STANDARD REFERENCE FIBERS FOR CALIBRATION OF THE OPTICAL TIME DOMAIN REFLECTOMETER

B. L. Danielson
C. D. Whittenberg
T. Drapela
Optical Electronic Metrology Group
National Institute of Standards and Technology

Calibration of optical time domain reflectometers by military and industrial users can be achieved by a number of published test procedures. For some performance parameters, a particularly convenient method for establishing measurement verification and traceability to national standards is through the use of a standard reference fiber. NIST has begun a program to evaluate such test lightguides. Prototype standard reference fibers have been characterized for spectral attenuation, group delay, group index, and length. This paper describes measurement methods and tolerances for these devices.

INTRODUCTION

The optical time domain reflectometer (OTDR) is a versatile instrument that is widely used in optical system diagnostics [1]. The performance specifications for OTDRs can be evaluated by detailed test procedures such as those described in Reference 2. A standard reference fiber (SRF) is a transfer standard that can be used in interlaboratory comparisons of these procedures and as a calibration device that provides measurement assurance at specific test points where the more detailed evaluation facilities are not possible. The SRFs described are commercial, single-mode fibers selected for uniform backscatter and rewound on a reel under controlled tension. The reference fiber is then characterized by transmittance measurements, which are generally more accurate than the corresponding backscatter estimates. For the initial fibers, the characteristics chosen are spectral attenuation, group index, group delay (at 1300 nm), and length.

The length of optical fibers can be measured either mechanically or optically. Properly calibrated winding machines can yield accurate and reproducible length measurements of fairly long (kilometer) samples. A more versatile approach is based on the time of flight of an optical pulse. Delay can be mapped into distance through the relation:

$$L = \frac{cT_d(\lambda)}{N(\lambda)} \tag{1}$$

where $T_d(\lambda)$ is the group delay of the optical pulse, $N(\lambda)$ is the group index, and c is the speed of light in a

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vacuum. Knowledge of both $T_d(\lambda)$ and $N(\lambda)$ at a common wavelength is sufficient to determine length.

SPECTRAL ATTENUATION

We use the cut-back method to measure the fiber attenuation as a function of wavelength in the spectral interval 1200-1600 nm. A computer-stepped monochromator selects the wavelength from a white-light source. A measurement consists of two data sets: second on a short reference length (2 m) of the same fiber. Attenuation is calculated from the difference between corresponding points in the two data sets. Details and required procedures of the cut-back method are outlined in Reference 3. Attenuation values have an estimated uncertainty of approximately 0.01 dB/km. A schematic diagram of the experimental apparatus is shown in Fig. 1.

