https://ntrs.nasa.gov/search.jsp?R=20190026990 2019-09-26T19:03:29+00:00Z

Space Flight Optoelectronics and Photonics Qualification

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2) Science Systems and Applications (SSAI), Inc.

SAE Photonics Reliability Meeting
April 15, 2019

https://photonics.gsfc.nasa.gov

Meet the Photonics Group of NASA Goddard
Over 20 years of space flight hardware development, testing, & integration

Back row L-R: Erich Frese, Joe Thomes, Marc Matyseck
Middle row L-R: Rick Chuska, Eleanya Onuma, Cameron Parvini, Rob Switzer
Front row L-R: Hali Jakeman, Melanie Ott, Diana Blair,

Trevon Parker

Alexandros Bontzos

Clairy Reiher

Alejandro Rodriguez

All great things require a great team!

https://photonics.gsfc.nasa.gov

Outline

Introduction

- Photonics Group Capabilities & Facilities
- Approach to Development and Fabrication of Space Hardware

Qualifying Optoelectronics and Photonics for Space

- Define ‘Qualification’
- Environmental Parameters
- Summary of Previous Missions
- Technology Readiness Enhancement of Indium-Phosphide Photonic Integrated Circuits (InP PIC)

Matters of Reliability

- Risk postures, Schedule and Cost
- Failure Modes for Optoelectronics and Photonics
- Screening and Qualifying Commercial Off-The-Shelf (COTS) Components
- Common Failure Modes

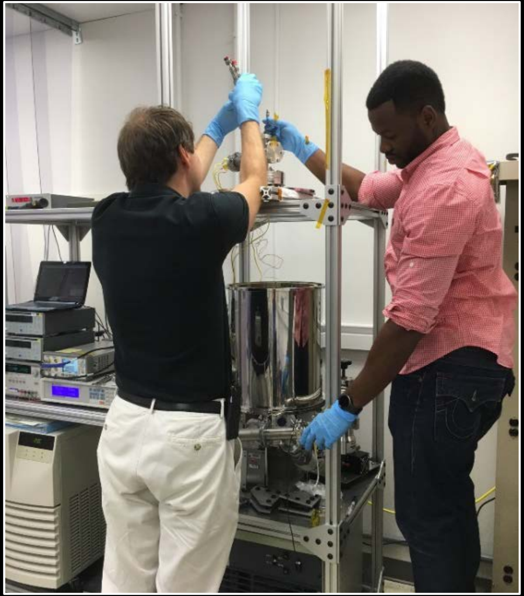
Summary and Final Notes

- The Gateway and the Future of Spaceflight Optoelectronics
- Qualifying COTS LiDARs, other Current/Future Projects

Custom Spaceflight Optical & Optoelectronic Subsystems using Commercial Components

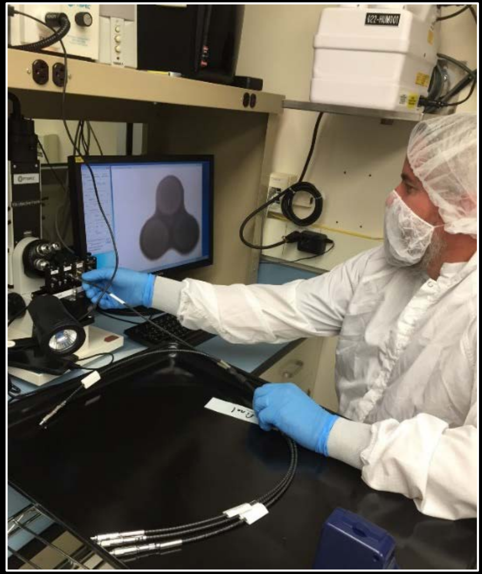
Integration

Materials Selection and Inspections



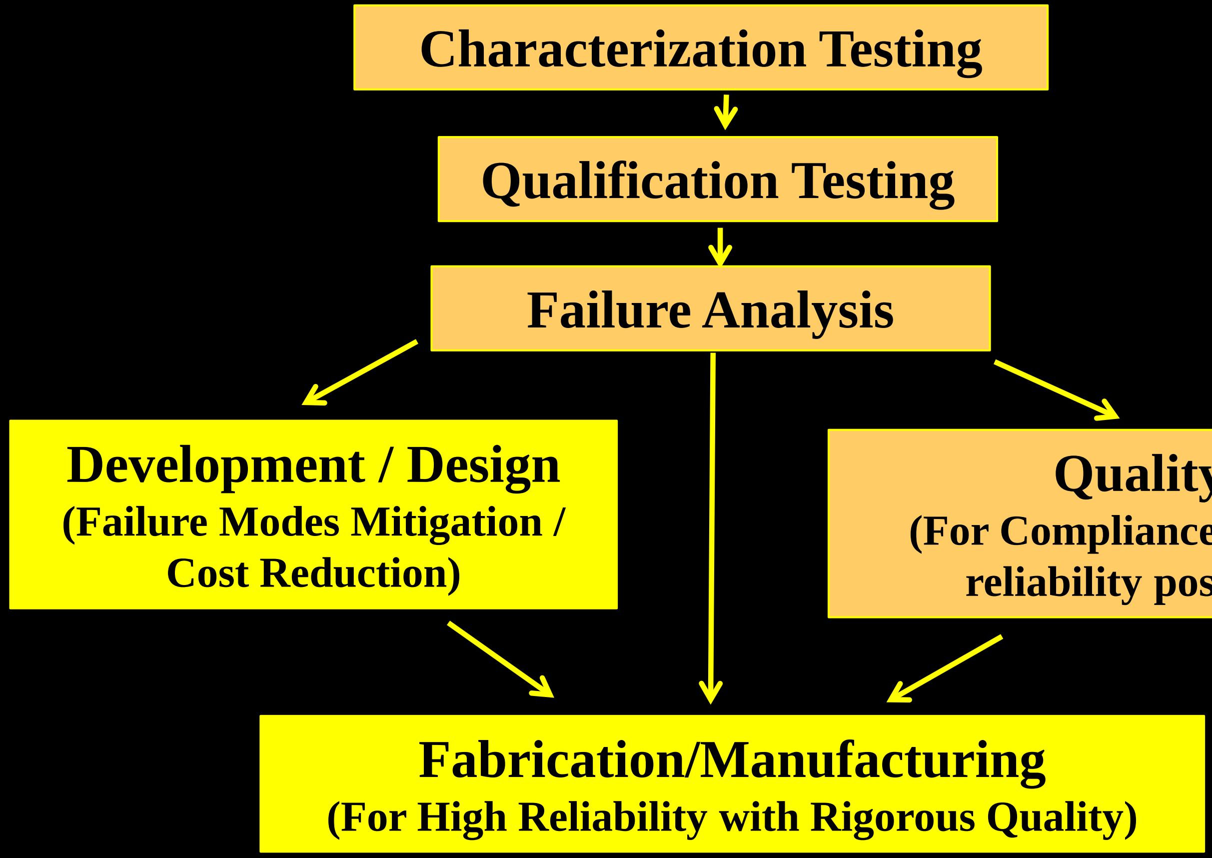
Environmental Testing

Manufacturing



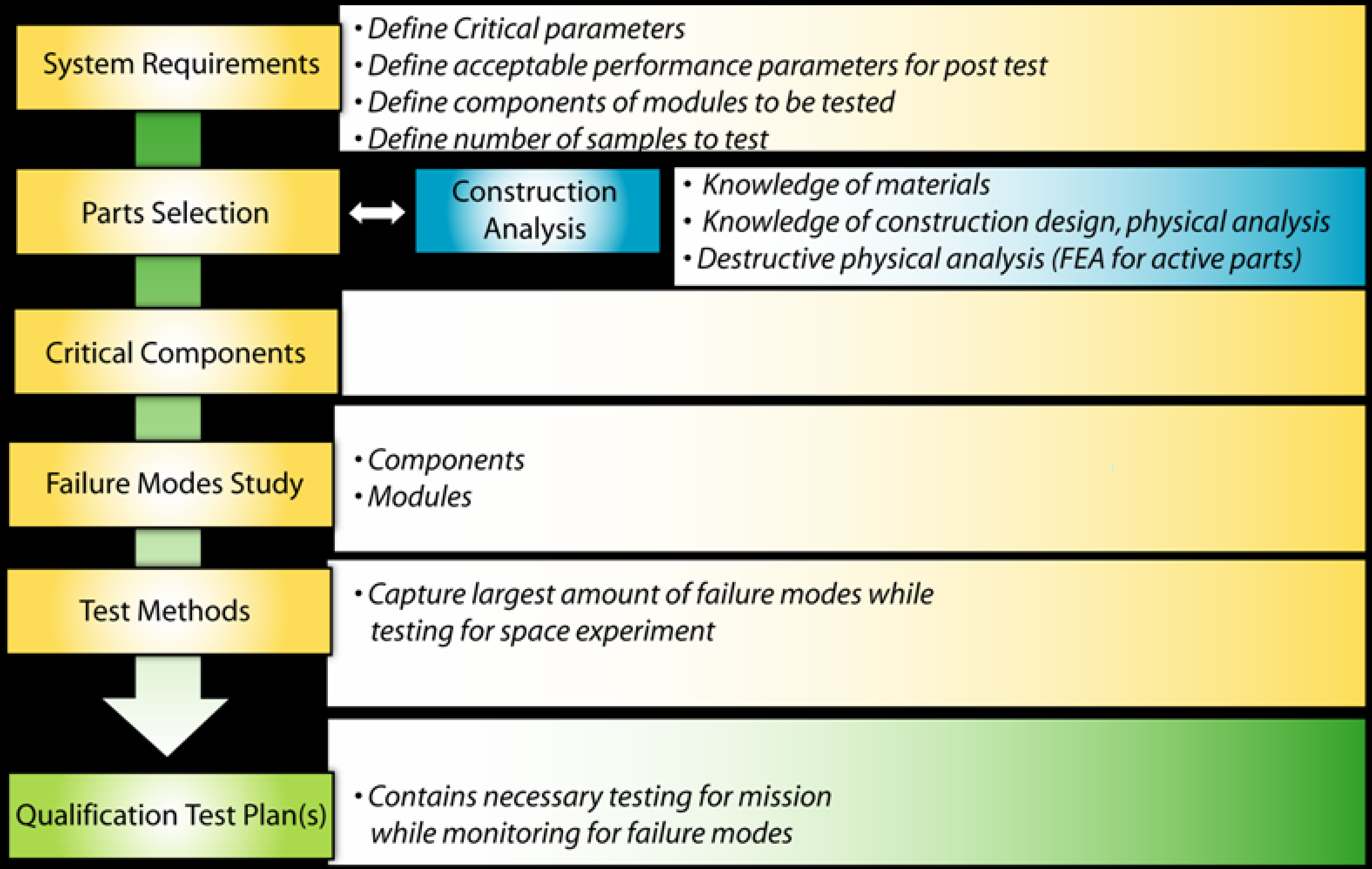
One Stop Shopping for Concept through Delivery

