Measurement of Nonlinear Coefficient of Ultra Bend-insensitive Optical Fiber

Manoj Gupta, Nagaraju Bezawada, and Pramod R. Watekar
Center of Excellence, Sterlite Technologies Limited, Aurangabad, India

Abstract— We present measurement results of nonlinear coefficient of bend insensitive fiber (G.657A2) at 1550 nm by direct continuous wave method. Measured nonlinear coefficient for G.657A2 fiber is 1.25 (W-km)$^{-1}$.

1. INTRODUCTION

Nowadays, the whole world is witnessing the fast and rapid optical communication based on dense wavelength division multiplexing (DWDM) networks. These networks carry high power densities and the rapid increase in the power put into an optical fiber gives rise to such phenomena as nonlinear optical effects. Nonlinear optical interaction will become prominent when optical power density is high and interaction between light signal and fiber medium takes place for longer distance. The intensity dependent refractive index (n2) leads to variety of nonlinearity effects such as self-phase modulation (SPM), cross-phase modulation (XPM) and four wave mixing (FWM) in the optical fibers and is thus a critical parameter for long haul networks. Typically, G.652 D fibers are used in long haul networks. However, G.657 A fibers, which are designed for access networks, are expected to see applications outside access network in future. This is due to their improved microbending performance and compatibility with G.652 D. So, it is important to understand nonlinear characteristics of these fibers. There are various approaches proposed in the literature to measure the nonlinear coefficient of optical fibers [1–3]. We have used continuous wave-SPM (cw-SPM) method.

In this paper, we present a nonlinear coefficient measurement results based on self-phase modulation for Sterlite's Bowlite G.657 A2 optical fiber. At high electric fields induced due to high optical power density, fiber medium behaves as an anisotropic medium. In this medium, electric polarization can be written as

$$P = \varepsilon_0 \left(\chi E + \chi^{(2)} E^2 + \chi^{(3)} E^3 + \dots \right) \tag{1}$$

where $\chi^{(2)}$, $\chi^{(3)}$, ... are higher order susceptibilities giving rise to nonlinear effect. For silica fiber, $\chi^{(2)}$ is zero and does not show any non linear effects. Third order nonlinear effects cause the various type of nonlinearity in the optical fibers. Cw-SPM method is based on measuring the nonlinear phase shift experienced by a dual-frequency beat signal and this beat signal is propagating along the fiber (neglecting dispersion) can be written as [4, 5]

$$E(t, L) = 2a \cos(\Delta\omega t) \exp(i\omega_0 t) \exp\left[i\varphi_{\mathrm{SPM}} \cos^2(\Delta\omega t)\right] \quad \text{and} \quad n_2 = \frac{\lambda}{4\pi} \frac{A_{eff}}{L_{eff}} \left(\frac{\varphi_{\mathrm{SPM}}}{P_{in}} \right) \tag{2}$$

where P_{in} is the input launch power of the signal into fiber, L_{eff} is the effective length of the fiber calculated by $L_{eff} = (1 - \exp(-\alpha L)/\alpha$, n_2 is the nonlinear refractive index and A_{eff} is the effective area which comes from averaging over the intensity profile of the mode in the fiber and is given by

$$A_{eff} = \frac{\left[2\pi \int_{-\infty}^{\infty} E^2 r dr \right]^2}{2\pi \int_{-\infty}^{\infty} E^4 r dr} \tag{3}$$

when beat signal is propagating in the fiber and interaction take place for longer distance, a typical spectrum is generated at the output as shown in Figure 1. I_0 and I_1 are the intensities of zero and first order harmonics respectively.

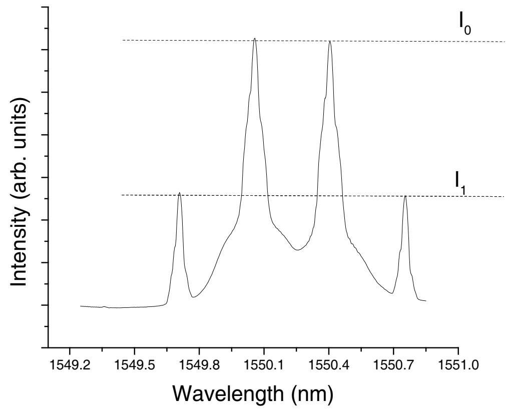

Figure 1: Typical spectrum generated by nonlinear effect.

2. EXPERIMENTAL SETUP

Two continuous signals centered at 1550.06 nm and 1550.23 nm were launched having power of 10 dBm each. The launch polarization of signals was adjusted using polarization controllers. These two signals are combined using a 50 : 50 splitters. The combined signal is amplified using a high power EDFA and launched into the fiber under test length of 1 km. A band pass filter (BW: 3.2 nm) is used to filter the noise. Output power spectrum was recorded by using optical spectrum analyzer (OSA). Resolution bandwidth of OSA was fixed to 0.02 nm. An attenuator of 20 dB loss was inserted before OSA for controlling power going to OSA input port.

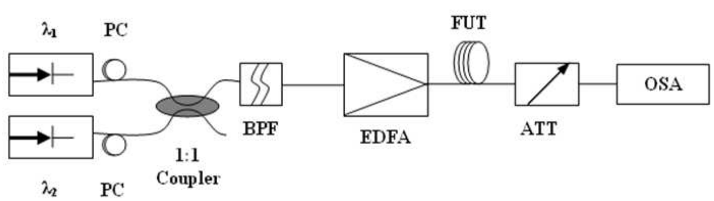

Figure 2: Experimental set for non linear coefficient measurement.

