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MODULE HIPOT AND GROUND CONTINUITY TEST RESULTS

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Hipot (high voltage potential) and module frame continuity tests are important parts of determining the suitability of solar modules for deployment into large arrays for electric power production. Since field arrays operate at hundreds of volts above (or below) ground potential at some point in the field, it is necessary to ensure adequate voltage isolation of the solar cell circuits. This subject is discussed in this presentation as outlined in Figure 1. The discussion is based on test procedures used at the Jet Propulsion Laboratory and as given in JPL Internal Documents Nos. 5101-161 and 5101-162.

The purpose of hipot and continuity testing (Figure 2) is to reveal potentially hazardous voltage conditions of modules before field installation. It also reveals leakage currents that potentially may result in significant loss of power or cause ground-fault system problems. The tests reveal first the current leakage potential and second how the leakage or hazardous voltages will be distributed. Notice the word "potentially" is used in all cases. If the hipot current leakage is a few microamperes too high or the frame continuity a few milliohms too high, one can't say that the module would be an immediate catastrophe if mounted in an array. However, the tests generally do indicate any weaknesses in the design that are potentially hazardous and need to be corrected. In the last few years, hipot and continuity tests have resulted in the highest failure rates of any measurements we make.

The hipot test procedure described in Figure 3 will be discussed first. Figure 4 shows typical equipment used. The Hipotronics HD115 tester supplies the needed voltage and measures the current leakage. The polyurethane boards shown in Figure 4 help isolate the lead wires and reduce any spurious current leakage external to the module.

The next several figures show some of the problems that arise in hipot and continuity testing.

The zinc-based feedthrough connector shown in Figure 5 and at the left side of Figure 6 had very low current leakage (0.6 μA) but corroded badly in the Block V humidity-freeze test. The module manufacturer substituted the stainless feedthrough shown at the right in Figure 6, containing what appeared to be the same internal rubber pottant. However, the latter passed 60 μA of current, resulting in hipot test failure in the connector alone. A minor change in the additives in the rubber caused the excessive leakage.

Figure 7 shows the back side of a simulated roof section holding a module laminate. The galvanized drip troughs around the glass laminate shown in Figure 7 and 8 were unconnected and required bonding wires (Figure 7). The module failed hipot because the black rubber gasket around the laminate was slightly conductive.

Polyvinyl butyral is a popular encapsulant and generally has adequate dielectric strength at room temperature to pass the hipot test. However, leakage increases by about 400 times at hot-day field temperatures (Figure 9). If high ground-fault currents might be a problem in a particular large array, modules should undergo leakage tests at elevated temperatures.

The continuity test used at JPL is discussed next, with illustrations in Figures 10 through 15. As shown in Figure 10, the JPL Block IV tests required a continuity test between metal components of the module frame with a 50-milliohm upper limit. Block V required a continuity test but without a stated limit. At first the same value was used as had been used for Block IV: 50 milliohms. Recently, a high-current continuity test was adopted. Current is passed through the module frame at a level of twice the short-circuit current. Maximum voltage drop permissible is 1 volt from the beginning of the test through a two-minute hold period. This high-current test was based on an interim report of a JPL-Underwriters Lab study. The final report, UL 1703, is the same test except that it calls for only a 1/2 volt drop.

Figure 11 shows the relationship between these tests. The module milliohm resistance is plotted against module short-circuit current. The milliohmmeter test used in Block IV and early Block V was independent of module current. The more recent tests appear as slanting straight lines on log paper. At high module currents the old test was easier to pass and vice versa for low module currents. This comparison assumes that high current will not burn out or weld together point contacts at the joints and that the basic frame resistance remains unchanged.

Figure 12 shows a continuity test setup using a Simpson Model 1699 milliohmmeter. Sometimes the resistance is greater than the instrument's 50-ohm full scale limit. A Fluke 8060AS multimeter shown at the left is used for resistance levels above 50 ohms. Most of the testing done in the past was done using the milliohmmeter and the data presented here was all obtained that way. In the photograph this module shows good continuity with approximately zero resistance. However, in Figure 13, modest forces are being applied to the corner, resulting in a reading on the next meter scale of more than 100 milliohms, a continuity test failure. At JPL the test is ordinarily run with and without "handling forces" applied.