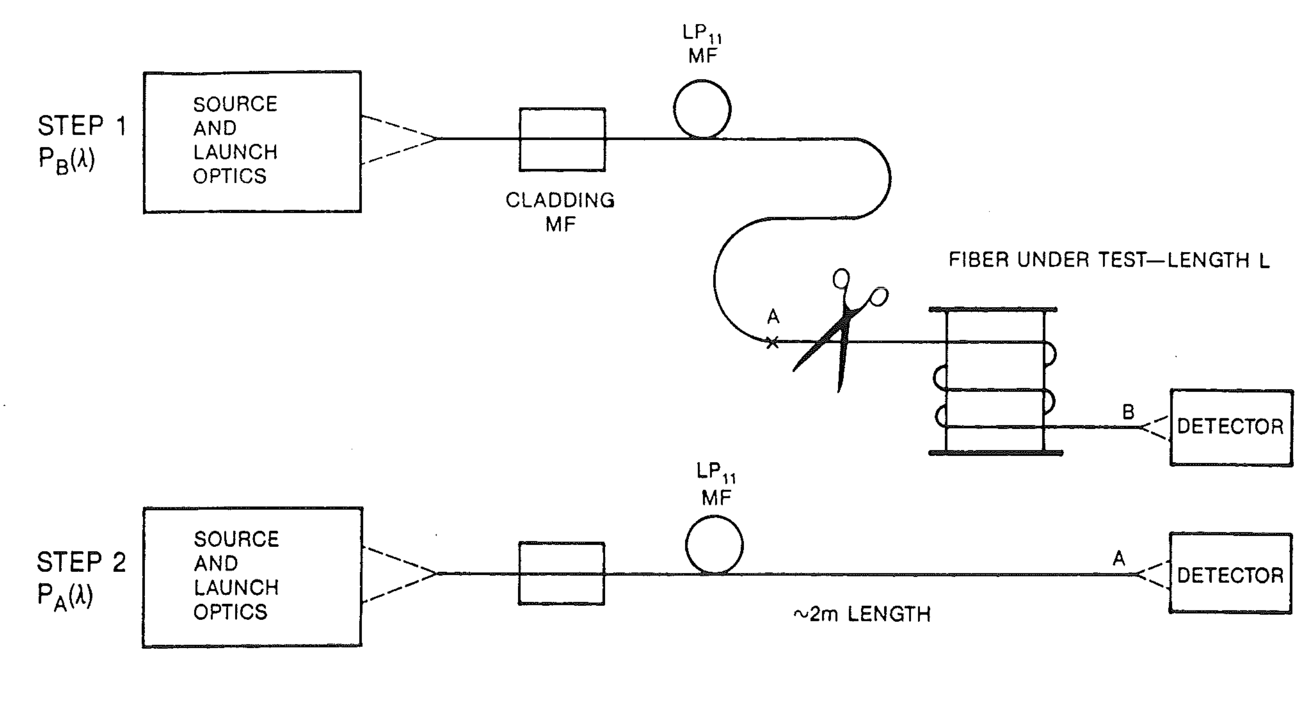
GROUP INDEX

Group index varies from sample to sample. Therefore, for the most accurate determinations of length, N should be measured for the fiber or cable under test. For this purpose we have developed an interferometric method that requires only about 5 cm of fiber [4]. The sample is placed in one arm of a Michelson™ interferometer as illustrated in Fig. 2. The group index can be obtained from the resulting signature when the other arm is scanned. If L_{AIR} is physical length measured by a travelling microscope and L_{OPT} is the optical path length between visibility maxima (see Fig. 3), then:

$$N = \frac{L_{opt}}{L_{AIR}} \qquad (2)$$

One of the main concerns with this method has to do with the uniformity of the reference fiber. Since the fiber can be sampled only at its ends, we need information on how the transmission properties vary between the ends. Studies on production fibers of a similar kind have demonstrated that the properties of interest are uniform to within 0.02 percent [5].

The total uncertainty of the group index determination, including sampling errors, fiber end angles, wavelength offsets, and precision, is about 0.03 percent.



$$\alpha(\lambda) = \frac{10}{L} \log \frac{P_A(\lambda)}{P_B(\lambda)} \frac{dB}{\text{UNIT LENGTH}}$$

Figure 1. Schematic Diagram of the Cut-Back Method for Attenuation

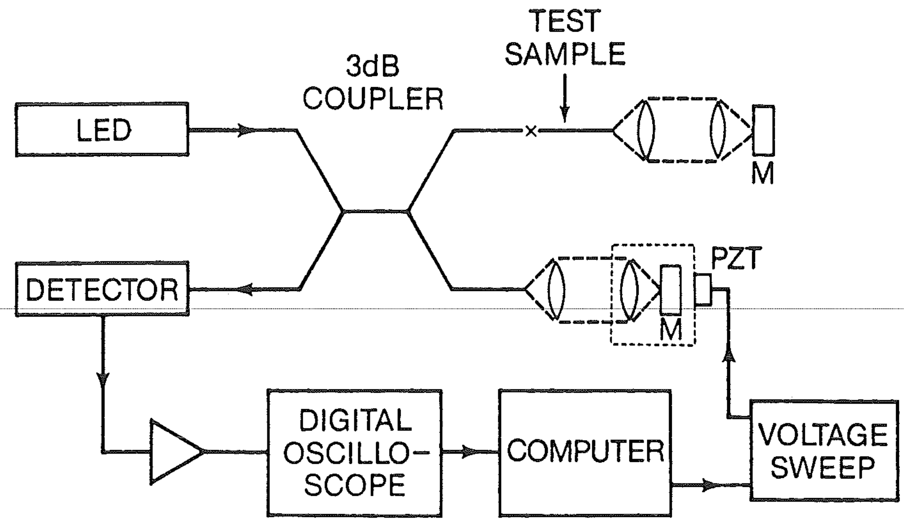


Figure 2. Experimental Setup for Measurement of Group Index with the Asymmetric Scanning Michelson Interferometer

