Stimulated Brillouin Scattering and Raman Amplification in Standard Telco Fibers for Metrology Applications

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***Summary* — In this contribution, the mutual interference of bidirectional Erbium doped fiber amplification of coherent optical frequency transfer and Raman amplification used for high speed data transmission, will be investigated experimentally.**

Keywords — coherent optical frequency; high speed data transmission; bidirectional transfer; shared fiber; Raman amplification; Brillouin scattering; metrology

I. INTRODUCTION

Large fiber based infrastructures for Coherent Optical Frequency (COF) and Precise Time (PT) transfers i.e. metrology applications, are becoming reality. However, long term economical sustainability of such infrastructures seem to be bind with shared fiber infrastructures (also including housing points in remote places), used for high speed data transmissions. Both COF and PT require fully symmetrical transmission optical channels in both directions in order to maintain highest stability possible. Here, the role of National Research and Education Networks (NREN) operators is essential as NRENs supported and continue with COF and PT transmission in their advanced fiber networks.

In the case of fiber sharing, the safe creation and operation of symmetrical bidirectional channels is fundamental. On top of that, modern high data rate transmission systems require sufficiently high Optical Signal to Noise Ratio (OSNR). It is necessary to remember that high OSNR for high speed data signals can be degraded by interference with other (i.e. COF and/or PT) channels easily. Such high values of OSNR are typically achieved by complementing prevalent amplification schemes, typically using Erbium Doped Fiber Amplifiers (EDFA), with Raman distributed amplification. In Raman deployment, amplification medium is the transmission fiber itself so there is some potential for interactions between high speed data signals with transfer of COF/PT signals. There are ongoing discussions, namely in NREN community and metrologists' community, whether COF/PT signals can be transmitted in the same fiber as high speed data signals

Here we show the results of interaction between bidirectional EDFA and Raman amplification and their aggregate effect on COF/PT signals in the standard telecommunication fiber and possible solution of this ongoing debate.

II. MOTIVATION

Coherent Optical Frequency and Precise Time transfer over bidirectional optical channels has evolved from laboratory setups onto thousand kilometers long fiber lines in the past 20 years. But with growing numbers of COF/PT transmission lines, economy aspects of the long term operation of any optical fiber infrastructure is quite challenging, bringing significant CAPEX (in the terms of Indefeasible Right of Use or IRU) and OPEX (hubs and terminals spaces rental, service fees). Based on these facts, the sharing telecomm fibers carrying both data and non-data traffic, is becoming rather unavoidable. One example can be Czech Infrastructure for Time and Frequency (CITAF), where COF/PT is already deployed on more than more than 1100 km of optical fiber lines but only 17 km are dedicated to COF/PT transfer exclusively. These COF/PT channels are for example wavelengths 1542.14 nm and 1540.56 nm, i.e. DWDM channels 44 and 46 in the middle of the C band used for data transmission.

At the present time, NREN and other operators deploy coherent transmission systems with flexible spectral allocation of high speed data channels as opposed to fixed spectral defined grids usually with 100 GHz or 50 GHz grids. This new flexible feature allows transmission of very high data rate channels with speeds up to 800 Gb/s. This is applicable to the CESNET optical network, where the optical backbone undergoes significant upgrade from non-coherent systems with fixed 50 GHz grid to coherent flexible spectrum allocation (available from 2021). During this upgrade, more than 120 Optical Add Drop Multiplexers (OADM) are installed, allocating more than 800 GHz of dedicated optical bandwidth for COF, PT and also for new emerging important quantum services like Quantum Key Distribution (QKD).

III. PRACTICAL RESULTS

Non-linear effects like Stimulated Brillouin Scattering (SBS), Stimulated Raman Scattering (SRS), Four Wave Mixing (FWM) and Self Phase Modulation (SPM) are well known and described excellently for example in [1]. Non-linear effects are usually unwanted but sometimes are useful. For example FWM can be used for wavelength conversions, SPM can create great broadband light sources and SRS and even SBS can be used for

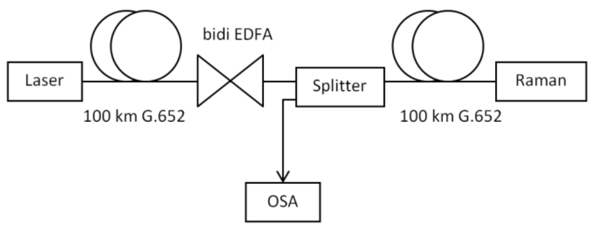

Fig.1. The experimental set up

amplification. It is interesting to note that for our high resolution spectral measurements, optical spectrum analyzer (OSA) based on SBS has been used.

