the solder on the cells which degraded had melted, indicating a very high temperature. It was also noted that the adhesive on several of the samples had darkened and cracked. Investigating the experimental setup more closely, it was found that the thermocouple temperature reading of 150° F was not the same as the temperature of the solar cell samples. Attaching a thermocouple to a solar cell and rerunning the test, it was found that the cells in the center of the cell holder experienced temperatures up to 450° F, and that the temperature of the samples at the side of the cell holder was approximately 235° F. There were two reasons for the higher temperature of the samples. First, in a vacuum a mechanical attachment to the heat sink is very inefficient, allowing the test samples to become very hot. Second, the quartz window focused the light source at the center of the cell holder causing the higher temperatures at the center.

Because of the limited number of test samples for this test, further ultraviolet irradiations on these special cells cannot be made The test did point out the temperature problem with the test fixture so that the test fixture and test procedure for the other ultraviolet irradiations could be altered.

Conclusions

No conclusions can be drawn from this experiment as to the effect of 240 equivalent sun hours of ultraviolet exposure upon the test samples It was noted that temperatures as high as 450° F were experienced by the samples The high temperatures were probably the predominate cause of the solar cell degradation.

Ultraviolet Qualification of Coverglass Adhesive, Test T-2

The object of this test was to qualify coverglass adhesive systems under ultraviolet irradiation Three different adhesive systems were investigated: Sylgard 184, RTV-602, and XR6-3489 Also, the results of the ultraviolet irradiation part of Test T-5 will be included in this portion of the report

Test Sample Description

The basic assembly configuration was two 12 mil thick, 1 by 2 cm, 7940 fuzed quartz coverglass with the adhesive sandwiched between The descriptions of the test samples are as follows:

Type 1: Sandwich configuration of 12 mil, 7940 quartz coverglass with antireflecting coating and the ultraviolet filter and RTV-602 adhesive backed by 12 mil, 7940 with no coating or filter

Type 2· Same as Type 1, except neither coverglasses have coatings or filters.

Type 3. Same as Type 1, except Sylgard 184 adhesive system

Type 4· Same as Type 1, except XR6-3489 adhesive system

Type 5: Same as Type 2, except XR6-3489 adhesive system

Type 6: Same as Type 1, except a Hughes special adhesive system

Test Apparatus

The source of the ultraviolet energy was a 5000 watt, Engelhard Hanovia, xenon compact arc lamp, Model 966C-39 The output of the lamp was maintained so that the ultraviolet energy striking the samples was 38 1 mw/cm^2 or three times the solar ultraviolet constant For part of the test, the output of the lamp was maintained so that the ultraviolet energy striking the samples was 12 7 mw/cm^2 or one solar ultraviolet constant

The vacuum chamber used for this test was the same as described in Test T-1 except for the following changes A suspension of silver in DC 704 vacuum oil was placed between the copperplate of the heat sink and copper cell holder This suspension of silver in DC 704 vacuum oil exhibits high thermal properties and was used to make better thermal contact The iron-constantan thermocouple was attached to one of the samples so that the temperature of the sample could be measured directly.

Since there was a focusing effect of the light source by the quartz window, an opaque sleeve was made to fit over the sides of the quartz window This sleeve was found very effective in reducing the temperature of the samples in the center of the test fixture The temperature of the samples during irradiation was held between 70 and 120° F

Transmittance curves of the samples from 0.4 to 1.1 microns were measured by a Beckman DK-2A Radio Recording Spectrophotometer

The effect of the change in transmittance of the samples upon the solar cell output was measured by placing the samples over a specially chosen 1 by 2 cm, Helcotek solar cell. The voltage-current characteristics were measured using the Hughes tungsten-xenon sun simulator. The sun simulator was calibrated and maintained at an intensity of 100 mw/cm^2, AMO, using a Hughes calibrated secondary standard. The temperature of the cell was maintained at 25° C using a water-cooled brass cell holder

Test Procedure

The coverslide sandwich assemblies were cleaned with MEK. Transmittance curves were taken over the range of 0 4 to 1 1 microns. Also, the voltage-current characteristics of a cell were measured for each sample by placing the sample on top of the cell

The samples were again cleaned with MEK. The coverslide assemblies were loaded into the copper cell holder with a small portion of the suspension of silver in vacuum oil between the sample and the cell holder. This was to ensure a better thermal contact. A thermocouple was attached to one of the samples. The copper cell holder was placed in the vacuum chamber and attached to the copper heat sink with the suspension of silver between the cell holder and heat sink. The quartz window was mounted to the test chamber making a vacuum-tight fit. The vacuum chamber was pumped down and maintained at a pressure of less than 10^{-6} torr. The opaque sleeve was placed over the sides of the quartz window

The vacuum chamber was placed in front of the xenon ultraviolet source at the proper position. Eight samples were placed at the one sun position for 48 hours and 32 samples were placed at the three sun position for 80 hours.

After the irradiations, the samples were removed from the vacuum chamber and cleaned with MEK. The transmittance curves and their effect on the performance of a solar cell were measured.

