DEVELOPMENT AND QUALIFICATION OF A FIBER OPTIC CABLE FOR MARTIAN ENVIRONMENTS

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I. INTRODUCTION

ChemCam is an instrument suite on the Mars Science Laboratory (MSL) mission that will launch to Mars in 2011. MSL is a rover-type lander that is capable of exploring large territories over the mission lifetime and includes a number of instruments for analysing rocks and soil. ChemCam includes a laser induced breakdown spectroscopy (LIBS) [1] instrument that samples the surface chemistry of target objects within about 10 m of the rover without having to physically move to the target to obtain emission spectra in the 240 nm to 800 nm range. The ChemCam laser and sensing telescope are mounted on the rover Remote Sensing Mast (RSM) and have 360 degrees of azimuthal range, and 180 degrees of vertical range, allowing sampling of any object within range and line-of-sight of the mast top. This capability can be used to select targets for further analysis by other MSL instruments.

The LIBS portion of ChemCam is split between the top of the RSM and inside the rover body. The laser and the telescope are located atop the mast and rotate to select and observe targets. The three spectrometers (UV, VIS, and NIR) are located inside the rover body, along with a demultiplexer (demux) that splits the signal into the three bands. The signal from the telescope is transmitted to the demux by the fiber optic cable that is the subject of this paper. The fiber optic cable (FOC) is a single 5.7-m long, broadband, mult-mode fiber that connects the telescope and demux and is exposed to the full martian environment in some places and subjected to significant temperature gradients as it runs from interior areas to exterior areas.

II. FIBER OPTIC SELECTION

The transmission requirements for the ChemCam FOC vary with wavelength and are shown in table 1. The values are for end of mission and include all sources of loss in the cable. Sources include bending loss, environmental degradation due to thermal cycling, mechanical motion, radiation environment during cruise to mars and from the rover's radioisotope power supply, and launch vibration. The test program for the cable was designed to verify that the flight cables would survive for 3 years in the Martian environment.

Table 1 ChemCam fiber optical cable transmission requirements vs. wavelength.

	Transmission Percent	Attenuation (dB)
240-300	54%	-2.68
300-335	74%	-1.31
380-470	80%	-0.97
500-800	85%	-0.70

The cable used for the FOC is a semi-custom combination of optical fiber and jacket. The selected cable is Polymicro FVA300330500 with a W.L. Gore Simplex jacket and Diamond AVIM 6236.6 connectors. The optical fiber is high OH (for UV performance) 300 μm core diameter, 330 μm cladding, and a 500 μm acrylate buffer, and a 0.22 numerical aperture (NA). This combination was selected based on a combination of prior experiences of the NASA Goddard Space Flight Center (GSFC) photonics group and tests of bending loss performance of optical fibers with different NA. Similar acrylate coated FVA fibers from Polymicro have been tested at GSFC for radiation performance [2] and performance over much of the temperature range [3] required for MSL.

The outer jacket is a custom-applied jacket (W. L. Gore FON1482) 1.4 mm in diameter. The jacket is a tight wrapped combination of ePTFE, fluoropolymer protective layers, and a braided Kevlar strength member. In preliminary testing a jacket with a loose PEEK tube around the fiber showed an almost complete loss of transmission after a 109 C temperature soak in a mockup of the RSM. Most of the performance in the jacket with the loose PEEK tube was recovered after careful heating of the jacket with a heat gun while pulling the cable straight, but the performance loss during bakeout made the loose-tube construction unsuitable for

ChemCam. The FON1482 construction showed no loss in performance during bakeout. The jacketed cable was "preconditioned" by thermally cycling the cut lengths between -30 C and +110 C forty times. The preconditioning induces shrinkage in the jacket material before connectorization, and forty cycles ensures that little or no shrinkage will occur in subsequent thermal cycles.

The commercially available Diamond AVIM connectors were selected for several of their features. The connector body ratchets and needs no staking to remain stable under launch vibration loads. The ferrules (2.5 mm "pilz" ferrules) are reliably sized to within a micron, allowing excellent repeatability in alignment when mated, and consistency from connector to connector. The installation of the connectors onto the cables was done by the GSFC photonics group. Fibers were centered in the ferrules to within 25 μm.

