International Journal of Computer Applications (0975 – 8887)
Volume 92 – No.7, April 2014

Overview of Stimulated Brillouin Scattering Effect and Various Types of Method to Eliminate this Effect

Fahmida Hossain Tithi
Department of Electrical and Electronic Engineering, Bangladesh University of Engineering and Technology
Dhaka, Bangladesh

M. S. Islam
Institute of Information and Communication Technology, Bangladesh University of Engineering and Technology
Dhaka, Bangladesh

Md. Tawhidul Anwar Tanna
United International University
Dhaka, Bangladesh

ABSTRACT
Stimulated Brillouin scattering (SBS) is a resonant nonlinear optical interaction with the material that results in transmitted light being scattered back towards the input. Although high power lasers are available to overcome the intrinsic loss of standard single mode optical transmission fibers (0.2 to 0.3 dB/km) but SBS places an upper limit on the optical power that can be transmitted through the link. Usually, SBS normally has a lower threshold power (≤1.4 mW) than other nonlinear effects. In this paper we see the SBS effect in optical fiber transmission system and different types of methods to eliminate this effect. Here we propose two new approaches to eliminate this effect.

Keywords
Stimulated Brillouin scattering, intrinsic loss, threshold power, nonlinear effects.

1. INTRODUCTION
Fiber nonlinearities become a problem when several channels coexist in the same fiber and results high optical power. Interactions among propagating light and the fiber can lead to interference, distortion or excess attenuation of the optical signals. Nonlinear effects are determined by the total power per channel. The most important types of nonlinear scattering within optical fibers are stimulated Brillouin scattering (SBS) and stimulated Raman scattering (SRS). The non-linear phenomenon of SBS, first observed in 1964 [1, 2]. Once the power launched into an optical fiber exceeds a certain level, which is known as threshold level or threshold power, most of the light is reflected backward direction due to SBS. When light is scattered to the backward direction, the output power is not more increased [3,4] . Over the years, many research works have been carried out to analyze SBS effect SBS on transmission performance and developed many techniques to eliminate this effect.

In this paper we have studied and reviewed the different types of research methods and also propose new methods to compensate the delirious SBS effect in optical fiber transmission system.

2. STIMULATED BRILLOUIN SCATTERING EFFECT

2.1 Basic Concepts
In scattering effects, energy gets transferred from one light wave to another wave at a longer wavelength or lower energy. The lost energy is absorbed by the molecular vibrations, or phonons, in the medium. Stimulated scattering is affected by the threshold level. The most important types of nonlinear scattering within optical fibers are SBS and SRS.

The SRS is a nonlinear parametric interaction between light and molecular vibrations. Optical phonon participates in SRS but acoustic photon participates in SBS. Due to SRS power transferred from shorter wavelength channels to the longer wavelength channels. SRS occurs in both directions, either forward or backward direction.

The non-linear phenomenon of SBS and its effect, first detected in 1964 [5].When launched power into an optical fiber exceeds threshold level; most of the light is reflected backward direction. This phenomenon is known as SBS. Input signal is known as pump wave and which signal is generated due to this scattering process that is known as Stokes wave. SBS occurs only in the backward direction i.e., when input power exceeds threshold power, Stokes power shifted to the backward direction. Pump wave losses power while Stokes wave gains power.

2.2 SBS Mechanism
The SBS is a nonlinear process that can occur in optical fibers at large intensity. Quantum mechanically the Brillouin shift originates from the photon-phonon interaction. The basic mechanism of SBS phenomenon is illustrated in Fig. 1

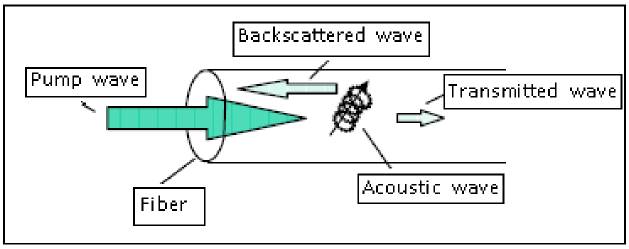

Fig.1: Basic SBS mechanism

The pump wave creates acoustic wave in transmission medium through a process called electrostriction. The interaction between pump wave and acoustic wave creates the generation of back propagating optical wave which is called Stokes wave. When acoustic waves travel through the solid, transparent glass material, they induce spatially periodic local compressions and expansions which in turn cause local increases and decreases in the refractive index. This phenomenon is known as photoelastic effect. The magnitude of the photoelastic effect increases with increasing input optical power. When the input power reaches a SBS threshold level, the refractive index of the fiber has been acoustically altered to a degree such that a significant portion of the optical signal is back-scattered. So, we can say that the acoustic wave alters the optical properties of the fiber, including the refractive index. This fluctuation of refractive index scatters the incident wave and creates Stoke wave which propagates in the opposite direction.

