

Simple source for broadband Brillouin slow light in optical fibers

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Abstract—Spontaneously broadened emission from a distributed feedback laser diode operated just above threshold is used as a pump source in Brillouin slow light systems. The pump spectrum could this way be extended to several GHz.

I. INTRODUCTION

To date, Brillouin slow & fast light has been considered as a promising technique to provide all-optical buffers for future all-optical routers since it can be readily realized in standard optical fibers with a simple benchtop configuration at room temperature at any wavelength. However, the inherent narrow bandwidth of stimulated Brillouin scattering (SBS) in optical fibers is seen as a limitation for an implementation of this system in practical applications. The natural linewidth of SBS in a standard fiber is as narrow as 30 MHz due to the slow decaying nature of acoustic vibrations, making the data rates in such delay lines restricted to 50 Mbit per second.

However, a remarkable feature of the SBS gain coefficient is its linear dependence on the pump intensity. It means that if a polychromatic pump wave is involved in the SBS process, each frequency component contained in the pump spectrum can generate its own gain resonance at its specific frequency given by the phase matching condition for stimulated Brillouin scattering [1]. The combination of each gain spectrum represents the effective Brillouin gain spectrum, so that the spectral distribution of SBS gain can be substantially engineered and shaped by simply modifying the pump power spectrum. Consequently, the effective SBS gain spectrum can be expressed by the convolution of the pump power spectrum and the intrinsic Brillouin gain spectrum [2,3]. This way, delaying for a 17-ps pulse signal was successfully demonstrated in Brillouin slow light [4].

During the past few years, many reported experiments demonstrated broadband Brillouin slow light, but in most systems, the extension of SBS bandwidth tends to rely on three major mechanisms: direct current modulation applied to the pump laser [2,4,5], optical frequency comb as Brillouin pump [6] and filtered amplified spontaneous emission from optical amplifiers [7]. In this paper, we propose a novel technique to realize broadband Brillouin slow light based on an extremely simple configuration compared to the existing configurations.

II. PRINCIPLE

The power spectrum of the light emitted from a semiconductor laser is optimized to match a large signal bandwidth up to several GHz range by setting the current through the laser diode just above threshold. In this low current regime, the fraction of amplified spontaneous emission in the dominating stimulated coherent emission remains fairly important, so that the important phase noise leads to a substantial broadening of the laser output spectrum, in inverse proportion to the emitted power [8], resulting in a linewidth that can be orders of magnitude larger than in normal operating conditions. Using this type of spectral emission, a broadband SBS resonance can be simply achieved with two crucial advantages compared to other techniques: first, it eliminates the need of broadband noise generator that dithers the current applied to the pump laser and external electro-optic modulators, significantly simplifying the experimental layout. Second, the spectral width of the emitted light is yet flexibly tunable by simply changing the injection current.

To demonstrate the feasibility of the proposed scheme, a commercial distributed feedback (DFB) laser diode was driven at different injection currents just above threshold and used as Brillouin pump. Its output was delivered into a Brillouin gain medium, in our case a long optical fiber. A continuous wave (CW) signal generated from a distinct DFB laser diode was launched into the fiber from the opposite end, so counter-propagating with respect to the pump wave and undergoing SBS interactions. The signal frequency was swept through the Brillouin gain resonance and the amplitude of the transmitted signal was

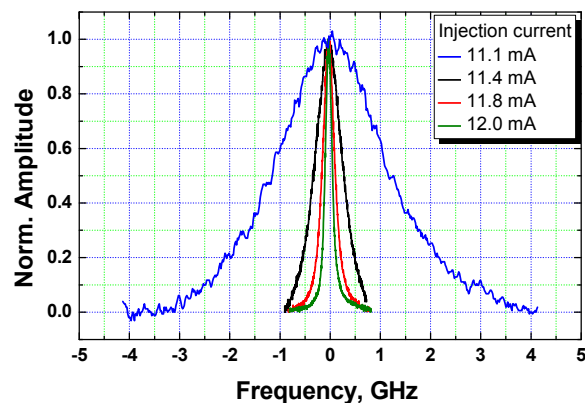


Fig. 1. Variation of signal amplitude as a function of frequency for different pump driving currents (laser threshold current=11 mA), as a result of the Brillouin gain generated in a 1-km fiber. The frequency origin is set arbitrarily to the peak gain frequency. The gain is normalized to highlight the spectral broadening.

