Design and Build of Electronic Systems for High Altitude Balloons

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Who Am I

• Graduated from University of Saskatchewan with Masters degree in Electrical Engineering
• Worked several years at an Arctic research lab in northern Canada
• Started with building instruments for ballooning in 2012 at University of Saskatchewan
• Used to have hair on the top of my head and no grey in the beard 😁

Before Ballooning
2012

After Ballooning
2019
Our Research Group

• Heritage with the satellite instrument OSIRIS (Optical Spectrograph and InfraRed Imaging System) launched in 2001 (PI Dr. Doug Degenstein, Co-Investigator Dr. Adam Bourassa)
• 2011 Dr. Bourassa started the hardware development branch of the research group
• The goal is to build and test new instrumentation for future satellite mission(s)
• We have built instruments to demonstrate new technology or demonstrate a new technique
The Instruments and Launches

- **2014**
  - Timmins
  - ALI v1
  - OSIRIS-DM

- **2017**
  - Alice Springs
  - ALI v2

- **2018**
  - Timmins
  - ALI v2 Enhanced
  - CATS

- **2019**
  - Timmins
  - LIFE

- **2020**
  - Kiruna
  - ALI v2 Enhanced and Repaired
Grounding – A Continuing Journey

- This document can provide a starting point. BUT it is a good idea to talk with other experimenters.
- Depending on the gondola and the main power distribution there may be requirements for common ground isolation, shielding wiring, primary and secondary power supply isolation, etc.
- Having a grounding scheme to go with your design plans is a helpful (highly recommended).
- If possible, know how any COTS parts are grounded. If not possible, plan to adapt as required during mechanical installation.
Grounding – A Continuing Journey with some mistakes along the way…

2014
- Separate Power Supply Boxes
- Custom Power Supplies
- Power Returned Through Ground Wire

2017
- Custom Power Supplies
- Enclosure and electronics ground point not well defined

2018
- COTS Power Supplies
- Electronics 0volts mostly isolated from chassis ground. Each instrument had one COTS part with an exception.

2019
- COTS Power Supplies
- Same general grounding as 2018 but this required modification for the new instrument configuration.
- Second control box isolated from main control box.
2014 Grounding – The Instruments

ALI v1 – Aerosol Limb Imager
Tested an Acousto Optical Tunable Filter to select desired bands of visible light.

OSIRIS-DM - Optical Spectrograph and InfraRed Imaging System Development Model
Tested a multiple line of sight instrument.
2014 Grounding – Attempted Star Ground - Do Not Do This

Long Power Cables with Low Voltages

Potential Current Through Chassis

Ground Loop

Circuit common ground; triangle is sometimes left out for clarity.

Chassis ground; may not be shown for clarity.
2014 Grounding – What It Looked Like

Power Supply Box
OSIRIS-DM

Power Supply, Computer Boxes for Both ALI and OSIRIS-DM

Amazingly both instruments worked. Mostly.
2017 Grounding – The Instrument

ALI v2 – Aerosol Limb Imager
Upgraded camera for images in visible and NIR wavelengths.
Upgraded AOTF (larger field of view and dual transducer for visible and NIR filtering)
Upgraded electronics.
2017 Grounding – Eliminated Separate Power Supply Box

Ground path to chassis in optics box from commercial camera housing.

- Primary +V
- Primary 0v
- Optics Box
2017 Grounding – What It Looked Like

Power Supply, Computer and Peripheral Controls Box

ALI v2

Unfortunately ALI v2 did not work. More on this later…
2018 Grounding – The Instruments

CATS (Canadian Atmospheric Tomography System) and ALI v2 Enhanced Electronics Boxes

CATS and ALI v2 Enhanced Optics Boxes
2018 Grounding – ALI v2E and CATS very similar

- Primary +V
- Primary 0v
- Primary +V
- Primary 0v

Ground path to chassis in optics box from commercial camera housing.

- 2 Mohm Isolation Resistor
- Circuit common ground; triangle is sometimes left out for clarity.
- Chassis ground; may not be shown for clarity.
2018 Grounding – What It Looked Like (ALI v2E)

There are some exceptions for grounding with RF signals. I won’t go into detail about that here.

Both ALI v2E and CATS had successful flights.
2019 Grounding – The Instrument

LIFE (Limb Imaging Fourier transform spectrometer Experiment)
2019 Grounding – LIFE – Same General Scheme as 2018 Except ...