Figure 14 shows the test setup for the newer high-current continuity test. The power supply provides current to the module, generally through the precision shunt shown here. The dial gauges are only coarse indicators but now, at low voltage and high current, digital voltmeters are used to give precise values.

Notice the heavy battery clamps and lead wires. The photo shows the small voltage leads attached improperly. The contact resistance of the battery clamps are frequently 10-15 milliohms. A module with high short-circuit current through this contact resistance will produce a false high voltage and apparent failure. The proper way to attach the leads is to the polished metal frame close to the large clamps.

Figure 15 shows a portion of a two-piece, U-shaped metal frame joined by a riveted joint at each end of the module. The rivets seemed to be well installed and tight. Behind the flange is an ordinary inspection mirror showing the small metal clip that serves to hold the two pieces together. Unbelievably, these two parallel joints showed a combined resistance of over 200 megohms.

The results of the testing are shown in Figures 16-19. For the approximately 250 individual modules in Figure 16, initially 10% and 12% failed hipot and continuity, respectively. All of these didn't complete environmental tests, so there is a smaller population for final tests. 16% and 31% failed final tests, respectively. For the data on sets of modules, in Figure 17, one failure per set is considered a failure of the whole set.

For the sets there was initially a 26% failure in hipot and 9% in continuity. After environmental testing, these failures went to 36%. The last two columns take the most critical viewpoint. If we use the criterion that any failure of hipot or continuity, either before or after environmental exposure, causes the set to fail, there was a 69% failure rate. In spite of these gloomy statistics, most of these problems could be fixed easily. A little more care in fabrication, keeping the bus bars and other conductors a little farther from the frames, better metal joining, etc., would lower the failure rates significantly.

Figure 18 shows the voltages at failure of individual modules. Initially, the clear bars show that relatively few modules failed until the 1000-2000 V range was reached. More than half of all modules that failed did so in this range below 2000 V. After environmental tests the voltage at failure rises, with one failing below 500 V but a considerable number getting to 3000 V only to fail in less than one minute.

Figure 19 shows the resistance in ohms at failure. Initially, there were more failures at more than one ohm than at less than one ohm. After environmental testing the situation was reversed. The right side of Figure 19 is distorted. Initially, high resistance was read simply as "greater than 50 ohms." Later, the digital ohmmeter was used showing that most of these "greater than 50 ohms" were probably "greater than 10 megohms." Therefore, these two bars should be considered in the same group. Notice there are no readings between 10 and 50 ohms and, probably, nothing between 10 ohms and several megohms.

Figure 1. Contents

- PURPOSE OF HIPOT AND CONTINUITY TESTING
- HIPOT TESTING - EQUIPMENT, PROCEDURES, PROBLEMS
- CONTINUITY TESTING - EQUIPMENT, PROCEDURES, PROBLEMS
    - OLD AND NEW PROCEDURES - MILLIOHMMETER VS HIGH CURRENT
- RESULTS OF RECENT TESTS

Figure 2. Purpose of Hipot and Continuity Testing

- REVEAL POTENTIALLY HAZARDOUS VOLTAGE CONDITIONS OF INSTALLED MODULES
- REVEAL LEAKAGE CURRENTS THAT POTENTIALLY MAY RESULT IN SIGNIFICANT LOSS OF POWER OR CAUSE GROUND FAULT SYSTEM PROBLEMS
- REVEAL BY THESE TWO TESTS FIRST, THE CURRENT LEAKAGE POTENTIAL AND SECOND, HOW THE LEAKAGE OR VOLTAGES WILL BE DISTRIBUTED.

Figure 3. Hipot Test

- APPLY DC VOLTAGE AT A RATE NOT TO EXCEED 500 V/SEC TO 3000V, BOTH POLARITIES, BETWEEN THE MODULE CELL STRING AND THE METAL FRAME AND HOLD FOR ONE MINUTE.
- LEAKAGE IS LIMITED TO 50 μA WITH NO SIGNS OF ARCING OR FLASHOVER.

