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Investigation of Fast Light in Long Optical Fibers Based on Stimulated Brillouin Scattering

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Abstract: A simple method to generate a negative time delay in SBS-based fast-light systems using Brillouin gain and loss is shown. We achieved a maximum negative time delay of 32.4 ns in one long fiber segment.

OCIS codes: (999.9999) Fast light; (290.5900) Scattering, stimulated Brillouin

Slow and fast light means the control of the velocity of light pulses by light [1]. During the last years a number of experiments and results for slow and fast light in optical fibers based on stimulated Brillouin scattering (SBS) were presented [2-7]. Especially the concept of fast light propagation in optical fibers has attracted much recent interest since it offers the possibility to develop timing tools for all-in-optical signal processing, equalization of distorted optical data streams and fast read out of optical buffers.

The group index of a waveguide n_g is described by the equation: $n_g = n+\omega\, dn/d\omega$ [8]. Due to SBS loss it is possible to decrease n_g continuously from 1.46 (under normal conditions, refraction index n) to 0 and also to negative values by changing the term: $\omega\, dn/d\omega$ [3]. Without Brillouin loss the absolute time delay in an optical fiber is given by: $t_0 = L\, n_g/c_0$ and with Brillouin loss: $t_B = L\, n_g/c_0 - Leff\, n_{gB}/c_0$. Therefore, the relative time delay for slow and fast light systems can be described as: $T_d = 1/c_0(L_{eff} n_{gB})$.

The measured time delay T_d for a standard single mode fiber (SSMF) with a length of 11.8 km and a Lorentzian distributed Brillouin gain of -12 dB (respectively loss) is -8.4 ns [2,3]. For very high pump powers the Brillouin gain is -12 dB for a 2 m SSMF. The result is that the group index becomes negative (n_{gB} = -0.7) this leads to a negative time delay of T_d = -14.4 ns [3]. Fast light propagation with zero amplification or loss in a 2 km SSMF offers a time delay of -7.3 ns. This result is based on the balanced superposition of a broadened Brillouin gain and natural loss spectrum [6].

Here we investigate light acceleration of up to 32 ns in a long optical fiber. On the one hand, a long fiber has a high absolute attenuation (≈ 12 dB for a 50 km SSMF). This limits fast light generation since it depends on the Brillouin loss. Together with the fiber loss this would result in a very high attenuation of the probe pulse. On the other hand, the Brillouin threshold is very low for long fibers. A few milliwatt of pump power are sufficient to initiate SBS. Our method is based on an idea which was presented in [6,7].

Figure 1 shows our principle experimental setup. We used a fiber laser followed by a Mach-Zehnder modulator (MZM) for generating the pulse spectrum at a wavelength of 1550 nm. This wavelength is equivalent to the signal frequency f_S. The pulse generator excites Gaussian pulses with a repetition rate of 1 MHz and a pulse width of 35 ns. These pulses were transmitted over a 50 km SSMF and an optical circulator (C), (port 2 to 3); finally detected by a PIN photodiode and evaluated in the time domain by an oscilloscope. From the other side a pump spectrum was coupled into the same SSMF over the circulator (port 1 to 2). Due to this very long SSMF the required pump power can be reduced drastically. For the generation of the Brillouin spectrum, we used two uncorrelated distributed feedback (DFB) laser diodes as pump lasers at 1550 nm (equal to pump frequency f_P). Each pump laser engendered a Brillouin gain spectrum at f_P-f_B and a Brillouin loss spectrum at f_P+f_B, with f_B as the natural Brillouin shift in the fiber. In a SSMF f_B is approximately 11 GHz. In our experimental setup the pump laser 1 generated the Brillouin gain spectrum, with the line centre Brillouin gain g_B at the signal frequency f_S. Therefore, it is necessary that $f_S = f_{P1} - f_B$. We broadened the Brillouin gain spectrum by a direct modulation of pump laser 1 with a noise source. Furthermore, pump laser 2 generates the maximum Brillouin loss $-g_B$ at the signal frequency f_S according to the relationship $f_S = f_{P2}+f_B$. Under the condition that $f_S = f_{P1}-f_B = f_{P2}+f_B$ the signal frequency as well as the Brillouin gain and loss superimpose. The power of Brillouin gain and loss is adjustable by an erbium-doped fiber amplifier (EDFA) and a tunable optical attenuator (TOA). The result is an added tunable Brillouin loss within a tunable broadened Brillouin gain at the signal frequency. The -3 dB bandwidth of the broadened gain spectrum is 160 MHz.

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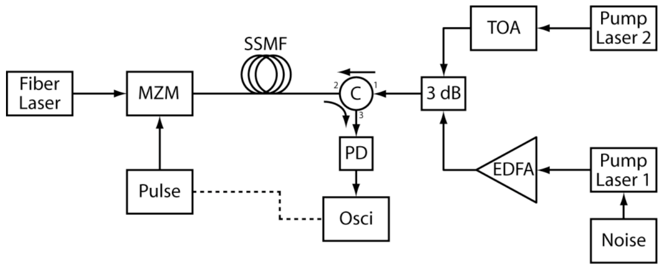

Figure 1: Experimental setup. MZM: Mach-Zehnder modulator; Pulse: pulse generator; SSMF: standard single mode fiber; C: circulator; PD: PIN-photodiode; Osci: oscilloscope; 3 dB: 3 dB coupler; TOA: tunable optical attenuator; EDFA: erbium-doped fiber amplifier; Noise: noise generator

Figure 2 shows the negative time delay as a function of the power of pump laser 2 for different pump powers (5.5 mW, 8.7 mW, 13.8 mW and 21.9 mW) of laser 1. The specified power values in Figure 2 are measured at the port 2 of the circulator. The measured time delay is specified as the time difference between the transmission time under the condition of stimulated Brillouin scattering (SBS) and without SBS; $T_d = t_B - t_0$, where $t_0 = L\, n_g/c$. For increasing pump power of laser 2 the negative time delay increases. For moderate pump powers (5.5 mW, 8.7 mW) of laser 1 the time delay as a function of pump power of laser 1 is linearly. For higher pump powers of laser 1 we allready start with a negative time delay. This is due to the case that for large gains $G = g_0 I_P L_{eff}$ the time delay becomes negative even for a Brillouin gain [5].

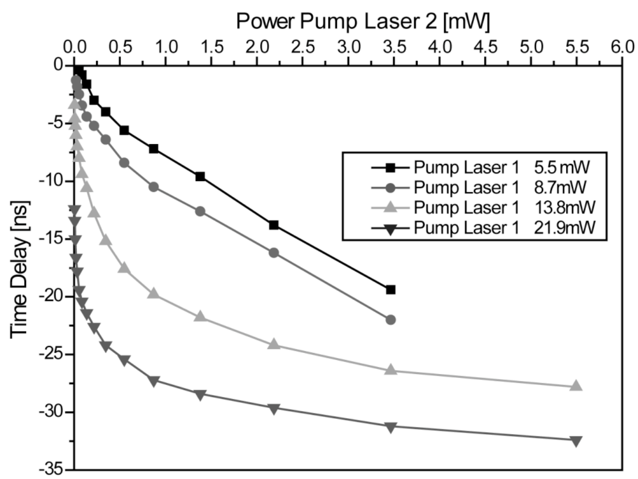

Figure 2: Negative time delay against Brillouin loss pump power for different gain pump powers

In conclusion we have shown that by the superposition of Brillouin gain and loss fast light in optical fibers can be achieved. With this method we obtain a maximum negative time delay of 32.4 ns in a 50 km SSMF.

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