Performance testing of lidar components subjected to exposure in space via MISSE 7 mission

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ABSTRACT

The objective of the Materials International Space Station Experiment (MISSE) is to study the performance of novel materials when subjected to the synergistic effects of the harsh space environment for several months. MISSE missions provide an opportunity for developing space qualifiable materials. Several laser and lidar components were sent by NASA Langley Research Center (LaRC) as a part of the MISSE 7 mission. The MISSE 7 module was transported to the international space station (ISS) via STS 129 mission that was launched on Nov 16, 2009. Later, the MISSE 7 module was brought back to the earth via the STS 134 that landed on June 1, 2011. The MISSE 7 module that was subjected to exposure in space environment for more than one and a half year included fiber laser, solid-state laser gain materials, detectors, and semiconductor laser diode. Performance testing of these components is now progressing. In this paper, the current progress on post-flight performance testing of a high-speed photodetector and a balanced receiver is discussed. Preliminary findings show that detector characteristics did not undergo any significant degradation.

Keywords: MISSE 7, Space Qualification, Lidar components, International Space Station (ISS), STS-129, STS-134

1. INTRODUCTION

The goal of MISSE program is to evaluate the performance, stability, and long-term survivability of materials and components planned for use by NASA, Department of Defense (DOD), other federal agencies and private entities on future Low Earth Orbit (LEO), synchronous orbit, and interplanetary space missions. The study of combined effects of radiation, ultraviolet (UV) light and atomic oxygen in space due to long term exposures will help in developing space qualifiable elements for future space missions. In-situ space testing is critical since it is difficult and not economical to conduct these studies inside simulated terrestrial facilities. The development of new generations of materials will allow our nation to continue maintain technological superiority related to space endeavors.

NASA's Langley Research Center (LaRC), Hampton, Virginia has managed the MISSE projects till recently. Other NASA Centers participating in MISSE project include Glenn Research Center, Cleveland; Goddard Space Flight Center, Greenbelt, Maryland, Johnson Space Center, Houston, Texas, the Jet Propulsion Laboratory, Pasadena, California, and Marshall Space Flight Center, Huntsville, Alabama.. Several DOD and industry partners including the Boeing Company have been involved with this effort. MISSE program is a direct successor of the Mir Environmental Effects Payloads (MEEP) that were attached for over a year to the Mir Docking Module of the space station Mir between shuttle flights STS-76 and STS-86 [1].

2. AN OVERVIEW OF THE MISSE PROGRAM

MISSE is a series of experiments and so far, five MISSE missions have been successfully completed. More than 1500 samples have been tested on the MISSE project. Samples include chemicals, sensor devices, opto-mechanical elements, polymers, coatings, and biological materials and species, composites. The MISSE project has also provided educational opportunities for students. MISSEs 3 and 4 have transported approximately 8 million basil seeds for science experiments of children to stimulate interest in space science.

A suitcase shaped rugged box known as Passive Experiment Containers (PECs) is used to transport the selected materials to and from the ISS. PECs were originally developed and used by NASA's Langley Research Center, Hampton, Virginia, for ISS Phase I Risk Mitigation Program experiments conducted on the Russian Mir space station.

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Specific steps required for transporting materials include specimen preparation, fixing specimens inside a holder, integration of specimen holder on a tray, integration of trays in a PEC and integration of PEC inside a carrier for ease of transport. All these tasks are carried out in clean room environment.

The PEC is tested for survivability under launch conditions by subjecting it to appropriate shock and vibration environment. Subsequent to several months of space exposure, the PEC will be transported back to the Earth to undergo tests. The resulting test characteristics when compared with original characteristics before launch will provide an understanding of their survivability in space conditions. Furthermore, it will provide insights into required space qualification processes for future space applications.

During space walk, also known as extra-vehicular activity (EVA) (i.e., when an astronaut works outside of a spacecraft), the PECs are attached to the handrails or at a specific location that is exposed to space environment. Two possible mounting positions known as ram and wake are available. The materials in the ram side will be predominantly subjected to atomic oxygen environment where as those materials in the wake side will mostly undergo UV exposure. After exposure in space, MISSE PEC is retrieved in the same manner as it was deployed. The material samples are tested in laboratory conditions to see if they still possess their unique properties needed to complete space missions. MISSE PECs have active and passive detectors to give a time-history reading, or a reading of what happened to the materials at certain points in time. Back on the ground, tests will be conducted to determine the effects of its exposure for several months in space. The passive detectors report a cumulative measure of the following environments that the test specimens are exposed to namely UV exposure, atomic oxygen exposure, molecular contamination, tray temperature and man-made debris.