Figure 4. Hipot Test Setup

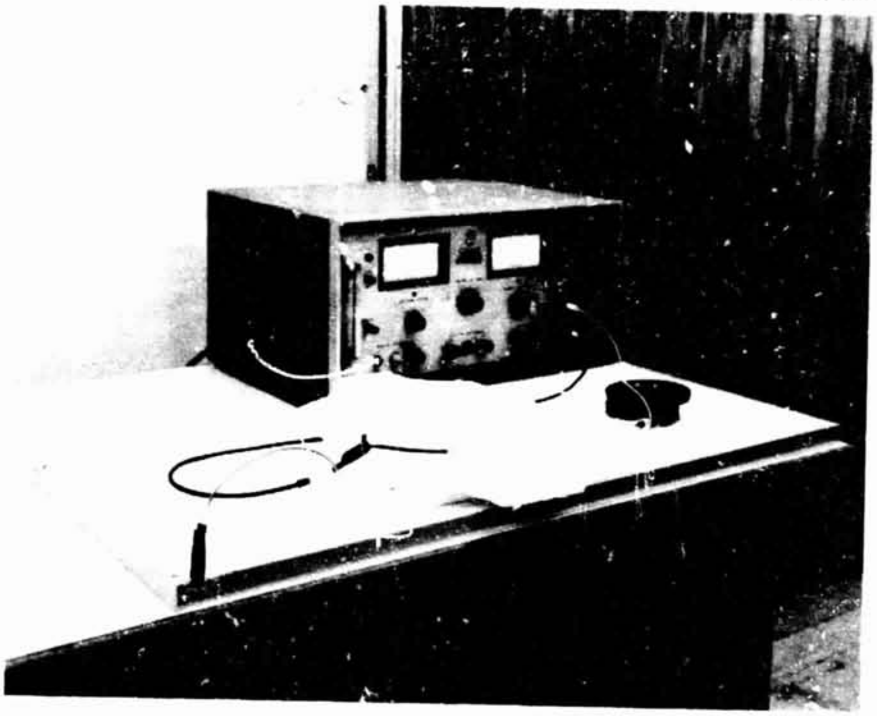

Figure 5. J-Box With Zinc-Based Connector Feedthrough

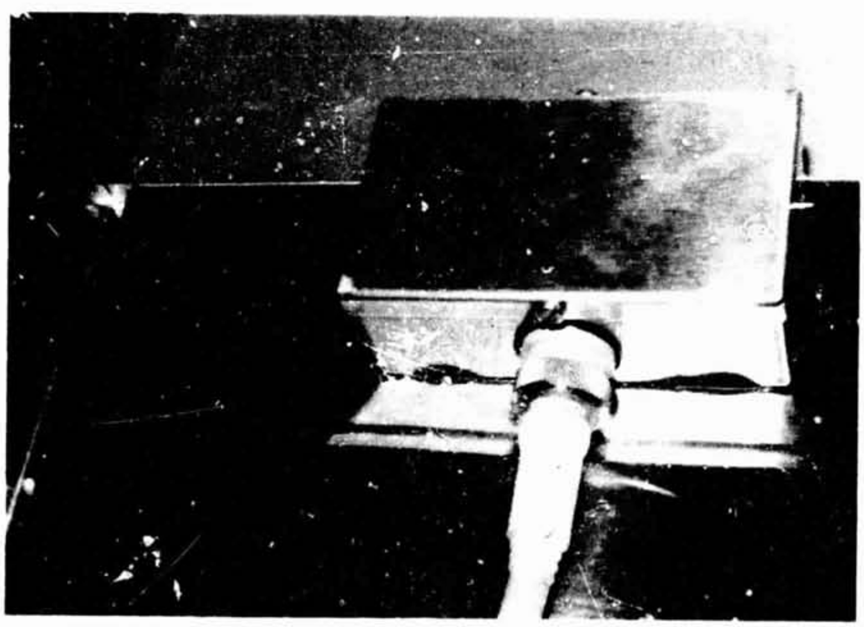

Figure 6. Zinc Alloy and Stainless Feedthroughs

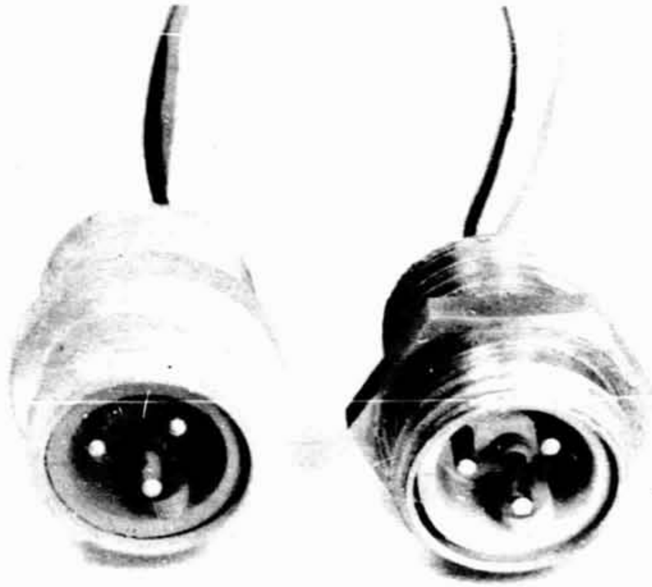

Figure 7. Module in Simulated Roof Section

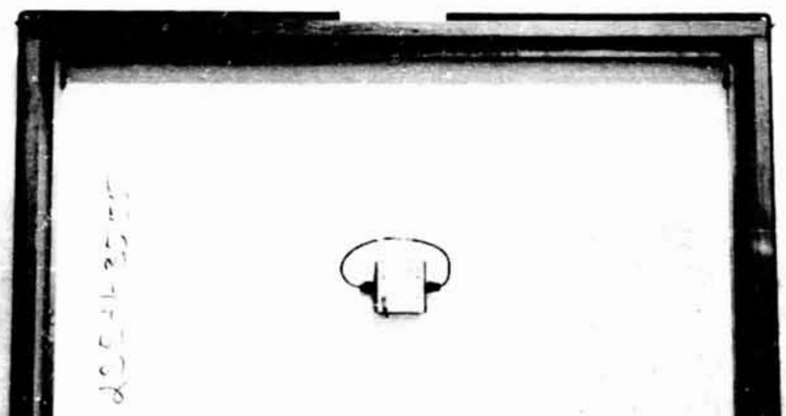

Figure 8. Roof Drip Troughs and Module Gasket

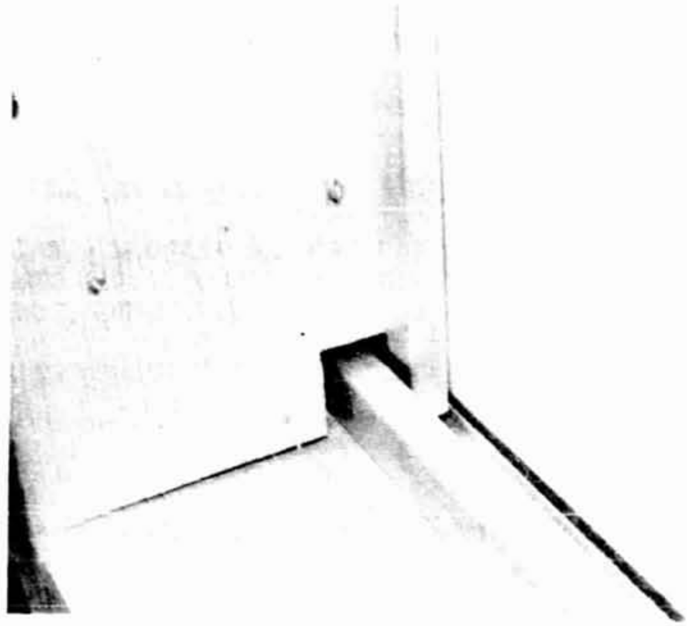

Figure 9. Dc Leakage Current vs Temperature and Voltage

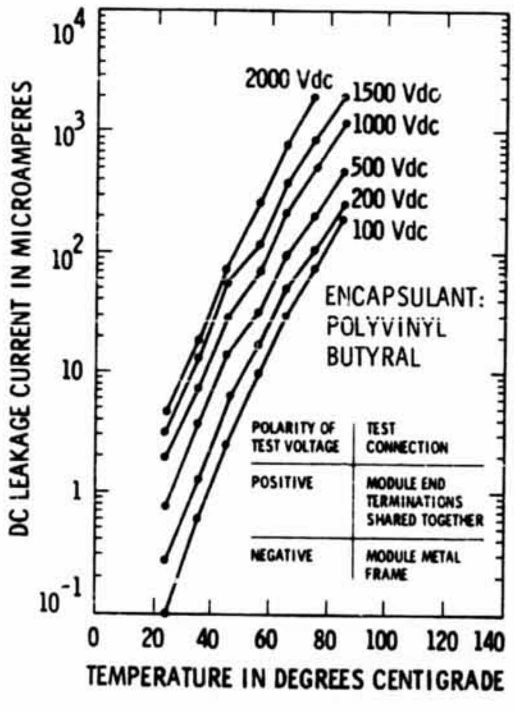

Figure 10. Continuity Test

- BLOCK IV: 50 MILLIOHMS MAX RESISTANCE BETWEEN METAL COMPONENTS OF THE MODULE FRAME.
- BLOCK V: CONTINUITY TEST WAS REQUIRED BUT THE TEST VALUES WERE UNDEFINED UNTIL RECENTLY.
  - EARLY ON – SAME LIMITS WERE USED AS FOR BLOCK IV: 50 MILLIOHMS.
  - LATELY – APPLY CURRENT FROM ZERO TO TWICE THE SHORT CIRCUIT CURRENT IN FIVE SECONDS BETWEEN GROUND AND THE OTHER METAL COMPONENTS AND HOLD FOR TWO MINUTES. MAXIMUM VOLTAGE DROP IS ONE VOLT.
  - UL 1703 – ALSO TWICE THE SHORT CIRCUIT CURRENT BUT MAXIMUM VOLTAGE DROP ALLOWED IS 1/2 VOLT.

