World Academy of Science, Engineering and Technology
International Journal of Electronics and Communication Engineering
Vol:10, No:1, 2016

# The Effects of Signal Level of the Microwave Generator on the Brillouin Gain Spectrum in BOTDA and BOTDR

M. Yucel, M. Yucel, N. F. Ozturk, H. H. Goktas, C. Gemci, F. V. Celebi



***Abstract***—In this study, Brillouin Gain Spectrum (BGS) is experimentally analyzed in the Brillouin Optical Time Domain Reflectometry (BOTDR) and Brillouin Optical Time Domain Analyzer (BOTDA). For this purpose, the signal level of the microwave generator is varied and the effects of BGS are investigated. In the setups, 20 km conventional single mode fiber is used to both setups and laser wavelengths are selected around 1550 nm. To achieve best results, it can be used between 5 dBm to 15 dBm signal level of microwave generator for BOTDA and BOTDR setups.

***Keywords***—Microwave signal level, Brillouin gain spectrum, BOTDA, BOTDR.

## I. Introduction

OPTICAL fibers have been used in many different applications. The most known application is in the area of telecommunications [1]. Optical fibers have been utilized not only in the telecommunications but also common in fiber sensor systems. There are a lot of application areas of the fiber sensors such as medical, security, chemical, military, environmental etc. Different physical quantities can be measured such as temperature, strain, vibrations, pressure, speed, distance, gases, etc. by fiber optic sensors [2]-[17].

Recently, distributed fiber optic sensors aiming security are very popular. They make use of back scatterings in fiber optic cable. The best-known back scatterings in the fiber are Rayleigh scattering that has an elastic effect; the Brillouin and the Raman scatterings that belong to the inelastic effect [1].

In this paper, stimulated Brillouin based distributed fiber optic sensors are analyzed by using two techniques, which are BOTDA and BOTDR. When the input signal power exceeds the threshold in a single mode fiber (SMF), Stimulated Brillouin Scattering (SBS) that is a nonlinear optical process occurs. Various fundamental and applied aspects of SBS were studied and a great deal of papers is published recently about the researches that belong to SBS. The details of the SBS can be found in [7]-[12].

M. Yucel is with the Faculty of Technology Dept. of Electrical and Electronics Eng., Gazi Univ., Ankara, Turkey, (Corresponding author, Phone: 90312-202-8523; Fax: 90312-202-8947; e-mail: muyucel@gazi.edu.tr).

H. H. Goktas is with the Department of Electrical and Electronics Eng., Yildirim Beyazit Univ., Ankara, Turkey, (e-mail: goktas@ybu.edu.tr).

M. Yucel is with the Yenimahalle Vocational and Technical High School, Ankara, Turkey, (e-mail: ymurat77@gmail.com).

C. Gemci is with CYMSOFT Information Technologies, Ankara, Turkey, (e-mail: cemal@cymsoft.com).

N. F. Ozturk is with the Institute of Science Gazi Univ., Ankara, Turkey, (e-mail: nailferhatozturk@gmail.com).

F.V. Celebi is with the Department of Computer Eng., Yildirim Beyazit Univ., Ankara, Turkey, (e-mail: fvcelebi@ybu.edu.tr).

## II. Theory of the Brillouin Scattering

In the Brillouin scattering theory, the process of scattering can be defined as the nonlinear effect between light and acoustic wave and this scattering can be spontaneous or stimulated. When an oscillating electric field at the pump frequency known as $f_P$, then the electrostriction process produces a macroscopic acoustic wave at the frequency $f_B$, where $f_B$ is the Stokes shift. In the spontaneous Brillouin scattering, pump photons are suppressed. This results in creation of Stokes photon and an acoustic phonon concurrently. The energy conservation and momentum conservation (MC) must be followed in similar scattering processes [18]-[21].

For conservation of energy, $f_B$ is close to equal to $f_P - f_S$, where $f_S$ is frequency of stokes wave. MC needed is $k_A = k_P - k_S$ difference, where $k_A$, $k_P$ and $k_S$ are momentum vectors of acoustic, pump and Stokes waves respectively.