Results

The detailed results are displayed in Tables 5 and 6. Table 5 shows results of the ultraviolet irradiation on the coverglass sandwich configuration having a coverglass with no antireflective coatings or ultraviolet filters. The effect of the irradiation on cell output can be summed up in the following average normalized short-circuit current:

RTV-602	0 998
XR6-3489	1 000

TABLE 5. RESULTS OF ULTRAVIOLET IRRADIATIONS ON SAMPLES USING COVERGLASSES WITH NO ANTIREFLECTIVE COATINGS OR ULTRAVIOLET FILTERS

Adhesive System	Sample No	Transmittance at 0 8 μ, %			Transmittance at 0 425μ, %			Short Circuit Current			Environment	Comments
		Before	After	Δ	Before	After	Δ	Before I_{sc}	After I'_{sc}	I'_{sc}/I_{sc}		
RTV-602	9-1	92 0	92 3	+0 3	90 3	89 5	-0 8	46 3	46 6	1 006	48 hours at 1 sun	Small chip out on corner
	9-2	91 9	92 3	+0 4	91 8	90 5	-1 3	46 4	46 2	0 996	48 hours at 1 sun	*
	9-3	92 0	91 5	-0 5	90 0	88 6	-1 4	46 4	—	—	48 hours at 1 sun	Broken sample
	9-4	92 0	92 0	0 0	91 3	91 2	-0 1	46 4	—	—	48 hours at 1 sun	Broken sample
	10-1	91 8	94 2	+2 2	91 7	90 4	-1 3	46 4	—	—	80 hours at 3 suns	Broken sample, sample not sufficiently cleaned before
	10-2	93 2	91 2	-2 0	93 7	88 6	-5 1	46 3	—	—	80 hours at 3 suns	Broken sample
	10-3	92 5	93 3	+0 8	93 1	90 2	-2 9	46 4	46 4	1 000	80 hours at 3 suns	*
	10-4	94 0	92 7	-1 3	91 7	92 7	+1 0	46 4	46 3	0 998	80 hours at 3 suns	*
XR6-3489	13-1	91 0	93 0	+2 0	89 8	90 6	+0 8	46 4	46 5	1 002	48 hours at 1 sun	*
	13-2	92 0	92 5	+0 5	91 3	91 4	+0 1	46 3	46 3	1 000	48 hours at 1 sun	*
	13-3	93 0	92 8	-0 2	92 2	91 1	-1 1	46 3	46 6	1 006	48 hours at 1 sun	Cracked sample
	13-4	92 8	92 0	-0 8	90 9	91 6	+0 7	46 3	—	—	48 hours at 1 sun	Broken sample
	14-1	92 0	94 0	+2 0	90 7	87 2	-3 5	46 4	44 5	0 959	80 hours at 3 suns	Thermocouple attached, sample not sufficiently cleaned before
	14-2	94 0	93 0	-1 0	93 7	90 8	-2 9	46 2	46 1	0 996	80 hours at 3 suns	*
	14-3	92 6	93 8	+1 2	93 0	88 8	-4 2	46 3	46 3	1 000	80 hours at 3 suns	*
	14-4	93 7	93 0	-0 7	93 0	89 6	-3 4	46 5	—	—	80 hours at 3 suns	Broken sample

*Experimenter's interpretation of usable data

TABLE 6. RESULTS OF ULTRAVIOLET IRRADIATIONS ON SAMPLES USING COVERGLASSES WITH BOTH ANTIREFLECTIVE COATINGS AND ULTRAVIOLET FILTERS

Adhesive System	Sample No	Transmittance at 0 8μ, %			Transmittance at 0 425μ, %			Short Circuit Current			Environment	Comments
		Before	After	Δ	Before	After	Δ	Before I_{sc}	After I'_{sc}	I'_{sc}/I_{sc}		
RTV-602	1-1	90 8	—	—	83 8	—	—	46 8	—	—	80 hours at 3 suns	Sample destroyed
	1-2	87 2	86 0	1 2	84 0	51 0	-33 0	46 7	44 2	0 946	80 hours at 3 suns	Vacuum oil deposited on sample, cracked sample
	1-3	90 0	88 5	-1 5	84 0	81 1	-2 9	46 8	45 6	0 974	80 hours at 3 suns	*
	1-4	90 8	88 0	-2 8	84 0	81 0	-3 0	46 7	44 6	0 955	80 hours at 3 suns	Vacuum oil deposited on sample
	2-1	92 3	89 5	-2 8	84 7	82 8	-1 9	46 4	43 3	0 933	80 hours at 3 suns	Thermocouple attached, sample not sufficiently cleaned before
	2-2	94 2	90 0	-4 2	86 6	82 0	-4 6	46 4	45 6	0 982	80 hours at 3 suns	*
	2-3	94 6	89 0	-5 6	88 3	83 8	-4 5	46 4	—	—	80 hours at 3 suns	Broken sample
	2-4	93 0	89 5	-3 5	88 0	82 8	-5 2	46 5	45 4	0 976	80 hours at 3 suns	*
XR 6-3489	5-1	91 0	90 0	-1 0	85 5	83 4	-2 1	46 1	44 4	0 963	80 hours at 3 suns	Thermocouple attached, sample not sufficiently cleaned before
	5-2	93 5	92 0	-1 5	87 2	85 5	-1 7	46 4	45 7	0 985	80 hours at 3 suns	*
	5-3	92 2	90 2	-2 0	85 0	82 2	-2 8	46 4	45 0	0 970	80 hours at 3 suns	Sample cracked
	5-4	91 3	91 3	0 0	84 8	83 1	-1 7	46 2	45 2	0 978	80 hours at 3 suns	*
	6-1	91 5	91 0	-0 5	83 8	81 3	-1 5	46 3	44 2	0 955	80 hours at 3 suns	Thermocouple attached, sample not sufficiently cleaned before
	6-2	93 2	90 5	-2 7	88 3	86 4	-1 9	46 4	45 7	0 984	80 hours at 3 suns	*
	6-3	94 0	91 0	-3 0	87 8	83 2	-4 6	46 4	45 4	0 978	80 hours at 3 suns	*
	6-4	94 0	91 0	-3 0	87 2	82 3	-4 9	46 5	45 7	0 983	80 hours at 3 suns	*
Sylgard 184	16-1	92 5	88 2	-4 3	82 8	80 2	-2 6	46 4	44 5	0 959	80 hours at 3 suns	Thermocouple attached, sample not sufficiently cleaned before
	16-2	92 5	89 8	-2 7	83 6	77 8	-5 8	46 3	45 5	0 983	80 hours at 3 suns	*
	16-3	92 5	90 0	-2 5	82 0	78 5	-3 5	46 4	45 8	0 987	80 hours at 3 suns	*
	16-4	92 5	91 0	-1 5	82 0	76 3	-5 7	46 2	45 8	0 991	80 hours at 3 suns	*
Hughes Special	19-1	92 0	92 0	0 0	71 2	79 2	+8 0	46 1	44 6	0 967	80 hours at 3 suns	Thermocouple attached, sample not sufficiently cleaned before
	19-2	89 5	92 0	+2 5	79 0	76 8	-2 0	46 7	45 3	0 970	80 hours at 3 suns	*
	19-3	90 0	92 0	+2 0	71 5	77 8	+6 3	46 6	45 7	0 981	80 hours at 3 suns	*
	19-4	93 0	92 5	-0 5	77 0	83 5	+6 5	46 3	45 3	0 978	80 hours at 3 suns	*

