# SOLAR ARRAY PASSIVE FUNCTIONAL TESTS

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## ABSTRACT

Passive functional tests are required to monitor the health of Mars Pathfinder solar arrays. To accomplish this, a Solar Array Ground Support Equipment Testbed (SAGSET) was proposed with five passive tests to be performed in sequence: positive and negative bus isolation from substrate; solar array string isolation from substrate; string blocking diode forward conduction; string blocking diode reverse leakage; and dark forward IV (DFIV) curves of the solar array strings. It was established that the DFIV test could not easily discriminate a good cell string from a damaged cell string. String capacitance measurements proved to be a superior alternative, Both the DFIV and capacitance tests suffer from one basic problem - the impact of a loss of cell area in one cell is reduced by the remaining series cells in the string. However, tests showed a factor of 4.6 temperature sensitivity advantage and a factor of 18 to ?2 cell area loss sensitivity advantage for capacitance measurements. Using these findings the SAGSET was reconfigured to have seven passive tests. The DFIV test was deleted and three tests were added: solar array string continuity; string parallel capacitance; and string series capacitance, All of these passive solar array tests were successfully computerized using the SAGSET. The capacitance is measured as a component of both a series and parallel network which includes resistance as the other component. The series capacitance test impedance angle may prove to bc as useful as the capacitance measurement. Problems usually encountered with cracked cells are not easily identified by any type of passive testing so a visual inspection of an array is still recommended.

## INTRODUCTION

The Mars Pathfinder mission uses three different solar arrays - one for the cruise phase; onc for the landed phase; and one on the independent Microrover experiment. All three of these arrays arc body mounted and are assembled as part of their respective structures early in the integration process, Early integration leads to two problems with the solar arrays. First, the solar arrays are exposed to subsystem and system level environmental tests over and above the environmental tests performed as acceptance tests for the arrays themselves. Second, the arrays can not easily be accessed for testing. As a result of these problems, an array functional test plan was developed which relies upon a series of passive "health" checks of the arrays. The original functional test plan included these checks to be run initially and then after any major environmental trauma.

This plan was based upon experience and two sources of information. The first source [1] states, "The testing of the dark for ward solar cell array characteristics has received considerable attention for two reasons: (a) solar simulators which illuminate large areas or volumes sufficiently uniformly so that arrays mounted to spacecraft can be meaningfully tested may not be avail able, and (b) large articulated, oriented arrays already integrated to a spacecraft and mounted in a stowed condition cannot be readily unfolded for testing. The dark forward test method is the only presently known method which is applicable for these cases." The second source [2] states, "The dark forward current measurement is a powerful alternative method to determine the characteristics of solar cells, arrays and generators. Although there is a direct relation between dark current characteristic and IV-characteristic, the dark current measurement does say nothing about the current generation under illuminated conditions. Therefore this method will be preferable (sic) used for generators that have already been measured with solar simulators under conditions, where the application of light is not reasonable e.g. in test chambers or in transport containers."

## MARS PATHFINDER REQUIREMENTS

The exposure to environmental and transportation stresses raises an obvious concern over the health of the arrays. However, after integration there is no longer any practical or economical way to perform illuminated tests. The usual way to address this concern is to perform a visual inspection and a continuity test of the array strings. A visual inspection is not feasible on Mars Pathfinder lander and Microrover solar arrays. Due to the possibility of biological contamination, a plastic biological contamination barrier film is placed on these arrays making them very difficult to inspect. A cell string continuity test also has serious limitations since it only checks for the presence of a conductive path and gives no information as to whether or not there has been any electrical insulation degradation or any cell cracking and attendant loss of effective cell area.

## SAGSET DEVELOPMENT

In order to perform the array health checks and meet the other project constraints such as test time, it was decided to build a SAGSET. The original SAGSET hardware consisted of a control computer, which incorporated two relay boards with 32 relays each and two digital multimeters (DMMs); and a separate bipolar power supply which was IEEE-488 bus compatible. This equipment was designed to run a solar array passive functional test series consisting of five different functional tests:

(1) Positive and negative bus isolation from substrate;
(2) String positive end isolation from substrate;
(3) Forward conduction of array string blocking diodes;
(4) Reverse leakage of array string blocking diodes and
(5) Dark forward IV (DFIV) curves of each array string.

It is very important to note that the functional testing described above requires that a special test connector be assembled as part of the array and have the following connections: one pin connected directly to the positive end of each array string (not including the string blocking diode connecting to the positive bus); one pin connected to substrate ground, one pin connected to the negative bus; and one pin connected to the positive bus. This test connector can be standardized and used to adapt the SAGSET to a wide variety of solar arrays having up to 32 parallel cell strings.

During a design review of the SAGSET the ability of DFIV testing to discriminate a good cell string from a damaged cell string was questioned. A close reading of the literature cited above [1 -?] showed that there had been earlier concerns about the this problem. This led to a search for alternate testing methods.

