Micron Optics, Inc.
os4400 Series Temperature Sensing Cable
Test Summary — Preliminary

The following tests have been completed on the os4400 series temperature sensing cables to confirm performance and the long term reliability of the product under extreme environmental conditions. The tests include the following:

- 500 Temperature Cycles with a maximum range of -40 to +100°C
- 20 Cycles of -40 to +100°C of Full 39 Sensor Cables
- High Temperature Soak with Tension
- Low Temperature Soak with Tension
- Submerged Long Term Cable Soak
- Cable Splice Joint Pull Test
- Cable Pull and Bend Test
- Cable Bending Test

The above tests were designed to understand and verify the long term performance of the os4410 and os4420 temperature sensing cables and to eliminate any potential failure modes.

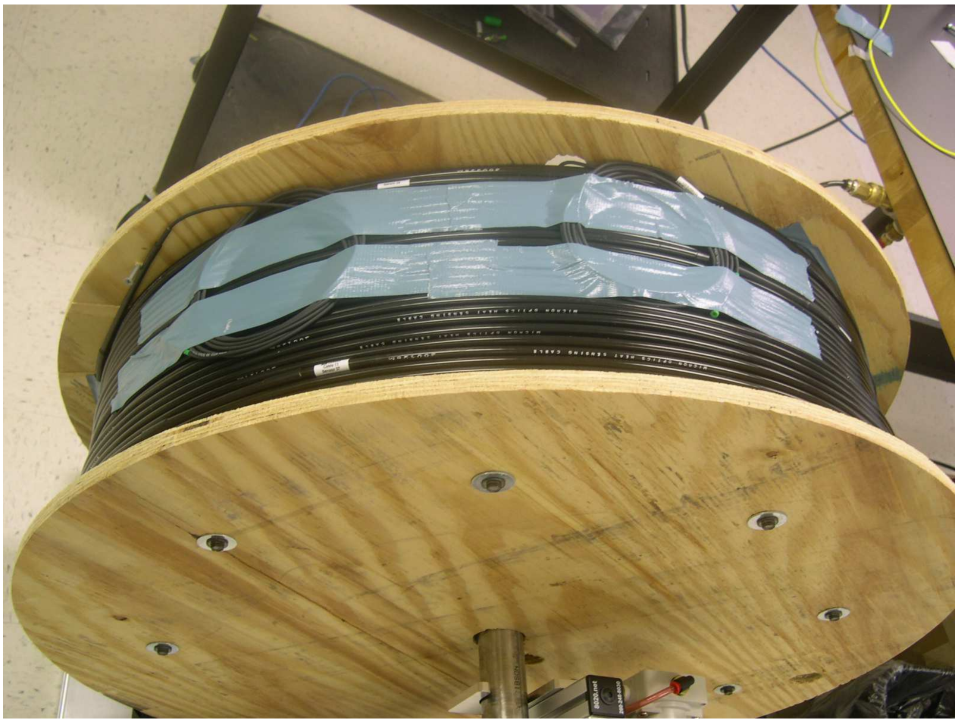

Figure 1 - Cable Coiled on Reel

500 Temperature Cycles

To determine the long term reliability of the os4400 temperature sensing cable under harsh temperature cycling, one cable with five temperature sensors and one strain FBG was cycled from -30 to 75°C at a rate of approximately one degree/minute for the first 280 cycles. The temperature range was then increased to -40 to 100°C for the remainder of the 500 cycle test. To perform this test the cable was removed from the reel and coiled up into a 24 inch diameter coil in order to fit into the temperature chamber. In figure 2 below both temperature and loss are plotted for the first 20 cycles after increasing the temperature range to -40 to 100°C.