Table 1: Optical parameters for sterlite bowlite's G.657 A2.

Fiber Type	**Cable Cutoff**	**MFD @1550 nm**	**Effective Area (A_{eff})**	**Dispersion at 1550 nm**	**Attenuation**
G.657 A2	1251 nm	9.45 µm	67.1 µm^2	17.45 ps/nm-km	0.192 dB/km

3. RESULTS AND DISCUSSION

Total phase shift faced by signal while propagating (β_0 as propagation constant) inside the fiber of length L is given by

$$\varphi_{\text{SPM}} = \beta_0 L + \gamma L_{eff} P_{in} \tag{4}$$

γ is called nonlinear coefficient which is defined as $K_0 n_2 / A_{eff}$. When a continuous wave dual frequency beat signal used as a pump signal, the resultant spectrum is discrete (because electric field signal is continues and periodic in time domain), consisting of harmonics of the beat frequency as shown in Figure 1. The nonlinear phase shift induced in the optical fiber by self phase modulation (SPM) effect and corresponding power are determined from the discrete shape of the spectrum, i.e., relative ratio of the spectral components given by [2, 3]

$$\frac{I_0}{I_1} = \frac{J_0^2\left(\frac{\varphi_{\text{SPM}}}{2}\right) + J_1^2\left(\frac{\varphi_{\text{SPM}}}{2}\right)}{J_2^2\left(\frac{\varphi_{\text{SPM}}}{2}\right) + J_1^2\left(\frac{\varphi_{\text{SPM}}}{2}\right)} \tag{5}$$

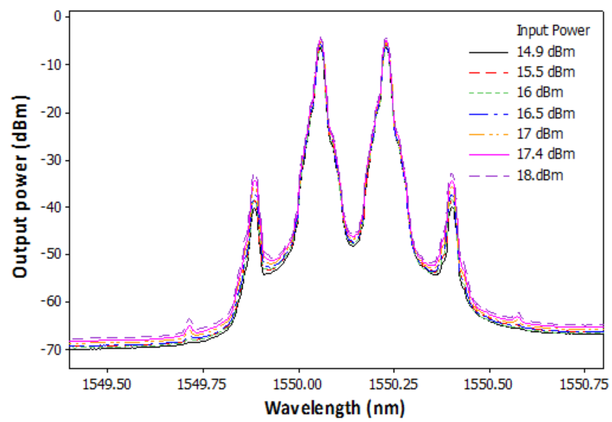

Figure 3: Output power spectrum at different input launched power level into fiber sample of G.657 A2.

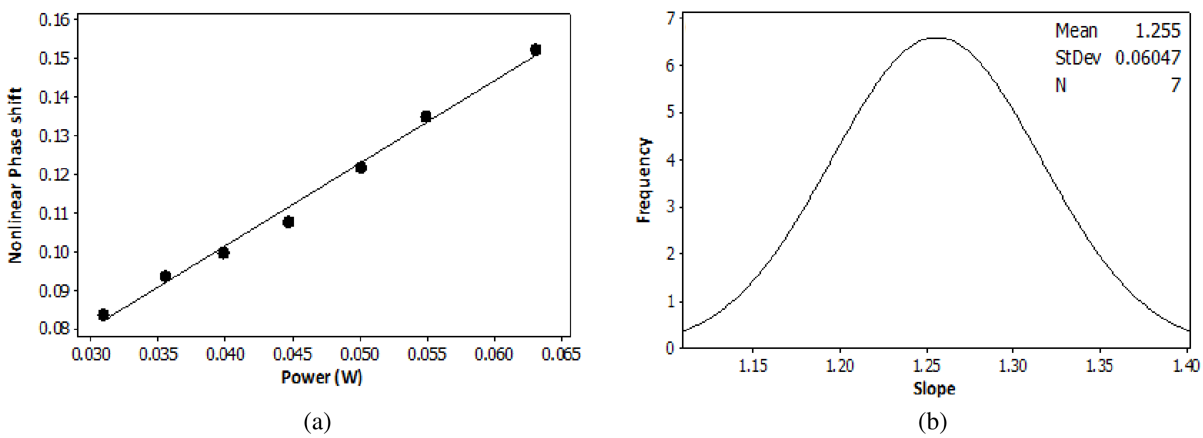

Figure 4: (a) Phase shift variation due to changing the input power (b) histogram of several measurement of nonlinear coefficient for G.657A2.

Multiple spectrums were plotted at different input power level as shown in Figure 3 to confirm that phase behavior should be linear as shown in Figure 4(a). The value of self-phase (φ_{SPM}) was calculated using the Equation (5) and by knowing the value of mode field diameter and attenuation in fiber it is then possible to measure the value of nonlinear refractive index (n_2) as well coefficient (γ). The value of nonlinear coefficient depends on state of polarization and this could generate the uncertainty in the result so we took repeatability of results and found the deviation from mean by the unit of 0.06 as shown in Figure 4(b).

4. CONCLUSION

In this paper, we measured the nonlinear coefficient of bend insensitive fiber (G.657 A2) and its average value was calculated 1.25 $(\text{W-km})^{-1}$.

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