When $\nu_A$ is acoustic velocity, and then dispersion relation can be written with (1), (2) [18];

$$f_B = \nu_A + |\overrightarrow{k_A}| = \nu_A\,|\overrightarrow{k_P} - \overrightarrow{k_S}| \tag{1}$$

$$f_B = 2\,\nu_A|\overrightarrow{k_p}|\,\sin\frac{\theta}{2} \tag{2}$$

In (1) and (2), $\theta$ is the angle between $k_P$ and $k_S$ and they are taken nearly equal. The frequency shift depends on $\theta$. If $\theta=0^{\circ}$, frequency shift (FS) is also equal to zero and FS only can be seen backward direction. If $\theta=\pi$, FS is maximum at backward direction. If the maximum backward shift given with Brillouin FS $v_B = f_B/2\pi$ formula, from (1) and (2) [18];

$$|\overrightarrow{k_p}| = 2\pi n/\lambda_p \tag{3}$$

will be calculated with this definition. Where, n is reflective index of SMF, $\lambda_p$ is pump wavelength. Consequently, SBS can transfer all power from the pump to the scattered wave [20]-[21].

For stationary conditions, SBS can be described by (4), (5). For simplification, $f_P \cong f_S$ and $\alpha_P \cong \alpha_s$ can be accepted. Wave Equations can be written;

$$\frac{\partial I_s}{\partial z} = -g_B\, I_s I_P + \alpha_s I_s \tag{4}$$

$$\frac{\partial I_P}{\partial z} = -g_B I_s I_P - \alpha_P I_P \quad (5)$$

In (4) and (5), $I_s$ and $I_P$ are the light intensity of signal and pump light respectively, $\alpha_s$ and $\alpha_P$ are the fiber attenuation, $g_B$ is the Brillouin gain coefficient of the fiber.

For the Brillouin threshold estimating, pump depletion can be neglected. Using $I_P(z) = I_P(0)\, e^{-\alpha z}$ and integrating it over fiber length L, (6) can be written as [19], [20];

$$I_S(0) = I_S(L)\exp(g_B P_0 L_{eff}/A_{eff} - \alpha L) \quad (6)$$

when $P_0 = I_P(0) A_{eff}$ is the input pump power, $A_{eff}$ is effective mode area and $L_{eff}$ is the effective fiber length of fiber considering fiber loss and fiber absorbability, then (7) can be written;

$$L_{eff} = \frac{1}{\alpha}[1 - \exp(\alpha L)] \quad (7)$$

Equation (8) shows how a Stokes signal incident at z=L grows in the backward direction because of Brillouin amplification occurring as a result of SBS. The peak value of the Brillouin gain is given by;

$$g_B(\Delta f) = g_0 \frac{\gamma\left(\frac{\Delta f_B}{2}\right)^2}{\Delta f^2 + \left(\frac{\Delta f}{2}\right)^2} \quad (8)$$

where $\gamma$ is polarization coefficient. $\Delta f_B$ is the bandwidth of Brillouin gain [18], [19];

## III. Experimental Setup

Fig. 1 shows Brillouin optical time domain analyzer (BOTDA) scheme. The input laser signal is applied by the continuous wave (CW) tunable laser source (TLS) that has SANTEC TSL-210V. The wavelength of the laser is around 1550 nm and modulated into microwave (MW) signal generator by using electro-optic modulator (EOM) as the pump of the SBS, and then pulsed input signals are amplified with Erbium Doped Fiber Amplifier (EDFA). After, amplified signals pass through port 1 to port 2 of the optical circulator; the signals propagate along SMF having a length of 20 km. The CW laser signal is launched at the opposite end of the fiber that is called the probe signals. Back-scattered SBS signal is passing through port 2 to port 3 of the optical circulator. Then, SBS signals are amplified by the second EDFA and divide by 3 dB coupler that are being sent to high-resolution optical spectrum analyzer (OSA) and photo diode (PD). Finally, electrical signals at the output of PD are amplified by the radio frequency amplifier (RFA), which is analyzed by the radio frequency spectrum analyzer (RFSA).

Fig. 2 shows Brillouin optical time domain reflectometry (BOTDR) scheme. BOTDR utilizes only pulse laser and laser pulses propagate along single direction of SMF as it can be seen from the Figs. 1 and 2. Fig. 2 uses same optical component with Fig. 1 except CW laser source.