2.2 SBS Effect During Transmission

The scattering effect transfers power from incident wave to the reflected wave. The lost energy is absorbed by molecular vibrations in the fiber. Due to this loss of energy, the reflected wave has a lower frequency than the incident wave.

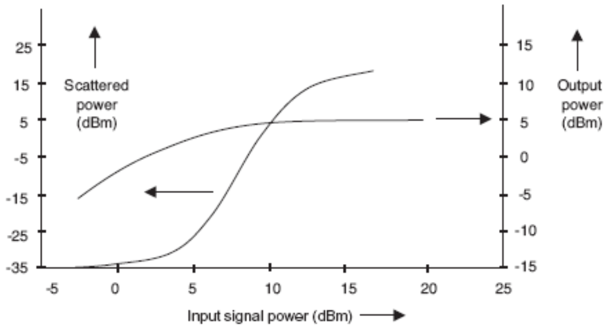

Fig. 2: Illustration of SBS effect [6]

The SBS effect is depicted in Fig. 2. From Fig. 2, we see that with increasing input power output power also increased. But at a certain point output power is saturated i.e., output power is not increased; most of the power is reflected to the backward direction with increasing input power. Due to the SBS effect high power transmission is not possible, we don't get expected output power due to the backscattering.

Brillouin scattering manifests itself through the generation of a backward propagating Stokes wave downshifted from the frequency of the incident pump wave by an amount determined by the nonlinear medium. The stoke waves carries most of the input energy, once the Brillouin threshold is reached. The process of SBS can be viewed as a parametric interaction among the pump wave, the Stokes and anti Stokes wave and an acoustic wave. The pump field generates sound waves in the fiber which induce a periodic modulation of the refractive index due to the pressure.

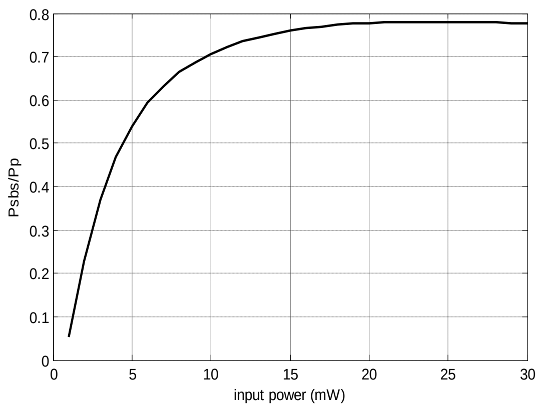

Fig. 3: P_{sbs}/P_p versus P_p

Fig. 3 shows the normalized Stokes power versus pump power. Here, P_{sbs} indicates backscattered power or Stokes power and P_p indicates input pump power. This plot is called the reflectivity curve. The power of SBS scattering light increases gradually as the fiber-launch power increased. When the fiber-launch power reached a certain point, the SBS scattering light power increased dramatically, indicating that it has crossed the threshold power of SBS. In Fig. 3, we have used the ratio of scattering light power, P_{sbs} to the fiber-launch power, P_p as the vertical axis and P_p as the horizontal axis and obtained the reflectivity curves of SBS.

SBS is a problem for signal quality. It has some harmful effects such as attenuation, power saturation, back-propagation etc. Attenuation is due to the loss of energy *i.e.*, power transfer from pump wave to reflected wave. SBS limits maximum amount of power that can be transmitted through a fiber. At a certain point output power is not increase with input power *i,e,*; power is saturated. From Fig. 2. 1, we see this effect of SBS clearly. Due to the SBS affect most of the power reflected to the backward direction when input power exceeds more 14 mW. It creates noise in transmitter and saturates amplifiers. SBS causes bit error rate degradation, for that reason it is a serious problem for single channel system. So, we need to suppress the SBS effect and enable the system to transmit larger amount of optical power at the receiving end.

3. VARIOUS METHODS

Jaworski *et al*. (2001) has shown that threshold power can be increased using two methods. One method is optical phase modulation (dithering) and another is initial pulse modulation and spectrum scattering by propagating in double-clad fiber. By applying these methods optical signal spectrum is widened and suppressed due to four wave mixing in the fiber. The simulation results provide satisfied output result [7].

Lee *et al.* (2003) has used fiber Bragg grating (FBG) for SBS suppression. For suppressing the SBS effect they used a FBG fabricated within the 'photosensitive' fiber. They used a sampled FBG consisting of 4-cm-long samples over 1m long optical fiber with 10 cm sampling period [8]. They reported that 15 ns pulses with 2 KW peak power can be transmitted though a 1-m long fiber with little energy loss. Finally they proved through numerical simulation that SBS effect can be suppressed with a proper design of a fiber Bragg grating.