Terrestrial laboratories may provide limited environmental test conditions while in space, the components are simultaneously exposed to several conditions which normally are difficult to simulate. In many cases, the combined effect of being exposed to all of the environmental elements at once would provide insights into ruggedization for future space applications. The details of MISSE 1 to MISSE 6 missions can be found at NASA's MISSE webpage [2]

3. SALIENT FEATURES OF THE MISSE 7 MISSION

MISSE-7 is a suite of experiments that include over 700 new and affordable materials. The selected MISSE 7 specimens also have potential use in advanced systems for space applications. For MISSE-7 there are two PECs, 7A and 7B, which will be mounted on the outside of the ISS and hold samples on both sides of the PECs. PEC 7A's orientation will be zenith/nadir (space facing/Earth facing) while PEC 7B will face ram/wake (forward/backward) relative to the ISS orbit

Primary Responsibilities of MISSE 7A and 7B were carried out by Naval Research Laboratory and Air Force Research Laboratory, respectively. Glenn Research Center managed the MISSE 7 mission. NASA LaRC and Boeing played key roles. Besides above agencies, industry collaborators, and academia had experiments on MISSE 7B. NASA LaRC provided a flight worthy package with laser and lidar components along with other logistics support. This effort in NASA LaRC was a follow-on effort to MISSE 6 mission [3].

Figure 1 shows the laser and lidar components that were sent on MISSE 7 missions. The flight worthy package included 1.5 micron Fiber Laser, coherent receiver, several laser gain media, acousto-optic tunable filter, acousto-optic modulator, electro-optic modulator, and high power laser diode bar. NASA LaRC is involved with Active Sensing of CO2 over Nights, Days and ASCENDS and other lidar programs. ASCENDS is a mid-size, tier II future NASA mission [4]. Currently, several of these components are being used in ASCENDS related airborne and field test campaigns. These components have potential to be incorporated into future space based instrumentation based on their space qualification tests.

