# “Slow Light” in stimulated Brillouin scattering: on the influence of the spectral width of pump radiation on the group index: Comment

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**Abstract:** In a recent paper by Kovalev *et al* [Optics Express 17, 17317 (2009)] the coupled equations describing stimulated Brillouin scattering (SBS) were solved in the Fourier domain. The main conclusion driven by the authors was that SBS pump spectral broadening was not effective in increasing the interaction bandwidth. While the calculations are essentially correct, the interpretation of the results leads to erroneous conclusions.



**OCIS codes:** (999.9999) Slow light; (060.4370) Nonlinear optics, fibers; (290.5900) Scattering, stimulated Brillouin; (350.5500) Propagation.

## References and links

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Stimulated Brillouin Scattering (SBS) has been demonstrated as a very efficient tool to provide a flexible control of the group velocity of light in optical fibres [1]. The main advantage of SBS over other slow-light mechanisms is that the spectrum of the interaction can be engineered to fit different requests in terms of bandwidth and distortion of the signal [2].

Surprisingly, a recent theoretical study [3] ended up to the conclusion that pump spectral broadening has close to no impact on the spectral width of the interaction, hence contradicting not only these experimental works but also abundant previous literature (theory and experiments) on SBS since the late sixties. Furthermore, this assertion contradicts the basic principle of SBS suppression in long optical fiber links through pump frequency dithering. The analytical results contained in [3] are substantially correct. However, the interpretation of the results is based on an erroneous assumption that misled the authors to our opinion.

A rigorous derivation of the coupled SBS equations in the frequency domain is given in [3]. The evolution of the signal field at the Stokes frequency is found to be:

$$\left|\tilde{E}_S(z,\omega)\right| = \left| e^{-i\frac{\omega n}{c}z}\left[\tilde{E}_S(0,\omega) + \frac{k_S}{2n}c_\rho\int_0^z \tilde{E}_P(\omega)\otimes\rho^*(x,\omega)e^{i\frac{\omega n}{c}x}dx\right]\right| \qquad (1)$$

where $E_P$ and $E_S$ are the pump and signal fields, respectively, $c_\rho$ is an elasto-optic coefficient, $k_S$ it the wave-vector at the signal frequency, $n$ is the refractive index and $\otimes$ denotes convolution. $\rho(\omega)$ is the acoustic amplitude represented as a scalar material density wave. Note that the right-hand side of Eq. (1) (Eq. (11) in [3]) is functionally dependent on the field

#121640 - $15.00 USD Received 17 Dec 2009; revised 1 Feb 2010; accepted 19 Mar 2010; published 31 Mar 2010

$E_S$ through the acoustic wave and therefore it cannot be considered as a solution to the Stokes field, but rather as a reformulation, in integral form, of Eq. (8) in [3].

The authors correctly interpret Eq. (1) in the sense that the added SBS-generated Stokes signal is a result of reflection of the pump radiation by the acoustic wave, which is created by interference between the pump and the original Stokes fields. This interpretation of SBS is certainly not in contradiction with the one appearing in conventional textbooks. The authors also correctly point out that whatever the spectrum of $E_P$, the spectrum of the acoustic wave vanishes rapidly for $\omega > \Gamma_B$, $\Gamma_B$ being the natural linewidth (see Eq. (9) in [3]). It is true that $\rho(\omega)$ represents the spectrum of the acoustic wave, but it cannot be merely identified to the optical spectrum of the interaction and *does not provide a direct limit to the bandwidth of the scattered photons*. It can be seen in Eq. (1) that, independently on how narrow $\rho(\omega)$ might be, the spectrum of the scattered photons will depend mostly on the spectrum of $E_P$ [4]. This reflects the dynamics of the SBS interaction with wideband pumps: for wide bandwidths of $E_P$, the gain spectrum maps the spectrum of the pump.

The fact that the acoustic wave spectrum does not require to map the optical wave spectrum to make the interaction broadband can be simply understood by returning to the basic relation giving the resonance condition:

$$\Omega_B = 2\frac{V_A}{c/n}\omega_P \tag{2}$$

This equation shows that the frequency of the acoustic wave $\Omega_B$ at resonance depends linearly on the optical frequency of the pump, scaled down by a factor given by twice the ratio of the sound and light velocities in the medium. It equally means that if the pump spectrum spreads over a frequency interval $\delta\omega_P$ the acoustic wave only needs to span over a frequency interval scaled down by the same factor to fulfil the resonance condition. But, since the resonance shows a natural linewidth $\Gamma_B$, all frequency components within the pump spectrum giving a resonance condition that lies within $\Gamma_B$ will generate an acoustic wave that cannot be discerned from that generated by the pump central frequency. Inverting Eq. (2), we determine the pump spectral range $\Delta\omega_P$ over which an acoustic wave is generated within the natural linewidth $\Gamma_B$ as $\Delta\omega_P$ = 243 GHz. This result clearly shows that an observable broadening of the acoustic wave spectrum is highly unlikely over bandwidths normally used in single-pump Brillouin slow light systems (<10 GHz).

The subsequent reasoning to calculate the group index change achieved in the fibre is not fully adequate to describe the slow light interaction. The phase index change is calculated as $\Delta n = c_\rho|\rho(\omega)|/2n_0$. From here, the group index change is estimated through the corresponding derivative. While this $\Delta n$ is a good way to evaluate the "local" phase index change induced by the acoustic wave, the relevant quantity to estimate here is the end-to-end nonlinear phase shift induced in the signal by the Brillouin interaction.

We have to remind here that, in general, the group velocity of an arbitrary medium cannot be derived directly from the microscopic polarization response. The propagation constant of the mode has to be calculated and from here the group velocity can be obtained. Using the phase index change induced by the acoustic wave in the medium (the $\Delta n$ shown above), the same authors of [3] deny in a former recent publication [5] that the delaying achieved through SBS is a "slow light" effect. Brillouin slow light essentially comes from the nonlinear phase induced in the signal by the reflected wave through the interaction, and can therefore not be derived from the pure microscopic polarization change induced in the medium. Reducing the "slow light" denomination to a pure material polarization effect would not only exclude SBS but also photonic crystals and coupled resonators from the list of possible "slow light" systems. However they all exhibit a steep spectral response for the propagation constant and can be characterized by the same parameters (delay-bandwidth product, fractional delay, etc) as those used for a system based on a pure material microscopic response like EIT.

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