III. QUALIFICATION AND TESTING

The FOC qualification program included simulation of relevant environments that the FOC would be exposed to during its life, including environments prior to launch. Table 2 summarizes the qualification program. The testing consisted primarily of attenuation measurements made on the FOC before, during, and after environmental tests, depending on whether the cable would be exposed to the environment in an operating mode or non-operating mode. The full-motion mockup of the RSM shown in Fig. 1 was used for motion testing the cable.

A. Attenuation Measurements

Transmission and Attenuation measurements were done using two different spectrometer systems. For tests where the attenuation was measured before and after the test, an Acton Research SpectraPro 300i grating spectrometer was used for wavelength selection, with a photomultiplier tube (PMT) sensitive in the range 190-900 nm. Light was supplied by a Micropak DH-2000-BAL deuterium/halogen light source. The output of the light source was fed to an integrating sphere and from the integrating sphere into a pair of reference FOCs coupled together and then into the spectrometer. The reference FOCs were made from the same lot of cable as the development and test cables. Baseline dark current and transmission measurements were made with the two reference cables coupled together, and attenuation (insertion loss) measurements were made by inserting the FOC under test in between the two reference cables.

Table 2 FOC Qualification Program

Test	Description	Measurements
Motion life	Motion of the fiber in the azimuth and elevation twist capsules for 3x the number of start/stop cycles and degrees of rotation that the cable would see in a 1 year mission, with temperature varying from -90 C to +70 C	Attenuation vs. wavelength before and after test, as well as at intermediate points during test.
Attenuation vs. motion and temp	Measurement of transmission vs. wavelength at discrete rotations over 180 degrees of elevation (every 30 degrees), 360 degrees of azimution (every 30 degrees), and -90 C to +70 C in temperature (20 degree increments)	Attenuation vs wavelength (240 to 800 nm, 10 nm steps) at each Temperature, Elevation, Azimuth point.
Radiation	Expected change in transmission due to full mission radiation exposure	Done by analysis based on tests of related fiber designs.
Planetary protection	Thermal soak at 109+- 3 C for 50 hours	Attenuation vs. Wavelength before and after test
Thermal Cycling	50 cycles -135 C to +70 C mounted on thermal/mechanical static model of the RSM	Attenuation vs. Wavelength before and after test
Cable Vibration	7.9 grms, 3 axes, 2 minutes/axis	Attenuation vs. Wavelength before and after test
Connector Vibration	8.3 grms 14.4 grms, 3 axes, 2 minutes/axis	Attenuation during test
Packaging Qualificaton and Verification (PQV)	3 Martian years of temperature cycling over the seasonal temperature ranges	Attenuation vs. wavelength before and after test, as well as at intermediate points during test.