## SYSTEM ANALYSIS

### Consideration of Capacitance Testing

In an effort to develop an alternative test with fewer problems than the DFIV test it was decided that a cell string capacitance test was an excellent candidate. This became apparent when the results of previous work [3,5] on solar cell impedance and capacitance measurements was considered. However, both the original DFIV and the new capacitance tests still suffer from one basic problem - the impact of a loss of cell area in one cell is reduced by the remailing series cells in the string. Thus there developed two separate criteria for the evaluation of a passive string health test: sensitivity of the measurements to array temperature changes, and sensitivity of the measurements to a loss in cell area. Evaluation of these criteria are detailed below.

### Temperature Sensitivity

DFIV measurements have a temperature sensitivity which is about -2.1 mV/series cell/° C, similar to the illuminated open circuit voltage ($V_{oc}$) temperature coefficient. The DFIV temperature sensitivity then is -0.23%/°C when a bias voltage of 900 mV is applied across each series GaAs/Ge cell. The temperature coefficient for GaAs/Ge cell capacitance was measured to be 0.05%/°C, therefore there is a factor of 4.6 temperature sensitivity advantage for capacitance measurements.

### Cell Area Loss Sensitivity

Cell area losses of 25% and 50% were considered since the loss of less than 25% is not too serious and the loss of more than 50% would probably result in an open string due to the cell interconnect configuration. The modelled sensitivity of the DFIV voltage to damage on a single cell in a 40 cell series string is about +0.045% for a 25% area loss and +0.11 % for a 50% area loss. Similarly, the modelled sensitivity of the string capacitance to damage or I a single cell in a 40 cell series string is about -0.83% for a 25% area loss and -2.44% for a 50% area loss. This gives a factor of 18.4 to 22.2 cell area loss sensitivity advantage for capacitance measurements.

### Other Capacitance Testing Advantages

There are some other testing considerations besides the evaluation criteria stated above. A DFIV test requires the generation of a voltage sweep from zero to the string $V_{oc}$ and the collection of a number of data points. Even though the data is generated by the same test equipment each time there will be differences in the data sets which will require interpolation rather than a direct one-to-one comparison of the data. The DFIV test also requires that the cell string be DC biased up to the string $V_{oc}$ while a capacitance test is done without a DC string bias and only a 10 01 20 kHz, 2 VRMS test voltage is required.

### Capacitance Testing Disadvantages

The solar array must be in total darkness when the string capacitance is measured, while this is not necessary when performing the DFIV test. This is likely to be inconvenient in some situations. However, this must be done to assure good repeatability of the measurements by preventing any cell-generated voltage bias which, in turn, will directly influence the measured string capacitance.

## LABORATORY RESULTS

### Silicon Array Tests

DFIV: A 37 cell (45.6 cm²) series string silicon BSR array was tested using a dark forward test current of 806 mA and a dark forward voltage at 25 °C of 558 mV/series cell. The temperature sensitivity y of -0.3!, %/°C was measured, equivalent to about -2 mV/series cell/°C. The change in voltage at the test current was +0.19% for a 50% damaged cell.

Capacitance: The same 37 cell silicon array was capacitance tested and showed a 0.23 %/°C temperature sensitivity, somewhat higher than other silicon BSR cells. The measured change in string capacitance for a 50% damaged cell of -2.94%, This compares very well with the calculated string capacitance change of -2.63%.

### GaAs/Ge String Tests

A 4 cell (4 cm²) series string GaAs/Ge array was assembled and capacitance tested. Individual cell capacitances ranged from 423 to 465 nF. About 5% of the area of the lowest cell was removed which resulted in a measured change in cell capacitance of -4.61% and a change in string capacitance of -1.46%. Again, the measured value compares nicely with the calculated string capacitance change of -1.25%.

## OPERATIONAL RESULTS

### Modification of the SAGSET Configuration,

As a result of the review and further analysis the SAGSET was modified to add an IEEE-488 compatible RCL impedance meter with the capability of measuring both parallel and series impedance components. A block diagram depicts the layout (see fig. 1). The SAGSET functional test plan now consists of seven different tests:

(1) Positive and negative bus isolation from substrate;
(2) String positive end isolation from substrate;
(3) Forward conduction of array string blocking diodes;
(4) Reverse leakage of array string blocking diodes;
(5) String continuity for each string;
(6) Parallel capacitance and resistance for each string, and
(7) Series capacitance and resistance for each string

### Field Test Results

Upon completion of the SAGSET, it was moved to the solar array contractor's facility. Following final array assembly, baseline measurements were made using the SAGSET and a solar simulator. Similar tests were made after environmental testing and any necessary array reworking. Considerable enthusiasm developed for the SAGSET, because it would automatically accomplish in 25 minutes what a skilled technician could do manually in three hours, In addition, data collection accuracy and data analysis were greatly improved.

Because of the care in array assembly, the SAGSET did not uncover any substrate shorts, diode failures or string continuity problems. The strings requiring rework had visually cracked cells and moderate current limiting was detected during the electrical test with a solar simulator. At such a low level of cell damage, the SAGSET test data was ambiguous.

