AlbertaSat

Ex-Alta 2

Hyperion Testing Plan

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University of Alberta

Institute for Space Science Exploration and Technology

Document Authentication

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The undersigned acknowledge that they have reviewed the Hyperion Testing Plan, and they authorize the objectives, rules, and organization of the project as described in this document. Any changes to this Hyperion Testing plan will be coordinated with and approved by the undersigned or their designated representatives.

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Record of Document Changes

Version	Effective Date	Author(s)	Section(s) Changed	Description of Change(s)
0.10	N/A	Dineth Jayasekera, Shirley Wang	All	Creation of Document
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1.00	July 20, 2020		All	PCB Component Testing Finalized

Executive Summary

This document outlines the testing to be done on the various components of the Hyperion solar panel system being flown on the Ex-Alta 2 cubesat, and is largely based on standard ECSS-E-ST-20-08C [R1]. The following sections outline the equipment needed for tests, the safety measures taken before, during, and after testing, the procedures for each test, and the pass-fail criteria for each test.

The XTJ Prime solar cell assembly (SCA) will be tested to ensure that the cells meet the specifications outlined in the datasheet provided by Spectrolab, in addition to any other specifications given to AlbertaSat at the time of purchase. Testing done on the SCAs will include electrical performance testing, visual inspections, and verification of the pre-installed bypass diode on the XTJ-Prime solar cells.

The solar panels, or the photo-voltaic assembly (PVA), will go through various qualification tests to ensure that they are capable of providing power required for the Ex-Alta 2 mission, in addition to withstanding a LEO environment. Testing on the PVA will include qualification testing and acceptance testing. This ensures that the Hyperion PVA is capable of performing as designed and will be ready for flight aboard Ex-Alta 2. Tests will ensure that the solar panels are capable of withstanding a range of temperatures and humidities, in addition to a reasonable amount of electro-static discharge (ESD). Testing on the Hyperion PVA will be conducted during and after assembly to ensure that the solar panels are built to mission specifications.

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List of Figures

Reference Documents

Ref. No	Document Name	Description
R01	ECSS-E-ST-20-08C_REV-1-Photovoltaic Assemblies and Applications	Standards document for PVA and SCA assembly.
R02	XTJ Prime Solar Cell Datasheet	XTJ Prime Solar Cell Datasheet.
R03	26.62 cm XTJ Prime Data Sheet	
R04	Nimals Thesis - Nanosatellite Electrical Power System Development	
R05	Solar Panel GitHub Repository	
R06	ASTM E1462-12 Standard Test Methods for Insulation Integrity and Ground Path Continuity of Photovoltaic Modules	Used section 7.2 in page 3 for the Insulation Integrity, Insulation Resistance
R07	Solar Cell Capacitance Determination Based on RLC Resonant Circuit	Used information from this to write the overview of a Capacitance Test in section 3.4.4
R08	Solar Cell Capacitance Measurement Paper R. Blok	Research paper on Time domain capacitance measurement for Multi-Junction PVA and SCA
R09	ASTM D1193-99: Standard Specification for Reagent Water	Standard Specification for Reagent Water
R10	TX2-PW-406 Ver 1.00 Hyperion Solar Panels Interface Control Document	
R11	CV-2289 Adhesive Datasheet	
R04	Electrostatic Discharge Testing on Meteosat 3rd	

	Generation Photovoltaic Assembly	
R13	ECSS-Q-ST-70-06C Particle and UV Radiation Testing for Space Materials	ECSS document detailing UV radiation process
R14	Solar Cell Radiation Handbook NASA	
R15	Thermal Annealing of Radiation Damage in Solar Cells - Goddard Space Flight Center	
R16	Test Techniques for Voltage and Humidity-Induced Degradation of Thin Film Photovoltaic Modules -Jet Propulsion Laboratory	
R17	ISO-23038: Space systems — Space solar cells — Electron and proton irradiation test methods	Electron and proton irradiation test methods for photovoltaic cells
R18	ISO 9211-4: Optics and photonics - Optical coatings - Part 4 Specific test methods	
R19	Accelerated UV Testing and Characterization of PV Modules with UV - cut and UV - pass EVA Encapsulants by Kshitiz Dolia	
R20	Electrical Isolation Design and Electrochemical Corrosion in Thin Film Photovoltaic Modules - Jet Propulsion Laboratory	
R21	Solar Radiation - Qiang Fu, Page 1859	Got values of solar intensity of UV light from this (for the UV test)
R22	ASTM E948-16: Standard Test Method for Electrical Performance of Photovoltaic Cells Using Reference Cells Under Simulated Sunlight	

R23	ASTM E2236 - Standard Test Methods for Measurement of Electrical Performance and Spectral Response of Non Concentrator Multijunction Photovoltaic Cells and Modules	
R24	ASTM: E1802 – 12 - Standard Test Methods for Wet Insulation Integrity Testing of Photovoltaic Modules	
R25	Solar Cell Performance Measurement F.C Treble	Research paper on basic methods of how solar cells can be measured (from 1965 so is a bit dated)
R26	<Removed>	
R27	ecss-q-st-70-02c Thermal Vacuum Outgassing Test	ECSS document detailing how the Thermal Vacuum Outgassing test should be carried out

Overview

This document outlines the testing to be done on the various components of the Hyperion solar panel system being flown on the Ex-Alta 2 cubesat, and is largely based on standard ECSS-E-ST-20-08C **[R01]**. The following sections outline the equipment needed for tests, the safety measures taken before, during, and after testing, the procedures for each test, and the pass-fail criteria for each test.

The XTJ Prime solar cell assembly (SCA) will be tested to ensure that the cells meet the specifications outlined in the datasheet provided by Spectrolab, in addition to any other specifications given to AlbertaSat at the time of purchase. Testing done on the SCAs will include electrical performance testing, visual inspections, and verification of the pre-installed bypass diode on the XTJ-Prime solar cells.

The solar panels, or the photo-voltaic assembly (PVA), will go through various qualification tests to ensure that they are capable of providing power required for the Ex-Alta 2 mission, in addition to withstanding a LEO environment. Testing on the PVA will include qualification testing and acceptance testing. This ensures that the Hyperion PVA is capable of performing as designed and will be ready for flight aboard Ex-Alta 2. Tests will ensure that the solar panels are capable of withstanding a range of temperatures and humidities, in addition to a reasonable amount of electro-static discharge (ESD). Testing on the Hyperion PVA will be conducted during and after assembly to ensure that the solar panels are built to mission specifications.

The tests in this document should be performed in the following order:

1. SCA Acceptance Tests (Chapter 2)
2. PCB Component Tests (Chapter 3)
3. PVA Tests (Chapter 4)
    a. In-Process PVA Tests
    b. Qualification PVA Tests
    c. Acceptance PVA Tests

The solar panels will have been qualified engineering models once all SCA acceptance tests have been performed on the solar cells, the PCB component tests have been performed on each panel, and the PVA tests have been performed on each panel.

1. Safety and Handling Procedures

The following procedures are to be followed in all testing and handling of Hyperion components to ensure operational safety.

1.1. Environmental Conditions

Atmospheric conditions during inspection, testing, and storage, unless specified otherwise, must be as follows:

1. Pressure: 101.325 ± 3.3 kPa
2. Temperature: 23 ± 5 C
3. Average relative humidity: 40 - 60%

In addition, the room cleanliness level should be airborne particle count: Class 8 ISO 14644-1. Any deviation from the above conditions should be recorded [R1].

1.2. Test tolerances and accuracies

In the following tests, the accuracy of the instruments and equipment used to measure and control test parameters should be an order of magnitude higher than the tolerance on the variable to be measured, with the exception of mass and temperature measurements. The accuracy of mass measurements should be better than ±1% of the mass or 0.01g, whichever is more accurate. The test temperature tolerances for any thermal testing are given in table 1.1 below. All equipment and instruments used should be calibrated properly before testing. Instruments should be recalibrated daily during testing **[R01]**.

Vernier Calipers should always be padded before use in measurement. Refer to 5.3 Vernier Caliper Padding

Temperature Range (°C)	Tolerance (°C)
-40 to -30	-10/0
-30 to +60	-5/+5
+60 to +70	0/+10

Table 1.1 - Temperature test tolerances. This shows the maximum acceptable deviation in temperature during a thermal test [1] i.e. the temperature can vary from -50 to -40 when conducting thermal cycling at -40 ℃.

1.3. Parts, materials, and process parameters

1.3.1. Toxicity

1. Identify, and create a log of materials used during the design/construction process that can cause injury. Toxic materials can be identified by checking the case/packaging for the below Hazard symbols

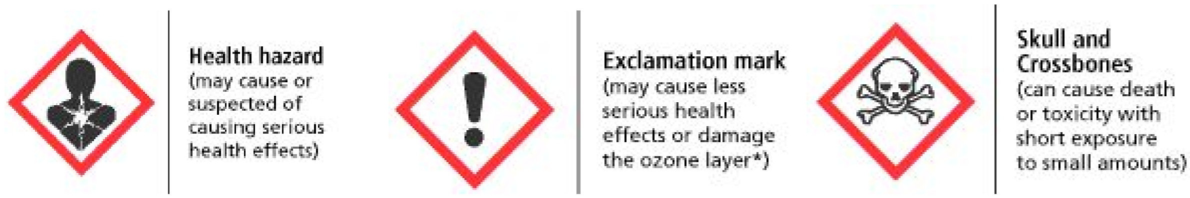

Figure 1.1 - WHMIS 2019 health hazard symbols

2. Not all companies use these symbols so also look for health/toxicity warnings on labels
3. Use gloves and other appropriate protective apparel when handling toxic materials (ie: face masks)
4. Describe precautions to be taken when handling these materials.

1.3.2. Flammability

1. Identify, and create a log of flammable materials used in the design/construction process. Toxic materials can be identified by checking the case/packaging for the below Hazard symbols

Figure 1.2 - WHMIS 2019 flammable/explosive hazard symbols

2. Not all companies use these symbols so look for warnings about flammability/ combustibility on labels.
3. Ensure that flammable materials are stored safely, and are not used in situations where they may combust (ie: used near possible ignition sources and oxygen)

1.3.3. Corrosion

1. Consider the effects of corrosion on the photovoltaic cells during both storage, and during operation. This can be done by estimating the corrosion rate of the PVA system for both the duration in storage and in operations and estimating the level to which the PVA might corrode in that duration.
2. Take the atmosphere conditions 101.325 kPa at 27 C for 5 years.

Figure 1.3 - WHMIS 2019 corrosive hazard symbol

3. Look for electrolytic corrosion erosion near metal-metal interfaces with current flow, and contact with an electrolyte. This is most common near batteries or similar devices.

1.3.4. Magnetism

1. Use only non-magnetic materials. Any permanent magnets used should be recorded. Check for closed loops in the PCB, 90° angle traces, and minimum high speed trace lengths by reviewing all board designs for Hyperion. The Hyperion does not have high speed traces however this is something to keep on mind.

1.3.5. Critical materials

1. All silver cladding used must be annealed, and must be 99.9% pure silver
2. There can be no pure Tin, Cadmium, or Zinc in the finished space-qualified solar panels.
    a. Pure Tin can be a tin alloy with less than three atomic percent of the alloying metal.
    b. Pure Cadmium and Zinc refer to when they are used non-mixed or unalloyed.
3. Solar panels containing Beryllium Oxide should be clearly identified

All of these requirements are from [R01].

2. Solar cell assembly and component level testing

Testing done on the SCA will be to verify that the XTJ Prime solar cells will perform to specification given in the datasheet in **[R02]**. All testing in this section is to be done at atmospheric pressure and room temperature. Testing on XTJ Prime solar cells will involve visual inspections, power generation characterisation, and bypass diode characterisation.

2.1. Visual inspection

All SCAs received from Spectrolab must be visually inspected to ensure that they are free of physical defects and that they are within the dimensions given within the datasheet. The following tests analyze the various parts of the SCA and ensure that each is capable of performing properly and withstanding a LEO environment **[R01]**.

Materials:

1. Magnifying glass
2. Padded Digital vernier calipers - Refer to Vernier Caliper Padding

2.1.1. Visual inspection for defects in the solar cell

1. Search for edge chips, corner chips, surface nicks and record any found.
    a. Edge chips: Defects along the edges of the cell
    b. Corner Chips Defects near the corners of the cell
    c. Surface nicks: Defects or blemishes on the surface of the cell
2. Estimate the length, and area of each defect using calipers and your judgement. The maximum length of each defect is shown below. Solar cells which fail this criteria will be rejected.

