Balloon Gondola Payload User Guide

ANGSTROM DESIGNS

NASA AFRC Flight Opportunities Program 4
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Overview

The Angstrom Designs balloon flight program is capable of flying payloads to 110,000 ft and making sun pointed measurements on its payloads. The typical application for the gondola is generation of solar simulator calibration standards, typically single junction cells or isotypes of multi-junction solar cells. Angstrom Designs provides a full turnkey solution for this application that includes solar cell holder hardware, IV measurement electronics, baffles, conducting the flight, and processing measurement result data to provide a calibration report after the flight. Additionally, the gondola was designed to be a flexible platform so custom payloads and applications can be flown as well.

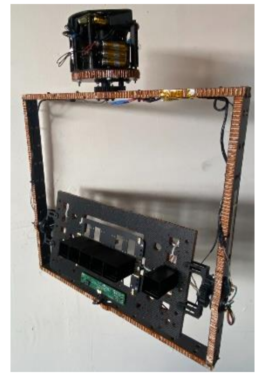
Figure 1: Balloon gondola.

This document provides an overview of the balloon flight program outlining capability and some common applications.

Contents

Balloon Gondola

The gondola has several features available to payload providers during the balloon flight including sun-pointing, telemetry, redundant GPS tracking systems, and IV measurement electronics. The gondola payload plate is also highly adaptable to payload form factors as described in more detail in the Interface Control Document. The gondola pointing system and IV electronics are programmable and can be tuned to meet the payload needs.

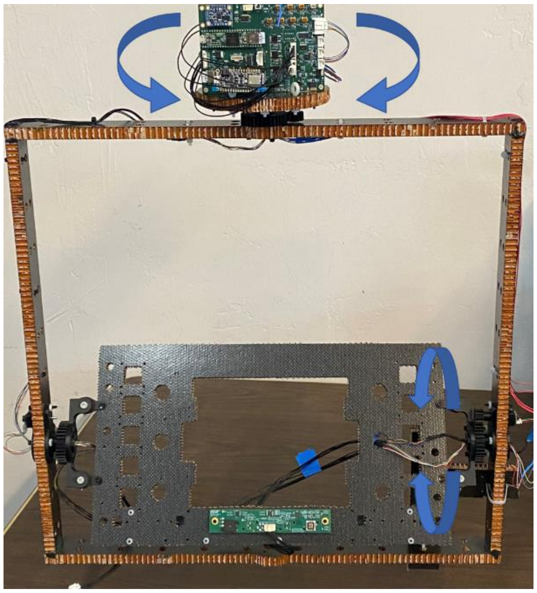

Figure 2: Angstrom Designs high altitude balloon gondola; degrees of rotation/control illustrated.

Capability

Services Provided

The following are optionally provided by the vehicle:

- Power: 5 V, 1.2 A
- Payload control over I2C with custom vehicle programming
- Data storage
- Flight telemetry
    - Temperature
    - Altitude
    - Sun-pointing angle

Flight Profile

The typical balloon flight profile is shown in the table below.

Parameter	Typical
Max Altitude	120,000 ft.
Min Temperature	-40 C
Max Temperature	+30 C
Max Payload Mass	1 kg
Pointing Accuracy	1 deg

Passive IV Electrical Specifications

The IV curves on solar cells can be measured using various means but the electrical specifications remain the same. The electrical specifications are defined in the table below.

Parameter	Description	Min	Typ	Max	Unit
Cell RTD	PT1000 (1 KΩ)		1000		Ω
Cell Voltage		0	-	28.5	V
Cell Current		0	-	2.25	A

Gondola Tracking Systems

The balloon gondola is equipped with fully redundant tracking systems to ensure smooth payload recovery. The main tracking system uses in-house hardware and software to track the gondola during flight and run continuous flight predictions that ensure the payload recovery team is on site when the balloon lands. The backup tracking system is independently powered and uses a COTS system to track the gondola.