*Experimenter's interpretation of usable data

Table 6 shows the results of the ultraviolet irradiation on the coverglass sandwich configurations having a coverglass with both the antireflective coatings and ultraviolet filters. The effect of the irradiation on cell output can be summed up with the following average normalized short-circuit current:

RTV-602	0.977
XR6-3489	0 982
Sylgard 184	0.987
Hughes Special	0.976

Conclusions

The conclusions of this test program are as follows: The adhesive systems did not degrade under the 240 equivalent ultraviolet irradiations This is indicated in the samples that consisted only of the fuzed quartz glass The sandwich configurations which had both the antireflective coating and ultraviolet filters degraded approximately 1 to 3 percent. This indicates that either the antireflective coating or the ultraviolet filter degraded.

Thermal Cycle and Thermal Soak Effects on Solar Cells – Test T-3

The purpose of this test was to investigate the effects of thermal cycling and thermal soaking on solar cell performance as a function of coverglass thickness, grid line design, coverglass adhesive type, and adhesive application technique The significant cell property under investigation is a possible grid line degradation due to this environment.

Test Sample Description

Centralab, 2 by 2 cm, 10 ohm-cm, N/P, Ag Ti bar contacts, 12 mil thick, boron doped, silicon solar cells were used for this test. The grid line designs were both solderless and completely solder dipped. Two adhesive systems were used, RTV-602 and XR6-3489, 12 and 60 mil thick, 7940 fuzed quartz coverglasses were employed. Two adhesive application techniques were utilized which involved applying the coverglass to the cell (cell on the bottom) and the cell to the coverglass (cell on the top). The test sample size for the completely solder dipped cells was four for each assembly configuration, resulting in 32 samples. These cells were Centralab cells which Hughes had purchased for another program. These test samples had 12 mil coverglass attached which was removed for this test program. The cells were then cleaned and solder dipped. The test sample size for the unsoldered cells was five for each assembly configuration, resulting in 40 samples. These unsoldered cells were obtained from Centralab and represent current production cells. A total of 72 test cells was used in this test. The detailed definitions of the test samples are summarized in Table 7.

TABLE 7. CELL DESCRIPTION OF TEST T-3

12 Mil Coverslides	60 Mil Coverslides
1) Cell Nos. 101 to 105 a) Adhesive: RTV-602 b) Cell bottom	9) Cell Nos. 121 to 125 a) Adhesive: RTV-602 b) Cell bottom
2) Cell Nos. 106 to 110 a) Adhesive: RTV-602 b) Cell top	10) Cell Nos. 126 to 130 a) Adhesive: RTV-602 b) Cell top
3) Cell Nos. 111 to 115 a) Adhesive: XR6-3489 b) Cell bottom	11) Cell Nos 131 to 135 a) Adhesive: XR6-3489 b) Cell bottom
4) Cell Nos. 116 to 120 a) Adhesive: XR6-3489 b) Cell top	12) Cell Nos. 136 to 140 a) Adhesive: XR6-3489 b) Cell top
5) Cell Nos 301 to 304 a) Adhesive: RTV-602 b) Cell bottom	13) Cell Nos. 318 to 321 a) Adhesive: RTV-602 b) Cell bottom
6) Cell Nos. 305 to 308 a) Adhesive: RTV-602 b) Cell top	14) Cell Nos. 322, 323, 325, and326 a) Adhesive: RTV-602 b) Cell top
7) Cell Nos. 309, 310, 312, and 313 a) Adhesive: XR6-3489 b) Cell bottom	15) Cell Nos. 327 to 330 a) Adhesive: XR6-3489 b) Cell bottom
8) Cell Nos. 314 to 317 a) Adhesive: XR6-3489 b) Cell bottom	16) Cell Nos. 331 to 334 a) Adhesive: XR6-3489 b) Cell top

Note:

The 100 series numbers are the solderless cells, the 300 series numbers are the solder dipped cells

