Detection of Stimulated Brillouin Scattering in Bi-directional Fiber-optic Links

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***Summary*—We propose a method for detection of stimulated Brillouin scattering that may occur in bi-directional fiber-optic links used for time and frequency transfer. Under favorable conditions, this non-linear phenomenon converts the signal propagating in the link into the back-propagating noise and thus disturbs the link performance. This problem can be detected by beating the Brillouin and the Rayleigh scattered fields on a photodiode. While the frequency difference between the noise from both Brillouin and Rayleigh scattering is about 11 GHz, an electrical signal of such a frequency can be observed at the photodiode output. Its further processing is performed in electrical domain and includes frequency downshifting (using mixer and a local oscillator) and the power measurement. On this basis, it can be estimated whether the Brillouin scattering may have a significant impact on the operation of the link.**

***Keywords*—bi-directional fiber optic link, Brillouin scattering, Rayleigh scattering**

I. Introduction

Fiber-optic links are nowadays considered as an important solution for accurate time and frequency (T&F) transfer. Two-way transmission capability in a single fiber and possibility to perform signals amplification in the optical domain (using e.g. dedicated single-path bi-directional amplifiers – SPBA - based on Erbium-doped fiber) provide an unsurpassed symmetry for the forward and backward signals paths that is highly desirable for the propagation delay stabilization [1]. On the other hand, optical noise (e.g. resulting from Rayleigh scattering or amplified spontaneous emission - ASE) can freely propagate in the fiber along with the desired signals. This, combined with the possibility of occurring high levels of the optical power introduced by the amplifiers, carries a risk of triggering the stimulated Brillouin scattering (SBS).

The current method of avoiding SBS relies on careful link design and optimization, aimed to eliminate conditions for triggering this phenomenon. However, the SBS can grow over a long distance that makes it difficult to point the exact part of the link, where it began to develop. The problem becomes relevant if we consider an automatic link performance optimization [2], where triggering SBS as a result of a wrong optimization step, can disable proper operation of entire procedure or even the whole link.

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We propose a method for detection of the SBS in a running link. This information could be used to prevent the link performance disturbance either by manual tuning of setting the amplifiers' gains or by incorporating it in algorithms of automatic link optimization.

II. Method

The SBS converts the desired signal propagating in the link into the back-propagating noise [3]. The characteristic feature of this phenomenon is about 11 GHz frequency shift (~0,08 nm) between the signal and the noise spectra. At the same time, the signal causing the SBS is subjected to the Rayleigh backscattering, but this time the scattered noise spectrum remains unshifted. In a proposed solution, the optical noise from these two processes is supplied to a photodiode, where it undergoes beating. This results in about 11 GHz (equal to the shift of noise from SBS) electrical signal at the output of the photodiode. A simplified diagram with marked directions of propagation of desirable signal and the noise (from both, Rayleigh and Brillouin scattering), is shown in Fig. 1. The link is split near the SPBA, thus the noise is amplified before it reaches the photodiode. This results with higher current at its output.

In the further processing, the electrical signal from the photodiode is pre-amplified and downshifted to a band around

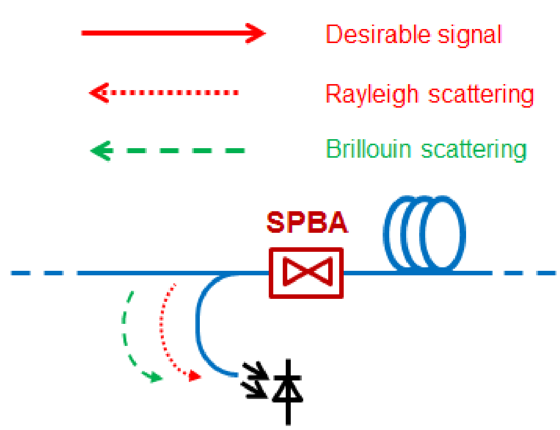

Fig. 1. A simplified diagram with marked directions of propagation of desirable signal and noise. A photodiode is part of the SBS detector and it is supplied with the noise from both Rayleigh and Brillouin scattering. SPBA – single-path bi-directional optical amplifier.

