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Experimental Measurement of Multiple Brillouin Stokes Orders in a Fibre Amplifier Under Pulsed Excitation

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Abstract

The influence of optical gain on SBS is explored experimentally in an Er-doped fibre, and the observation of multiple Stokes orders for pulsed excitation reported.

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In long passive optical fibres excited by narrow linewidth sources, stimulated Brillouin scattering (SBS) is the first non-linear effect to reach threshold [1]. In optically amplifying fibre, the SBS characteristics are drastically modified, and the threshold power can reach μW levels [2]. This is particularly important in long lengths of fibre lightly doped with Erbium to provide distributed gain, as has been proposed for practical amplifier systems [3]. Above a certain threshold power, the electrostrictive phonon gain provided by interference of the forward pump and backward Stokes waves coherently amplifies the phonon population at the resonant frequency, resulting in a sudden stimulated surge in Stokes power. At sufficiently high pump powers, this process can continue, producing a cascade of successive Stokes orders. In passive fibre, the threshold power at which SBS becomes significant is governed by the temperature, the modal area and the pump laser linewidth [2]. In this paper, SBS in a 60 m long Erbium-doped fibre amplifier (EDFA) is explored for excitation by 80 nsec pulses at various different levels of EDFA gain. A cascade of first, second, third and fourth Stokes orders is observed; previous work reported only two Stokes orders under similar conditions [4].

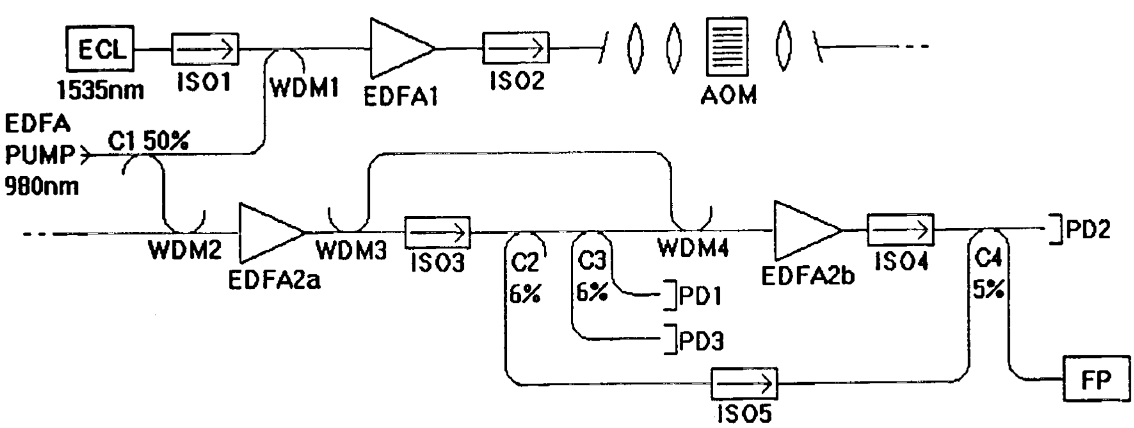

Figure 1: Schematic diagram of the experimental set-up

The experimental set-up is shown in Figure 1. It consists of a narrow band source and an amplifier (EDFA1) operating in the CW mode, and a pulsed acousto-optic modulator (AOM) followed by a two stage amplifier (EDFA2a and EDFA2b). The SBS was observed in this second stage amplifier (EDFA2b). The pump for the EDFA's was supplied by a Ti-sapphire laser operating at 980nm, the output of which was divided equally between the two amplifiers using a 50/50 coupler (C1). The launched EDFA pump power was monitored at a previously calibrated spare port of EDFA1's pump coupler (WDM1); approximately 1% of EDFA1's pump power emerged from this port. The spare port of EDFA2a's pump coupler (WDM2) was used to provide a feedback signal for stabilization of the launched Ti-sapphire pump power. The source used was a tunable external cavity semiconductor laser (ECL) with a pigtailed fibre lead, operating at 1535 nm with a specified output of 500 μW and a linewidth of 100 kHz. The ECL output was first amplified by EDFA1 (length 3 m, dopant concentration 800 ppm and NA 0.15) providing a maximum saturated gain of 17 dB (output signal level equalled 14 dBm). A second isolator (ISO2) was included together with an angled polished fibre end [5] to prevent the amplifier from lasing. The AOM was gated at 100 ns with a pulse repetition frequency of 1.67 kHz. This produced optical pulses in the fibre of 80 ns duration and 10%−90% rise and fall times of 60 ns. The second amplifier consisted of two stages (a and b) of 25 m and 60 m lengths of Erbium doped fibre (Erbium absorption 0.95 dB/km, cut-off 920 nm, NA 0.24). The isolator (ISO3) between them not only prevents lasing, but also increases the available gain of EDFA2a by suppressing backwards-travelling amplified spontaneous emission from EDFA2b [6]. A low-loss optical path for the EDFA pump is provided via the two couplers WDM3 and WDM4. The small signal gain of each stage was about 24 dB at a total pump power of 50 mW.