TABLE 8. RESULTS OF TEST T-3 SHOWING ACTUAL OUTPUT DATA FOR THE SOLDERLESS CELLS

Cell No	Prefab			Postfab			50 Cycles			100 Cycles			150 Cycles			200 Cycles		
	I_{sc}	V_{oc}	I at 0 44v	I_{sc}	V_{oc}	I at 0 44v	I_{sc}	V_{oc}	I at 0 44v	I_{sc}	V_{oc}	I at 0 44v	I_{sc}	V_{oc}	I at 0 44v	I_{sc}	V_{oc}	I at 0 44v
101	138 0	561 9	127 75	135 29	559 9	127 5	135 49	558 9	126 0	135 9	560 9	128 50	134 9	562 7	127 0	134 7	561 6	125 5
102	142 2	565 9	117 25	139 89	560 9	118 25	139 39	565 3	119 5	139 8	566 5	122 50	139 3	567 9	121 0*	139 0	567 0	119 25
103	137 9	561 9	121 0	135 59	558 9	124 25	135 69	561 4	125 0	135 9	562 8	125 50	135 3	562 9	125 75	135 2	563 3	125 75
104	135 9	564 9	118 75	130 09	560 2	120 75	133 09	563 2	123 0	133 0	564 3	122 75	132 7	566 5	123 5	131 6	565 0	121 50
105	135 9	560 9	122 5	133 79	559 7	124 0	133 50	560 1	126 5	134 1	561 0	126 75	133 1	563 1	125 25	133 2	561 9	125 0
106	137 2	564 2	125 25	134 30	559 7	126 25	134 79	562 6	127 25	134 8	562 9	127 25	134 6	563 0	126 25	134 2	563 5	125 75
107	135 3	564 1	117 25	133 39	559 9	122 5	133 40	562 8	125 25	133 4	563 5	124 50	133 2	563 6	123 75	131 8	563 9	122 5
108	137 3	565 9	120 75	135 49	560 2	127 25	135 39	565 0	129 5	135 1	565 4	128 50	135 3	565 9	128 25	133 7	566 2	126 5
109	139 1	590 1	121 75	137 09	583 9	122 5	136 69	588 1	123 75	136 4	587 5	122 25	136 3	588 1	122 25	135 2	588 2	120 25
110	–	–	–	134 71	552 9	118 0	134 06	557 5	123 5	134 6	557 9	121 50	134 2	558 9	123 0	133 3	558 9	121 25
111	137 9	563 9	125 5	135 40	559 9	123 25	135 30	563 4	125 0	134 9	563 6	123 75	135 0	564 6	123 75	134 6	564 6	123 5
112	137 0	562 2	122 25	134 79	560 9	118 75	134 49	560 5	122 5	134 3	561 0	120 50	133 9	562 0	120 0*	133 9	563 4	120 0
113	138 0	567 9	126 25	135 49	556 9	121 5	135 10	566 3	124 0	135 2	566 3	122 75	134 8	567 3	121 25	134 6	568 7	123 0
114	141 9	560 9	125 5	139 49	560 9	121 75	139 39	560 0	124 25	138 5	560 2	122 75	138 8	561 8	122 75	138 9	562 5	123 75
115	137,4	563 9	128 5	135 20	560 0	125 0	135 20	562 7	127 5	135 2	562 8	126 00	134 9	563 9	126 0	133 4	564 2	124 75
116	137 9	563 9	126 5	135 69	558 9	123 0	135 39	562 7	126 0	135 6	562 5	123 75	135 4	563 9	124 5	133 9	564 1	123 75
117	136 9	566 9	125 5	134 20	560 2	123 75	134 59	564 9	126 25	134 9	564 5	123 25	134 6	565 9	124 25	133 3	566 3	123 25
118	135 9	563 0	121 5	133 69	560 9	118 0	133 99	563 3	122 0	133 9	562 7	121 00	133 9	563 9	120 5	133 0	564 2	119 75
119	135 8	561 9	126 25	133 09	556 9	122 5	133 29	561 6	125 5	133 5	560 9	124 0	133 2	561 7	124 75	132 8	562 4	122 5
120	137 0	563 9	131 5	135 20	558 9	126 25	135 59	563 5	131 0	135 2	563 1	129 0	135 1	564 0	129 5	134 1	564 7	127 0
121	137 4	562 1	129 0	137 29	560 9	128 25	137 00	561 1	131 0	137 2	560 9	129 75	136 9	561 2	128 25	135 9	562 8	127 25
122	139 9	561 9	121 75	140 09	559 9	123 25	140 00	560 9	124 75	138 9	560 5	124 25	139 0	561 1	123 25	138 2	561 9	121 0
123	132 2	564 9	122 25	134 29	567 9	124 0	134 69	564 2	127 0	134 4	563 7	125 75	133 8	564 3	124 0	133 9	564 8	122 5
124	137 0	566 9	129 25	137 02	562 9	131 0	137 30	566 5	132 75	137 6	565 5	132 50	136 7	566 0	130 75	136 1	567 3	130 0
125	135 9	563 1	126 25	135 97	563 9	127 25	136 00	562 2	129 25	135 7	561 4	127 25	135 1	561 9	127 25	135 3	561 2	125 5
126	138 9	565 9	129 25	139 89	561 9	129 0	140 19	565 5	132 5	140 0	564 5	130 0	139 7	565 4	130 0	139 4	561 6	127 5
127	136 1	563 2	126 75	137 25	561 7	127 0	137 69	563 1	130 0	137 6	562 2	127 75	137 1	562 9	127 25	136 1	561 4	126 5
128	139 2	563 9	128 50	139 29	561 9	129 25	140 00	564 3	133 0	139 9	563 1	130 75	139 4	564 1	131 0	139 4	563 4	130 25
129	141 0	567 1	125 0	141 29	555 9	127 0	141 00	556 4	127 25	140 9	555 5	125 25	140 1	556 1	124 75	140 9	556 3	124 75
130	132 5	565 9	126 5	133 39	560 9	123 75	133 39	565 7	128 25	133 6	564 9	127 25	132 9	566 0	126 75	132 9	564 4	125 0
131	135 3	565 9	126 0	136 39	561 8	126 0	136 42	566 5	129 25	136 5	565 9	127 00	136 1	566 5	125 75	136 5	566 2	126 5
132	138 9	570 9	131 25	138 40	571 0	131 25	138 39	570 4	133 75	138 4	569 9	131 50	137 9	570 9	131 25	137 8	569 5	130 0
133	138 3	562 9	126 0	139 19	558 9	126 75	139 00	562 4	128 25	138 7	561 4	127 0	138 5	562 4	126 75	138 6	561 9	125 5
134	140 2	562 9	125 25	140 39	561 9	125 5	140 49	563 4	128 25	140 3	562-5	127 0	139 2	563 3	127 5	139 7	562 3	126 25
135	138 9	564 9	129 5	138 19	560 9	129 0	139 10	563 9	132 0	138 8	563 2	130 75	138 1	562 5	129 0	138 6	563 2	130 25
136	137 2	562 1	122 75	138 89	559 9	123 5	139 00	562 2	127 5	139 3	561 4	125 50	138 3	561 9	124 0	137 9	561 2	120 75
137	135 9	564 0	126 25	137 19	558 9	126 0	137 29	564 7	130 25	137 4	563 2	128 50	136 4	564 0	127 0	137 3	564 0	128 25
138	138 0	568 9	129 75	138 69	562 9	129 0	138 59	567 9	132 5	138 9	566 9	130 50	138 2	567 5	129 75	138 3	566 3	129 75
139	136 9	564 9	130 25	137 69	559 9	130 0	137 19	564 2	133 0	137 4	563 2	131 25	136 4	563 9	131 0	136 9	562 6	131 25
140	137 9	565 2	129 75	137 79	561 9	128 0	137 89	563 6	131 75	137 9	562 9	129 25	137 4	563 7	129 50	137 2	563 6	129 75