Figure 11. Continuity Test: Various Test Limits

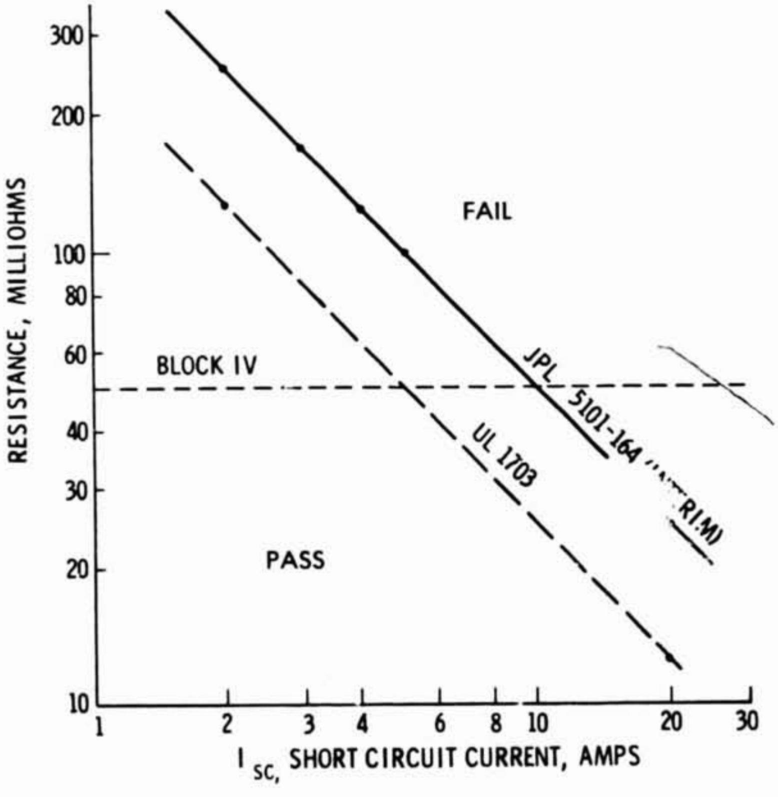

Figure 12. Continuity Test Setup

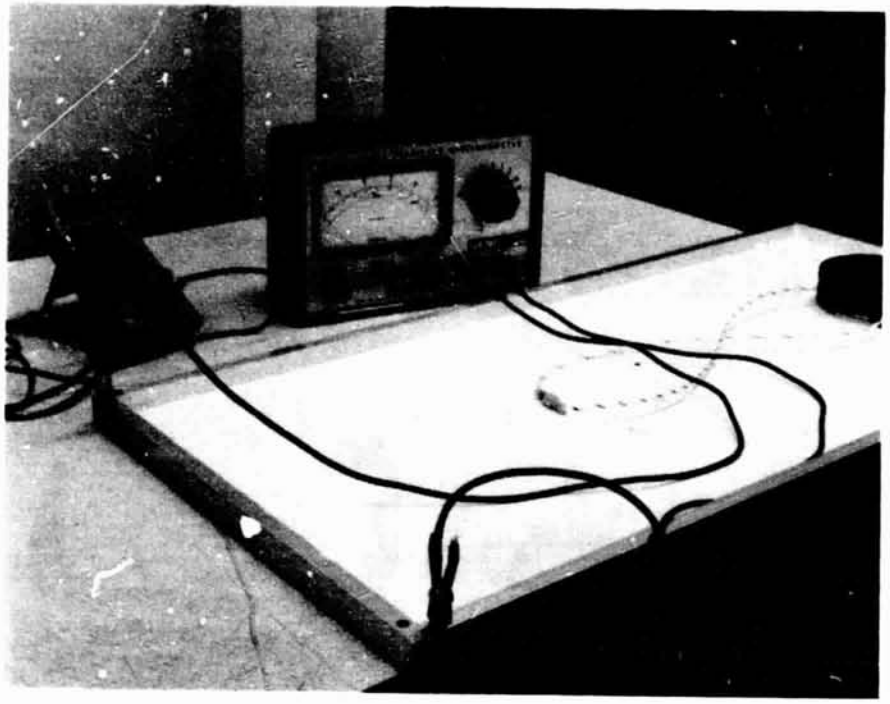

Figure 13. Applying Moderate Forces to Corner Joint

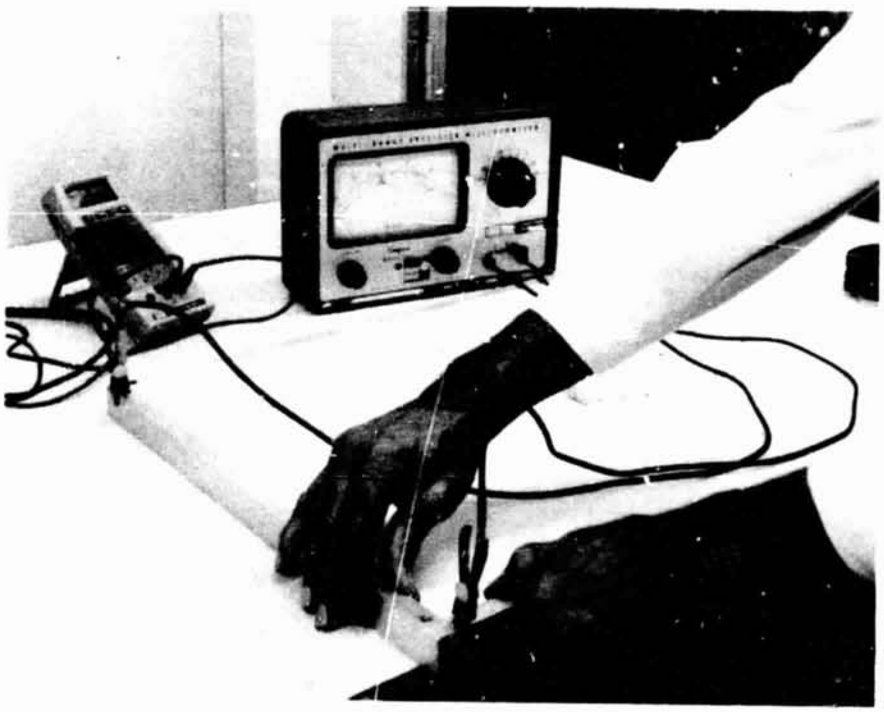

Figure 14. High-Current Continuity Test

