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Paper No. 6

## SOLAR PANEL ACCEPTANCE TESTING USING A PULSED SOLAR SIMULATOR

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### ABSTRACT

Utilizing specific parameters as area of an individual cell, number in series and parallel, and established coefficient of current and voltage temperature dependence, a solar array irradiated with one solar constant at AMO and at ambient temperature can be characterized by a current-voltage curve for different intensities, temperatures, and even different configurations. Calibration techniques include: uniformity in area, depth and time, absolute and transfer irradiance standards, dynamic and functional check out procedures. Typical data are given for individual cell (2x2 cm) to complete flat solar array (5x5 feet) with 2660 cells and on cylindrical test items with up to 10,000 cells. The time and energy saving of such testing techniques are emphasized.

## 1.0 INTRODUCTION

### 1.1 Purpose of Acceptance Tests

In almost all programs for the fabrication of solar panels or arrays, a final test is desired by the customer prior to delivery. This test can range in complexity from a simple visual examination to a complicated Acceptance Test Plan and Procedure. The purpose of this paper is to discuss a typical program where a visual inspection and electrical performance testing utilizing a pulse solar simulator is included.

### 1.2 Types of Tests

After the completion of all manufacturing steps in the fabrication of a solar panel, it is then submitted to the Quality Assurance Department for a final visual examination. Prior to this time the panel has undergone production visual inspections and any rework or additional cleaning has already been accomplished. This visual examination, usually under a 10X microscope, may be the final Spectrolab contact with the panel just prior to shipment or it may be the starting point for an exhaustive acceptance test procedure. Table 1 is a typical Acceptance Test Procedure (ATP) test sequence. Items 1 through 5 represent the electrical

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## ACCEPTANCE LEVEL TEST SEQUENCE

1. Visual Inspection
   022186-10

2. Electrical Performance
   022183 Para. 3.8

3. Blocking Diode Reverse Leakage
   022185 Para. 3.9

4. Insulation Resistance
   022185 Para. 3.10

5. Electrical Bonding Test for Shields
   022185 Para 3.12

6. Thermal Cycle Test
   022185 Para. 3.11     8 cycles at $+71^{\circ}C$ to $-141^{\circ}C$

7. Visual Inspection
   022186-10

8. Electrical Performance
   022185 Para. 3.8

9. Blocking Diode Reverse Leakage
   022185 Para. 3.9

10. Insulation Resistance
    022185 Para. 3.10

11. Visual Inspection
    022185-10

12. Electrical Bonding Test for Shields
    022185 Para. 3.12

13. Final Visual Inspection
    022186-10

TABLE I

testing required on this particular type of panel before and
after any other environmental testing is accomplished. In some
programs there are acoustical, vibration, shock, thermal-vacuum
testing, and others in place of the thermal cycle testing re-
quired in Step 6 of this example. In such cases where the panel
is subjected to the other tests in addition to thermal cycle,
the steps 1 through 5 would be repeated between each type of
test. Some programs require the interruption of the thermal
cycle or thermal vacuum test at specific intervals for the test-
ing of the electrical performance.

Other electrical performance testing is accomplished depend-
ing upon the particular electrical configuration of the panel.
For example, if there are diodes in the circuit then the protect-
ion offered by the diode from leakage and blocking characteristics
are measured. If the solar cells are bonded upon an aluminum
substrate with a epoxy glass insulation then the isolation of
the circuit from the substrate skin is usually a required measure-
ment.

## 1.3 Theory Of Test

The theory or philosophy of the test is to show that the
panel is fabricated in such a manner that under expected oper-
ational conditions it will have a high reliability of success
for the life of the satellite. In general, all solar panel
designs and components have already undergone qualification pro-
gram and QTP. The acceptance test on each panel is to verify
that the individual panel has been manufactured to the required
standards to be similar to that of the panel already qualified.

For panels which have physical dimensions giving an
area less than a square meter, the handling of the panel presents
no major problem and the transporting from one test area to a
second and return is not necessarily difficult. But as the size
of the panels get much larger the potential for damage from trans-
porting and mounting increases, this also greatly increases the
rework and inspection time. The use of a solar simulator which
have a larger area of high uniformity and quality corresponding
to that of sunlight outside of the earth's sensible atmosphere
is difficult to find if a steady state test is contemplated.
If, however, a pulse simulator can be used, then the panel is
positioned from a point or line source of radiation that during
a useable period of time accurately simulates the sun's spectrum
and irradiance. The amount of electricity required to operate a
pulse simulator versus a steady state simulator is only a small
fraction. For a data point every minute; for a pulse simulator
this can be a complete IV curve for a panel, circuit or individual
cell, the power requirement can be less than 5 kilowatts average
with the peak power less than 10 kilowatts. For a steady state
solar simulator with an irradiated area of a circle five meters
in diameter, the power could be 400 kilowatts just for the lamp
system.

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A pulse simulator allows the panel to be tested at ambient temperature only. Because of this it is necessary to know the relationship of the electrical output of the solar panels as a function of temperature. The coefficient of current change and voltage change with temperature is known and is inputed into the computer and the IV curve of the desired temperature can be plotted directly by the computer. More is said about this later.

## 2.0 EQUIPMENT DESCRIPTION

### 2.1 Solar Simulator

The large area pulsed solar simulator system consists of two major subsystems, the pulse illuminator system and the data acquisition and processing system. Its major components consist of a Pulse Forming Network Assembly and an Illuminator Assembly. Within the PFN assembly is a high voltage power supply and a sophisticated charge sensing device, which determines the exact point at which the energy in the PFN should be discharged. The Illuminator Assembly, or lamp housing, contains the two Xenon flash lamps and the lamp igniter, as well as any auxiliary optics necessary to meet the desired performance levels.

