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A STUDY ON RAYLEIGH BACKSCATTERING NOISE IN SINGLE FIBER TRANSMISSION PON

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Abstract

In this paper, we measured the distributed Rayleigh backscattering (RB) noise along the length of the fiber optic network by a certain method. Rayleigh backscattering noise which is generated by some distributed reflections of random index fluctuation along the optical fiber may cause severe degradation problems in bidirectional transmission performance of passive optical network (PON) system. Some experiments have been conducted to study the RB noise impairment by measuring the total detected backscattered power in single fiber transmission using power meter. Then these results were extracted to find the RB noise as a function of fiber length. Common calculated results that were published everywhere was verified by our measurement results show that the average RB noise is about -32 dB with about 1 dB discrepancy for 25-115 Km fiber transmission for about 0 dBm launched input optical power. The modulated DFB laser diode by 10 Gb/s data rate on-off-keying signal (OOK) for amplitude modulation was used as an optical transmitter. We believe that our simple architecture can be deployed to build a more complex system network for the future bidirectional transmission in the long reach wavelength division multiplexing-passive optical network (LRWDM-PON) systems.

Keywords: Rayleigh backscattering (RB) noise, optical fibers, passive optical network (PON), bidirectional transmission.

Introduction

The major motivation behind the use of silica optical fibers (Figure 1) is the large bandwidth offered by fiber optic communication systems. However, intrinsic loss hinders the utility of optical fibers to the maximum level [1]. So, it should be treated in such a way that it will not much degrade the performance of the system by certain methods of reductions [2-4]. Basically, there are three major losses mechanisms in GeO_2-doped fused silica optical fibers: (1) intrinsic and extrinsic *absorption* losses, (2) elastic and inelastic *scattering* losses, (3) macro- and micro-*bending* losses.

In this research work, we focused our study on the elastic scattering losses only, in order to narrowing our scope. We hope that the results of this study will be useful in the future for Rayleigh backscattering (RB) noise mitigation schemes in the bidirectional and loop-back structure of WDM-PON transmission systems.

The rest of the paper is organized as follows. The second part describes the basic mechanisms of scattering losses, its theoretical formula, and the RB noise description in a bidirectional loop-back transmission system. The third part is given to the experiments and measurement results. Finally, the last part concludes the main results of the paper.

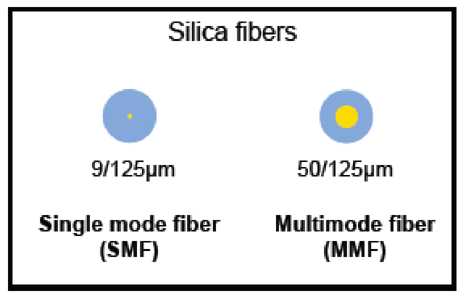

Figure 1. Two kinds of silica optical fibers based on their core/cladding diameters [1].

Basic Mechanisms

Elastic Scattering Losses

The scattering of light may be thought of as the redirection of light that takes place when an electromagnetic (EM) wave (i.e. an incident light ray) encounters an obstacle or non-homogeneity discrete particle [5, 6]. When scattering particles are very small compared to the wavelength of incident radiation, which is $\mathbf{r < \lambda/10}$, the scattered intensity on both forward and backward directions are equal. This type of scattering is called the Rayleigh scattering. In this type of scattering, the scattered intensity varies inversely as the fourth power of wavelength. For larger particles ($\mathbf{r > \lambda/10}$), the angular distribution of scattered intensity becomes more complex with more energy scattered in the forward direction. This type of scattering is called the Mie scattering. In Rayleigh and Mie scattering, both the scattered and incident radiations have the same wavelength and hence, this two scattering process are called the elastic scattering.

In elastic scattering (especially Rayleigh scattering), the frequency (or the photon energy) of the scattering light will remain unchanged. The mechanism of this scattering doesn't cause the elimination or conversion of optical energy, but simply forces a part of optical wave escaping from the waveguide. By contrast, during the inelastic scattering [*stimulated Brillouin scattering* (SBS) arises when a strong optical signal generates an acoustic wave that produces variations in the refractive index, and *stimulated Raman scattering* (SRS) arises when there is an interaction between lightwaves and the vibrational modes of silica molecules], the frequency of the scattered light is shifted downward (The scattered wave is downshifted in frequency. It is called a Stokes wave after George Stokes, who found the frequency downshift in the process of luminescence in the 19th century).

$$\alpha_s = \frac{(0.76+0.51\Delta n)}{(\lambda/\mu m)^4}\left[\frac{dB}{Km}\right] \quad (1)$$

The numerator could be substituted by C with value ranges from 0.7~0.9 [(dB/Km).µm^4]. So, the equation above will be simplified to be:

$$\alpha_s = \frac{C}{\lambda^4} \quad (2)$$

for λ=1550 nm, α_s varies from 0.12~0.16 dB/Km.

