Interlaboratory measurements of the nonlinear coefficient of standard SMF and DSF fibers using an interferometric method and an SPM based cw dual-frequency method

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Abstract:

In this work we present interlaboratory measurements of the nonlinear coefficient n_2/A_{eff} for standard SMF and DSF fibers. Two different measurement methods were used by two different groups. One of the method is based on the detection of the Kerr phase shift by a self-aligned interferometer. The other method is an SPM based cw dual-frequency method. Interlaboratory comparison shows that the values found with the two methods are in good agreement.

INTRODUCTION

The implementation of Erbium-doped fiber amplifiers and chromatic dispersion compensation allows for long distance data transmission. Along with the technique of wavelength division multiplexing (WDM), this leads to an important amount of power inside the fiber over long distances, and optical nonlinearities start to play a significant role. Their magnitudes depend on the ratio n_2/A_{eff}, where n_2 is the nonlinear refractive index of the fiber and A_{eff} the effective area of the mode. There are different methods to measure n_2/A_{eff}, based on SPM or XPM induced phase shift detection using interferometric and non-interferometric schemes [1]. The interferometric detection scheme [2] presents the advantage that it can be implemented more easily. But a disadvantage is constituted by its susceptibility to the environmental perturbations that leads to a poor stability. With one of the setups presented here we reached a considerable improvement of this technique by using a self-aligned interferometer [3] with a Faraday mirror. This method [4] has the advantage to be simple and all fiber implementable and the fluctuations due to the environmental perturbations are completely removed. On the other hand, non-interferometric schemes have the disadvantage that their measurement accuracy strongly depends on the measurement conditions. However, the SPM based cw dual-frequency method [5,6], with its simple measurement setup, gives the accurate value of n_2/A_{eff} according to the measurement conditions given in Refs. [5] and [6].

We give a brief description of the two methods used and present interlaboratory fiber nonlinear coefficient measurements for Dispersion Shifted Fibers (DSF). The values found are in good agreement among the two methods.

INTERFEROMETRIC METHOD (METHOD A) [3,4]

Due to the power dependence of the refractive index, a pulse with peak power P and wave number k, travelling along a fiber of length L, will acquire a power dependent phase change ϕ given by:

$$\phi(P) = \phi_l + \phi_{nl} = n_0 kL + kL_{eff} \frac{n_2}{A_{eff}} Pm \qquad (1)$$

The fiber losses are accounted for by the effective length $L_{eff} = 1/\alpha\,[1-\exp(-\alpha L)]$, with fiber loss coefficient α. The polarization parameter m depends on the polarization characteristics of the test fiber and the signal polarization state. It is equal to 1 for the case of a polarization maintaining fiber if the light is coupled into one of the two axes. For the case of a sufficiently long standard telecom fiber with a complete scrambling of the polarization, it was demonstrated that m=8/9 [7]. Using (1), a measure of the acquired phase shift allows to determine the ratio n_2/A_{eff} or, through an independent measurement of A_{eff}, the value of n_2. The setup of the self-aligned interferometer is shown in Fig. 1 and is described in more detail in Ref. [4]. Due to its robustness against any environmental perturbations the proposed method is well suited to routinely measure the nonlinear coefficient. Moreover the presence of the FM allows to easily exchange the FUT without necessitating any further readjustments of the interferometer. It is possible to show that the detected power P_{OUT} at the exit of the interferometer is equal to

$$P_{OUT}(P) \propto P\cos^2(\Delta\phi), \qquad (2)$$

where $\Delta\phi$ corresponds to the nonlinear phase shift acquired along the FUT [4],

$$\Delta\phi(P) = \frac{2\pi}{\lambda} PL_{eff} \frac{16}{45} \frac{n_2}{A_{eff}} \qquad (3)$$

SPM BASED CW DUAL-FREQUENCY METHOD (METHOD B) [5,6]

When two intense signals with wavelength separation of $\Delta\lambda$ are launched into a fiber, SPM acts on the beat envelope to create sidebands in the frequency domain. Then, the optical power ratio of the input signals (I_0) to the first sideband (I_1) is related to the nonlinear phase shift ϕ_{SPM}. When the chromatic dispersion is negligible, this relationship can be expressed as (4) using n-th order Bessel function J_n.