Raman fiber amplifier based SBS suppression with dispersion shifted fiber is reported in [9]. The method uses the spectral broadening of the signal due to cross phase modulation induced by the pump. They showed that experimental method to suppress the SBS effect by using the advantages of Raman fiber amplifier.

As the bandwidth of the scattered wave due to SBS is smaller (≥25 MHz) and it also distorts the signal of individual channels [10]. Hu *et al.* (2005) studied the SBS effect on the radio-over-fiber (RoF) distribution systems. They demonstrated that the modulation depth of the optical micro-wave signal can suppress the SBS effect. They proposed how the position of the optical filter can influence the performance of a RoF system due to SBS and also discussed the overcoming the SBS effect by the eye-diagram of received signal with pre-filtering and post-filtering. The experimental results showed that SBS threshold increases with the modulation index.

Hedge *et al.* (2007) studied the effect of a photonic bandgap in a photonic crystal fiber. They demonstrated an analytical model for SBS effect and showed that SBS effect can be minimized by using the elastic grating structure model [11]**.** Their analytical solution showed that SBS threshold increases with elastic-grating coupling coefficient and they verified the analytical results by numerically solving equations for the variety of different photonic bandgap sizes**.**

Gray *et al*. (2007) demonstrated 502 Watts of power from a pump limited, single mode, narrow linewidth fiber amplifier [12]. To achieve high power operation in a narrow linewidth amplifier a double-clad Erbium doped fiber was fabricated. They reduced SBS effect by minimizing the overlap between the optical and acoustic fields in the fiber core.

Lei *et al.* (2009) analyzed and showed that SBS effect can be eliminated using the nonlinear effect through simulation [13]. They solved the modified nonlinear Schrödinger equation (NLSE) in the Erbium doped fiber amplifier (EDFA) and NLSE in the passive fiber by using the split step Fourier and Local error method (SSFM-LEM). They used master oscillator power amplifier (MOPA) for their research work. From their simulation result they have showed that wavelength broadening is increased with fiber length and spectrum broadening is also increased with fiber length.

Multi-frequency phase modulation is also reported to improve threshold power and eliminate the SBS effect. Liu *et al.* (2009) investigated the effect of SBS on the equal-amplitude spectral lines based on multi-frequency phase modulation numerically and experimentally. The SBS threshold of three, five, seven, and eleven equal-amplitude spectral lines are obtained [14].

Du *et al.* (2010) theoretically treated the SBS effect [15]. In this paper, a two-stage amplification all-fiber amplifier system is set up to investigate SBS effect in multitone-driven high-power amplifiers. In one case the system is seeded with a 1064 nm single frequency laser with output power of 43 mW. In another case the system is seeded with a narrow-linewidth laser with center wavelength around 1064 nm and output power of 45 mW. They showed that the SBS threshold in multitone-driven narrow-linewidth high-power amplifiers can be enhanced.

We have already observed from the above mentioned works that different researchers investigated and developed different methods, techniques and tools to eliminate SBS effect. Some of the research works were carried out analytically, numerically and / or experimentally. From the above literature review, we have observed that most of the research works have addressed SBS suppression using fiber Bragg grating, photonic crystal fiber, Raman fiber amplifier, master oscillator power amplifier, double-clad fiber etc. Various proposed methods suppressed SBS effect in different amounts. They were able to improve SBS threshold power for SBS reduction.

In Table 1, we have established a comparison among different research works. Liu *et al.* have experimentally worked SBS suppression based on multi-frequency phase modulation [14]. They have observed that the threshold power after modulation is in reverse proportion to the maximum square of amplitude moduli of fundamental frequency and the nth harmonic wave. For three equal amplitude modulation signals threshold power raised up to 68 mW. Hayashi *et al*. have analyzed on SBS threshold representing bit-error degradation in single-mode optical fiber transmission considering different boundary conditions [16]. They have improved SBS threshold power up to 73 mW at 0.82 modulation index. Lei *et al*. have raised the SBS threshold level using high power short pulse fiber amplifier [13]. They have improved threshold power up to 70 mW and spectral broadening up to 18 MHz at 100 km using SPM only.

Here we propose two new methods to eliminate this SBS effect. The new idea is creating a non-uniform Brillouin spectrum along the fiber is also an effective way to reduce the SBS because it reduces the maximum effective gain coefficient. This can be done by changing the dopants level, applying distributed stress, or using a temperature gradient along the fiber during manufacturing. Before directly applying this approach in manufacturing, simulation or analytical study may be a viable option.

Another way to reduce the SBS is to reduce the overlap between the optical and acoustic field. The simple step index profile made of GeO_2 doping is not suitable for this purpose because the fundamental optical and acoustic mode has very similar field distribution. Appropriate doping materials may be searched to overlap the above mentioned fields.