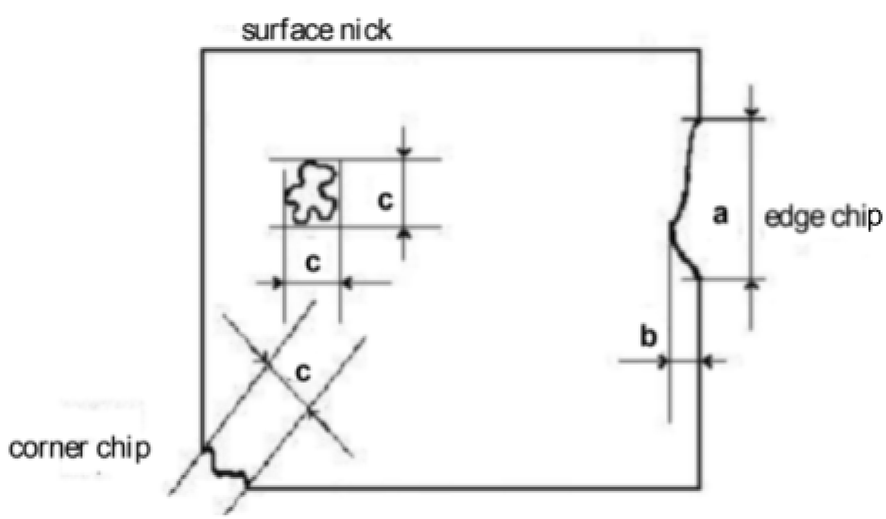

Figure 2.1 - Diagram of Cell Defects [1]

a	b	c
12	1.1	5

Table 2.1 - Maximum Dimension of Each Defect (mm) [R01]

3. The sum of all the areas of the defects found in step 2 must not exceed 1.33 cm^2
4. Focus on defects in the contact weld area as these could weaken interconnections between cells. Use judgement to decide whether the defects will cause any problems.
5. Check for fingerprints. Clean any found using Isopropyl alcohol and cleanroom wipes. Clean by wiping in one direction, the perpendicular direction and repeating.

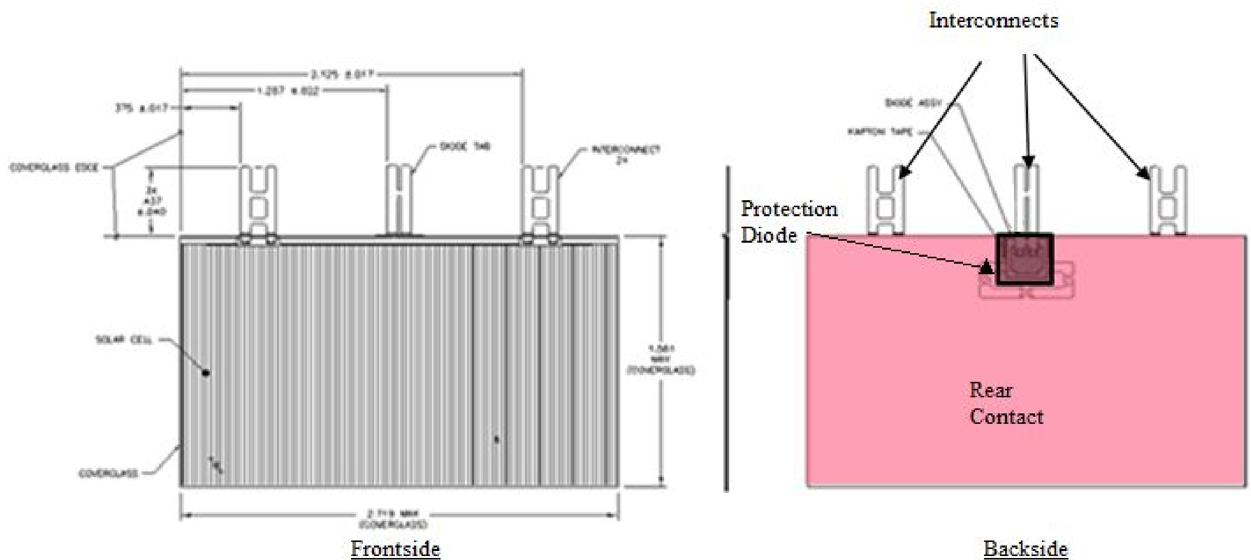

Figure 2.2 - Location of contacts

2.1.2. Visual inspection for defects In the coverglass

1. Inspect the SCA to ensure that the coverglass covers 100% of the bare solar cell.
2. Small surface defects less than 5mm in length on the coverglass can be ignored if the coverglass completely covers the solar cell.
3. Coverglasses with dirty and contaminated surfaces cannot be used. Clean using the isopropyl alcohol and cleanroom wipes. Carefully wipe in one direction, then wipe perpendicularly. Repeat.
4. Check for areas where the anti-reflective coating is missing/ scraped off. Estimate the area of any such regions. The sum of all such regions cannot exceed 0.8 cm^2
5. The coverglass should not contain any bubbles larger than 0.02mm^2. Measure areas using digital vernier calipers.
6. A coverglass cannot have
   a. Cracks with a visible separation

   b. More than 3 cracks
   c. Meeting cracks with non-meeting ends separated by more than 2 mm
7. There should be no discolouration or delamination of the adhesive except in the area opposite the rear welds (where the connecting cells rear welds would attach)
8. Voids in the adhesive must be less than 0.6 mm in depth
9. The total estimated area of bubbles should not exceed 0.5 mm^2 - bubbles smaller than 0.02 mm^2, and bubbles less than 2 mm away from the interconnector edges can be ignored for this test.

2.1.3. Visual inspection for defects In the rear contacts

1. Any SCAs with the following defects should not be used
   a. Any drops and spatter are smaller than 0.1 mm in diameter and 0.05 mm in height.
   b. Edge delaminations should not exceed 0.75 mm.
   c. Defects should not exceed 5.3 mm^2.

2.1.4. Visual inspection for defects in the interconnectors

There can be no breaking, tearing, or deformation of the interconnectors.

Pass-fail criteria

SCAs which do not meet the above requirements should not be used in the final PVA. These cells can be used for testing if the defect does not change the property being tested for.

2.2. Dimensions and mass inspection

2.2.1. Inspection of dimensions

This checks that the SCAs meet the dimensions given in the XTJ Prime documentation [R02].

Materials:

- Measuring tape
- Padded Digital vernier calipers/micrometer
- Mass scale
- Cleanroom wipes
- Isopropyl alcohol (99% or higher)

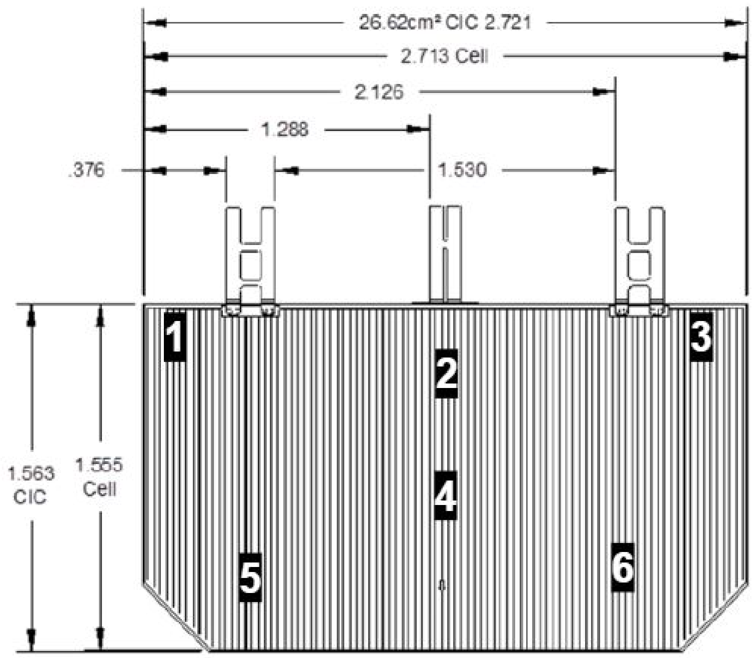

Figure 2.3 - Diagram of XTJ Prime Cell showing measurement points for cell thickness [R03]

Procedure:

1. Use the measuring tape to measure the length of each side of the SCA, and note down the dimensions of each SCA.
2. Measure and note down the thickness of the SCA at the numbered points shown in Figure 2.3 using calipers. Calculate the average thickness.
3. Check if the average thickness is between 80-225 µm. Note any cells which fall outside of this range.
4. Compare measured dimensions with the circuit diagrams, and footprints to ensure that all SCAs fit within the outlines of the PCB Board.

2.2.2. Mass compliance

Weigh each solar cell on a mass balance that meets the minimum tolerance stated in Section 1.2. Divide the mass of each Solar cell by its total area (Mass / 26 cm^2) and check if the obtained value is between 50-84 mg/cm^2 **[R02]**. Any solar cells outside of this range do not meet Mass Compliance.

2.3. Electrical performance measurement

This test measures the full IV characteristic curve of the XTJ Prime SCAs. Isc, Voc and Pmax are found/calculated from the curve. The measured Isc, Voc, and Pmax of the SCA are compared with the expected values.

Follow the manufacturer's guidelines when setting up and calibrating the Solar Simulator.

Materials:

- Calibrated continuous solar simulator (Probably G2V Optics)
- Dark box/room
- Decade box
- Arduino system for data logging with current and voltage sensors

Procedure

1. Ensure that the solar simulator has been calibrated to emit 1 S.C (solar constant) at AM0, there is no spectral mismatch, and that the testing area is lit uniformly using test in appendix A.
2. Connect the circuit as shown in Figure 2.5- the arrangement of the dark box, stand, and distance ***x*** can be found by referring to the manufacturer's guidelines. Use a Kelvin Connection (4 terminal connection) when connecting the sensors.

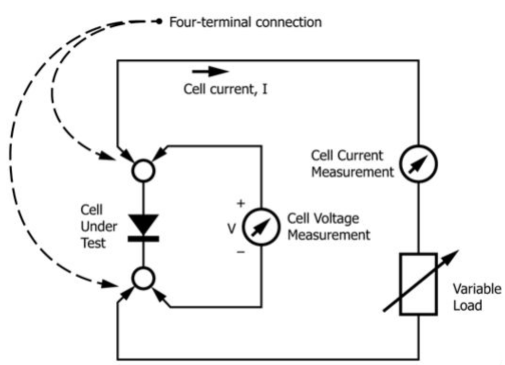

Figure 2.4 - I-V Measurement circuit schematic

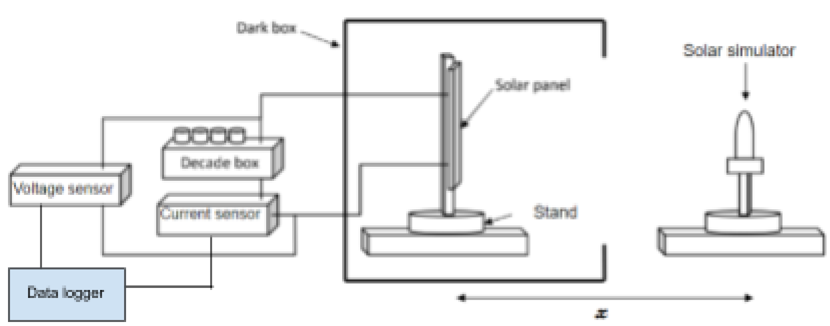

Figure 2.5 - Electrical performance measurement set-up [R04]

3. Set the decade box to 120 kΩ, and turn on the data-logging system. The voltage measured is Voc. If the current is non-zero, increase the decade box resistance until the current sensor reads zero and measure Voc.
4. Slowly decrease the decade box resistance from 120 kΩ by 1kΩ incrementally until the current reading starts to decrease significantly (~5%), at which point the resistance should be decreased by 100Ω incrementally (instead of 1kΩ) - this is done to accurately graph the sharp downward curve
5. Log the data into an excel spreadsheet to draw the IV curve, and derive Voc, Pmax,and Isc from this curve. This is easiest if the data logger directly logs to an excel sheet.
6. Repeat this procedure for all SCAs

Pass-Fail Criteria

The measured parameters for SCAs can be at most 3% below the expected values for Isc, Voc and Pmax [R2].

Expected I_{sc}: 0.467 A
Expected V_{oc}: 2.72 V
Expected P_{max}: 3.51 W

SCAs which do not meet the pass-fail condition, but have a percentage difference of 5% can still be used in testing.

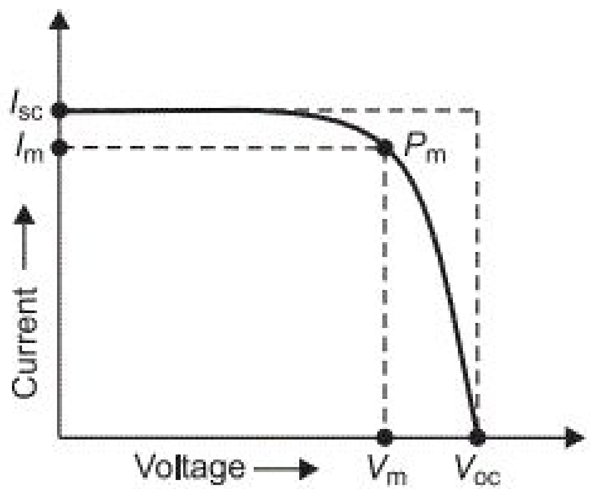

Figure 2.6 - Characteristic I-V curve

3. PCB component testing

In addition to the solar cells on Hyperion, there are other electrical components that need to be tested to ensure that they are in proper working condition. Such components include the magnetorquers on the starboard and zenith solar panels, the 3 temperature sensors, 3 photodiodes, voltage and current buffers, and ADC present on each panel. The following tests are designed to analyze the electrical signals on each component and check to see that they are within the expected range for proper operation. For all following instructions on testing and assembly, please refer to the schematics for each panel shown in the summary schematic and layout documents **[R05]**. These tests need to be performed for every panel.

