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Twelve channel optical fiber connector assembly: from commercial off the shelf to space flight use

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ABSTRACT

The commercial off the shelf (COTS) twelve channel optical fiber MTP array connector and ribbon cable assembly is being validated for space flight use and the results of this study to date are presented here. The interconnection system implemented for the Parallel Fiber Optic Data Bus (PFODB) physical layer will include a 100 /140 micron diameter optical fiber in the cable configuration among other enhancements. As part of this investigation, the COTS 62.5/125 micron optical fiber cable assembly has been characterized for space environment performance as a baseline for improving the performance of the 100/140 micron diameter ribbon cable for the Parallel FODB application. Presented here are the testing and results of random vibration and thermal environmental characterization of this commercial off the shelf (COTS) MTP twelve channel ribbon cable assembly. This paper is the first in a series of papers which will characterize and document the performance of Parallel FODB's physical layer from COTS to space flight worthy.

Keywords: ribbon cable, MTP, array connector, fiber optic, space flight, parallel FODB, COTS, communications, interconnection, technology validation.

1. INTRODUCTION

The Fiber Optic Data Bus (FODB) was scheduled for integration on NASA's Earth Orbiter 1 satellite to reduce nonrecurring engineering and to flight validate the technology for future hyperspectral imaging and high rate spacecraft applications. The Spaceborne Fiber Optic Data Bus (SFODB) is a standardized high speed, fault tolerant fiber optic network designed to meet the on-board data handling needs of future high rate remote sensing satellites. The IEEE P1393 SFODB consists of multichip modules which implement a ring-based architecture. Operating up to 1.1 Gbps, FODB's performance is over three orders of magnitude greater than the current, flight proven 1773 fiber optic protocol. FODB's high data transfer rate and software configurable Asynchronous Transfer Mode based protocol uses the IEEE P1393 Standard and provides users extraordinary flexibility with which to design their data handling architectures. The Parallel FODB (PFODB) implements all aspects of the IEEE P1393 standard except that the primary, cross-strap, bypass, and redundant links are replaced with a 12 channel parallel link with 8 bits of data, a byte clock, a frame synchronization signal, and two backup channels which provide redundancy for the primary 10 channels. The COTS-based, 12-channel parallel fiber optic transmitter and receiver pair were developed specifically for Parallel FODB through a NASA SBIR by Optical Networks, Inc (ONI). The 12 channel fiber optic interconnection system discussed in this paper is being implemented for the PFODB.

In alignment with the mission goals of EO-1 for smaller size, lighter weight and low cost technology, we chose the commercial off the shelf (COTS) standard MTP 12 channel array connector and 12 optical fiber ribbon cable assembly for the PFODB flight application. The MTP array connector chosen is made by US Conec Ltd. and the optical fiber ribbon cable is made by W.L. Gore and Associates. The optical fiber for this application is a Spectran commercial grade multimode fiber. With regard to weight and cost reduction, the MTP connector is roughly 33 times lighter and more than 20 times less expensive than the traditionally used 38999 connectors. The goal for the cable interconnection of the FODB application in space flight was to select a COTS cable assembly and determine which parts of the system had to be enhanced for the space flight environment and enhance only those parts. The validation of this cable assembly was to be performed through analysis of the components that make up the system and through the characterization of the system through environmental testing. The testing conducted would be focused only on bringing out the known failure mechanisms of optical fiber cable assembly systems.

In choosing a commercial cable assembly system there were several issues to address to make this COTS system space flight worthy. The greatest concern was the outgassing characteristics of the system materials and the ability of the system to

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withstand the harsh environments of space flight which include elevated vibration levels, wide thermal variations and radiation exposure. According to actively measured thermal data provided by W.L. Gore on their 12 channel optical fiber ribbon cable using 62.5/125 micron optical fiber, the average power losses at –15 °C for 12 ft of cable were .01 dB. No data was available on cable shrinkage; however, it was expected that the Kynar jacket would shrink no more than the W.L. Gore FON1008 that was tested in reference 2 (see Section 6). Thermal testing would be necessary to verify whether this was a correct assumption.

Outgassing Issues: After reviewing the materials of the MTP connector and ribbon cable for outgassing characteristics the material of greatest concern was the Kraton 7410 (Dynaflex G 7410 thermoplastic rubber) boot. A test was conducted to confirm the thermal vacuum outgassing characteristics of this material per ASTM E-595-90 (total mass loss, TML< 1% and collected volatile condensable materials, CVCM < .1%) and resulted in an average TML of 15.53% and an average CVCM of 10.04%. Since this material was well beyond the acceptable levels for a space flight environment it needed to be changed to a non outgassing material. US Conec elected to change the boot material to Flexane 80 which has been confirmed by the manufacturer to meet the ASTM-E595 requirement. All other materials of the cable assembly were used unchanged.

Vibration Issues: To mitigate some of the effects of the vibration environment on coupling between the connector assemblies, to maximize power coupling from the ONI modules to the fiber, and to make the ONI termination procedure more effective, the best choice for optical fiber was a 100 micron core/140 micron cladding graded index from Spectran: part number, BFO4432-01. Choosing the larger core fiber made it necessary to have a new MTP ferrule fabricated for the larger outer diameter of this optical fiber. The commercial MTP ferrules are only available for a 125 outer diameter optical fiber. US Conec agreed to fabricate the new ferrules for the FODB application.

Radiation Effects: The choice to use a commercial grade fiber in a COTS cable assembly brought up the issue of radiation effects on the optical fiber. An analysis was conducted of the environment of EO-1 and previous data gathered on this optical fiber. Based on this analysis the following parameters were taken into account: an environmental temperature minimum of –15 °C, a total dose of 15 Krads, a worst case instantaneous dose rate of $4*10^{-2}$ /sec, and lengths of fiber of 12 ft maximum. The conclusion of the analysis provided a worst case scenario of no more than .13 dB power loss as a result of the radiation induced effects on EO-1.