Actually, there is also another formula to calculate the Rayleigh scattering losses in optical fibers [7]. For pure silica glass an approximate equation for the Rayleigh scattering loss is given by this equation:

$$\alpha(\lambda) = \alpha_0\left(\frac{\lambda_0}{\lambda}\right)^4 \quad (3)$$

where α_0 = 1.64 dB/Km at λ_0 = 850 nm. This formula predicts scattering losses of 0.291 dB/Km at 1310 nm and 0.148 dB/Km at 1550 nm. As we can see, all equations give the same range value for α_s , so either way can be used to calculate the Rayleigh scattering losses in optical fibers.

Rayleigh Backscattering Noise

Measuring the distribution of the light scattered in the backward direction as a function of fiber length down a fiber-optic assembly also can be useful in identifying breaks, bad splices, and non-reflective events [8]. Rayleigh backscattered light had benefited function in optical fiber sensors [9-11], but optical losses due to Rayleigh backscattering (RB) in optical fibers have caused a considerable problems in optical communication systems. Some investigations of noise due to RB have been presented in many areas, such as fiber-optic gyroscope based on Rayleigh backscattering in a fiber-ring resonator [12], light backscattered from absorbing solutions illuminated by a giant-pulse ruby laser [13], the direct observation of backscattering induced by sidewall roughness in high-index contrast optical waveguides based on total internal reflection [14], Rayleigh scattering acts as an equivalent mirror which can generate high levels of multiple reflection noise in lightwave systems employing optical amplifiers [15], in using the backscattering fluctuations as fiber's signatures [16], to estimate the optical loss in acrylic polymers by theoretical modification [17] and also in bidirectional optical communication and wavelength-reuse fiber systems [18-22].

In a bidirectional system, data is transmitted in both directions over a single fiber (Figure 2). If we compared with the unidirectional system, bidirectional system will reduce the number of fibers and enhance the efficiency of bandwidth usage twice by using the same wavelength for both downstream and upstream transmissions in a wavelength-reuse system. However, the system will be more sensitive to RB effect and also SBS and SRS and other fiber nonlinearities due to the higher power levels in the system. For bidirectional optical systems which are employing single mode laser diodes, RB noise may cause considerable receiver sensitivity degradations. In fact, typically RB loss of about -31 to about -33 dB of the 0 dBm launched optical power to the 20 Km feeder fiber can't be avoided. RB in the transmission fiber must be taken into account when we calculated the performance of the bidirectional transmission system, especially in a wavelength-reuse system (loop-back access configuration or re-modulation scheme). Thus in this case, RB noise has become a limiting factor that causing system impairments in bidirectional optical communications.

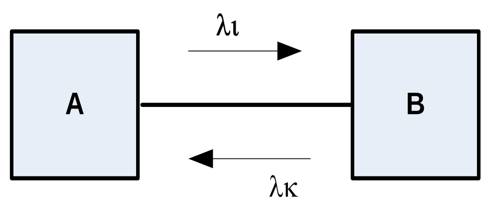

Figure 2. A bidirectional transmission system with wavelength reuse mechanism, where λi = λk.

Experiments and Results

Here, we performed experiments to verify the calculated results that published everywhere, by adopted simple measurement setup of PON (passive optical network) upstream transmission link [23] which is shown in Figure 3. The backscatter factor is the ratio of the backscattered power to the energy launched into the fiber, which is important in long-range fault location since it determines the magnitude of the signal and hence the range which the apparatus can cover.

DFB laser diode was modulated with 10 Gb/s data rate PRBS (pseudo-random-binary-sequence) 2^{31}-1 on-off-keying signal (OOK) before injected into the single optical fiber. Optical circulator was placed in between the laser source and optical fiber to manage the data traffic of signal get into and reflected back from the drop fiber transmission. Optical circulator is a non-reciprocal multi-port passive device that directs light sequentially from port to port in only one direction. Either it is port 1, port 2, and port 3 can be used as input and output, depends on which direction the light comes and goes. Power meter was used to measure the total detected backscattered power because this equipment can measure the total output power precisely, rather than OSA (optical signal analyzer). To avoid reflections, angle connector was placed at the terminated end of the fiber.