There are two portions to PCB component testing: testing done prior to assembly of the PCB (discounting the solar cells), and testing done after.

3.1. Pre-PCB assembly testing

3.1.1. Mechanical board dimension check

Materials:

- Padder vernier calipers

Procedure:

1. If digital, zero the calipers.
2. Measure all dimensions of the panel, recording them and the nominal dimensions given in the panel drawings.
3. Repeat steps 1 and 2 for all panels.

Pass-Fail Criteria:

If any recorded measurement differs from the nominal by more than +/- 0.2 mm, highlight it and tentatively fail the panel. It could be fine, but more review is necessary.

3.1.2. Electrical continuity check

This is done to find any electrical breaks in the board made during or after manufacturing

Materials:

- Multimeter

Procedure:

To test the continuity of all nodes on the board, look to the schematics for the appropriate board [**R05**].

1. Set a multimeter to 'Continuity mode', the symbol will look like propagation waves: 
2. Touch the probes together and listen for a beep to indicate that the multimeter works. The beep indicates continuity (no breaks in the circuit).
3. Referencing all nets shown to connect in the schematic, check continuity by pressing the terminals to the appropriate pads ensuring a short. DO NOT press too hard, as to damage the copper pads.
4. Note down any electrical breaks.
5. Repeat steps 3 and 4 for all boards.

Pass-fail criteria:
Pass if there are no electrical breaks. Fail if there are breaks.

3.1.3. Grounding resistance check

This is used to ensure that the resistance between ground nodes is minimal. The test can be performed at room temperature and pressure.

Materials:

- Multimeter

Procedure:

To test the continuity of all nodes on the board, look to the schematics for the appropriate board **[R05]**.

1. Set a multimeter to test for resistance.
2. Place the probes at different ground nodes and record the resistance measurement

Pass-fail criteria:
Pass if maximal resistance is less than 5 Ohms. Fail otherwise.

3.2. Post-PCB assembly testing

Once the Pre-PCB assembly tests have been completed, and the panels have been assembled, the following tests are to be completed. If all components have been added, ensure to clean the board before testing, and ensure that there are no physical defects on the components on the board. The board can be cleaned manually, or with an ultrasound board cleaner.

3.2.1. Electrical continuity check

This is done to find any electrical breaks in the board made during or after manufacturing. Ensure to complete a visual inspection of the boards before to verify the absence of solder bridges and other electrical no-nos.

Materials:

- Multimeter

Procedure:

To test the continuity of all nodes on the assembled board, look to the schematics for the appropriate board [**R05**].

1. Set a multimeter to ‘Continuity mode’, the symbol will look like propagation waves: 
2. Touch the probes together and listen for a beep to indicate that the multimeter works. The beep indicates continuity (no breaks in the circuit).
3. Referencing all nets shown to connect in the schematic, check continuity by pressing the terminals to the appropriate pads ensuring a short. DO NOT press too hard as to damage the copper pads.
4. Note down any electrical breaks.
5. Repeat steps 3 and 4 for all boards.

Pass-fail criteria:

Pass if there are no electrical breaks. Fail if there are breaks.

3.2.2. Magnetorquer testing

The onboard magnetorquers are designed to serve as an alternative way of controlling the attitude of Ex-Alta 2, as opposed to the COTS ADCS. They operate by running current through a copper trace circling a portion of the solar panel PCB, inducing a magnetic dipole moment that then torques the spacecraft. A more in-depth study is necessary, but for the working nature of the magnetorquer, the only thing that is necessary to test is the resistance of the copper trace as well as ensuring that constant power application produces no obvious issues.

3.2.2.1. Power Consumption

This test ensures that at 3V3, the trace will consume a nominal amount of power.

Materials:

- Multimeter/Ohmmeter

Procedure:

1. Measure and record the resistance across the two magnetorquer terminals (labelled as MAG1 and MAG2 on the schematics).

Pass-fail criteria:

Pass if the measured resistance is within 5% of the nominal resistance (10.89 Ohm). Fail otherwise.

3.2.2.2. Voltage Applications

This test ensures that DC, continuous power application will not result in damage to the board.

Materials:

- 3V3 power supply (350mA)
- Thermal camera

Procedure:

1. Apply a 3V3 supply across MAG1 and MAG2 terminals for 10 minutes, monitoring the temperature of the board, recording the maximum temperature every minute, including at test start.

Pass-fail criteria:

If the temperature range exceeds 10 degrees difference across the minimal and maximal temperatures, the magnetorquer is failed.

3.2.3. Photodiode testing

The photodiodes on the Hyperion solar panels will serve as a sensor for whether or not there is incident light on the solar panel the photodiode is on. There are a total of 3 photodiodes on each solar panel, giving a total of 15 photodiodes to test on each panel. For the schematics of each photodiode, see the Photodiode_Sun_Sensor.SchDoc in **[R05]**, or Figure 4.2 in the next section.

Materials:

- Multimeter
- Dark room/box to test the photodiodes while dark
- Light source

Procedure:

1. Connect the board to GND and 3V3.
2. Place the solar panels in a dark box/room that will simulate the solar panel in eclipse
3. Connect the negative probe of the multimeter to the GND node of the solar panel, connect the positive probe of the multimeter to the V_Photo node, and measure and record the output voltage on the multimeter. The output should be 0V.
4. Repeat step 2 and 3 on a surface with sunlight incident on the photodiode. The multimeter should read above 2.3 V. Ensure that the diode is operating at saturation in order to find the maximal voltage.

Pass-Fail Criteria:

If the photodiode provides a saturated voltage measurement underneath 2 V and over 2.5 V, the system is considered to have failed.

3.2.4. Temperature sensor testing

The temperature sensors on the Hyperion solar panels are capable of sensing temperatures ranging from -55°C to 150°C. The goal of this test is to test the range of temperatures that the Ex-Alta 2 mission will be flying in. This test will need to be performed on all 3 temperature sensors on all boards. The temperature will be increased in step sizes of 5°C between -40°C and 70°C. If the board cannot be cooled appropriately with the apparatus available, do the test starting at the minimum temperature possible.

Materials:

- Arduino data logging system.
- Thermometer
- Temperature chamber

Procedure:

1. Connect GND and 3V3 to the board and connect the arduino (or other measurement unit) to the output node of the temperature sensor.
2. Place the unit in the oven/temperature chamber. Cool the assembly to the minimum temperature.
3. Start recording the voltage outputted from the sensor and begin to raise the temperature. Ensure recording of the voltages and measured temperature of the chamber.
4. Warm the chamber at a rate of 5°C/min until it reaches the maximum temperature.
5. Return to room temperature and remove setup from the chamber.

Pass-Fail Criteria:

Ensure that the measured voltages are within uncertainty of the specified output ranges given in the sensor's datasheet.

3.2.5. Voltage and current sensor testing

The voltage and current sensors are designed to measure a voltage in the range of 0 ~ 5.440 V, and 0 ~ 1.44 A, respectively. For the measurements, refer to Figures 3.1 and 3.2.

Materials:

- Constant current source
- Constant voltage source
- Multimeter/arduino

Procedure:

1. Connect GND and 3V3 to the board and connect the arduino (or other measurement unit) to the output node of the current sensor.
2. Connect the current source in series with the sense resistor, with initially 0 A of current running through it.

3. Increase current up to a maximum of 1.5 A in increments of 50 mA maximally, measuring the output voltage everytime you step the current. Alternatively, if using an arduino, measure the current continuously.
4. Zero the amount of current and remove the power source. Now, apply a zeroed voltage source across the V+/GND terminals.
5. Again, while recording, step the voltage up from 0 V to 5.5V in 500 mV steps, maximally.
6. Remove the voltage source.

Pass-Fail Criteria:

If the output voltage exceeds 2.6 V in either the current or voltage tests, the test fails. Else, pass.

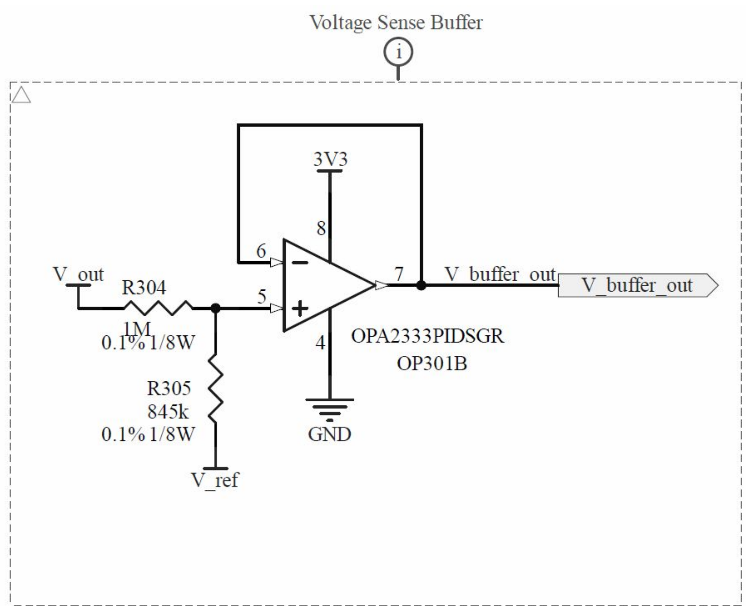

Figure 3.1 - Voltage sense schematic.

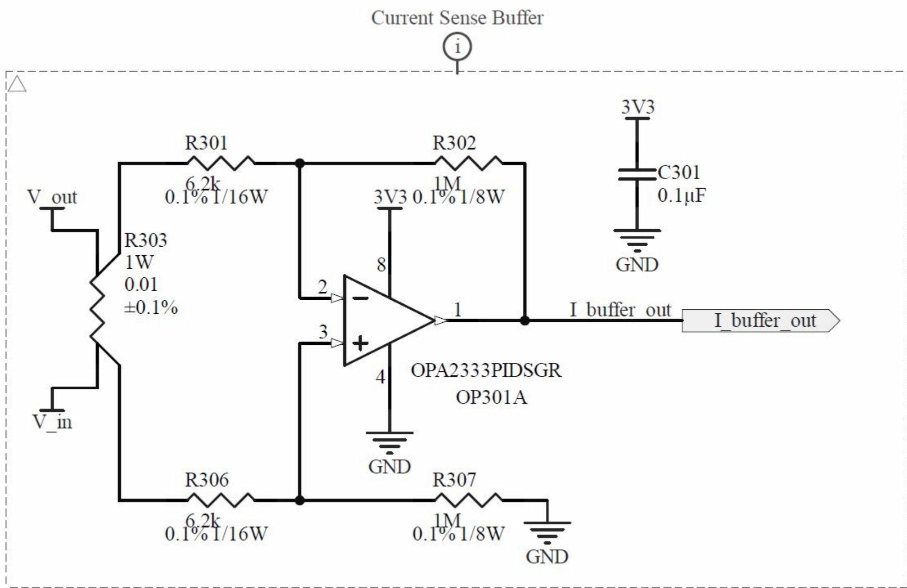

Figure 3.2 - Current sense schematic

3.2.6. Deployment mechanism testing

This is done to ensure that the burnwire deployment mechanism functions as designed.

3.2.6.1. Burnwire resistor cycling

This is done to ensure that the burnwire resistor does not fail after cycling the mechanism repeatedly.

Materials:

- Breadboard and assorted wiring
- Vishay 21 Ohm resistor (VSH-CPF1)
- Voltage supply (7-8.5V)
- DMM

Procedure:

1. Setup the resistor on the breadboard so that it is connected in parallel with the voltage source, but do not complete the circuit or turn on the power supply. Ensure that the resistor is far enough from the breadboard so that the hot resistor does not melt the plastic.
2. Place the DMM in shunt with the resistor.
3. Apply an 8.5 V source across the resistor and start to record the measured resistance across the resistor as it starts to heat. If at any point the resistor breaks, record the amount of time it took to break. Remove the voltage source after 5 minutes.
4. Repeat steps 1-3 (or 3 if the resistor doesn't break) at 0.5 V steps between 7 and 8.5 V.

Pass-Fail Criteria:

The resistor in question fails if it breaks at any point during the test.

Note: If the resistor fails, a new resistance value will need to be selected (likely candidate).

3.2.6.2. Burnwire thread burning

This is done to ensure that the burnwire fails when the resistor heats.

Materials:

- Assembled boards and hinge-mounted deployable.
- Vishay 21 Ohm resistor (VSH-CPF1)
- Voltage supply (7-8.5V)
- DMM

Procedure:

1. This test uses the boards as assembled (the deployables must be hinged onto the satellite). Set this up.
2. Tie the deployable down to the body mounted panel using Nylon thread, wrapped around the Deployable Burnwire resistors (see Figure 3.X). Then apply 8.4 V to *VKnife*, with GND at

PortKnifeReturn. Time how long it takes for the nylon to burn through and the deployables be released. If the panel has not deployed after 5 min, proceed to step 3.

3. Turn off the voltage source. Ensure that the deployables are not damaged after being released.
4. Repeat steps 2 and 3 at 0.5 V steps between 7 and 8.5 V.
5. Repeat steps 2-4 using Dyneema thread instead of Nylon.