Taking all of the above issues into consideration the only enhancements made to this COTS cable assembly were a new ferrule for the 100/140 micron fiber, a new boot, and the Spectran 100/140 optical fiber. All other components remained the same. For termination procedures an audit of the W.L. Gore facility was conducted to assure that the space flight cables could be assembled and terminated by W.L. Gore with inputs and procedures developed in partnership with US Conec. The MTP connector assembly is rated with an insertion loss of .35 dB/channel on the average. One of the goals of enhancing the termination procedure will be to lower the insertion loss of the connector to .2 dB or less for the 100/140 micron diameter optical fiber, and to decrease the insertion loss variation among the different MTP channels. The new ferrule from US Conec for the MTP is part number MTF-12MM140, and the connector bodies with the new non-outgassing boot are part numbers: Y0130 for female, and Y0131 for male. The W.L. Gore part number for the 12 channel optical fiber cable is FONB2442 with a Kynar jacket. W.L. Gore enhanced this part with 100/140 micron optical fiber from Spectran. With preliminary analysis and design enhancements to accommodate the space environment, completed validation and characterization testing was conducted on the already available COTS system with 62.5/125 optical fiber, the outgassing boot and the original ferrule.

2. VALIDATION OF THE MTP RIBBON CABLE ASSEMBLY FOR SPACE FLIGHT

The goal of this investigation was to characterize the 12 channel MTP array connector and 12 channel ribbon cable interconnection system and verify its performance and functionality under various environmental test conditions. The conditions of this testing were extracted from the EO-1 specification. Although the actual cable assembly to be used for FODB on EO-1 is an enhanced version of this cable assembly, the data gathered here would be used as a baseline for improving the performance of the 100/140 micron diameter ribbon cable assembly. Another purpose for this testing was to validate the other aspects of the system that were not able to be predicted during analysis and were not enhanced such as the cable configuration, the connector system and the termination system. The data presented here will be used as a reference for the next series of experiments in which the enhanced COTS assemblies will be tested for space flight use on FODB.

The testing conducted was designed to bring out the long and short term failure mechanisms associated with these types of systems. Vibration and thermal cycling testing was conducted per the EO-1 specification. Vibration testing was conducted followed by thermal cycling followed by a more intense vibration test.

2.1 RANDOM VIBRATION EXPERIMENT I

For measuring effects of random vibration on the MTP and ribbon cable assemblies, three cable sets were used for active measurements during testing. Each set had one channel actively monitored for the testing at three different axes. Two of the cable sets were tested for power loss before and after testing. All cable assemblies under test were 10 ft. long. A special fixture was designed and fabricated by Swales Aerospace such that an MTP adapter could be bolted to the vibration drum and repositioned in three different configurations to simulate vibration in three different axis directions. The fixture was tested to assure no resonant responses existed in the frequency range 20 to 2000 Hz. During vibration, a single channel was monitored actively (output of optical power) during each of the three axis tests. The fiber is rated for a 1300 nm wavelength of light so a source and detector set was used to propagate and monitor light at this wavelength.

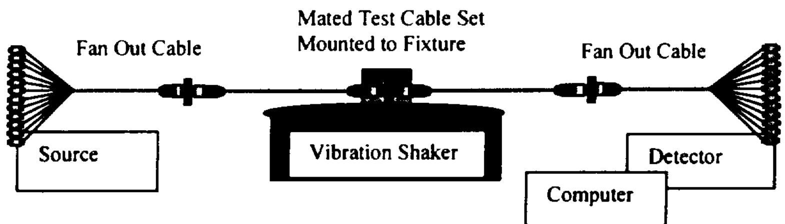


Figure 1: Random vibration test experimental setup

Figure 1 shows a rough sketch of the setup where the mated pair was held to the vibration fixture by a bolted MTP connector adapter. Each cable was mated to a fan out cable (MTP on one side and twelve ST connectors on the other) in which the channels could be separated for monitoring. The light source was the RIFOCS dual wavelength 252A (using 1300 nm) and was providing approximately 10 microwatts of optical power. The source was connected to a fan out cable and the fan out MTP was connected to one of the test cables. The output of the test cables was connected to the MTP side of the receiving fan out cable and the fan out ST of that channel was connected to a Tektronix P6703A optical to electrical converter and a Tektronix 1103 Tekprobe power supply. The output of the power supply was input to a Hewlett Packard HP34420A nanovolt meter and monitored by computer. The cables (although not shown in Figure 1) were taped down against the vibration fixture to inhibit the resonance vibration of the loose cable. The random vibration profile for this experiment was referenced from the EO-1 specification for protoflight level testing and is as follows:

Frequency (Hz)	Protoflight Level
20	.026 g^2/Hz
20-50	+6 dB/octave
50-800	.16 g^2/Hz
800-2000	-6 dB/octave
2000	.026 g^2/Hz
Overall	14.1 grms

Table 1: Random vibration profile for test one

The random vibration test was continued for one minute per axis and testing was conducted on each axis for all three cable sets (mated pairs) under test. Cable set 1 was used as a verification that the system was functioning properly and that data was being logged accurately. Active optical power data was also gathered for all three of the axis tests. Cable sets 2 and 3 were monitored actively and all channels were measured for power before and after the three axis tests of the random vibration experiment. Figure 2 illustrates the reference axes used for this experiment.

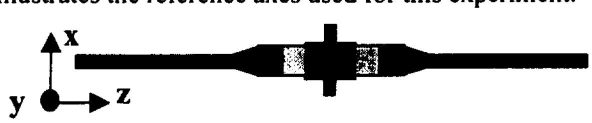


Figure 2: View from top of mated pair, fibers aligned side by side in gray ribbon cable.

For the active measurements channel #6 was monitored on cable set 1; channel #12 was monitored on cable set 2; and channel #9 was monitored on cable set 3. The post vibration power measurements with respect to the pre-vibration (reference) measurements of cable sets 2 & 3 are summarized in the first three columns of Table 2. Table 2 contains all post environmental testing results. This table will be referenced throughout this paper.