$$\frac{I_0}{I_1} = \frac{J_0^2(\phi_{SPM}/2) + J_1^2(\phi_{SPM}/2)}{J_1^2(\phi_{SPM}/2) + J_2^2(\phi_{SPM}/2)} \qquad (4)$$

Moreover, the relationship between ϕ_{SPM} and nonlinear coefficient can be expressed as

$$\phi_{SPM} = \frac{4\pi}{\lambda} L_{eff} P \frac{n_2}{A_{eff}} \qquad (5)$$

where P shows the average launched power. Thus, the nonlinear coefficient can be obtained by measuring the optical power ratio I_0/I_1 with various launched power according to the measurement conditions given in Refs. [5] and [6]. The setup of the SPM based cw dual-frequency method is shown in Fig. 2.

RESULTS

The measurements were done on three different fibers. A DSF fiber with λ_0 = 1556.4 nm, S=0.067 ps/nm^2/km (DSF-1), a DSF fiber with λ_0 = 1548.6 nm, S=0.060 ps/nm^2/km (DSF-2), and a standard single mode fiber with λ_0 = 1300 nm (G-1). Fibers DSF-1 and DSF-2 were also measured at NTT utilizing the self-phase modulation based cw dual-frequency method.

For each fiber different measurements were taken on different days in order to test the reproducibility of our measurements. The corresponding results are summarized in column A of Tab. I for method A. Note that the maximum absolute deviation from the average (MD) is used to characterize the reproducibility. Generally the reproducibility is quite good (<5%) although it varies somewhat from fiber to fiber (see Tab. I). Column B of Tab. 1 reports the values found with method B. Here instead of the MD, the standard deviation (SD) of different measurements is given. As one can see, the values are in good agreement with differences within the experimental errors. Using method A measurements were then performed as a function of the fiber length. We made a fiber cut-back procedure and for each fiber length we measured the nonlinear coefficient on a standard telecom fiber (G-1) with lengths ranging from 12 km to 2 km. For each length at least 3 measurements were taken in order to acquire some statistics and to find the error bars. All values are within a standard deviation of 6% demonstrating that method A is insensitive to the fiber lengths even for large values of chromatic dispersion.

CONCLUSION

In this letter we have presented an interlaboratory comparison of n_2/A_{eff} measurements on the same test fibers as measured by two different institutions using different methods, an interferometric method and a cw dual-frequency method. Good agreement between the measured values was found.

ACKNOWLEDGMENTS

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TABLE I

Values of the nonlinear coefficient n_2/A_{eff} for the different test fiber measured with the two methods proposed in this letter.

Fiber	Length (m)	Zero Wavelength λ_0 (nm)	Nonlinear Coefficient n_2/A_{eff} x 10^{-10} W^{-1}			
			A		B	
			Value	MD	Value	SD
G-1	11840	1302	3.6	5%	-	-
DSF-1	1990	1556.4	6.4	2%	6.3	5%
DSF-2	1990	1548.6	6.3	5%	6.6	5%