Pass-Fail Criteria:
If the panel fails to deploy at any voltage for both types of wire, the test is failed. To fail deployment, the burnwire must not break after one minute of exposure to heat from the resistor.

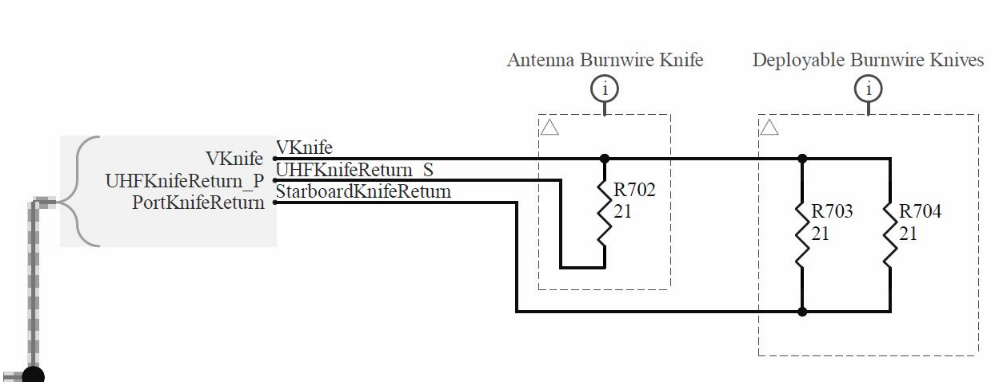

Figure 3.3 - Burnwire resistor schematic

4. Photovoltaic assembly testing

PVA testing will be done to ensure that the Hyperion solar panels are capable of withstanding the environment in space. Since the solar panels will be built in-house, testing will occur throughout the process of building the panels (dubbed in-process testing), qualification testing to investigate whether or not the solar panels can perform as designed, and acceptance testing to ensure that they will be acceptable to fly. Due to the similar nature of the tests described in the qualification testing and the acceptance testing, the sub-tests performed in each of them will be housed in a separate chapter.

4.1. SCA application testing

In-process testing is done to detect defects as early as possible during the manufacturing process of the PVA. By testing while the PVA is being manufactured, the manufacturer will be able to ensure that the solar panels are being built correctly and that the components that are placed on the boards themselves work correctly. In-process testing consists of:

1. Mass Measurement
2. Dry Insulation Test
3. Adherence to Substrate
4. Visual Inspection
5. Continuity check

4.1.1. Mass measurement

This test determines the add-on mass of the SCA laydown process along with any other components which are added to the board. The mass of the PCB Board is measured before and after the SCAs are attached.

Materials:

- Electronic mass balance (see section 1.2 Test Tolerances and Accuracies for information)

Procedure:

1. Place the mass balance on a stable surface
2. Wipe any debris on the balance and zero the balance.
3. Place the bare PCB Board for one side of the satellite on the balance. A clean container can be used to hold the board if required.
4. Re-measure the mass of the PCB Board once equipped with SCAs and any other components.
5. Calculate the add-on mass

Pass-Fail Criteria:

There are no pass/fail criteria for this board.

4.1.2. Dry insulation test

As a substitute to the wet insulation test that was recommended by the ECSS PVA standards, a dry insulation test will be performed on the Hyperion solar panels due to safety considerations. This is an electrical safety test used to verify that there is enough insulation between conductive components of the PVA [R06].

Materials:

- Megaohmmeter

Procedure:

1. Place the PVA on an insulated surface (i.e. wooden table). Make sure that the PVA is not illuminated by either placing it face down on the surface, or keeping it in a dark box.
2. Short the output leads together
3. Make sure the megohmmeter is turned off and connect the high potential red probe to the shorted output leads.
4. Connect the low potential black probe to the ground pad on the Athena/Burnwires header. Refer to diagram 4.x.
5. Turn the megohmmeter to the 1kV setting and ensure that there are no other connections to the 2 probes before pressing the Test button.

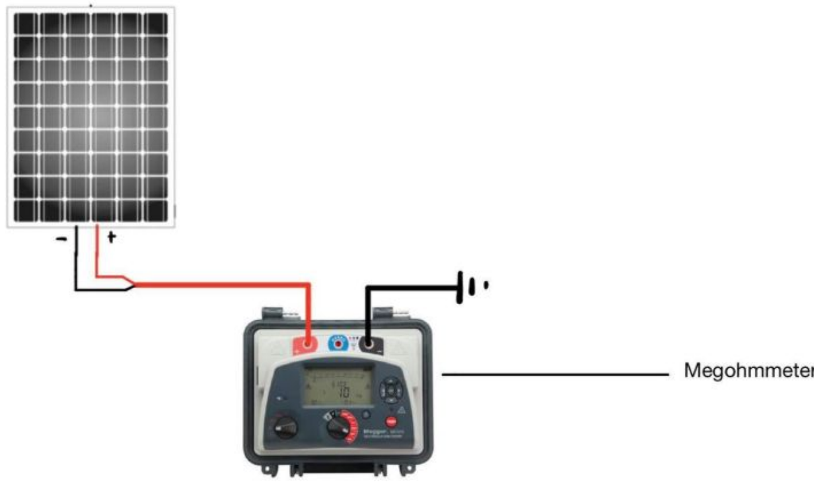

Figure 4.1 - Dry Insulation Test connections

Note: Have to decide on what a good value for insulation resistance should be. Several online sources suggest 40Ω / m^2 such as in [Sino Voltaics: PV Insulation Resistance Test]

4.1.3. Adherence to PCB

Testing the adherence of the solar cells to the PCB ensures that the cells will keep in electrical contact with the PCB while under a certain amount of force, but can still be removed for repairs and replacement [R1].

Materials:

- Kapton foil
- Scissors

Procedure:

1. Take a roll of Kapton foil and and mark 2 rectangles of 250 mm x 150 mm using a thin tipped marker
2. Cut out the rectangles using scissors or a paper cutter
3. Attach the two foils using about the same amount of adhesive as would be used to attach the solar cells [Solar cell application procedure]. Spread the adhesive uniformly on one foil. Keep the foil with adhesive on a clean surface, and carefully attach the edge of the foil to the second foil before attaching the rest. Refer to Figure 4.2.
4. Make sure that all air bubbles are removed by pushing them out using a ruler/similar tool
5. Once attached, cure for the manufacturer-specified time at the manufacturer-specified temperature.
6. Perform a peel test with a force of 1.8 N/cm. Make sure that the separation occurs for an area larger than 50% of the total area of the Kapton foils.

Pass-Fail Criteria:

The Adherence to PCB test will be considered to have failed if the Kapton foils do not separate for an area larger than 50% of their total area. If this is the case, change the amount of adhesive used in the substrate attachment process. Repeat this test to check whether the pass/fail criteria is met.

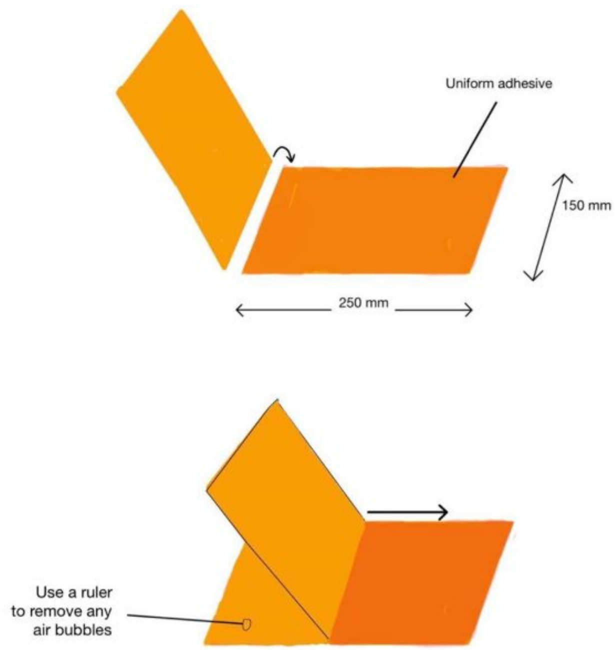

Figure 4.2 - Attaching the 2 Kapton foils described in step 3

4.1.4. Visual Inspection

This check is to be done during and after the stringing process to ensure that the solar cells have been attached properly and to ensure that there are no defects in the PCB or solar cells that might affect the electrical performance of the PVA [R1].

Materials:

- Calipers

Procedure:

1. Measure the dimensions of each of the 5 PCB boards listed below. Compare with the expected dimensions in the CAD diagrams given in the Hyperion ICD document.
   For reference, the diagrams for each solar panel in the ICD can be found on pages:
   a. Zenith solar panel - pg. 8
   b. Port solar panel - pg. 9
   c. Starboard solar panel - pg. 10
   d. Port deployable solar panel - pg. 11
   e. Starboard deployable solar panel - pg. 12

2. Perform the Visual Inspection outlined in section 2.1 for each solar cell in the string
3. Check for excess epoxy and solder. Excess epoxy or solder is any residue that is not useful i.e. epoxy leaking out between the SCA and the PCB board.
4. Clean any streaks/ dirt on the coverglass

Pass-Fail Criteria:
Any board wfhose size deviates from the expected measurements by more than 0.2 mm should be analyzed to ensure that the extra size will not create an issue.

4.1.5. Electrical continuity check

This is done to check all strings, photodiodes, and harnesses to find any electrical breaks that were created after the application of the cells. Each solar panel will have to be tested individually.

Materials:
- Multimeter

Procedure:
1. To test the continuity of the strings on the solar panel:
   a. For the solar panel being tested, set up the circuit shown in Figure 4.1 for the string being tested. The string should be placed under a lamp before starting the continuity check.
   b. Set the multimeter to measure current. Connect the red probe to the current jack (labelled mA or A if there is no mA jack), and the black probe to the com jack. Set the multimeter to measure DC Current. The symbol is an ‘A’ with a solid and broken line above it:
   
   c. Connect the positive DMM terminal to V_PV+ and the negative terminal to V_PV- as shown on Figure 4.1.
   d. Check that the current measured by the ammeter is above 50 mA. This test is not too concerned with the value of the current [R1].
   e. Repeat steps a and b for all strings across the solar panel (there should be 3).
2. To test the continuity of the photodiodes on the solar panel:
   a. Set a multimeter to ‘Continuity mode’, the symbol will look like propagation waves:
   
   b. Touch the probes together and listen for a beep to indicate that the multimeter works. The beep indicates continuity (no breaks in the circuit)
   c. Identify the (+) point where the black probe should be placed, and the (-) point, where the red probe should be placed. The positive and negative sides can be identified by checking the polarity of the diode. Fig. 4.2 shows where to place each probe.
   d. Place a lamp or a light over the panel when testing the continuity of photodiodes. Ensure that all external sources of power are turned off (i.e. 3V3)

   e. There should be a beep for every path tested. The multimeter will display a resistance measurement. Note this value down. Note down resistances which are greater than 3 Ω.
   f. Note down any diodes where a beep was not heard. Check the opposite polarity (i.e. red and black probes switched) to ensure that you didn't confuse the polarities before doing so.
   g. Remove the lamp/light and check and keep the circuit in a dark box. Repeat steps a-f while the circuit is in a dark box
   h. Note down any photodiodes that show continuity in the dark.
   i. Repeat steps a-h for the remaining strings on the solar panel
3. Repeat steps 1 and 2 for all solar panels

Pass-fail criteria:

PVA strings will pass the continuity check as long as there is appreciable current flow during this test (> 50mA) **[R01]**. Any photodiodes that fail the continuity check should be rechecked. If the second check fails they should be replaced.