Channel	Post Vibration Test 1, Cable Set 2 (dB)	Post Vibration Test 1, Cable Set 3 (dB)	Post Thermal Measurements Cable Set 2, (dB)	Post Thermal Measurements Cable Set 3 (dB)	Post Random Vibration Test 2, Cable Set 2, (dB)	Post Random Vibration Test 2, Cable Set 3, (dB)
1	0.09	-0.31	-0.56	-0.64	-0.16	-0.68
2	0.33	0.67	-0.27	-0.15	0.02	0.00
3	0.07	-0.05	-1.52	-0.75	-1.16	-0.68
4	-0.09	0.46	-0.33	-0.02	-0.70	0.33
5	-0.07	0.04	-0.61	-0.16	-0.06	0.45
6	0.16	-0.58	-0.47	-0.25	0.02	-0.81
7	0.06	-0.35	-0.84	0.17	-0.14	-0.40
8	0.05	0.10	-0.59	-0.28	0.09	0.40
9	0.10	-0.17	-0.67	-1.07	-0.52	-1.40
10	-0.06	-0.59	0.04	0.08	0.31	0.15
11	0.03	0.64	0.68	1.77	1.16	1.76
12	0.00	0.05	-0.40	-0.30	0.14	-0.15

Table 2: Optical power measurements of cable test sets 2 & 3 post random vibration testing

For cable set 2 the average value is .056 with a standard deviation of .11 dB, and for cable set 3 the average value is -.008 dB with a standard deviation of .43 dB. The maximum loss for cable set 2 was -.086 dB and for cable set 3 was -.58 dB. When measuring the initial power of each of the cable sets, the standard deviation of these measurements was .56 dB for cable set 2 and .55 dB for cable set 3. For the reference (pre-vibration) measurements of the cable assembly some of the wide variation in measurements was occurring as a result of the fan out cables (they were not able to be mated together due to gender mismatch). It would seem logical that the variation of the post vibration measurements calculated in dB with respect to the reference measurements should have less variation among the different optical fiber channels. Optical power measurement uncertainty is partially a result of ST mating repeatability on each channel of the fan out cable. The uncertainty resulting from this interconnection system will occur for each of the channels and this effect was not quantified for these experiments. The uncertainty will be quantified in the experiments scheduled for the 100/140 micron diameter system. The instability of the source may also account for a part of the power variation and uncertainty.

For the active measurements taken from channel #6 of cable set 1 during random vibration test 1, the results of each axis (z, y, and x) test are in Figure 3. Each of the Figure 3 data plots have a full scale range of .1 microwatt for each of the minute long (per axis) tests. The largest optical power fluctuations or transients occurred during the y axis test, where after a power drop of .03 dB in the first 20 seconds, the transients where no more than .03 dB from maximum (positive) transient above the average value of approximately 7.5 microns to the minimum (negative) optical power transient. During the x axis test a slight power decrease of .01 dB occurred at 20 seconds, then the output remained steady at approximately 7.49 microwatts. During the z axis test the optical power remained steady at approximately 7.39 microwatts.

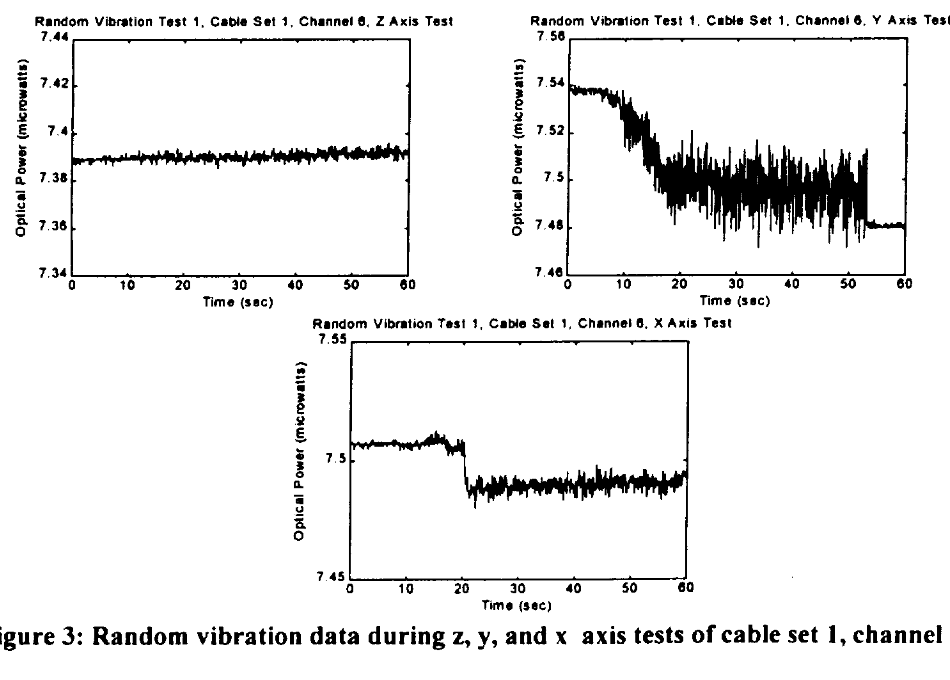


Figure 3: Random vibration data during z, y, and x axis tests of cable set 1, channel #6

The data sets from random vibration test one of cable set 2 where channel #12 was monitored are in Figure 4. Each of the scales in Figure 4 are a full range of .1 microwatts for each of the minute long (per axis) tests. For the three tests the optical power remained steady at: 9.46 for the z axis, 9.47 for the y axis and at approximately 9.42 for the x axis.

