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PHASE IX FIBER OPTIC CABLE MICROBENDING AND TEMPERATURE CYCLING TESTS

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ABSTRACT

Optical fibers represent the back bone of the current communication networks. There performance in the field lacks long term testing data because of the continuous evolution of the manufacturing of fibers and cables. An optical fiber cable that is installed in NASA's KSC have experienced a dramatic increase in attenuation after three years of use. The attenuation has increased from 0.7 dB/km to 7 dB/km in some fibers. A thorough study is presented to assess the causes of such attenuation increase. Material and chemical decomposition testing showed that there are no changes in the composition of the fiber which might have caused the increase in attenuation. Microbending and heat cycling tests were performed on the cable and individual fibers. It is found that the increase in attenuation is due to microbending which is caused by excess stress exerted on the fibers. This was the result of manufacturing and installation irregularities.

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Mustafa A.G. Abushagur

1. INTRODUCTION

Optical fiber networks are considered as an ideal medium for communications because of their extremely high data rates, light power throughput, security and immunity to interference. Fiber networks have made the current revolution in information possible. Optical fibers are very small in size vulnerable to environmental influences and need to be cabled to allow ease of handling and protection. The cabling and installation cause an increase in fiber attenuation. After installation and during the life of the cable, estimated to be well beyond 20 years, the fiber attenuation should not increase more than a fraction of a dB/km. Increase in attenuation after installation causes serious problems in system performance such as decrease in signal-to-noise ratio (SNR) and increase in bit-error-rates (BER). Cables after being installed are susceptible to the environmental changes. Penetration of hydrogen in the fiber either due to water infusion or a chemical reaction between the cable components is of a great concern [1-3]. Macrobending and microbending are also major contributors to attenuation increase [4-5].

In this report we present a case study on an optical fiber cable that was installed in 1993 at NASA's Kennedy Space Center. This particular cable demonstrated dramatic increase in attenuation over a very short period of use. The cause of such increase is investigated and reported in this paper. In Section 2 we present the background of the problem. The methodology of testing is introduced in Section 3. Results of material testing is included in Section 4. Microbending test results are given in Section 5. Summary and conclusions are given in Section 6.

2. BACKGROUND

Kennedy Space Center is one of the pioneer users of fiber optic technology because of its need for high data rate networks. It has installed since the early 1970's more than 13,000 miles of fibers between its Space Shuttle facilities. In September 1993, PHASE IX network was installed between five nodes as shown in Figure 1.