How Do You Develop and Fabricate Hardware?



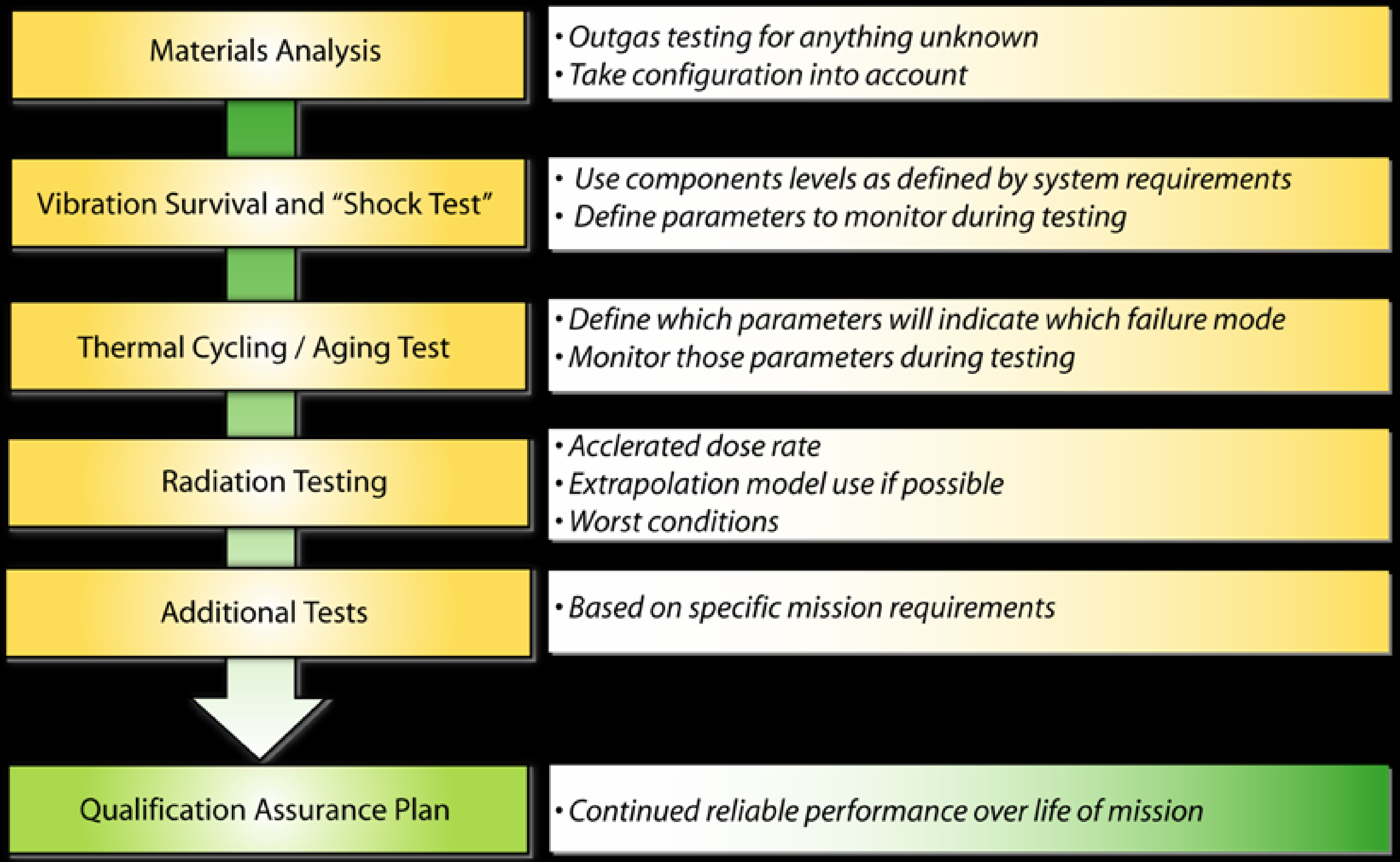
Risk mitigation to reduce cost - use space flight component failure mode knowledge;
Design out what you can –through configuration; packaging, materials, processes, screening.

COTS Technology Assurance Approach



(1) Reference: *Photonic Components for Space Systems*, M. Ott, Presentation for Advanced Microelectronics and Photonics for Satellites Conference, 23 June 2004.

COTS Space Flight “Qualification”



(1) *Photonic Components for Space Systems*, M. Ott, Presentation for Advanced Microelectronics and Photonics for Satellites Conference, 23 June 2004.

We perform selection, test and qualification of laser components the way the Parts Lab supports EEE parts.

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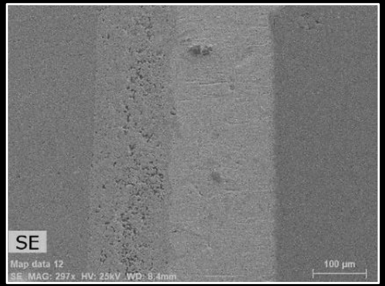
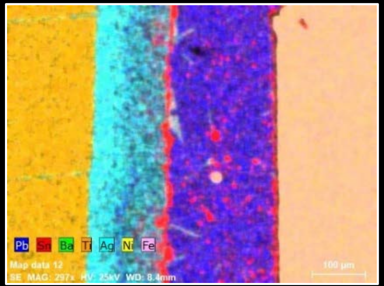
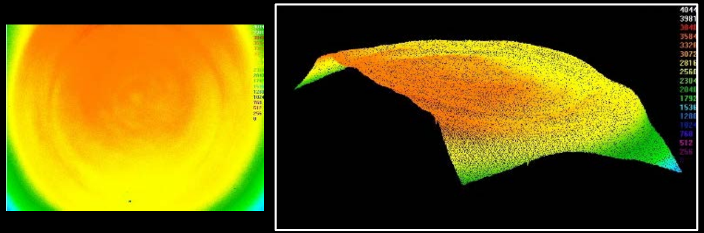
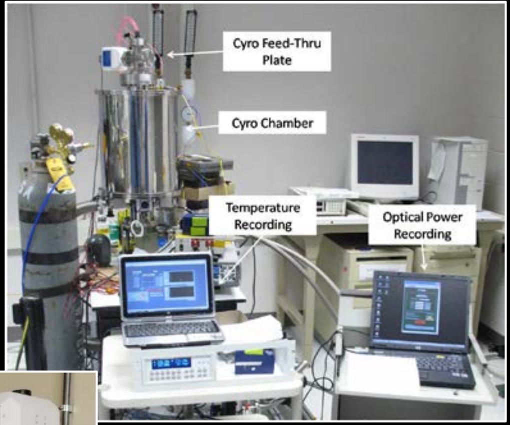




10 k X Mag SEM & Material Identification



LED Beam Profile



Cryogenic Test Facility

Materials Screening / Construction Analysis

→ **Optical Inspection & Screening**

→ **Performance Characterization**

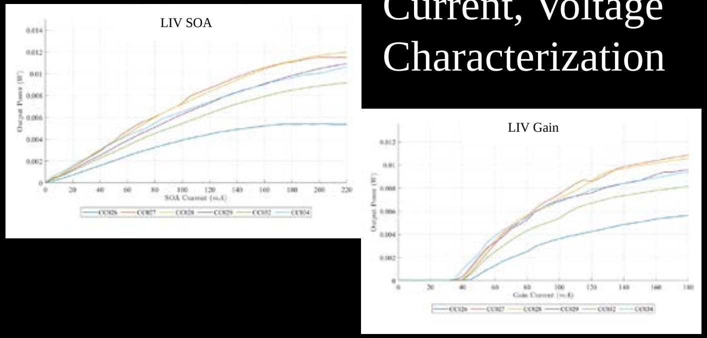
→ **Vibration / "Shock" Testing**

→ **Thermal Cycling / Vacuum**

→ **Radiation Testing**

→ **Additional Testing?**

Optical Power, Current, Voltage Characterization



Radiation Test Equipment

White Light LED Testing in Environmental Chamber

Random Vibration Test & Shock Equipment

Issues to Consider

- Schedule, shorter term
- Funds available,
- Identify sensitive or high risk components.
- System design choices for risk reduction.
- Packaging choices for risk reduction.
- Quality by similarity means no changes to part or process.
- Qualify a “lot” by protoflight method—you fly the parts from the lot qualified, not the tested parts.
- Telcordia certification less likely now for non communication type applications.
- Process changes at the component level happen often.