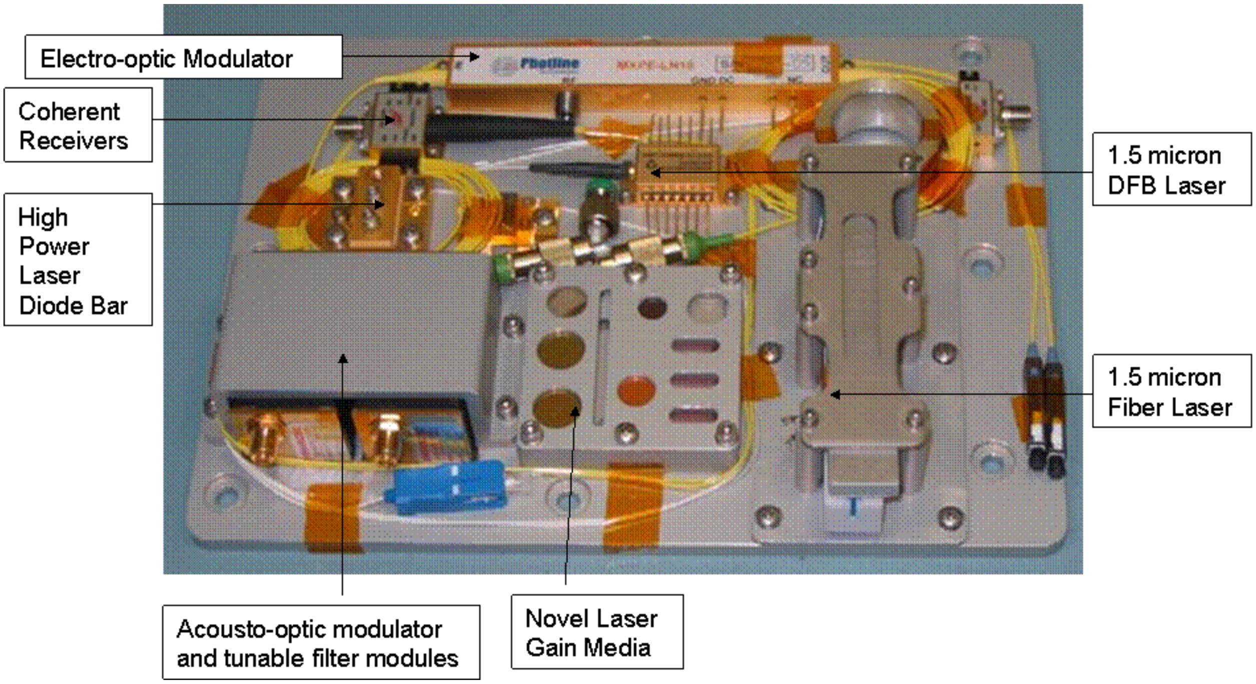

Figure 1. Laser and Lidar components mounted on a flight worthy package that was sent by NASA LaRC.

4. MISSE 7 LAUNCH AND RETURN

MISSE-7 was mounted to the ISS's exterior on an EXPRESS Logistics Carrier (ELC). The power and data were provided by the ISS.. It used the ISS communication system uplink/downlink capabilities to receive commands downlink data. For this, no crew interaction was required. Prior to launch, the ExPRESS Payload Adapter (ExPA)platform on which the PEC were mounted as shown in Figure 2.

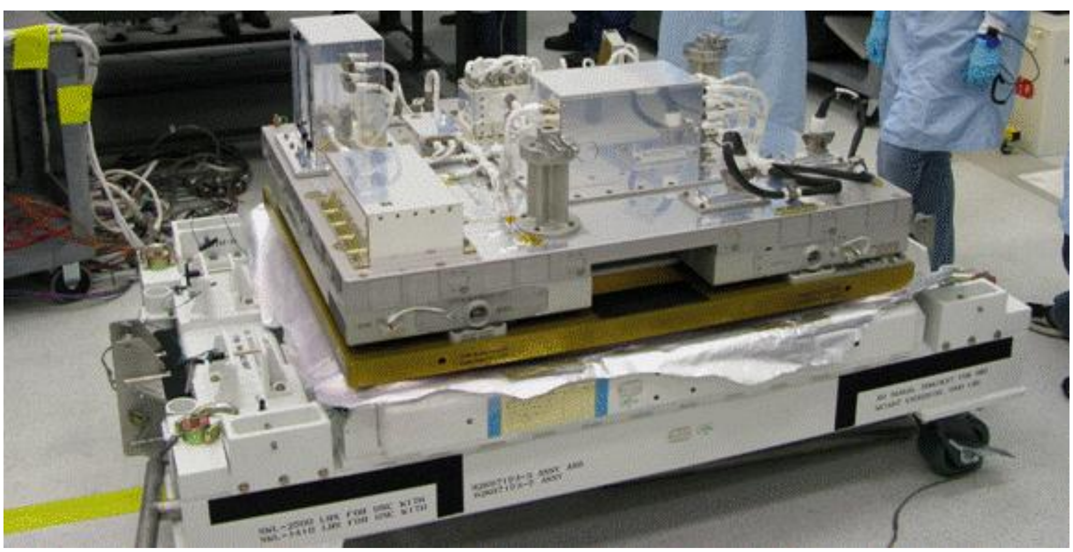

Figure 2. The ExPRESS Payload Adapter (ExPA)platform on which the PECs were mounted.

MISSE-7 was launched on Space Shuttle mission STS-129. MISSE 7A & &B were attached outside the ISS on the EXPRESS Logistics Carrier 2 (ECL2) on the S3 truss, and then opened and exposed to space during a spacewalk on November, 23, 2009. MISSE 7 was retrieved by spacewalking astronauts on STS 134 on early morning hours of May 20, 2011, PEC 7A and PEC 7B from their external operating location on the ISS and transferred to the STS-134 Shuttle payload bay. Further details on the shuttle missions related to MISSE missions can be found in references [5-8].

