CHARACTERIZATION OF LOCALIZED AND STATIONARY DYNAMIC BRILLOUIN GRATINGS

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Abstract

We experimentally generate localized and stationary dynamic Brillouin gratings (DBGs) in a 5m long polarization maintaining fiber (PMF) by phase modulation with a pseudo-random bit sequence (PRBS). The DBGs are characterized in terms of length, bandwidth, reflectivity and optical signal-to-noise ratio (OSNR) by measuring the distribution of the complex reflected signal along the fiber through swept-wavelength interferometry (SWI). The performance of optimal noise-less modulation formats are estimated and compared to the PRBS case.

Index Terms – Dynamic Brillouin gratings, Nonlinear optical processing.

I. INTRODUCTION

Recently, DBGs [1], generated through stimulated Brillouin scattering (SBS), have been envisaged as an efficient architecture to realize wide and fast dynamic tunable microwave photonics filters [2], optical filters [3], optical delay lines [4], all-optical signal processing [5], radio signal processing [6] and high resolution sensing [7]. In PMFs, two counter-propagating pump waves, polarized along one of the principal axes of the fiber generate an acoustic wave that actually modulates the refractive index in the longitudinal direction. A probe signal launched on the orthogonal axis is back-reflected by the isotropic acoustic wave that actually constitute a dynamic grating. Similarly to fiber Bragg gratings (FBGs) [8], DBGs properties can be designed by properly imposing specific refractive index variations along the fiber. The main difference between FBGs and DBGs is that, once realized, FBGs can be weakly and slowly tuned only mechanically, while the DBGs can be dynamical reconfigured by a proper design of the acoustic wave, that essentially depends on the correlation between the pump waves [5]. For example the acoustic wave, and hence the DBG, can be spatially localized, with a prescribed apodization function, in a short portion of the fiber by properly modulating the phase of the pumps [9,10], realizing DBGs that are both localized and stationary [9,10]. Such DBGs have been experimentally demonstrated by Antman et al. [9] using the PRBS modulation, that is not optimal owing to the generation of spurious off-peak correlation points along the fiber [11]. Here, we experimentally generate localized and stationary DBGs in a PMF by PRBS modulation, and different configurations of DBGs are demonstrated. Heterodyne SWI is used to measure the complex transfer function of the DBGs, obtaining the distributed characterization in modulus and phase. From the complex transfer function the length, the bandwidth, the reflectivity and the OSNR are determined, the transfer function under optimal conditions is also estimated and quantitative insight on the correlation noise is obtained.

II. EXPERIMENTAL SETUP

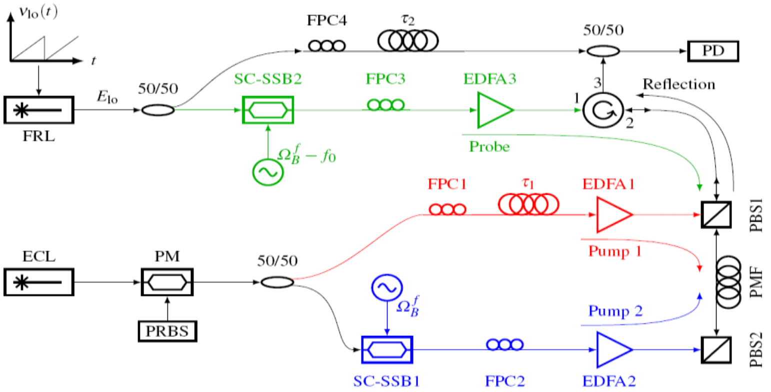

FIG. 1 – Experimental setup.