(2) Reference: *Optical Society of America Frontiers in Optics, Session on Space Qualification of Materials and Devices for Laser Remote Sensing Instruments I, Invited Tutorial*, M. Ott, September 2007.

Define "Qualification"

Are you rich or are you poor?

- $$$$= MIL-STD's + Telecordia + NASA or Space Requirements
  - Lifetime Lot buys for COTS parts or anything that will go obsolete.
- $$$ = Telecordia + NASA or Space Requirements
  - Buy critical parts , qualify by Lot.
- $$ = COTS Approach for Space Flight (NASA Requirements)
  - Requires careful planning especially with materials selection
  - Lot specific testing
  - Destructive physical analysis/ packaging or construction analysis necessary early on
  - Radiation testing performed early in selection phase – saves schedule later.

(3) Reference: *Implementation and Qualification Lessons Learned for Space Flight Photonic Components, Invited Tutorial* M. Ott, International Conference on Space Optics, Rhodes Greece, October 2010.

Environmental Parameters

- Vacuum requirements
  - (Materials Analysis or Vacuum Test or both)
- Vibration requirements
- Thermal requirements
- Radiation requirements
- Other Validation Tests

(2) Reference: *Optical Society of America Frontiers in Optics, Session on Space Qualification of Materials and Devices for Laser Remote Sensing Instruments I, Invited Tutorial*, M. Ott, September 2007.

Environmental Parameters: Vacuum

Vacuum outgassing requirements:

- ASTM-E595,
  100 to 300 milligrams of material
  125°C at 10^{-6} Torr for 24 hours
  Criteria: 1) Total Mass Loss < 1%
  2) Collected Volatile Condensable Materials < 0.1%
  - Configuration test
  - Optics or laser nearby, is ASTM-E595 enough?
    -ask your contamination expert

1) Use approved materials, outgassing.nasa.gov
2) Preprocess materials, vacuum, thermal
3) Decontaminate units: simple oven bake out, or vacuum?
4) Vacuum test when materials analysis is not conducted and depending on packaging and device.

Space environment; vacuum is actually 10^{-9} torr, best to test as close as possible for laser systems.
Many chambers don't go below 10^{-7} torr.

(2) Reference: ***Optical Society of America Frontiers in Optics, Session on Space Qualification of Materials and Devices for Laser Remote Sensing Instruments I, Invited Tutorial*, M. Ott, September 2007.**

Vibration Validation Testing

Frequency (Hz)	Level
20	0.013 g^2/Hz
20-50	+6 dB/octave
50-800	0.08 g^2/Hz
800-2000	-6 dB/octave
2000	0.013 g^2/Hz
Overall	9.8 grms

Frequency (Hz)	Level
20	0.052 g^2/Hz
20-50	+6 dB/octave
50-800	0.32 g^2/Hz
800-2000	-6 dB/octave
2000	0.052 g^2/Hz
Overall	20.0 grms

Frequency (Hz)	Level
20	0.026 g^2/Hz
20-50	+6 dB/octave
50-800	0.16 g^2/Hz
800-2000	-6 dB/octave
2000	0.026 g^2/Hz
Overall	14.1 grms

Frequency (Hz)	Level
20	0.156 g^2/Hz
20-50	+6 dB/octave
50-800	0.96 g^2/Hz
800-2000	-6 dB/octave
2000	0.156 g^2/Hz
Overall	34.63 grms

(4) Reference: *Optical Fiber Assemblies for Space Flight from the NASA Goddard Space Flight Center, Photonics Group,* M. Ott International Symposium On Reliability Of Optoelectronics For Space (ISROS), May 14, 2009, Cagliari, Italy

Environmental Parameters: Vibration

Launch vehicle vibration levels for small subsystem (established for EO-1)

Frequency (Hz)	Protoflight Level
20	0.026 g^2/Hz
20-50	+6 dB/octave
50-800	0.16 g^2/Hz
800-2000	-6 dB/octave
2000	0.026 g^2/Hz
Overall	14.1 grms

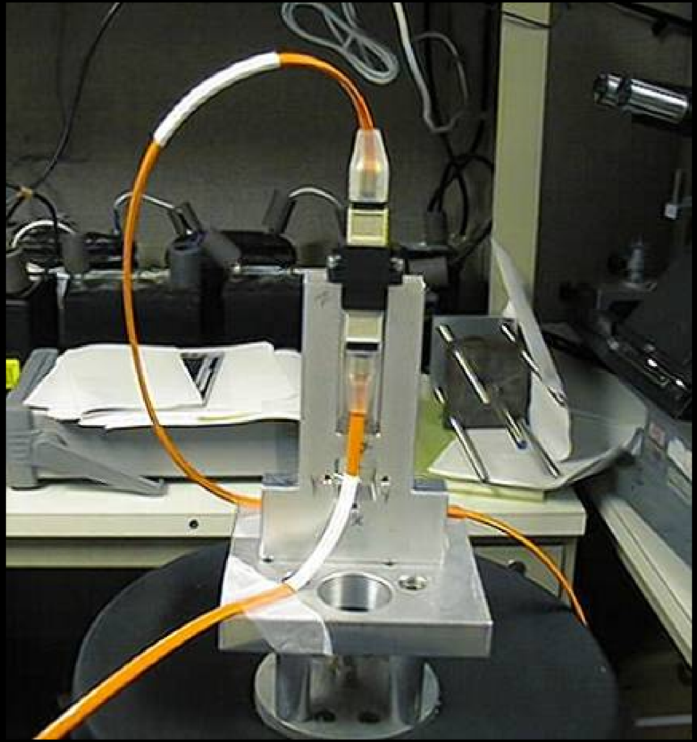
However, this is at the box level, twice the protoflight vibration values establish the correct testing conditions for the small component.

(2) Reference: *Optical Society of America Frontiers in Optics, Session on Space Qualification of Materials and Devices for Laser Remote Sensing Instruments I, Invited Tutorial*, M. Ott, September 2007.

Environmental Parameters: Vibration

Launch vehicle vibration levels for small component (based on box level established for EO-1) on the "high" side.

Frequency (Hz)	Protoflight Level
20	0.052 g^2/Hz
20-50	+6 dB/octave
50-800	0.32 g^2/Hz
800-2000	-6 dB/octave
2000	0.052 g^2/Hz
Overall	20.0 grms



3 minutes per axis, tested in x, y and z

(2) Reference: *Optical Society of America Frontiers in Optics, Session on Space Qualification of Materials and Devices for Laser Remote Sensing Instruments I, Invited Tutorial*, M. Ott, September 2007.

Environmental Parameters: Thermal

There is no standard, typical and benign –25°C to +85°C.
–45°C to +80°C, Telcordia; -55°C to +125°C, Military

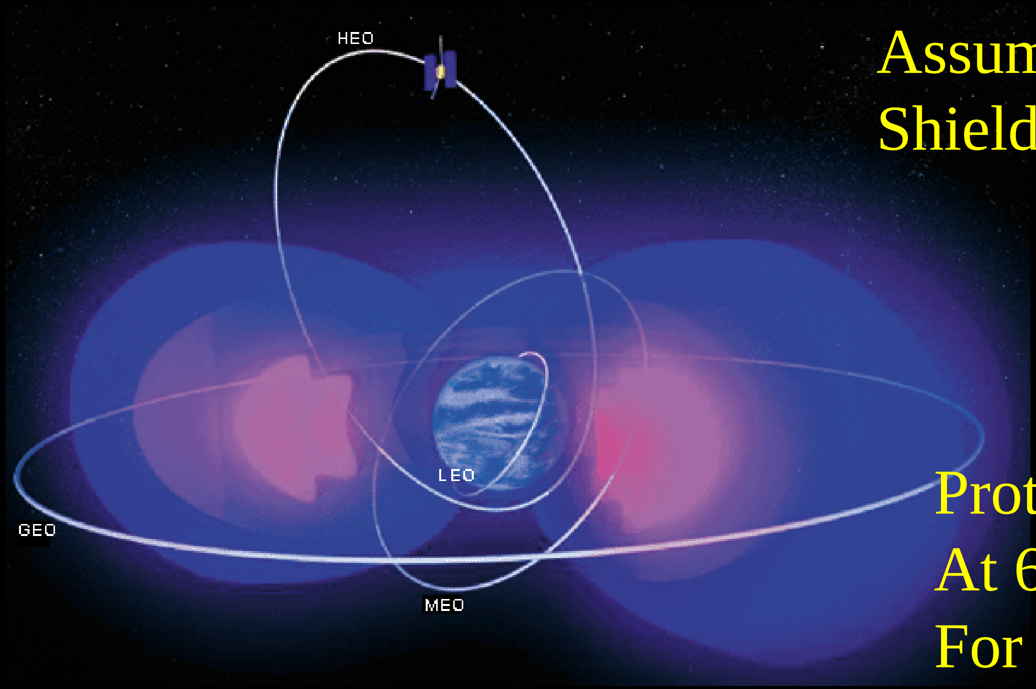
Depending on the part for testing;
- In situ testing is important,
- Add 10°C to each extreme for box level survival

Thermal cycles determined by part type, schedule vs. risk
- 30 cycles minimum for assemblies, high risk
- 60 cycles for assemblies for higher reliability
- 100 or more, optoelectronics and longer term missions.