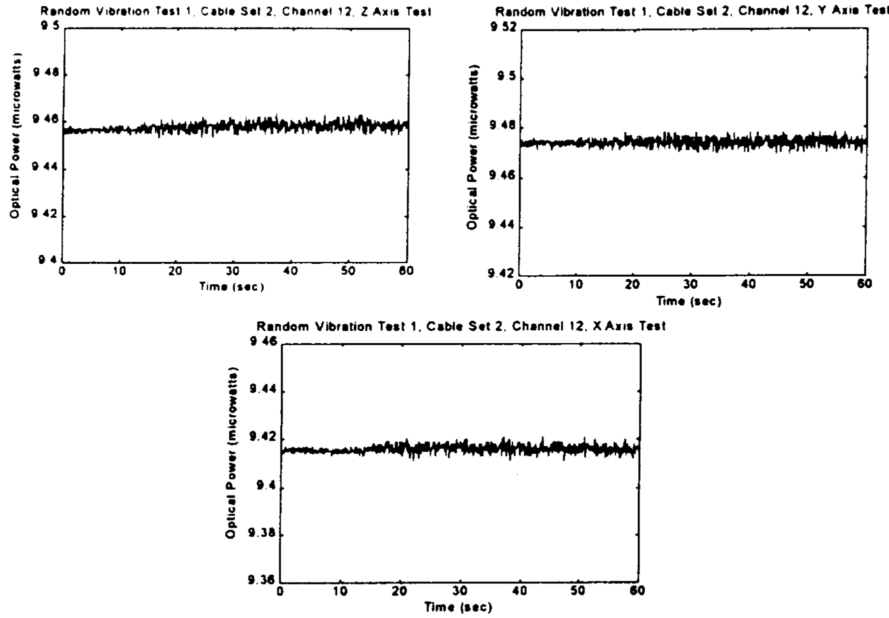


Figure 4: Random vibration data during z, y, and x axis tests of cable set 2, channel #12

Figure 5 contains all three axis plots of random vibration test for cable set 3, where channel #9 was monitored during vibration of the connector assembly. In comparison to Figures 3 and 4 the full range scales in Figure 5, x and y axis tests, are several times larger to capture the entire trace during testing. For the z axis test, the scale was as previous, .1 microwatt total range and the power decrease during the minute long test was .03 dB or more precisely .03 dB over a duration of 50 seconds (with transients much less than the overall power decline). The full scale range for the y axis test is .4 microwatts and the power loss over the minute long duration was .12 dB with two negative transients at -.05 dB with respect to the average power at that second time during the vibration test. For the x axis test the full scale range is .5 microwatts with a power decline of .23 dB during the duration of the one minute test.

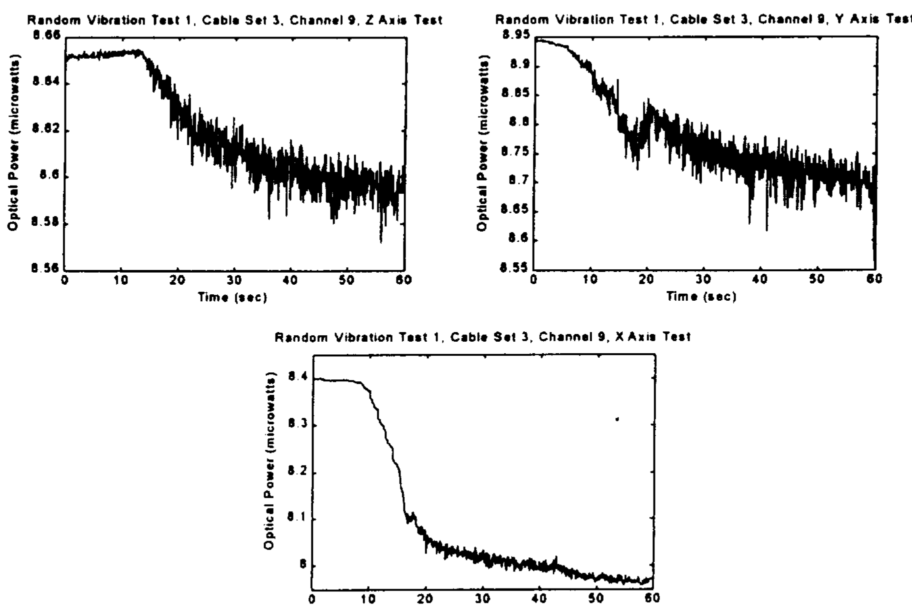


Figure 5: Vibration data during z, y, and x axis tests of cable set 3, channel #9

It was interesting to note the decline in power in test set 3 that was not in data collected for test set 1 and 2. The reason for this decline in power during the x and y axis test was surmised to be the fatigue of the MTP adapter. The maximum transients during the testing duration did not exceed .24 dB during any of the tests for all cable sets. The same MTP adapter was used for testing of all three cable sets. It was assumed by these results that the adapter may have become fatigued by the time the third cable set was being tested (mostly because of being bolted down and then removed repeatedly each time the connector assembly had to be tested in a different direction). In the second set of vibration testing a different adapter was used for each cable test set but used throughout the vibration test of all three directions and the results are similar to those presented here. Therefore, it can not be assumed at this time that the MTP adapter became fatigued during the vibration testing. In table 3 the results of all three axes tests for all cable sets under active monitoring for random vibration test one are summarized.

Cable Set	Optical Channel	Axis Test	Maxiumum Value (microwatts)	MinimumValue (microwatts)	Range of Fluctuations (dB)
1	# 6	Y	7.54	7.471	< 0.04
1	# 6	X	7.513	7.48	< 0.04
1	# 6	Z	7.396	7.385	< 0.01
2	# 12	Y	9.478	9.469	< 0.01
2	# 12	X	9.421	9.411	< 0.01
2	# 12	Z	9.464	9.453	< 0.01
3	# 9	Y	8.945	8.563	< 0.12
3	# 9	X	8.401	7.958	< 0.24
3	# 9	Z	8.655	8.572	< 0.04

Table 3: Results of power fluctuations during random vibration testing with active monitoring

By noting the larger fluctuations of cable set 3 it is obvious that the cable set performed approximately an order of magnitude worse than the other two cable sets. Due to the results gathered from the second set of random vibration tests (second vibration test results are in table 5) it is safe to conclude that the MTP adapter being used repeatedly was not the factor in the larger transients of cable set 3. For the other cable sets any power decline or fluctuation less than .02 dB could be attributed to the measurement instability of the source set up (source noise) and by using a minimal integration time for registering measurements from the nanovolt meter. Upon conclusion of the random vibration tests pictures were taken of the optical fiber end faces to detect any damage as a result of the vibration testing. No damage occurred as a result of vibration testing.