TABLE 9. RESULTS OF TEST T-3 SHOWING ACTUAL OUTPUT DATA FOR THE COMPLETELY SOLDER DIPPED CELLS

Cell No	Prefab			Postfab			50 Cycles			100 Cycles			150 Cycles			200 Cycles		
	I_{sc}	V_{oc}	I at 0 44v	I_{sc}	V_{oc}	I at 0 44v	I_{sc}	V_{oc}	I at 0 44v	I_{sc}	V_{oc}	I at 0 44v	I_{sc}	V_{oc}	I at 0 44v	I_{sc}	V_{oc}	I at 0 44v
301	140 2	560 9	126 75	140 59	550 9	112 75	140 00	554 6	119 75	139 9	557 1	118 0	140 6	554 3	118 0	140 6	558 4	119 25
302	138 9	564 9	125 5	136 69	556 9	120 0	136 89	561 7	124 25	136 8	561 7	123 25	135 9	561 4	123 25	137 1	562 6	113 75
303	141 9	562 9	128 75	139 59	561 9	127 50	140 19	561 5	129 5	139 8	561 3	128 75	139 1	561 9	128 75	140 1	562 0	129 75
304	141 9	558 1	120 0	139 49	551 9	95 0	139 29	554 2	99 75	131 4	555 9	83 0	129 4	554 9	82 5*	131 6	555 6	83 0
305	143 9	563 1	113 5	140 79	560 9	106 75	141 29	561 9	102 75	141 0	561 6	100 75	140 3	563 5	101 5	141 1	562 6	101 25
306	143 0	557 2	129 25	139 99	560 0	126 75	140 10	556 2	128 25	139 5	556 0	127 50	139 2	555 6	127 0	140 3	556 3	127 25
307	137 7	562 9	119 50	137 39	556 9	115 5	137 89	560 1	120 0	137 4	560 9	119 25	137 1	561 4	119 0	137 3	561 0	118 5
308	144 9	565 4	124 25	142 89	561 9	89 25	142 79	560 5	90 75	142 2	559 9	89 75	141 5	563 9	90 5	142 6	561 7	90 25
309	143 0	564 1	125 75	141 29	560 9	110 0	141 39	558 6	110 0	140 8	558 0	108 50	140 1	554 6	106 25	141 4	557 9	108 75
310	143 1	559 1	126 50	141 50	561 0	128 0	141 80	557 9	128 5	141 2	557 3	128 25	141 0	557 9	128 0	141 4	557 5	128 25
312	141 1	563 4	127 25	139 79	556 9	113 75	139 89	558 8	116 25	139 7	559 0	115 25	139	558 9	114 5	139 6	557 9	102 5
313	141 0	563 0	128 25	139 39	554 9	122 0	139 39	558 2	125 5	138 9	559 9	124 75	138 9	557 2	124 25	138 3	559 2	124 0
314	143 0	557 9	121 25	Filter on ohmic strip			—	—	—	141 7	561 0	122 0	141 1	557 9	120 0	140 6	556 4	119 25
315	143 2	565 5	134 25	140 46	551 9	128 5	140 89	550 7	121 25	140 0*	559 2	118 5	127 1	560 1	90 5*	113 8	551 3	55 25
316	138 1	560 9	127 0	139 69	557 9	126 25	137 19	558 0	128 25	136 7	557 4	128 5	137 0	558 9	127 5	137 1	558 2	126 75
317	144 4	563.9	122 25	141 89	559 9	111 75	142 39	559 4	113 5	141 4*	560 3	112 5	142 0	559 0	112 0	141 3	559 9	111 5
318	143 0	563 5	129 75	143 39	555 9	130 25	143 49	561 1	133 5	143 1	561 3	133 0	141 8	563 4	131 5	141 4	561 4	131 25
319	140 8	564 5	124 25	139 98	554 9	107 0	139 89	560 7	110 25	139 6	560 6	110 25	138 9	559 9	108 5	138 3	559 6	107 0
320	144 0	562 4	131 5	142 79	551 9	111.0	102 69*	555 6	70 25*	101 6*	559 4	70 25	99 9	558 9	68 25*	—	—	—
321	143 1	563 1	129 25	143 39	552 9	130 0	143 69	557 0	129 0	143 9	557 9	119 50	142 9	558 4	127 5	143 1	559 9	126 5
322	141 1	561 0	121 50	143 00	554 9	122 25	142 30	560 2	126 0	143 3	559 2	126 50	142 4	559 7	125 5	142 3	559 6	124 5
323	142 5	564 7	127 75	141 79	561 9	125 75	142 59	561 9	129 0	142 5	561 9	117 25	142 1	563 4	116 5*	142 9	561 7	116 75
325	141 4	560 6	129 0	138 90	549 9	120 5	139 69	553 8	121 5	138 6	557 5	122 75	137 9	558 1	122 25	137 7	558 5	121 0
326	139 9	561 0	124 0	140 50	559 9	124 5	140 10	549 4	123 5	140 4	549 8	122 75	136 3	552 6	111 5*	136 9	552 7	110 5
327	144 2	559 9	121 5	141 10	548 9	84 75	141 0	555 2	88 5	136 5*	555 6	88 0	138 9	556 9	86 75	140 9	554 8	88 75
328	139 1	555 3	119 0	140 69	550 9	120 75	141 0	550 8	121 25	142 3	551.6	123 00	139 9	553 9	121 25	141 2	552 1	121 0
329	141 9	564 9	124 75	144 22	560 9	128 25	143 20	562 4	128 5	144 1	562 2	128 75	142 9	564 9	128 75	143 7	563 3	118 5
330	137 0	557 5	116 25*	143 2	554 5	126 75	142 90	553 6	127 5	143 2	555 2	128 00	142 4	554 0	126 75	141 9	554 0	125 75
331	140 0	561 9	125 0	141 69	552 9	126 0	141 39	559 4	128 5	141 3	559 9	129 25	140 3	561 1	128 25	140 7	559 7	126 5
332	147 2	564 1	119 25	148 43	560 8	126 0	148 20	561 0	128 0	148 5	560 9	129 25	147 2	562 1	127 25	147 3	561 9	126 25
333	144 4	562 8	128 0	144 99	552 9	118 75	144 59	560 7	122 75	144 9	561 2	124 00	144 3	563 6	122 75	144 3	560 9	122 25
334	140 1	564 9	124 75	122 19*	553 9	101 5	121 70*	559 0	104 0	122 6*	560.4	104 5	121 6	559.9	104 25	121 8	559 3	104 25