The input pulse to the second stage was monitored via the 6% coupler C3 at PD1, and the output pulse was observed at PD2. The backwards travelling SBS, i.e., the odd Stokes orders, were sampled by C3 and observed at PD3. The even Stokes orders, including the zero order, were recorded at PD2. The 6% coupler (C2) was used to combine the odd and even Stokes orders for frequency analysis at a Fabry-Perot interferometer (FP). The isolator ISO5 was included to prevent feedback (via C4 and C2) between EDFA2a's output and input.

Figure 2(a) shows the space/time relationship of the observed components, i.e., the input and output pulses plus any Stokes waves present. The horizontal axis represents distance along the fibre amplifier with the input port on the left. The vertical axis represents time, signals emerging from the input and output ports of EDFA2b being shown on the left and right axes respectively. The space-time characteristic of the input pulse is a straight line from the input end of the fibre at $t=0$ to the output end of the fibre at $t = Ln/c$ where t = time, L = fibre length, n = refractive index and c = velocity of light in a vacuum; the slope of this characeristic is the velocity of propagation of the pulse along the fibre. The 80 nsec pulses have a physical length of 16 m in the fibre. Using such a diagram it is possible to predict the points in space-time at which the components originated by projecting back from the input and output ports at the propagation velocity.

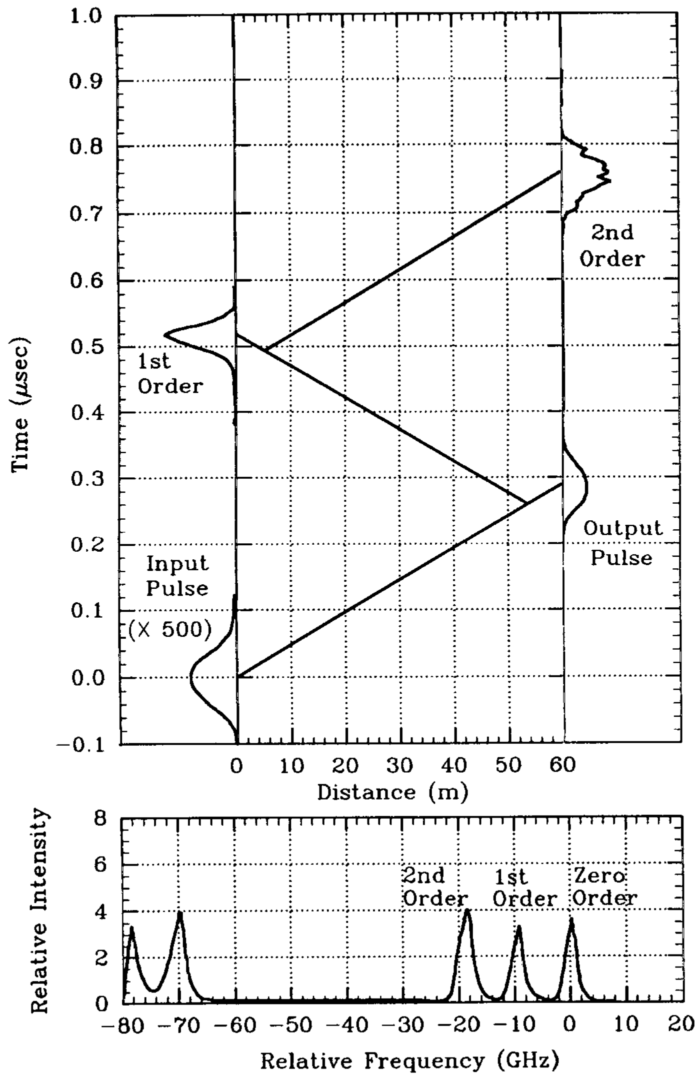

Figure 2: (upper) Space-time diagram showing the input and output pulses from EDFA2b (980 nm pump power of 103 mW) and a peak injected power of 2.9 mW at 1535 nm; (lower) Frequency spectrum of the forward and backward travelling pulses.