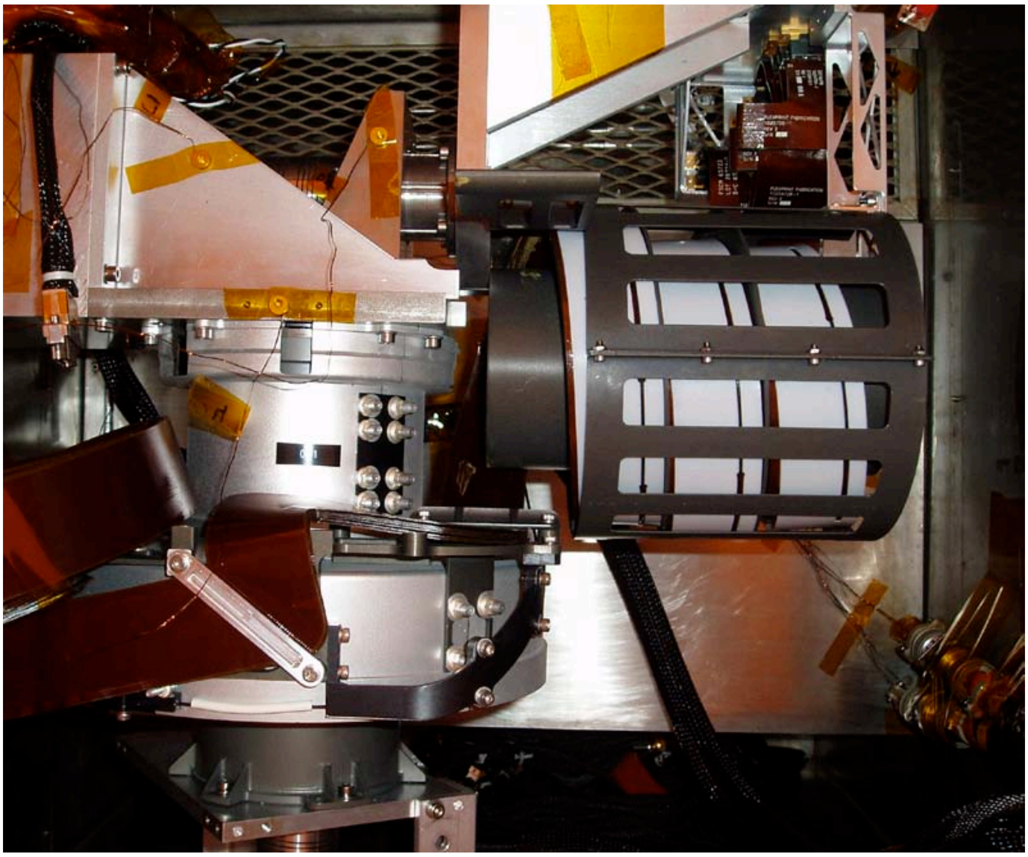

Fig. 1. The mechanical mockup of the MSL Remote Sensing Mast used for testing the ChemCam fiber optic cable in motion. The mockup accurately copies the interfaces and motions of the RSM and the optical fiber.

For tests where transmission or attenuation was measured during the test, an Oriel Cornerstone 130, 1/8 m monochromator was used, with a 300 l/mm blazed grating, a xenon arc lamp and Newport 918-UV detector with a Newport 2935-C power meter. The monochromator and power meter were controlled by the same computer and custom software that controlled the motion of the RSM mockup so that optical data could be accurately correlated to mechanical motion in the test when necessary.

B. Planetary Protection Bakeout, Random Vibration, and Thermal Cycling

These three tests were performed in sequence on an engineering model cable mounted in the static test fixture shown in Fig. 2. The fixture accurately mimics the thermal expansion characteristics and interfaces of the RSM and rover top-deck, but is "folded" so that the assembled fixture will fit into a 60x60x60 cm chamber. The routing of the cable on the mast and the top deck duplicates the number of turns, their angles, and the shape of the routing in the top deck channels, but routes the fiber so that it remains in the envelope of the base. A cable was mounted on this fixture and subjected to the 109+-3 C bake out for 50 hours to meet planetary protection and contamination control requirements. Attenuation was measured before and after the test in the range 240 to 800 nm and no change in attenuation was observed.

The fixture and cable mounted on it were then subjected to the random vibration test. The motion-life test fixture was not designed to be robust enough to survive the random vibration test, so this test fixture was designed to support the full vibration test. The cable was tested for 2 minutes per axis at 7.9 grms, with simple optical continuity checks between axes. Data from before and after vibration are shown in Fig 2. After vibration, the cable showed an apparent increase in performance that was traced to drift in the lamps in DH-2000 light source. After replacement of the lamps, the drift was no longer observed.

Additional vibration testing was done on the AVIM connectors with short segments of optical fiber attached. In the connector tests, transmission was measured during the vibration (3 axes, 2 minutes/axis). After testing to 7.9 grms and observing no change in transmission during the test, additional tests were done at 14.4 grms, again with no change in transmission observed.