Knowledge of packaging and failure modes really helps with cycles determination.

(2) Reference: *Optical Society of America Frontiers in Optics, Session on Space Qualification of Materials and Devices for Laser Remote Sensing Instruments I, Invited Tutorial*, M. Ott, September 2007.

Environmental Parameters: Radiation



Assuming 7 year mission,
Shielding from space craft

LEO, 5 – 10 Krads, SAA
MEO, 10 –100 Krads, Van Allen belts
GEO, 50 Krads, Cosmic Rays

Proton conversion to Total Ionizing Dose (TID)
At 60 MeV, 10^{10} protons/Krad for silicon devices
For systems susceptible to displacement damage

Testing for displacement damage: 3 energies in the range ~ 10 to 200 MeV.
If you have to pick one or two energies stay in the mid range of 65 MeV and lower. Less probability of interaction at high energies.
Ballpark levels: 10^{12} p/cm^2 LEO, 10^{13} p/cm^2 GEO, 10^{14} p/cm^2 for special missions (Jupiter).

(2) Reference: ***Optical Society of America Frontiers in Optics, Session on Space Qualification of Materials and Devices for Laser Remote Sensing Instruments I, Invited Tutorial,*** **M. Ott, September 2007.**

Environmental Parameters: Radiation

(2) Reference: *Optical Society of America Frontiers in Optics, Session on Space Qualification of Materials and Devices for Laser Remote Sensing Instruments I, Invited Tutorial*, M. Ott, September 2007.

Typical space flight background radiation total dose
30 Krads – 100 Krads over 5 to 10 year mission.

Dose rates for fiber components:

- ICESat-1 was GLAS, 100 Krads, 5 yr, .04 rads/min
- Mercury Laser Altimeter, 30 Krads, 8 yr, .011 rads/min (five year ave)
- Earth Orbiter-1, 15Krads, 10 yr, .04 rads/min
- ISS Extra vehicular, 1 Mrad/year, 2 rads/min

Any other environmental parameters that need to be considered?

For example,

1) radiation exposure at very cold temp, or prolonged extreme temperature exposure based on mission demands.

2) Motion during cold exposure.

Optoelectronics Mission Highlights

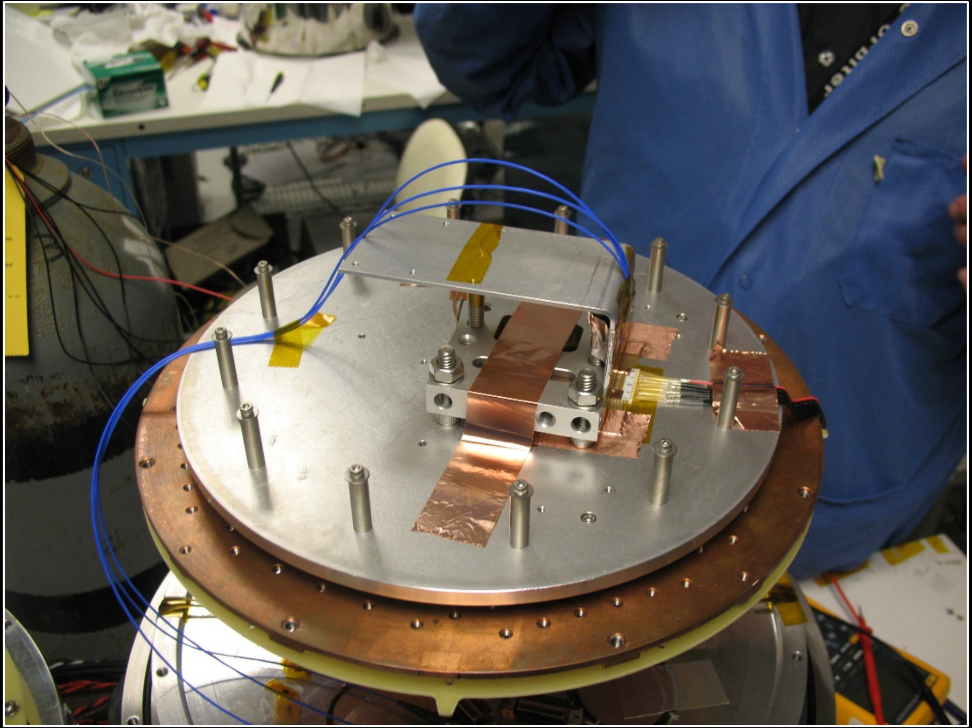
(communications transceivers tested in last 20 yrs not included in table)

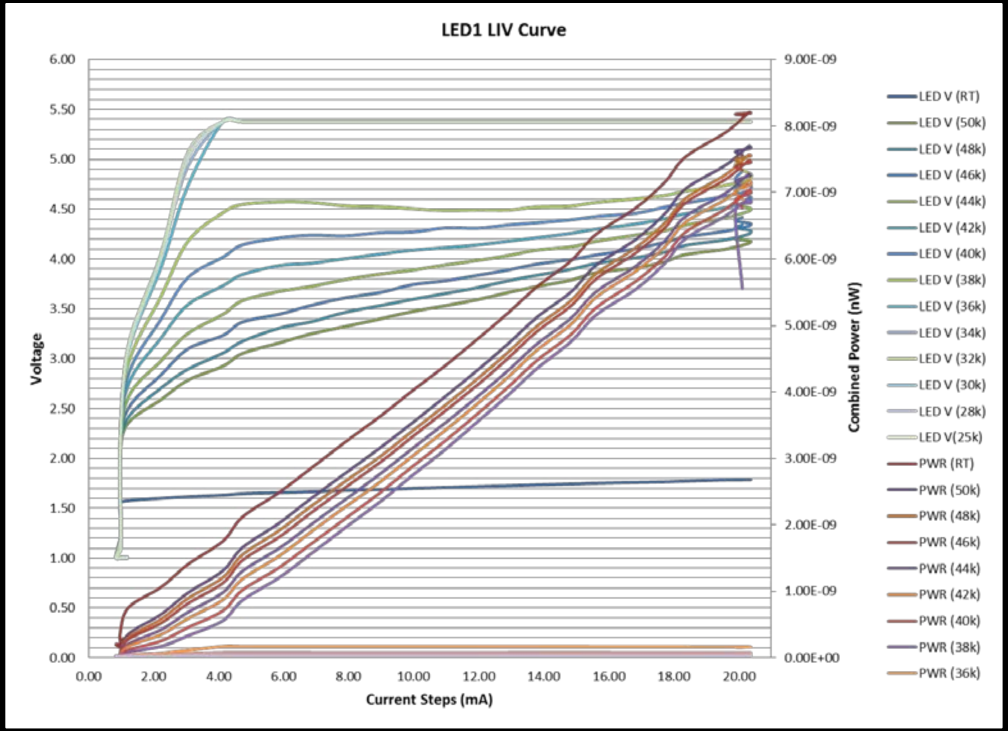
Project	Part Type	Wavelength (nm)	Quantity	Dates	Screening	Qualification	Radiation	Packaging Analysis
SAA Harris	Laser Diode	635, 660	30	2009	x	x		x
JWST	LED	633	6	2009		x		
TSIS/GLORY	Photodiode	140 – 1100	25	2010	x			x
LADEE/MAVEN	LED	450 – 650	50	2010	x	x		
SSCP	LED	450 – 650	290	2012	x	x		x
GOES-R	LED	315	4	2012				x
ATLAS	Photodiode	400 – 1100	10	2013	x			
OTES	Photodiode	450 – 1050	60	2014	x	x		x
OTES	Pyroelectric Detector	4000 – 50000	24	2014	x	x		x
SSCP	LED	635	842	2010-2013	x	x	x	x
ATLAS	LED	520	300	2012 - 2013	x	x	x	x
Solar Orbiter	Laser Diode	850	70	2013 - 2014	x	x		x
Solar Orbiter	Photodiode	450 – 1050	70	2013 - 2014	x	x		x
OTES	Laser Diode	850	50	2014 - 2015	x	x		x
MOMA	Micropirani	N/A	25	2014 - 2015	x	x		x
SSCO	LED	450 – 650	1000	2016-2019	x	x	x	x
SAA ASU	Laser Diode	850	45	2017 - 2018	x	x		x
SAA ASU	Pyroelectric Detector	4000 – 50000	43	2017 - 2019	x	x		x
NASA GCD Program	Photonic Integrated Circuit	1550	8	2018 - Present	x	x	x	x

James Webb Space Telescope (JWST)

- LEDs were evaluated for use in a cryogenic environment.