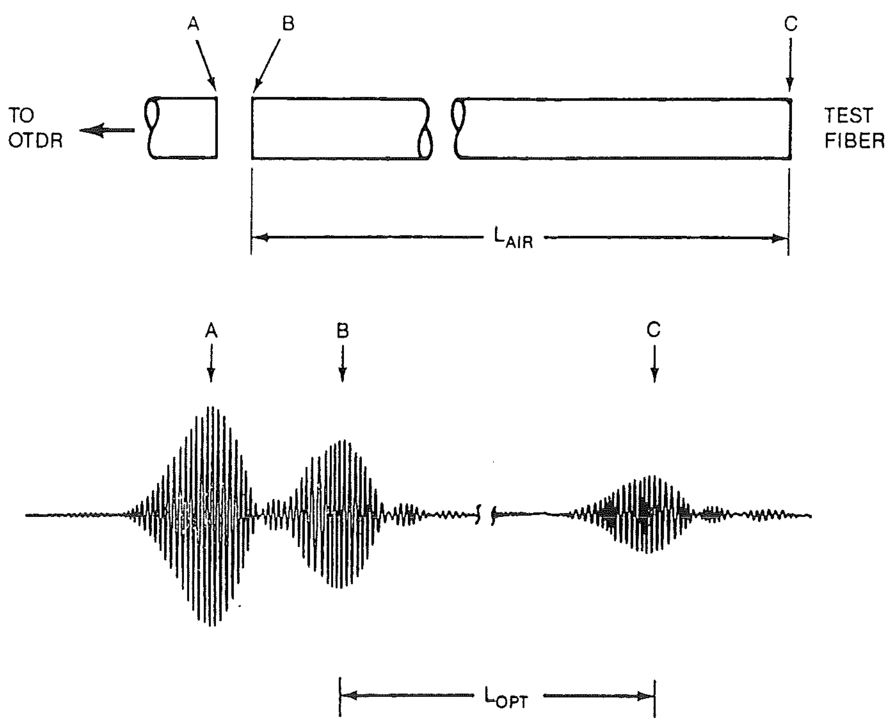


Figure 3. Typical Interferograms [(B) and (C) Are Generated from Fresnel Reflections at the Two Ends of the Fiber Sample]

GROUP DELAY

The time of flight $T_d(\lambda)$ of an optical pulse was obtained with the apparatus shown in Fig. 4. The optical pulse delay was matched with an electrical pulse delay from a commercial digital delay generator. The equality of delay times was established by alignment with a fiducial point on an oscilloscope. The displayed optical pulse had a full duration at half maximum of about 600 ps.

Most of the group delay uncertainties were associated with errors inherent in the digital delay generator such as aging, jitter, and temperature stability. The total uncertainty in group delay measurements was estimated to be about 0.004 percent for a 7-km test fiber.

LENGTH

Using Eq. (1) and the principle of propagation of errors, we can estimate our fiber lengths to about 0.03 percent. The group index uncertainties dominate the error budgets for length.

We should emphasize that the length of the reference test fiber is not required in order to calibrate the distance measuring accuracy of the OTDR. This is so because the reflectometer does not measure length directly but, rather, time delay. Therefore, we need only specify $T_d(\lambda)$, along with any given group index, in order to establish the accuracy of values of length computed by the OTDR. However, calibration laboratories should have the facilities for measuring N in order to obtain correct distance or length values for test fibers.

CONCLUSIONS

Standard reference fibers are convenient devices for making measurement comparison on instruments and systems designed to characterize optical fibers. We have described methods for determining group index, group delay, length, and spectral attenuation in some prototype reference fibers that are intended for calibration of optical time domain reflectometers.

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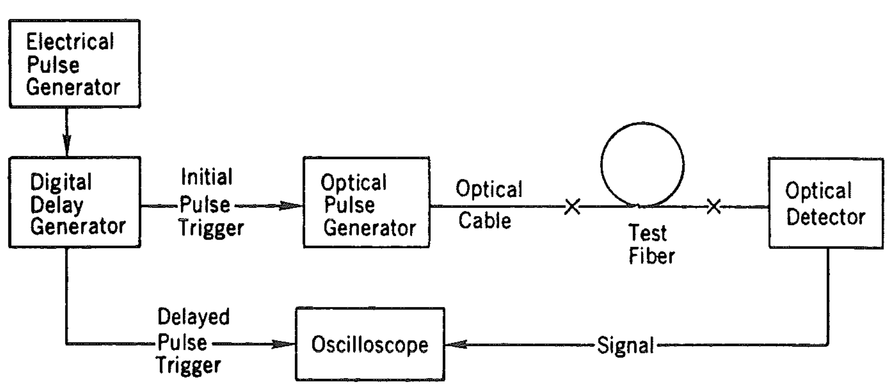

Figure 4. Experimental Setup for Measurement of Group Delay in the SRF (The Electronic Delay in the Digital Delay Generator Is Made Equal to the Optical Delay in the Fiber)