Schematics:

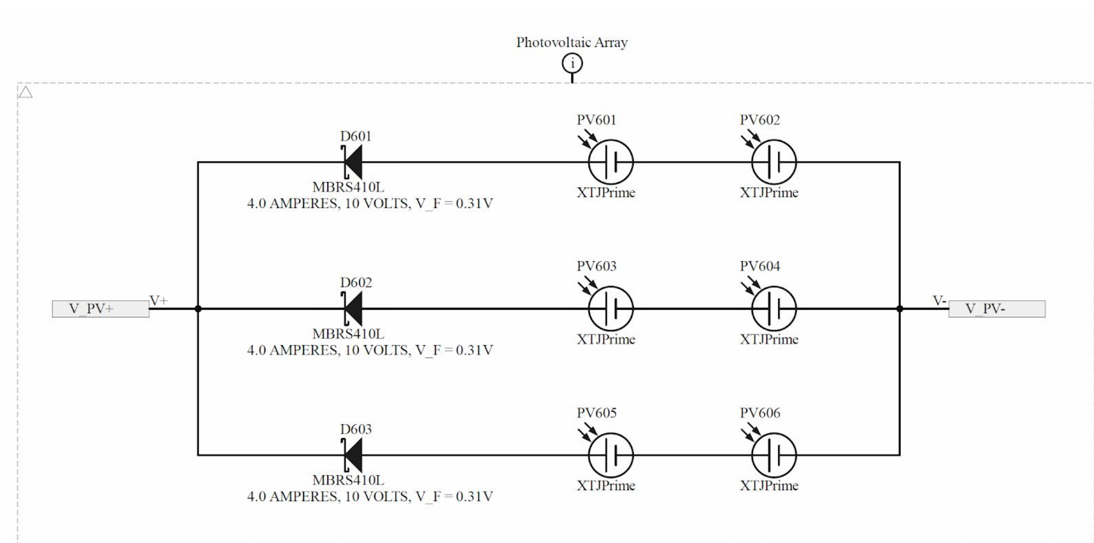

Figure 4.3 - Solar Cell Continuity Check Schematic

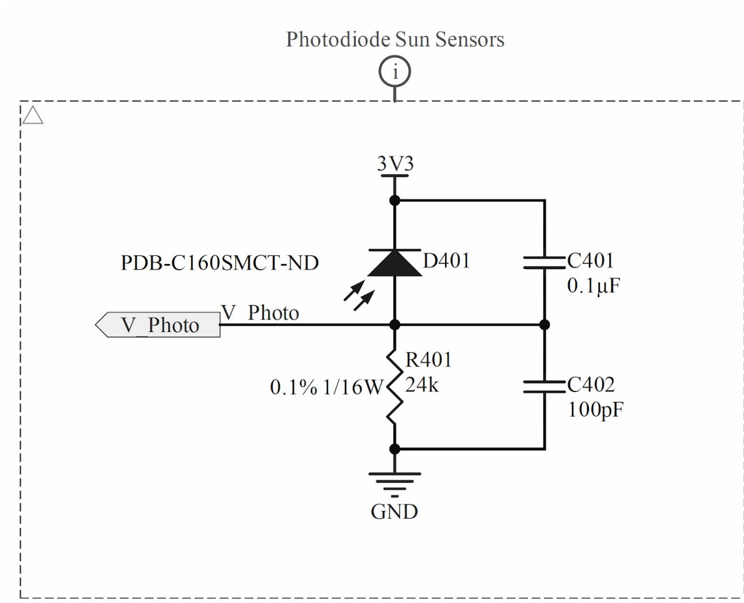

Figure 4.4 - Solar Panel Photodiode Sun Sensor Schematic

4.1.6. Grounding resistance check

This is used to ensure that the resistance between ground nodes is minimal. The test can be performed at room temperature and pressure.

Materials:

- Multimeter

Procedure:

To test the continuity of all nodes on the board, look to the schematics for the appropriate board **[R5]**.

3. Set a multimeter to test for resistance.
4. Place the probes at different ground nodes and record the resistance measurement

Pass-fail criteria:

Pass if maximal resistance is less than 5 Ohms. Fail otherwise.

4.1.7. Blocking diode Test

This test checks that the reverse current of the blocking diodes is negligible compared to the string current.

Materials

- Multimeter
- Power Supply

Procedure:

1. Keep the solar cells in the PVA under test face down, or keep the PVA in a dark box. We don't want a live circuit for this test.
2. Set the multimeter to measure current
3. Connect the Power supply in series with the multimeter and place the positive and negative probes as shown in diagram 4.x.
4. Set the Power supply to 4.8V
5. Note down the current through the string being tested.
6. Repeat for each string of the PVA.

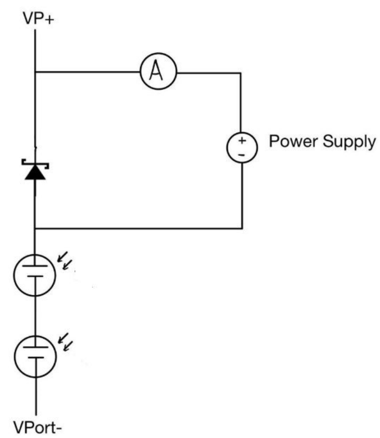

Figure 4.5 - Blocking Diode test schematic for the Port Solar Panel

Pass-fail criteria:
The reverse current measured in the blocking diode test should be less than 5mA

4.2. Qualification testing

The qualification testing done verifies that the design works for the extremes of the mission, in the case of Ex-Alta 2 and the Northern Spirit missions, generating power in a LEO. A failure of qualification testing indicates a problem in the design that needs to be investigated and dealt with during a redesign. The qualification testing consists of a subset three different tests:

1. Humidity test
2. Fatigue thermal cycling test
3. ESD test

Each of these 3 tests also consists of various checks that will be performed in addition to the specific test. The order of these tests and checks can be found in table 3.1. The number in each box indicates the order that the test and checks will be done in, i.e. for the humidity test, the full visual inspection should be done first, then the electrical health check, and so on. The definitions for the tests and checks depicted in the table will be given in chapter 3.4, with the numbers in brackets beside the test denoting the specific section each check is in.

In the case that the PVA does not pass qualification testing, an investigation will be launched to determine why the test(s) failed, and a redesign will be done to fix the resulting problem found in the investigation

Test	**Check**	**Humidity Test**	**Fatigue Thermal Cycling test**	**ESD Test**
	Full Visual Inspection (3.4.1)	1, 5	1, 6, 10, 14	1, 5,
	Electrical health check (3.4.2)	2, 6	2, 7, 11, 15	2, 6
	Electrical Performance (3.4.3)	3, 7	3, 8, 12, 16	3, 7
	Capacitance		4, 17	
Humidity Test		4		
ESD Test				4
Fatigue thermal cycling			9	
Vacuum thermal cycling			5, 13	

Table 4.1 - The order of checks and tests to be done for each test

4.3. Acceptance testing

Once the qualification testing of the PVA has finished, and the design has been fully verified, acceptance testing for the Hyperion Solar Panels will begin. All completed PVAs are to be put through acceptance testing to ensure flight worthiness. The table below describes the order of the tests and checks to perform on the solar panels in order to verify that they are in an acceptable state to fly aboard the cubesat. The numbers in parentheses beside each check denote the section that the check is housed in chapter 5.4.

Test	**Order**
Full Visual Inspection (3.4.1)	1, 5, 9
Electrical health check (3.4.2)	2, 6, 10
Capacitance	3, 12
Electrical performance check (3.4.3)	4,7,11
Thermal Cycling	8

Table 4.2 - Shows the order in which checks should be run for acceptance testing.

4.4. Definitions of tests

The following section describes the process for each check and test given in the tables in chapters 3.2 and 3.3. The following tests will be performed at room temperature and pressure unless otherwise noted.

4.4.1. Full visual inspection

This test is the combination of the SCA inspection and the in-process inspection, found in 2.2 Dimensions and Mass Inspection and 4.1.4 Visual Inspection respectively.

Procedure:

1. Complete the in-process visual inspection process outlined in section 3.1.4
2. Complete the SCA visual inspection process outlined in chapter 2.1

Pass-Fail Criteria:

Any failures of the sections referred to will result in the failure of the full visual inspection.

4.4.2. Electrical health check

This test ensures that there is electrical continuity across different nodes of the circuit. Additionally it looks at the ground node to ensure that there is minimal resistance at different points of the node.

Process:

1. Complete the electrical continuity check process found in 3.1.2 Electrical Continuity Check
2. Complete the Grounding Resistance test found in 4.1.6 Grounding Resistance test
3. Complete the Blocking Diode test found in 4.1.7 Blocking Diode test

4.4.3. Electrical performance measurement

This test measures the full IV characteristic curve of the PVA. Isc, Voc and Pmax are found/calculated from the curve. This check is used to determine the degradation of the PVA during testing by finding I_{sc}, V_{oc}, and P_{max} before and after testing and comparing the values.

Procedure:

1. Follow the procedure outlined in Section 2.3 using the PVA under test instead of the SCA.

Pass-Fail Criteria:

A difference of less than 5% in Pmax between each value will be considered satisfactory.

4.4.4. Capacitance test

The purpose of his test is to measure the capacitance of the PVA. Capacitance is a good measure of the quality and health of a solar cell **[R07]**. This is done by switching a PVA from short-circuit to open-circuit (or vice-versa), recording the step response ***dv/dt,*** and using this to find the solar panel's capacitance **[R08]**. The effect of the shunt diode and blocking diode can be ignored as they don't have a significant effect on total capacitance.

Figure 4.6 shows the equivalent schematic of the circuit used for the test. The harness used should have short coaxial cables and should be tightly twisted to reduce parasitic inductance which could otherwise cause errors in measurements. The Zener diode is connected in parallel with the drain-source channel of the MOSFET to prevent damage to the SCA from high voltages. This will only be used on the off-chance that the MOSFET has no built in flyback diode.

Materials:

- Calibrated continuous solar simulator
- Low-resistance power mosfet (recommended: BUZ345 **[R08]**)
- Signal generator
- High speed digital oscilloscope (Bandwidth > 100 MHz)
- Zener diode - to protect against high voltages (not needed if flyback diode is sufficient)
- A twisted, short harness with coaxial cables to reduce parasitic inductance

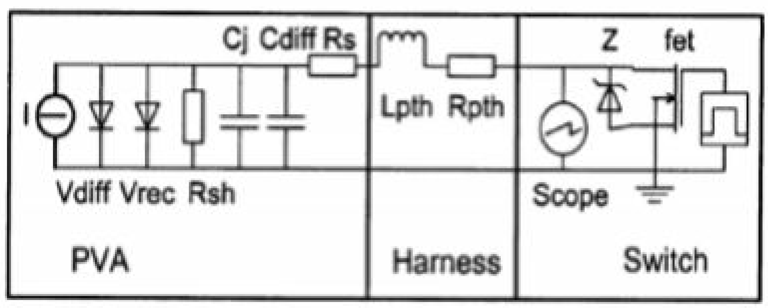

Figure 4.6 - Equivalent schematic of measurement circuit

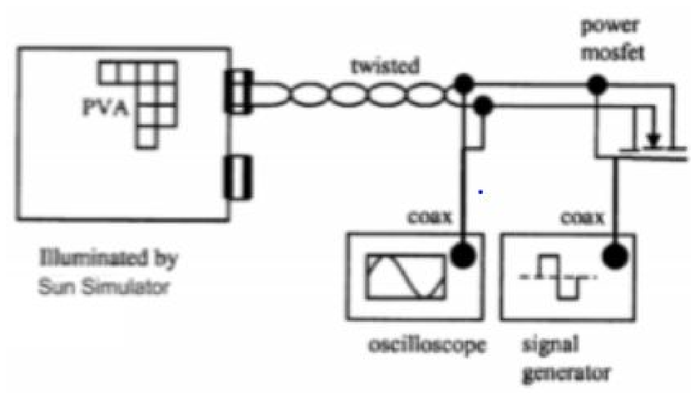

Figure 4.7 - Physical Diagram of the Measurement Circuit

Procedure:

1. Calibrate the solar simulator according to the solar cell calibration section and set the illumination to 1 S.C
2. Connect the circuit components according to Fig. 4.6

   a. The positive end of the signal generator should be connected to the MOSFET gate and the negative end is connected to ground
   b. The MOSFET source is connected to ground
   c. The Zener diode is connected in parallel across the MOSFET drain-source channel
   d. The oscilloscope is connected in parallel across the ground and the drain
   e. The positive end of the string is connected to the drain, the negative end is connected to ground
3. Set the signal generator to its square wave setting, and set Vmax greater than Vgate (normally 10-15 V)
4. Set the square wave to a frequency greater than 100HZ (doesn't matter too much)
5. Record the *v-t* characteristic displayed on the oscilloscope while the solar cell is illuminated

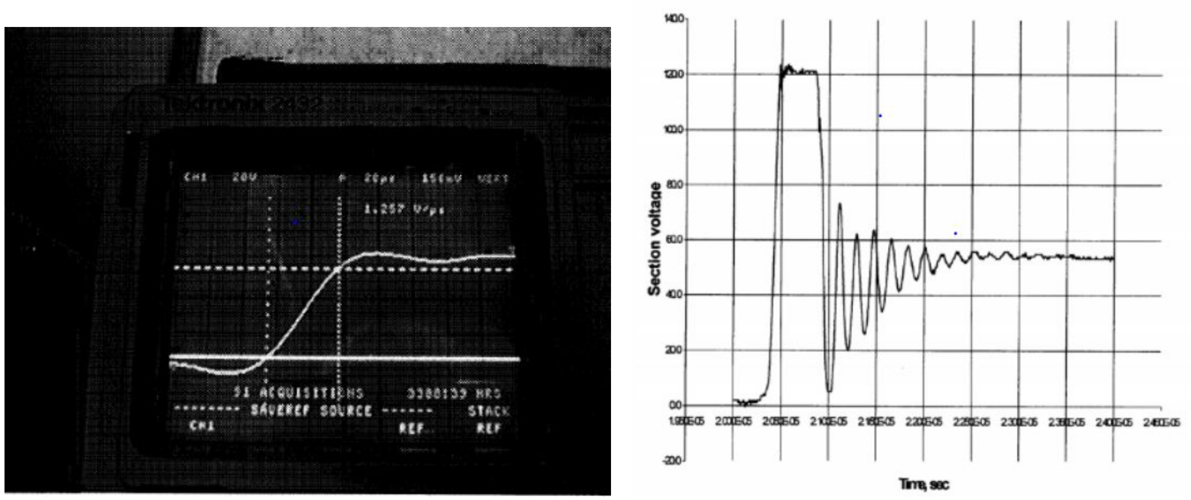

Figure 4.8 - a) A typical v-t characteristic (left)
and b) a realistic v-t characteristic due to parasitic inductance (right)