TABLE 10. UNCORRECTED AND CORRECTED NORMALIZED CURRENT AT 0. 440 VOLT AFTER 200 THERMAL CYCLES SHOWN INDIVIDUALLY AND FOR CELL GROUPS (300 CELL SERIES

Cell No	$\frac{\text{I at 0 440 Volt – 200 Cycles}}{\text{I at 0 440 Volt – Postfab}}$ R	Corrected (RX 0 9954)	Comments	Average Normalized Current at 0 440 Volt
301	1 058	1 053		1 003
302	0 948	0 944		
303	1 018	1 013		
304	0 874	0 870	Cell damaged in fabrication.	
305	0 948	0 944		0 992
306	1 004	0 999		
307	1 026	1 021		
308	1 011	1 006	Cell damaged in fabrication	
309	0 989	0 984		0 972
310	1 002	0 997		
312	0 901	0 897		
313	1 016	1 011		
314	–	–	Filter on ohmic strip	0 999
315	0 430	0 428	Cell cracked after 50 cycles	
316	1 004	0 999		
317	0 998	0 993	Cell damaged in fabrication	
318	1 008	1 003		0 986
319	1 000	0 995		
320	–	–	Cell damaged in fabrication Cell completely damaged after 150 cycles	
321	0 973	0 969		
322	1 018	1 013		0 956
323	0 928	0 924	Filter delamination after 100 cycles	
325	1 004	0 999		
326	0 888	0 884	Filter delamination after 100 cycles	
327	1 047	1 042	Cell damaged in fabrication	0 986
328	1 002	0 997		
329	0 924	0 920		
330	0 992	0 987		
331	1 004	0 999		1 010
332	1 002	0 997		
333	1 029	1 024		
334	1 027	1 022	Cell damaged in fabrication	

TABLE 11. UNCORRECTED AND CORRECTED NORMALIZED CURRENT AT 0.440 VOLT AFTER 200 THERMAL CYCLES SHOWN INDIVIDUALLY AND FOR CELL GROUPS (100 CELL SERIES)

Cell No	$\frac{\text{I at 0 440 Volt – 200 Cycles}}{\text{I at 0 440 Volt – Postfab}}$ R	Corrected (RX 0 9954)	Average Normalized Current at 0 440 Volt
101	0 984	0 979	
102	1 008	1 003	
103	1 012	1 007	0 999
104	1 006	1 001	
105	1 008	1 003	
106	0 996	0 991	
107	1 000	0 995	
108	0 994	0 989	0 995
109	0 982	0 977	
110	1 028	1 023	
111	1 002	0 997	
112	1 010	1 005	
113	1 012	1 007	1 003
114	1 016	1 011	
115	0 998	0 993	
116	1 006	1 001	
117	0 996	0 991	
118	1 015	1 010	1 000
119	1 000	0 995	
120	1 006	1 001	
121	0 992	0 987	
122	0 982	0 997	
123	0 988	0 983	0 983
124	0 992	0 987	
125	0 986	0 981	
126	0 988	0 983	
127	0 996	0 991	
128	1 008	1 003	0 992
129	0 982	0 977	
130	1 010	1 005	
131	1 004	0 999	
132	0 990	0 985	
133	0 990	0 985	0 995
134	1 006	1 001	
135	1 010	1 005	
136	0 978	0 974	
137	1 018	1 013	
138	1 006	1 001	1 000
139	1 010	1 005	
140	1 014	1 009	