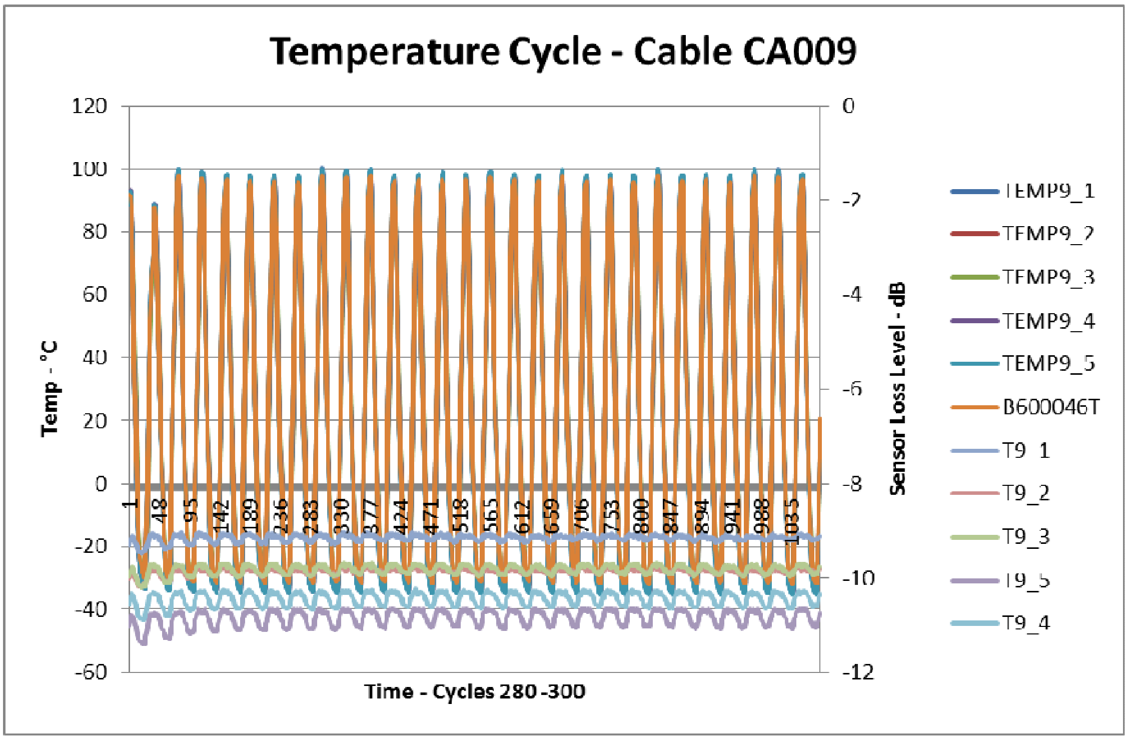

Figure 2 - Graph - Sensor Temperature and Loss

Variation in loss as a function of temperature was an issue of concern during the development phase of the product. An analysis of the loss as a function of temperature is shown in figure 3 below. Note that the figure shows the maximum loss variation for the last two sensors on the end of the cable, the worst case scenario.

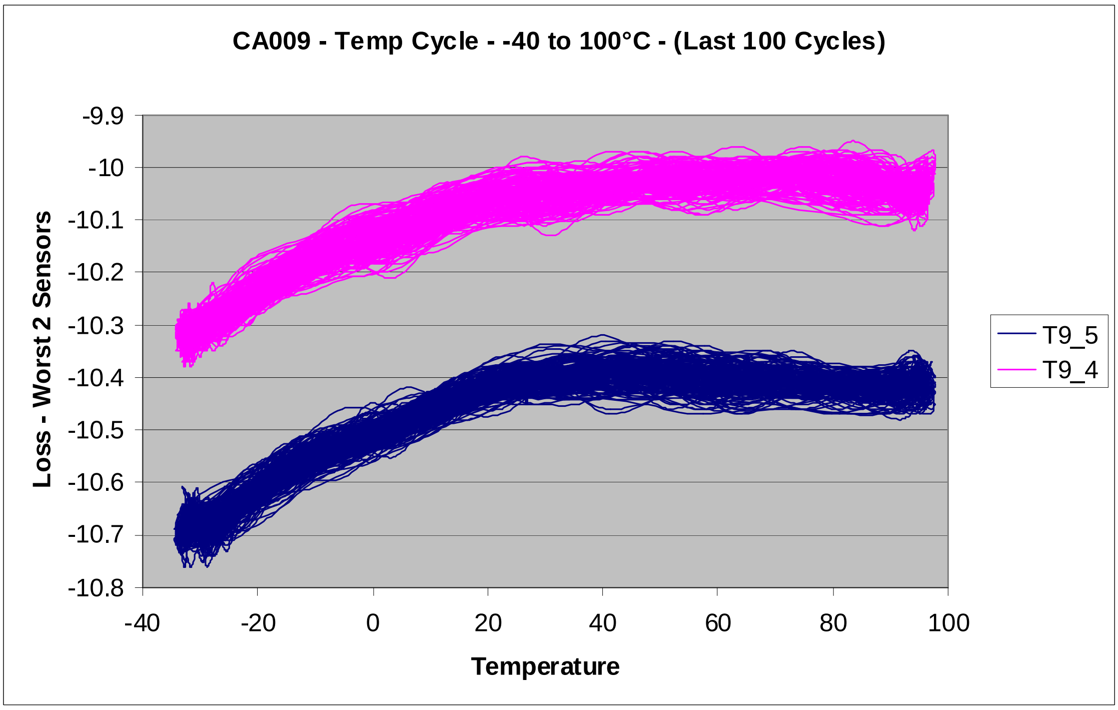

Figure 3 - Sensor Loss Variation

<u>20 Cycles of Full 39 Sensor Cables</u>

Two os4400 cables were produced with 39 sensors each, the maximum number of sensors possible in a cable. Cable CA011 sensors had six meter spacing for a total cable length of 234 meters. Cable CA012 had two meter sensor spacing for a total cable length of 78 meters. Each cable was coiled on a separate reel and placed in a large chamber and temperature cycled for 20 cycles of -40 to 100°C. Data is shown in figures 4 and 5 below for Cable 11. Figure 4 shows the first 20 sensors which are on the inside of the reel. After the first 13 cycles the dwell time at -40 and 100°C was increased to give more time for the temperature to stabilize at each point. Cable 12 having much less thermal mass because of the shorter length came very close to reaching both the -40 and 100°C limits.