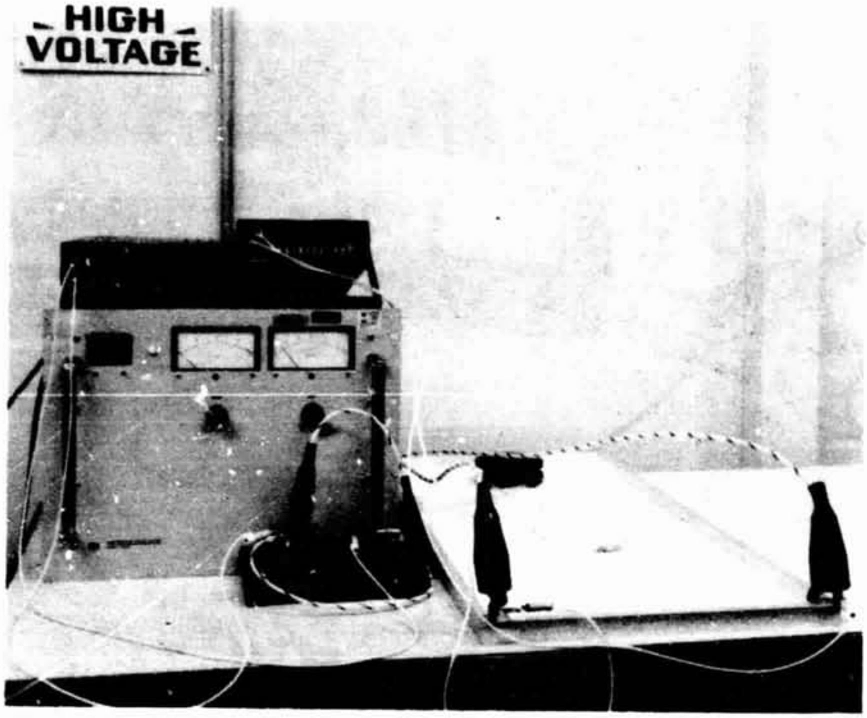

Figure 15. High-Resistance Riveted Joint

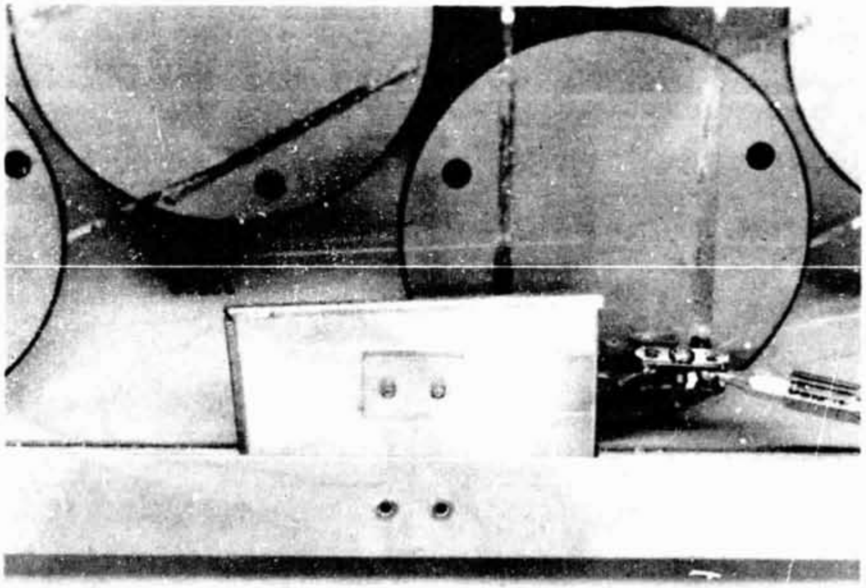

Figure 16. Results of Hipot and Continuity Tests for Individual Modules

	INITIAL TESTS		FINAL TESTS	
	NUMBER TESTED	PERCENT FAILED	NUMBER TESTED	PERCENT FAILED
HIPOT	280	10	192	16
CONTINUITY	238	12	149	31

Figure 17. Results of Hipot and Continuity Tests for Sets of Modules

	INITIAL TESTS		FINAL TESTS		SETS THAT FAILED ONE OF THE FOUR TESTS	
	NUMBER TESTED	PERCENT FAILED	NUMBER TESTED	PERCENT FAILED	NUMBER OF SETS	PERCENT FAILED
HIPOT	35	26	36	36	29	69
CONTINUITY	33	9	28	43		