2.2 THERMAL CYCLING AND AGING EXPERIMENT

Again, as with the random vibration testing, two types of data were recorded. Data was recorded actively (optical power output from the system recorded) during thermal cycling, on one channel only per cable test set. The second type of data was recorded before and after measurements of all channels per cable test set. Cable sets 2 and 3 were used for the thermal cycling testing. In addition to optical power measurements, optical fiber end face pictures were again taken to check for damage to the terminations during this aging test (see summary section 3). The temperature profile for the first test using cable set 2, was: -20°C to +85°C, 1°C/min, dwell at extremes of 15 minutes, for 30 cycles total. The second test using cable set 3 had a profile of -20°C to +85°C, 3 °C/min ramp up rate and 2 °C/min ramp down rate, for 42 cycles. In each case the cables were connected and optical power measurements were made prior to testing. The mated cable set was then placed into the chamber without disconnecting the mated pair. The same mated pair that was vibration tested was placed in the oven for the thermal cycling aging. Once again, during the active monitoring of the thermal effects on the cable assembly the same optical channel was monitored as was monitored during the vibration testing. The setup was identical to that for the random vibration test as in Figure 1 with the thermal chamber (Tenney Benchmaster BTC) now housing the mated pair and a Hewlett Packard HP6237B power supply used to power the RIFOCS source.

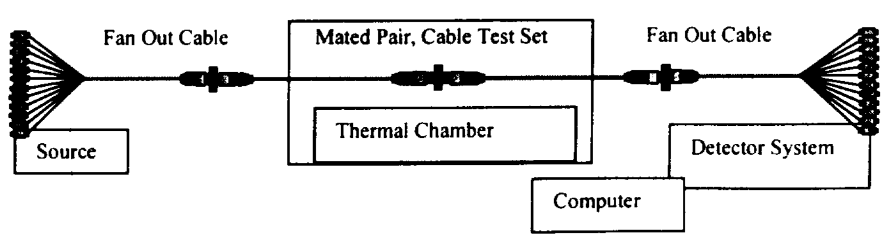


Figure 6: Thermal cycling experimental test set up.

Cable test set 2 was tested first and data was recorded. Figure 7 shows the data gathered during the first 12 cycles of thermal cycling testing and Figure 8 shows the data gathered during the last 15 cycles of thermal cycling. The test of cable set 2 was a 30 cycle test and cycles 13 and 14 were not gathered due to computer malfunction. In Figures 7 and 8 there is a slow decline in power during the duration of the test. The full range scale in Figure 7 is .6 microwatts and the plot shows a decline in power of .17 dB by the end of the 12th cycle. In Figure 8 the full range scale is .3 microwatts and the power decline by the last cycle (taking into account the Figure 7 data) was -.24 dB. The slow decline was an unexpected result and further calibration tests were conducted to confirm that the slow decline in power was related to the instability of the source. Ignoring the slow drift in power, a rough comparison can be made between the optical power at room temperature and the optical power at -20°C within a given thermal cycle. This comparison results in a loss of roughly -.017 dB at -20°C with reference to the power at 25°C within a cycle and a total optical power cycle variation of .37 dB from cycle minimum to cycle maximum of the cable assembly optical performance during a single thermal cycle.

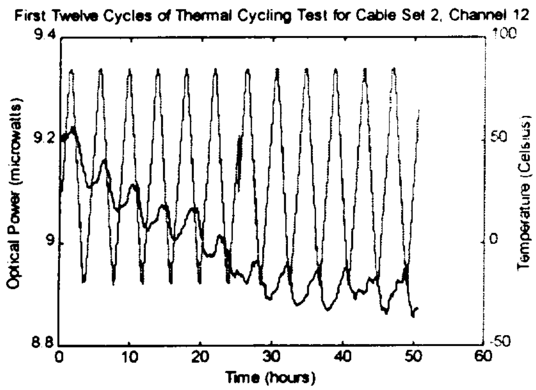


Figure 7:
First 12 cycles of cable set 2 thermal cycling 30

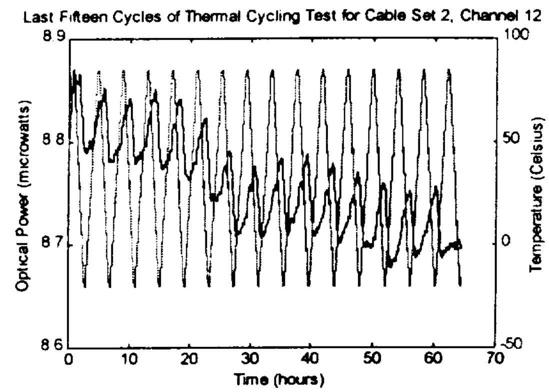


Figure 8:
Last 15 cycles of cable set 2 thermal cycling 30

Figure 9 is the data collected for the thermal cycling test for cable set 3 during the active monitoring of channel #9 during cycling testing for 42 cycles test from -20°C to +85°C. During this test there was a slow drift increase in power most likely due once again to source instability. The low temperature losses are approximately -.16 dB with respect to the room temperature optical power and the high temperature power increase is approximately .16 dB above the room temperature optical power output of the cable assembly.