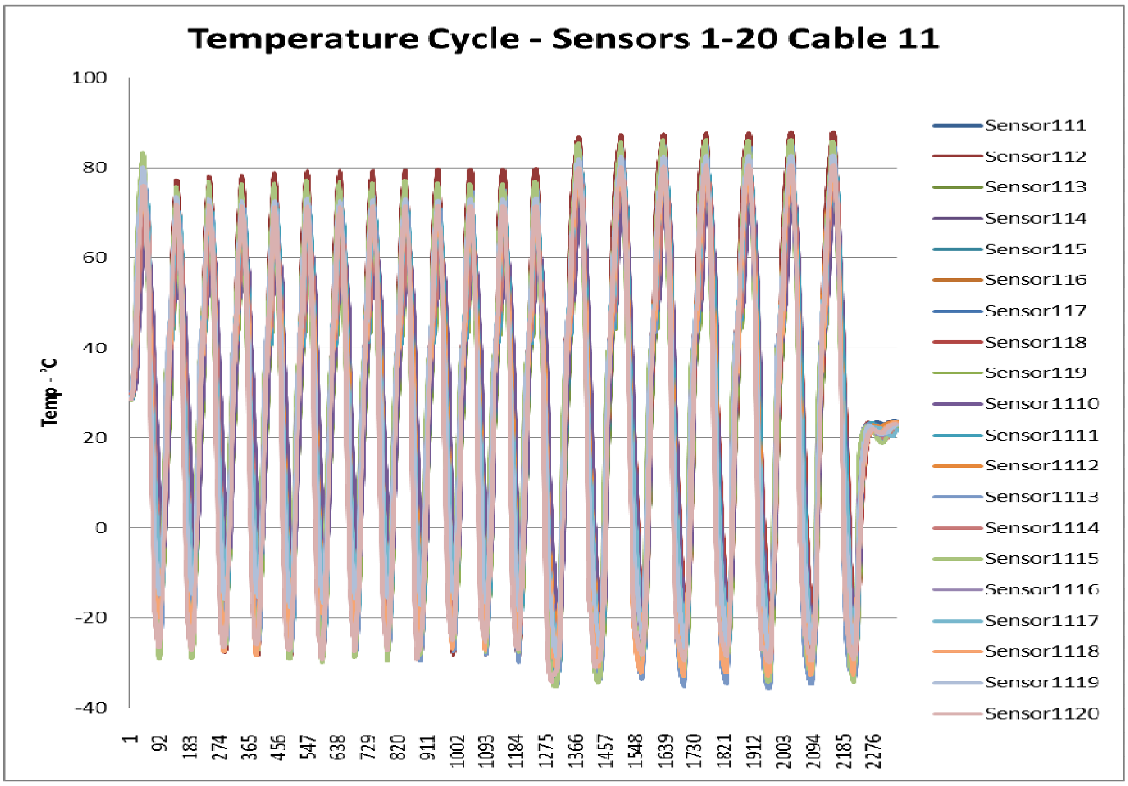

Figure 4 - Cable 11 - Sensors 1-20

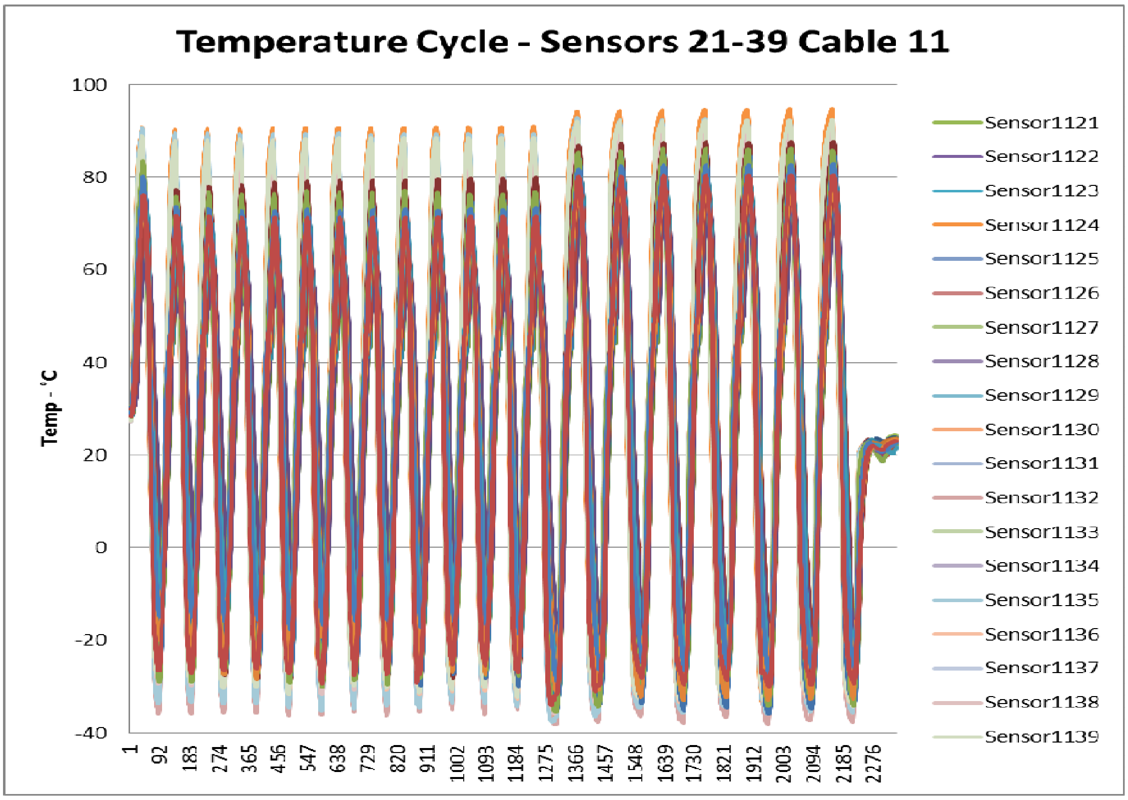

Figure 5 - Cable 11 - Sensors 21-39

Loss variation for this cable was very good, less than 1.6dB for 39 sensors. Note that the low numbered sensors were at the far end of the cable, the furthest from the sm125 sensing instrument and therefore include the cumulative loss for all of the sensors between the specific sensor and the instrument. Data is shown in figure 6 below. Each dot represents the variation in loss, the maximum loss minus the minimum loss at any point in the 20 cycle test.