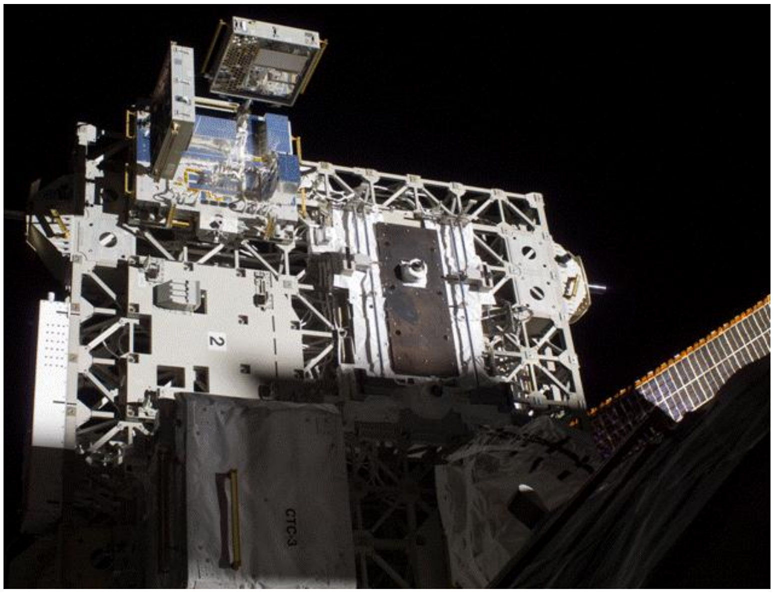

Figure 3. MISSE 7 on orbit.

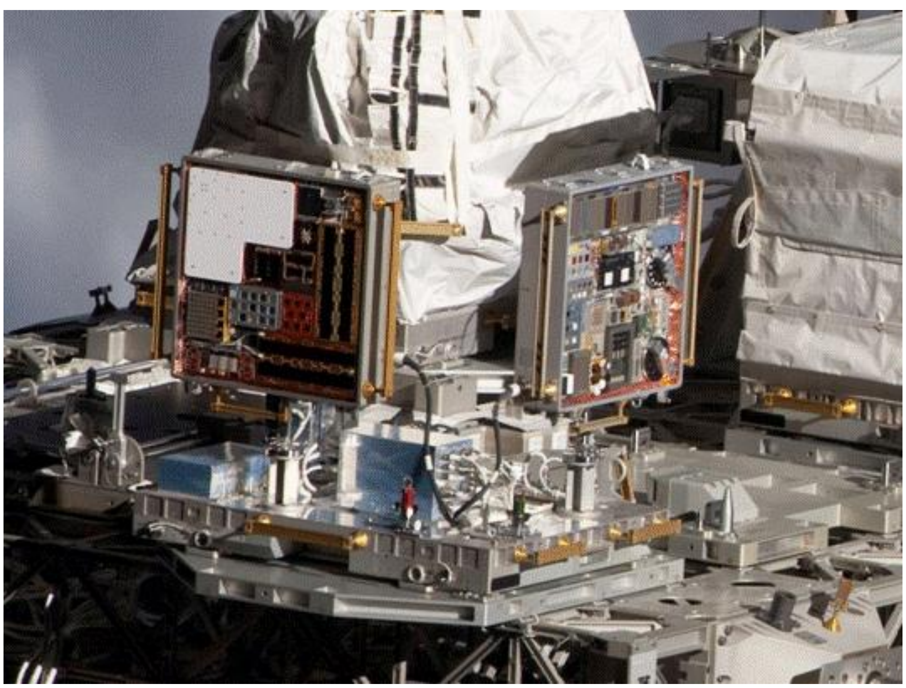

Figure 4. Zenith tray of MISSE 7A and Ram Tray of MISSE 7B. Photograph taken on 2/19/2010.