•A SET OF MODULES IS A GROUP OF MODULES OF THE SAME TYPE FROM A MANUFACTURER AND AVERAGES EIGHT IN NUMBER

Figure 18. Voltage at Failure: Hipot Test

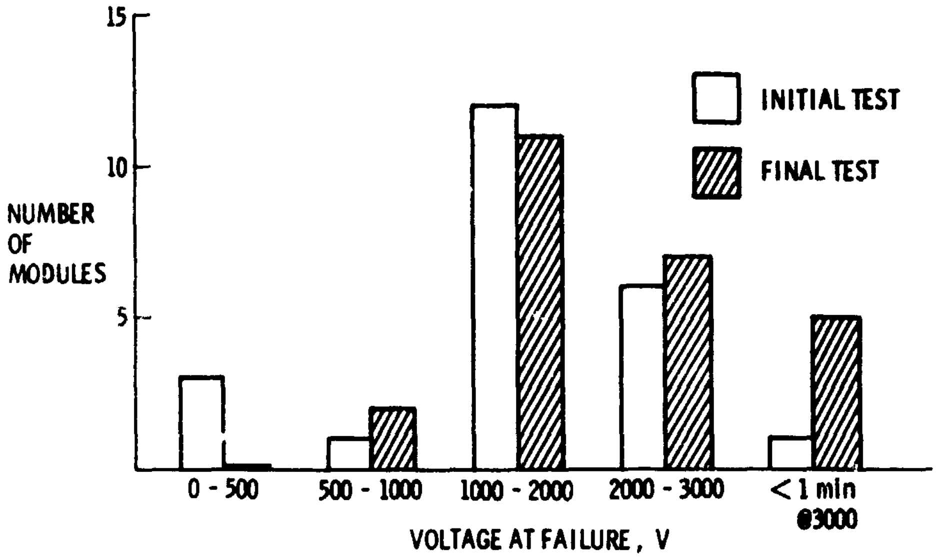

Figure 19. Resistance at Failure: Continuity Test

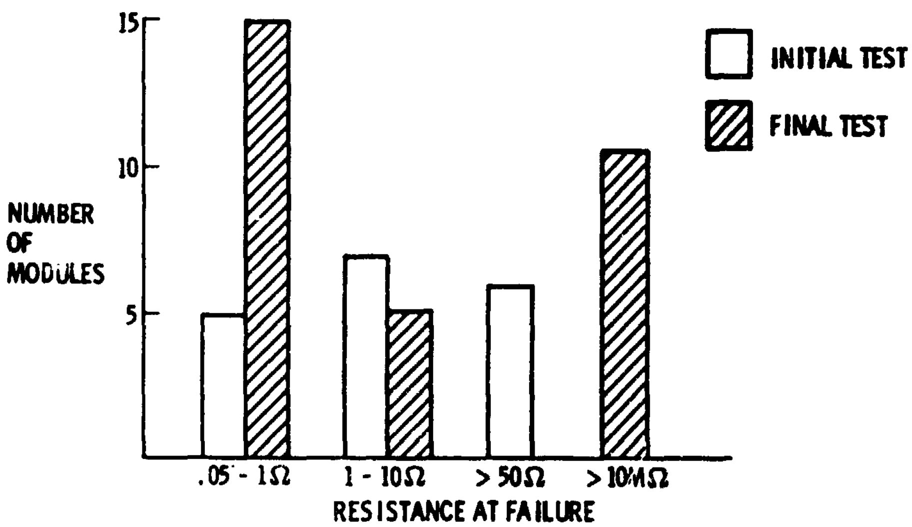

Figure 20. Summary

- HIPOT AND CONTINUITY TESTS HAVE CLEARLY DEFINED LIMITS FOR PASS-FAIL IN JPL PROCEDURES
  - CONTINUITY LIMITS FOR BLOCK V TESTS ARE DERIVED FROM UNDERWRITERS LABORATORY STUDIES
- THESE TESTS RESULT IN MANY FAILED MODULES. A MAJORITY OF THE MODULE DESIGNS FAIL IF THE CRITERION OF ONE FAILURE PER SET OF EIGHT IS USED
- A MAJORITY OF THE FAILURES CAN BE PREVENTED BY SIMPLE CHANGES IN DESIGN OR MODULE PROCESSING