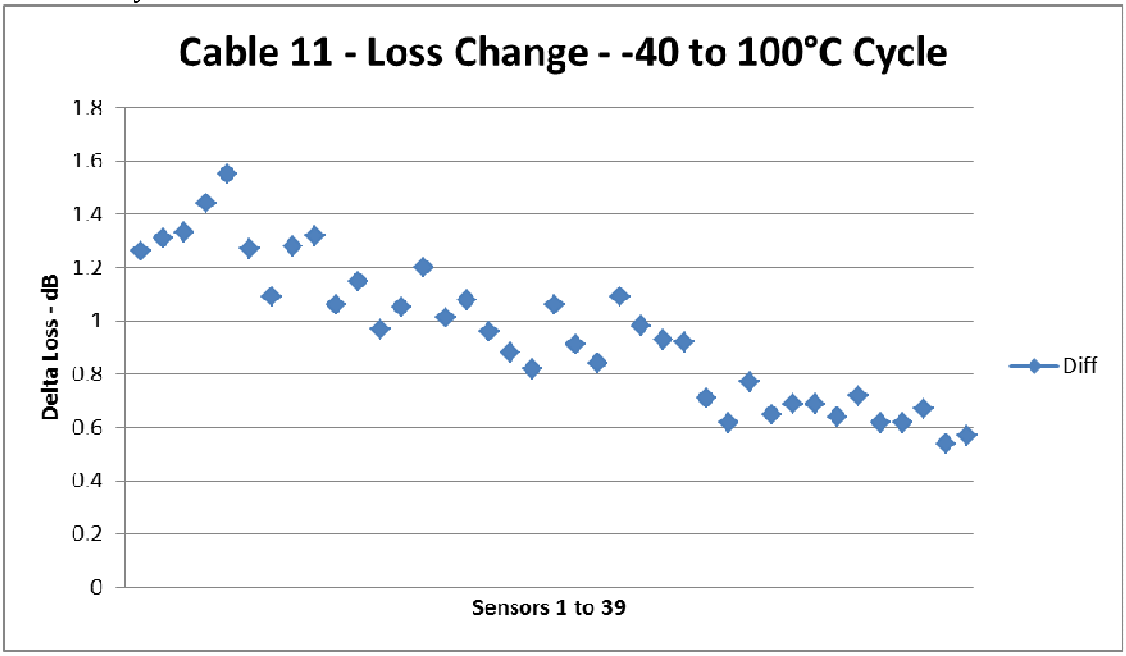

Figure 6 - Cable 11 - Sensor Loss Variation

Similar data is shown below for cable 12. Note the one end of the cable came loose during the first 13 cycles and had to be re-secured. The loss data represents the last 7 cycles only.