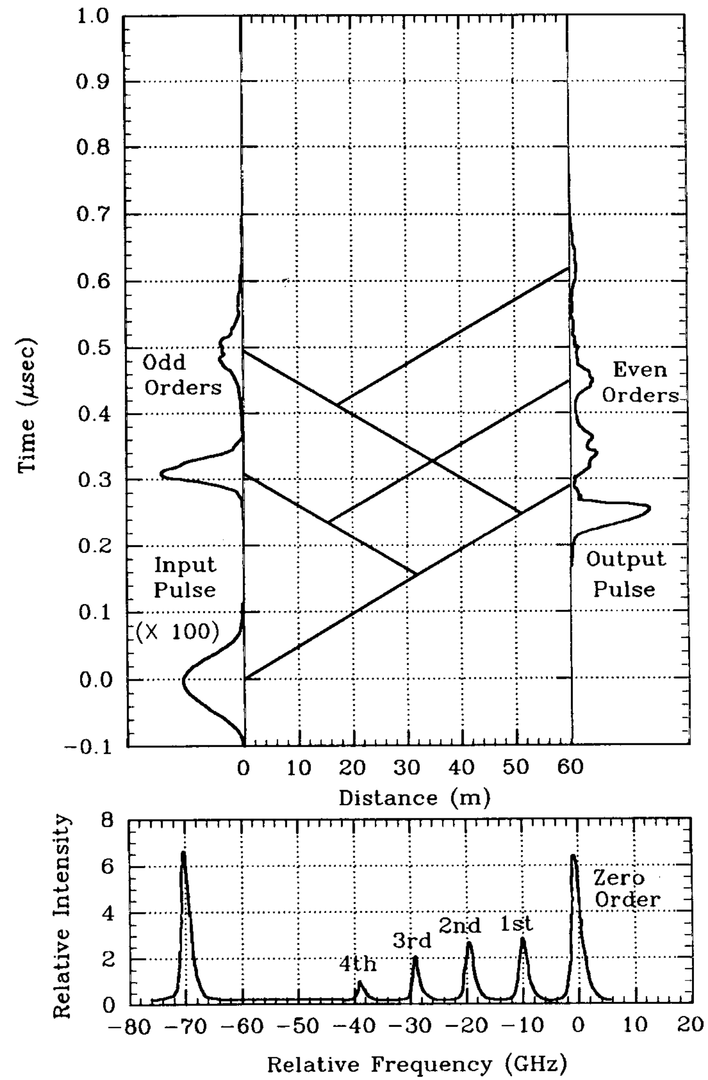

Figure 3: Same as Figure 2, for a 980 nm pump power of 300 mW and an injected peak 1535 pulse power of 19 mW.

Figure 2(b) shows the output from the Fabry Perot. The free spectral range was set to 70 GHz and the trace adjusted to give 10 GHz/division.

Increasing the EDFA pump power results in the increase in both the input pulse intensity (SBS pump power) and the EDFA gain. These combined effects reduce the propagation distance in the fibre prior to reaching the SBS threshold.

As the input pump power is increased, so does the power propagating in the 1st order Stokes wave. At some point it is capable of generating its own Stokes component. This is seen to happen in Figure 2(a) after a length of approximately 48 m. As the pump power is further increased higher order Stokes waves are generated. Figure 3(a) shows the presence of the 3rd and 4th order Stokes waves with a pump power of 300 mW per amplifier.

In conclusion, strong multiple Stokes orders of stimulated Brillouin scattering can be generated in relatively short lengths (only 60 m) of optically amplifying fibre pumped by 80 nsec pulses. In the talk, more detailed results will be provided and discussed.

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