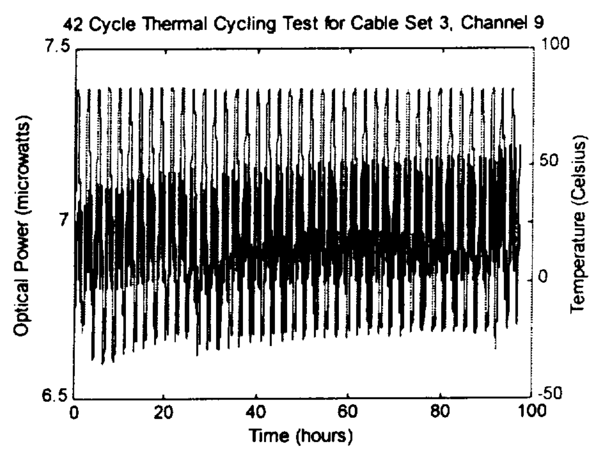


Figure 9: Thermal cycling 42 cycles from –20 °C to +85 °C, 3 °C /min up, 2 °C /min down, optical power on left axis, temperature on right axis for cable set 3

The optical power measurements after thermal cycling for all 12 channels of both cable sets are in Table 2. Once again, the wide variation of these post test measurements can be attributed to MTP channel to channel uncertainty, source instability, ST repeatability, and the uncertainty associated with using a different reference cable for each channel. The average post thermal loss calculated for cable set 2 was -.46 dB with a standard deviation of .52 dB and for cable set 3 was -.13 dB with a standard deviation of .70 dB. After thermal cycling testing another set of endface pictures were taken (see summary).

2.3 RANDOM VIBRATION EXPERIMENT II

A second random vibration test was conducted on cable sets 2 and 3. The profile used for this test was double the prototype levels defined in the EO-1 specification for components. The profile of this test is summarized in Table 4.

Frequency (Hz)	Protoflight Level
20	.052 g^2/Hz
20-50	+6 dB/octave
50-800	.32 g^2/Hz
800-2000	-6 dB/octave
2000	.052 g^2/Hz
Overall	20.0 grms

Table 4: Random vibration profile for second set of vibration testing

These levels were used in a test of three minutes duration per axis as opposed to the random vibration test done prior to thermal testing of one minute/axis. During this test each cable set used one adapter for all three axis tests which was changed after completion of testing cable set two and prior to testing cable set three. This test monitored the same channel as before: for cable set 2, channel #12; and for cable set 3, channel #9. Figure 10 shows the data gathered for the second random vibration test on cable set 2 for all axes and Figure 11 shows the data gathered for all axis tests for the vibration testing on cable set 3.

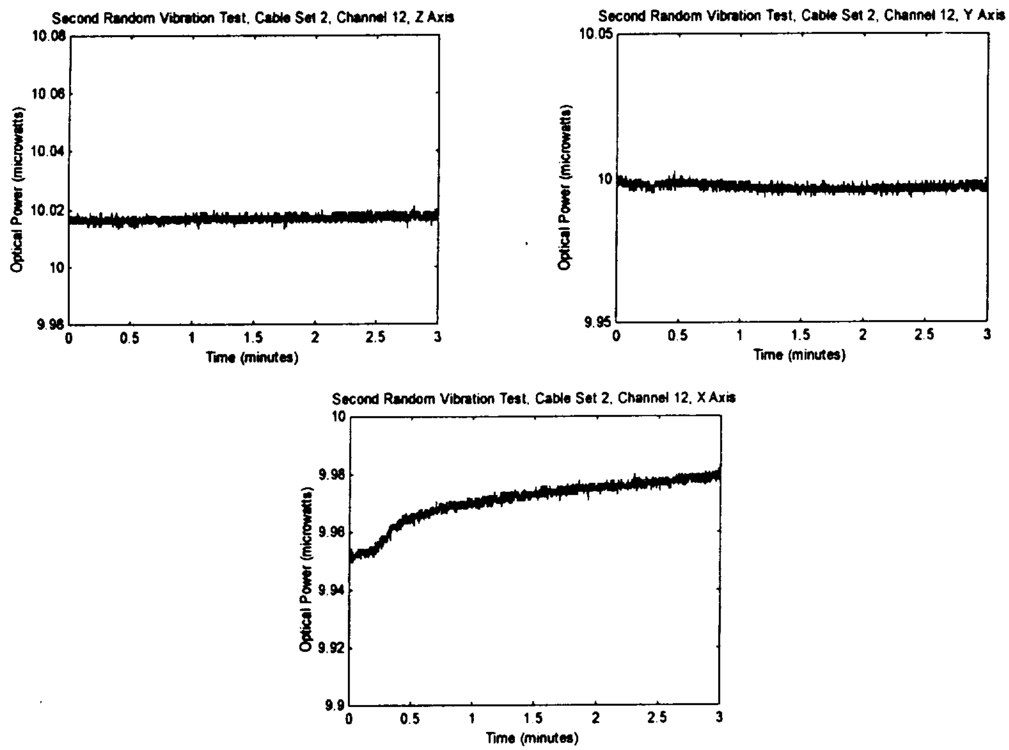


Figure 10: Random vibration test two (z,y and x axis tests) on cable set 2 with active monitoring of channel #12

The full range scales of all the plots in Figure 10 are .1 microwatt. From the random vibration tests conducted on cable set 2, the results show that the optical power level remained steady at: 10.02 microwatts for the z axis test, at 10 microwatts for the y axis test, and 9.98 microwatts (.01 dB power increase due to source noise) during the x axis test. The full range scale for the z axis data plots of cable set 3 is .2 microwatts and .5 microwatts is the full range scale for the data gathered from the y and x axis random vibration tests for this series of vibration tests. There is a slight increase in power (.03 dB), after which the largest transient is -.04 dB (with respect to the average power at that second) near the end of the z axis test. During the y axis test the optical power decreased by -.08 dB and later in the test a negative transient occurs that is -.16 dB with respect to the average optical power at that second. During the x axis test an increase of .16 dB occurred in the first 30 seconds of the test, dropped to -.05 dB by the end of the first minute and then stayed steady at 8 microwatts. For the cable set 3 data, the largest power transients occurred during the y axis test and the least occurred during the z axis test. This was also true of the first random vibration test for cable set 3: the largest transients occurred during the y axis test and the optical power was the most stable during the z axis test.