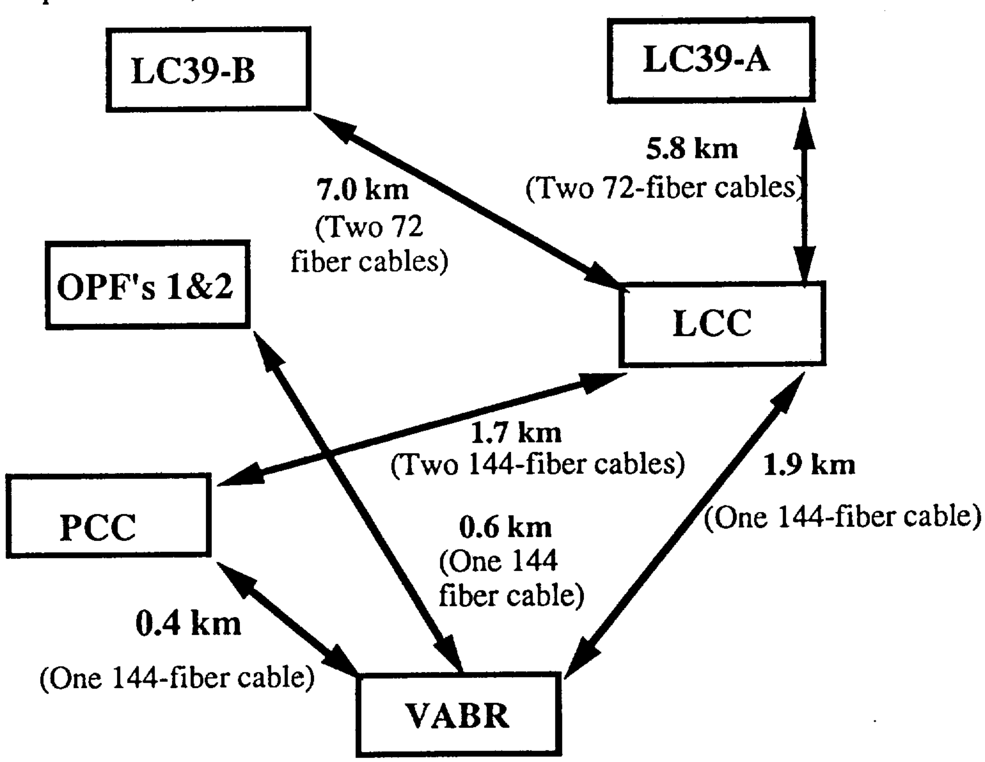

Figure 1. Fiber optic network between the Space Shuttle facilities.

This network is made out of 9 cables totaling 31.9 km. Most of the fibers are graded index multi-mode fibers and three of cables have few single-mode fibers. All the fibers were tested for their attenuation after installation and met the specification of less than 1 dB/km. The fibers were tested again in 1994 and were within specification. In early 1996, a deterioration of performance and an increase in the BER was noticed. Measurement of the attenuation of the fibers on April 26, 1996 showed that most of the fibers attenuation has increased drastically. Attenuations were measured and found to be between 0.8 and 7.8 dB/km with an average of 2.61 for a particular cable (LCC-PCC). These measurements were made at wavelength of 1300 nm. Similar attenuation increase took place at 1550 nm. The single-mode fibers in cable (VABR-LCC) did not show any increase in attenuation. The LCC-PCC cable was then removed from underground for further testing that can not be done while installed. The attenuation of the fibers were immediately measured on April 29, 1996. The attenuation of the fibers were dropped after removal to the range from 0.7 to 3.1 dB/km with an average of 1.23 dB/km , see Figure 2.

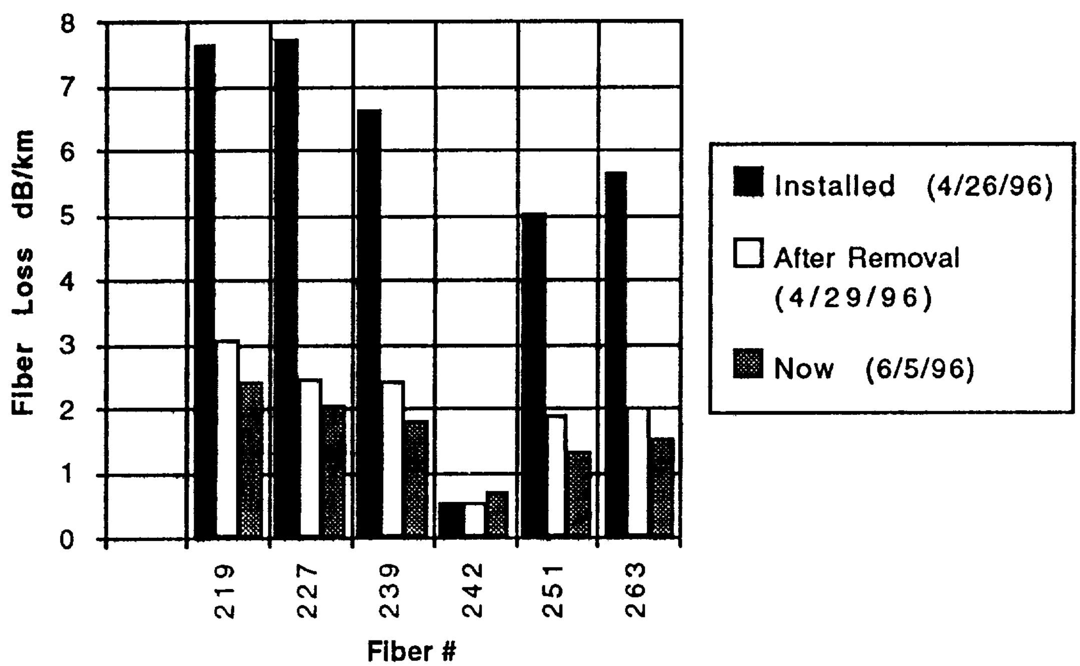

Figure 2 Test fiber attenuation while installed and after removal.

