SINGLE-MODE FIBER GEOMETRY AND CHROMATIC DISPERSION: RESULTS OF INTERLABORATORY COMPARISONS

Timothy J. Drapela, Douglas L. Franzen, and Matt Young
National Institute of Standards and Technology
325 Broadway
Boulder, CO 80303

The National Institute of Standards and Technology (NIST) recently completed two interlaboratory comparisons with members of the Telecommunications Industry Association (TIA). Participants included most major fiber and cable manufacturers in North America. We evaluated test procedures for geometry and chromatic dispersion. In both cases, the measurement spread in the industry was due mostly to systematic differences among laboratories. Measurement agreement would be significantly improved through the use of reference fibers.

GEOMETRY

A previous international geometry comparison (1989), organized through CCITT and coordinated in North America by NIST, gave a spread (1 σ) of 0.38 μm for cladding diameter. An interim report concluded that the agreement should be improved if the industry wanted to further reduce tolerances. Participants in the comparison received fiber samples consecutively cut from fiber spools; consequently, sample nonuniformity could have influenced the results.

In the present study, participants used the gray scale method to measure cladding diameter, noncircularity, and concentricity error. The gray scale method, based on video microscopy, is the most common method used by industry and is described in TIA test procedure FOTP-176.[1] A near-field image of a cleaved fiber end is obtained with a video microscope. The outside boundary of the cladding is digitized, and an "edge table" is compiled. Cladding diameter is then determined by curve-fitting to the edge table data. Calibration is accomplished by measuring reticles and/or reference fibers of known dimension.

Participants in the TIA comparisons measured the same cleaved fiber ends, so sample uniformity was not an issue. An individual fiber was contained in a protective metal housing designed to fit into a gray scale system, Fig. 1. In this configuration, the fiber is extended for measurement; the brass barrel can rotate and is indexed to indicate a specific angular orientation.

Results from TIA members were compared to the diameters measured at NIST with a contact micrometer and a scanning confocal microscope (SCM).[2] The contact micrometer measures fiber diameter approximately 1 mm from the cleaved end. The micrometer jaws consist of a fixed cylinder (the anvil) and a moveable spindle, both made of polished, hardened steel. Differential displacement of the spindle is measured by an optical interferometer. In the SCM, the fiber endface is scanned across a focused HeNe laser beam, and the location of the cladding edge is determined by observing the reflected light. The contact micrometer and SCM have been compared, and cladding diameter measurements agree within 30 nm. When measuring the comparison fibers, NIST measured cladding diameter at four angular orientations: 0°, 45°, 90° and 135°.

Comparison of cladding diameters of five fiber samples are shown in Fig. 2. The measurement spread (1 σ), averaged over all fibers, for the eight participants is 0.15 μm. This is a substantial improvement over the previous comparison and reinforces the need to measure the same fiber ends. Results shown in Fig. 2 are the differences for each measured fiber with respect to the NIST contact micrometer (solid horizontal line). The NIST value for a given fiber is the average of the 0°, 45°, 90°, and 135° diameters. The square data points are the four-diameter participant averages, whereas the circular points are the participant values using the curve-fitting method described in FOTP-176. With the exception of Participant 4, there is no statistical difference between the two diameters. Figure 2 indicates that the overall measurement spread is largely due to systematic differences among participants; that is, a given participant's results are closely grouped. Table 1 is the average offset and standard deviation of the offset for each participant with respect to NIST. The average offset standard deviation among gray scale participants is 0.027 μm. If each participant's data were corrected for an offset, the overall measurement spread would dramatically decrease; this emphasizes the need for reference fibers. Comparison results were also obtained for noncircularity, with a worst-case measurement spread (1 σ) of 0.07 %, and for concentricity error, with a worst-case measurement spread (1 σ) of 0.04 μm.

CHROMATIC DISPERSION

The comparison of test procedures for measuring chromatic dispersion in single-mode fibers was carried out over a two-year period, from mid-1989 through late 1991. Seven fibers, donated by various fiber manufacturers, were used in the comparison. Five of the fibers were dispersion unshifted; two were dispersion shifted. The fibers were color coded for identification and put into a loose-tube buffer. This cable was then cut into 5.1 km and 2.7 km lengths. Participants were asked to measure the zero-dispersion wavelength λ_0, the dispersion slope at that wavelength, S_0, and the dispersion coefficient $D(\lambda)$ at 1310 nm, for both lengths of fiber.