The other major subsystem of this simulator is the data acquisition and processing system. This system synchronized with the operation of the pulsed simulator measures panel I-V performance characteristics, performs an analog to digital conversion on all data, stores the digital information, provides mathematical corrections and prints out uncorrected and/or corrected panel I-V characteristics. Major components of this system include a standard cell, an electronic load, digital data processing equipment, and a digital X-Y plotter. See Figure 1.



FIGURE 1

### 2.1.1  Illuminator Assembly

Two FX-47C-6.5 xenon pulse flash tubes are utilized in the illuminator system. They are positioned at the rear of a large light baffle. The primary purpose of this light baffle is to block unused radiation emitted from the flash lamp for personnel protection. The side panel of this baffle assembly is easily removable to provide direct access to the flash lamps.

The illuminator uses 2 E.G. and G. Model No. FX-47C-6.5 xenon lamps connected in series. When pulsed at approximately 2900 A, two of these lamps produce one solar constant over a 17 ft. diameter test plane. In the spectral region between 4000 $\overset{o}{A}$ and 10,000 $\overset{o}{A}$, the deviation of the total simulator irradiance from the NRL Johnson curve is typically less than 3%. At 9000 $\overset{o}{A}$, the deviation is greater due to the presence of the xenon emission band. However, in the pulsed mode low pressure xenon lamps radiate much less spectral energy in this region than the steady state high pressure xenon tubes. By increasing lamp current, the spectral curve can be shifted down in the red region and up in the ultra-violet, or vice versa. This flexibility allows a close match to the AMO spectrum without optical filtering. See Figure 2.

### 2.1.2  Pulse Forming Network Assembly

The pulse forming network is packaged separately. The PFN assembly contains a specially designed high voltage power supply and a charge sense circuit.

The PFN is an 8 mesh delay line especially tailored to match the lamps and produce a light pulse of controlled shape. Eight 240 microfarad capacitors rated at 5 KV are used. A special inductor (wound of #2 AWG solid wire) was designed for this system, which makes it capable of providing a pulse shape that is nearly flat for 1.0 millisecond, the period in which the I-V curve is generated.

The D.C. Power Supply is designed to charge the eight 240 microfarad capacitors in the PFN to 5000 VDC in less than 20 seconds. It consists of a current limited high voltage transformer, a full wave diode bridge and an abort circuit. In the event that either the interlock loop is broken during the PFN charging sequence, or the charge voltage exceeds a predetermined maximum value, the stored energy is dumped harmlessly through the action of a vacuum switch into two 250 ohm, 250 watt resistors in the PFN assembly.

The high voltage transformer has a maximum output short circuit of 1.8 amperes which eliminates the need for a current limiting resistor in the charging loop. Initially about 40 amperes are
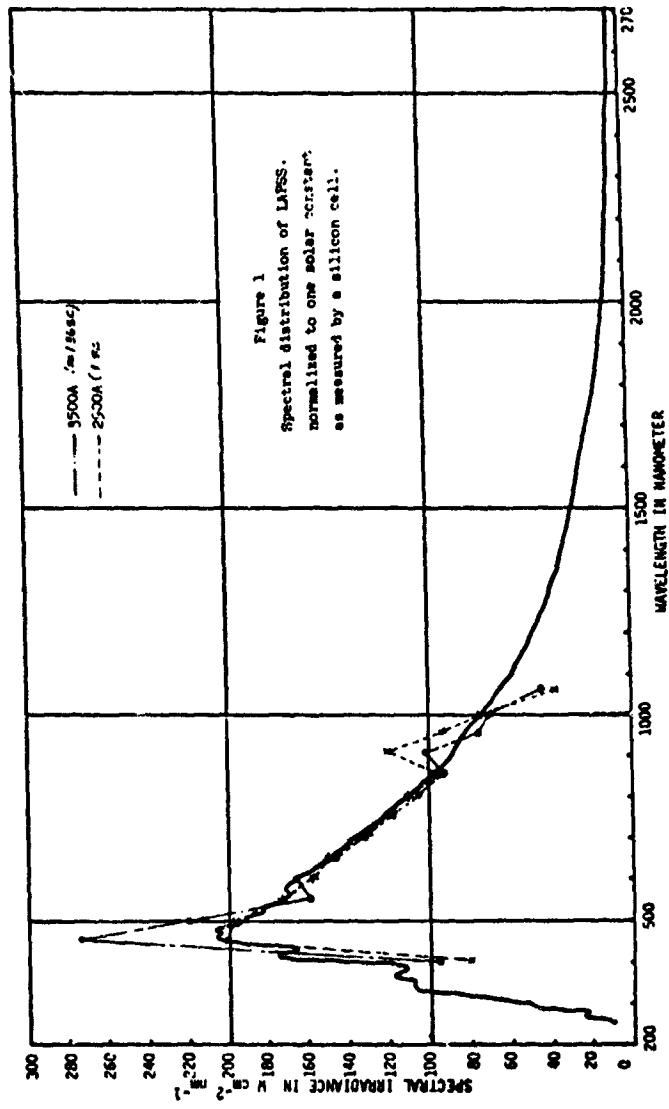
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Figure 1
Spectral distribution of LAPSS,
normalized to one solar constant,
as measured by a silicon cell.

SPECTRAL IRRADIANCE IN W cm⁻² nm⁻¹

WAVELENGTH IN NANOMETER

FIGURE 2
SPECTRAL IRRADIANCE VS WAVELENGTH

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drawn from a 200 volt single phase AC source at the start of the
charge cycle, decreasing rapidly as the voltage rises.

### 2.1.3 Electronic Load

Solar panel loading during the light pulse from the illumin-
ator is accomplished by the electronic load. The circuitry is
similar to a high speed voltage regulated power supply. The
solar panel under test represents a load on the power supply and
a source of load voltage. As the power supply voltage is varied
from zero to full scale value, the I-V characteristic of the
solar panel is swept from short circuit current to open circuit
voltage. As this occurs, both panel current and panel voltage
are monitored.