The increase in attenuation can be due to several factors [4]. These are in general can be classified in two categories: material composition change and microbending. The material change is due to infusion or generation of mainly hydrogen especially in an O-H chain. This is the result of water infusion in the core of the fiber or might be generated by a chemical reaction between the different components of the cable, especially the gel compound and fiber coating. Microbending can be caused by cable aging, which results in cable shrinkage, manufacturing and installation problems, or deterioration of the fiber protective coating or the gel.

3. TESTING METHODOLOGY

The removed cable was tested to determine the cause of attenuation increase. The tests were designed to investigate both attenuation sources and were conducted on a set of test articles listed in Table 1. PHASE V cable is a cable that was installed prior to PHASE IX cable in similar environment but still within attenuation specification and is used for comparison purposes. Both cables were manufactured by the same company (Chromatic) using fibers from two different vendors Spectran and Corning). The Spectran and Corning fiber test spools are similar to those fibers in PHASE IX and PHASE V cables, respectively, but never been cabled.

Two separate sets of tests were conducted. The first set focused on the possibilities of a chemical change in the fiber and cable components. The second set focused on microbending and what might have caused it from both fiber and cable elements. The following two section present the tests and results.

TABLE 1 1 km PHASE IX test fibers

Length	Item
1 km	PHASE IX FM66 cable
50 meters	PHASE IX FM66 cable
50 meters	PHASE V cable
50 meters	Spectran fiber test spool
50 meters	Corning fiber test spool
50 meters	Fibers, from PHASE IX cable, in buffer tube
50 meters	Fibers, from PHASE IX cable, without buffer tube

4. MATERIAL AND CHEMICAL TESTS

Fibers used for communication are made from fused silica, SiO_2, and GeO_2 is used to allow the index of refraction variations required. The existence of other impurities in the fiber are the major cause for absorption of the light energy. The lead factor in absorption in the wavelengths of interest is the OH. The tests carried in this investigation were based on determining the contents of the fiber and cable elements. A comparison between a number of test items listed in Table 1 were carried. The samples were analyzed by optical microscopy, inductively coupled plasma (ICP) spectroscopy, anion-ion chromatography, and scanning electron microscopy (SEM) with energy dispersive spectrometry (EDS) and wavelength dispersive spectrometry (WDS). The test data showed that all fiber cores have Ge, Si and O. Spectran fibers contain some P in the core. From all the tests there was no evidence of the presence of any hydrogen increase which might have caused the attenuation problem. The material content of the fiber coatings, the gel, and the cable sheeting were found to be the same for all test samples. There was a visible difference between the primary coating of the Sepctran and Corning fibers. The first seems to have a coarse texture when examined under the microscope. The secondary coating of the Spectran fiber is found to be much softer than that of Corning fibers. In order for the fiber to be protected against outside stresses the primary coating need to be soft and the secondary coating to be hard. If the secondary is soft it fails to protect the fiber and causes an increase in microbending.

White light test was also performed to investigate the material composition change in the fibers. This test provides the means to measure the attenuation of the fiber across the spectrum. The results of this test showed that the fibers in the cable and those on the test reels have similar attenuation spectrum. This concludes that there was no change in the fiber composition and there was no hydrogen infustion into the fiber. However the test showd that Spectran fibers have same attenuation at both 1300 and 1550 nm wavelengths, while Corning fibers have lower attenuation at 1550 nm.