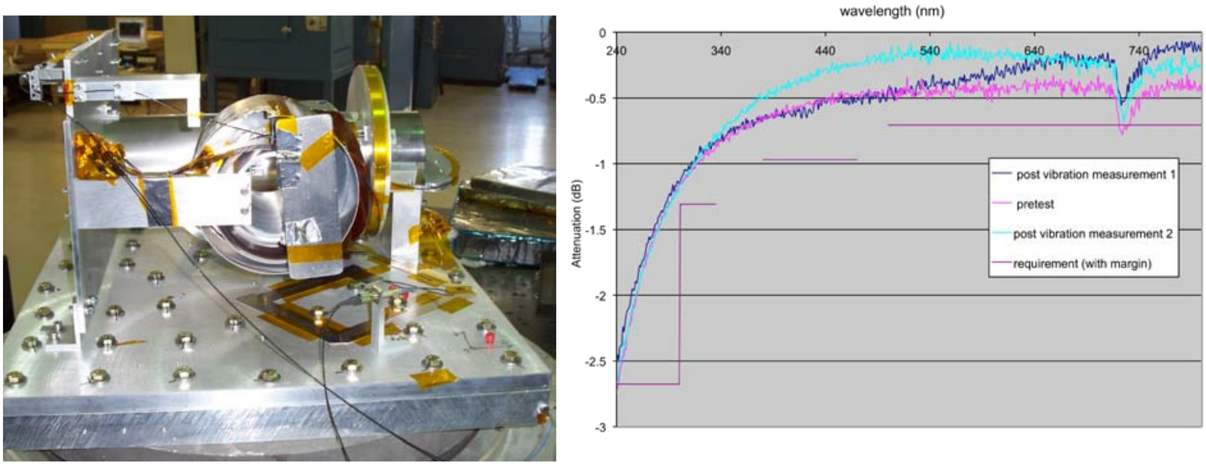

Fig 2 RSM thermal and mechanical simulator (left) and attenuation data from vibration testing (right)

C. Motion-Life Testing

Motion-life testing of the FOC was done on a separate cable mounted in the test fixture shown in Fig. 1. The motion life test consisted of 24750 revolutions of the elevation twist capsule, and 45,000 revolutions of the azimuth mandrel, where each revolution is a sweep through 360 degrees. The twist capsules were swept rapidly through their motions with frequent starts, stops, and direction changes. During the motion of the fixture and cable, the temperature of the chamber was varied between -90 C and +70 C, using a temperature distribution approximately like that expected on Mars. To simiulate temperature variations at the terminations (located inside the rover body and head of the RSM) the connectors were maintained at temperatures above -40 C by limiting heaters, but allowed to float in temperature above -40 C. No change in performance of the cable was observed through this testing, despite a separation of the outer fluoropolymer jacket at the entrance to the elevation twist capsule shown in Fig. 3. The cable routing was modified to secure the cable end and flat Teflon guide to the adjacent electrical cables (broad cable to the left of the FOC in Fig. 3) and the test was repeated without incident, again with no detectable change to the optical fiber performance.