Six participants used the differential phase shift method, in which $D(\lambda)$ is determined from the differential group delay between two closely spaced wavelengths. λ_0 and S_0 are determined by curve-fitting to the dispersion data. The source is typically one or more sinusoidally modulated LEDs filtered by a monochromator. Further details of this method are given in FOTP-175.[1]

Three participants used the phase shift method, in which spectral group delay data are obtained from measuring the relative phase shifts of modulated sources at three or more wavelengths. λ_0, S_0, and $D(\lambda)$ are determined from equations fitted to the spectral group delay. The sinusoidally modulated source can be either multiple laser diodes or filtered LEDs. Further details of this method are given in FOTP-169.[1]

Three participants used the time domain method described in FOTP-168.[1] In this method, a Nd:YAG fiber Raman laser or several laser diodes are used, and the spectral group delay data at several wavelengths are obtained directly in the time domain. Dispersion parameters are obtained by fitting to the spectral group delay data.

For dispersion-unshifted fibers, the fit to the group delay for all three methods is a 3-term Sellmeier equation; the dispersion is the first derivative of this equation.

We restrict our analysis here to the dispersion-unshifted fibers. Overall results have been calculated, in the form of mean values $\pm$ 1 σ for each fiber. Long and short lengths exhibit very similar behavior in these statistics. The overall measurement spreads (1 σ) averaged over the five long dispersion-unshifted fibers, are 0.93 nm for λ_0, 0.0016 ps/(nm^2·km) for S_0, and 0.08 ps/(nm·km) for D(1310 nm).

We also examined the relative offsets among participants. Figure 3 shows the offsets from the average measured zero-dispersion wavelength value for each fiber, for each of the participants. Each point for a given participant represents one of the five long dispersion-unshifted fibers. Similar plots have been made for S_0 and D(1310 nm). These three graphs are similar in the conclusions that can be reached. There are no readily identifiable systematic offsets between measurement methods. There are, however, clear systematic offsets among participants.

Analysis can be done on the statistics of these offsets. An average offset taken over all five dispersion-unshifted fibers and the standard deviation of the offset is calculated for each participant. This standard deviation is related to the participant's random error. Table 2 shows the average value of the zero-dispersion wavelength offset and the offset standard deviation for each participant, for the long fibers; the average offset standard deviation is 0.16 nm. For the short lengths, the corresponding value is 0.35 nm. In this case, the length of the fiber has a significant effect. The average offset standard deviations for the long fibers are 0.0004 ps/(nm^2·km) for S_0 and 0.016 ps/(nm·km) for D(1310 nm). For the short fibers, these values increase to 0.0008 ps/(nm^2·km) for S_0 and 0.03 ps/(nm·km) for D(1310 nm). The average offset standard deviations are all roughly twice as high for the short lengths than for the long lengths. This implies larger random error for shorter lengths. The main reason for including long and short lengths in this study was to verify this effect.

Analysis of the dispersion-shifted fibers is more complicated but is worth brief mention. The overall statistics for these fibers compare favorably with the previous five fibers. The offset statistics, on the other hand, are not as precise. The average offset standard deviations are roughly double.

This comparison shows acceptable overall spread in dispersion measurements by three different methods, with no apparent method-dependent offsets. Also, for these lengths of fiber, differences are due to systematic offsets among participants, with the random error small. If better agreement is desired, calibration fibers could be used to significantly reduce the offsets. This possibility is currently being examined.

ACKNOWLEDGMENTS

We thank the following organizations for their participation in these comparisons: Alcatel Cable Systems, Inc.; AT&T Bell Technologies; Bellcore; Corning, Inc.; GTE Laboratories, Inc.; Litespec, Inc.; Northern Telecom; Photon Kinetics; Raynet Corporation; Siecor Corporation; Spectran Corporation; York Technology, Inc. We thank Casey Shaar of Photon Kinetics for providing the design of the fiber housings.