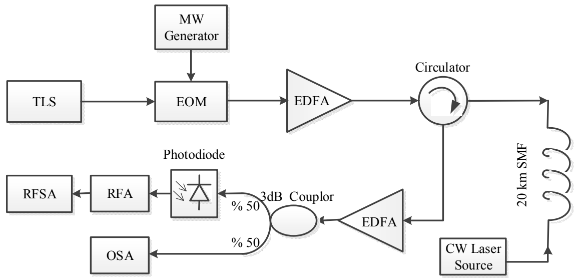



Fig. 1 Brillouin optical time domain analyzer (BOTDA) experimental setup

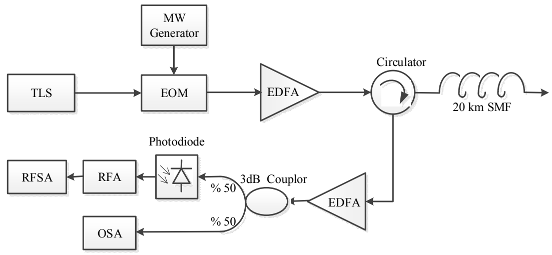
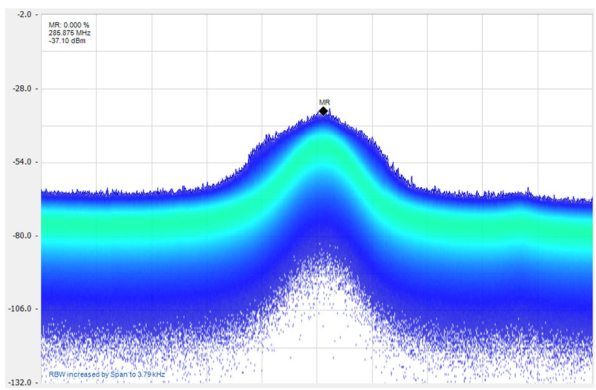


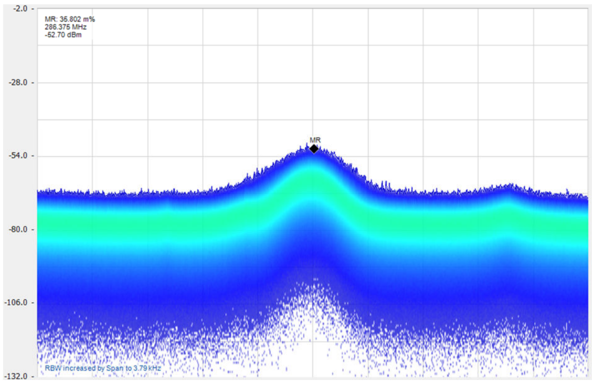

Fig. 2 Brillouin optical time domain reflectometry (BOTDR) experimental setup

## IV. Results and Discussions

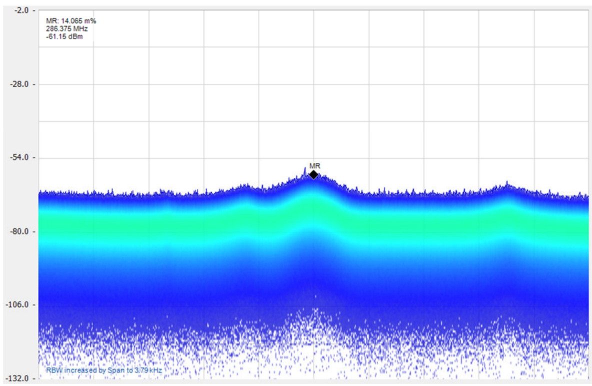
Firstly, BOTDA that is shown in Fig. 1 is analyzed. MW signal generator modulates the CW laser signal and, it propagates through SMF, and power level of the MW signal is varied between -20 dBm to +20 dBm. Fig. 3 shows BGS for various signal levels. It can be observed from the Fig. 3 that the Brillouin scattering increased by increasing the power level of MW generator, however different result is obtained at the +20 dBm signal level. At this signal level, BGS peak power is lower than +15 dBm because of the Stokes line that reaches the saturation power level.