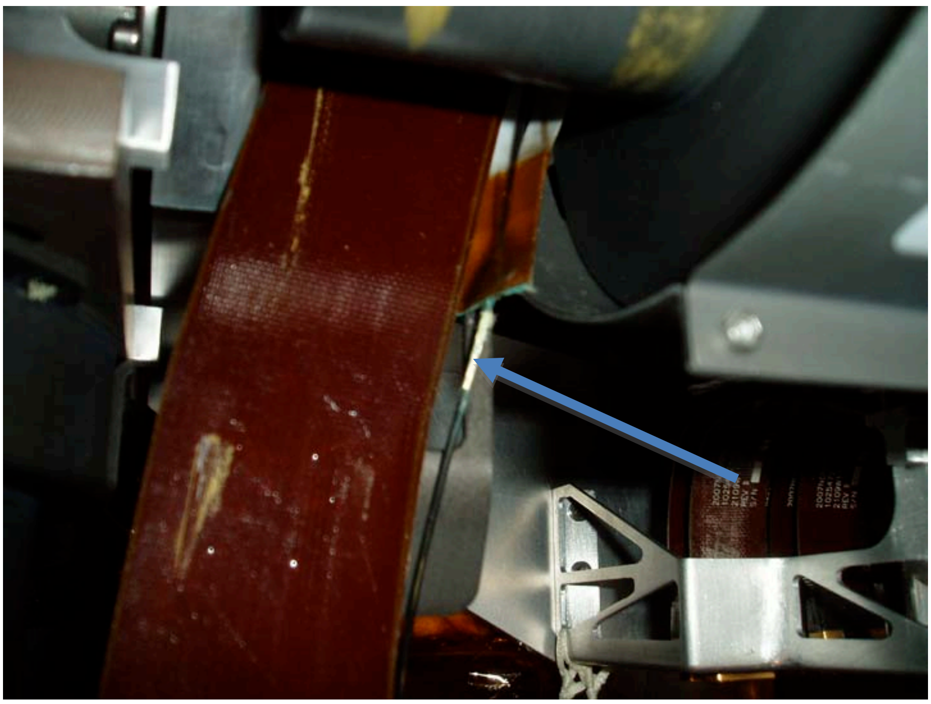

Fig 3 Separated outer jacket in motion life test. The arrow points to the kevlar braid strength member in the cable that was exposed after the jacket separated.

D. Attenuation vs. Motion and Temperature

The same test setup from Fig. 2 was used to verify that the optical fiber performance would not vary with the orientation of the twist capsules or with temperature. This test was performed immediately after the motion life test, on the same cable that was tested without the separation of the outer jacket. Again, the connectors were maintained above -40 C with limiting heaters to simulate the gradients resulting from the higher temperature in the rover body and the assembly atop the mast unit. The temperature of the system was stepped from -90 C to +70 C in 20 C increments, and at each temperature both twist capsules were stepped through their full ranges of motion in 30 degree increments. At each combination of temperature, elevation, and azimuth a transmission measurement was made using the Oriel Cornerstone monochromator system, stepping through the wavelength from 240 nm to 800 nm in 10 nm increments. Data for three sets of position angles at -90 C are shown on the left in Fig. 4. The mean change in attenuation at zero elevation and zero azimuth vs. temperature is shown on the right in Fig. 4. The outlier data points at 5 C and 25 C fall on a smooth curve with the other data points if the data are re-ordered by time, suggesting a slow drift over the weeklong test. Measurements made with the Acton spectrometer suggest that the drift is in the measurement system rather than the FOC.

E. Packaging Qualification and Verification

Packaging qualification and verification (PQV) testing of the cable consisted of temperature cycling two engineering model units for 2010 cycles to simulate 3 full years of exposure to temperature extremes on Mars. The temperature extremes went as low as -135 C and as high as 109 C (to simulate planetary protection bakeout). Approximately 2/3 of the cycles went from -105 C to +40 C, and 1/3 from -135 C to +15 C. The cables were periodically removed from the test chamber and their attenuation was measured. Changes were observed to be less than about 2%, and within the measurement error of the spectrometer. Data are shown in Fig. 5.

F. Radiation

Radiation qualification of the fiber was initially to be done by test and the cable described earlier with a loose-tube jacket construction was successfully radiation tested. After the cable was redesigned, a combination of the cost and schedule of radiation testing, combined with availability of existing data on very similar cables led to qualification by analysis. The GSFC Photonics Group had previously tested 200 μm and 400 μm cables with similar Gore Simplex jacketing [2-4]. The MSL radiation requirement of 20 krads falls within the range covered by the previous testing and so we can extrapolate predictions from the previous results to estimate that the additional attenuation in the cable due to radiation damage will be between 0.5 and 1 dB. Comparing this to the changes in performance in the other tests, this loss is likely to be the dominant change in performance of the fiber optic over the mission lifetime.