In summary all the chemical and material tests performed leads to the conclusion that the attenuation increase in PHASE IX cable was not caused by material composition change in the fibers but must be some other such microbending.

5. MICROBENDING TESTS

Microbending loss occurs when small, periodic perturbations are introduced in fiber [6-8]. These perturbations in the optical fiber cause it to deviate from being a perfectly circular cylindrical waveguide. So any external stresses on the fiber will cause such loss. This can be the result of the cabling process of the fiber or after installation as a result of the cable shrinkage due to aging or environbmental factors. The fibers are made in such a way to resist microbending by coating them with a soft then a hard plastic coating [9], also by being placed in buffer tubes. These measures do improve the microbending resistance of fibers. Aging problems of the coating itself is need to be studied. In this section we report the investigation that has been carried to determine the microbending loss of the fiber cable understudy. By isolating the different factors that cause the microbending we should be able to determine the major source of this loss. We have performed two separate tests one on the 1 km PHASE IX cable and the second test on the 50 m samples listed in Table 1. The first of these tests is a temperature cycling which simulates the effects of cable shrinkage. By decreasing the temperature of the cable it shrinks and induces stresses on the fibers. Increasing temperature higher than room temperature causes the cable to expand and releases the fibers from the stress. The temperature cycling test started at 20 ^{o}C then lowered to -20 ^{o}C and then raised gradually to 60 ^{o}C and then back to 20 ^{o}C. The second test is a microbending resistance test performed on short lengths of fibers.

5.1 1 km Cable Test

The 1 km cable was placed in a thermal chamber where both temperature and humidity were controlled and monitored, see Figure 3. The cable was on a spool.

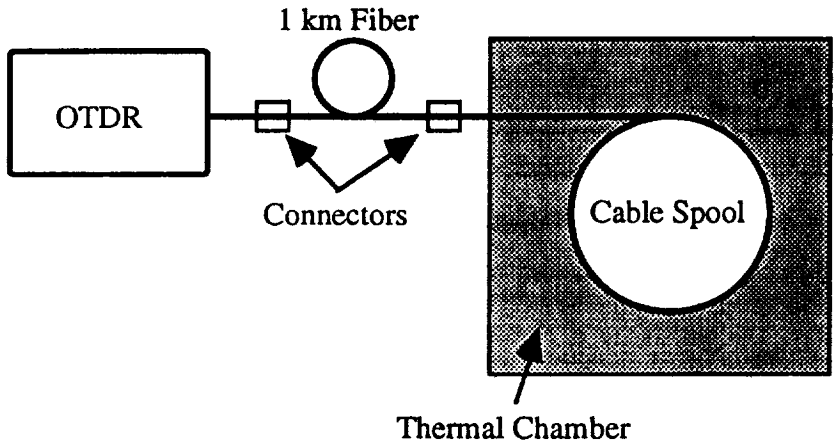

Figure 3. Experimental setup for temperature-attenuation measurement.

The temperature was measured with two thermo-couples one on the surface of the spool and the other was buried will within the cable. The test started at room temperature then reduced to - 20 ^{o} C and then raised to 60 ^{o}C. The temperature in the chamber was left at each step overnight to allow the temperature to reach the inside of the cable. The attenuation of six fibers was measured at each of these temperatures. The attenuation measurements are plotted in Figure 4.

The fiber attenuation is very high at -20 ^{o}C since the cable sheeting contracted and induced stress on the fibers. As the temperature increased the attenuation dropped very rapidly till about 0 ^{o}C and decreased with much slower rate onward. The attenuation of the tested fibers is different. The attenuation range of the fibers is about 3 dB/km at -20 C and all converge to within 0.2 dB/km range at 60 ^{o}C. Fiber 242 tested within specification throughout the tests even when the cable was installed except for the range of temperatures lower than 0^{o}C. This fiber shows the minimum attenuation and does not change much between 0 and 60 ^{o}C. While fiber 219 which demonstrated the highest attenuation while installed displays the highest attenuation throughout the temperature test shown in Figure 4. Fibers 219 and 227 are in the same buffer tube as well as 242 and 251 are in another buffer tube.

