System Performance Evaluation of Stimulated Brillouin Scattering Based Narrowband Rectangular Optical Filter

Wei Wei[1, 2], Yves Jaouën[2], Lilin Yi[1*], Elie Awwad[2] and Michel Morvan[3]
[1]State Key Lab of Advanced Optical Communication Systems and Networks, Shanghai Jiao Tong University, Shanghai 200240, China
[2]Institut Télécom, Télécom ParisTech, CNRS UMR 5141, 46 Rue Barrault, 75634 Paris, France
[3]Institut Télécom, Télécom Bretagne, CNRS UMR 3192 LAB-STIC, 29238 Brest, France
**lilinyi@sjtu.edu.cn*

Abstract: We propose a narrowband rectangular optical filter based on stimulated Brillouin scattering with flexible bandwidth and ~1-dB passband ripple. Only small performance penalty is observed when employing the filter into the OFDM system.
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1. Introduction

As a promising candidate for the next generation of optical transmission networks, the multi-band orthogonal frequency-division-multiplexing (MB-OFDM) technique has shown its inherent advantages of high spectrum efficiency, anti-interference ability and especially the flexibility for the sub-wavelength optical switching [1]. In the MB-OFDM networks, the optical filter is the key component to realize sub-band add or drop functions and also determines the resolution of the switching. Thus a narrowband rectangular optical filter with wavelength and bandwidth tunability is highly desired.

Such kind of rectangular filters with large bandwidth have already been achieved by using liquid-crystal on silicon (LCOS) [2] and tunable bulk-gratings technique [3]. However, for bandwidth less than 10 GHz, the passbands of these filters tend to Gaussian shape, which cannot completely meet ultra-narrow sub-wavelength switching requirements [3]. Several methods have been proposed to implement GHz-bandwidth filter including specially designed fiber Bragg gratings (FBG) [4], Fabry–Perot etalons [5] and stimulated Brillouin scattering (SBS) [6], etc. Among all the above methods, SBS based active filter have been considered as one of the most promising techniques which can work as a filter and an amplifier at the same time with wavelength and bandwidth tunability. However, it is very difficult to control the pump spectrum precisely in the previous works, therefore the exact flat top and sharp edge as the ideal rectangular filter can be hardly achieved.

In this paper, we propose an active narrowband rectangular optical filter based on SBS effect with 1.2~2.2-GHz bandwidth and 20-dB gain. By controlling the pump spectrum precisely with feedback compensation [7] and utilizing nonlinearity management in a single Brillouin gain peak fiber [8], a steep-edged flat-top filter has been achieved with ~1-dB passband ripple. In order to verify the feasibility of the filter in the OFDM system which is the foundation of the sub-band switching, we measure the system performance of the proposed filter by amplifying an OFDM signal with quadrature-phase-shift-keying (QPSK) and 16-quadrature-amplitude-modulation (16-QAM) formats on each sub-carrier for the first time. Only less than ~0.7-dB signal noise ratio (SNR) penalty is induced at the bit error rate (BER) of 1e-3 when the signal bandwidth is less than 1.5 GHz which proves the filter effectiveness.

2. Rectangular filter generation

Theoretically, in order to obtain the ideal rectangular SBS gain spectrum, a pump consisting of equal-amplitude spectral lines with interval equaling the natural SBS gain bandwidth is required. In the previous work [7], we generate an electrical comb using an arbitrary waveform generator (AWG) and then modulate it on the light to generate the pump. Given the nonlinear responses of electrical and optical components, the flat electrical spectral lines lead to uneven SBS gain as shown in Fig.1 (a), thus a feedback compensation is proposed to digitally control the amplitude of each electrical spectral line according to the measured SBS gain so as to optimize the shape of the targeted SBS filter as shown in Fig. 1 (b). With the increase of the filter bandwidth, the increasing pump power and number of spectral lines cause remarkable four wave mixing (FWM) effect which redistributes the pump power and generates new spectral lines at the stop band as shown in Fig. 1 (a) and (b) in the color of yellow. Thus we propose a nonlinearity management method shown in Fig. 1 (c) to mitigate the FWM components [8]. We set frequency interval of the electrical spectral lines randomly around the natural SBS gain bandwidth instead of the equal interval. In this case the new spectral lines generated by the FWM are no longer superposing on the original lines. As a result, the power of these new spectral lines are very small compared to the original lines and can just induce tiny gain or even under the threshold of SBS effect. Therefore the flatness of the passband is greatly improved and the unwanted gain out of the passband can be partly suppressed as well.