Test Procedure

The test cells were subjected to 200 thermal cycles between the temperature limits of +70° F to -200° F. The samples were stabilized at -200° F for a 15 minute soak period during each cycle A margin of 20° F was maintained during the soak period The samples were not stabilized at the +70° F temperature limit. A vacuum of 10^{-6} to 10^{-7} was maintained throughout the thermal cycling and soak periods

The cell voltage-current characteristics were measured before and after fabrication and after each 50 cycles using the X-25 solar simulator (supplied by JPL) Three Hughes supplied control cells and a Balloon Flight Standard Cell No 408 were employed to calibrate and check the intensity of the simulator. The intensity of the light source was maintained at 140 mw/cm^2, AMO After every 10 test samples, a control was measured to ensure consistency. The cells were mounted on a water-cooled block with temperature maintained at 25° C

Results

The detailed cell outputs for this test are shown in Tables 8 and 9. This data is the uncorrected data for the cells' output at short-circuit current, open-circuit voltage, and current at 0.440 volt The cells' output for the prefab, postfab, 50, 100, 150, and 200 thermal cycles is indicated. Observing the output of the control cells throughout the test, it was noted that the control cells' output during postfab calibration was down Comparing the control cells' output for postfab and after 200 thermal cycles, a current correction factor was calculated for current at 0.440 volt. This correction factor was used in the final analysis Tables 10 and 11 show the uncorrected and corrected normalized current at 0.440 volt after 200 thermal cycles Also indicated is the average normalized current at 0 440 volt for each group of cells.

Solderless Cells (Cell Number 100 Series). All the cells on the average survived the 200 thermal cycles except for the 121 to 125 series cells. The average normalized current at 0.440 volt for this series of cells was 0.983, indicating about a 2 percent loss in current at 0.440 volt. These cells were the solderless cells with 60 mil coverslides placed on top of the RTV-602 adhesive.

Solder Dipped Cells (Cell Number 300 Series) Some of the cells in this series were damaged in fabrication The cells were probably damaged when the old coverslides were removed. The cells that were damaged in fabrication were not included in the averaged results. Also, it was observed that several of the cells cracked, which was probably due to the fabrication technique. The cell series 322, 323, 325, and 326 appeared to degrade the greatest amount. Two of the samples exhibited a coverslide delamination These cells were the solder dipped cells with 60 mil coverslides placed on top of the RTV-602 adhesive. The average normalized current at 0 440 volt for this series of cells was 0.956, indicating about a 4 percent loss.

It was observed that there was more scatter in the electrical output data of the solder dipped cells than in the solderless cells. The reason is that the solder on the P contact makes a rough surface, resulting in an uncertain contact with the cell holder.

Conclusions

With the exception of the cells where assembly damage is suspected, the samples that were exposed to the 200 thermal cycles and thermal soaking periods survived quite well. Additional data analysis is in progress.

Electron and Proton Tests

The electron and proton tests include the test plans T-4 through T-12. The cells for both the electron and proton tests have been fabricated and preirradiation calibrations have been completed The voltage-current characteristics have been measured using the JPL X-25 solar simulator. The intensity of the light source was maintained at 140 mw/cm^2, AMO. The temperature of the cells was held at 25° C.

Test plans T-6 and T-7, the low energy proton irradiation of exposed bus bar areas and bar gap areas, require a mask for the small exposed areas Both metal and glass masks will be employed for these experiments. The masks are currently in fabrication.

The facility to be used for the electron irradiation will be the JPL particle accelerator The irradiation will be performed in air. The facility to be used for the proton irradiation will be the NASA Ames particle accelerator The irradiation will be performed in vacuum.

PROJECT MILESTONES

As scheduled, the Solar Cell Radiation Flight Experiment will be acceptance tested and delivered to the spacecraft assembly area on 31 January 1969. Figure 13 presents a schedule for the major project milestones to be completed.

Several milestones have been completed that are of special significance to the program, including:

1) Completion of signal processor breadboard fabrication and evaluation testing

2) Completion of ultraviolet radiation testing

3) Completion of solar cell thermal cycling tests

4) Completion of solar cell fabrication and calibration tests prior to electron and proton radiation tests

5) Completion of solar panel and installation design

6) Receipt of all critical components

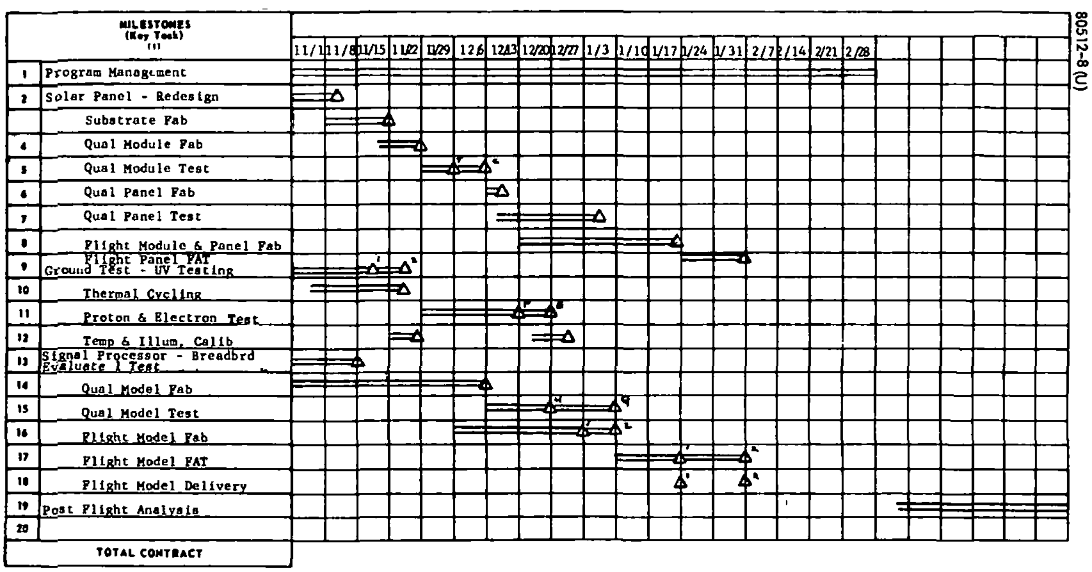


Figure 13. ATS-E Solar Cell Radiation Flight Experiment Milestone Chart

PROJECT ORGANIZATION

The Solar Cell Radiation Flight Experiment for the ATS-E spacecraft has been assigned to the Jet Propulsion Laboratory for implementation At JPL, Dr. Bruce Anspaugh has been assigned the key role as principal investigator.