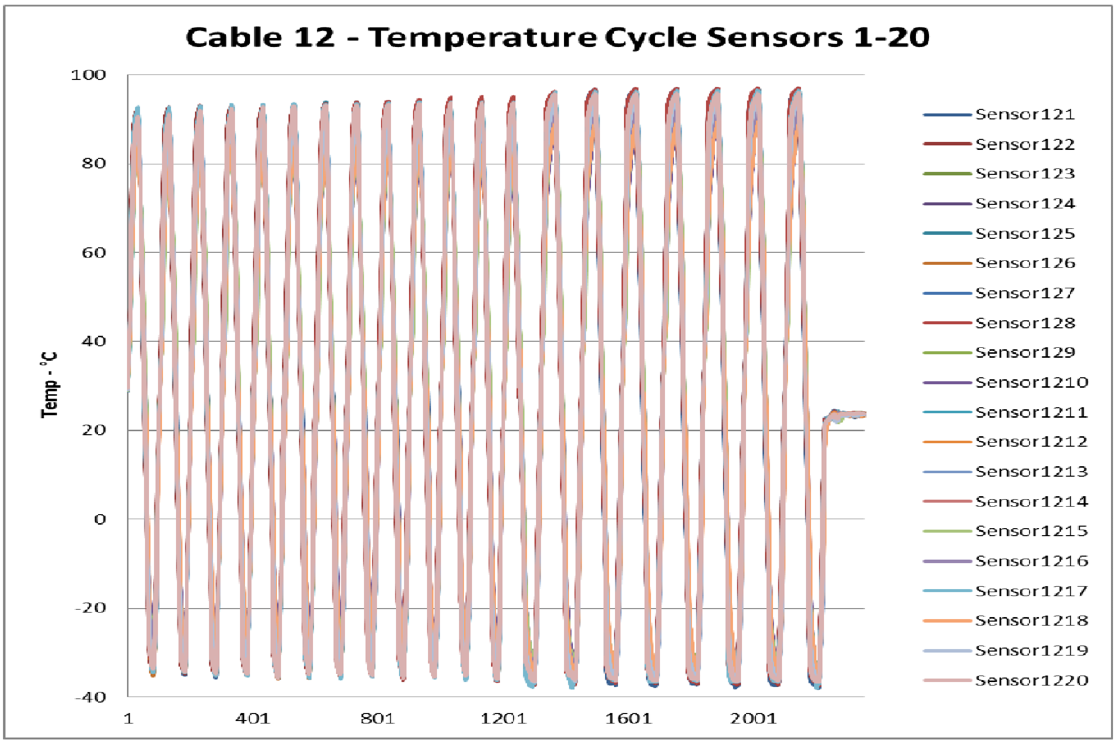

Figure 7 - Cable 12 - Sensors 1-20

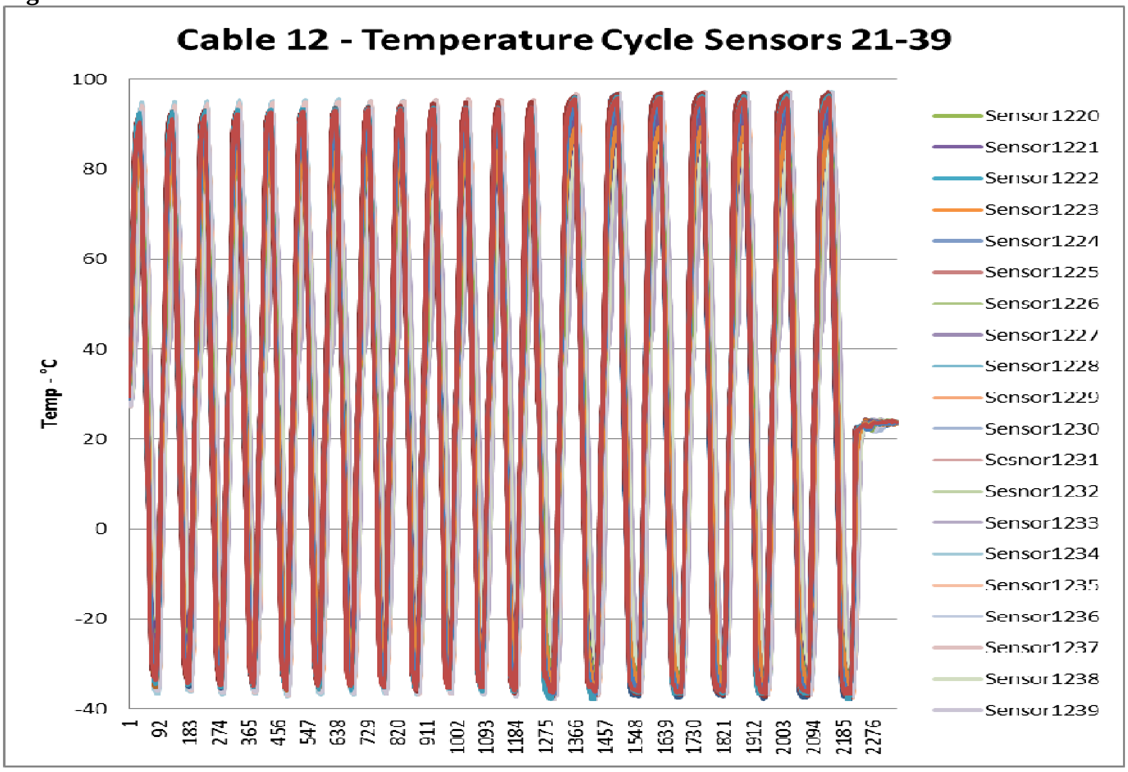

Figure 8 - Cable 12 - Sensors 21-39

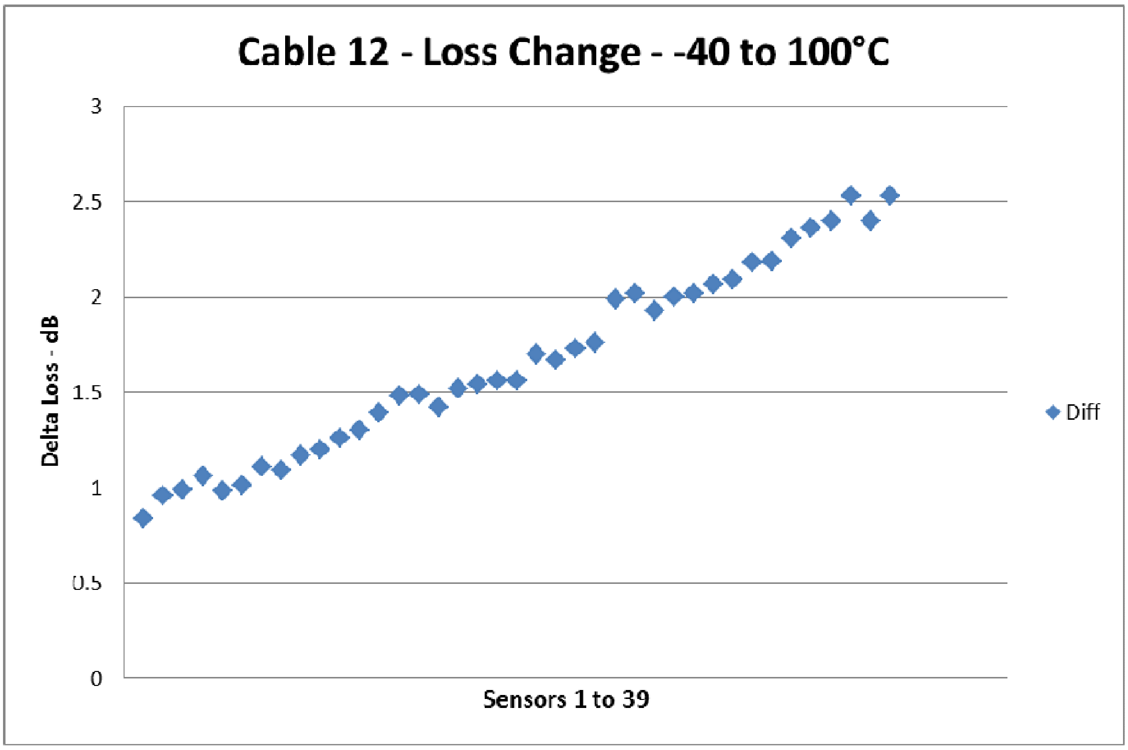

Figure 9 - Cable 12 – Effect of Temperature on Cumulative Optical Loss at each Sensor Point

<u>High Temperature Soak with Tension</u>

Three cables were tested under tension and up to 100°C to determine the mechanical integrity under a combination of parameters. The cables tested each had a minimum of five temperature sensors and one strain FBG in series with the temperature sensing fiber. Each cable was approximately 25 meters long and suspended with a force gage to monitor tension on the cable. A heater cable was attached to the underside of the os4400 temperature sensing cable and insulated with two layers of convoluted slit sleeving. A temperature controller was used to control the heater cable temperature. The table below summarizes a sampling of the test results.