The authors would like to acknowledge the support from the European Community's Seventh Framework Programme [FP7/2007-2013] under grant agreement n° 219299 (GOSPEL project) and the Swiss National Science Foundation through project 200020-121860.

measured as a function of signal frequency, as shown in Figure 1. It is clearly observed that the SBS bandwidth is broadened as the injection current is set close to the threshold current of 11 mA. The SBS gain bandwidth was very flexibly expanded to 153 MHz, 274 MHz, 620 MHz and 2.45 GHz using four different injection currents, respectively, and can readily match any signal bandwidth up to several GHz.

III. EXPERIMENTS AND RESULTS

Figure 2 depicts the schematic diagram of the experimental setup. A 1-km standard optical fiber was used as a Brillouin gain medium and its Brillouin shift was measured to be 10.86 GHz. Two conventional temperature and current-controlled distinct DFB laser diodes emitting at 1550 nm were used to generate a CW Brillouin pump and a signal pulse, respectively. The current applied to the pump laser was adjusted at 11.8 mA in order to obtain the proper pump spectrum broadening (274 MHz), so as to properly adapt to the signal bandwidth of 75 MHz when the gain narrowing factor of 3 due to the gain exponentiation in high Brillouin amplification regime is taken into account. Its output power was measured to be 300 μ W, thus requiring a strong amplification using an erbium doped fiber amplifier (EDFA) showing a 30 dBm saturation power. The EDFA output power was controlled by a variable optical attenuator before entering into the fiber.

A distinct DFB laser was optically gated through a fast external electro-optic modulator in order to generate a signal pulse train, resulting in a 6 ns FWHM signal pulse at a repetition rate of 1 MHz. A polarization controller was used to match the states of polarization between the signal and the pump, so that the Brillouin gain, hence the signal delay, is maximized through the SBS process. The pulsed signal was then sent into the fiber in opposite direction to the pump wave.

To observe the delaying effect induced by the Brillouin gain, the pump power was varied from 0 mW to 250 mW by 50 mW steps. The waveforms of the delayed signal pulses after propagating through the fiber were measured as a function of the pump power using a fast detector and displayed on a digital oscilloscope. It is clearly observed that the signal is continuously delayed proportionally to the pump power as in any typical Brillouin slow light system. Figure 3 shows the normalized time waveforms of the delayed pulses for a set of fixed pump powers: 0 mW, 150 mW, 200 mW, 250 mW. The largest signal delay achieved was 6.18 ns, corresponding to 1-bit delay, at a pump power of 250 mW and the delayed pulse was moderately broadened by a factor of 1.4 due to the well-known

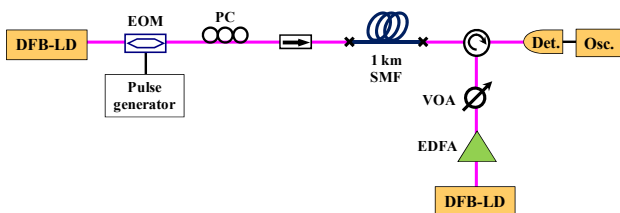


Fig. 2. Experimental set-up to realize a broadband SBS slow light.

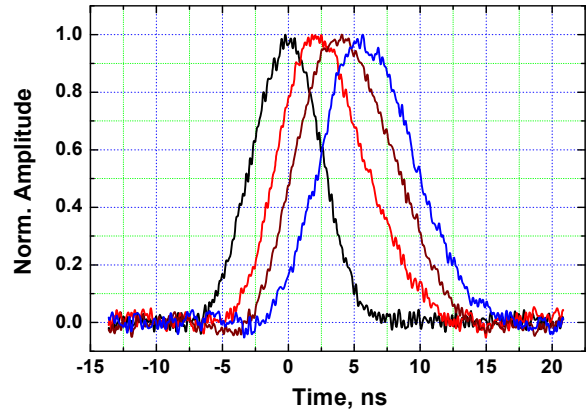


Fig. 3. Normalized time traces of the temporally delayed signal pulses for different pump powers, clearly showing signal delays up to 1 bit.

spectral filtering effect [9].

IV. CONCLUSIONS

We have experimentally demonstrated a very simple method to achieve all-optical time delays for broadband signals, based on stimulated Brillouin scattering in optical fibers. It must be pointed out that the scheme proposed in this paper results in a large simplification of the set-up but shows identical performances to other reported schemes. It demonstrates that a controlled natural phase noise can be an elegant solution to realize broadband Brillouin pumping. It also offers the advantage of a better efficiency when compared to the spectral filtering of an incoherent source, since all the generated light is actually exploited. The drawback is the low emission power that requires a robust optical amplification.

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