### In-House Test Results

The engineering model for the rover solar array was tested in a centrifuge and parts movement caused some cell damage to one string. When the array was tested with the SAGSET, the affected string had the highest voltage and the lowest current readings in the string continuity test. In addition, it had the highest series resistance during the series capacitance and resistance test. Though not strikingly apparent, the results were certainly not ambiguous and indicated possible problems.

### Fault Prediction Capability

The sequencing of each functional test is such that any fault that will affect the results of a following test is tested first. In addition, specification files are built for each type of scalar array to be tested, These files contain information on the required levels of applied voltage or current and the required pass/fail limits for all of the functional test measurements

## SAGSET MEASUREMENT CAPABILITIES

### Voltage and Current

The DMMs are capable of resolving 1 UV and have an accuracy of 0.03% plus 6 times the resolution. They can therefore read 100 UV to an accuracy of ±6%. Current readings are the voltage measured across a wirewound 10 ohm, 10 W resistor.

### Capacitance and Resistance

The RCL meter has an accuracy of 0.1 % or about 1 pF, whichever is greater. The capacitance of the 25 foot test cable is automatically nulled-out at the start of a test and the meter is internally calibrated when turned on.

## SAGSET SAFETY FEATURES

For safety, the bipolar power supply (see Fig. 1 ) has built-in current and voltage limiting and the output is fused. In addition, the bipolar power supply output has over voltage protection for both output polarities and blocking diodes are employed in the test circuitry to prevent inadvertent voltage reversal.

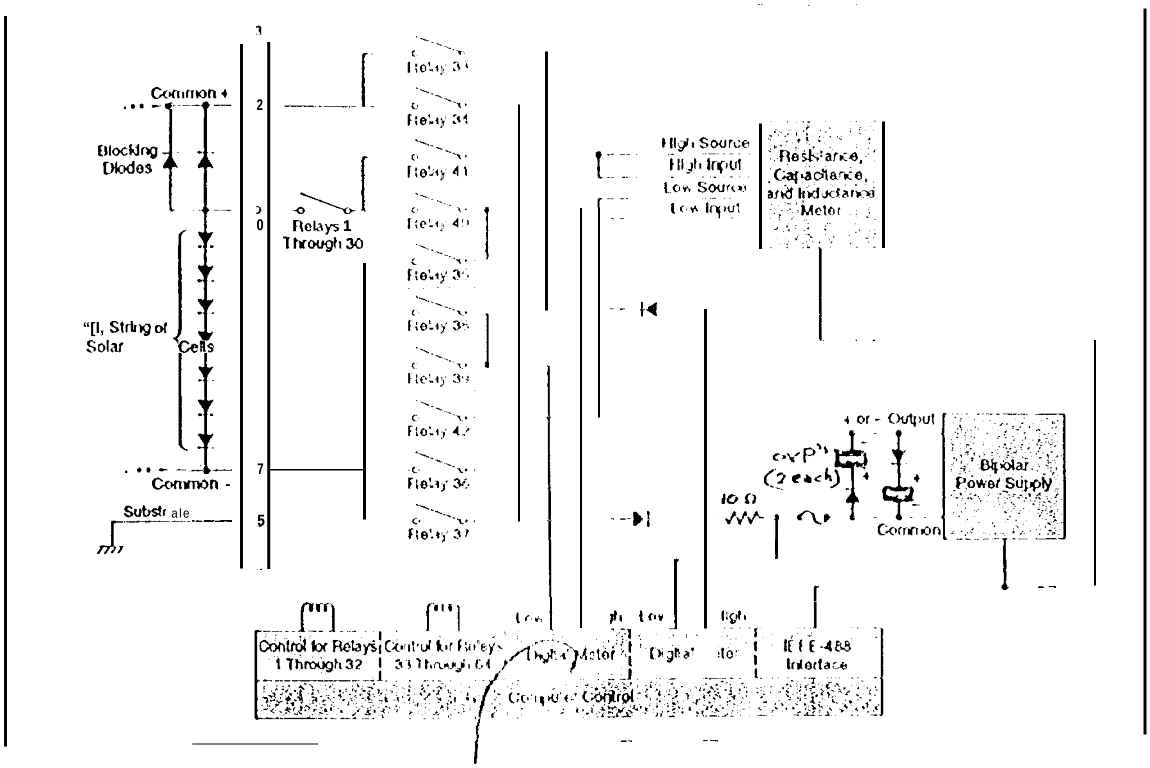


Figure 1, SAGSE Block Diagram

## CONCLUSIONS

The SAGSET was a very successful first attempt at computerizing a number of passive solar array tests which are usually done manually. It can be simply adapted to testing a wide variety of solar arrays if they are fitted with a standard test connector. The time required for a full series of tests, 25 minutes, is only about one-sixth the time required to do them manually. Automatic data acquisition eliminates errors and provides for the immediate analysis of the test data. In addition, modeling and test results show string capacitance measurements to be about twenty times more sensitive to cell area loss than the DF IV test. This makes it easier to detect problems due to cracked cells although they are not easily identified by any known type of passive testing therefore visual inspection Of the array is still recommended.

## ACKNOWLEDGEMENT

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