A Novel Far-Field Scanning Technique for Rapid Measurement of Optical Fiber Parameters

Jeffrey L. Guttman, Razvan Chirita, and Carmen D. Palsan
PHOTON, inc., 6860 Santa Teresa Blvd., San Jose, CA 95119
phone:408-226-1000, fax: 408-226-1025, e-mail: jguttman@photon-inc.com

Abstract: A new far-field scanning technique allows for accurate measurement of Mode-Field Diameter and Effective Area of single-mode fibers in less than 20 seconds with greater than 64 dB dynamic range. The Numerical Aperture is measured in real-time. An instrument based on this technique is described, and measurement results are presented.

1. Introduction

A new technique for rapidly scanning the far-field of optical fibers is described. The far-field data is used for computing parameters of single-mode and multi-mode fibers in accordance with the Telecommunication Industry Association/Electronic Industries Association (TIA/EIA) Standard Direct Far-Field (DFF) Methods. The Mode-Field Diameter and Effective Area of single-mode fibers is obtained in less than 20 seconds with greater than 64 dB dynamic range. The Numerical Aperture of multi-mode fibers can be obtained in real-time with up to 24 dB dynamic range.

The speed of the measurement makes it possible to test greater numbers of fibers economically. It also provides the ability to acquire statistical data, and potentially eliminate variations in measured parameters due to source fluctuations. Finally, the technique lends itself to the design of compact instruments suitable for portable field use.

2. Measurement Technique

An instrumentation system was constructed based on the measurement technique. The principle of operation of the system [1] is as follows: The end of the optical fiber under test is positioned at the axis of rotation of an optical fiber collector. The plane of rotation of the optical fiber collector is the far-field measurement plane. The collected light then propagates to a stationary InGaAs detector. The detector signal is amplified by a transimpedance amplifier followed by a voltage amplifier with a total programmable gain range of 140 dB. The amplified signal is input to an automated PC based data acquisition system. An optical encoder on the rotating collector and a phase-lock circuit provide motion control and precise angular sampling.

The distance between the end of the fiber under test and the optical collector is 6.62cm. A 500 μm diameter pinhole at the entrance to the optical collector yields a 0.43° detector field-of-view at the source. The data is acquired with an angular sampling resolution of 0.055°. The scan rate is 10 Hz, so single far-field scans are obtained in 50 ms, with updates obtained every 100ms. The system operates under control of MS Windows-based software. The scan unit dimensions are 16.5 cm x 16.5 cm x 20.3 cm (6.5 in. x 6.5 in. x 8 in.).

The far-field data is obtained by acquiring multiple high speed scans at different incremental gain settings. The data from these multiple scans are then reassembled to provide the far-field pattern in less than 20 seconds. This method makes it possible to obtain far-field profiles with dynamic range comparable to that obtained using conventional lock-in amplifier techniques, but at much higher speed. In the present system the gain ranging method allows far-field profiles to be obtained with dynamic range of 64 dB for a single-mode fiber source operating at a power level of 1mW. For a 1 Watt fiber source, the obtainable dynamic range is 94 dB.

During data acquisition, to obtain adequate signal-to-noise ratio (SNR) at each gain setting, an appropriate number of averages are used. When the individual scan data is reassembled to obtain the final profile, an algorithm is used for detection of amplifier saturation and rejection of invalid data.

3. Measurement Results

Measurements were made using a Fabry-Perot laser diode source operating at a nominal wavelength of 1300 nm and output power of 2 mW. A typical far field profile obtained for a sample single-mode fiber is shown in Figure 1. The data shows the complete scan range from -90° to +90° with signal amplitude ranging over 9 decades. Two sets of cusps are clearly defined, and two more cusps can be seen where the signal approaches the background noise level at the 0.1 amplitude level.

