Suppression of Stimulated Brillouin scattering with a Raman Fiber Amplifier

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We present the experimental suppression of Stimulated Brillouin scattering with a Raman Fiber Amplifier based on a dispersion-shifted fiber. In our configuration, the co-propagating CW pump generates cross phase modulation on the optical signal, which induces a spectral broadening. The SBS threshold is thus raised without the requirement of any specific modulation format or additive supervisory channel. 500 MHz Broadening was observed for 500 mW pump power leading to an increase of the optical budget on a 25 km fiber link by 10 dB. This highlights a benefit of a co-propagating pump in comparison with the classical counter-propagating scheme.

Introduction

Stimulated Brillouin scattering (SBS) is one of the various optical nonlinear effects that limit the power in optical telecommunication fiber system. SBS is an inelastic scattering. It consists in a coupling between an optical wave and acoustical vibration inside a nonlinear medium. In optical fibers, the acoustic wave backscatters the signal with a frequency shift of 11GHz. This effect can be stimulated providing amplification with a gain bandwidth of 10-100MHz [1]. This effect can be detrimental because it limits the optical power that can be injected in the fiber. Indeed, as power is converted from one wavelength to another, there is a depletion of the signal. The power threshold of this effect is given by $P^{th} = 21.A_{eff} / g_B L_{eff}$ where A_{eff} is the effective core area, L_{eff} is the effective length of the fiber and g_B is Brillouin gain peak value.

A traditional way of limiting this effect is to use a modulation of the source to broaden its optical spectrum. Indeed, if the spectral width of the source become comparable with the width of the Brillouin gain, the threshold will decrease since [2]:

$$\tilde{g}_B = \frac{\Delta\upsilon_B}{\Delta\upsilon_B + \Delta\upsilon_P} g_B \tag{1}$$

where $\Delta\nu_B$ is the Brillouin spectrum bandwidth and $\Delta\nu_P$ is the signal linewidth.

This broadening can be done by direct current modulation of a semi-conductor laser where the chirp will broaden the spectrum or by modulating the phase of the signal by an external phase modulator that would also broaden artificially the spectrum.

Another category of technique consists in using nonlinear optical Kerr effect to produce the spectral broadening. This method [3] was used to suppress SBS by directly modulating a supervisory channel. This channel induced cross phase modulation on the signals of a WDM transmission link system. The signal was broadened and could reach higher power without undergoing SBS. However this method could be detrimental since the interplay of the XPM of a modulated channel with the dispersion of the fiber can be a source of crosstalk.

We propose to use a derivation of this method by taking advantage of the XPM induced by a strong pump to broaden the spectrum of the signal. This pump is used at the same time to provide Raman amplification to compensate the loss of the fiber. Stimulated Raman scattering (SRS) is another inelastic scattering coupling light with molecular vibration of the medium. It also provides gain but with a frequency shift of 13THz and a bandwidth of 5THz. Moreover SRS is bi-directional and can occur in both co- and counter-propagating scheme. The versatility of the Raman fiber amplifiers (RFA) makes them very attractive for long haul optical fiber telecommunication links. With a suitable combination of pumps it is possible to reach high gain and noise figure flatness. However there is still debate on the advantages of either forward or backward pumping scheme see for example [4] and references therein. In this paper we highlight, a new consideration to take into account in RFA design.

Experimental set-up

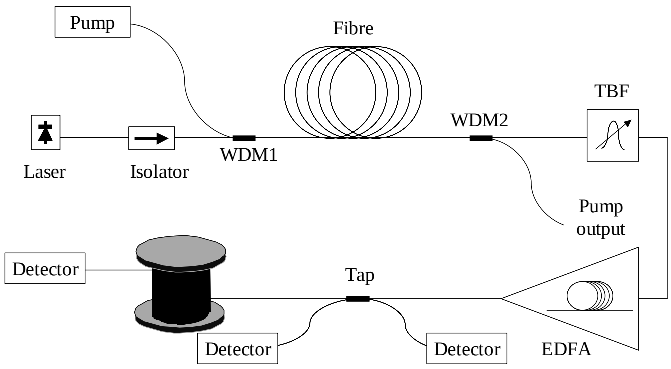

Fig. 1 experimental set-up

Our experimental set-up is shown in figure 1. An external cavity tunable laser with 150kHz linewidth was injected inside the fiber through a wavelength division multiplexer (WDM) that was used to couple the signal with a pump. This one was a Raman fiber laser source emitting unpolarized light at 1455nm within a linewidth of 0.5nm. This pump provides Raman gain around 1550nm. An isolator prevented Raman backscattered power to perturb the laser source. The WDM was spliced to a 6km long dispersion shifted fiber that present higher nonlinear coefficient than standard single mode fiber because of a smaller effective area. At the output, most of the remaining pump power was filtered by another WDM used as a demultiplexer. The rest of the pump was filtered by a tunable bandpass thin film filter with 0.5nm bandwidth.