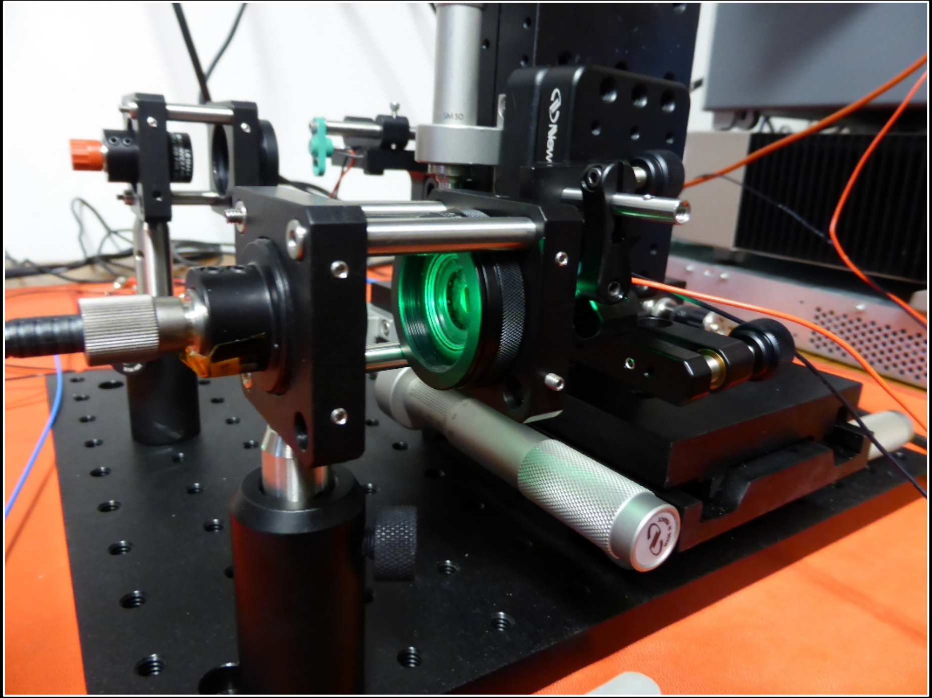
- In-situ electro-optical measurements were acquired to assess the component’s performance characteristics.

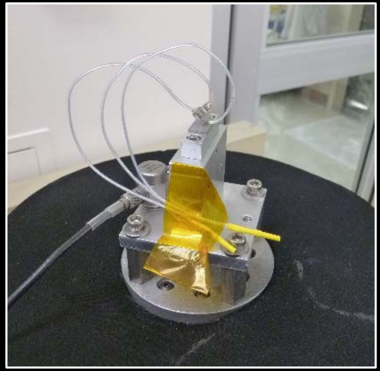


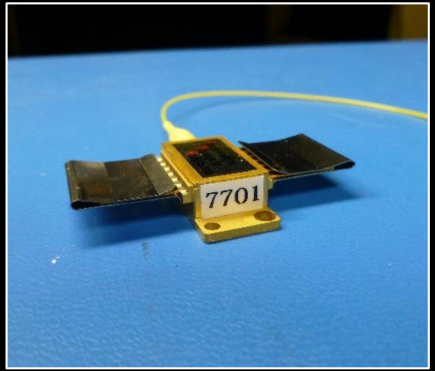


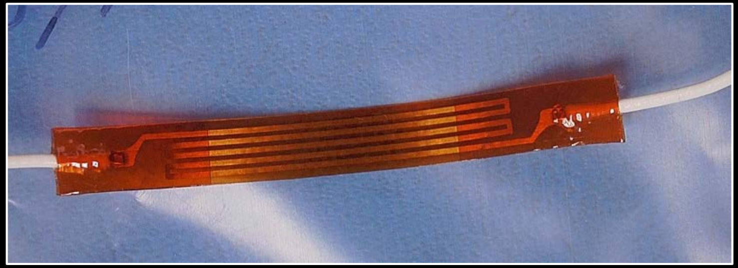
ATLAS (ICESAT-2)

- The Code 562 Photonics Group was involved in the testing or evaluation of seven components used on the ATLAS instrument, currently operating on ICESAT-2.
- Testing included: visual inspections; thermal, electrical, and optical characterization; random vibration; radiation testing; and destructive physical analysis.



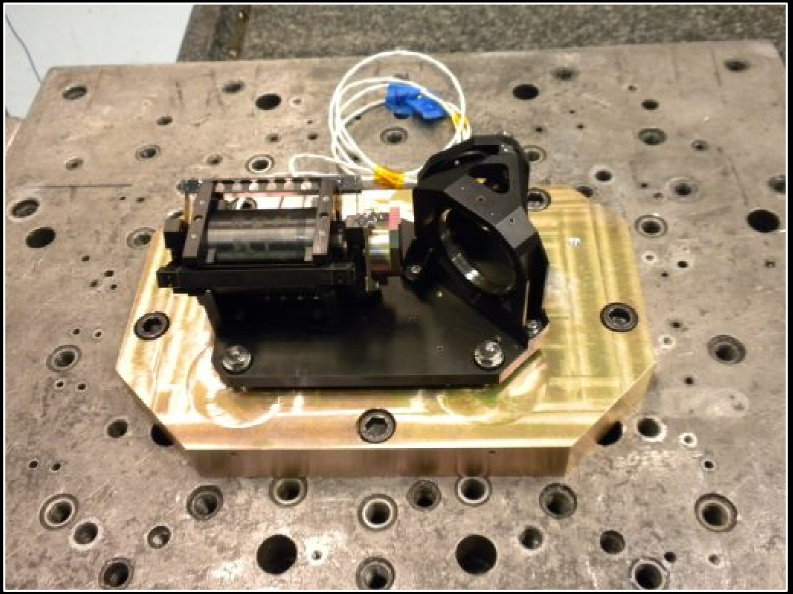


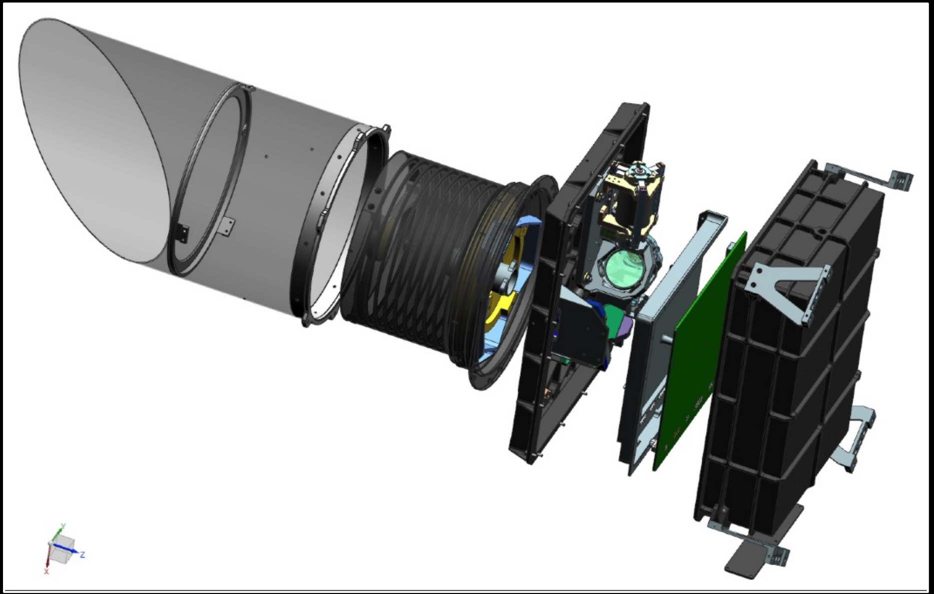




OTES (OSIRIS-REx) Mission to Bennu

- The OTES instrument is a point spectrometer on board the Origins, Spectral Interpretation, Resource Identification, Security, Regolith Explorer (OSIRIS-REx) spacecraft.
  - It is capable of mapping the asteroid Bennu’s material composition, with a 4-50 micrometer wavelength range.
  - OTES was developed at the School of Earth and Space Exploration at Arizona State University.



