Optical Fiber Characterization

NBS Special Publication 637, *Optical Fiber Characterization* [1], is a two-volume compilation of previously published NBS Technical Notes concerning the characterization of optical fibers used for telecommunications. The Technical Notes appeared in the late 1970s and early 1980s, which was the period of commercial infancy of optical telecommunications fiber. During that period, the commercially viable fibers were of the multimode type rather than single mode; that is, they supported the transmission along the fiber of a number of electromagnetic modes having different combinations of electric field and magnetic field configurations. Consequently, SP 637 (as this publication is commonly called) is mainly concerned with the characterization of multimode fiber. While single mode fibers could be fabricated, the technology to exploit them was not readily available at the time. In the earliest fiber, large concentrations of the highly polar hydroxyl radical (OH) in the glass caused high loss at the long wavelengths effective for single-mode operation. Also, the small core size of single-mode fiber requires connectors, splices, and special sources to be aligned with high dimensional accuracy, and it took years to develop such components that could be manufactured at an acceptable cost. Multimode fibers with core diameters in the 50 μm to 100 μm range could be easily joined with low loss, and light from laser diodes with large emitting areas could be readily launched into the large cores in a simple manner. The large core size also allowed the use of LED (light emitting diodes) sources in designing practical systems.

There were no standard measurement procedures available in the early period of development of optical fiber. An effort was started by the military to draft "mil standards" for fiber. It was a useful start, and a standards document was produced. However, the technical challenges were difficult, and rapid changes were occurring in the industry. A larger United States standards effort, principally among manufacturers, started in the Electronic Industries Association (EIA). NBS staff attended the first EIA organizational meetings where attendees determined the important technical areas and established a network of committees. It was soon evident that there was a role for NBS. Manufacturers had developed their own measurement methods, and in many instances different technical

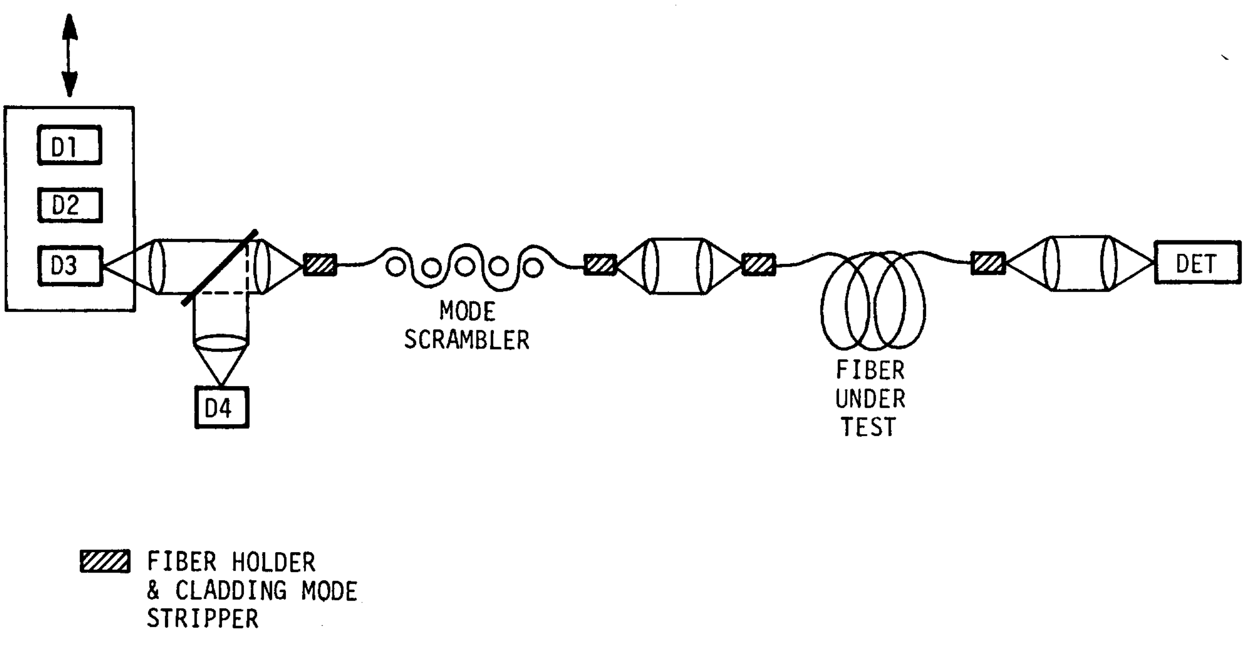

Fig. 1. A schematic diagram of early apparatus used to measure material dispersion by simultaneous propagation of pulses from pairs of laser diodes. Such measurements are important in avoiding interference between pulses of different wavelengths that are transmitted down a single optical fiber.

approaches were being employed. NBS acted as a neutral party to evaluate many procedures through round robin comparisons.