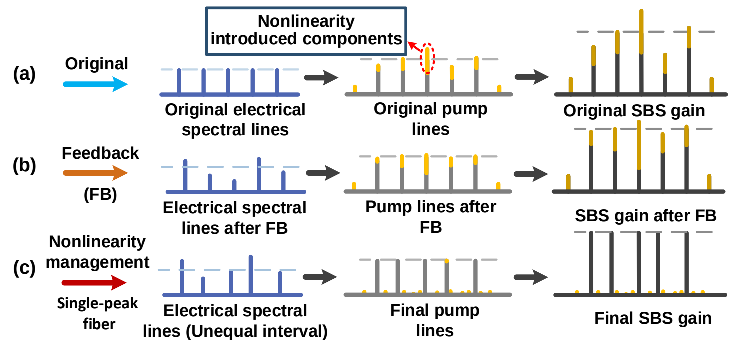

Fig. 1. The electrical spectral lines, pump lines and the SBS gains in different cases

The filter revision setup is shown in Fig. 2. A distributed feedback (DFB) laser operating at 1543 nm is split into two branches. In the upper branch, an AWG is used to generate the electrical spectral lines with random frequency interval within ±1-MHz deviation from the natural SBS bandwidth of 20 MHz, i.e. 19 MHz, 20 MHz and 21 MHz. Then it is modulated on the light to generate the optical carrier-suppression single-sideband (OCS-SSB) SBS pump lines utilizing an I&Q modulator (IQM). The OCS-SSB signal is then amplified by an erbium doped fiber amplifier (EDFA) and launched into the 25-km single-peak fiber. The SBS gain is ~11-GHz away from the pump as shown in Fig. 2 (i). In the lower branch, a sweeping signal covering the whole SBS gain region from an EVNA is modulated on the light to generate the probe signal. After removed the left sideband by an optical bandpass filter (BPF) shown in Fig. 2 (ii), the probe light goes through the fiber and is amplified once it sweeps within the SBS gain region as shown in Fig. 2 (iii). A polarization controller (PC3) is used to achieve the maximum SBS gain. The probe signal is then detected by a photodiode (PD) and sent into the EVNA. The amplitude response are measured by the EVNA and the SBS gain spectrum can be obtained by subtracting the results with and without the SBS amplification.

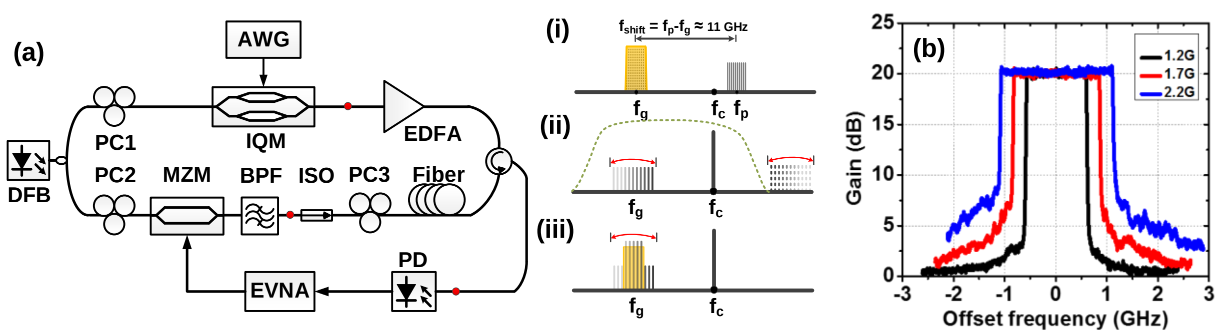

Fig. 2. (a) The SBS filter setup and the gain measurement, (b) Amplitude responses of the proposed filter

After feedback compensation for several times, the SBS filter with very steep edges and ~1-dB ripple passband has been obtained as shown in Fig. 2 (b) which is very close to the ideal rectangular filter. The filter bandwidths are 1.2 GHz, 1.7 GHz and 2.2 GHz which correspond to 60, 85 and 110 pump lines respectively. The gains are set to 20 dB which also can be flexibly changed by changing the pump power.

3. System experiment and results

The OFDM system setup is shown in Fig. 3. In the transmitter part, the light from an external cavity laser (ECL) at ~1543 nm is modulated by the electrical OFDM signal from the AWG with QPSK and 16-QAM modulation format for each subcarrier at the sampling rate of 2.5-G Samples/s. 128 subcarriers are used taken into account the ~100-KHz ECL laser linewidth. The signal bandwidth can be changed by changing the number of empty subcarriers at the edges. After passing through the fiber, the single polarization OFDM signal is amplified by the proposed active SBS filter with steep edges and flat top whose pump is inversely launched into the fiber ~11-GHz away. In the receiver part, the received power from the transmitter is tuned at -12 dBm by using an EDFA and an optical attenuator, corresponding to the optimal received power of the coherent receiver. Meanwhile a broadband ASE noise source with an attenuator is added for the SNR-BER measurement. The OFDM signal is then detected by intradyne coherent receiver followed by high-speed real time oscilloscope and the QPSK and 16-QAM constellations are obtained by off-line processing. A more precise description of OFDM signal generation and detection is in [9].

