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Abstract: This article shows simulation results and first practical investigations of the optimization of a Brillouin spectrum with the natural bandwidth superimposed with two losses for fiber based slow light systems.

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

Different Slow-light techniques have been discussed and developed as a powerful tool to reduce the group velocity of light pulses during the last years. It has enjoyed much recent interest because of the potential system applications like optical tunable delay lines, synchronizers, equalizers and signal processors. Especially the nonlinear effect of stimulated Brillouin scattering (SBS) has become important for fiber based Slow-light systems. Among other things, the tailoring of the Brillouin spectrum to increase the maximum achievable time delays on the one side, and the reduction of the pulse distortion on the other side is one focus of the investigations nowadays [1-3].

In [4] we have presented a mechanism which provides the opportunity for a drastic enhancement of the maximum time delay. It was based on a superposition of one Brillouin gain spectrum with two additional Brillouin loss spectra on its wings. The results were an increase of the zero gain delay of more than 50 % and a maximum time delay of 120 ns in just one fiber spool. However, the input pulse with a temporal width of 30 ns was broadened to 85 ns which reduces the effective time delay, i. e. the time delay to pulse width ratio, to 1.4 Bit. But, the pulse distortions can be reduced by widen the gain spectrum [5].

Furthermore, the frequency separation of the two losses is of very special importance for the optimization of the Brillouin spectrum. A good result for a high effective time delay could be achieved with a high, broad, uniform and steep gain profile and group index, respectively [2]. This article shows simulations and first practical investigations of the optimization of the mechanism described in [4].

The propagation of a pulse in a Slow-light medium in dependence of the frequency ω is described by the complex wave number $k(\omega)$ [1]. For a Brillouin gain superimposed with two anti Stokes absorption lines with Lorentzian profiles it can be written as [4]:

$$k(\omega) = n_0 \frac{\omega}{c} + \frac{1}{z}\left(\frac{g_1\gamma_1}{(\omega-\omega_0)+j\gamma_1} - \frac{g_2\gamma_2}{\omega-(\omega_0-\delta)+j\gamma_2} - \frac{g_2\gamma_2}{\omega-(\omega_0+\delta)+j\gamma_2} \right) \tag{1}$$

where z is the length of the medium, ω_0 the line center of the gain distribution, c is the speed of light in a vacuum and n_0 is the refractive index; with $g_{1,2}$ as the line center gains of the amplification and absorption lines and $\gamma_{1,2}$ as its half of the (full width at half maximum) FWHM-bandwidths. The frequency separation between the two absorption lines is 2δ. The imaginary part of Eq. (1) leads to an amplification of the pulses and the real part to a phase change. Furthermore, the derivation of the real part leads to the group index change. If the gains and the bandwidths are supposed to be equal the overall gain spectrum depends only on δ. Hence, the gain profile can be optimized by the frequency separation of the two losses.

In Fig. 1 (top) the simulation results for a natural Brillouin gain are shown. The left diagram shows the frequency distribution of the group index as a function of δ. A high group index results in a high time delay and a wide group index or bandwidth corresponds to low pulse distortions. In the right diagram the normalized time delay and FWHM bandwidth in the line center of the group index as function of δ can be seen. By using only a natural Brillouin gain the maximum time delay and the maximum bandwidth are in the same region around $\delta \approx 1.7\gamma$. Hence, the maximum effective time delay should be located at the same point.

Our principle experimental setup has already been described elsewhere [4]**.** The measurement results for a Brillouin gain with a natural FWHM bandwidth of approximately 28 MHz can be seen in Fig. 2. The maximum time delay was achieved at $\delta \approx 1.7\gamma$. According to [5] and Fig. 1 (top right) the broadened pulse width decreases with increasing δ to a minimum which is also located at $\delta \approx 1.7\gamma$. Hence, the maximum of the effective time delay lies in the same region and the measurement is in a good agreement with the simulations.

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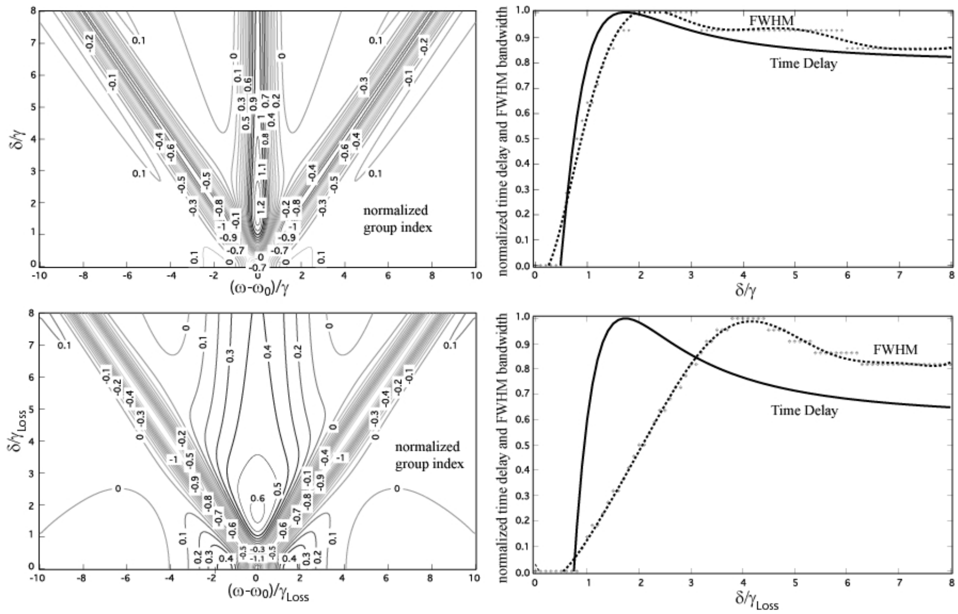

Fig. 1. Frequency distribution of the normalized group index (left), normalized time delay and FWHM bandwidth (right) as a function of the frequency separation of the two losses 2δ at $\omega=\omega_0$ for a natural (top) and a three times broadened (bottom) Brillouin gain.

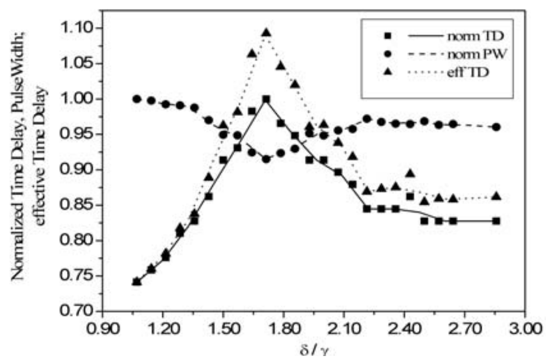

Fig. 2. Normalized time delay (norm TD, solid), pulse width (norm PW, dashed) and effective time delay (eff TD, dotted) as function of the frequency separation of the two losses.

In conclusion we have shown how a Brillouin gain profile consisting of one gain and two losses on its wings can be optimized by varying the frequency separation of the two losses 2δ. First measurements of the δ-optimization with a natural Brillouin gain have shown that the maximum effective time delay, the absolute time delay and the maximum FWHM bandwidth lay in the same region. But, for a broadened gain different δ-regions are expected which further allows optimizing the shape of the overall Brillouin spectrum as can be seen in Fig. 1 (bottom). Additionally, this allows the adaptation of the higher order terms of the complex wave number. In that case, a high time delay and a drastic reduction of the pulse distortions can be expected. However, this needs further investigations.

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