Cable	Temp - Max	Temp - Min	Tension	Duration	Loss	Strain
CA006	22°C	22°C	445N	16 hours	No change	No change
CA008	100	22°C	310N	120	No change	250µϵ
CA010	100°C	---	267N	14 days	No change	No change for constant temp.
CA010	100°C	22°C	267N	40 days	No change	No change

The graph in figures 10 and 12 below shows the effect of temperature on strain in the fiber. Cable CA008 had two strain FBGs while CA010 had one strain FBG, however both cables exhibited very little change in strain for varying temperatures.

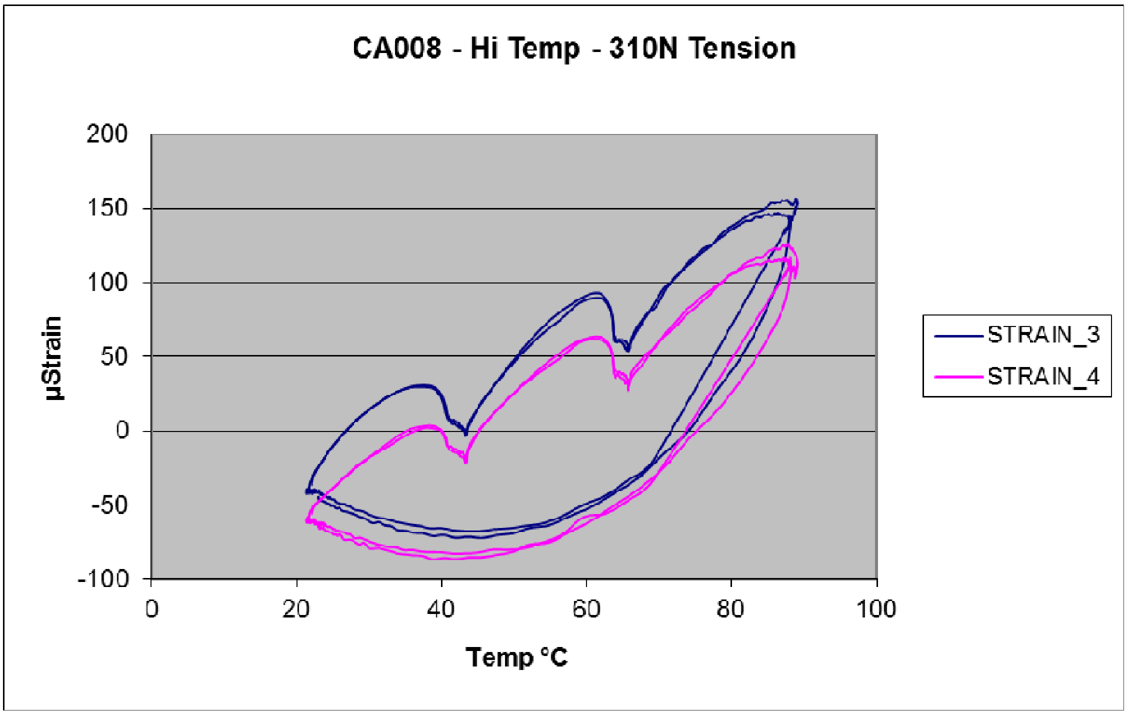

Figure 10- Cable CA008 – Effect of Temperature on Fiber Strain

To determine that sensor loss did not vary as a function of temperature while the cable was under tension, cable CA008 was suspended under 310 newtons of tension while varying the temepratureature from room temperature to 90°C and monitoring sensor loss. As indicated in figure 11, temperature of the cable had no effect on sensor loss.