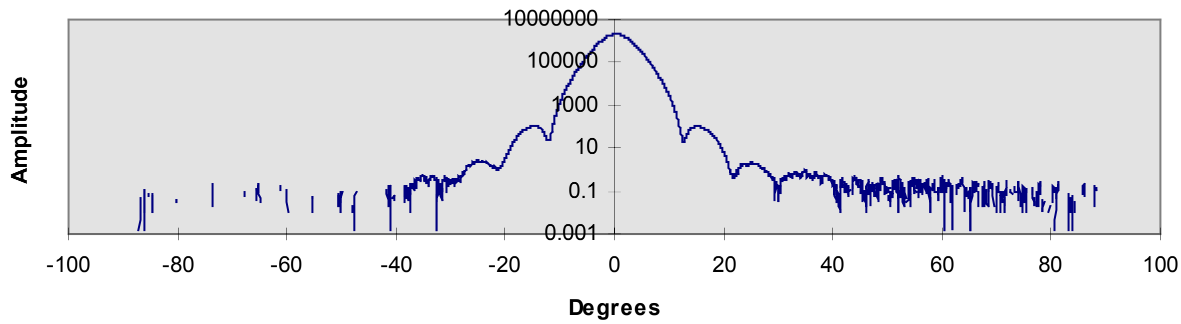

Fig. 1. Far-field profile of a single-mode optical fiber obtained with the new instrument.

The Mode-Field Diameter (MFD) is calculated using the Petermann II Integral in accordance with the TIA/EIA Standard DFF Method given in FOTP-191[2], with slight modification. In particular, the data is translated in angle by the centroid of the measured distribution. Also, the data is not folded. Instead, the integral is calculated for both negative and positive theta angles. The Effective Area, (A_{eff}) is calculated according to the TIA/EIA Standard DFF Method of FOTP-132 [3], using a threshold algorithm to eliminate noise from the computation and to more accurately determine the locations of the cusps, necessary for sign reversal of the data.

Comparative measurements of 2 different fibers were obtained to assess the accuracy of the technique. These fibers were measured independently by different laboratories using their far-field goniometric measurement systems, and then using the Photon inc. system. The far-field profiles obtained from these measurements are shown in Figure 2 and Figure 3. The numerical values for MFD are given in Table 1. The agreement is excellent.

Table 1. MFD values for the Comparative Measurements with Lab #1 and Lab #2

	Lab #1	Lab#2	Photon Inc.	Δ
Fiber #1	9.099 µm		9.092µm	0.007µm
Fiber #2		9.515µm	9.490	0.015µm

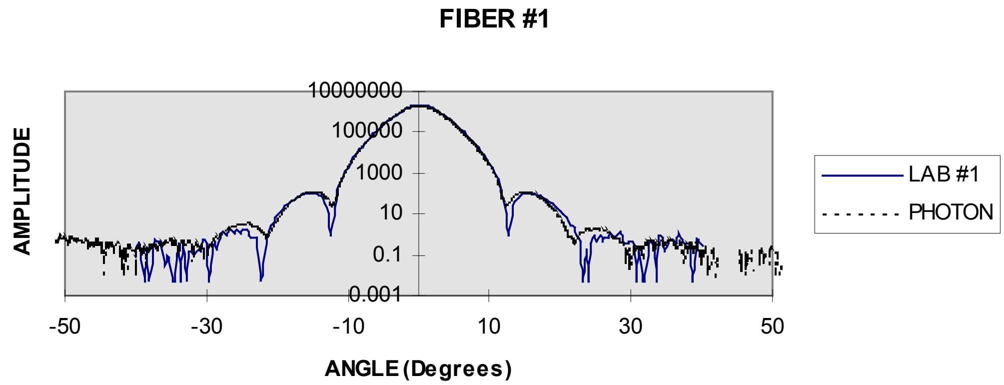

Figure 2. Comparative far-field measurements**:** ST single-mode fiber measured at Lab #1 and at Photon, inc.

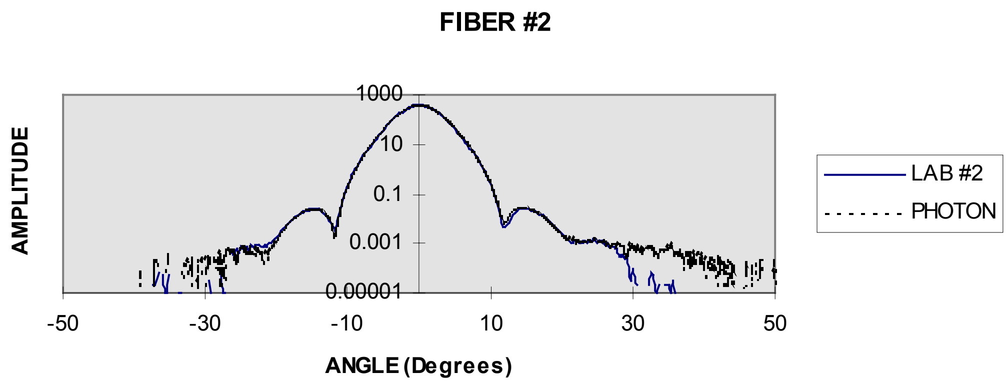

Figure 3. Comparative far-field measurements: bare single-mode fiber measured at Lab #2 and at Photon, inc.