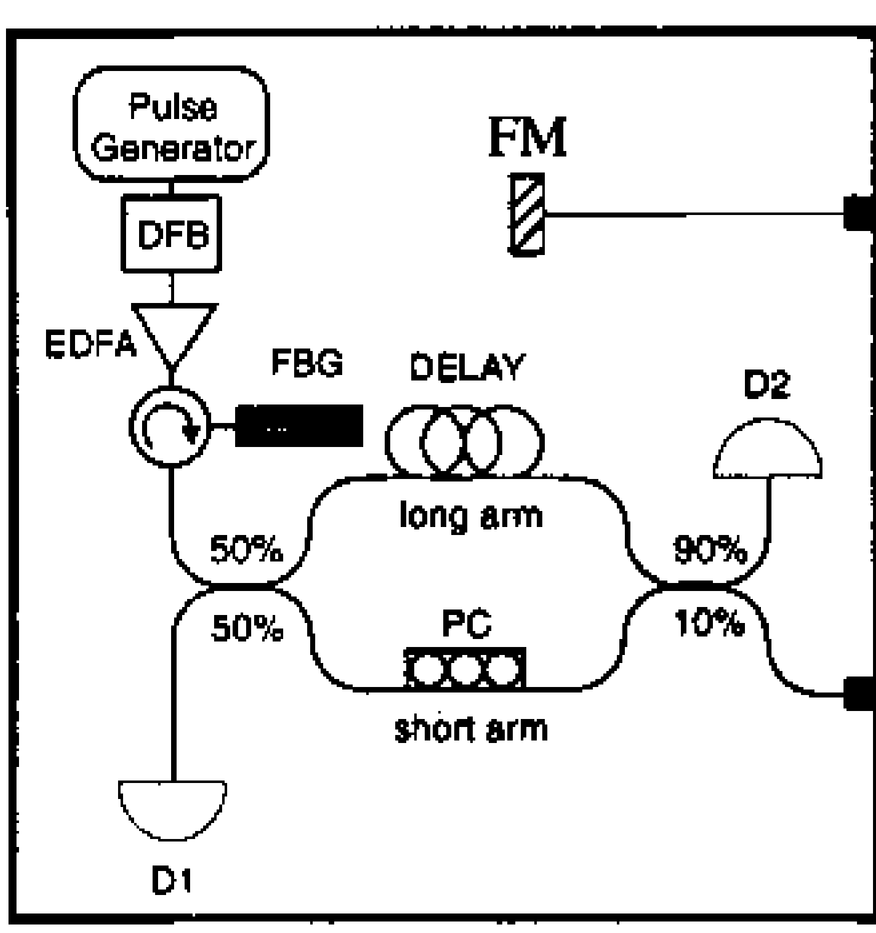

FIGURE 1
Experimental setup of the self-aligned interferometer. DFB distributed feedback laser, EDFA Erbium doped fiber amplifier, PC polarization controller, FUT fiber under test, FM Faraday mirror, D detector, FBG fiber Bragg grating.

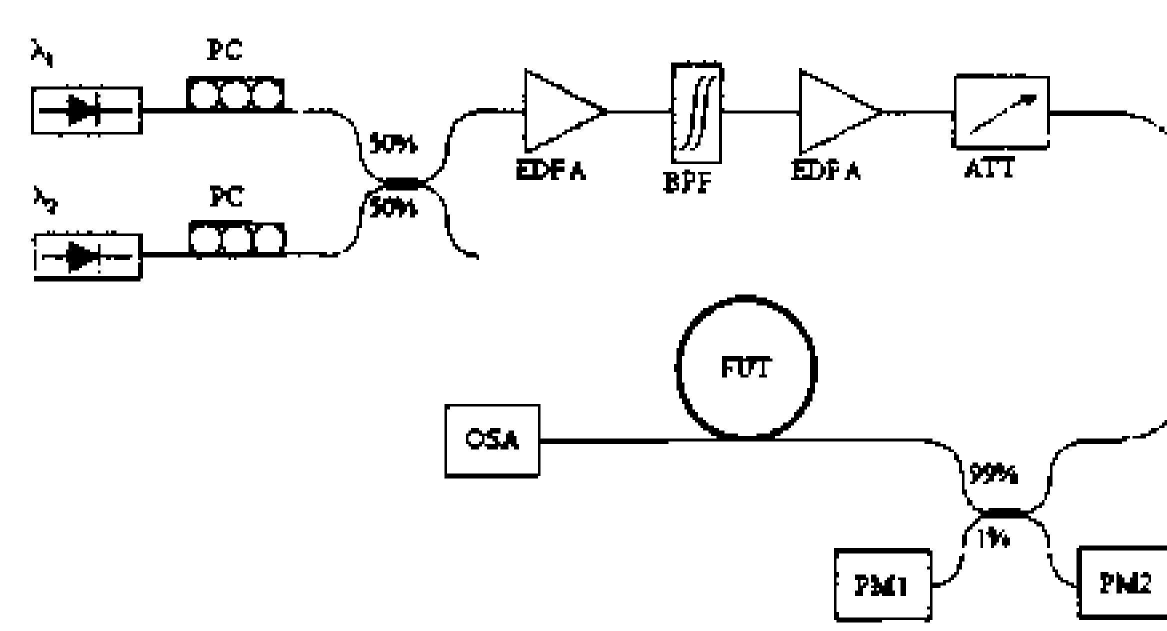

FIGURE 2
Experimental setup of the SPM based cw dual-frequency method. PC polarization controller, EDFA Erbium doped fiber amplifier, BPF Band pass filter, ATT Variable attenuator, PM Power meter, OSA Optical spectrum analyzer, FUT fiber under test. For the values measured with method A, the maximum absolute deviation from the average (MD) is used to characterize the reproducibility. For method B the standard deviation is shown.