### 2.1.4 Data Acquisition and Processing System

After initial system start-up, the solar simulator system is
operated from the teletypewriter located at the test console.
Test conditions, system constants, raw data, and corrected data
are printed out on the test console teletypewriter. The digital
plotter can be commanded to plot the corrected I-V curves for
visual interpretation.

The computer provides high speed storage as the data is taken
and provides the corrections for temperature and light intensity
required for all panel tests. In addition, the program provides
the timing signals necessary to coordinate system operation and
performs a validity check on all incoming data. The program is
user oriented, requiring simple commands, e.g. SET (to change para-
meters such as ambient temperature or standard cell sensitivity)
and RUN (to initiate a light pulse).

The keyboard is a standard teletype model 33 teletypewriter.
It provides communication with the computer at a rate of 10 char-
acters per second and provides a written record of all tests per-
formed. The program is loaded through the teletype tape reader.
Data may be recorded on punched tape as well as printed copy.

The plotter is a Hewlett Packard Model 7200A. Coupled to
the teletype, it is activated by commands from the computer and
can draw a curve up to 11 x 17 inches with a resolution of 10,000
divisions on each scale.

The system is operated from the Test Console, Figure 1.
Initial set-up requires controls located on the front panel of the
electronic load. Subsequent operation is controlled entirely via
commands typed into the computer.

### 2.1.5 Control Unit Controls and Indicators

Manually operated controls need be set only once for a given panel type. The voltage and current range switches are set to the lowest (value) compatible with the panel. The Pulse Network Voltage controls the pulse intensity. Once set to produce one solar constant AMO, it need be adjusted only rarely as the lamps age. The Sweep Duration switch allows selection of an optimum number of data points defining the panel curve (the sampling rate being fixed). The Interlock display shows the status of the safety interlock circuit which protects all cabinets having high voltage; depressing the display resets.

As a safety measure, the energy storage capacitor will charge only at the initiation of test sequence. It is not automatically recharged on completion of sequence, eliminating a major potential safety hazard.

### 2.1.6 Data Reduction

The following system constants must be introduced into the processor memory along with the raw test data so that the necessary mathematical manipulations can be accomplished to correct the data:

1. Electronic load voltage range.
2. Electronic load current range.
3. Ambient test temperature.
4. Selected correction temperature.
5. Current temperature coefficients.
6. Voltage temperature coefficients.
7. Cell area.
8. Number of cells in series.
9. Number of cells in parallel.
10. Calibration constants and zero levels for each of the three data channels.

The ranges are automatically read off the panel controls; the remainder are entered into the program's parameter table as described earlier.

### 2.2 Solar Panel Description

The solar panel phusical geometry and composition vary from one program to the next. Some panels are only small developmental ones that have only a few solar cells present. Others will have up to 10,000 cells. In many cases the panel will have a curved surface which the solar cells are bonded upon. Figure 3 is an example of 2 cells in parallel and connected 81 in series with a control tap at the 48th cell. Here the cells were mounted upon a
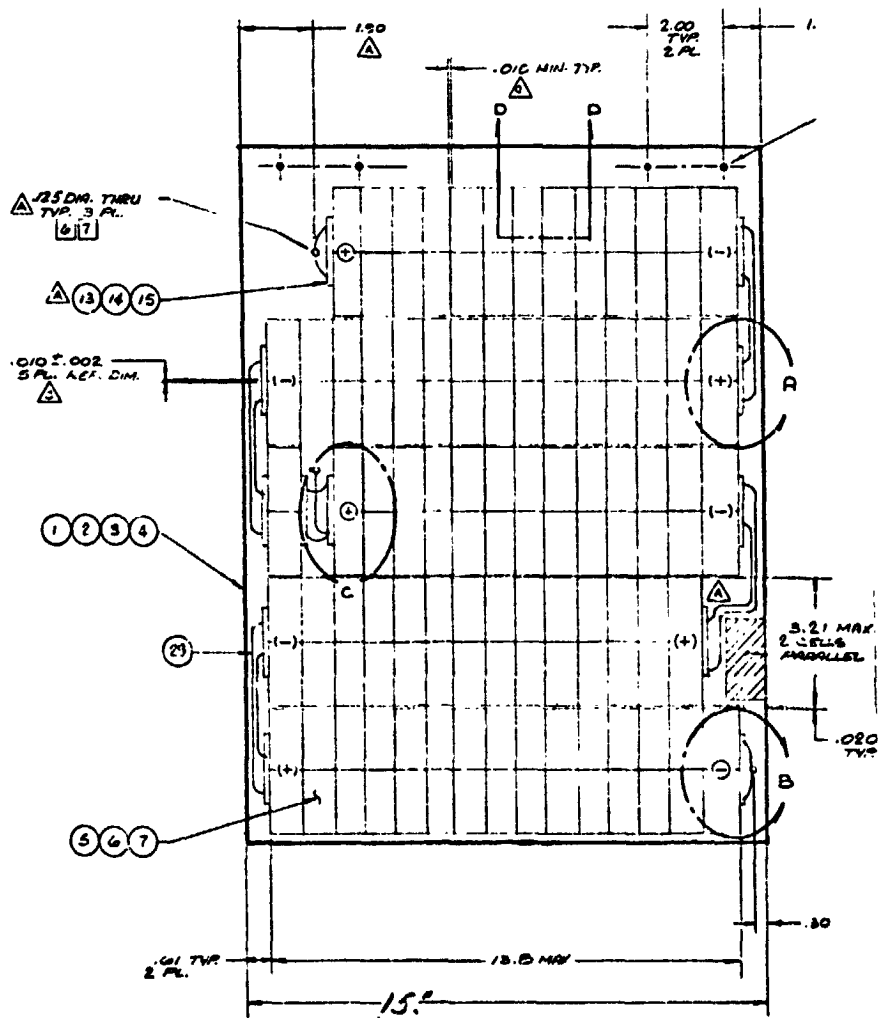
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FIGURE 3

TYPICAL SMALL DEVELOPMENT SOLAR PANEL

curved surface with an epoxy-glass insulation beneath the cells. In some programs the cells are mounted on a continuous cylindrical surface. Cylinders up to 7 feet in diameter have been covered with solar cells.