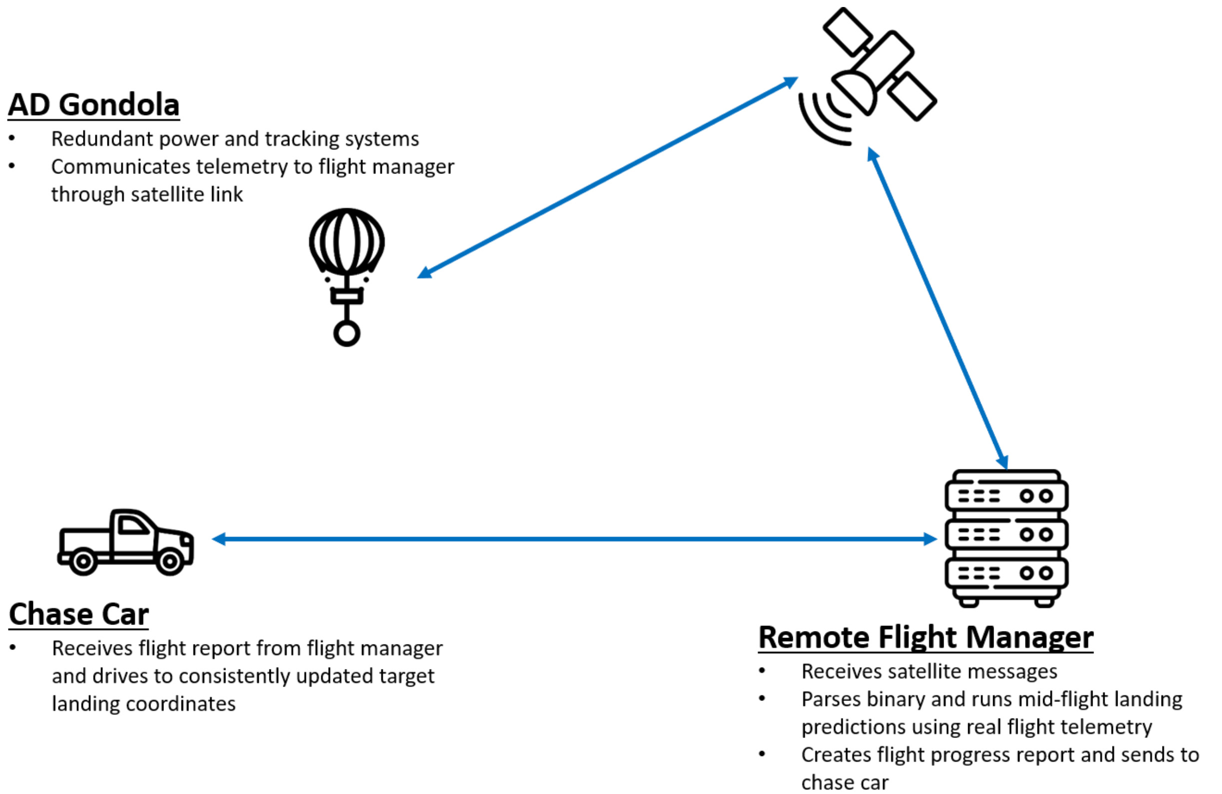

Figure 3: Angstrom Designs flight tracking system overview.

Mission Integration Timeline

The mission integration timeline from contract to flight is typically less than 3 months. A typical timeline is as follows:

Week 1: Contract Issued.

Week 1-2: Angstrom Designs ships payload support hardware (cell holders) to payload provider.

Week 2-4: Cells are sent to Angstrom Designs mounted on cell holders.

Week 5: Cells are integrated into the gondola and a system test is performed.

Week 6-10: Flight conducted, weather permitting.

Week 10-12: Post flight data analysis and payload returned.

Electrical Interface

The gondola can accommodate various payloads with multiple standard and customizable payload options. The *direct payload interface* can provide power and a programming interface to custom sophisticated payloads whereas the *cell interface* is more standardized and accessible for users who want to simply provide solar cells for a flight.

Direct Payload Interface

The direct payload interface allows the payload provider to directly use the gondola power and programming interface. The gondola has 8 direct payload slots. Each slot is a 4-pin MicroClasp (Molex P/N 0559320410) male connector that provides the payload with 5V, ground, and a 5-volt logic I2C connection (SDA/SCL). Payload slots 7 and 8 have a programmable power supply that can enable or disable power to the payload.