On Fig.1 is depicted the experimental set up. The unmodulated signal (representing a COF/PT signal) from the stable tunable laser is connected to the bidirectional EDFA and then launched into the 100 km of G.652 fiber. The Raman amplifier is connected to the end of the fiber. A standard optical splitter is used to record signals back reflected from the fiber.

As was noted above, SRS is used for amplification to improve OSNR, which is required for modern coherent high speed data signals. SRS is a rather broadband effect, which is desirable. On the other hand, SBS is not used for telco amplification too often, because an SBS-amplified spectrum is very narrow. But this means that SBS is quite significant for COF and PT metrology signals, which are very narrow in the spectral domain (because those signals are either unmodulated or modulated with rather low frequencies, when compared to high speed data signals).

Raman and Brillouin scattering are similar effects caused by the nonlinearity of silica (or any medium) however there are few important differences. Photons interact with molecules of silica medium and these interactions can be associated with phonons (vibrations). Phonons can be either optical or acoustic. Optical phonons are vibrational states where adjacent molecules oscillate not in phase and optical phonons have relatively high frequencies, for silica this frequency shift is approx. 13 THz (or 100 nm). Acoustic phonons are different vibrational states where adjacent molecules oscillate (almost) in phase and acoustic phonons have rather lower frequencies compared to optical phonons (caused by short lifetime of acoustic phonons i.e. strong acoustic absorption), for silica this frequency shift is approx. 11 GHz (or 0.085 nm) with so called intrinsic bandwidth of 60 MHz. Because of these characteristics, Raman scattering is used

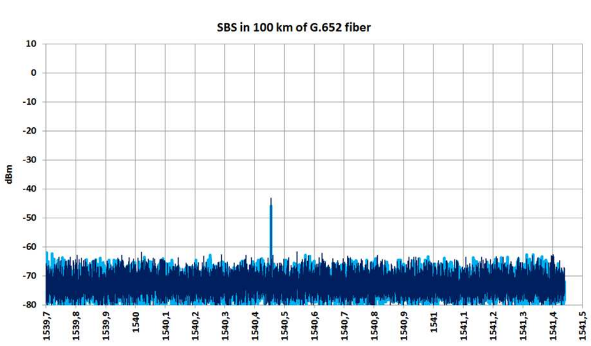

Fig. 2. SBS in G.652 fiber, bidi EDFA off, Raman amplification off

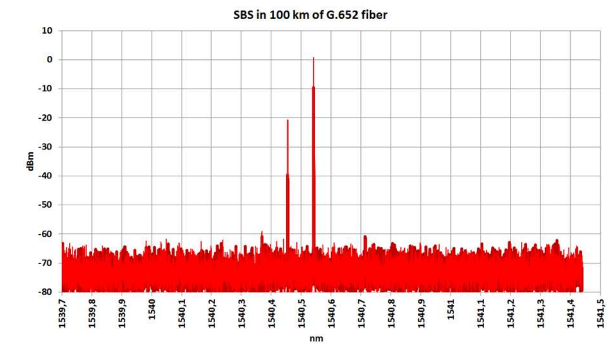

Fig. 3. SBS in G.652 fiber, bidi EDFA on, Raman amplification off

in telecommunications for amplification, but Brillouin amplifiers are rather infrequent. In both scattering processes, one photon is usually converted to a photon with lower frequency ('water flows downhill'), with remaining energy absorbed by photon – this is called a Stokes wave. Anti-Stokes waves can be also generated but this process is rather insignificant. Anti-Stokes waves (or frequency components or lines) can be created by Four Wave Mixing. FWM is another effect caused by nonlinear properties of silica, in this case two co-propagating optical beams with different frequencies interact, creating two frequency lines. In principle, more frequency lines could be produced (the fifth and sixths) but in this case, phase matching requirement satisfaction is unlikely (FWM depends strongly on relative phases of these frequency lines). So there is some potential for mutual interactions between SBS and SRS effects and of course with other non-linear effects too.

On Fig. 2 we can see the narrow laser signal tuned to 1540.46 nm with no EDFA amplification, and only this signal can be observed. The high precision OSA can measure both principal states of polarization, as shown on Fig. 2 in different colors, and the difference between them is approx. 2 dB.

When the bidirectional EDFA is switched on, new spectral lines are present, as can be seen on Fig. 3. So called Stokes and Anti-Stokes spectral lines are created. The Stokes line is stronger because the energy launched into the optical fiber is transferred to longer wavelengths with lower energy and Anti-Stokes spectral component is almost non-existent for such low energy in fibres. The difference in two polarizations is clearly visible and the difference is almost 10 dB for the Stokes spectral component and almost 20 dB for the original signal.