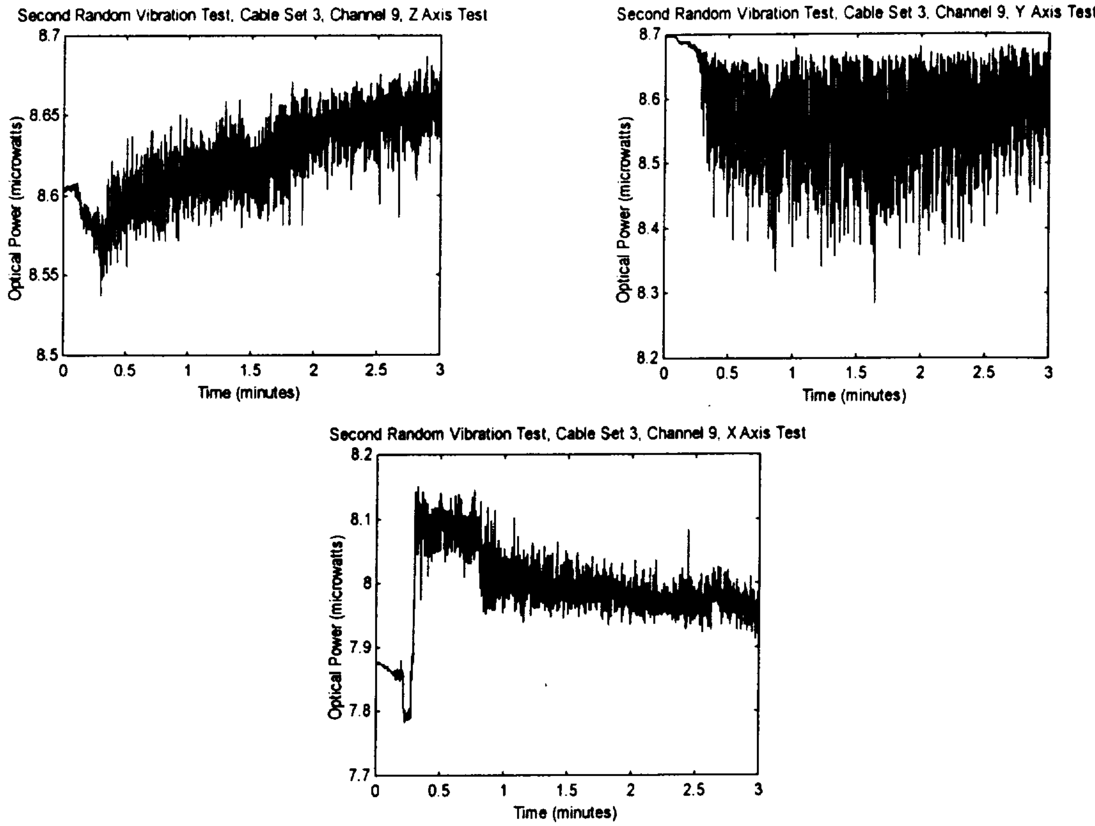


Figure 11: Random vibration test two on cable set 3 with active monitoring of channel #9 during the three minute z, y, and x axis test

The summary of results for the active testing of cable sets 2 and 3 during the three minute random vibration test are in Table 5. These results are very similar to the results in Table 3, with cable set 2 performing with no detectable transients greater than or equal to .01 dB. Again, cable set 3 performed an order of magnitude worse than that of cable set 2 with the greatest transients occurring during the y axis test and the least transients occurring during the z axis test. The values for transients during the x axis test are a bit larger than those detected in the first set of random vibration tests summarized in Table 3.

Cable Set	Optical Channel	Axis Test	Maximum Value microwatts	Minimum Value microwatts	Range of Fluctuation DB
2	# 12	Y	10.003	9.993	< 0.01
2	# 12	X	9.982	9.949	< 0.01
2	# 12	Z	10.021	10.013	< 0.01
3	# 9	Y	8.700	8.284	< 0.23
3	# 9	X	8.151	7.782	< 0.20
3	# 9	Z	8.687	8.537	< 0.08

Table 5: Optical power fluctuations of cable test set 2 & 3 during random vibration test 2.

The post vibration test values for all twelve channels of cable sets 2 and 3 are in Table 2. The average calculated loss with respect to the reference optical power measurements made prior to any environmental testing was -.08 dB with a standard deviation of .57 dB for cable set 2. For cable set 3 the average loss was -.09 dB with a standard deviation of .81 dB.