6. The *v-t* curve will likely have some second order effect due to harness inductance, as shown in Fig 4.8b. This curve would look more like fig. 4.8a if parasitic inductance is fully minimized, however this will not be possible in practice.
7. The stored sampling data should be loaded to a spreadsheet program (or other software) to draw a curve of best fit as seen in fig. 4.9

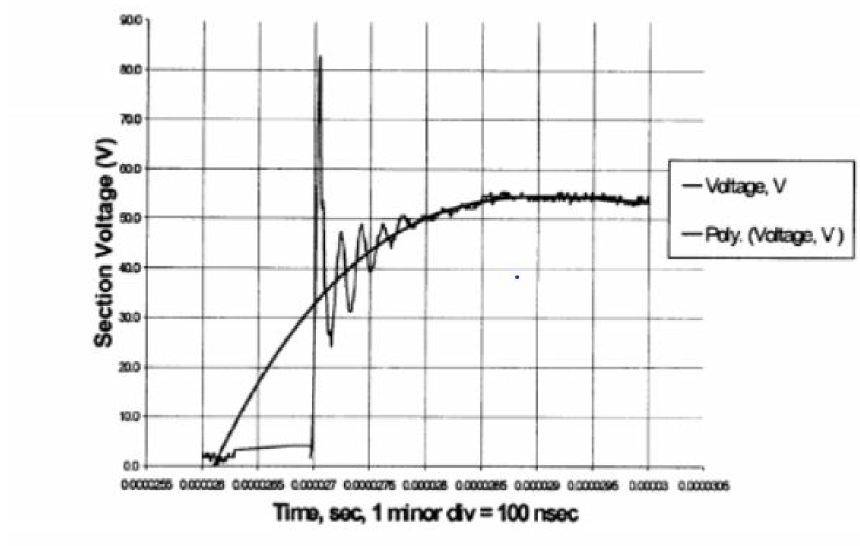

Figure 4.9 - v-t characteristic with line of best fit

8. Once the curve of best fit has been drawn, the value of the PVA capacitance can be found as follows.
   a. Draw a straight line through *0.1 x* V_{OC} and V_{MP}. V_{OC} and V_{MP} should be the values measured in the electrical performance measurement (3.4.3) (They should be around V_{oc} = 0.269V, V_{MP} = 2.41V).
   b. Find the gradient, this is *dv/dt.*
   c. ***i = Cdv/dt*** gives the equation shown in Fig. 8. This can be used to calculate the capacitance of the string.

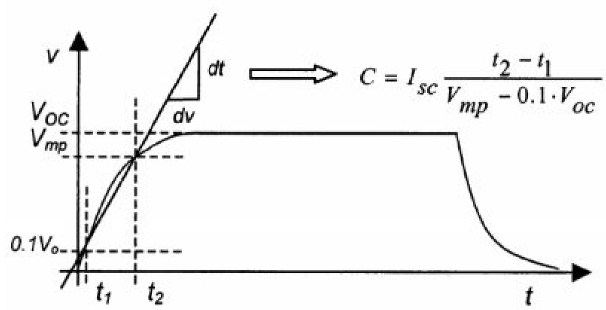

Figure 4.10 - A v-t characteristic with capacitance measurements

9. Find values of C for 5 strings to find the average.

Pass-Fail Criteria:

The test will be considered successful as long as there are no decreases in capacitance of more than 5% between checks.

4.4.5. Humidity Test

This is an accelerated humidity test that tests for corrosion and coverglass degradation.

Materials:

- Temperature-Humidity chamber
- High purity ASTM D1193-99 Type I water [R09]
- Arduino data logger

Fig 4.11 - PVA placed upright inside a Temperature - Humidity chamber

Procedure:

1. Before starting the test, ensure that the chamber has
    a. at least 50cm of unobstructed space around its heat vents for safe heat dissipation.
    b. refrigeration system condenser fins that have been cleaned recently
    c. a clean water cup, and unblocked water pipes in the water system
    d. A new, or clean gauze installed on the humidity sensor
    e. High-purity Type 1 water added to the water system
2. Place the test sample on the rack inside the chamber at ambient pressure. Position the PVA so that it does not obstruct the circulating air outlet
3. Try to minimize water condensation on the surface of the PVA by keeping it upright as shown in Fig 3.8.
4. Set the chamber temperature to 60°C and set the relative humidity to 90% using the control panel.
5. Close the chamber door using its locking mechanism, and keep the PVA sample inside for 30 days. Check on the PVA every few days to make sure that the chamber is working correctly. Use a soft cloth to wipe away accumulated drops of water on the PVA. This will not affect the outcome of the test as long as the PVA is returned to the chamber quickly once finished. This should be done in less than a minute.

Pass/Fail Criteria:

In order to be considered a successful test the PVA must pass all subsequent checks done. These checks are outlined in Table 4.1

4.4.6. Vacuum Thermal Cycling Test

The purpose of this test is to assess the reliability of test samples under a thermal stress equivalent to the number of eclipses that occur during one year in orbit for LEO missions.

Materials:

- Temperature circulation testing chamber
- Materials required for electrical performance test

Process:

1. Do a visual inspection of the testing coupon to make sure that there are no cracks on the PVA.
2. Link the PVA to the multimeter.
3. Turn ohmmeter to continuity mode
4. Put the PVA into the temperature circulation testing chamber. Pump the testing chamber to desired pressure.
5. Set the temperature range of the aluminum chassis in the vacuum chamber to be -40 °C to 70 °C for 10 or more cycles, each depending on time restrictions. The ECSS guidelines [R1] set 1000 cycles for testing. Set each cycle to sinusoidally oscillate every 93 minutes.
6. During the cycling procedure, check the electrical continuity for at least 2 cycles (if the measurement cannot be done during the 1000 cycles, it should be done separately, i.e. put the sample into the chamber, after 2 cycles, take it out and measure the electrical continuity)
7. After 10 cycles, wait for the chamber to recover to room temperature.
8. Vent the chamber. Take out the PVA, do visual inspection again for the number of cracked cells

Pass-Fail Criteria:

The test will be considered successful if the PVA has electrical continuity after the test (i.e. there is no open circuit during the test), the power output of the test coupon and the insulation is within 5% of the power measured in the electrical performance check, and there is at most one cracked cell.

Acronyms and Abbreviations

Update this to reflect the acronyms and abbreviations used in this report.

ADCS	Attitude Determination and Control System
CAD	computer aided design
Comms	Communications (as in Comms team)
CSDC	Canadian Satellite Design Challenge
CSDCMS	CSDC Management Society
cubesat	cube satellite
C&DH	Command and Data Handling (as in C&DH team)
Ex-Alta	Experimental Albertan
HEPA	high-efficiency particulate arrestance
PDM	product data management
UHF	ultra high frequency
VHF	very high frequency
Li-ion	Lithium-ion
1C, C/2 etc.	1 C-rate = the amp-hour rating of a cell
SC	Solar constant = 1366 W/m^2
AM0	Air Mass Zero (intensity rating)
BSC	Bare Solar Cell
SCA	Solar Cell Assembly
PVA	Photovoltaic Assembly
ESD	Electrostatic Discharge

5. Appendix A: Hyperion Testing Parameters

This table shows important quantitative dimensions/criteria tested for in this document.

Section	**Test**	**Criteria**	**Required Value**	**Justification**
SCA and Component Testing	Inspection of Dimensions	Average thickness	80-225 um	Datasheet [R2]
	Mass Compliance	Mass/Area	50-84 mg/cm^2	Datasheet [R2]
	Electrical Performance	Minimum Isc:	0.454 A	3% below datasheet value
		Minimum Voc:	2.64 V	3% below datasheet value
		Minimum Pmax:	3.41 W	3% below datasheet value
Pre-assembly Component Testing	Mechanical Board Dimension check	Board dimension	More than +/- 0.2 mm of nominal dimension	Power Team
	Grounding Resistance Check	Grounding resistance	< 5 Ohms	Power Team
Post-assembly Component Testing	Power Consumption	Resistance across magnetorquer terminals	+/- 5% of nominal resistance (10.89 Ohms)	Power Team
	Voltage Applications	Measured temperature	+/- 10 C of Max or Min temperature	Power Team
	Photodiode testing	Saturated voltage	Between 2 V and 2.5 V	Power Team
	Voltage and Current Sensor Test	Output voltage	Less than 2.6 V	Power Team
SCA Application Testing	Insulation Test	Insulation	40Ω/cm^2	Power Team
	Adherence to	Adherence	More than 50%	ECSS document

	substrate		separation at 1 N/cm2	[R1]
	Visual Inspection	Dimensions	Match dimensions shown in R10 to ± 0.5mm	Power Team
	Grounding Resistance Check	Grounding resistance	< 5 Ohms	Power Team
	Blocking Diode Test	Reverse current	< 5 mA	~ 1% of nominal current
PVA Testing	Grounding Resistance Check	Grounding resistance	< 5 Ohms	Power Team
	Blocking Diode Test	Reverse current	< 5 mA	~ 1% of nominal current
	Capacitance Test	Capacitance	< 5% drop between subsequent measurements	Power Team
	Electrical Performance	Minimum Isc	< 5% drop between subsequent measurements	Power Team
		Minimum Voc:	< 5% drop between subsequent measurements	Power Team
		Minimum Pmax:	< 5% drop between subsequent measurements	Power Team

6. Appendix B: Equipment Calibration

6.1. Vernier Caliper Padding

This section describes how to pad vernier calipers before using it for measurements. Padded calipers should be used as solar cells are susceptible to scratching by the calipers jaws.

Materials:

- Vernier Calipers
- Kapton Foil
- Scissors

Procedure:

1. Measure the dimension labelled ***a*** in Figure 6.1.
2. Draw 2 rectangles of (***a*** + 10mm) x 60mm on kapton foil using a fine tipped marker/pen.
3. Cut the rectangles out using scissors.
4. Remove ~ 10mm of the kapton foil film to expose the adhesive. Hold the kapton as shown in figure 6.2 so that 10mm hangs outside of the jaw. Attach the exposed kapton to the inside of one of the calipers jaws by pressing firmly. (refer to Figure 5.x)
5. Continue to unwrap the film 10mm at a time and wrap the kapton around the jaw. Ensure there are no air bubbles on the inside of the jaw. Use the extra 10mm to pad the sharp edges of the calipers.
6. Ensure that the kapton foil is applied evenly and uniformly on the inside jaw. This is not as important for the other sides.
7. Use scissors to remove any extra kapton around the sharp edge. Make sure the padding is not removed.
8. Repeat steps 1 to 7 on the second jaw.

Notes:

1. Zero the Vernier calipers before use

Figure 6.1: Digital Caliper annotation 1.

Figure 6.2: Digital Caliper annotation 1.

7. Appendix C: Unnecessary Tests

The following tests are SCA qualification tests, and should be done by Spectrolab as part of their design process.

7.1. Electron Irradiation

An accelerated life test that checks SCA performance degradation due to electron irradiation. This test has been deemed unnecessary because the cells likely come with a guaranteed performance due to electron irradiation, and because this test requires hardware that we are not likely to ever have access to.

Materials:

- Electron accelerator
- Thermocouple
- Data logging system for used for electrical performance measurement
- SCA or BSC

Note: The electron accelerator should have the following specifications

- Capable of 1 MeV electron radiation for about an hour at a flux of 5 x 10^11 e cm^-2s^-1
- Be able to sustain a vacuum of at least 10^-3 Pa
- Have a temperature controlled sample plate and thermocouple
- Have a coverage area that can fit an SCA. If this is not possible a pure metal foil can be used to expand the beam, however this will make calculations more complicated as we have to account for energy loss, geometries, etc.
- Flux and energy should have < 10 % uniformity. These values are available from the flux and energy profiles of the accelerator facility

Procedure:

(The specifics can be written once we know more about the electron accelerator and these lab conditions)

1. Set the electron accelerator to irradiate 1MeV electrons at a rate of 5 x 10^11 e cm^-2s^-1, at a pressure of 10^-3 Pa or below. A thermocouple should be attached to the SCA, and it should be kept at < 40 C on a temperature controlled plate.
2. The SCA or BSC should be kept with its face perpendicular to the beam of irradiated electrons.
3. The sample should be irradiated for about 33 minutes so that the irradiated fluence is about 10^15 particles per cm^2
4. Once irradiating is completed, SCAs should be stored in a dark, cool storage area to minimize temperature annealing. An electrical performance check (like in #11) should be done as soon as possible to get an accurate measure of the effect of the electron irradiation on the BSC/ SCA.

7.2. Photon Irradiation and Temperature Annealing

This test checks the performance of an SCA at 1 S.C (AM0) and checks the effect of temperature annealing after the irradiation. Temperature annealing is the phenomenon where defects caused by particle irradiation are annihilated due to the effect of a high temperature on the material. This test has been chosen as unnecessary as we do not have access to this kind of equipment, and because this phenomenon is not terribly relevant.

