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Evaluation of Fiber- Optic Connectors

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Evaluation of Fiber Optic Connectors

ABSTRACT

Two fiber optic connectors for field use in high efficiency, long distance systems are described and evaluated in this report. The transmission testing arrangement and other considerations are included with the test results. Techniques for optimizing the transmission through these connectors are also described and the results are reported. Many desirable characteristics of connectors for field use are considered and compared to the ITT and Amphenol connectors tested here.

INTRODUCTION

The fiber optic connector evaluation described here pertains to high efficiency systems using all glass, graded index fibers with a 125- μ m o. d. The systems utilizing these connectors must operate in

the hostile field environment of the Nevada Test Site. The goal is not only to evaluate the connectors, but also to find techniques for improving reliability and performance.

CHARACTERISTICS

The desirable characteristics of connectors for use in field experiments are as follows:

- Rugged construction.
- Reliable, with no loss in transmission after repeated assembly and disassembly.
- Sealed against dust and moisture.
- Impervious to temperature cycles ranging from 0 to 180°F.
- No portion of the bare fiber's outside diameter may be exposed to the atmosphere.
- Easily cleaned.
- Low transmission losses.
- Simple to terminate.
- Small size.
- Possible to refinish the end in case of damage.
- Versatile—can be used with various designs of gas blocked cables with different sizes of fiber buffers.

Connectors manufactured by Amphenol and ITT were evaluated for field use. Both have rugged metal construction, are small in size, versatile, sealed, easily cleaned, have no fiber exposed to atmosphere except the end, and can survive the temperature cycling expected in field use. Both require potting the fiber in the ferrule and optical polishing on the end face. Although the termination process is relatively simple, it requires approximately 30 min for each end after the buffered fibers have been stripped out of the cable. Several thousandths of an inch could be removed from the end of the Amphenol ferrule to repair a damaged fiber face. The fiber is located in a sapphire jewel in the ITT ferrule, which makes it difficult to repolish a severely damaged fiber.

TRANSMISSION TESTS

TESTING ARRANGEMENT

A universal test arrangement was devised that would allow for testing any type of connector. The radiation source and detector must accept any type of ferrule or plug and the arrangement must simulate a long (1 km or greater) transmission link similar to field experiments.

The source normally used for a data transmission link is a light-emitting diode (LED) transmitter; although it proved to be stable enough to use for testing purposes, it is made to accept only one type of plug. A more universal source consists of a tungsten halogen lamp (with a regulated power supply) focused on a small aperture and a microscope objective with a NA (numerical aperture) equal to or greater than the fiber. The aperture size is selected so that its reduced image, formed by the objective, is slightly larger than the core of the fiber (see Fig. 1).

The detector used for the test was an EG&G silicon detector attached to a model 550 radiometer. Various adapters were made to couple the connector plugs to the detector.

The technique used to simulate a long length of fiber with short test sections is to form a "mode

stripper" by wrapping five turns of the fiber around a 1/2-in. rod. This technique strips off the light rays that are marginal and would be lost over a long (1 km) length of fiber (Fig. 2).

This method has been described by other investigators.¹ However, in order to validate its effectiveness, tests were conducted using the mode stripper on short lengths and then comparing them with tests using a 1-km length and no mode stripping. The results agreed within 0.08 dB (the optimum values from 40 data points on each test were compared).

Tests were also conducted to compare an LED transmitter as a source with the microscope arrangement as a source. Transmission test results using the LED show -0.25 dB higher losses. This is probably caused by different illumination distribution characteristics and could vary from one transmitter to another.

1. P. Kaiser, W. C. Yung, N. K. Cheung, and L. Curtis, Loss Characterization of Biconic Single-fiber Connectors, NBS Special Publication 597 Boulder, Colo. (1980) p. 73.

FIG. 1. The microscope illumination source used in a universal test setup.

FIG. 2. The universal transmission testing arrangement.

TEST TECHNIQUE

Two short lengths of fiber approximately 2-m long were terminated with the connector type to be tested. One fiber containing the mode stripper was attached between a source and the detector. The energy transmitted through the fiber was measured, then the detector end was removed and coupled to one end of the second fiber. The other end of the second fiber was coupled to the detector and a second measurement was made. The two readings were then entered into

$$\text{loss in dB} = -10 \times \log_{10} \left(\frac{\text{second measurement}}{\text{first measurement}} \right)$$

to obtain the loss through the connector. Repeatability tests were made to ensure that disconnecting and reconnecting the fiber to the detector produced no detectable variation in the measurements.

This next section covers transmission test results for Amphenol 906 (see Fig. 3).

FIG. 3. A schematic view of an Amphenol 906 connector end termination with a fiber installed.

TEST SERIES

TEST 1

In this series of tests the LED transmitter was used as a source. The connection was made, the value was noted and then the plugs were disconnected and reconnected in a random manner to obtain 10 values. The ends were then switched and the process was repeated. The four different combinations were tabulated, reduced to dB values, and plotted in a histogram showing the spread in values obtained by this random process (see Fig. 4). The maximum, minimum, and average values are of particular interest. The minimum value for each set was established by rotating one end relative to the other and observing the transmission value (radiometric units used were $\mu\text{W}/\text{cm}^2$).

Table I shows the range in values for the four combinations and the optimum values when the connectors are assembled in a random manner.

TEST 2

The same process is repeated using the microscope arrangement as a source. The results are presented in Fig. 5. The average values for this arrangement are -0.25 dB lower than Test 1. The average transmission loss for the four combinations with 40 data points is -1.15 dB.

We next consider transmission test results for ITT FON-FJ-130 (Fig. 6).

TEST 3

The test procedure used for the ITT connectors was the same as the Amphenol Test 2, and the results are presented in Fig. 7. The average transmission loss for the four combinations connected in a random manner with 40 data points is -0.85 dB.