After the signal entered the fiber through optical circulator, then the downstream (forward) signal experiences the scattering along the optical fiber due to fiber non-uniformities when manufacturing time. Some amounts of the scattering light then travelling back to the previous direction it goes before, which is then detected by power meter. This is the total backscattered power. The rest of the light signal goes toward the angled connector and terminated with APC (angled physical contact) connector. To see the effect of Rayleigh backscattering in different distances, we changed the length of fiber by cascading each spool with 10, 20, or 25 Km different length as available in Optical Network Laboratory (ONL)-403. Table 1 and 2 show the measurement results of total backscattered power as a function of input optical power and Rayleigh backscattering (RB) noise as a function of fiber length, respectively. For optical fiber systems, laser sources used almost exclusively are semiconductor laser diodes.

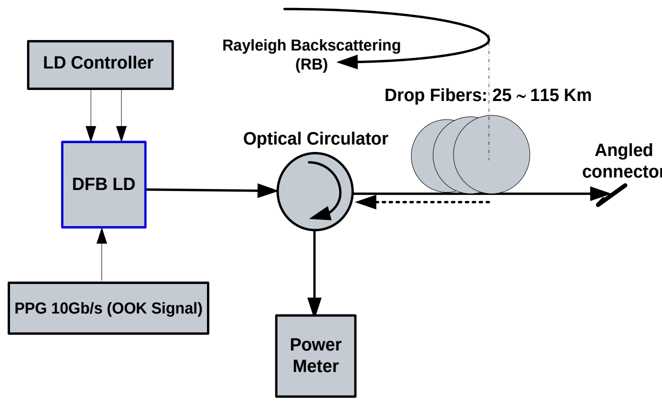

Figure 3. Experimental setup to measure the Rayleigh Backscattering (RB) noise in single fiber transmission.

So, here we used DFB (distributed feedback) laser diode with the center wavelength, λ= 1538.2 nm and SMSR (side mode suppression ratio) 38 dB. It was biased at current 45 mA and temperature controlled 20^{o}C used for optical transmitter, modulated by OOK signal with 0.25 V step (0.25 V, 0.5 V, 0.75 V) produced varied input optical power about ~0 dBm. The average Rayleigh backscattering noise from our experiments is about -32 dB for different fiber length varies from 25-115 Km fiber length. This result can be a proof that this value is agreed or matched with our advanced prediction.

Table 1. Measurements of total backscattered power as a function of input optical power.

(Assumptions: fiber connector and other equipment losses are negligible)

OOK Signal (V)	Input Optical Power (dBm)	Detected Backscattered Optical Power (dBm)					
		25 km	35 km	55 km	80 km	105 km	115 km
0.25	**0.774**	-32.236	-31.998	-31.862	-31.847	-31.845	-31.829
0.50	**0.808**	-32.206	-31.970	-31.836	-31.814	-31.812	-31.808
0.75	**0.829**	-32.196	-31.956	-31.819	-31.799	-31.797	-31.795

Table 2. Measurements of total Rayleigh backscattering (RB) noise as a function of fiber length.

(Assumptions: fiber connector and other equipment losses are negligible)

OOK Signal (V)	Rayleigh Backscattering noise (dB)					
	25 km	35 km	55 km	80 km	105 km	115 km
0.25	-33.010	-32.772	-32.636	-32.621	-32.619	-32.603
0.50	-33.014	-32.778	-32.644	-32.622	-32.620	-32.616
0.75	-33.025	-32.785	-32.648	-32.628	-32.626	-32.624

Conclusions

Rayleigh backscattering phenomena is an intrinsic loss or noise that always present (exist) in the transmission system. Bidirectional transmission is typically implemented in a loopback configuration in which the seed light and upstream signal operate at the same wavelength and travel in opposite directions within the same fiber. In our simple experiments, we used different fiber lengths to represent the different transmission links (vary from 25 Km to 115 Km). For transmission links longer than 20 Km, RB noise achieves about (average) -32 dB depending on the input optical power for certain laser wavelength. We believe that our simple setup can be employed (extended) to build the complex architectures for future bidirectional access network or long-reach WDM-PON systems.

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Biographies

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