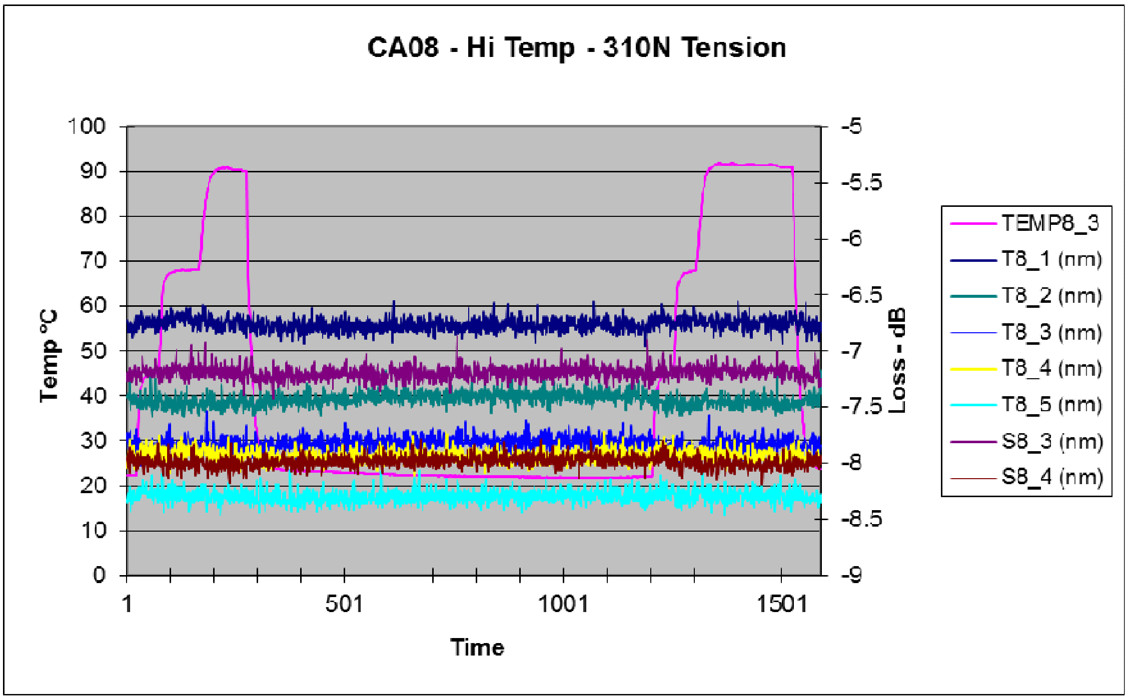

Figure 11 - Effect on Optical Signal Loss with Temperature Variation

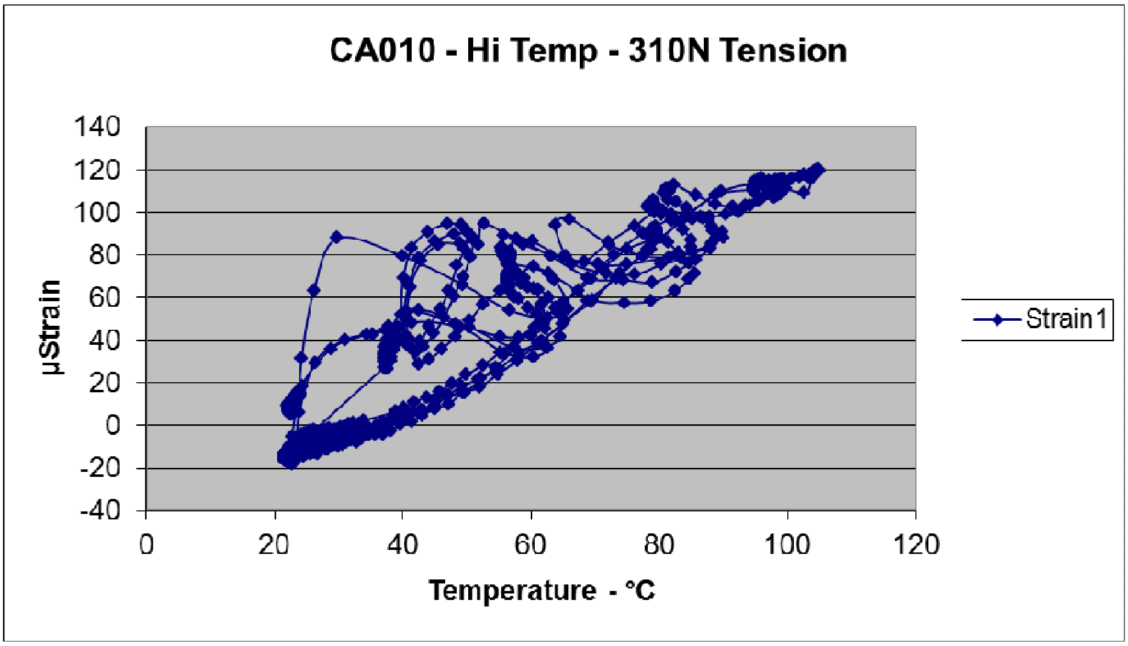

Figure 12 - CA010 - Effect of Temperature on Fiber Strain

<u>Low Temperature Soak with Tension</u>

To simulate real world operating conditions of an installed temperature sensing cable, a 53 foot long refrigerated reefer was rented for two one-week periods to simulate the effects of cold temperatures of a cable under tension. This report will focus on the second rental period where cables CA008, CA009 and CA010 were tested. The reefer's refrigeration capability resulted in temperatures as low as -26°C and would regularly go through a defrost cycle bringing the temperature up to as high as 15°C. Cables were installed in the reefer as shown in the photos below. One cable was installed on each side and the shorter cable, CA009 was installed diagonally in the reefer.

Figure 13 - Reefer Cable Installation

Figure 14 - Cable Tension Configuration

Figure 15 below shows typical results for all three cables being tensioned to 220N for one week and undergoing cold temperature cycling while under tension. Sensor loss variation was very stable over the total 40° variation in temperature. All three cables met expectations for this test. (Note that a safety spring and turnbuckle was used to set and maintain 220N tension throughout temperature cycling.)