Measurements were performed to assess the "push-button" repeatability of the instrument. Table 2 summarizes the results for 3 different series of measurements of MFD, and Table 3 summarizes the corresponding results for A_{eff}. The results for series "A", with 250, measurements, had a 3σ repeatability of 0.004 μm for MFD and 0.463 μm^2 for A_{eff}. Similarly, the series "B" measurement had a 3σ repeatability of 0.0054 μm for MFD and 0.485 μm^2 for A_{eff}, and for series 'C' the values are 0.0095 μm for MFD and 0.512 μm^2 for A_{eff}.

Table 2. Mode-Field Diameter "Push-Button" Repeatability for 3 Series of Measurements

Series (# of Measurements)	MODE-FIELD DIAMETER (μm)			
	MIN	MAX	MEAN	3 x STANDARD DEVIATION
A (250)	9.3886	9.3954	9.3920	0.0040
B (250)	9.3860	9.3953	9.3901	0.0054
C (1000)	9.4367	9.4588	9.4463	0.0095

Table3. Effective Area "Push-Button" Repeatability for the 3 Series of Measurements of Table 2

Series (# of Measurements)	EFFECTIVE AREA (μm^2)			
	MIN	MAX	MEAN	3 x STANDARD DEVIATION
A (250)	69.603	70.099	69.770	0.463
B (250)	69.444	70.035	69.727	0.4846
C (1000)	69.736	71.384	71.013	0.512

The results show the 3σ push-button repeatability of the instrument is better than 0.01 µm for MFD and approximately 0.5 μm^2 for A_{eff}. These values are of the same order of uncertainty due alone to problems associated with the computation algorithms for MFD and A_{eff}. Some of the variation in parameter values is also attributed to fluctuations in the source amplitude and wavelength during the measurement, as evidenced by the broader range of MFD and A_{eff} values for the longer series "C" measurements. Finally based on numerous series of measurements, the overall accuracy of the instrument is conservatively specified at ±0.5% for MFD and approximately ±1% for A_{eff}.

The measurement of Numerical Aperture (NA) is measured in accord with the TIA/EIA Standard using the Far-Field Method described in FOTP-177 [4]. Specifically, the NA is obtained from the sine of the 5% intensity half angle. Angular width measurements are obtained with a standard deviation of approximately 0.05°, which gives a 3σ variation of approximately ±0.001 in the NA value for typical single-mode optical fibers, which is better than ±1%.

4. Summary

A new technique has been developed for rapid measurement of the far-field profile of optical fibers. It provides far-field profile data with dynamic range comparable to that obtained using conventional lock-in amplifier techniques, but at a fraction of the time. The far-field data is used for computing parameters of single-mode and multi-mode fibers in accordance with the TIA/EIA Standard DFF Methods. The DFF method for MFD is referred to as "the reference method" [2]. The Mode-Field Diameter and Effective Area of single-mode fibers is obtained in less than 20 seconds with greater than 64 dB dynamic range for a 0dBm source. The NA of multi-mode fibers can be obtained in real-time with up to 24 dB dynamic range.

An instrument based on the new technique has measurement accuracy specified at ±0.5% for MFD and approximately ±1% for A_{eff}. The accuracy for NA measurement is better than ±1%. The speed of the measurement makes it possible to test greater numbers of fibers economically. It also provides the ability to acquire statistical data, and potentially eliminate variations in measured parameters due to source fluctuations. Finally, the compact size of the scan unit makes it suitable for portable field use.

5. References

1. Patent # 5,949,534

2. "Measurement of Mode-Field Diameter of Single-Mode Optical Fiber", Fiberoptic Test Procedure FOTP-191, Telecommunications Industry Association, Standards and Technology Department, 2500 Wilson Blvd., Suite 300, Arlington, VA, 22201 (1998).

3. . "Measurement of the Effective Area of Single-Mode Optical Fiber", Fiberoptic Test Procedure FOTP-132, Telecommunications Industry Association, Standards and Technology Department 2500 Wilson Blvd., Suite 300, Arlington, VA, 22201 (1998).

4. "Numerical Aperture Measurement of Graded-Index Optical Fibers", Fiberoptic Test Procedure FOTP-177, Telecommunications Industry Association, 2001 Pennsylvania Ave. N.W., Washington, D.C. 20006 (1992).