- **Primary +V**
- **Primary 0v**
- **Primary +V**
- **Primary 0v**

**Optics Box**

**BB Box**

**Board 1**

**Board 2**

**Power Supply and Computer Box**

- **V1**
- **V2**
- **V3**
- **V4**

- **Isolated with Optocouplers and Separate Power Supply**
2019 Grounding – LIFE – Same General Scheme as 2018 Except …

Primary +V
Primary 0v
Primary +V
Primary 0v

Board 1
Board 2

Optics Box
BB Box

Power Supply and Computer Box

Small Resistance Between Common 0 volts and Chassis Ground

Isolated with Optocouplers and Separate Power Supply

2019 Grounding – LIFE – Same General Scheme as 2018 Except …
2019 Grounding – What It Looked Like (LIFE)

LIFE had a very successful flight.
2019 Grounding – LIFE

• The instrument worked for 2 months with the signal ground connection.
• Two weeks prior to the campaign we had issues with the FTS. It was traced back to the grounding problem.
• Due to time we went with the “ground lifting” solution.
• Not ideal, but it worked. LIFE had a successful flight.
• More information can be found here: https://en.wikipedia.org/wiki/Ground_loop_(electricity)#Ground_currents_on_signal_cables
• Important lesson learned (I think): treat anything on a separate power supply as a “box” in the NASA grounding document.
2019 Grounding – LIFE – Future Modification

Primary +V
Primary 0v
Primary +V
Primary 0v

Power Supply and Computer Box

Board 1

0volt Signal Isolation of Some Kind

Board 2

Well Defined 0volt Reference Point

1-2 Mohm Bleed Resistor

BB Box

Optics Box

Isolated with Optocouplers and Separate Power Supply
Grounding – A Continuing Journey – What to Take Away

• We have been continuously learning how to improve our instrument grounding. Especially taking the grounding from the design to implementation. And we still haven’t got it perfect 😊

• Once implementing the hardware, grounding in the intended way can be tricky. Favourite line in NASA grounding document: “Note that sometimes the actual implementation may negate the intended effects” p. 6, NASA-HDBK-4001

• There are different ways of grounding and one way may be more suitable for your application then another.

• Spend time designing and reviewing your grounding scheme. Then keep reviewing as you are building.

• Measure the ground paths with a multimeter (on the resistance setting, not the diode setting)
Some Materials for Isolation Mounting

**Garolite (G10)**
- Electrically Isolating
- Thermally Isolating
- Strong, somewhat machinable.

**Titanium Washers/Spacers**
- Mostly Electrically Isolating
- Thermally Isolating
- Can be expensive and long lead time

**Teflon/PTFE Washers/Sleeves**
- Electrically Isolating

**Thermal Pads**

**Kapton Tape**

**Nylon Standoffs (oversize and get metal inserts on both ends)**
Power Supplies

- Select extended temperature range
- Select wide input voltage range that matches power distribution range. Generally battery voltage is high at beginning and then drops throughout the flight. There will also be an upper voltage for charging the batteries.

Chassis Mount DC-DC Converters
- Success with CUI Inc. products

Board Mount DC-DC Converters
- Success with Artesyn Embedded Technologies
Flight Computers
- Select extended temperature range
- We use some kind of PC104 form factor
- The required peripheral devices aid in selecting the computer and desired ports (analog inputs/outputs, digital inputs/outputs, serial communication, ethernet, usb, sata, etc.)

PC104 Computers
- Success with Winsystems Inc.
- Success with VersaLogic Corp.
Hard Drives
- Select extended temperature range
- We use a solid state drive (or two)
- SATA communication


SSD
- Success with Swissbit X-60 drives
Peripherals

- Select extended temperature range
- Depending on the application extra capability beyond the computer may be required
- We have required extra ethernet ports, additional digital I/O lines, direct memory access data transfer, CameraLink to GigE converters, stepper motor controllers, etc.

Peripherals

- Success with RTD Embedded Technologies Inc. (PC104 Stack)
- Success with Winsystems Inc. (PC104 Stack)
- Success with Applied Motion (stepper motors)
- And others…
Custom Electronics

- We now tend to try and minimize the number of custom boards. However, sometimes custom electronic boards are required.
- Likely good idea to plan on 2 or 3 versions of the board.
- If possible, get access to a small surface mount oven.

Reflow Oven

https://www.amazon.ca/Reflow-Infrared-Soldering-Machine-Automatic/dp/B06W2L1B71/ref=pd_sbs_469_4/138-8575161-5739272?_encoding=UTF8&amp;pd_rd_i=B06W2L1B71&amp;pd_rd_r=06c67f40-30d0-49e6-863a-607b293adb62&amp;pd_rd_w=q1MaM&amp;pd_rd_wg=Kbg7S&amp;pf_rd_p=f7748194-d8e4-4460-84c0-2789668108bc&amp;pf_rd_r=KBEWBJPQ1C0QTHJ0R6RS&amp;psc=1&amp;refRID=KBEWBJPQ1C0QTHJ0R6RS