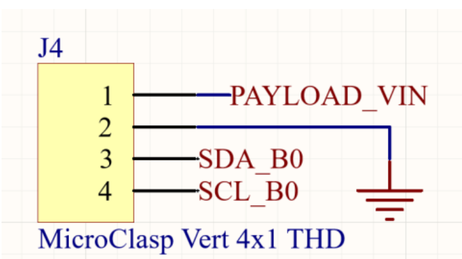

Figure 4: Direct payload connector interface

I2C Interface

Each payload slot has its own I2C line to avoid address conflicts between payloads, thus any address from 0x00 to 0xFF may be used. The gondola payload slots have pull-up resistors on the SDA/SCL lines; thus, the payload must not provide pull-ups.

Programming Interface

The gondola is programmable for specific payload needs. Custom commands can be sent over the I2C interface to payloads. The gondola provides on board memory for storing payload data if desired. Power to the payload can be programmed for slots 7 and 8 of the gondola payload connectors enabling mid-flight power cycling.

Cell Interface

Angstrom Designs manufactures cell holders and IV measurement electronics for the payload providers convenience. Standard cell holders are described below, although custom cell holders can be designed for payloads that have additional requirements. By using the vehicle cell interface, Angstrom Designs will provide cell holders and all measurement electronics for conducting mid-flight measurements. The only hardware from the payload provider is the cells themselves.

IV Measurement

The primary IV instrumentation used on the gondola is the Aerospace Measurement Unit (AMU) for its notable reliability and flight heritage recognized by the community. Angstrom Designs is a licensed manufacturer and reseller of the AMU. The AMU provides a variable passive load to sweep out IV curves on solar cells. Other measurements are also available on the AMU using Angstrom Designs firmware, such as conducting a max power point tracking (MPPT) measurement. Custom AMU applications and measurements can be developed by Angstrom Designs for payloads with specific needs. The AMU is also capable of sampling an external temperature sensor synchronously with solar cell measurements.

Figure 5: AMU used for measuring cell temperature and IV Curves.

The AMU has both USB and I2C command interfaces. The balloon gondola uses the I2C interface to trigger measurements and store the measurement results directly to the gondola memory. USB can be used to plug the AMU into a computer after the flight to make measurements on a cell under a solar simulator.

AMUs can be mounted directly to some cell holders or can be interfaced with using an Angstrom Designs Passive IV Meter (PIVM).

Passive IV Meter

The PIVM is an Angstrom Designs instrument that provides a connector interface to the AMU. This allows for use of a non-integrated cell holder, like the NSCAP holder or a custom design. The PIVM has a cell connector and power/communications daisy chain connectors.

Mechanical Interface

Overview

The gondola is highly adaptable to various payload form factors. Although there are standard sizes and hole patterns for the cell holders listed in this document, most standard solar cells and cell holders can mount to a custom payload plate with ease.