The experimental setup is shown in Fig. 1. The fiber used is a PMF of length 5m with a measured Brillouin shift $\Omega_B \approx 10.864$GHz. The pump wave P1 at frequency ν_1 is generated by an external cavity laser (ECL) while pump P2 at frequency $\nu_2 = \nu_1 - \Omega_B$ is obtained from P1 through a suppressed-carrier single sideband (SC-SSB1) modulator. The pump powers are controlled by Erbium-doped fiber amplifiers (EDFAs) and fiber polarization controllers (FPCs) are used to align their polarization to the PMF fast axis. Polarization beam splitters (PBSs) are used to couple all waves to the PMF. A phase modulator (PM) is used to modulate both pumps with the same PRBS signal, that actually controls the DBG apodization. The DBGs are interrogated by injecting a probe wave S, polarized along the slow axis, at frequency $\nu_s = \nu_1 - \Delta\nu$ (the shift $\Delta\nu \approx 45$GHz is due to the phase matching conditions and depends on the PMF birefringence [1]). The probe S is partially reflected by the DBGs at frequency $\nu_r = \nu_s - \Omega_B$. The DBGs characterization is performed by SWI through a local oscillator (LO) whose frequency $\nu_{lo}(t)$ is linearly swept with rate $\gamma \approx 350$GHz/s. The signal S is obtained from the LO by a frequency downshift to $\Omega_B - f_0$ ($f_0 = 5$MHz) through SC-SSB2; the offset f_0 is used to spectrally separate the DBG reflection from the Rayleigh scattering. At the photodiode (PD), the beat between the reflected signal R and the LO is detected as $I(t) \propto |H(\nu)| \cos[2\pi(f_0 + \gamma\tau)t + \phi_H(\nu)]$, where $\nu = \nu_{lo}(t), H(\nu) = |H(\nu)|e^{i\phi_H(\nu)}$ is the transfer function of the DBG and τ is the propagation delay difference between S and R. The delay τ_1 is selected so to place the DBGs at a distance $z_0 = 3$m from the fiber end. The DBG apodization function $h(z)$ can be obtained by applying a Fourier transform to measured data.

III. RESULTS AND DISCUSSION

We present [14] four different configurations of pump and probe powers (A, B, C and D).

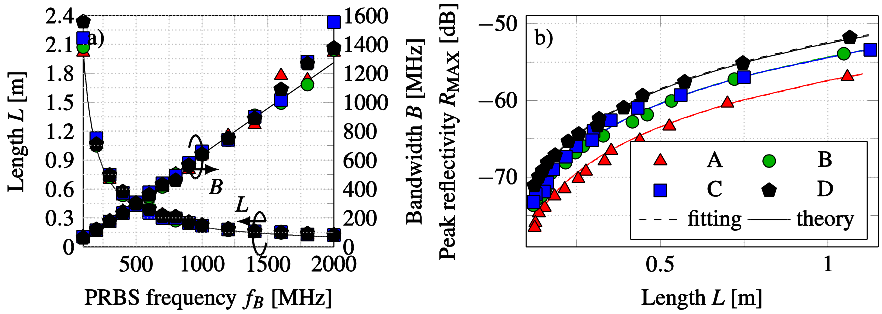

FIG. 2 – (a) Measured length and bandwidth of the DBGs for different PRBS frequencies. (b) Peak reflectivity as a function of the DBGs length L.

Figure 2(a) shows the DBG measured length L and bandwidth B as a function of the PRBS frequency f_B. The solid black curves are the theoretical values given by $L = v_g/f_B$ and B= $B_s f_B$, where B_s is the bandwidth of the sinc^2 function. Theory and the measured data are in remarkable agreement. By tuning the PRBS rate f_B, L and B can be modified. The measured reflectivity of the DBGs is reported in Fig.2(b) and is in remarkable agreement with the reflectivity theoretical values (solid curves) given by $R = P_1 P_2 \left(e^{\kappa L (P_1+P_s)} - 1\right)^2 / (P_1 + P_s)^2$ [12], where $\kappa \approx 0.1 W^{-1} m^{-1}$ is a fiber parameter determined by fitting the data; its value agrees with previous measurements on the same fiber using a different setup [13].

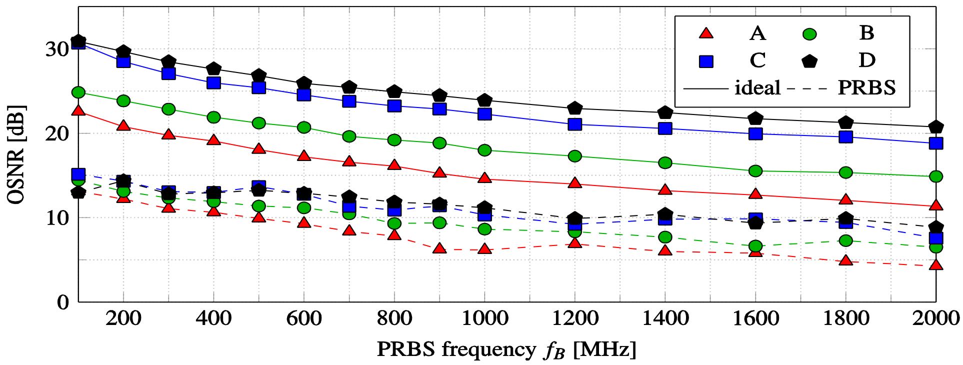

FIG. 3 – Fig. 7. Estimated OSNR for different PRBS frequencies f_B .