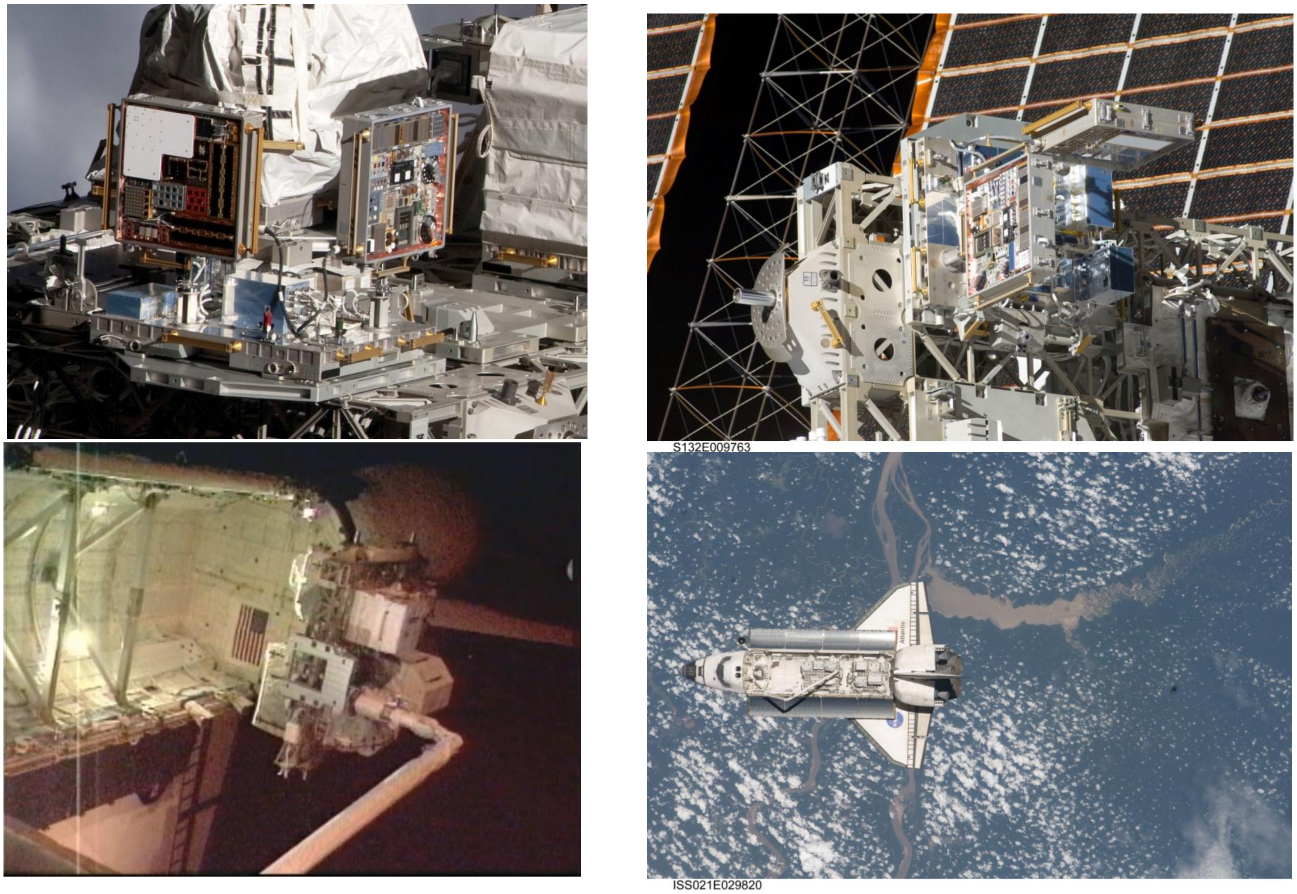

Figure 5. On-orbit pictures of MISSE 7.

5. RETRIEVAL OF MISSE 7 PEC

During its 1.5 year on-orbit mission, MISSE-7 has tested a variety of next-generation fiber lasers, solar cells and electronic devices and provided real-time downlink of science data. MISSE-7 has also continuously exposed cutting-edge material samples that will be analyzed in ground laboratories to determine how well they survived the space exposure effects of atomic oxygen, ultraviolet exposure, particle irradiation, and extreme temperature cycles. The on-orbit pictures of MISSE 7 taken by space shuttle crew are shown in Figures 3-5. The retrieved MISSE 7 package was disassembled at Marshall Space Flight Center. In November, 2011, the test unit from LaRC was returned for further testing. Post-flight testing of individual components on this package is now underway. In Figure 6, the returned unit along with the detector and the EO modulator modules are shown. From visual inspection of the package, it appeared that the entire package remained unaffected by space exposure except for fading of label marking and disfigurations of a coating on a substrate. The comprehensive testing of the EO modulator is being planned. The In the following section, preliminary results of performance testing of the high speed detector and balanced receiver are discussed.