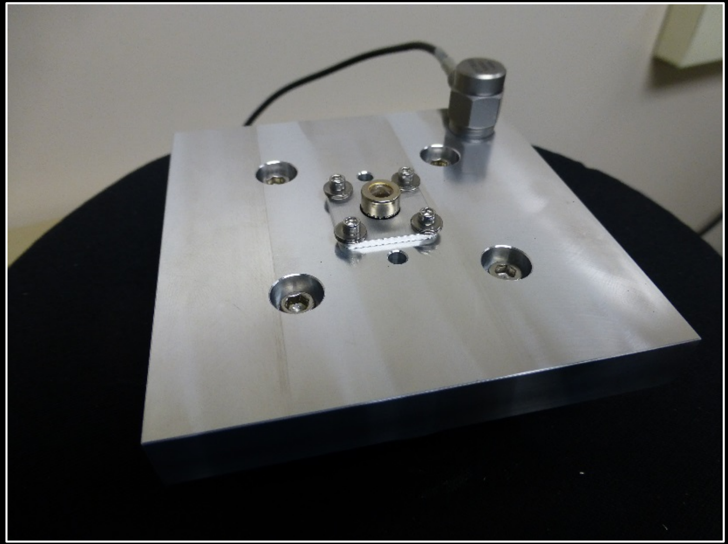


(5) Reference: http://spaceflight101.com/osiris-rex/osiris-rex-instruments/

Space Act with Arizona State University

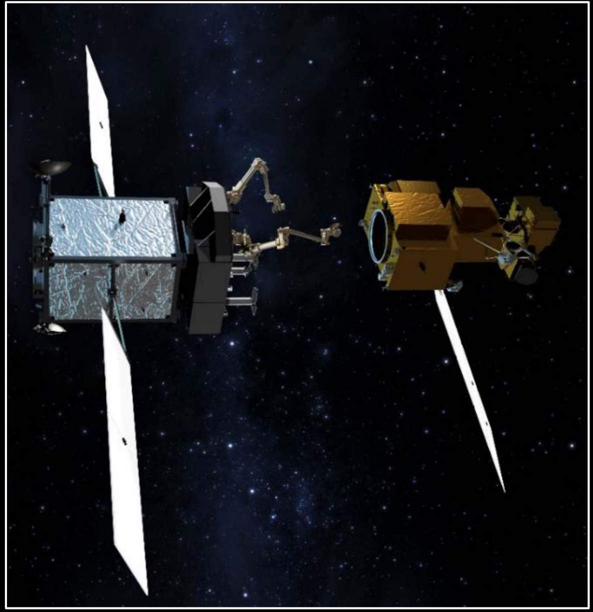
- ASU partnered with the Code 562 Photonics Group at GSFC through a Space Act Agreement to perform the screening and qualification of laser diodes, pyroelectric detectors, and photodiodes for both OTES and another application with space flight customers.

  - All testing was performed at GSFC by Photonics Group team members.



Vision Sensor Subsystem (Restore-L)

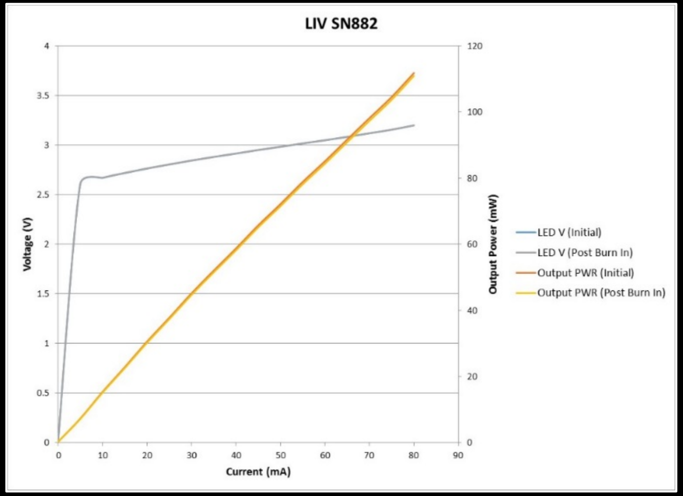
- The Restore-L spacecraft is a satellite servicing platform that can rendezvous, redirect, refuel, and thus enable missions to operate beyond their designed lifetimes.
- The Restore-L team required support in screening and qualifying white LEDs for their Vision Sensor Subsystem (VSS), used to illuminate targets for docking, arm maneuvering, and other servicing tasks.

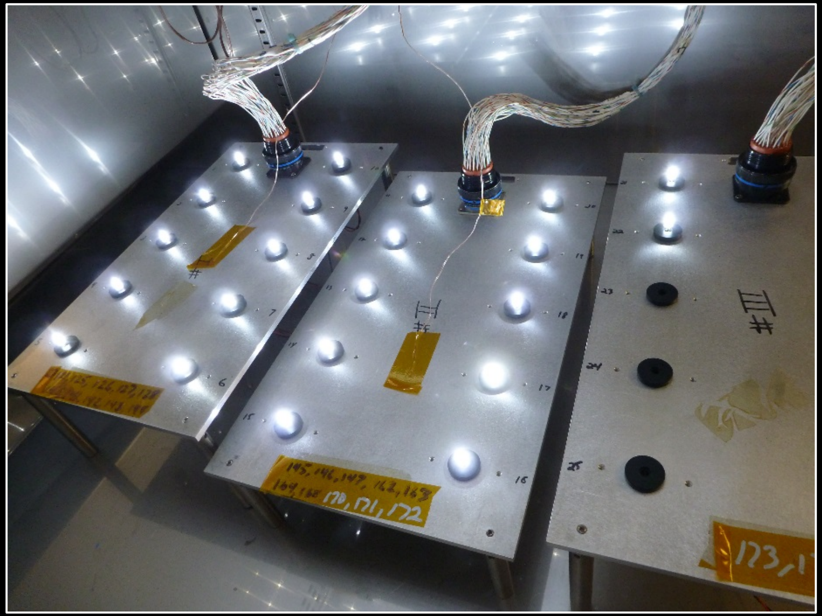


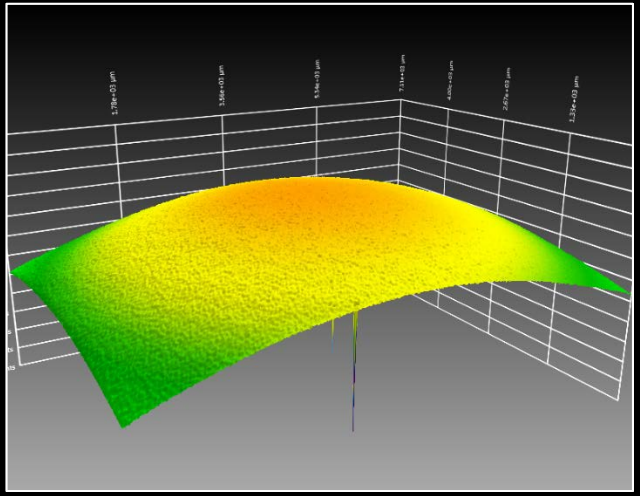
https://www.nasa.gov/feature/nasa-s-restore-l-mission-to-refuel-landsat-7-demonstrate-crosscutting-technologies

Vision Sensor Subsystem (Restore-L)

- At the end of long-term life testing and characterization efforts by the Photonics group, over 19 Gigabytes of electrical and optical performance data had been collected.
- Testing included: visual inspections; extensive electro-optical characterization testing; environmental testing; thermal qualification at multiple temperatures; and CCD imaging.







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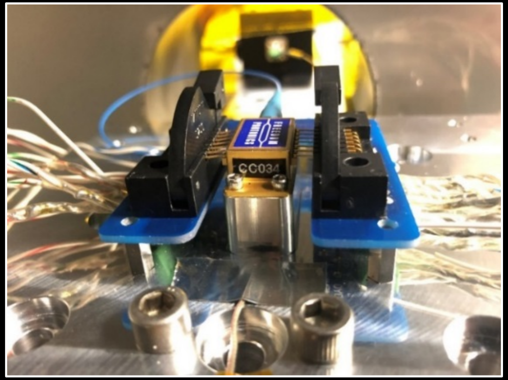
Indium-Phosphide (InP) Photonic Integrated Circuit (PIC) Evaluation

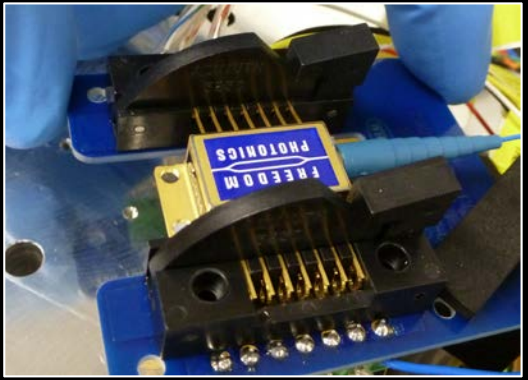
Motivation

- Demand for high-reliability, low size, weight and power (SWaP) components for future space applications.

Testing @ GSFC

- Performance baseline, vibration, thermal cycling, and radiation testing (planned).
- Carry-out highly repeatable, low system noise characterization.
- Utilize expertise in risk assessment and anomaly resolution.





Risk Postures and Approach

Risk adverse: Projects that have these optoelectronics as part of a critical system where failure is not an option, take a reduced risk posture.

Risk vs. cost and schedule: For projects where the component is redundant, not part of a critical system, or the project is a technology demonstration an increased risk posture can be applied.

The choice to screen and qualify is a ***necessity*** to reduce the overall risk exposure.

These activities are usually seen as optional for projects, who can opt for:

- CubeSat pilot missions
- Claiming “flight heritage” for demonstrations where flight heritage means “flight tested”
- Limited, accelerated qualifications in ***parallel*** to ETU builds

Schedule Considerations

Schedule

- Government projects are restricted by schedule, to the extent that **slips in schedule** are discouraged and can lead to **cancellation**.
- Commercial partners are ***strongly*** focused on schedule where business competition and product rollouts are concerned.

- Schedule for screening and qualification activities is generally accepted at face value for government projects.
- Commercial projects are usually more aggressive in reducing schedule due to competition.
- Knowledge of component failure modes can help design test plans more effectively for any schedule requirement.