(a)

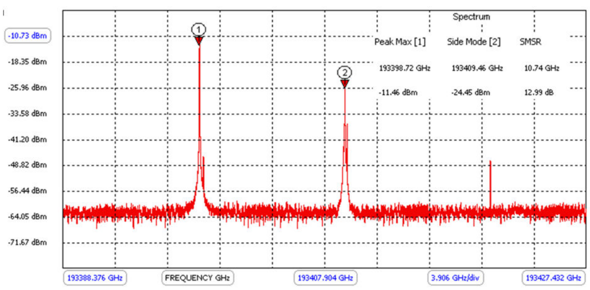



(b)

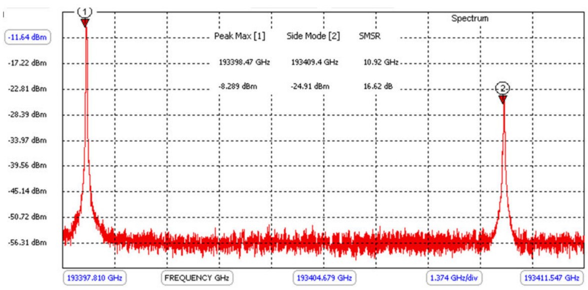



(c)

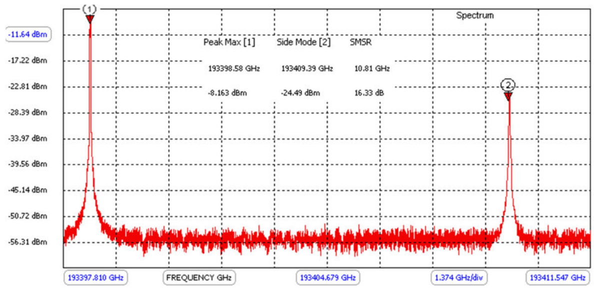
Fig. 3 Brillouin gain spectrums for the different signal levels for BOTDA setup (a) +15 dBm, (b) 0 dBm, (c) -10 dBm




(a)




(b)

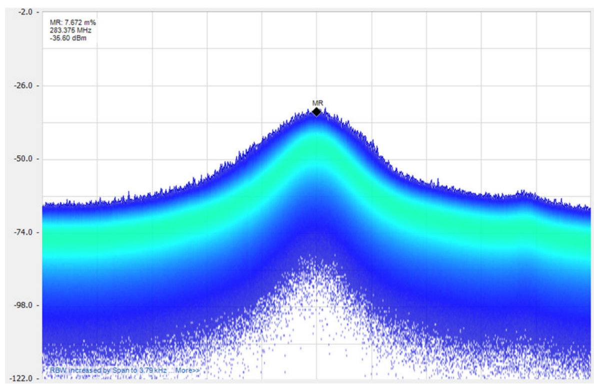



(c)

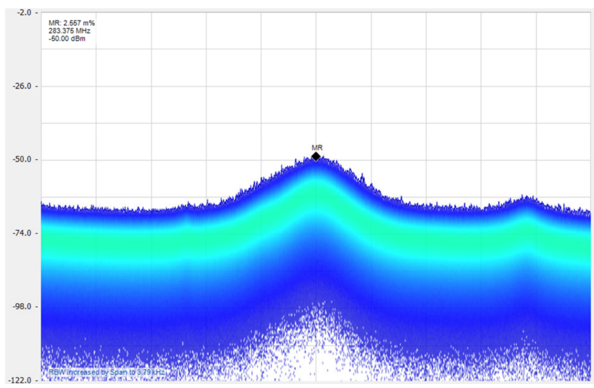
Fig. 4 Optical spectrums for the different signal levels for BOTDA setup (a) +15 dBm, (b) 0 dBm, (c) -10 dBm

The optical spectrums of the same MW signal levels are shown in Fig. 4. Frequency difference between two lasers is adjusted about the Brillouin back scattering frequency, which is around 10.85 Ghz, with the use of TLS. First peak is pump, second peak is probe and, third peak is the harmonic of the MW generator.

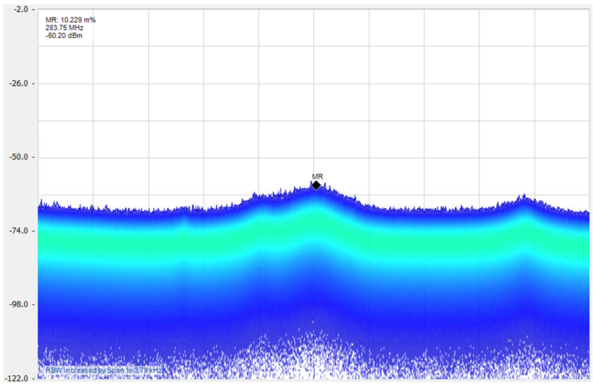
Secondly, BOTDR that is shown in Fig. 2 is analyzed. For this purpose, same procedure is followed with BOTDA. BGS for the various signal levels is shown in Fig. 5. It can be observed that Brillouin scattering increased by increasing the power level of MW generator.