Fiber optic technology is measurement intensive. Measurements can take place at fabrication, cabling, incoming inspection, and installation. Compared to single mode fibers, multimode fibers present significant characterization problems; thus quality control measurements were a substantial production cost for multimode fiber. The large core sizes result in hundreds of propagating waveguide modes having independent loss and group delay. Consequently, the transmission properties depend on how light is launched into the fiber; i.e., which waveguide modes are excited by the source. An early measurement round robin in 1979, conducted by NBS, revealed significant interlaboratory differences in the measurement of the attenuation coefficient. Such differences resulted from difficulties in achieving a common distribution of launched light and in following a specified methodology. In subsequent years, NBS worked closely with the Electronic Industries Association (EIA, which gave birth to the Telecommunications Industry Association), at its request, to standardize light launch conditions for measuring the transmission properties of graded-index optical fibers. Many of the issues involved in selecting and creating the launching conditions are contained in the chapters of SP 637.

Another factor adding to measurement uncertainty was the use of multiple test methods based on different technical approaches. Standards groups often allowed a multiplicity of test methods for any given parameter. A large part of the technical effort at NBS during this period was to determine the systematic differences between test methods.

It is of interest to put the work contained in SP 637 in historical perspective. Multimode fiber dominated the first telecommunication systems. The first wavelengths utilized were near 850 nm, followed later by applications at 1300 nm. In the early 1980s, the OH content of the glass, and consequently the attenuation, was greatly reduced. The highly desirable properties of single mode fiber became technically accessible, and operation was possible at a wavelength of 1550 nm, where the attenuation is a minimum. Compared to multimode fiber, single mode offers both reduced attenuation and substantially higher bandwidth. Thus today's long distance and metropolitan networks consist solely of single mode fiber.

Nevertheless, multimode fiber has found an important niche in high speed local area data networks with concepts such as "fiber to the desk" and "gigabit ethernet." The large core fiber offers inexpensive connections, high launching efficiency with large area sources, and the use of inexpensive plastic optics. Data rates for the more advanced systems are in the range of 1 Gbit/s to 10 Gbit/s. The Vertical Cavity Surface Emitting Laser (VCSEL) is a common source for high-speed multimode networks. This laser typically operates near 850 nm, which was the first wavelength window in the early multimode systems. Therefore, the contribution of SP 637 remains technically relevant to current high-speed local area networks.

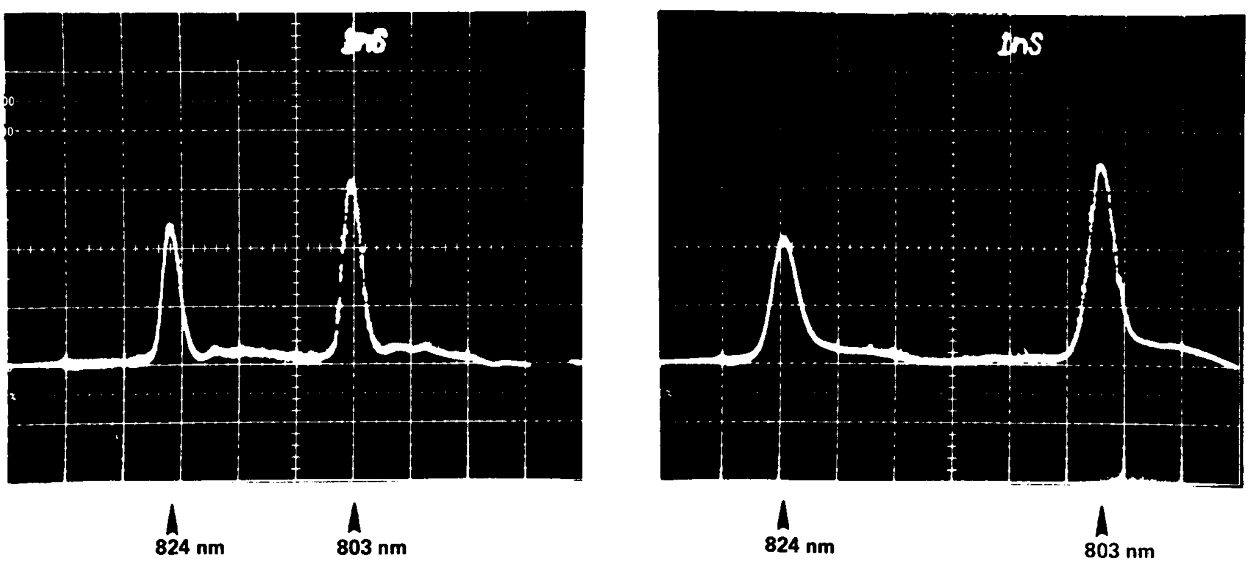

Fig. 2. An example of group-delay material dispersion with pulses at 824 nm wavelength (left pulse in each oscilloscope photograph) and 803 nm wavelength before (left photograph) and after propagating through a 1 km length of fiber.