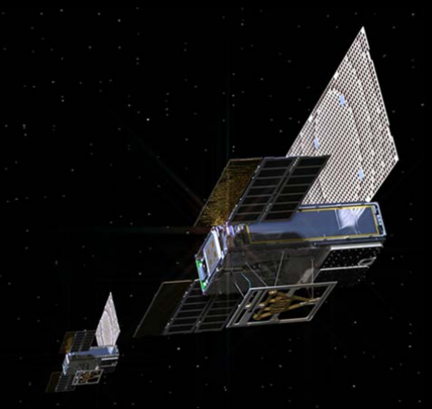
Cost Reduction

- Cost generally drives how extensive the screening and qualification testing is for risk adverse projects.
- Systems engineers need to understand clearly what requirements are being levied and why so that negotiations for cost reductions can happen more quickly.
- However, many times for reasons of cost and schedule there is not sufficient time or funding to perform a complete qualification
- Designing test campaigns from a ***failure mode*** perspective enables lower costs.

Failure Modes & Failure Mechanisms

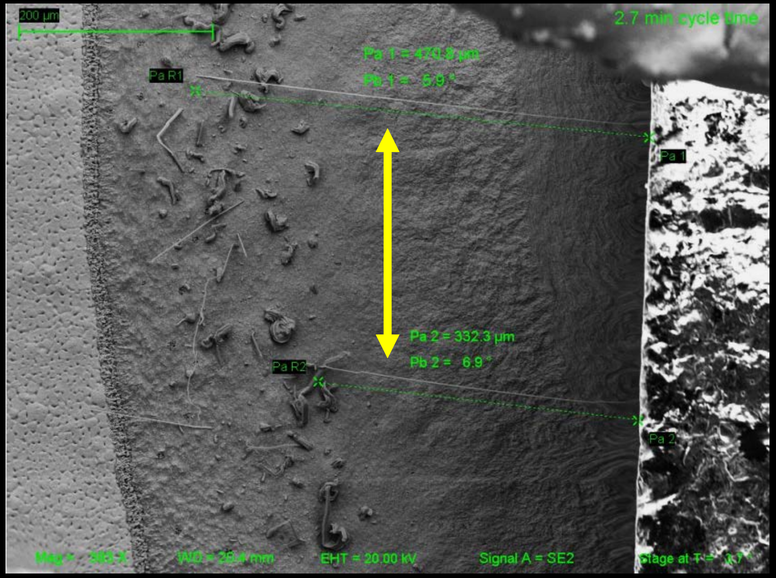
"… 22 percent of cubesats were never heard from after launch. That figure is significantly higher in special cases, such as some classes of university-built cubesats."

(6) Reference: https://spacenews.com/smallsat-developers-focus-on-improving-reliability/



"NASA's first interplanetary CubeSats fall silent beyond Mars"

(7) Reference: https://www.theverge.com/2019/2/6/18213594/nasa-marco-cubesats-deep-space-insight-mars-mission-communications-silent



SEM image of Tin Whiskers shorting a bond pad to packaging. (example)

NASA reliability studies on technologies new to spaceflight typically begin by establishing:

- Known Failure modes
- Known Failure mechanisms
- How to find these modes and mechanisms.
- General research on existing screening/qualification test data.

Screening and Qualifying COTS

- Optoelectronics is a burgeoning industry, being pioneered by both small and large firms.
- While established groups may have the lessons-learned and infrastructure to perform selection, screening, and qualification, new companies often lack such background.
- When dealing with components that have **not flown**, or are at a low TRL:
  - Component lots should **always** be screened.
  - Component configurations should **always** be qualified.
  - Flying on a Cubesat may be **insufficient** when compared to a qualification campaign (RIP Wall-E and Eve of NASA Insight).
  - Testing can be undertaken with application-specific parameters to build confidence.
  - Testing should be undertaken with the **physics** and **failure modes** in mind.
  - Be mindful of not introducing failures with test design: fixtures, test set up noise, and usage in actual application.

Screening and Qualifying COTS

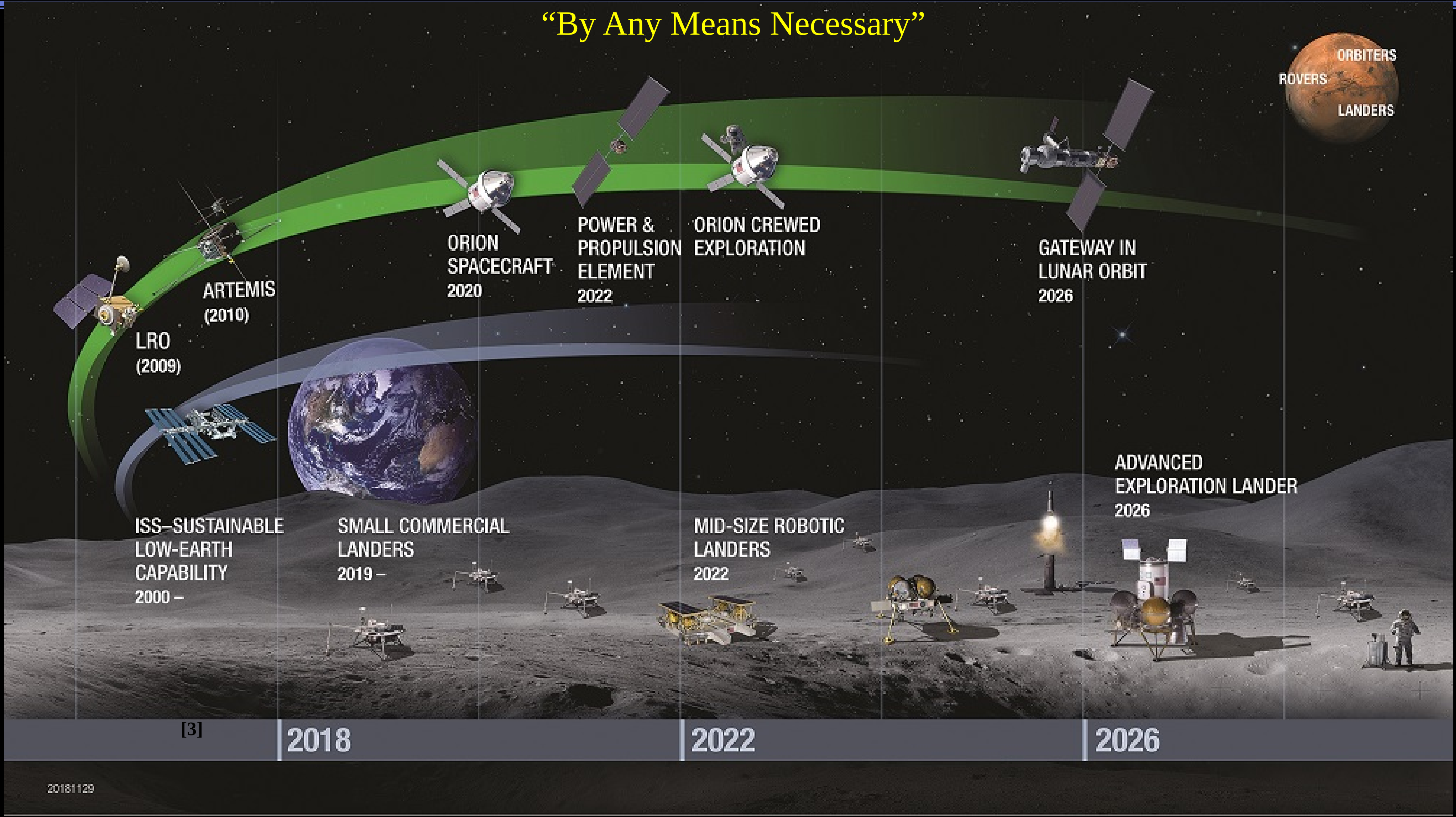
- When dealing with components that have flown in **some configuration**…
  - Components that have had a process or material change should be re-qualified.
  - Components that have been specified by a mission that has yet to fly do **not** have flight heritage (TRL 9).

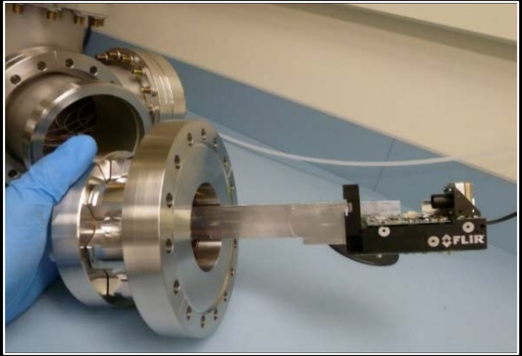
- Screening and qualification **does not** have to be expensive and time-consuming.
  - Using knowledge of failure modes to design the test campaigns can reduce the impact to risk, cost, and schedule.