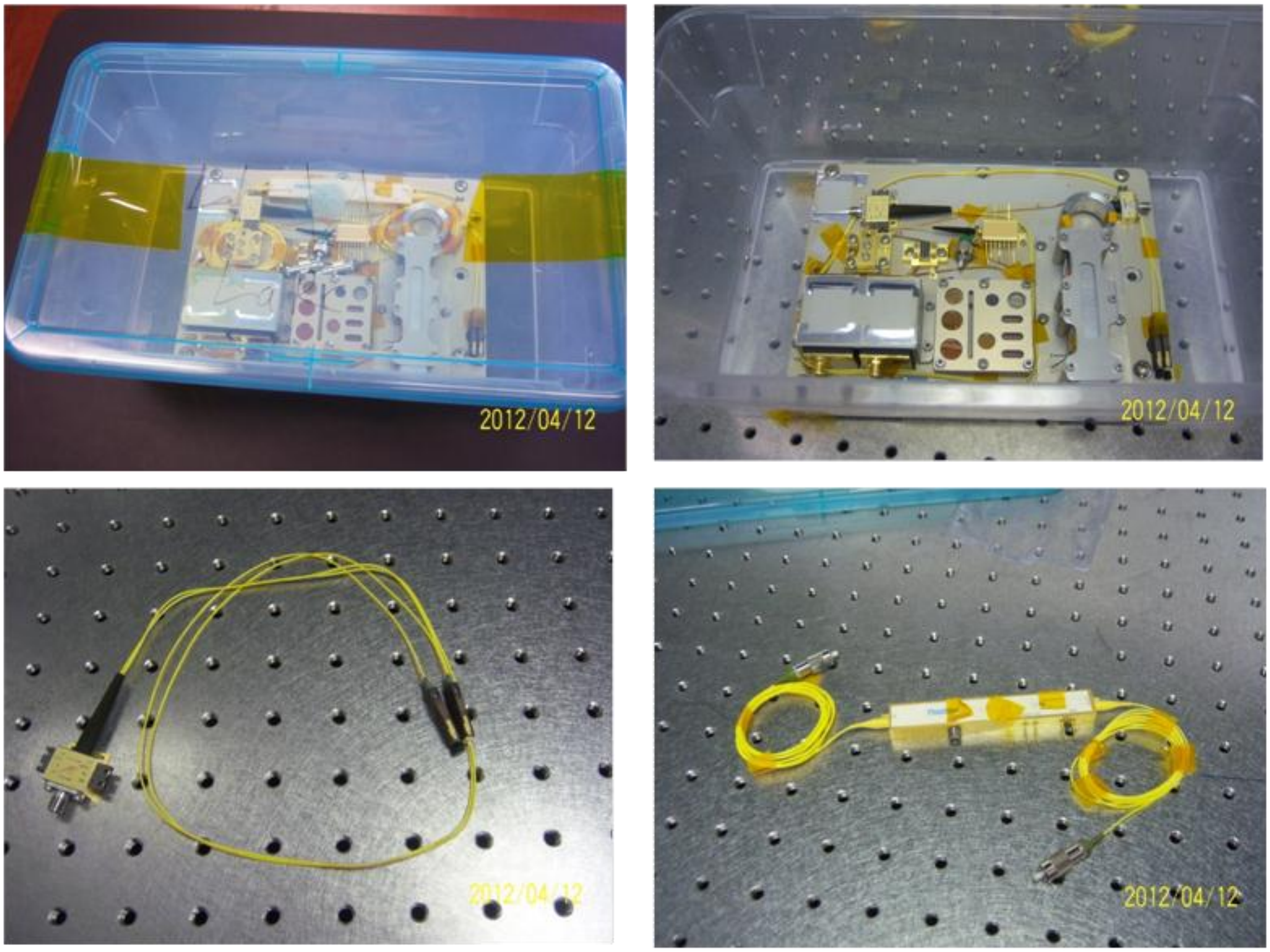

Figure 6. Returned package for post-flight tests. Top: Received package. Bottom Left: Balanced Receiver. Bottom Right: Electro-optic modulator.

6. PRELIMINARY RESULTS OF DETECTOR PERFORMANCE

The detectors modules that are being tested include (a) High Optical Power Handling Photodiodes to 20 GHz, model F720-14 N DSC30S 50S (b) Linear Balanced Photoreceiver with 14 or 20 GHz Bandwidth model F720-36 P R405 (balanced receiver). The former is a high-speed, high bandwidth PIN photodiode with 3 PIN K package and the latter is a balanced receiver with 8 PIN K package. These devices, based on InGaAs photodiode technology, are from Discovery Semiconductors, Inc. High speed photodiodes are hermetically sealed, high reliability, low harmonic distortion photodiode modules designed for high optical power applications with minimum bandwidths of 10, 14 and 18 GHz, respectively. The devices are well suited for receiver applications with optical preamplification, The R405 is an extremely linear PIN +Amplifier balanced optical receiver suited for a variety of digital and analog applications. The datasheets are available in Discovery Semiconductors, Inc. website [9]