The temperature test simulates a number of factors in the field. First, the temperature change throughout the year. Second, the aging effect which results in shrinkage of the cable. These results show the extent of the ability of the fiber to cope with such effects. The fibers are designed to resist such stress. The major function of the primary and secondary coatings of the fiber is to protect the fiber from external stresses [10]. The fibers in the cable show a continuous increase of attenuation with cable shrinkage (temperature decrease). The attenuation dropped as the stress on the fibers was released. The attenuation variations that are shown in Figure 4 might not be due to the cable shrinkage only. The fiber itself might experience attenuation change due to its coating. The second set of experiments attempts to isolate these different factors.

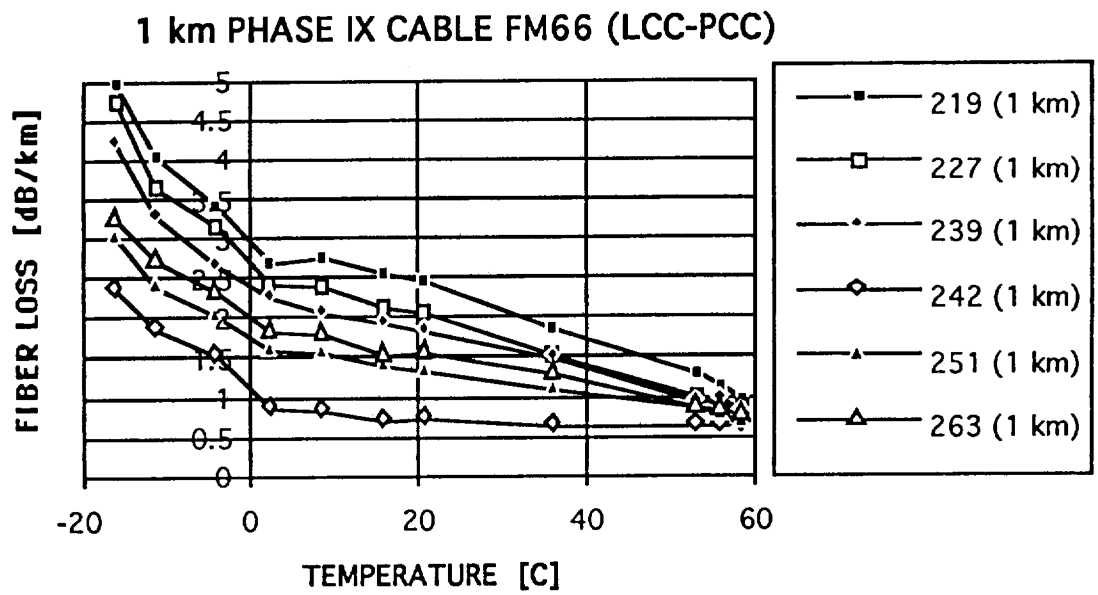

Figure 4. The attenuation of 6 fibers from PHASE IX cable is plotted as the temperature was increased from -20 ^{o}C to 60 ^{o}C.

5.2 50 m Cable and Fiber Tests

The second test conducted is on the 50 m fibers listed in Table 1. The attenuation measurements were made using the power meter instead of an OTDR since the fiber lengths are too short. The fibers and cables are placed in the same thermal chamber. The experimental setup is shown in Figure 5.