(a)

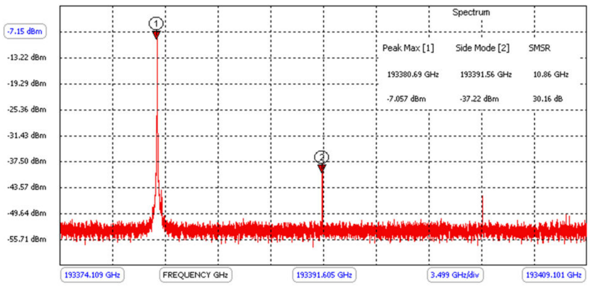



(b)

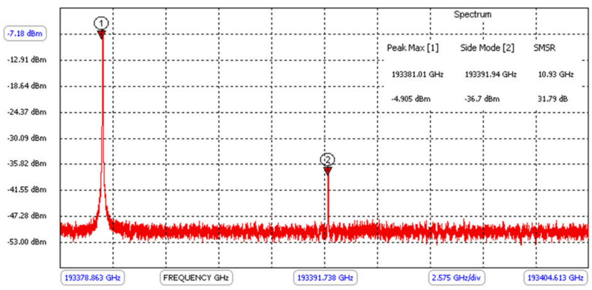


(c)

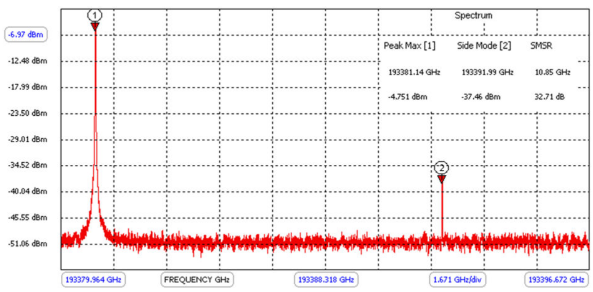
Fig. 5 Brillouin gain spectrums for the different signal levels for BOTDR setup (a) +15 dBm, (b) 0 dBm, (c) -10 dBm



(a)



(b)



(c)

Fig. 6 Optical spectrums for the different signal levels for BOTDR setup (a) +15 dBm, (b) 0 dBm, (c) -10 dBm

The optical spectrum of the same MW signal levels are shown in Fig. 6 for BOTDR. The first peak is pump and the second peak is Brillouin back-scattering signal.

Fig. 7 shows the variations of BGS peak power for various MW signal levels. BOTDA and BOTDR setups have the same properties except +20 dBm level for BOTDA setup.

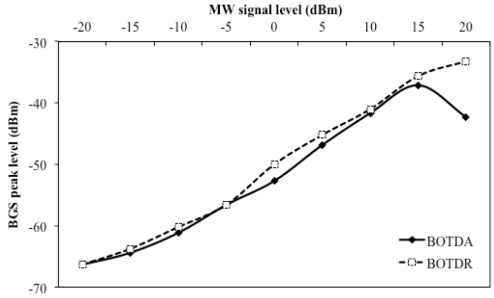



Fig. 7 The variations of BGS peak power versus MW signal levels

## V. Conclusion

Many variable parameters on BOTDA and BOTDR setups can be observed. BGS peaks are analyzed by varying the MW signal levels. The BGS of the BOTDR is proportional to the varied MW signal level. This response is also similar for BOTDA setup. However, BOTDA setup shows a nonlinear change for +20 dBm MW signal level. Finally, BOTDA and BOTDR setups can be used between 5 dBm to 15 dBm for best results.

## Acknowledgment

This work was supported by The Scientific and Technological Research Council of Turkey. (Project Number: 5130044)

## References

[1] R. Sifta, P. Munster, P. Sysel, T. Horvath, V. Novotny, O. Krajsa, M. Filka, "Distributed fiber-optic sensor for detection and localization of acoustic vibrations," *Metrol. Meas. Syst.,* vol. 22, no. 1, pp. 111–118, 2015.

[2] M.A. Soto, G. Bolognini, Pasquale, F.D., Thévenaz, L. "Simplex-coded BOTDA fiber sensor with 1 m spatial resolution over a 50 km range," *Optical Letters*, vol. 35, pp. 259-261, 2010.