On flat panels the geometrical arrangement of the cells is controlled by cutouts and other forbidden areas dictated by the customer. The general rule would be to localize individual electrical circuits in a particular area or in a geometrical pattern which may optimize potential shadowing problems or other restrictions which are mission generated.

On cylindrical panels the individual circuits must be confined to a particular small angle of the cylinder to minimize the output falloff caused by the curvature of the panel. For a first approximateion the electrical output will fall off proportional to the cosine of the angle of incidence. Therefore, if a single circuit covers up to 10 degrees of the angle of the cylinder, then the output could be reduced by the cosine of 10 degrees or approximately 1.5%.

Figure 4 shows a large flat panel with approximately cells. Figure 5 shows a cylindrical panel with approximately 10,000 cells.

## 3.0 TEST PROCEDURE

The electrical performance testing of the panel or circuits is not started until three basic calibrations are made on the simulator.

First the calibration simulator is checked against a known standard cell that has an output that can be traced to that of a standard cell flown on a balloon at high altitude. During this calibration of the simulator, both the standard cell to verify the operation of the simulator and the reference standard which is used in every test run, are mounted on the same cooling water supply. This assures that the test conditions of the standards are exactly the same. The standard cells are both mounted within a few inches of one another and in the same plane. The technician insures that the face of the standards are perpendicular to the axis of the simulator. Table 2 is the actual table used when entering the computer for the verification of the standard when the reference standard is serial number #1006. The IV curve that is generated from the running of the standard is then compared to the value specified for that standard. Only if it is within acceptable limits is the calibration of the simulator continued.

Second, the area of the simulators output beam that is going to be used in the actual test being conducted is mapped to determine the lack of uniformity in the test plane or test volume.
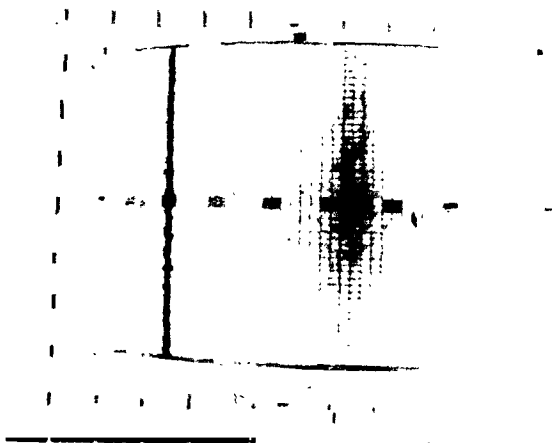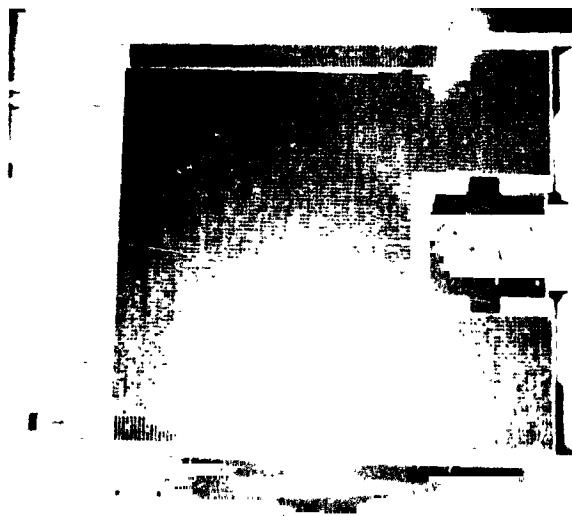
36

FIGURE 5

FIGURE 4

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## PARAMETER TABLE

| 1 | Cell Area | +00190 Sq. Millimeters |
|---|---|---|
| 2 | Cells Parallel | +00001 Cells |
| 3 | Cells Series | +00001 Cells |
| 4 | Ambient Temp | +00028 Degrees C |
| 5 | Standard Temp | +00025 Degrees C |
| 6 | I Temp Corr | +00025 Microamps/Sq Cm/Deg C |
| 7 | V Temp Corr | -02150 Microvolts/Deg C/Cell |
| 8 | AMO Cal Current | +00660 Tenths of Milliamps |
| 9 | Sample Count | +00150 Samples |
| 10 | Output Count | +00065 Output Values |
| 11 | Stand Cell FS I | +01000 Tenths of Milliamps |
| *12 | Stand Cell FS | +01004 A/D Counts |
| *13 | Voltage FS | +01004 A/D Counts |
| *14 | Current FS | +01004 A/D Counts |
| *15 | Stand Cell Zero | +00020 A/D Counts |
| *16 | Voltage Zero | +00019 A/D Counts |
| *17 | Current Zero | +00020 A/D Counts |

* Most recent calibration values are to be used if they differ
  from those specified.

TABLE 2

The size of the panel under test partially determines the total number of test points taken. For large area solar panels a test point usually is taken at one foot intervals or less. The irradiance should not vary by more than 2% over the total test area and the nominal value should be within 2% of the reference standard. Again this is a go/no type test. Figure 6 illustrates a non-uniformity map.

Finally, a dynamic calibration procedure is used to verify that the computer softward does not have some inherent problem caused by an inadvertant change to the program. Here a solar panel with a known output is irradiated by the simulator and the temperature parameters are varied to cause the IV curve to show the temperature dependence under three different conditions. If this and the above two tests are satisfactorily completed, then a solar panel can be tested.