Table 1: Comparison among different research works

Method/Techniq	**Type of study**	**Length of the link**	**Threshold power improvement**
Multi-frequency phase modulation [14]	Experimental	N/A	68 mW for three equal amplitude modulation signals
SBS gain reduction [16]	Analytical	67.3 km	73 mW at modulation index 0.82
Nonlinear SPM effect [13]	Simulation	100 km	70 mW for SPM only

4. CONCLUSION

Here we have observed the SBS effect in optical fiber transmission system when the transmitted power is appreciably high. In optical transmission system, we always strive for larger span length by feeding higher amount of power at the transmitter end. But unfortunately due to the SBS effect, when the input power exceeds the threshold level, certain amount of power gets reflected in the backward direction thereby saturates the transmitter. So, the only way to transmit relatively higher power, we need to increase the SBS threshold level. In this paper we also observe that different types of research method eliminate SBS effect in different ways. Our two new approaches also eliminate this SBS effect by reducing the maximum effective gain coefficient and using appropriate doping material to reduce the overlap between the optical and acoustic field.

5. REFERENCES

[1] Senior J. M., "Optical Fiber Communications", Chapter 1, Second Edition, Practice Hall International (UK) Ltd, 1993.

[2] Shiraki K., Oshani M. and Tateda T., "Suppression of stimulated Brillouin scattering in a fiber by changing the core radius", Electronics Letters, vol. 31, no. 8, pp. 668-669, 1995.

[3] Agrawal G. P., "Nonlinear Fiber Optics", Chapter 9, Academic Press, Elsevier, Third Edition, pp. 355-360, 2009.

[4] Willems F. W. and Muys W., “Simultaneous suppression of stimulated Brillouin scattering and interferometric noise in externally modulated lightwave AM-SCM systems”, IEEE Photonics Technology Letters, vol.6, no. 2, pp.1476-1478, 1994.

[5] Boyd R.W., “Nonlinear Optics”, Chapter 8, Academic Press, San Diago, 1992.

[6] Mao X.P., Takach R.W., Jopson R.M. and Dorosier R.M., “Stimulated Brillouin threshold dependence on fiber type and uniformity,” IEEE Photonics Tech.Leett., vol.4, pp.66- 69, 1992.

[7] Jaworski M. and Marcinial M., “Initial pulse modulation method for SBS counteracting in long distance optical fiber CATV link”, Proceedings of 3rd International Conference on Transparent Optical Networks, pp. 279-282,2001.

[8] Lee H. and Agrawal G.P., “Suppression of stimulated Brillouin scattering in optical fibers using fiber Bragg gratings”, Optical Express, vol. 11, no. 25, pp. 3467-3472,2003.

[9] Ranet G., Fotiadi A.F., Blondel M. and Megret P., “Suppression of stimulated Brillouin scattering with a Raman fiber amplifier”, Proceedings of IEEE Lasers and Electro Optics Society, Ghent (B), pp. 199-202, 2004.

[10] Hu L., Kaszubowska A. and Barry L.P., “Investigation of stimulated Brillouin scattering effects in radio-over-fiber distribution systems”, Optics Communications, vol. 255, no. 4-6, pp.253-260, 2005.

[11] Hegde R.S., Winful H.G. and Galvanaskas A., “Suppression of stimulated Brillouin scattering in a photonic crystal fiber”, Quantum Electronics and Laser Science Conference, QELS, pp.1-2, 2007.

[12] Gray S., Liu A., Walton D. T., Wang J., Li M. J., Chen X., Ruffin A. B., DeMeritt J. A. and Zenteno L. A., “Suppression of stimulated Brillouin scattering in high power, narrow linewidth fiber amplifiers” , Optical Express, vol. 15, no.25, pp. 17044-17050,2007.

[13] Lei Z., Jiping N., Cheng C., Weiyi Z. and Juntao W., “Analysis of a novel stimulated Brillouin scattering suppression mechanism through self phase modulation process in the high power short pulse fiber amplifier”, Journal of Optoelectronics and Biomedical Materials, vol.1 no.1, pp. 157-164, 2009.

[14] Liu Y., Lii Z., Dong Y. and Li Q., “Research on stimulated Brillouin scattering suppression based on multi-frequency phase modulation”, Chinese Optical Letters, vol. 7, no. 1, pp.29-31, 2009.

[15] Du W., Ma Y., Zhu J., Dong Wang, X., Zhou P. and Xu X., “Experimental study of the SBS effect in multitone-driven narrow-linewidth high-power all-fiber amplifiers”, Photonics Global Conference, pp. 1-3, 2003.

[16] Hayashi Y. and Ohkawa N., “ Stimulated Brillouin Scattering Threshold Representing Bit- Error Ratio Degradation in Single-Mode Optical Fiber Transmission”, Electronics and Communications in Japan, Part 1, vol. 79, no.5, pp.15-26,1996.