Materials:

- Constant solar simulator (not pulsed)
- Voltage logging system (similar to Arduino system used to test Buck/Boost Converter Circuits)
- Heating chamber
- Dark room/box

Figure 7.1: SCAs loaded inside a solar photovoltaic testing chamber

Procedure:

1. Keep SCAs under the solar simulator in a dark room/box according to some geometry. The SCAs should be kept at open circuit.
2. Set the solar simulator to 1 S.C (AM0). Irradiate the SCAs for 48h at 25 ± 5C
3. After 48h in the solar simulator, transfer the SCAs to heating chamber wearing nitrile gloves.
4. Place the SCAs standing up in the heating chamber as shown in Fig 18.1
5. Set the heating chamber to 60 C for 24h for temperature annealing
6. After 24h, carefully transfer the SCAs to a metal rack and store at a temperature below 50 C in a dark room.

Perform the electrical performance measurement outlined in 11) to check the SCAs performance after the irradiation. The results should match standard values (measured in the electrical performance test) to within ***5***% (this value can be decided later)

7.3. Ultraviolet Exposure Test (UV)

An accelerated life test to check SCA stability under UV light. This test has been deemed unnecessary because the cells come tested as such, and this test results in the guaranteed loss of multiple cells. We likely also do not have the required equipment.

Materials:

- UV Chamber with temperature control, capable of operating at 10^-3 Pa
- Sun-blind photo-diode (UV sensor)
- Thermocouple
- Data logging system to receive data from sensors
- Electrical performance measurement system (Same one from previous tests)

Ambient conditions for the work environment should be 22±3 C, relative humidity of 55±10%

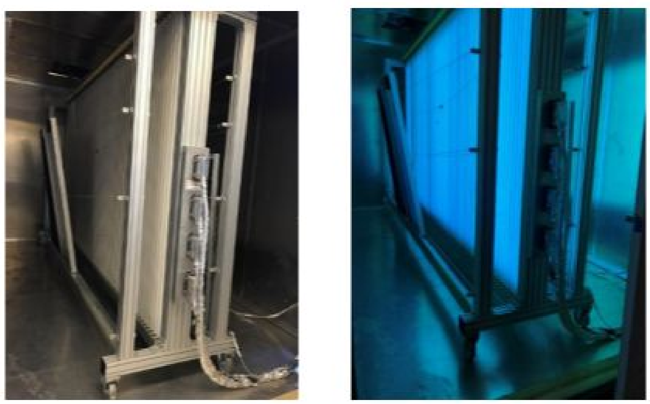

Figure 7.2: Inside view of a) unlit UV chamber b) lit UV chamber

Procedure:

1. Store sample cells at 22±3 C, relative humidity of 55±10%, in dark conditions before the test.
2. Set up the UV sensing system. The UV sensor should be in-plane with the SCA surfaces (not yet loaded) to measure UV irradiance
3. Set the UV chamber to irradiate UV at 200 nm, at 0.5 SC (5*0.1*1366 = 683 W/m^2), at the nominal operating temperature of 25±10 C
4. Check that the data from the UV sensor and thermocouple match the set conditions. If so, stop the irradiation and load the SCAs into the UV chamber.
5. One of the SCAs loaded into the chamber should be shorted. Isc will be continuously monitored and recorded using the electrical performance measurement system
6. Set the UV chamber to irradiate UV at 200 nm at 0.5 SC at the nominal operating temperature of 25±10 C for about 8 days.
7. The electrical performance of SCAs (save for one control SCA) should be checked at the beginning, middle, and end of the UV exposure. Carefully unload the SCAs and irradiate at 1 S.C

(or any stable intensity) while measuring the full I-V curve using the method outlined in Test #11. This does not have to be done at AM0. Once measured, the SCAs should be quickly (and carefully) returned to the UV chamber to continue with the UV exposure.

8. The SCAs should be inspected at the end of the UV test to check for coverglass browning, or any other significant visible defects.

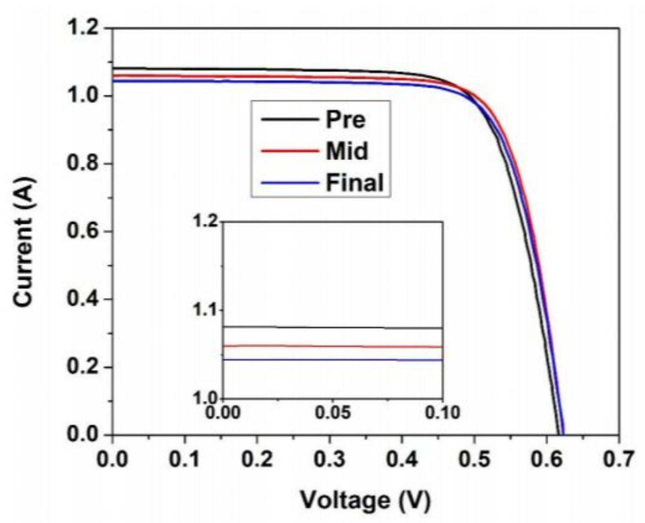

Figure 7.3: I-V curve of a solar cell measured during an accelerated stress test (0, 200 and 400 kWh/m2 UV dosage).

Pass-Fail Criteria:

1) Electrical performance of SCAs should not degrade to more than 70% of the UV loss factor used for EOL power analysis
2) The current output measured in step 7 should show exponential decay.
3) No major visible defects on the SCAs found in the visual check. Ie: significant coverglass browning, metal contact corrosion, etc.

7.4. Thermo-Optical Data

Thermo-optical data is used for computation of the solar panel operational temperature. There are two thermo-optical properties that need measuring: solar absorptance, and normal emittance. This test is not terribly relevant for the nominal functioning of the cells, or the design at hand.

Materials:

- Spectrometer*

*The spectrometer should meet the following requirements:

- Cover the range from 0.25 µm to 2.5 µm
- The wavelength resolution of the spectrometer should be compatible with the resolution used for the solar spectrum.
- The signal to noise ratio should be better than:
  1. ±1 % full scale in the region between 250 nm and 2000 nm;
  2. 5 % full scale in the region between 2000 nm and 2500 nm.
- The associated sphere should have a maximum port to total surface ratio of 5 %.

Procedure:

1. Before starting a measurement sequence, the 100 % and 0 % baseline should be taken (using the standard reference as applicable). The baseline should be measured at least once a day when equipment is switched on.
2. Take the transmitted (if the sample is transparent), and reflected spectrums between 250 nm and 2500 nm.
3. For transparent test pieces it is possible to calculate the absorptance by the same method, because:

$$\alpha(\lambda) = 1 - [\ (\lambda) + TR(\lambda)] \quad (*)$$

Where:
α is the solar absorptance, a function of wavelength
R(λ) is the spectral reflectance after 100 % reference correction;
T is the temperature in K.

4. For calculation of absorptance:

$$\alpha s = 1 - Rs$$

$$R_S = \frac{\int_{\lambda_1}^{\lambda_2} R(\lambda) S(\lambda) d\lambda}{\int_{\lambda_1}^{\lambda_2} S(\lambda) d\lambda}$$

where:
R(λ) is the spectral reflectance after 100 % reference correction;
S(λ) is the spectral solar irradiance (see ASTM E 490);
d λ is typically 1 nm;
λ 1 is 0,25 µm;
λ 2 is 2,5 µm.

NOTE: coverglass gain loss can also be measured by the method mentioned above using (*)

7.5. Coating Adherence

This test verifies the durability of the anti-reflection (AR) coating. This test will be used to check:

- Coverglass AR coating
- Solar cell contacts
- Integrated diode contacts

It has been deemed unnecessary because it degrades cells under stresses that the satellite would never encounter.

Materials:

- Clear, colourless adhesive tape with an adhesive strength on steel of at least 0.28 N/mm, with 12 to 13mm width.
- Black matte background
- White fluorescent lamps

Note: The tape should be free of foreign particles, or defects, and should be able to be unwound at a normal rate of speed.

Procedure:

1. Apply about 25mm of tape to the surface, leaving enough tape to securely grasp between your thumb and finger. (~ 1cm)
2. Rub the tape firmly onto the surface, ensuring good contact and reducing air bubbles.
3. Hold the SCA in one hand, and pull the tape off the surface by pulling the tape at an angle perpendicular to the coated surface. This should be done slowly (~ 2 to 3s for the 25mm)
4. The SCA/BSC should now be kept on a black matte surface and illuminated with a white lamp.
5. Inspect the SCA/BSC from a distance < 45cm for any damage in the coating/ coating removal. Smears or streaks left behind are not a problem.

7.6. Contact Thickness and Uniformity

This test has been deemed excessive and unnecessary as we already perform a simpler analog of this test.

Materials:

- Betameter

Procedure:

1. Keep the BSC on a clean surface, and rotate the betameter slowly in a clockwise direction around each metal contact starting from the edge of the contact. Take at least 5 readings from different angles for each 2cm along the contact, and record the values .
2. The uniformity of the readings can be found by calculating the deviation of the contact thickness at each distance along the contact.

3. The values found should match the values expected

7.7. Temperature Coefficients Check

The measurement is not a test, but measures the temperature coefficients for different parameters (ie: short circuit current). This data could be important for simulations, characterization, etc. This test is excessive and is not terribly valuable, which is why it has been deemed unnecessary.

Materials:

- All materials required to perform an electrical performance check
- Heating chamber capable of maintaining temperatures of -50C to 70C

Procedure:

1. Set the electronic performance check apparatus as described in section 2.1. Ensure that the equipment used are rated to be used between the maximum and minimum temperatures the solar cell assembly is to be tested at. The set-up should be assembled inside the chamber so that readings can be taken without opening the chamber. If this is not possible, minimize exposure of the set-up to outside conditions by closing the door immediately between changes made.
2. Set the heat chamber to the lowest temperature to be tested (~-50C) and keep the apparatus inside the chamber for 8h.
3. Once Step 2 is complete, perform an electronic performance check and find the values for all electrical parameters.
4. Repeat this process for 6 temperatures between -50C and 70C (-50C, -30C, -10C, 10C, 30C, 50C, 70C)
5. Find all electrical performance parameters and find the temperature coefficients of each parameter by least square fitting. This can be done by plotting each parameter against temperature.

7.8. Outgassing

The purpose of this test is to test whether the RML or CVCM that will be released from the sample are less than the maximum allowed amounts. This test is incomplete. Some notes to follow regarding this general test:

- Recovered mass loss (RML) should be less than 1%, where RML is the total mass loss of the specimen itself without the absorbed water.
- Collected volatile condensable material (CVCM) should be less than 0.1% of total mass when heated at 125 C in vacuum and collected at 25 C, where CVCM is the quantity of outgassed matter from a test specimen that condenses on a collector maintained at a specific temperature for a specific time.
- Procedure for this test (ECSS-Q-ST-70-02)
- The following figures outline the tests.

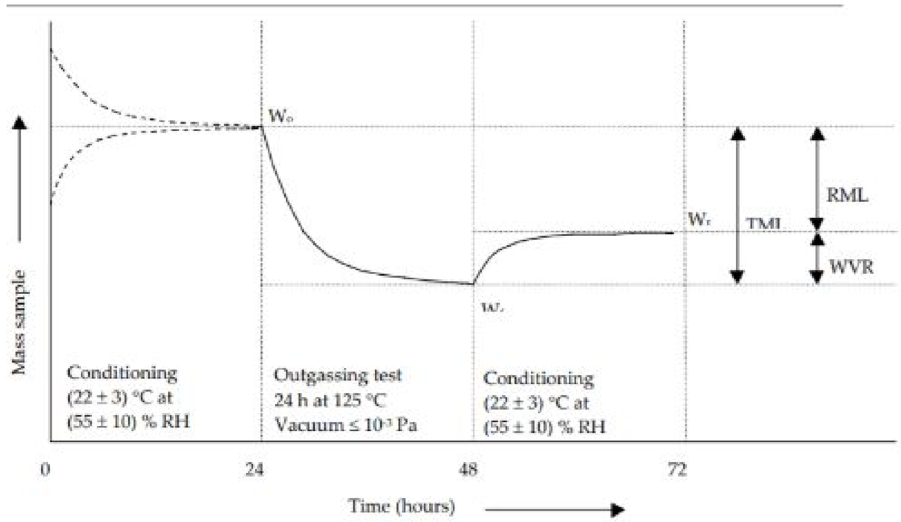

Figure 7.4: General outgassing test schematic and description. Parameters for the sample.

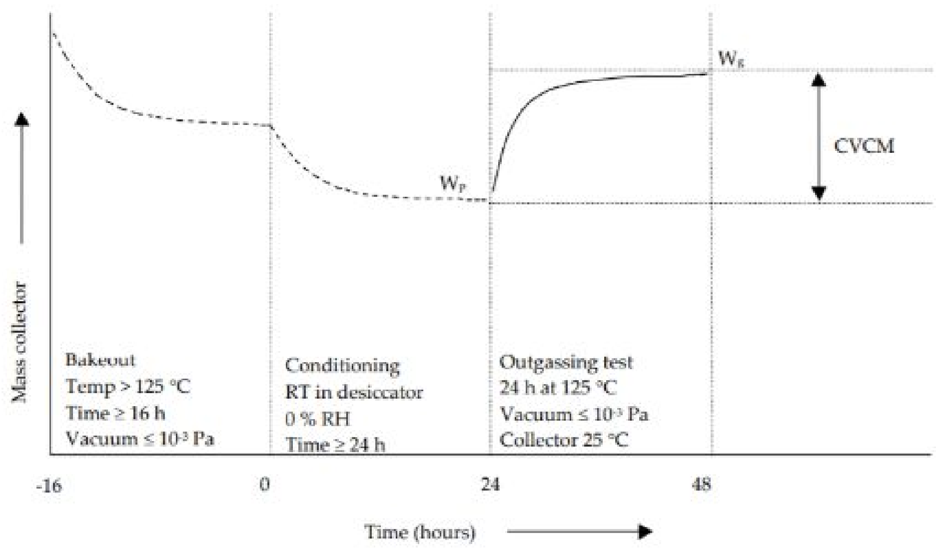

Figure 7.5: General outgassing test schematic and description. Parameters for the collector plate.