Mounting the panel in the test area, which is a completely blackened room with black drapes and no reflective surfaces, is dependent upon the geometry of the solar panel. Small panels which can be easily supported by either a table, covered with black felt, or supported by wires in the test area. However, the larger panels as shown in Figures 5 and 6 are supported on their own handling fixtures, as in the case of completed cylinders or hemi-cylinders, or from special overhead support hardpoints.

The surface temperature of the solar panel is monitored with thermal sensors taped to the front side of the panel and a digital readout is used with an accuracy of 0.1 degree centigrade. Here the panel is allowed to come to thermal equilibrium with the ambient temperature of the room. The time required to accomplish this depends upon the thermal mass of the solar panel involved. The temperature is monitored until this is reached.

4.0 ELECTRICAL PERFORMANCE

4.1 Types of Output

The standard output of the simulator is an IV curve which starts at the short circuit current and continues until the open circuit voltage is reached. A typical panel has been tested on the pulse simulator to illustrate the typical output. A panel was tested which had four cells in parallel and five cells in series. The panel was fabricated from 2 cm by 2 cm solar cells. The effective surface area was 3.80 square centimeters. Table 3 shows the actual parameters used in the particular test. Note that the panel temperature was at 22 degrees centigrade while the output curve was plotted at 28 degrees centigrade. In Figure 7 the IV curve is drawn for the 22 degree as well as the 28 degree centigrade. This is included to show the effect of the temperature difference. At the particular setting of the table, only
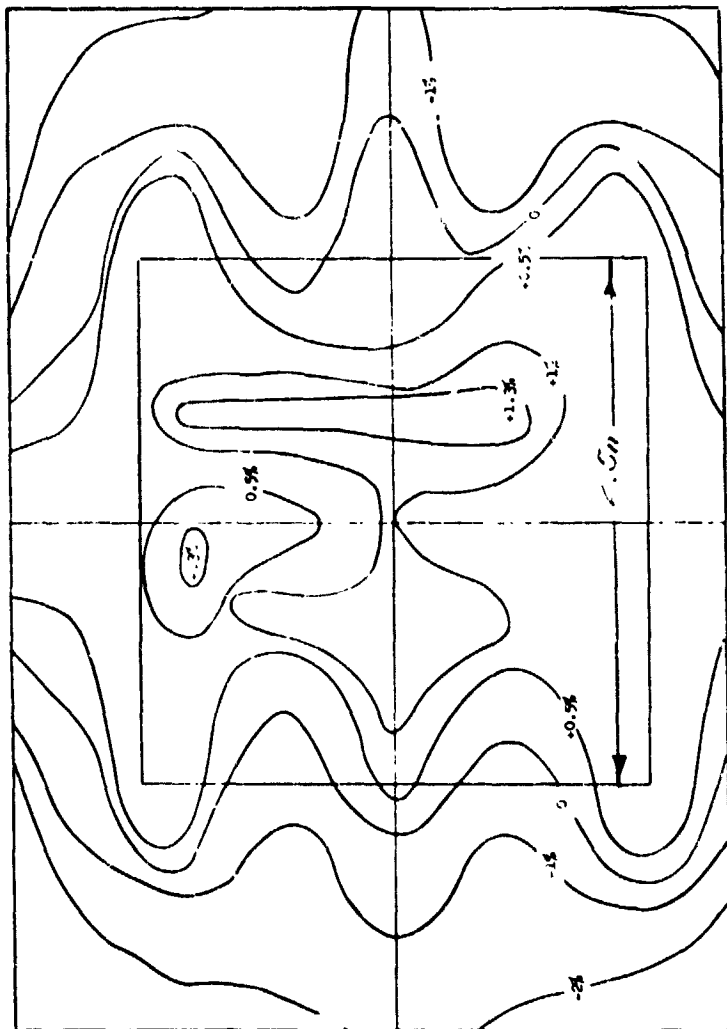
FIGURE 6

MAP OF NON-UNIFORMITY

CURRENT (MA. X _/0_ )

VOLTAGE (VOLTS x _5_ )

SOLAR CONVERTER E . _URVE

SPECTROLAB     Q C FORM 3001

SYLMAR CALIFORNIA   DATE _7 Dec 76_

PROJECT _IEI= PAPER_

SERIAL NO _____

□ CELL □ MODULE ☒ PANEL DESIGNATION.