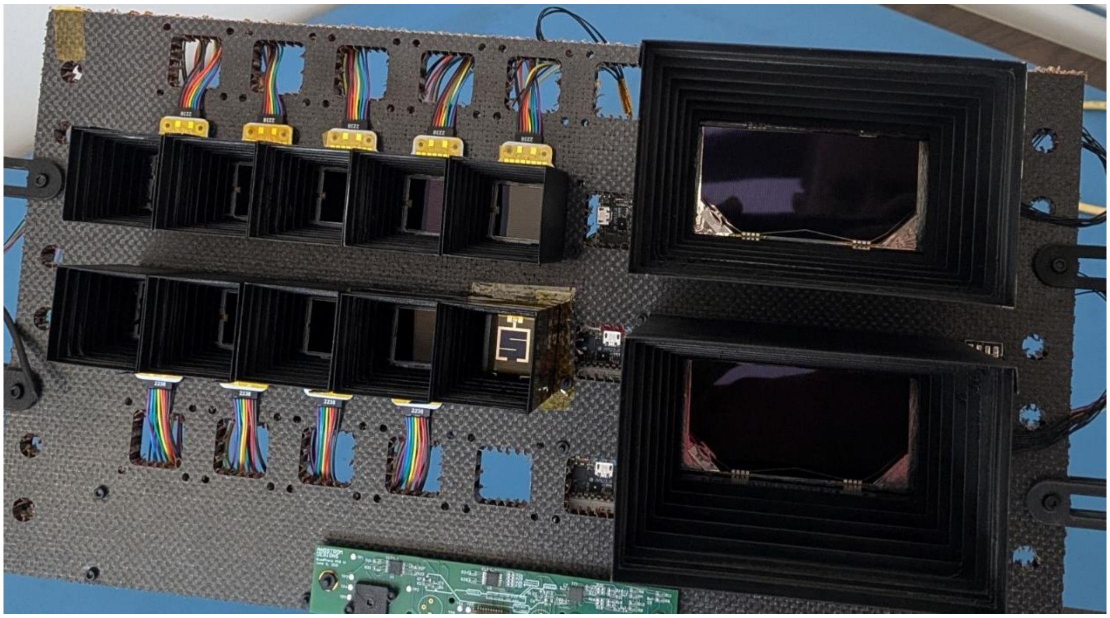

Figure 6: Balloon gondola payload plate designed for many small research solar cells and customized to include 2 larger solar cells

Mass

The payload must not exceed 1 kg.

Cell Holders

The function of a cell holder is to make thermal and electrical connection to the solar cell under test. Various cell holders have been developed throughout the community and Angstrom Designs manufactures a number of these common form factors.

NSCAP Cell Holders

The Near Space Calibration of Advanced Photovoltaics (NSCAP) cell holder standard was developed on a USSF program and is used widely throughout the community for space flight, balloon flight, and cell testing. The cell holder features an aluminum plate with an embedded RTD for accurate measurement of cell temperature. The cell is mounted using DC 93-500 or an equivalent encapsulant to ensure good adhesion and thermal connection to the cell holder. Large copper pads are exposed to solder the cell terminals. An 8-pin connector (Omnetics A19309-001) provides electrical access to the cell terminals and RTD.

For a balloon flight, the NSCAP cell holder is typically connected to an Angstrom Designs PIVM.

NSCAP cell holders are available in standard form factors for ~2x2 cm cells or ~4x8 cm cells.

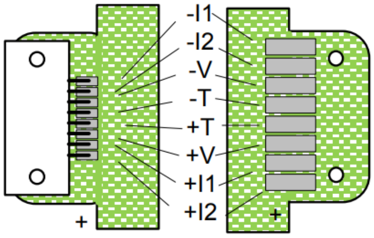

Figure 7: Connector pinout for NSCAP cell holder.

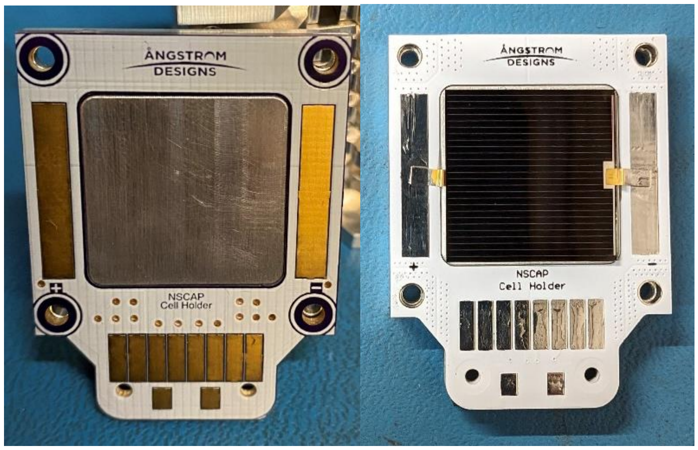

Figure 8: 2x2 cm NSCAP holders with and without a cell.

AMU Cell Holders

The AMU Cell Holder directly connects the AMU to the cell on a single PCB using no cables. The cell is mounted to a large copper pad using DC 93-500 or an equivalent encapsulant to ensure good adhesion and thermal connection to the cell holder. The copper pad extends directly under an on-board RTD for good thermal conductivity to the on-board temperature sensor. An AMU is directly soldered to the cell holder which minimizes series resistance on cell measurements. An additional benefit of soldering the AMU directly to the cell holder is that it ensures the calibrated measurement conditions of the solar cell persist after the flight for use during solar simulator calibration.

Figure 9: 2x2 cm bare AMU cell holders.