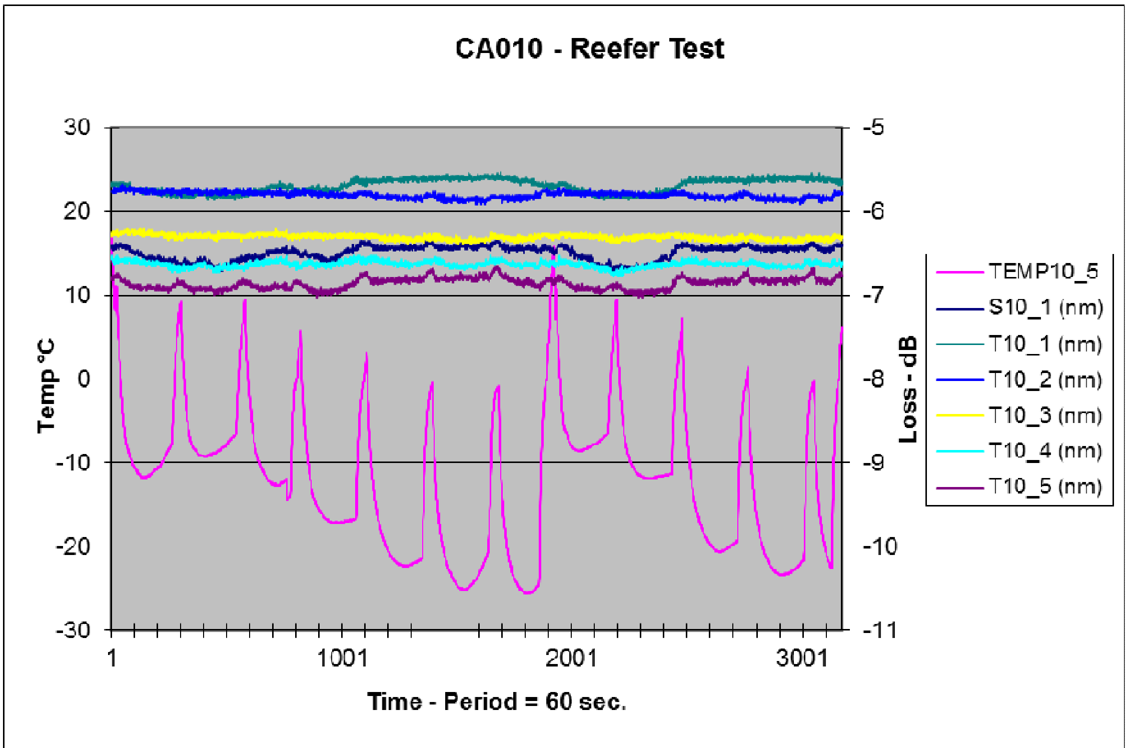

Figure 15 - Results - One Week Cold Temperature Testing

<u>Submerged Long Term Cable Soak</u>

Many potential applications for the os4400 temperature sensing cable are anticipated to be outdoor, harsh environments, either in ground or under water at various times. To test for water penetration, two samples of cable tube were fabricated with a sensor section, a cable end cap and a transition to the 3mm cordage on the cable end. One sample was configured as an os4410 and the other was configured as an os4420 cable. The total length of the test ran for one year under varying pressures in a static water pressure tank. Figure 16 below reveals the time and pressure profile for the cable tube samples while under test. For the duration of the test, no water penetrated the cable tube.

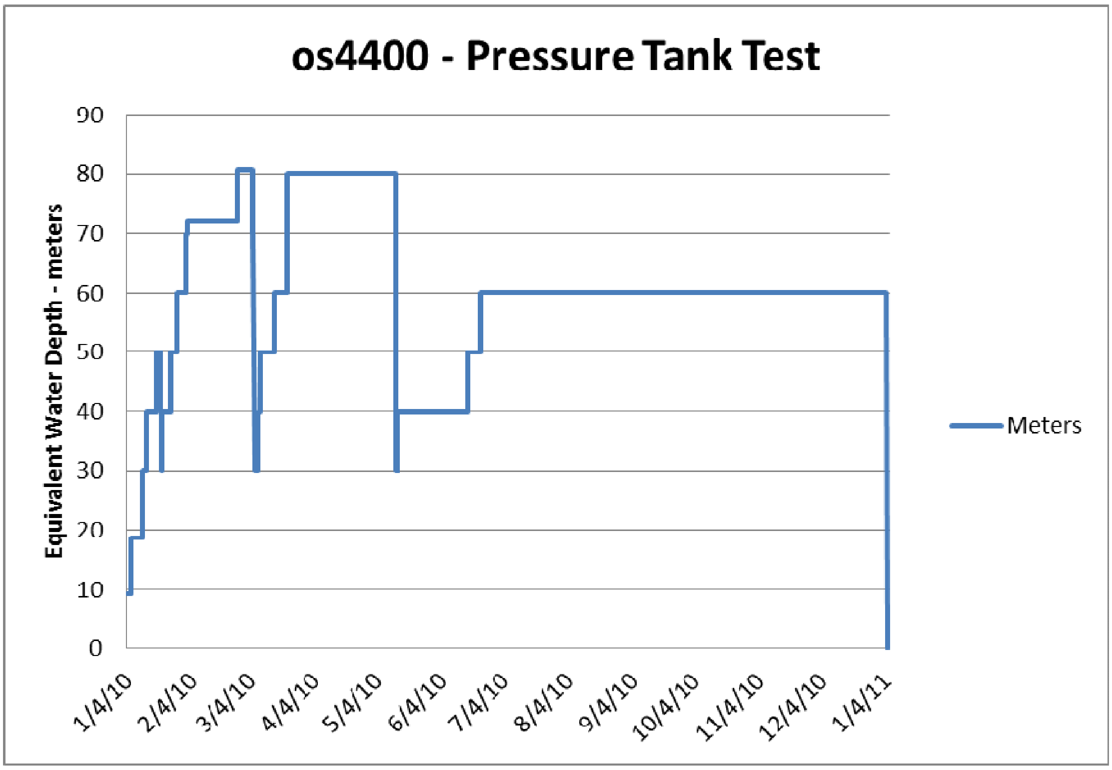

Figure 16 - Submersion Test

Cable Splice Joint Pull Test

To ensure cable integrity and proper functioning of the os4400 temperature sensing cable for the life of the product under various environmental conditions, much effort was devoted to insuring a strong bond of the cable tube at each sensor point. Several methods of joining the cable tube sections together were evaluated and a combination of mechanical and epoxy bond was selected as a method sufficient to withstand the anticipated extreme conditions. Several splice joint samples were prepared and pull tested to failure. The results displayed below are in newton:

Test Condition	Max. Load - N	Std Dev - N
Room Temp.	2037	288
100°C	1045	145

Cable Pull and Bend Test

Verification of the ability to install a cable and pull it around a sheave was completed by pulling an actual cable including the sensors around a 760mm diameter sheave while maintaining a tension of 110 newton. All sensors were visually inspected with no signs of damage. The cable was also measured optically with no deterioration in performance.

Cable Bend Test

Both the os4410 and the os4420 cables were tested for the potential kinking at the sensor when pulled to a tighter diameter than the minimum recommended. The cables were observed for permanent, non-recoverable deformation after bending that would reduce the strength of the cable. The test was conducted by starting with the specified minimum diameter and pulling the diameter smaller in approximately 40mm increments then inspecting the cable for permanent deformation. The process was repeated until failure was observed. Results are shown in the table below along with the minimum recommended bending diameter.

Type	Diameter (mm)	Failure Observed
os4410	323	Yes
os4420	280	No
Spec.	760	min. recommended