_4 Parallel x 5 Series_

SOURCE □ SUN □ TUNGSTEN ☒ XENON

_ COLLIMATED          □ UNCOLLIMATED

TEST TEMP _22, 28_ C _____ °F

TEST NO _____ PROC NO _____

Isc = _527_  Voc = _____

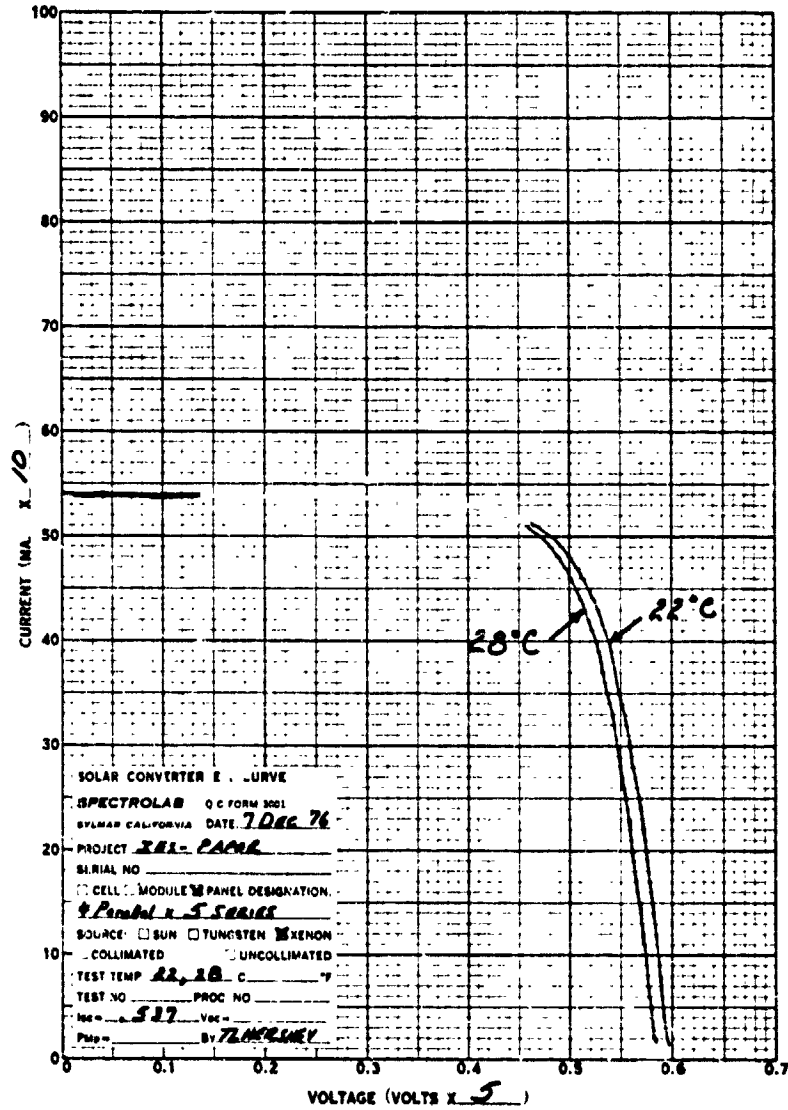Pmp = _____ BY _T. Hershey_

22°C

28°C

FIGURE 7

SOLAR PANEL IV CURVE

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65 data points were requested to be plotted, therefore, the curve
did not completely reach the open circuit voltage point. The
actual data for each of the points can be printed on the teletype
terminal as well as plotted.

The above IV curve was for a simple panel with only one cir-
cuit and no additional complications, however, there are panels
which have curved surfaces and multicircuits which require special
electrical connections. For example, if there are four circuits
on a flat panel then the total output of the panel can be given
including the diode drop associated with the diodes. Further,
if each of the individual circuits (it is assumed they are con-
nected in parallel, which is normal) are to be measured and
excluding the diode then there again is little complication.
However, most customers desire that the total panel and the in-
dividual circuits be plotted and the effect of the diode included.
Here the individual circuits are shorted out inside the diode
(i.e. on the circuit side of the diode) and then the circuit
under test is then tested with only its shorting wire removed.
Except for the diode leakage (which has been measured by other
test procedure) then the desired individual circuit with diode
can be measured.

Another complication arises when the circuit under test is
on a curved surface and the curvature causes a considerable
variation in depth of field of the pulse simulator as well as
the angular effect. Here an analytical technique is used to
evaluate the combination of the two effects and a reduced output
specification is given for those special circuits. Where com-
plete or hemi-cylindrical arrays are involved, only portions
the cylinder are tested at a time and then the cylinder is ro-
tated. Usually one circuit at a time is tested and the panel or
array is analytically summed to determine the output under space
conditions. However, where the number of cells in any one pro-
jected area element varies greatly due to outputs or circuit
irregularities, then the total area is irradiated and then the
cylinder rotated through a small angle and repeated until a
measure of the output variation can be estimated (knowing it
is only an approximation).

Two other techniques are used which are worth mentioning.
First, if the output of a panel is needed in the negative voltage
region in addition to the positive then it is possible to back
bias the array or panel by the use of batteries and pulse the
simulator in the usual manner. The general output of the panel
can be determined even though the exact voltage may be indeter-
minant due to the high speed of the data collection on the vary-
ing output of the batteries. In general, the requirement for
extrapolating the short circuit current back in the negative
region is defined in such a way that this is acceptable. Secondly,
if the panel develops a problem while undergoing test or just a
low power problem then an individual circuit can be probed (care

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being taken not to shadow the cell or cells under test). If a cell
or submodule has a crack or other nonvisible problem many times
it can be located with a relative small amount of time in trouble-
shooting. Usually the total IV curve is not required in the
trouble shooting mode once the general area of the panel has been
isolated and then only the short circuit current is required to
find the low cell. By masking techniques it is possible to lo-
cate which cell in a parallel group of cells in a submoudle is
low.

## 4.2 Parameter Variation

As shown in Table 3 the ambien and standard temperatures
can be specified as part of the data input. Here, if the room
temperature is 22 degrees centigrade, that should be entered into
the computer. However, any temperature can be specified as the
standard temperature, i.e., the temperature desired for the out-
put of the data. (The actual temperature of the standard solar
cell is controlled by the water bath at 28 degrees centigrade
unless changed for some other reason.) The value in the table
for the item 8 AMO CAL CURRENT is the short circuit current of
a particulat standard cell (S/N 1006) at 28 degrees centigrade.