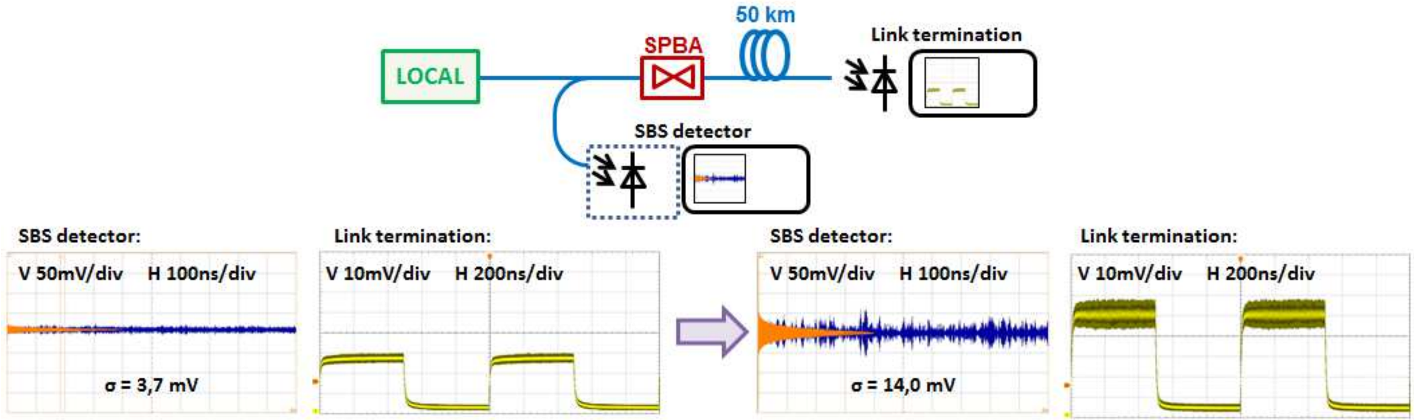

Fig. 2. Measurements results before (left) and after (right) the SPBA gain increment. The impact of the SBS on the link performance is not yet critical, but noticeable both at the link termination and at the tested SBS detector output.

2-2,5 GHz using a mixer and a local oscillator. The following band-pass filter reduces the out of band noise. Then the signal is supplied to the root mean square (RMS) power meter or to the oscilloscope for further analysis. A block diagram of the electric part of the detector is shown in Fig. 2.

III. VALIDATION

The developed SBS detector was tested using one of the boundary modules (LOCAL) of the T&F transfer system, followed by the SPBA (equipped with the SBS detector) and about 50 km of the fiber on a spool. While the transfer system operates bi-direcitionally using slightly different wavelengths for both directions, the SBS from the forward desirable signal has not influence on SBS from the backward desirable signal and vice versa. Therefore for the validation purposes, the second boundary module (REMOTE) was replaced by the photodiode and the oscilloscope that allowed to observe the square waveform transmitted through the link and possibly degraded by the occurrence of the SBS. At the same time, the second oscilloscope allowed to observe the SBS detector output. The example of the measurements results is shown in Fig. 3.

At first, the gain of the SPBA was set to provide ~25 mV peak-to-peak signal at the link termination. Increasing the gain of the SPBA by about 3 dB has made the results of the SBS visible – the high level of the square waveform has become significantly noisy. At the same time, the standard deviation of the noise at the developed SBS detector output increased from 3.7mV to 14.0mV (about 3.8x). The impact of the SBS on the link performance is not yet critical, but the very fact of its occurrence is detectable.

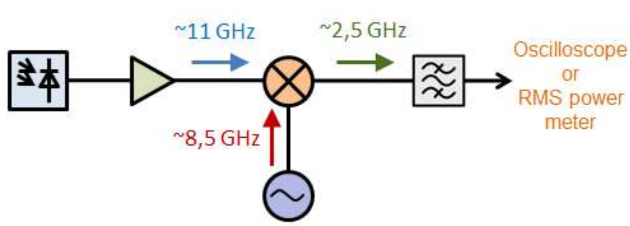

Fig. 3. A block diagram of the electric part of the SBS detector. Please see description in the text.

IV. CONCLUSIONS

The Brillion scattering detector allows to detect if the SBS process is triggered early enough to take precautions and prevent its destructive impact on the link performance. Due to its design, the detector makes it possible to monitor the link during its normal operation.

The detector uses the noise from both Rayleigh and Brillouin scattering that arises and propagates in a single fiber (including a branch supplying signals to the photodiode in the SBS detector). It allows avoiding the problems with the polarizations of these two signals as they are always aligned.

In the bi-directional T&F transfer systems there is a need to use two separate SBS detectors, one for each propagation directions. A separate issue is whether the set of detectors needs to be placed in each optical amplifier installed along the link or just is some of them (e.g. located near the boundary modules). Determining a reasonable location for the SBS detectors to react early and more precisely to the occurrence of potentially hazardous effects, as well as the proper use of this information in the link performance optimization process will be the subject of further research.

REFERENCES

[1] J. Kodet, P. Pánek, I. Procházka, "Two-way time transfer via optical fiber providing subpicosecond precision and high temperature stability," Metrologia, vol. 53, 2016, pp. 18-26.

[2] K. Salwik, Ł.Śliwczyński, P. Krehlik, J. Kołodziej, "Optimization of time and frequency fiber-optic links exploiting bi-directional amplifiers, based on real-time performance measurement," Opt. Fiber Technol., vol. 62, 2021, 102465.

[3] M. O. van Deventer, "Fundamentals of Bidirectional Transmission Over a Single Optical Fiber," London: Springer, 1996, pp. 105-127.