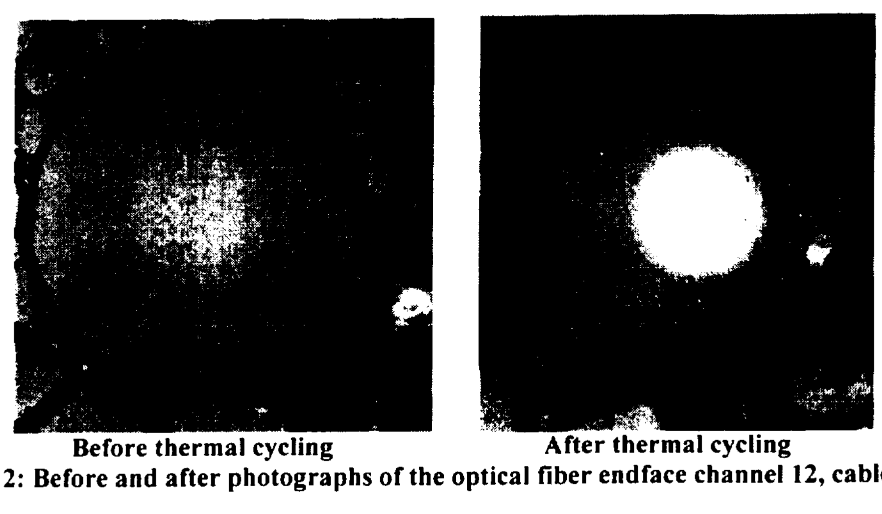
3. SUMMMARY

The post test optical power loss results for cable set 2 and 3 are in Table 6. Although the average loss is well below 1 dB for both cable sets after the second random vibration test, the standard deviation is large. As the cable assembly is aged as a result of environmental testing each channel degrades at a different rate and therefore after each test is completed the distribution of loss becomes wider in comparison to the distribution prior to that environmental test. Since the fan out cable assemblies with ST connectors were not characterized for uncertainty, the uncertainty associated with usage of these test cable assemblies during this experiment can not be propagated to the uncertainty results shown in Table 6. It is also true that the MTP connector optical power variability between connector channels also added to the uncertainty and was not characterized for these experiments. Some uncertainty is due to the instability of the source used for these experiments. The slow decline in power was measured at -.34 dB over an 85 hour period for test 1 without the nanovolt meter in the monitoring set up, and at -.15 dB over a 65 hour test with the nanovolt meter in the monitoring setup. In spite of unknown quantified results for the sources of error, the experiments conducted here do provide enough information to ascertain whether or not these COTS cable assemblies will survive the space flight environment of EO-1.

Post Test Measurements	Cable Set 2 (dB)	Cable Set 3 (dB)
Vibration Average Loss	.056	-.008
Vibration Standard Dev.	.11	.43
Thermal Average Loss	-.46	-.13
Thermal Standard Dev.	.52	.70
Vibration 2 Average Loss	-.08	-.09
Vibration 2 Standard Dev.	.57	.81

Table 6: Averages and standard deviation of post testing measurements for each test conducted for cable sets 2 and 3.

Pictures of the optical fiber endfaces of each channel in the cable sets were taken before and after all environmental testing. One of the endface pairs (channel #8 on each end of the cable set 3 mated pair) were damaged by ineffective cleaning procedures used after random vibration test one, but before thermal cycling. The post thermal cycling pictures showed cracking related to this damage but do to the fact that the mated pairs appeared to be mirror images of one another, it was surmised that the damage occurred prior to thermal testing. After the second set of random vibration tests were completed, the endface pictures taken of channel #8 of cable set 3 showed very little change in the damage already on the endfaces prior to the second set of vibration tests. The cracks did not propagate to destroy the interconnection during vibration testing or during thermal testing (since it was concluded that the damage occurred prior to thermal cycling). However, on one of the endfaces of cable set 2 channel 12 (on one side of mated pair only) damage as a result of thermal cycling was found.



Before thermal cycling **After thermal cycling**

Figure 12: Before and after photographs of the optical fiber endface channel 12, cable set 2.

Recall that cable set 2 had endured a 30 cycle thermal test with a ramp rate of 1 °C/min. In Figure 12 the before and after thermal cycling photographs are shown for channel 12 (side A, meaning only one side of mated pair) of cable set 2. From noting that the background, which is the connector ferrule, of the post thermal cycling photograph is out of focus with respect to the optical fiber endface, it is apparent that the fiber endface is now out of plane with respect to the connector ferrule. Notice also that the post thermal picture shows that the optical fiber endface has cracked and has cladding damage. It is evident that the 12th channel of cable set 2A has pistoned out from the ferrule and most likely had become damaged by doing so. Of all cable assembly end faces (48 total) photographed this appeared to be the only optical fiber to piston and cause damage as a result of environmental testing.

4. CONCLUSIONS

Presented here are the results of testing the twelve channel 62.5/125 micron diameter optical fiber MTP array cable assembly using the commercial W.L. Gore ribbon cable configuration. Although several enhancements to this cable assembly are being made for space flight this COTS cable assembly was tested as a precursor to the testing that will be conducted on the new enhanced version of this cable assembly when it is available. Three tests were conducted to test the cable assembly's ability to withstand the space flight environment of EO-1. The first test conducted was a random vibration test at the protoflight levels from the EO-1 specification, the second test was thermal cycling and aging, and the third was a second random vibration test at twice the levels of the first vibration test conducted. Three cable assemblies were tested but only two of the cable assemblies were used for actual data collection where the other was used to verify all test set ups prior to testing. The two cable assemblies that had data recorded were monitored actively on one channel consistently throughout the duration of each environmental test. Both cable assemblies did not exceed .24 dB for vibration related transients during either of the vibration tests. The average (of the 12 channels of each connector mated pair) calculated post vibration losses for cable sets 2 and 3 were nearly zero after the first random vibration test. After thermal cycling the average loss was calculated to be less than -.50 dB and after the second series of random vibration tests was less than -.10 dB. The standard deviation among this data increased to .57 dB for cable set 2 and to .81 dB for cable set 3 after the second series of vibration tests was completed. Due to each of the channels degrading at different rates it makes sense to have a wider standard deviation as testing progresses. Without a quantified uncertainty for each of the channels in the fan out cables used as the reference cables to connect the MTP cable assembly to the monitoring equipment, no quantified results on the uncertainty associated with the degradation of the cable assemblies can be ascertained from the data presented here. What can be said about the uncertainty is that it is affected by the MTP variability across the 12 channels of the cable assembly which is related to termination procedures. Also adding to the uncertainty is the noise related to source instability that was measured to be as large as -.34 dB over several days. Of all terminations in this study only one appeared to have pistoned during the thermal cycling test and resulted in a damage to the optical fiber endface. The data gathered here will be incorporated in formulation of the test plan for the 100/140 micron MTP cable assembly scheduled for testing later this year. The information and experimental data of the enhanced 100/140 micron COTS MTP ribbon cable assemblies will be presented next year upon completion of all validation and characterization testing.

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