AMU cell holders are available in standard form factors for ~2x2 cm, ~4x8 cm, and ~8x8 cm cells.

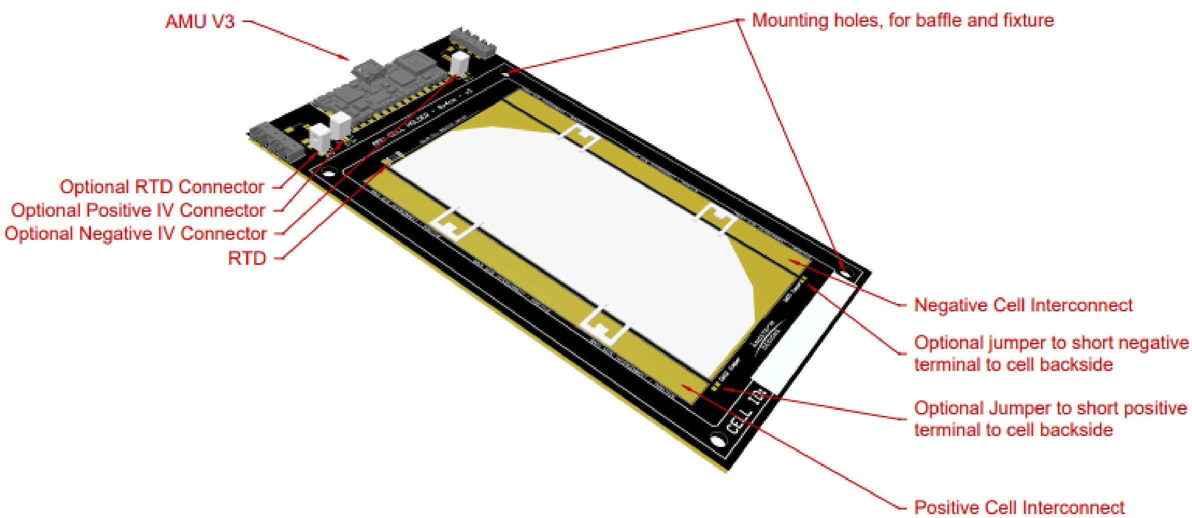

Figure 10: 4x8 cm AMU cell holder mechanical drawing.

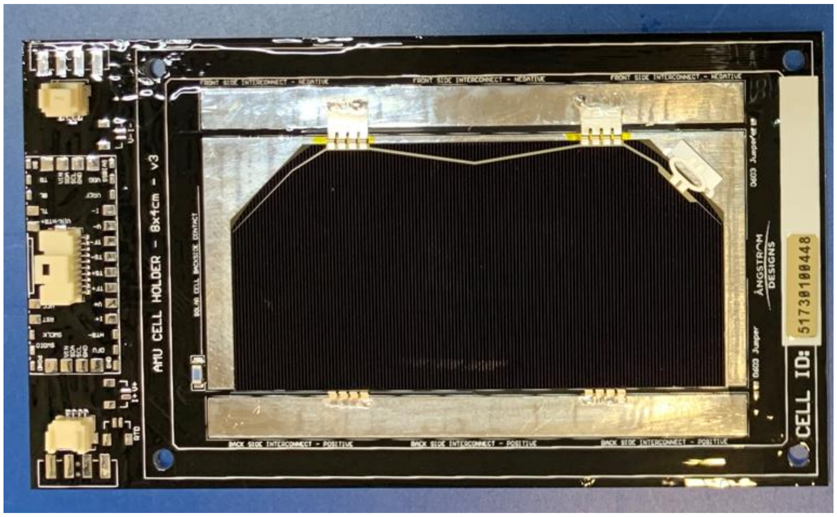

Figure 11: 4x8 cm AMU cell holder with cell mounted. Cell holder optioned for disconnected AMU so jumper connectors are installed.

Custom Cell Holders

Some payloads have specific requirements that don't work with the cell holders described above. In this case Angstrom Designs can design and manufacture custom cell holders that meet the payload needs.