[3] Hao, H., Li, W., Linze, N., Chen, L., Bao, X. "High resolution DPP-BOTDA over 50 km fiber using return to zero coded pulses," *Optical Letters*, vol. 35, pp.1503-1505, 2010

[4] Soto, M.A., Bolognini, G., Pasquale, F.D. "Optimization of long-range BOTDA sensors with high resolution using first-order bi-directional Raman amplification," *Opt. Express*, vol.19, pp. 4444-4457, 2011.

[5] Andrew, M. "Stimulated Brillouin Scattering in Single-Mode Optical Fiber", *Phd. Thesis*, University of Virginia, 1997.

[6] M.N. Alahbabi, "Distributed Optical Fiber Sensors Based on the Coherent Detection of Spontaneous Brillouin Scattering," *Phd. Thesis*, University of Southampton, Optoelectronic Research Centre, 2005.

[7] A. Kobyakov, M. Sauer, and D. Chowdhury, "Stimulated Brillouin scattering in optical fibers," *Advances in Optics and Photonics*, vol. 2, pp.1-59, 2010.

[8] E. Lichtman, R. G. Waarts, and A. A. Friesem, "Stimulated Brillouin scattering excited by a modulated pump wave in single-mode fibers," *Lightwave Technology*, vol. 7, pp. 171–174, 1989.

[9] A. Yeniay, M.-M. Delavaux, and J. Toulouse. "Spontaneous and stimulated brillouin scattering gain spectra in optical fibers", *Lightwave Technology*, vol. 20, pp.1425-1432, 2002.

[10] R.W. Boyd, K. Rzazewski, and P. Narum. "Noise initiation of stimulated brillouin scattering," *Physical Review*, vol.42, pp. 5514-5520, 1990.

[11] R.G. Smith., "Optical power handling capacity of low-loss optical fibers as determined by stimulated Raman and Brillouin scattering", *Applied Optics*, vol.11, pp. 2489-2494, 1972.

[12] D. Cotter., "Stimulated Brillouin scattering in monomode optical fiber," *Journal of Optical Communications*, vol.4, pp.10-19, 1983.

[13] D. Cotter., "Observation of stimulated Brillouin scattering in low loss silica fiber at 1.3 µm." *Electronics Letters*, vol.18, pp.495-496, 1982.

[14] S. Sato Y. Koyamada, S. Nakamura, and an nd W. Chujo H. Sotobayashi. "Simulating and designing Brillouin gain spectrum in single-mode fibers," *Journal of Lightwave Technologies*, vol.22, pp.631-639, 2004.

[15] A. Loayssa, R. Hernadez, D. Benito, and S. Galech., "Characterization of stimulated Brillouin scattering spectra by use of optical single-sideband modulation," *Optical Letters*, vol.29, pp.638-640, 2004.

[16] D.A. Fishman and J.A. Nagel., "Degradations due to stimulated Brillouin scattering in multigigabit intensity-modulated fiber optic systems," *Journal of Lightwave Technologies*, vol.11, pp.1721-17-28, 1993.

[17] S.P. Smith, Z. Zarinetchi, and S. Ezekiel, "Narrow-linewidth stimulated brillouin fiber laser and applications," *Optical Letters*, vol.16, pp.393-395, 1991.

[18] Singh, S. P., Gangwar, R., Singh, N., "Nonlinear Scattering Effects in Optical Fibers," Progress *in Electromagnetics Research*, PIER 74, pp.379–405, 2007.

[19] Xiaorui Li, Huaping Gong, Shuhua Li, Jianfeng Wang, "Experimental Investigation on Pulse Light Stimulated Brillouin Scattering in the Optical Fiber," *Communications and Photonics Conference and Exhibition*, Shanghai, pp.1-8., 13-16 Nov 2011.

[20] M. Yücel, H. H. Göktas, M. Yücel, N.F. Öztürk, "The fiber optical sensing based on Brillouin scattering," in Proc. *22th, Signal Proces and Commun. App. Conf. (SIU)*, Trabzon, Turkey, 23-25 April 2014, pp. 838-841.

[21] M. Yücel, M. Yücel, N.F. Öztürk, H. H. Göktas, "The analyzes of the Brillouin scattering for the different fiber types," in Proc. *23th, Signal Proces and Commun. App. Conf. (SIU)*, Malatya, Turkey, 16-19 May 2015, pp. 632 – 635.