The OSNR for different f_B is quantified in Fig. 3; for the PRBS (dashed curves) it is calculated as $OSNR = \int_D |h(z)|^2 dz \, / \int_{Z-D} |h(z)|^2 dz$, where Z and D represent the fiber and the DBG integration domains. The OSNR decreases for increasing f_B (decreasing length). Shorter gratings have lower reflectivity and so the weight of off-peak reflections becomes larger [9]. The measured OSNR is higher than the prediction of [9], but also the power levels used here are higher than those in [9]. The OSNR penalty spans from about 7 to 18dB, decreases for increasing f_B and it depends on the power levels involved. In particular, higher power levels determine higher penalty. By filtering measured data [14] to eliminate noise, the OSNR of low correlation sequences [11] can be estimated (solid curves).

IV. CONCLUSIONS

We experimentally generated and characterized localized and stationary DBGs in a PMF through PRBS phase modulation of the pumps. The characterization of DBGs has been performed through SWI. From the complex transfer function of the DBGs, the length, the bandwidth, the reflectivity and the OSNR have been determined. All features depend on the PRBS frequency. The reflectivity depends mainly on the pumps powers, while the OSNR depends also on the probe power. The performance of reduced noise gratings generated in ideal conditions have been compared to those generated by PRBS that are affected by off-peak correlation noise.

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REFERENCES

[1] K.Y. Song, W. Zou, Z. He, and K. Hotate, *“All-optical dynamic grating generation based on Brillouin scattering in polarization-maintaining fiber,”* Opt. Lett. 33(9), 926-928 (2008).

[2] J. Sancho, N. Primerov, S. Chin, Y. Antman, A. Zadok, S. Sales, and L. Thévenaz, *“Tunable and reconfigurable multi-tap microwave photonic filter based on dynamic Brillouin gratings in fibers,”* Opt. Express 20(6), 6157-6162 (2012).

[3] F. Chiarello, D. Sengupta, L. Palmieri, and M. Santagiustina, *“Characterization of reconfigurable ultranarrowband optical filters realized by localized dynamic Brillouin gratings,”* ECOC 2015, Spain, P.1.10 (2015).

[4] S. Chin and L. Thévenaz, *“Tunable photonic delay lines in optical fibers,”* Laser Photon. Rev. 6, 724-738 (2012).

[5] M. Santagiustina, S. Chin, N. Primerov, L. Ursini, and L. Thévenaz, *“All-optical signal processing using dynamic Brillouin gratings,”* Sci. Rep. 3, 1594 (2013).

[6] L. Ursini and M. Santagiustina, *“Applications of the dynamic Brillouin gratings to ultrawideband communications,”* Photon. Technol. Lett. 25(14), 1347-1349 (2013).

[7] K.Y. Song, S. Chin, N. Primerov, and L. Thévenaz, *“Time-domain distributed fiber sensor with 1cm spatial resolution based on Brillouin dynamic grating,”* J. Lightwave Technol. 28(14), 2062-2067 (2010).

[8] T. Erdogan, *“Fiber grating spectra,”* J. Lightwave Technol. 15(8), 1277-1294 (1997).

[9] Y. Antman, N. Primerov, J. Sancho, L. Thévenaz, and A. Zadok, *“Localized and stationary dynamic gratings via stimulated Brillouin scattering with phase modulated pumps,”* Opt. Express 20(7), 7807-7821 (2012).

[10] M. Santagiustina and L. Ursini, *“Dynamic Brillouin gratings permanently sustained by chaotic lasers,”* Opt. Lett. 37(5), 893-895 (2012).

[11] Y. Antman, N. Levanon, and A. Zadok, *“Low-noise delays from dynamic Brillouin gratings based on perfect Golomb coding of pump waves,”* Opt. Lett. 37(24), 5259-5261 (2012).

[12] D.-P. Zhou, Y. Dong, L. Chen, and X. Bao, *“Four-wave mixing analysis of Brillouin dynamic grating in a polarization-maintaining fiber: theory and experiment,”* Opt. Express 19(21), 20785-20798 (2011).

[13] D. Sengupta, M. Santagiustina, F. Chiarello, and L. Palmieri, *“Generation of dynamic Brillouin grating in polarization maintaining fiber,”* Proc. SPIE 92021Q (2014).

[14] F. Chiarello, D. Sengupta, L. Palmieri, and M. Santagiustina, *"Distributed characterization of localized and stationary dynamic Brillouin gratings in polarization maintaining optical fibers,"* Opt. Express 24, 5866-5875 (2016)