Among the measurements on multimode optical fiber discussed in SP 637, attenuation is perhaps the most important fiber parameter because it establishes the maximum length of fiber along which signals may be sent without requiring a repeater (a device that amplifies the signal for transmission along the next section of fiber). At the time SP 637 appeared, a premium was charged for lower loss fibers, so there was a financial incentive for reliable values of the attenuation parameters. Next in importance is probably bandwith, a measure of the potential information carrying capacity of the fiber. Bandwidth is specified in the frequency domain, but can be measured in either the time or frequency domains. SP 637 describes methods for obtaining 200 ps duration pulses from laser diodes for time-domain measurements, along with methods for launching the light into the fiber. SP 637 also describes a system for measuring the fiber frequency response directly in the frequency domain.

The author also discusses the radiation pattern of light at the exit end of the optical fiber and describes systems for measuring radiation patterns, giving comparisons with other methods for measuring core diameter and "numerical apertures." The radiation pattern measurements are straightforward and without much controversy in their implementation, but they are important because they are commonly practiced in the trade and commerce of fibers.

SP 637 also describes a technique called "refractive-ray scanning (RNF)" to determine the refractive index profile across a fiber diameter. The index profile is not a parameter specified in the trade and commerce of fibers, but it is very important to fiber manufacturing. Only by having the appropriate near-parabolic shaped index profile can the full bandwidth potential of graded-index fibers be achieved. SP 637 describes the construction of an RNF system and a novel method for calibrating the absolute value of refractive index using a series of index-matching fluids of known refractive index.

The efforts described in SP 637 provided the impetus for future NBS/NIST programs in optical fiber metrology. In following years, the work was greatly expanded and concentrated on single-mode fibers. Within NIST, staff was added, and the program grew from project to group status. Fiber metrology is now a major component of the Optoelectronics Division. In 1980, NBS staff initiated the "Symposium on Optical Fiber Measurements." This conference, held biennially for 20 years, is one of the premier international conferences on optical fiber measurements. NIST staff now chair committee positions within the Telecommunications Industry Association and serve on the program committees of major conferences devoted to lightwave communications.

Douglas L. Franzen joined NBS as a National Research Council Postdoctoral Fellow in 1970 and spent his first six years developing improved methods of measuring the output power of lasers. In 1976, he and two colleagues initiated the Optical Fiber Measurement Program at NBS. Thirteen standards, which provide the measurement basis needed by manufacturers to control and enhance quality and to demonstrate compliance with purchase specifications, are based on Franzen's research. In 1980, he helped found the biennial Symposium on Optical Fiber Measurements, and he has continued to serve as its general chairman. His work has been recognized by a number of awards, including election as a Fellow of the Optical Society of America; Department of Commerce Bronze, Silver, and Gold Medals; the Applied Research Award of NIST; and the NTT (formerly Nippon Telegraph and Telephone Corporation) Director's Award, for collaborative work on an innovative optical sampling instrument.

Gordon W. Day has been a leader in optoelectronics work at NBS/NIST since 1976. He has advanced the NIST efforts to meet special measurement needs of the emerging lightwave communications industry, especially for optical fibers, lasers, and optical fiber sensors. In 1993 he was given the responsibility of forming a new division at NIST dealing with optoelectronics. Day's research has been in the metrology related to optoelectronics and has resulted in more than 130 publications and a variety of awards, such as the Gold and Silver Medals of the Department of Commerce, two IR-100 Awards from R&D Magazine, and a Technology Transfer Award from the Federal Laboratories Consortium. He is a fellow of both the Institute of Electrical and Electronics Engineers (IEEE) and the Optical Society of America. In 1999-2000 he was President of the IEEE Lasers and Electro-Optics Society.

Prepared by D. L. Franzen.

Bibliography

[1] G. E. Chamberlain, B. L. Danielson, G. W. Day, D. L. Franzen, R. L. Galawa, E. M. Kim, and M. Young, *Optical Fiber Characterization, Volumes 1 and 2,* NBS Special Publication 637, National Bureau of Standards, Gaithersburg, MD (1982).