REFERENCES

1. Fiberoptics Test Procedures (FOTPs) can be obtained from: Telecommunications Industry Association-Electronic Industries Association, 2001 Pennsylvania Avenue, N.W., Washington, D.C. 20006.

2. M. Young, S. E. Mechels, P. D. Hale, "Optical Fiber Geometry: Accurate Measurement of Cladding Diameter," paper presented at Conf. on Precision Electromagnetic Measurements, Paris, June 9-12, 1992; IEEE Trans. Inst. and Meas. (submitted).

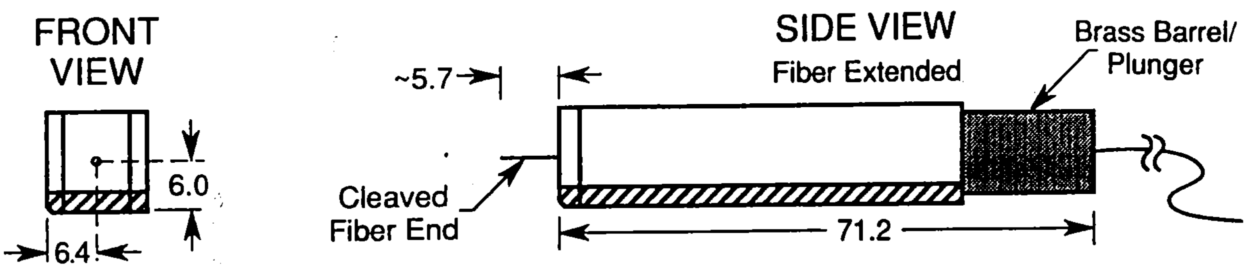

Figure 1 Diagram of fiber housing used in the geometry comparison, showing brass barrel pushed forward and hence, fiber end extended. (Dimensions are in millimeters.)