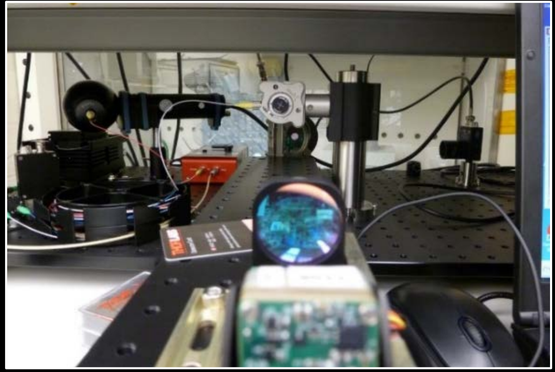
- As devices become more advanced and integrated, isolating failure modes becomes more difficult and arguably **more necessary.**

Gateway Roadmap

https://spacenews.com/is-the-gateway-the-right-way-to-the-moon/





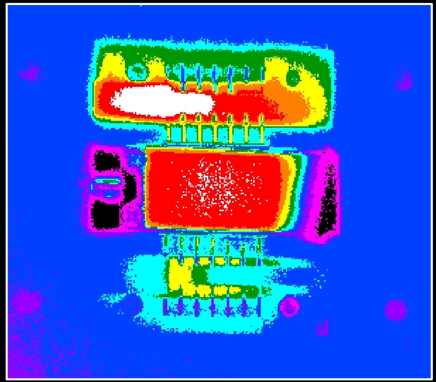


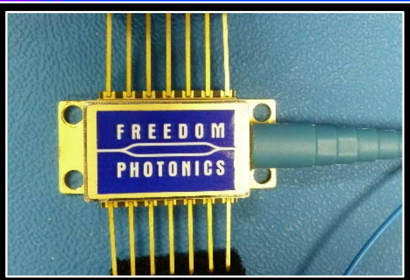
COTS LiDARs for Lander Autonomy

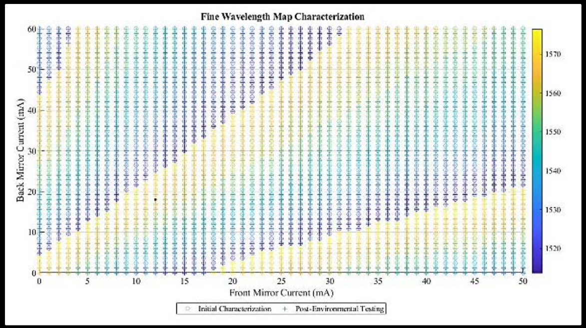
Tunable Lasers for Orbiter Communications

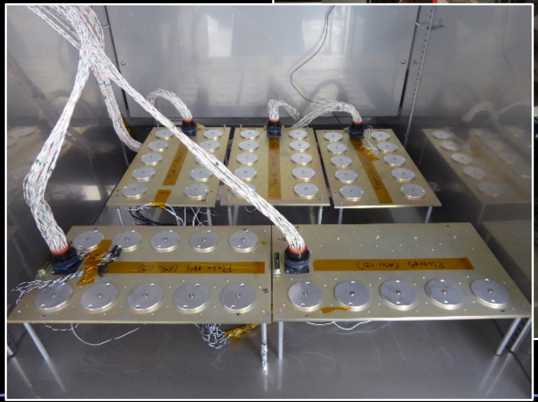
Qualifying Optoelectronics & Photonics for Space

Detectors for Rover Spectroscopy



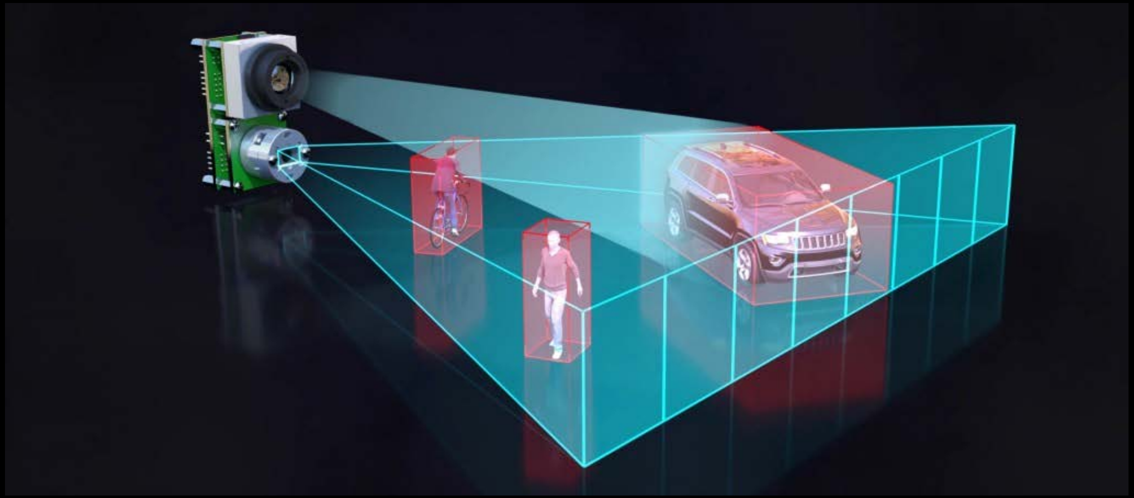






To be published on https://photonics.gsfc.nasa.gov

Qualifying COTS LiDARs for Lander Applications



https://www.allaboutcircuits.com/news/solid-state-LiDAR-is-coming-to-an-autonomous-vehicle-near-you/

COTS LiDAR instruments have generated interest for use in space applications including:

- Docking
- Real-time hazard avoidance
- Remote sensing
- Improved lander and rover autonomy
- Rendezvous with asteroids and other spacecraft

COTS LiDAR technologies are commonly used today in the following terrestrial applications:

- Autonomous vehicle systems
- Small-footprint, light weight drone development
- Land surveying/Civil Engineering
- DIY and industrial robotics

https://www.nasa.gov/content/morpheus-prototype-uses-hazard-detection-system-to-land-safely-in-dark

Summary and Conclusions

- NASA GSFC Code 562 Photonics Group has been screening and qualifying photonic components for more than the past 20 years.
  - Trends indicate decreasing component size, weight, and power (SWaP).
  - Screening and qualification **does not** have to be expensive and time-consuming.
  - Parts that we have qualified ahead of flight exhibit higher reliability and lifetime.
- When dealing with components that have flown in **some configuration** it’s up to the project **and** vendor to qualify, be honest with flight heritage, and **re-qualify when necessary**.
  - Systems engineers need to have a full understanding of why and what the requirements are such that they can negotiate for cost savings on test plans.
  - Parts engineers may try and levy EEE parts test plans that may not take into account optoelectronics.
  - Vendors should communicate regarding procedural changes on “heritage” parts to continue to be considered “preferred” suppliers. It allows testing to be conducted to address changes efficiently.
- Contracting non-profit independent test houses (NASA, institutions are examples) creates naturally secure collection points for failure modes, mechanisms, and test data.
  - Agreements similar to Space Acts allow test houses to convey failure information without divulging proprietary information from previous work.

Thank You to Our Partners!
(not all are listed here)

NASA — JSC, GSFC, KSC, MSFC
DIAMOND the fiber meeting
GORE Creative Technologies Worldwide
Polymicro Technologies — A Subsidiary of molex
ULTRA Communications
MIT Lincoln Laboratory
Honeywell
NUFERN
Lightpath
esa
MIT
Fermilab
ZEPHYR PHOTONICS
Gooch & Housego — Enabling Photonic Technologies
cnes — Centre National d'Études Spatiales
APL — The Johns Hopkins University Applied Physics Laboratory
Los Alamos National Laboratory — Est. 1943
OZ Optics
ofs — A Furukawa Company
asi — agenzia spaziale italiana
DARPA
SSL
CeramOptec
ITT
Kayser-Threde
Ball
CARLISLE Interconnect Technologies
Sandia National Laboratories
FiberTek
HARRIS — Technology to connect, inform and protect
OSI Optoelectronics — An OSI Systems Company
Air Force Research Laboratory
Mii MICROPAC
JPL
FREEDOM PHOTONICS
NIST — National Institute of Standards and Technology, U.S. Department of Commerce

And thank you for your time.

Acronyms

- ASTM = American Society for Testing and Materials
- ASU = Arizona State University
- ATLAS = Advanced Topographic Laser Altimeter System
- COTS = Commercial Off the Shelf
- CCD = Charge Coupled Device
- DIY = Do It Yourself
- EEE = Electrical, Electronic, and Electromechanical
- EO-1 = Earth Observing-1
- ETU = Engineering Test Unit
- GCD = Game Changing Development
- GEO = Geosynchronous Orbit
- GOES-R = Geostationary Operational Environmental Satellite-R Series
- GLAS = Geoscience Laser Altimeter System
- GSFC = Goddard Space Flight Center
- GRMS = Root-Mean-Square Acceleration
- ICESat-2 = Ice, Cloud, and land Elevation Satellite-2
- InP PIC = Indium-Phosphide Photonic Integrated Circuit
- ISS = International Space Station
- JWST = James Webb Space Telescope
- LADEE = Lunar Atmosphere Dust Environment Explorer
- LED = Light Emitting Diode
- LEO = Lower Earth Orbit
- LiDAR = Light Detection and Ranging
- LIV=Light-Current-Voltage
- MAVEN = Mars Atmosphere and Volatile Evolution
- MEO = Medium Earth Orbit
- MIL-STD = Military Standards
- MOMA = Mars Organic Molecule Analyzer
- OTES = OSIRIS-REx (Origins, Spectral Interpretation, Resource Identification, Security-Regolith Explorer) Thermal Emission Spectrometer
- SAA = Space Act Agreement
- SAE = Society for Automotive Engineers
- SEM = Scanning Electron Microscope
- SSCO = Space Servicing Capabilities Office
- SSCP = Space Servicing Capabilities Project
- SWaP = Size, Weight and Power
- TID = Total Ionizing Dose
- TSIS = Total and Spectral Solar Irradiance Sensor
- TRL = Technical Readiness Level
- VSS = Vision Sensor Subsystem

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