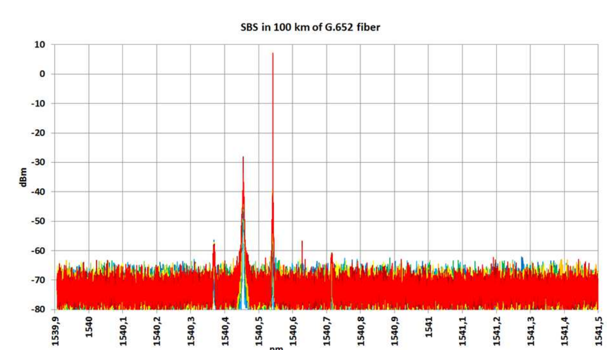

Fig. 4. SBS in G.652 fiber, bidi EDFA on, Raman amplification on

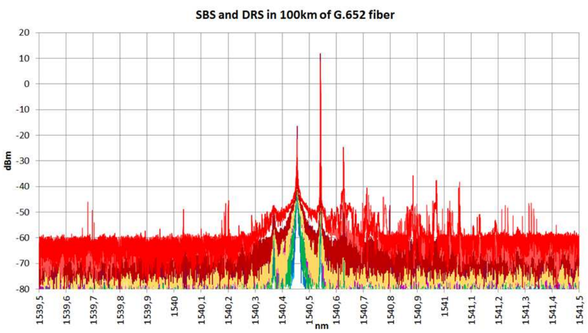

Fig. 5. SBS and DRS in G.652 fiber, with Raman pumping set to 1 W

When Raman amplification is added to bidirectional EDFA, more spectral lines can be observed, as can be seen on Fig. 4.

The original signal launched into the fiber is visibly broader due to the effect of SPM. One Anti-Stokes spectral line is created and two additional spectral components are present. Similar spectral components can be created as results of FWM and it is not always possible to distinguish them. The Raman amplifier was set to 500 mW and different curves correspond to different output powers set to the bidi EDFA.

But Raman Effect in silica is rather weak so very high pumping powers are usually used to achieve the sufficient amplification – up to 1 W. Unfortunately with higher pumping powers, another unwanted phenomena called Distributed Rayleigh Scattering (DRS) comes into play and results are more spectral lines, but their behavior very chaotic, quick and unpredictable. DRS must be avoided and during our experiments, Raman pumping optical powers was limited to 900 mW.

We observed new spectral lines during experiment. These new frequencies appeared at certain spacing: 0.085 nm and 0.17 nm. These new lines are result of Brillouin scattering because SBS shift in silica is approx. 11 GHz or 0.085 nm but FWM is also responsible for new spectral components and unfortunately FWM can create the same frequency spacing as SBS. Detailed overview of new frequency lines is shown on Fig. 6.

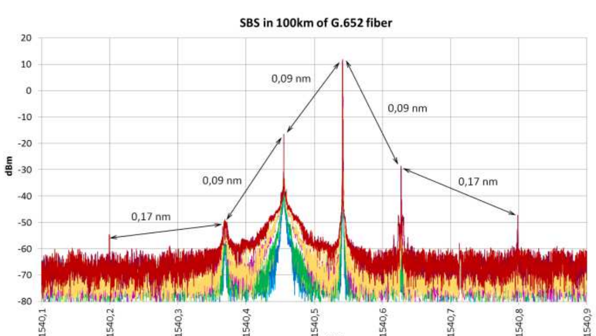

Fig. 6. Detailed overview of new spectral lines

IV. CONCLUSIONS

We observed new spectral lines not only during experiments but also on 'live' fibers, carrying standard data traffic. Unfortunately it is not possible to perform any of experiments described in this contribution in operational network, hence we feel that this contribution can be useful for both metrologists and networking engineers.

COF/TF signals can be transmitted in the same data networks, but clear deterioration of high speed data signals is expected with high optical powers and deployment of bidi EDFAs. This was observed in previous experiments – this must be avoided to keep error-free data transmission.

We focused on the standard G.652 fibers, which show relatively large chromatic dispersion and are widely deployed in all optic fiber networks. In our future work we will target and will results for fibers with lower and negative dispersion (i.e. G.655+ and G.655- fibers), which are much more sensitive to all mentioned non-linear effects. We also have plans to investigate new fibers G.654-like, with bigger effective area and ultra-low losses. Such fibers are better choice for coherent systems and long-haul fiber networks and have been also deployed in last years.

We would like to emphasize one aspect which is frequently marginalized – very different mindsets of metrology scientists and people responsible for 'invisible' functioning of fiber data networks, including long haul terrestrial and submarine ones.

This is not easy and even difficult imposition, but it is our objective to be complementary to tasks which are being solved in international projects like [2]. But we are very positive and we see this contribution as a continuator of contributions like [3] and the number of posters dealing with COF and TF topics presented during EFTF 2022 is really promising and confirming our motivations.

ACKNOWLEDGMENT

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