TABLE 3

| | | |
|---|---|---|
| 1 | Cell area | +00380 sq millimeters |
| 2 | Cells parallel | +00004 cells |
| 3 | Cells series | +00005 cells |
| 4 | Ambient temp | +00022 degrees C |
| 5 | Standard temp | +00028 degrees C |
| 6 | I Temp corr | +00025 microamps/sq cm |
| 7 | V Temp corr | -02150 microvolts/deg c/cell |
| 8 | AMO cal current | +00660 tenths of milliamps |
| 9 | Sample count | +00150 samples |
| 10 | Output count | +00065 output values |
| 11 | Stand cell FS I | +01000 tenths of milliamps |
| 12 | Stand cell FS | +01020 A/D coun |
| 13 | Voltage FS | +01020 A/D coun |
| 14 | Current FS | +01015 A/D coun |
| 15 | Stand cell zero | +00003 A/D coun |
| 16 | Voltage zero | +00008 A/D coun |
| 17 | Current zero | +00008 A/D coun |

Figure 8 illustrates the temperature dependence of the
small panel discussed above with 4 cells in parallel and 4 sub-
modules in series. These cells are nominally 2 cm by 2 cm.
The items 6 and 7 in the parameter table are the coefficient of
temperature dependence of the current and voltage. The voltage
dependence in general, over a limited temperature region, is
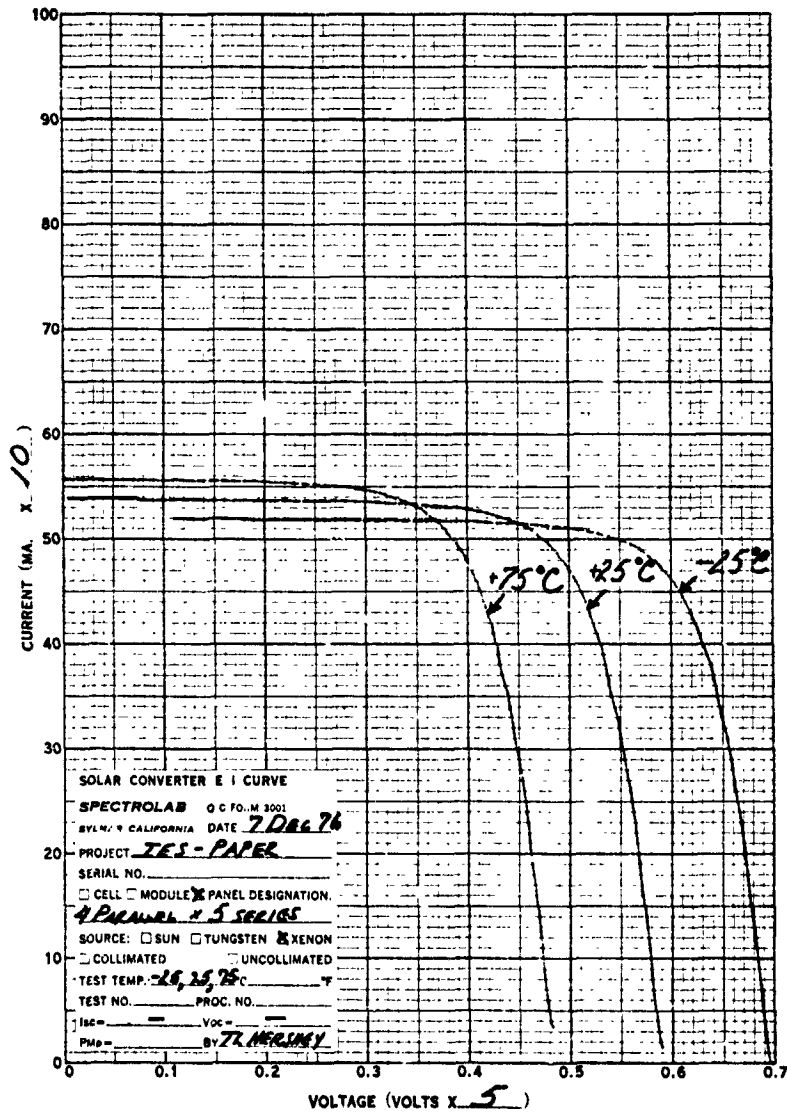the value in the table. For a specific type of cell and large

FIGURE 8

IV CURVE SHOWING TEMPERATURE DEPENDENCE

temperature region the actual value should be determined experimentally. The current correction term is area dependent, therefore the item 1 of the taole is used to correct for the area of an individual cell. Here agai. the specific value for a cell should be determined experimentally. In Figure 8 the temperatures were 75, 25 and -25 degrees centigrade. They were used to illustrate the technique only.

Some applications of the simulator require that the irradiance level be varied from an Air Mass Zero (essentially outer-space irradiance with no atmospheric attenuation) to some other value. Figure 9 illustrates the difference in the above panel at 25 degrees centigrade and at two irradiance levels, approximately Air Mass Zero and Air Mass One (AM1 is nominally the irradiance at Sea Level under a given set of conditions).