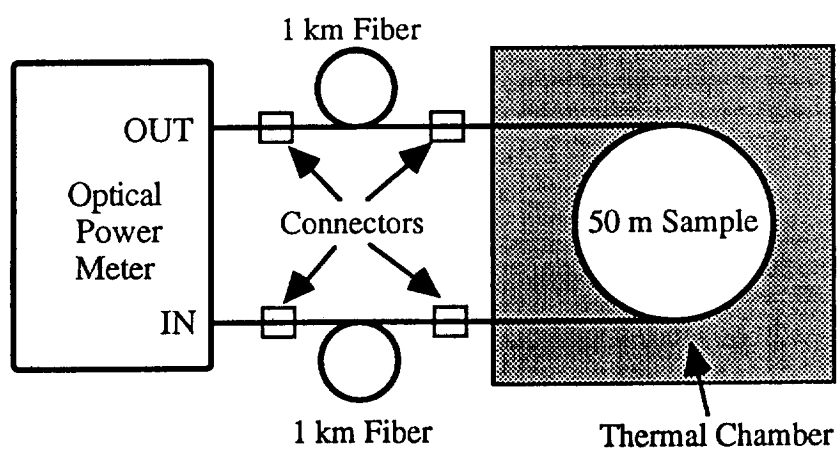

Figure 5 Experimental setup for the 50 m fibers and cables testing.

The temperature was changed from +20 to -20 and then to +60^{o} C. The attenuation was measured after at least four hours from the time the chamber's temperature was changed. Two 1 km fibers were placed one between the light source and the test fiber and the second between the test fiber and the photodetector. The power meter uses as a reference the power output when the network in Figure 5 is connected excluding the test fibers. The attenuation reading of the test fibers includes the loss of one set of connectors, and one fusion splice. The readings for each fiber were taken several times to assure repeatability and accuracy.

The attenuation of the single fibers, two of the test spools and two are taken from PHASE IX cable were measured over the entire temperature range and the results are shown in Figure 6. The attenuation of the test spool fibers stayed almost constant over the temperature range from -20 to 60 °C. The fibers taken from the cable demonstrate the same behavior as those in the cable shown in Figure 5. Their attenuation increases rapidly after the temperature drops below freezing. The only difference between the two sets of fibers is that the environment they have been in over the last four years and the color coating, since the test spool fibers do not have any color coating. The fibers taken from the cable were cabled and installed in the field. Attenuation increase at low temperatures is either due to the color coating or a damage in the primary coating. The fiber glass itself do not exhibit such attenuation change with temperature. As temperature decreases the coatings of the fibers will shrink much more than the fiber itself. This intern causes an induced stress on the fibers leads to microbending losses. The coefficients of expansion of the fused silica is about $5x10^{-7}$ /°C, while it is the range of $10\text{-}22x10^{-5}$ /°C for Polyethylene (PE) which is typically used for the primary and secondary coatings of the fiber.

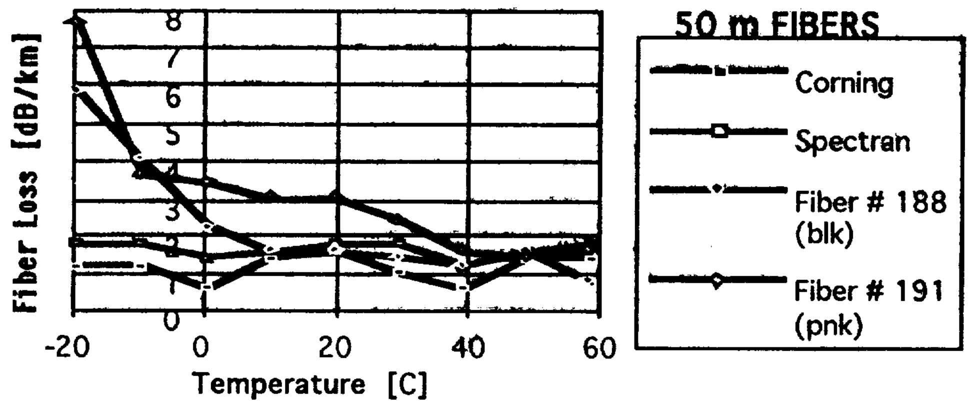

Figure 6

The next set of 50 m fibers tested are those removed from PHASE IX cable but left inside their loose buffer tubes which are filled with gel. These are four fibers with ID# 233, 239, 253 and 263. The attenuation curves as a function of temperature are shown in Figure 7 All fibers show slight attenuation increase for temperatures lower than 0 °C. Fiber 253 demonstrates the best performance. The reason for this increase is similar to that mentioned for the previous set of fibers in Figure 6. Also it can be seen from the comparison between the losses at room temperature and higher for these fibers and those in Figure 6 that the buffer loose tube has no effect on the fiber losses.