Under subcontract to JPL, the Space Systems Division of Hughes Aircraft Company is responsible for development, qualification, and delivery of the Flight Experiment. The Space Systems Division also has the prime responsibility to NASA Goddard for fabrication of the ATS-E spacecraft. Figure 14 depicts the organization for the Solar Cell Radiation Flight Experiment Project and its relationship with the Hughes ATS Project Office.

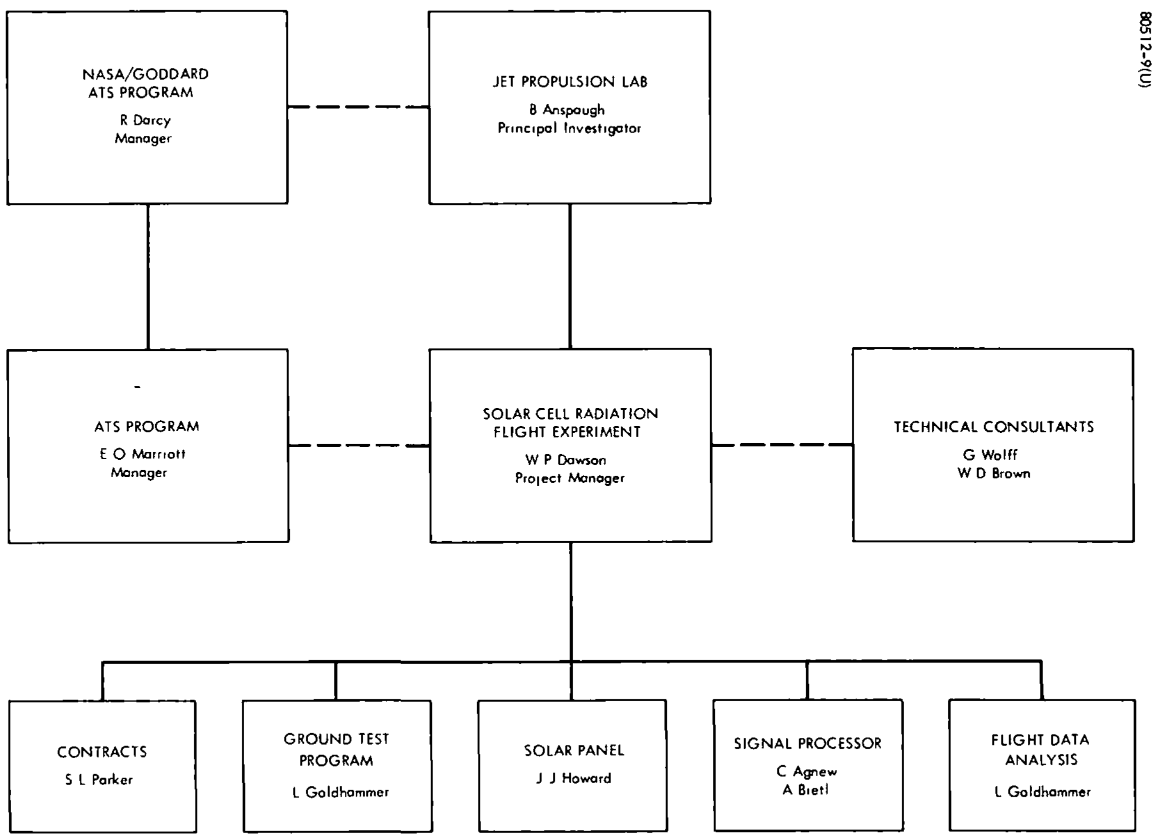


Figure 14. Solar Cell Radiation Flight Experiment Project Organization

3. CONCLUSIONS

The Solar Cell Radiation Flight Experiment has been configured and designed to interface with the ATS-E spacecraft and will provide adequate flight data permitting an evaluation of the radiation effects on solar cells.

The successful completion of the Signal Processor Breadboard evaluation tests confirmed the design assumptions for experiment accuracy and permitted the start of fabrication of qualification and flight model units.

The early results from the ground test program must be evaluated as preliminary data in that the final, and most relevant, evaluation is dependent on the results of the planned electron and proton radiation tests scheduled for completion in January 1969. The preliminary data indicates that, within the range of coverslide thicknesses and adhesives evaluated, mechanical cell failure does not result from thermal cycling.

4. RECOMMENDATIONS

Hughes Aircraft Company recommends that the Jet Propulsion Laboratory review and approve the Solar Cell Radiation Flight Experiment design and data presented in this first quarterly progress report.

Hughes requests and solicits comments and suggestions from JPL, NASA, and industry personnel for improvement in the Flight Experiment and ground test programs.

5. NEW TECHNOLOGY

This report does not contain items of new technology developed by Hughes Aircraft Company under this contract However, the solar cells subjected to evaluation in this program were furnished on a no-cost basis to Hughes and the Government, and the fabrication processes used to manufacture the solar cells may be considered proprietary by the manufacturers