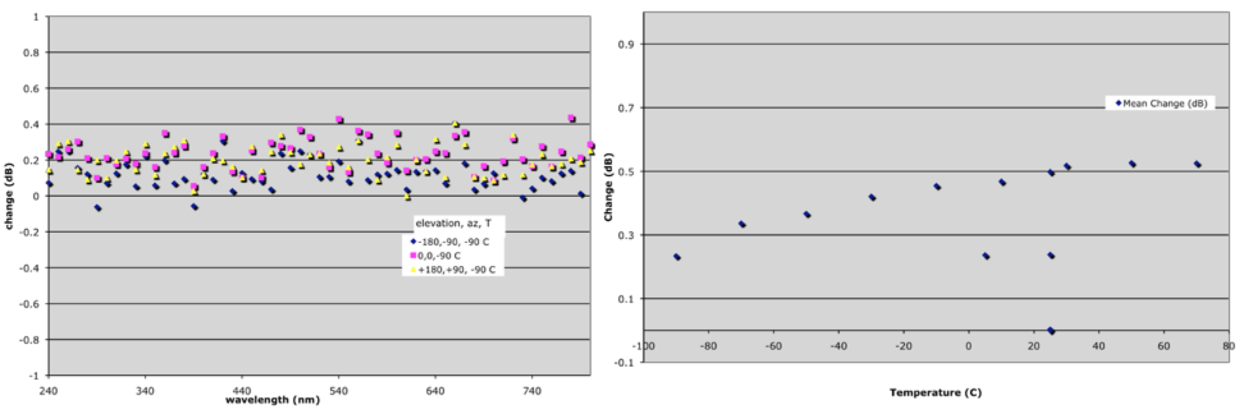

Fig 4 Change in attenuation vs temperature and position angle at -90 C and three different sets of azimuth and elevation angles, referenced to +25 C and 0 elevation, 0 azimuth (left). Mean change over all wavelengths vs temperature at 0 elevation and 0 azimuth (right). See text for explanation of the trend.

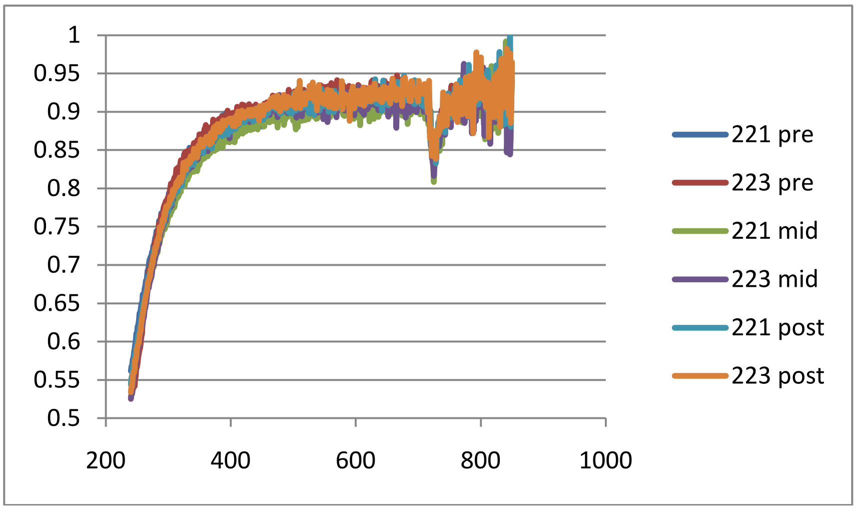

Fig 5 PQV Test data from before, during and after the PQV test for cables number 221 and 223.

IV. SUMMARY

We have qualified the ChemCam fiber optic cable, manufactured from readily available standard and semi-custom components, for the martian environment. The cable has been exposed to extremes of temperature as low as -135 C and as high as 109 C with no observable loss of performance. It also showed no loss in performance from the mechanical stresses of launch vibration and motion in the elevation and azimuth twist capsules of the remote sensing mast. The primary source of degradation is expected to be the radiation environment, resulting in less than 1 dB of performance loss over a 3 year lifetime.

V. REFERENCES

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VI. ACKNOWLEDGEMENTS

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