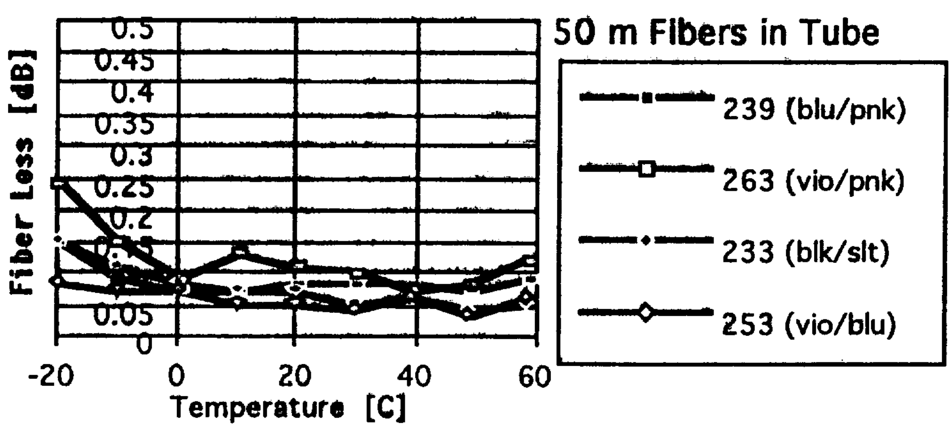

Figure 7.

The third set of 50 m fibers tested are those in PHASE IX cable. The fibers test are those with ID# 219, 227, 239, 242, 251, and 263. These are the same test fibers in the 1 km PHASE IX cable. The attenuation shows similar behavior as those of the 1 km cable. A large increase in attenuation as the temperature drops below freezing. The attenuation is shown in Figure 8. Again here also fiber 242 shows the best performance. The high attenuation of fiber 239 may be due to a bad connector or this particular segment of the fiber has such an attenuation.

The last group of 50 m fibers tested was those in PHASE V cable. The attenuation of these fibers are given in Figure 9. The four fibers test are identified by their colors and those of the loose tube. Two of the fibers did not show any change in attenuation as temperature changes while the other two showed slight increase in attenuation for temperatures below freezing. This leads to fact that either this cable does not shrink as that in PHASE IX or the fibers and in particular their primary coating are able to alleviate the effect of any induced stress. This cable continuously functions within attenuation specifications after five years of operation.