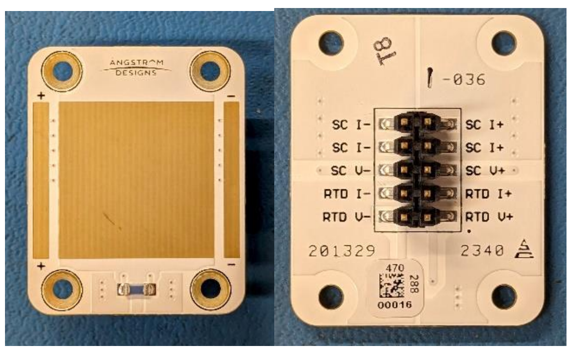

Figure 12: Custom cell holders designed to a specific payload requirement.

Custom payloads not on cell holders

Custom payloads that are not mounted to solar cell holders can be mounted directly to the tilt plate. Custom payloads should not exceed a mass of 1kg and an area of 14.75 x 7.75 inches. If the sun angle sensing (and pointing) capabilities are not needed, the maximum area can be expanded to 14.75 x 9.0 inches. The maximum height depends on the moment of inertia but is generally limited to less than 6.0 inches.

Customization of the tilt plate includes custom versions of the plate or addition of mounting holes to existing plate designs.

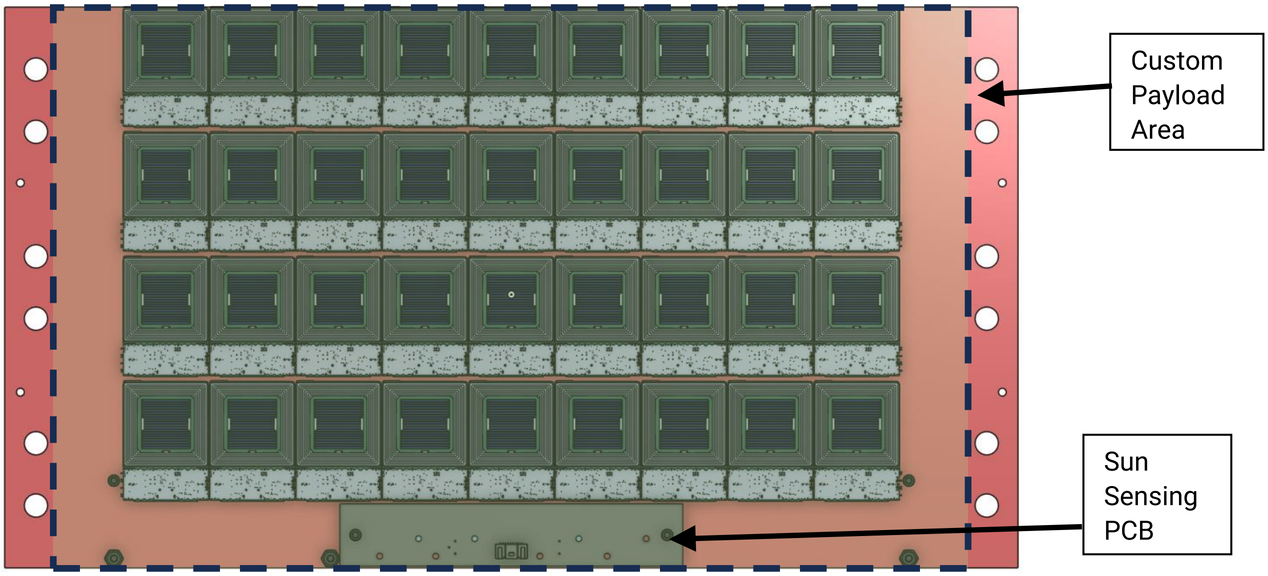

Figure 13: Gondola tile plate custom payload area

Environmental Requirements

Payloads and interfaces must survive the following conditions:

- Temperatures of -80C to +60C
- 1g acceleration shock load
  - Shock loads occur at transition from ascent to descent and on landing
- There are no vibration requirements beyond standard handling

Applications

Solar Cell Measurements

The sun pointed gondola is designed to test solar cells at AM0, in the near space environment. The primary purpose for this measurement is to use tested solar cells as calibration standards for solar simulator ground tests; however, there are other benefits to flying solar cells on the balloon.