5.0  SUMMARY

This paper describes a system used in the acceptance testing of large area solar panels or arrays where close spectral match and high uniformity of irradiance is required. The versatility of irradiance, temperature variation have been included. The total amount of electrical energy as well as the operator and technician time required make this a system very attractive for present day use.
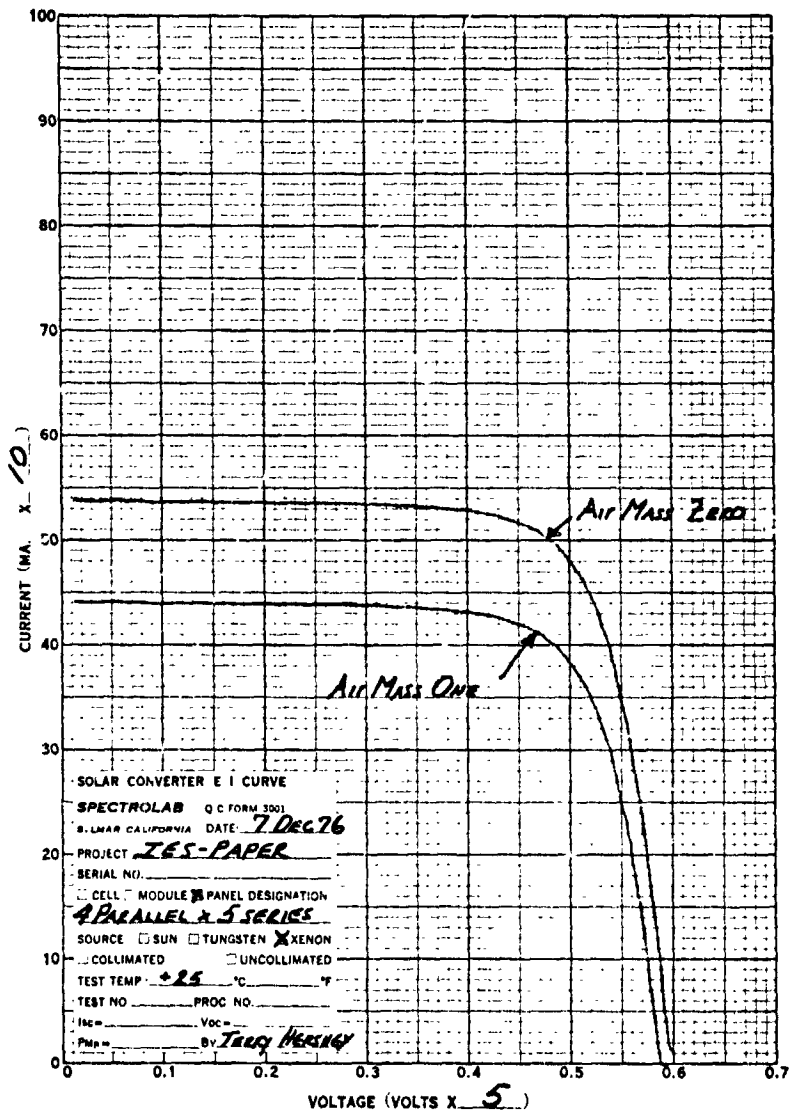
CURRENT (MA. X _10_)

VOLTAGE (VOLTS X _5_ )

Air Mass Zero

Air Mass One

SOLAR CONVERTER E I CURVE

SPECTROLAB   Q C FORM 3001

S. LMAR CALIFORNIA  DATE: _7 Dec 76_

PROJECT _ZES-PAPER_

SERIAL NO.

CELL ☐ MODULE ☐ PANEL DESIGNATION

_4 Parallel x 5 Series_

SOURCE ☐ SUN ☐ TUNGSTEN ☒ XENON

☐ COLLIMATED            ☐ UNCOLLIMATED

TEST TEMP _+25_ °C _____ °F

TEST NO _____ PROC NO.

Isc= _____ Voc =

Pm= _____ By _Terry Hershey_

FIGURE 9

IV CURVE SHOWING IRRADIANCE DEPENDENCE

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Paper No. 7

# LABORATORY FACILITY FOR STUDYING LASER DAMAGE
# OF SATELLITE MATERIALS

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*St. Louis, Missouri*

## ABSTRACT

The development of high energy lasers (HELS) has progressed to the point that the
vulnerability of materials to such laser irradiation requires investigation. The heat-
ing process due to these lasers causes temporary or permanent thermal effects that
can change the thermo-optical properties of irradiated samples. Hence, there has
arisen a need to develop and test new materials and components that are not vul-
nerable to HEL irradiation. This paper describes a laboratory facility designed to
permit testing the response of materials to high energy laser radiation.

The HEL testing described in the paper requires uniform irradiance of the test
specimen and a means for varying the irradiance in a controlled manner. As the
laser beam typically is highly nonuniform, a method is described for producing a
uniform intensity beam from an initially nonuniform beam.

A Sylvania model 941 $CO_2$ electric discharge laser is the laser source for these tests.
Intended for use primarily in industrial welding applications, this laser has been de-
signed for reliable operation at relatively high power with little regard to mode
purity. The paper describes a tapered parallelepiped beam integrator of square
cross-section into which the incident beam is imaged by a zinc selenide lens. Multi-
ple reflections from the highly polished interior walls of the copper integrator cause
an overlapping of the input spatial pattern to produce an output beam with nearly
uniform cross-sectional intensity. The output is imaged by a series of gold-plated
mirrors onto the sample. Beam uniformity of $\pm 10\%$ peak-to-average is readily
achieved.

The time variance of the intensity is obtained by controlling the laser discharge cur-
rent with a programmable microprocessor. Operating open-loop from a real-time
power meter, the microprocessor adjusts the laser power to agree point-by-point
with pre-programmed levels.

There is a great variety of material types currently requiring vulnerability testing,
but a relatively few property measurements can be used to provide nearly complete
thermophysical characterization. These properties are temperature, emittance, solar
absorptance, far infrared reflectance and transmittance, and material outgassing.
The laser exposure is performed while the materials are in a vacuum environment
since this duplicates orbital conditions. Moreover, the measurement of properties
by which material response is determined is also performed in-situ. This approach
satisfies the concern that exposing materials to the air after testing may induce
changes in properties that would not occur otherwise. Stable operation of equip-
ment is a prime requirement of this approach because the elapsed time between

pre-test and post-test measurements can be several hours or longer. On the other hand, absolute measurements are not required since changes in properties provide a sufficient characterization. The achievement of these goals is discussed in detail.

The design of the vacuum chamber used in this testing is also discussed. Basically, the chamber is a system with ports around the circumference at two levels. The upper level ports are designed for interfacing the optical measurement apparatus, while the lower level ports are for the laser exposure station, pressure monitoring instrumentation, electrical passthrus, and spares.

Specimen for laser exposure and optical measurement are attached to retaining rings, which in turn are mated to a flat, octagonal carousel. The retaining rings have been designed to permit secure mounting of the samples while maintaining thermal isolation of the sample from the mount. The carousel is mated to a hub that slides on a shaft for vertical motion between the upper and lower levels. The shaft can be rotated to position any sample in any direction. Both rotation and translation are controlled externally by double o-ring sealed arms that pass through a flange at the bottom center of the chamber.