FIG. 4 Amphenol 906 transmission data taken from Table I showing the distribution of 40 points. The four combinations of terminated ends were mated and remated 10 times each in a random manner. The source for this test was an LED transmitter.

TABLE 1. Test No. 1 for Amphenol 906 connectors using an LED transmitter. The terminated ends of the two fiber lengths are numbered 1, 2 for one length and 3, 4 for the other. Loss values are in decibels.^{a,b}

Combination 1			Combination 2		
End No. 1 (transmitter)			End No. 1 (transmitter)		
End No. 2 to 3			End No. 2 to 4		
End No. 4 (detector)			End No. 3 (detector)		
-1.4			-0.84		
-1.9			-0.68		
-1.8			-0.68		
-1.9			-0.86		
-1.6			-1.07		
-1.9			-0.94		
-2.7			-0.64		
-2.0			-0.86		
-2.2			-1.2		
-2.1			-1.3		
-1.95 averaged			-0.9 averaged		
-1.07 optimized			-0.49 optimized		
Combination 3			Combination 4		
End No. 2 (transmitter)			End No. 2 (transmitter)		
End No. 1 to 4			End No. 1 to 3		
End No. 3 (detector)			End No. 4 (detector)		
-1.8			-1.6		
-2.0			-1.2		
-1.4			-0.77		
-1.2			-1.2		
-1.6			-1.2		
-2.0			-1.0		
-2.1			-1.0		
-2.0			-0.9		
-1.4			-1.4		
-1.3			-1.6		
-1.68 averaged			-1.2 averaged		
-1.2 optimized			-0.69 optimized		

^a Average transmission loss for the four combinations coupled in a random manner was -1.4 dB.

^b Average transmission loss for the four combinations when each combination is optimized was -0.86 dB.

FIG. 5. The same Amphenol connectors tested in the same way as in Fig. 4, but using the microscope illumination source.

FIG. 6. A schematic view of the ITT connector end termination with a fiber installed.

FIG. 7. ITT connectors tested in the same way as in Fig. 5.

TRANSMISSION TEST USING OPTICAL COUPLING COMPOUND

Two sources of transmission loss when coupling fibers together are reflections from the faces and Fresnel diffraction. These losses can be minimized by the use of an optical coupling compound. The compound used for the tests was Dow Corning Q2-3067. Two sets of ITT connectors were assembled and disassembled 10 times, each with coupling compound applied to the faces. The results of this test can be seen in Fig. 8. The average transmission loss was lowered from -0.85 to -0.42 dB. One would expect to see the same decrease if the compound were applied to the Amphenol connectors. The lowest transmission loss observed during this series of tests was -0.14 dB.

FIG. 8. ITT connectors using optical coupling compound between the end faces. Again the connections were not optimized, but were made in a random manner as in Fig. 4, 5, and 7.

DURABILITY TEST

During the course of the transmission tests and after they were completed, the faces were inspected for damage. No damage was observed despite the repeated assembly and disassembly. One reason for this is that the glass faces never come into contact. During the polishing process, the glass is removed at a faster rate than the surrounding material leaving the fiber face a few μm below the surrounding surface. In the case of the ITT ferrule, the fiber is mounted in a sapphire jewel which polishes very slowly. The Amphenol ferrule has four stainless steel pins that fix the fiber location. When glass polishing compound is used as a polishing agent,

there is little material removed from the soft stainless steel pins. The recessed faces were observed in photographs taken on a scanning electron microscope and interferograms (see Figs. 9(a) and 9(b)).

After repeated mating of the Amphenol connectors, the plastic sleeve that aligns the ferrules tends to stretch. When this is observed, it should be replaced with a new sleeve. Care must be taken to clean the ITT ferrules before assembling them in the connector body, because the fit is very close and galling can occur.

ILLUMINATION PROPAGATION IN THE CLADDING

As an adjunct to these tests, transmission through the cladding for short lengths of fibers was investigated. All-glass, graded-index, $125\text{-}\mu\text{m}$ o.d. fibers with a $62\text{-}\mu\text{m}$ core and with lengths as short as 0.5 m were tested. Launching conditions were varied from collimated illumination to matched NA and over-matched NA. The output was scanned with a radiometric measuring instrument called a micro-image-scanner. During the test, the NA of

the collecting optics was varied from a value that matched the fiber to one that over-matched the fiber's NA. The scanning aperture relative to the magnified image of the fiber core was 1:4.5. The maximum amount of illumination that was measured in the cladding for any test was -20.0 dB (1%) relative to the core. The illumination profile is shown in Fig. 10.

FIG. 9. (a) A photograph of an Amphenol 906 connector taken with a scanning electron microscope. The instrument was used in the derivative mode so the turned down edges appear to be turned up. The fiber can be seen in the space between the four pins and slightly recessed. (b) The fringes on the fiber are spaced closer together relative to the fringes on the pins, showing again that the fiber is recessed.

FIG. 10. An illumination profile of the light emitted from a fiber. The fiber has a $62\text{-}\mu\text{m}$ core and a $125\text{-}\mu\text{m}$ o.d. Light from cladding is approximately -20 dB below the peak illumination in the core. Some edge integration can be seen due to the size of the scanning aperture.

CONCLUSION

Either of these connectors meets all the criteria set forth and is suitable for field applications. For optimum performance the ferrules should be rotated to a "best aligned" position by observing the transmission with a power meter. The receiver detector response can also be used for this purpose. Excessive pressure should not be applied during the alignment process, because damage to the ferrule

end faces can result. Further reduction in transmission losses can be achieved by use of optical coupling compound.

Using only four connectors of each type does not provide a large statistical base. However, the results should be indicative of what one can expect to achieve with these units.