(a) **High speed photodiode:** In this case, the bandwidth response, dark current and responsivity were measured at 1550 nm. The responsivity was found to be 0.66 A/W. The dark current was 4.32 nA. These tests were carried out at 73.8 ^{o}F. When compared to the data sheet, these measured values are within anticipated ranges specified in the datasheet. The frequency response curve is shown in Figure 6. This curve can be compared with that provided in the data sheet and is shown in Figure 7. So far, no meaningful post-flight degradation in bandwidth, responsivity, or dark current has been observed. Other parameters including common mode rejection ratio are being characterized. Also, besides electro-optical characteristics of these InGaAs photodiodes, other parts of the modules such as fiber optic cables, fiber optic connectors, metal housings, mm wave substrates, solder joints, amongst other things will be tested for degradation due to exposure.

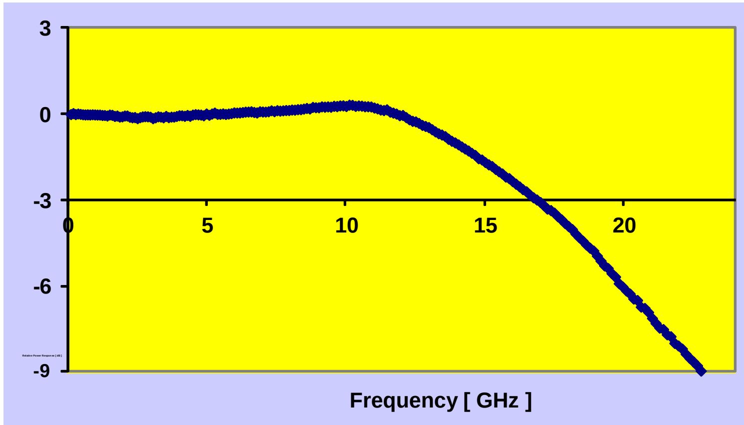

Figure 6. Measure frequency response curve for the high-speed photodiode.

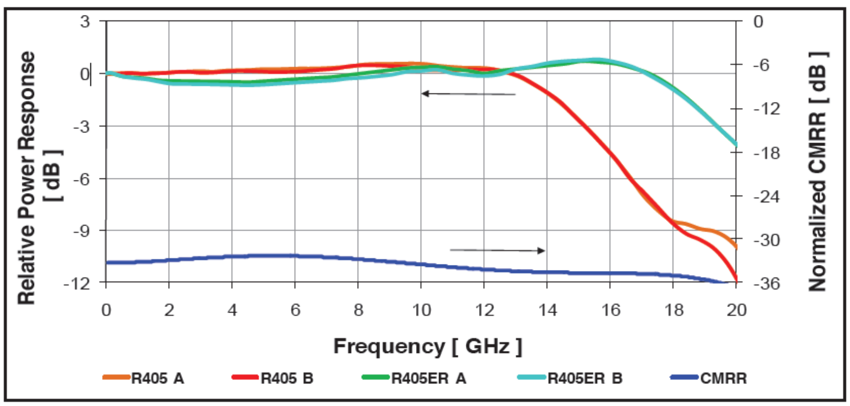

Figure 7. Typical frequency response curves & common mode rejection ratio for the high-speed photodiode.

(b) **Balanced Receiver:** Similar tests for the balanced receiver are being carried. The dry current is found to be little higher than anticipated. At this time, the results are being compared with previous test results corresponding to particular batch. These results are being analyzed and will be presented soon.

7. SUMMARY AND CONCLUSIONS

The objective of the MISSE program is to study the performance, stability, and long-term survivability of novel materials when subjected to the synergistic effects of the harsh space environment. So far , seven MISSE missions have been completed. The MISSE 7 mission was launched in November 2009 and returned to the Earth in May 2011 on STS 134. Several specimens and devices for use in Laser and Lidar systems for potential use in ASCENDS and other future NASA missions were selected. These specimens will undergo similar tests to look into deviations from pre-exposure characteristics. Over the next few months, we will be studying carefully not only the electro-optical characteristics of these InGaAs photodiodes, but also other parts of the modules such as fiber optic cables, fiber optic connectors, metal housings, mm wave substrates, solder joints, amongst other things. This data will allow us to design even better and rugged InGaAs photodiode modules for future space flights.”

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[8] http://www.nasa.gov/mission_pages/station/science/misse.html.

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