Circuit Board Stencil

https://www.oshstencils.com

Circuit Board and Parts

https://oshpark.com/
https://www.digikey.ca/
Cables and Connectors

- **Cables**: we try to use PTFE (Teflon) or some variant as much as possible. [example: https://www.digikey.ca/product-detail/en/belden-inc/83049-002100/BEL1610-100-ND/7388997]

- **Cables**: can look for oven/furnace cable for PTFE shielded cabling. [example: https://www.mcmaster.com/8219k61]

- **Ribbon Cable**: we use Fluorinated Ethylene-Propylene (FEP) insulated cables. [example: https://www.digikey.ca/product-detail/en/3m/3601-50-100/MJ50C-5-ND/1885743]

- **Cable Termination**: we use wire-end ferrules and terminal blocks. [example ferrule: https://www.digikey.ca/product-detail/en/weidmuller/9026030000/281-3097-ND/491807]

- **Connectors**: we use dsubs and cylindrical. Generally try to get military spec connectors. Avoid Cadmium and Tin if possible. [example: https://www.digikey.ca/product-detail/en/amphenol-industrial-operations/PT02E12-3P-025/PT02E-12-3P-025-ND/1209804]

- **Heat Shrink**: we try to use Polyvinylidene Fluoride (PVDF) [example: https://www.digikey.ca/product-detail/en/3m/MFP-1-4--CR-48--BX/KY014C-ND/269609]

- **Cable Shielding**: we use braided copper tubing. [example: https://www.digikey.ca/product-detail/en/techflex/MBN0.50SV50/1030-1170-ND/2502613]

- **NASA Outgassing**: https://outgassing.nasa.gov/
Thermal Management

- Started using a general rule of thumb: If you can put your finger on the part and hold it there, you are probably ok. If not, you likely need to thermally strap the part.
- Now, we use the thermal simulator in SolidWorks to help in the thermal design.
- Generally the part(s) with the lowest hot operating temperature and the highest cold operating temperature will be the limiting constraint.
- We add heat with power resistors or polymide thermofoil heaters.
- For thermal strapping we use thin copper strips or Panasonic Pyrolytic Graphite sheets.
Thermal Management


Dow Corning 340 Heat Compound for heat transfer. (https://www.mcmaster.com/10405k83)

Thermal Management – Solidworks Thermal Simulator Package

- Power dissipation of all parts were defined
- All parts started at 25 degrees C
- Baseplate set at -40 degrees C
- Simulated temperatures after 10 hours
Thermal Management – Heaters and Heater Controllers

**Heaters**

- Success with Polyimide (Kapton) Thermofoil heaters from Minco Components
- Success with chassis mount power resistors from Vishay Dale

**Temperature Controllers**

- Success with Wavelength Electronics PID temperature controllers (PTC#K-CH)
- Success Minco Components Miniature DC Controller (CT325PD2C1)

**Platinum RTD Sensors**

- Success with Minco Components Bolt-On and Economy Sensors
Testing

- A good general rule is: Test as you fly.
- We make adapter boxes to emulate the power connections. This allows us to test and operate with our actual flight cables.
- We also make an adapter box to emulate the communication cable.

Power Adapter: One side emulates gondola connectors. Other side is made to easily connect lab power supplies.

Communication Adapter: One side emulates gondola ethernet connection. Other side is made to easily connect standard ethernet cable.
Testing

• Obviously: the more time you can test and operate the instrument the better (get confidence for flight)
• If possible (highly recommended) test in a Thermal Vacuum Chamber (TVAC)

LIFE Sky Testing

LIFE TVAC Testing
Flying

• After all the hard work, you get to fly. Stomach butterflies acceptable 😊
Ballooning Stories

• After the flight there are always ballooning stories. Some are good, some are not so good.

2014: during launch countdown OSIRIS-DM computer would not boot. Both instruments operated successfully. Image courtesy CSA.

2017: 27 minutes after launch a power supply failed. We did not get any measurements.

2018 and 2019: Three different instruments. All flew successfully. A team effort. Share the experience. HAVE FUN 😊

Image from LIFE 2019 Campaign. L-R: Jeff Langille, Paul Loewen, Connor Schentag, Ethan Runge, Adam Bourassa, Daniel Letros.
The End
Design and Build of Electronic Systems for High Altitude Balloons
Some Acronyms:

ALI - Aerosol Limb Imager
AOTF - Acousto Optical Tunable Filter
CATS - Canadian Atmospheric Tomography System
COTS - Commercial Off The Shelf
LIFE - Limb Imaging Fourier transform spectrometer Experiment
NIR - Near Infrared
OSIRIS - Optical Spectrograph and InfraRed Imaging System
RF - Radio Frequency