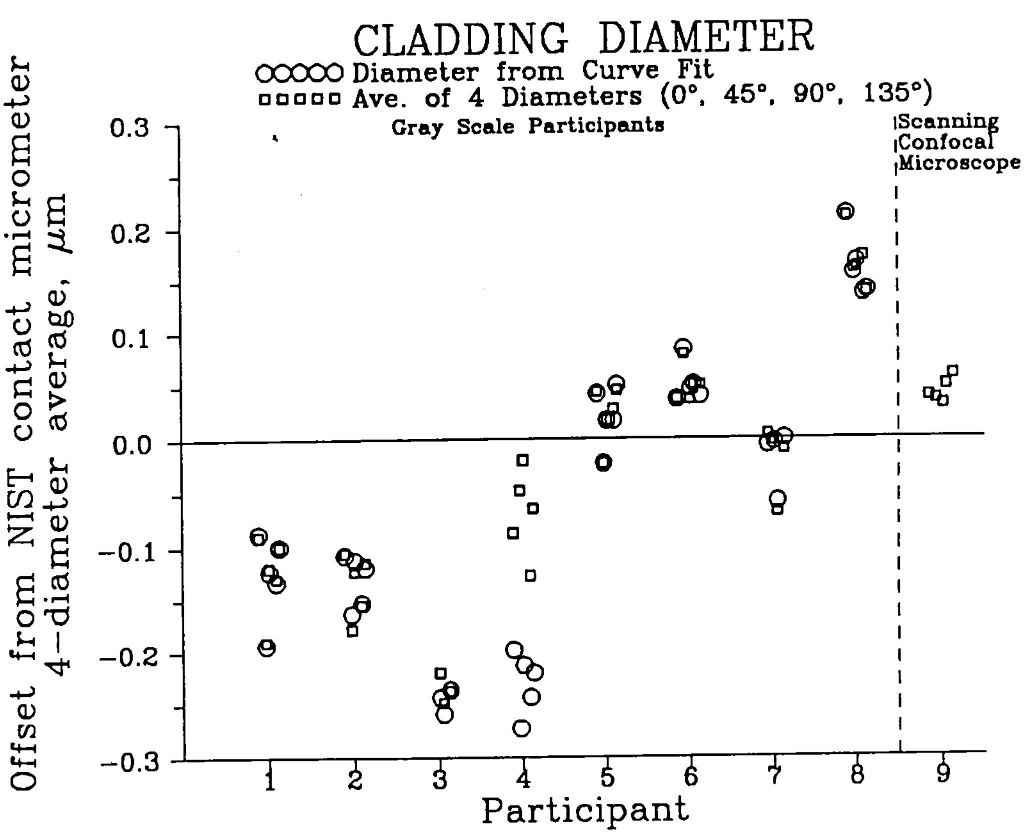

Figure 2 Participant offsets from NIST contact micrometer average values of cladding diameter, for five comparison fibers. Gray scale offsets of best-fit and 4-diameter average values are shown. SCM values are shown for comparison.

CLADDING DIAMETER
GRAY SCALE BEST-FIT OFFSETS FROM
NIST CONTACT MICROMETER
4-DIAMETER AVERAGE

Participant	Average Offset, μm	Standard Deviation, μm
1	-0.127	0.041
2	-0.131	0.025
3	-0.246	0.012
4	-0.229	0.029
5	+0.021	0.029
6	+0.052	0.019
7	-0.017	0.028
8	+0.163	0.030
	Avg.	0.027

Table 1 Average and standard deviation of offsets of gray scale best-fit values from NIST contact micrometer four-diameter average values of cladding diameter, taken over five housed fiber samples, for each participant.

ZERO-DISPERSION WAVELENGTH
OFFSETS FROM AVERAGE VALUES
LONG FIBERS (5.1 km)

Participant	Average Offset, nm	Standard Deviation, nm
1	-0.86	0.08
2	+0.21	0.11
3	-0.28	0.12
4	+0.85	0.08
5	-1.10	0.15
6	+0.43	0.13
7	+1.09	0.08
8	+0.26	0.14
9	+1.04	0.06
10	-1.79	0.16
11	+0.61	0.51
12	-0.45	0.35
	Ave.	0.16

Table 2 Average and standard deviation of offsets from average values of zero-dispersion wavelength, taken over five long dispersion-unshifted fibers, for each participant.

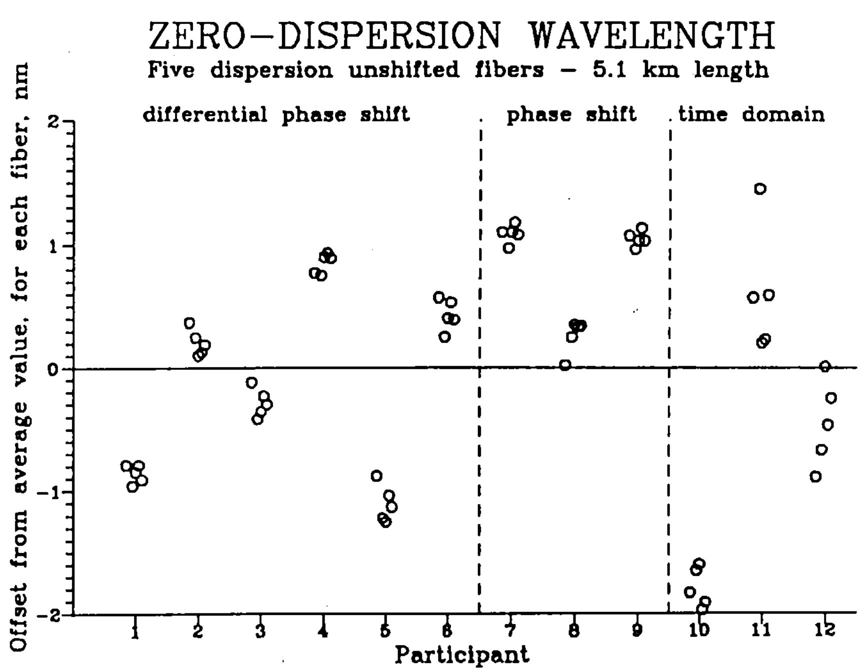

Figure 3 Participant offsets from average values of zero-dispersion wavelength, for long lengths of five dispersion-unshifted fibers. (Five points per participant correspond to measurements on five fibers.)