Solar Simulator Calibration Standards

Solar simulator calibration standards are crucial for making accurate solar simulator measurements on the ground. Calibration standards are typically isotypes for multi-junction cells of the same technology. By flying the isotypes to AM0 on the balloon, the cell short-circuit current can be measured to make a direct measurement of the impact of the AM0 solar irradiance spectrum on the cell sub-junction isotype. Bringing the isotype back to a solar simulator, you can tune the simulator to reproduce the short-circuit current in the solar cell which calibrates the simulator irradiance spectrum to excite the same number of charge carriers in the cell as was done at AM0. This method effectively removes error from the measurement of the cell QE and solar simulator irradiance spectrum, which is an alternative, error prone, way of calibrating a solar simulator.

Temperature Coefficients

Solar cell temperature coefficients are notoriously difficult to measure in the lab. Accurate measurement of temperature coefficients would require measurement of the cell I_{sc} and V_{oc} under a solar simulator while precisely controlling junction temperature. An additional source of error in this method is that the cell QE changes over temperature thus the solar simulator spectral irradiance should be tuned to continue exciting the correct number of charge carriers in the cell over temperature. The equipment and procedures required to do this accurately in a lab have not yet been developed. However, since the cell naturally undergoes a temperature swing from about -40 C to +30 C on a typical balloon flight, it's possible to accurately measure the cell temperature coefficient during the flight with direct AM0 irradiance.

Cell Technology Comparison

Solar cell technology selection is a crucial step in the early stages of any space program. The low-cost nature of the Angstrom Designs high altitude balloon program allows for the direct comparison of multiple cell technologies at beginning of life in the AM0 environment. By procuring multiple candidate technologies, mounting them onto identical cell holders with identical measurement hardware, they can be flown together on a single flight to directly compare cell performance under identical conditions.

Radiation Studies

Since no solar simulator perfectly (or even closely) matches the sun irradiance spectrum, particularly in the UV, solar simulator-based radiation studies are prone to errors and require a lot of time and attention to detail to get the measurement right. The balloon flight program provides a relatively cheap and easy way to make the same measurements by conducting repeat flights on the same cells. Essentially, cells can be flown once at BOL conditions, then be irradiated, and flown again to determine EOL performance. This can be done by successively irradiating the cells a little more between each flight to measure the cell performance from BOL to EOL.

R&D Solar Cell Studies

Perovskite solar cells are an area of significant investment in the space power community. Calibrating solar simulators to test perovskite cells is a notoriously difficult task as iterations on the cell technology can modify the cell QE from generation to generation. Thus, flying several research cells on a balloon can provide an easy, cost-effective, way to directly compare cell performance from various generations on a single or a series of flights. In addition, the programmability of the gondola and IV electronics allows for custom measurements to be made for cells that have specific requirements. In the case of perovskite solar cells, maximum power point tracking is an important measurement as cell IV measurements can have hysteresis. The Angstrom Designs balloon gondola has proprietary firmware that's capable of making MPPT measurements on cells as needed.

Spectroscopy Measurements

Atmospheric attenuation occurs when measuring the solar irradiance spectrum through earth's atmosphere. Spectroscopic measurements over altitude are useful for understanding the composition of earth's atmosphere and how it can change over time. The sun-pointed gondola is capable of powering and flying small spectrometers to near-AM0 conditions while measuring atmospheric attenuation throughout the flight. This has a plethora of uses, from predicting solar cell performance at certain altitudes for solar powered HALE vehicles to understanding how the composition of earth's atmosphere changes over time.

Camera Testing

Cameras are an area of significant area of investment for both spacecraft and aircraft. New camera technologies are being introduced at a high rate and many require flight tests to understand how they perform at altitude, either capturing images of Earth's surface or images in space. The programmable gondola control system can be modified to point a camera in any given direction to conduct tests.

Glossary

AM0 – Air-Mass Zero, the solar irradiance spectrum at earth's orbit in space.

BOL – Beginning Of Life, typically used to describe solar cell performance at the beginning of a mission.

EOL – End Of Life, typically used to describe solar cell performance at the end of a mission.

IV – Current-Voltage characteristics of a solar cell.

MPPT – Max Power Point Tracking, an algorithm for balancing the cell load such that it generates the maximum amount of power while measuring that power.

QE – Quantum Efficiency, a measure of a solar cells ability to produce a charge carrier for an incident photon at a given wavelength.