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Random Telegraph Signal vs Random Binary Sequence for Suppressing the Stimulated Brillouin Backscattering

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Launching constant-intensity light waves or long duration optical pulses into optical fibers is indispensable in a variety of applications such as fiber lasers and amplifiers, fiber-optic parametric devices, and optical fiber sensing. In such continuous wave (CW) or quasi-CW optical systems, stimulated Brillouin scattering (SBS) is the most detrimental nonlinear effect. The SBS process couples acoustic phonons to the photons of the forward traveling optical field and backward scattering Stokes lightwave through a phase-matched third-order nonlinear interaction [1]. As the peak power of an optical pump launched into the fiber increases, SBS enhances dramatically the acoustic wave that couples the optical power from the forward lightwave into a reflected one with a lower frequency reduced by ~11 GHz; this way the pump power drastically depletes. Due to the rather long phonon lifetime of ~5 ns, the SBS is a narrow linewidth process that requires a highly coherent light and thus can be substantially suppressed by broadening the optical pump spectrum via modulation.

The effective SBS gain spectrum resulting from the modulated light is given by the convolution of the Lorentzian gain and the normalized power spectral density (PSD) of the modulated pump $S(f)$ as follows [2].

$$g(f) = \frac{g_{\mathrm{B}}}{1 + 4\left(\frac{f}{f_{\mathrm{FWHM}}}\right)^2} \otimes S(f), \qquad (1)$$

in which $g_{\mathrm{B}} = 3 \times 10^{-11}$ m/W is the maximum Brillouin gain, $f_{\mathrm{FWHM}} = 30$ MHz is the Brillouin full width at half maximum (FWHM) bandwidth, and $\otimes$ denotes the convolution operation. In order to keep the intensity of light fixed it is necessary to use phase or frequency modulation. A very common way to do so is through an electro-optical phase modulator driven by a pseudo-random binary sequence (PRBS) which applies 0 and π phase shift to the optical field [3]. The performance limit of PRBS with a bit duration of T is given by a complete random binary sequence (RBS) shown in Fig.1 (a) with spectrum $S_{\mathrm{RBS}}(f) = T\mathrm{sinc}^2(Tf)$ [4].

Instead of using random phase shift, a novel approach to phase modulation is a random pulse width modulation of consecutive 0 and π phase shift with an average bit duration of T. Although there are many possibilities for the probability distribution of the pulse width, an exponential distribution of $e^{-t/T}$ with mean T is chosen since the process is theoretically memoryless and it can be practically implemented using a weak laser beam and a single-photon detector connected to a flip-flop switch. The signal produced this way is called the random telegraph signal (RTS), shown in Fig.1 (b), with the spectrum $S_{\mathrm{RTS}}(f) = T/(1 + (\pi T f)^2)$ [5]. Fig.1 (c) depicts the normalized Brillouin gain spectrum given in Eq. (1) for three cases, no modulation, RBS-modulation and RTS-modulation. It is evident that by using modulation the peak gain decreases and so the threshold power increases. Therefore, the RTS can give higher threshold compared to the RBS and thus any PRBS modulations.

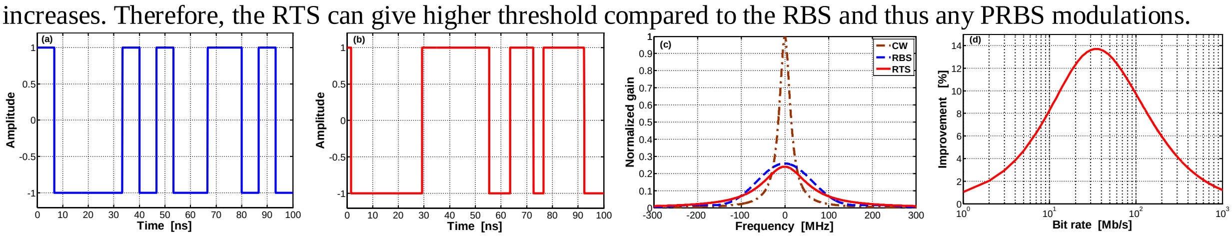

Fig. 1 The modulating pulse sequences (a) RBS and (b) RTS for 150 Mb/s; Brillouin gain spectrum (c) in three cases: unmodulated, RBS-modulated, and RTS-modulated with 150 Mb/s; (d) the improvement percentage of the threshold power using RTS instead of RBS versus the bit rate.

The improvement behavior of using the RTS for suppressing the SBS compared to the RBS versus the modulation bit rate is shown in Fig.1 (d). The vertical axis indicates the increase in the SBS threshold power achieved using the RTS instead of the RBS. As it is clear, for typical values of bit rate the proposed RTS signal acts better than the RBS and the optimal bit rate in which there is almost 14% improvement is close to the Brillouin bandwidth. Moreover, in the used range of 100-200 Mb/s the threshold increases by more than 6%.

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