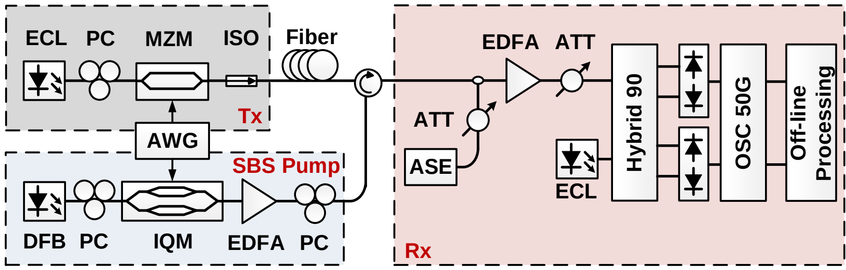

Fig. 3 OFDM system setup

Fig. 4 (a) shows the SNR-BER curves for the QPSK format. The performance difference with and without proposed SBS filter is inconspicuous. Meanwhile for 16-QAM cases shown in Fig. 4 (b), the SNR penalty are only ~0.3 dB and 0.7 dB at BER of 1e-3 when the bandwidth are 1 GHz and 1.5 GHz respectively. Larger penalty (i.e. ~0.2 dB for QPSK and ~1.8 dB for 16QAM at BER of 1e-3) are observed when the filter bandwidth is increased to 2GHz with larger pump power which will consequently induce larger noise. Fig. 4 (c), (d) and (e), (f) show the QPSK and 16-QAM constellations without and with the SBS filter respectively with 2 GHz bandwidth and ~30 dB SNR. After amplified by the SBS active filter, the constellation points are still clear and distinguishable. The result has proved that the SBS gain induced penalty is not significantly. It also validates the feasibility of the proposed rectangular SBS gain filter in the OFDM system and the potential application in the MB-OFDM switching.

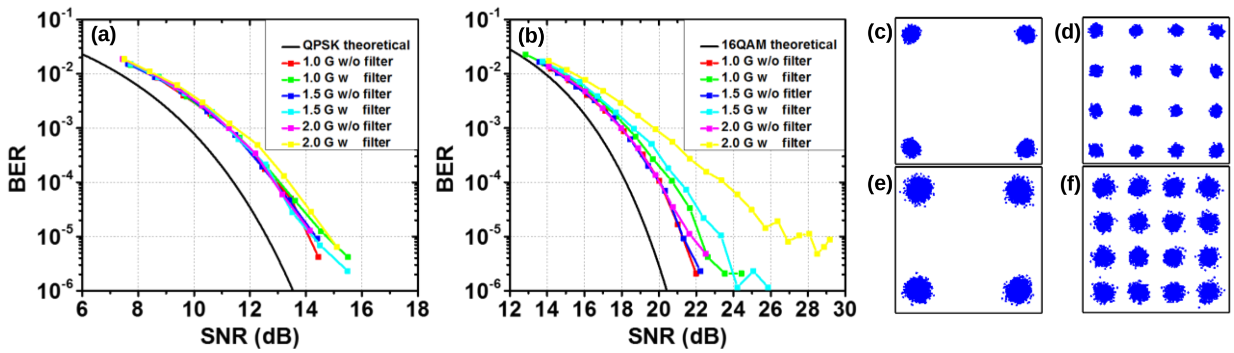

Fig.4. (a) BER-SNR curves for QPSK (b) BER-SNR curves for 16-QAM. The constellation diagrams of (c) QPSK (d) 16-QAM without SBS filter and (e, f) with SBS filter.

4. Conclusion

We have presented a narrowband rectangular optical filter based on stimulated Brillouin scattering and evaluated the performance of the filter in OFDM systems with QPSK and 16-QAM modulation formats. The proposed steep-edged flat-top filter with ~1-dB passband ripple and 20 dB gain only brings less than 0.7-dB SNR penalty at BER of 1e-3 when the signal bandwidth is less than 1.5 GHz. Moreover, the filter wavelength and bandwidth tunability can boost the OFDM flexibility to the maximum. Therefore, the proposed filter is almost an ideal pre-amplifier and add/drop switch for the MB-OFDM signal.

5. Acknowledgement

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6. References

[1] R. Dischler et al., OFC2010, OTuM7.
[2] C. Pulikkaseril et al., Opt. Express **19**, 8458-8470 (2011).
[3] E. Pincemin et al., J. Lightwave Technol. **32**, 2202-2219 (2014).
[4] X. H. Zou et al., Opt. Lett. **38**, 3096-3098 (2013).
[5] M. W. Pruessner et al., Appl. Phys. Lett. **103**, 11105 (2013).
[6] Y. Stern et al., Photon. Res. **2**, B18-B25 (2014).
[7] W. Wei et al., OFC2014, W4F.5.
[8] W. Wei et al., ECOC2014, p.1.7.
[9] E. Awwad et al., Opt. Express, **21**, 22773-22790 (2013).