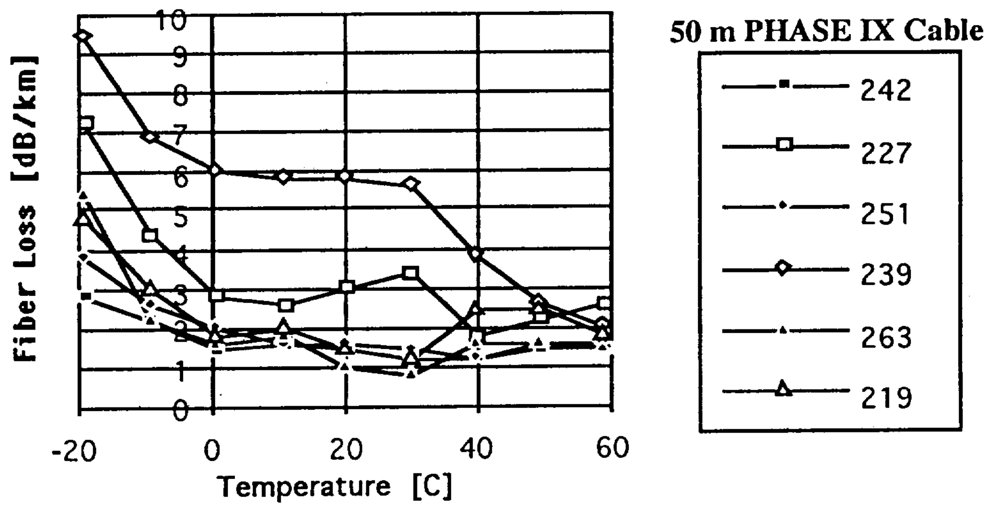

Figure 8

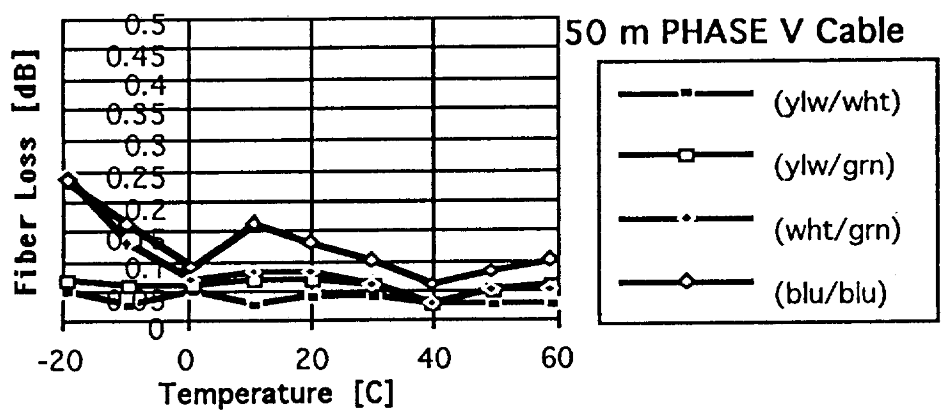

Figure 9

6. SUMMARY AND CONCLUSIONS

The increase in the fiber attenuation in PHASE IX cable installed at NASA's KSC was investigated and analyzed. Material and microbending tests were performed on a set of fibers from the defective cable and others. The chemical composition of the fibers showed that there is no difference between the fibers in the defective cable and others which will cause such an increase in attenuation. There is clearly a difference in attenuation performance between the fibers in PHASE IX cable and others which can be attributed to microbending. The losses of the fibers in the cable decreased when they were taken outside of the cable and left in their loose buffer tube. The increasing rate in attenuation for temperatures below freezing is much higher for cabled fibers. The primary coating of the fibers in PHASE IX cable have more granularity than the test spool fibers which have a more homogeneous primary coating when it is examined under the scanning electron microscope. The reason behind this increase in microbending loss is the result of a number of factors, namely:

1. The shrinkage of the outer jackets of the cable due to aging and temperature change.
2. The degradation of the primary coating of the fiber by either aging or chemical reaction which might have taken place between the gel and the coating.
3. The shrinkage in the outer cable jackets after being stretched during installation. This might cause the cable core central member to be compressed and causes an outward pressure on the fibers.
4. An excess of fiber in the cable during cable manufacturing. This causes the fibers to be forced against each others in the loose buffer tubes.

The question which is still need to be answered is why the fiber attenuation was higher when it was installed? and what causes this increase to appear almost three years after installation? From the preceding tests and the different attenuation contributing factors this increase might be explained as follows. The cable when it was manufactured it has an inherent stress on the fibers caused by excess length in fiber and core strength member. This stress was within the tolerance range of the fiber coating so it did not show in the attenuation measurements. As the cable settled after installation and shrunk due to aging it induced an intolerable stress on the fiber which showed a sudden increase in attenuation. The increase of attenuation might be also a result of the deterioration of the fiber primary coating. This reasoning might justify the increase in attenuation after three years of use but it does not justify the decrease in attenuation resulted when the cable was removed from the duct. The reason which might justify this decrease is that when the fiber was installed it was stretched and by aging the shrinkage triggered the increase in attenuation. As soon as the fiber was removed from the duct the attenuation decreased because it was released from the tension it was under. In summary a number of the factors outlined earlier in this section contributed collectively to the attenuation increase.

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