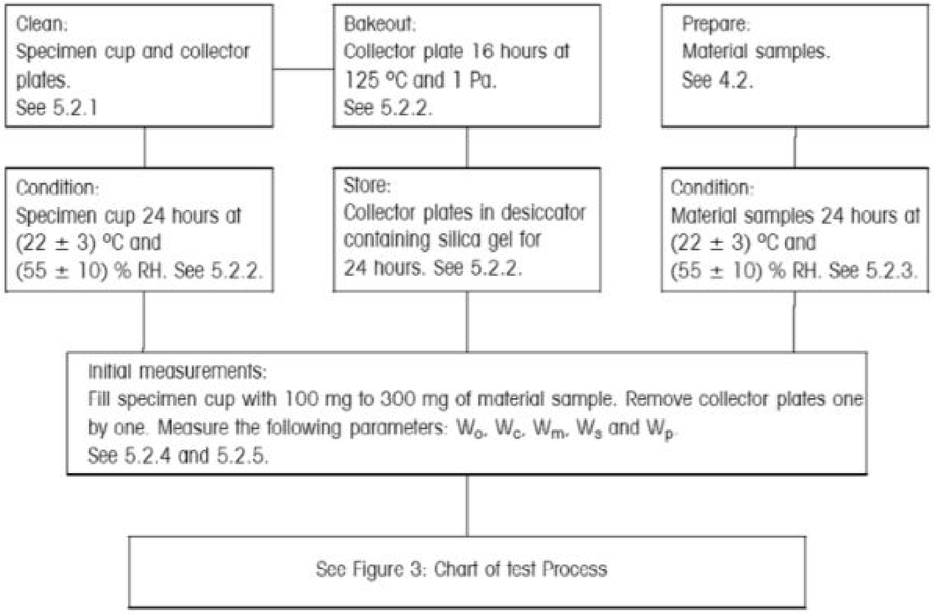

Figure 7.6: Flow chart of preparation and initial measurements.

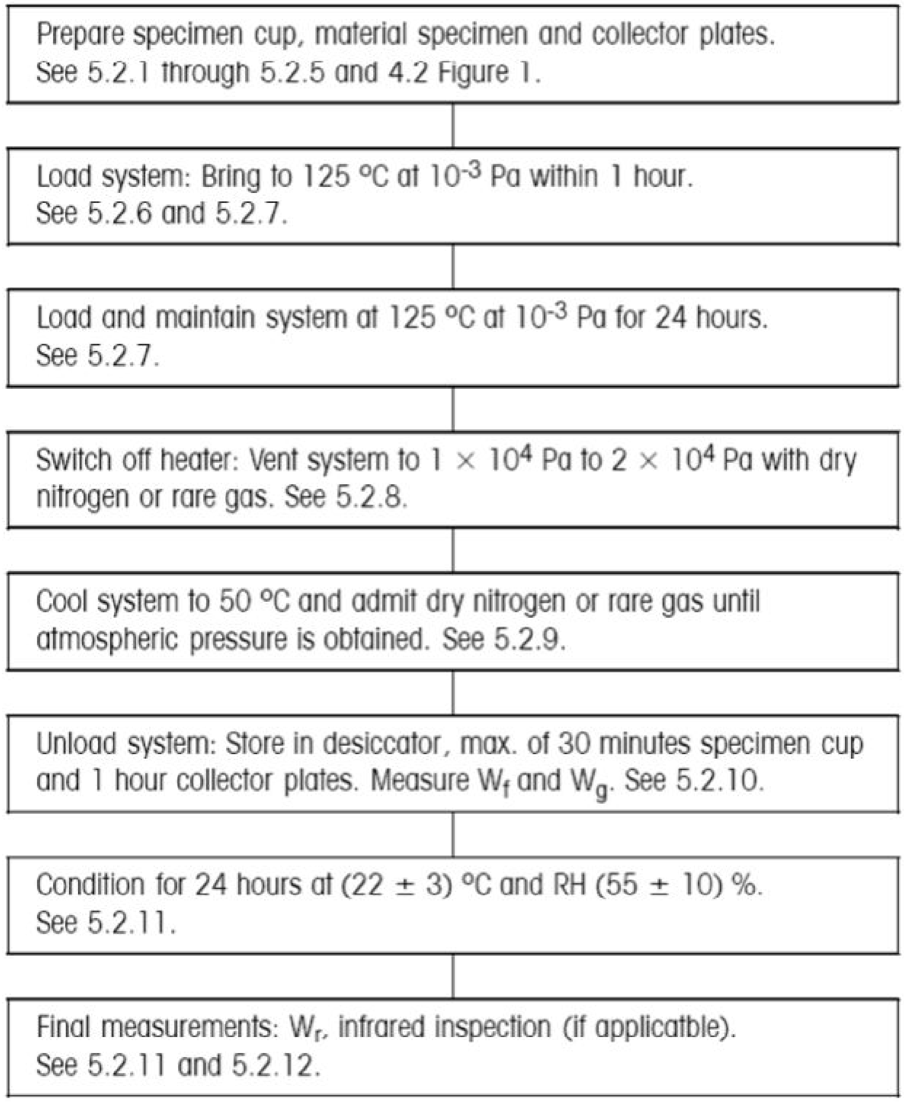

Figure 7.7: Flow chart of test process.

7.9. Surface Conductivity Test

This test has been decided to be unnecessary as we will not be using conductive coverglasses for our SCAs.

7.10. Reflectance Test

It has been decided to skip this test as it is used for the characterization of the coverglass (which comes installed) and requires complex apparatus.

7.11. Hemispherical Reflectance

This test has been decided to be unnecessary, as this is only part of acceptance criteria for silicon BSR cells [R1].

7.12. Coverglass gain-loss

This test will not be useful as the BSR comes with a coverglass installed.

7.13. Active Passive Interface Test

This test has been decided to be unnecessary as it is used for single junction GaAs-Ge

7.14. Spectral Response

This check helps characterize the spectral response of an SCA, and can help detect defects in SCAs after certain tests.

7.15. ESD Test

The ESD test is designed to test whether or not the solar array can survive the charging environment in LEO. It's been deemed to complicated to perform on Hyperion.

Materials:

- AlbertaSat Vacuum chamber (10^{-4} Pa)
- Solar array simulator
- High voltage cable feed-throughs (up to 5 kV) connected to the power supply and the coupons
- Non-interacting surface potential recorders (0-20 kV)
- Simultaneous ESD current transient monitoring and recording
- Visual observation, photography and video recording during the test (a camera may need to be placed into the vacuum chamber to achieve visual observation)
- High voltage power supplies (around 300 V)
- Trigger method (Plasma)

Test Diagrams:

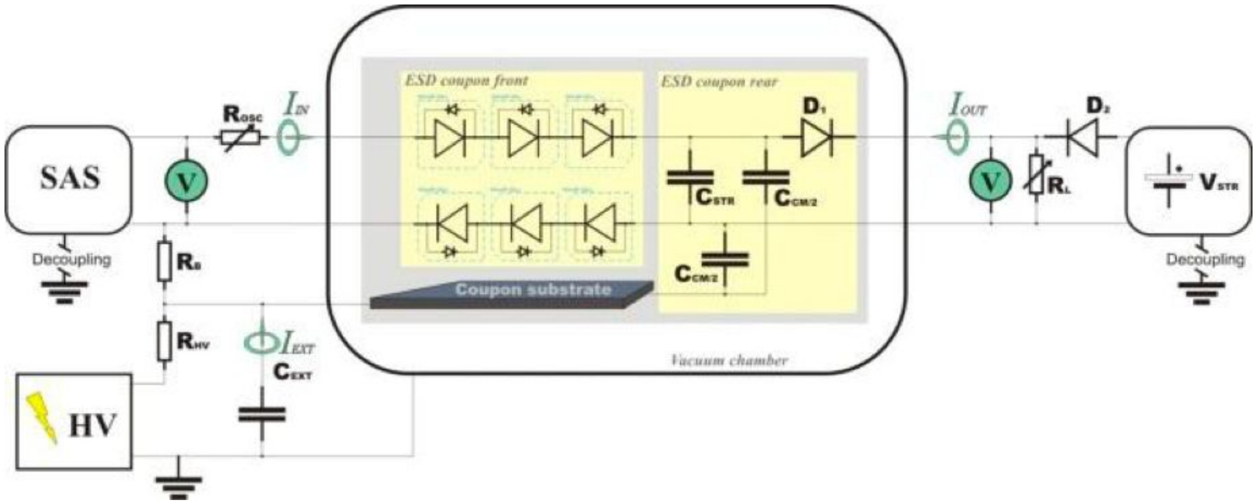

Figure 7.8 - ESD testing setup

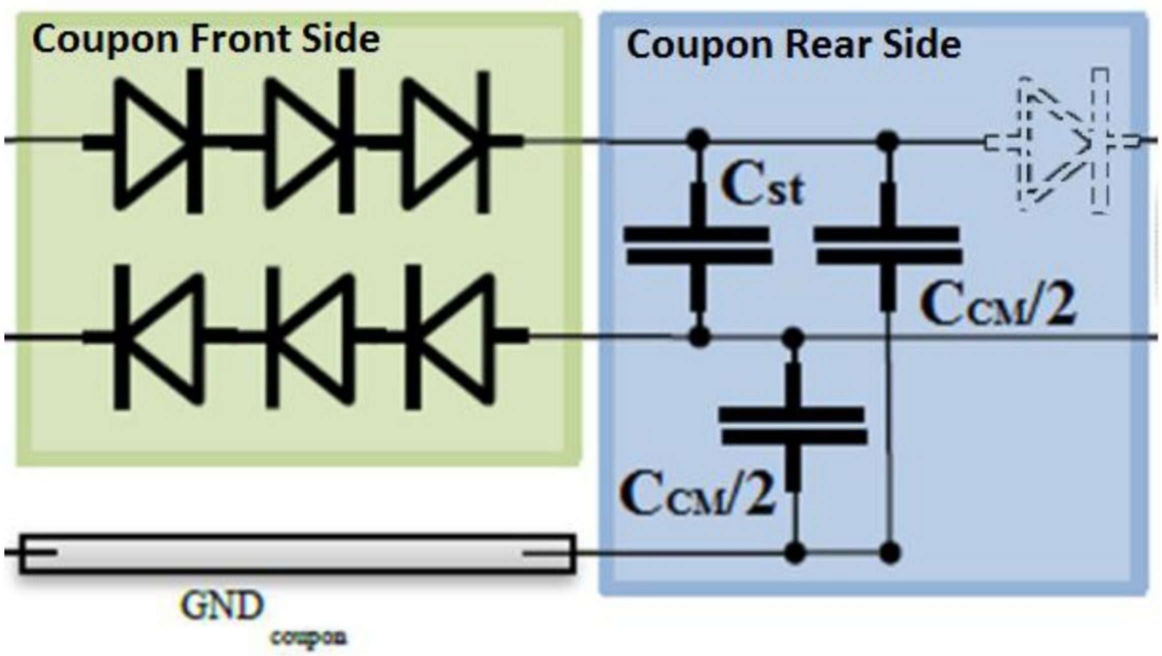

Figure 7.9 - Testing Coupon inside the Vacuum Chamber

Diagram Notes:

- HV contains a high voltage power supply (~5 kV) and a high energy electron beam (keV level)
- The additional power supply (V_{STR}+ D_2) and the blocking diode $D_1$is used to maintain the desired voltage gap
- $R_L$is a variable resistance to allow SAS to impose different voltages and currents to the string (can be replaced by a decade box or a jumper)
- The V and I marks are the measuring points

- The value of all the capacitors are expected to be obtained from the solar cell datasheet and the capacitance test

Process:

1. Connect circuit as in Figure 3.9 with the power sources turned off
2. Short the left part outside the chamber, turn V_{STR} in constant current mode, apply small current (~10 mA) to test the conductivity of the diodes
3. Suspend the ESD coupon in the vacuum chamber, then pump the vacuum chamber
4. Turn on the recording devices
5. Turn on the electron beam, apply different currents and voltage gaps (voltage difference across the capacitor) to the strings.
6. After 10 primary discharges (counted visible arcs) are observed, turn off the power sources and the recording devices, ground the solar array (ESD coupon), then take out the solar array
7. Visual check the solar panel to see if there's any visible damage (such as burned area and small cracks)
8. Measure the IV curve of the solar array and compare with the original IV curve

Pass-Fail Criteria:

This test will be considered successful if no sustained arcs occur between the solar cells, which have a large chance of damaging the cells, the insulation between cell strings is not degraded, and the insulation between the solar cell network and the solar cell structure is not degraded.