In the first part of the experiment the light was analyzed by a scanning Fabry-Pérot (FP) spectrum analyzer with FSR of 15GHz and finesse of 150 resulting in a resolution of 100MHz. To measure wide spectra, we used a 1.2GHz resolution optical spectrum analyzer (OSA) based on a diffraction grating.

In the second part of the experiment we amplified the signal with a +20dBm saturation output power erbium doped fiber amplifier (EDFA). The signal was then injected in a 25km long DSF. Such high power signal undergoes SBS and a part of the signal is backscattered toward the fiber input. In order to monitor the backscattered power, we used a 1% tap coupler between the fiber and the EDFA. This also allowed monitoring the power injected into the fiber from the EDFA.

Results and interpretation

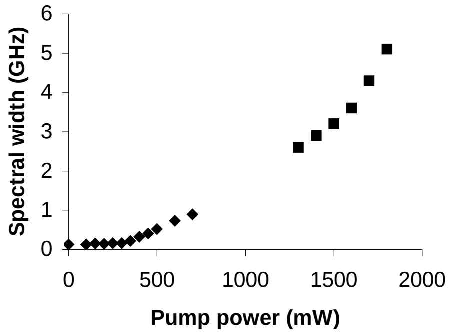

Fig. 2: Spectral broadening of the signal at the output of the RFA measured with the FP ♦ and with the OSA ■

Figure 2 shows how the spectral linewidth of a 1550nm signal is broadened when the pump power is raised. This broadening is a consequence of the cross phase modulation induced by the pump on the signal. Indeed, if we set the wavelength of the signal to 1600nm outside of the Raman gain band, the signal still undergoes broadening excluding the Raman effect as a cause of the broadening. For backward pumping configuration, the broadening does not occur what was already outlined in [5]. The pump has a broad spectral linewidth composed of a multitude of longitudinal modes. The signal undergoes a different nonlinear phase shift from each of the component, resulting in the broadening of the signal.

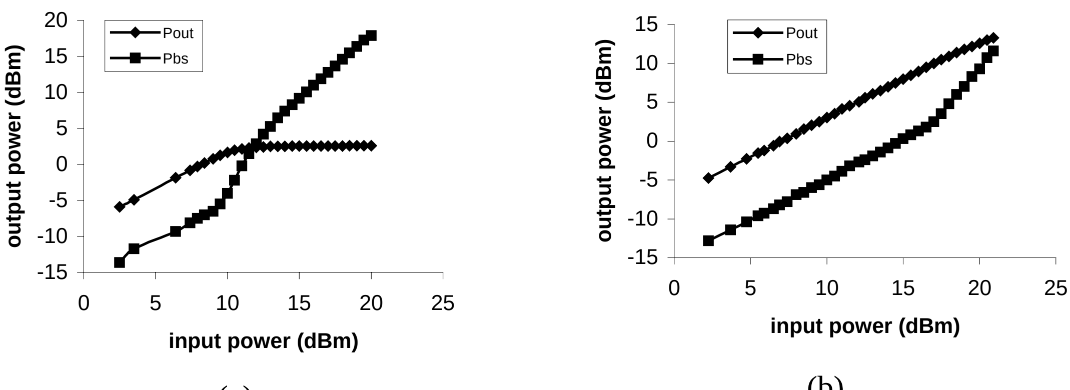

Fig. 3: Output power (Pout) and SBS backscattered power (Pbs) as a function of the input power in the case of (a) a narrow bandwidth signal and (b) a signal spectrally broadened by XPM

This broadening can be used as a new way to suppress SBS. In our experiment, the pump was set to 500mW providing enough Raman gain in order to compensate the losses of the fiber. The corresponding linewidth for the broadening of the signal is

500MHz. According to the theory and considering a 100MHz bandwidth for the SBS gain spectrum of a DSF [1], this should raise the SBS threshold by a factor ~5 as outlined by eq. (1).

Fig. 3 presents the curves of the output and backscattered powers as a function of input power while the signal propagates in the 25km fiber. In Fig. 3 (a), the output power of the narrow bandwidth signal quickly saturates around +2.5dBm. At the same time the backscattered power grows and consume almost all injected power.

For the broadband signal characteristics shown in Fig. 3 (b), we see that the output power grows linearly up to a value more than 10dB higher than in the previous case.

Conclusion

We demonstrated a new way to suppress SBS in optical fiber by taking advantage of a Raman fiber amplifier. The method uses the spectral broadening of the signal due to XPM induced by the pump. This highlights a new advantage of the co-propagating pumping scheme in such amplifiers.

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