Brillouin Filtering with Enhanced Noise Performance and Linearity Using Anti-Stokes Interactions

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Abstract: The anti-Stokes component of a stimulated Brillouin scattering interaction enabled low-power and high-resolution bandpass filtering, with improvements in linearity and signal-to-noise ratio of upto 3dB and 8dB, respectively when compared to using the Stokes component.
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1. Introduction

The processing of analog information through photonic techniques is gaining a lot of interest owing to the flexibility, high speed and broad bandwidth offered by photonics. While several advances have been made in this field, high-resolution RF photonic signal processing remains challenging due to the limitation in the availability of optical components with sub-100 MHz responses. Stimulated Brillouin scattering (SBS), a nonlinear optical process has emerged as a key technology to release this bottleneck owing to its inherent ~10 MHz resonance response. SBS results in a narrowband gain resonance at the Stokes frequency (ω_p-Ω) red-shifted from the pump (ω_p), and a loss resonance occurring at the blue-shifted anti-Stokes frequency (ω_p+Ω), where Ω is the SBS shift.

While several SBS-based RF functionalities have been demonstrated [1], limited efforts have been made towards optimizing their performance. There is a stringent requirement to meet important RF metrics [2]: insertion loss, signal-to-noise ratio (SNR) and linearity for SBS-based RF photonic components to replace conventional electronic devices. Most demonstrations rely on the Stokes component, however, it is well-understood that the SBS gain saturates at high signal powers, thus limiting the dynamic range of the RF system [3]. Also, SBS-gain-based filters are incompatible with low-insertion-loss RF photonic links that rely on large optical powers [2]. Furthermore, the SBS gain process can lead to large SNR penalties [4]. The anti-Stokes interaction on the other hand can offer a route to mitigate these issues, since the loss response does not saturate as strongly as the gain response. Also recently, the anti-Stokes interactions have also been harnessed to demonstrate optoelectronic oscillators [5] with low phase noise.

In this paper, we demonstrate bandpass filters using the anti-Stokes interaction to reduce the effects of gain saturation and signal degradation when compared to using the Stokes interaction, without introducing any additional RF loss. This paves the way for the implementation of SBS filters in RF photonic links requiring high signal quality.

2. Principle of Operation

The principle of operation is shown in Fig. 1. A phase modulator has several advantages when compared to an intensity modulator, including a more linear operation and no bias drift. Phase modulation results in the generation of two sidebands that are equal in amplitude and out-of-phase by π. These waves interfere destructively at the photodetector resulting in a negligible RF component. If Brillouin gain is applied to one of the sidebands, then the condition for destructive interference is not met within the SBS bandwidth, resulting in the generation of a bandpass response. Compared to a filter formed purely using single sideband modulation that maps the SBS response one-to-one to the electrical domain, a higher selectivity can be achieved since the RF signals destructively interfere outside the SBS bandwidth [1]. This is especially important for applications with a low power budget, since a low SBS

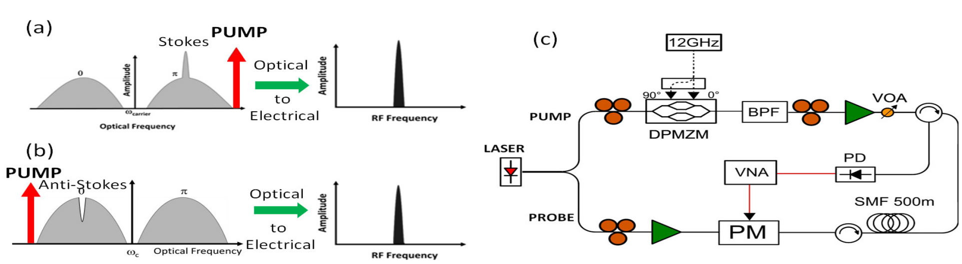

Fig. 1. Principle using: (a) SBS gain, and (b) loss, and (c) experimental setup. DPMZM- Dual Parallel Mach Zehnder modulator, BPF- bandpass filter, VOA- variable optical attenuator, PD- photodetector, VNA- vector network analyzer, SMF- single mode fibre, PM- phase modulator.

pump power can result in filters with high selectivity. However, the dynamic range is limited since SBS gain saturates at higher RF powers [3]. Therefore, the SBS loss response was used to improve the dynamic range as shown in Fig. 1 (b). The SNR improvement is due to the slow build-up of the anti-Stokes wave compared to the Stokes component [6], resulting in a weaker influence of the spontaneously generated photons contributing to noise.

3. Experiments and Results

The experimental setup consists of a laser that is split using a 3dB coupler as shown in Fig. 1 (c). The upper (pump) path consists of a dual parallel Mach Zehnder modulator (DPMZM) biased for single sideband modulation with carrier suppressed (driven by a 12 GHz signal generator) and a tunable bandpass filter for improved filtering of the sideband. The lower arm is amplified before being phase modulated to have a low RF insertion loss [2] and the signal is propagated in a 500-m-long optical fibre, which is the SBS medium. The processed probe is detected by a photodiode and measured using a vector network analyser (VNA) that also drives the phase modulator. The filter was seeded by an RF tone and the VNA was replaced by an RF spectrum analyser to measure the SNR.

With the DPMZM set for upper sideband-suppressed carrier, SBS gain was applied to the probe sideband as shown in Fig. 1 (a). A bandpass filter response (inset of Fig. 2(a)) with a 3-dB bandwidth of 26 MHz and a passband level of -15 dB was realized at an input RF power of -30 dBm. The RF power was varied to measure the dynamic range and noise figure as a function of input RF power. The experiments were repeated for the case of SBS loss, with the DPMZM biased to suppress the carrier and the upper sideband, and the pump power was slightly increased to maintain the passband level of -15 dB. The electrical spectrum shown in Fig. 2 (a) shows that there is an SNR penalty of 8 dB when using the Stokes component compared to the anti-Stokes component for an RF power of 10 dBm. This is mainly due to two effects: (1) the strong gain saturation at high signal powers [3] reduces the passband level, and, (2) higher noise power as explained in section 2. Fig. 2 (b) shows the SNR improvement of the anti-Stokes filter as a function of input RF power. At input signal powers below -15 dBm, the measured noise power is close to the electronic noise floor, hence the improvement in SNR cannot be observed for these powers. Fig. 2 (c) plots the passband level as a function of input RF power, and it is observed that the passband level saturates at higher signal powers resulting in the reduction of the passband level by up to 3.5 dB when using the Stokes interaction, while a penalty of only 0.5 dB is observed for the case of the anti-Stokes interaction.

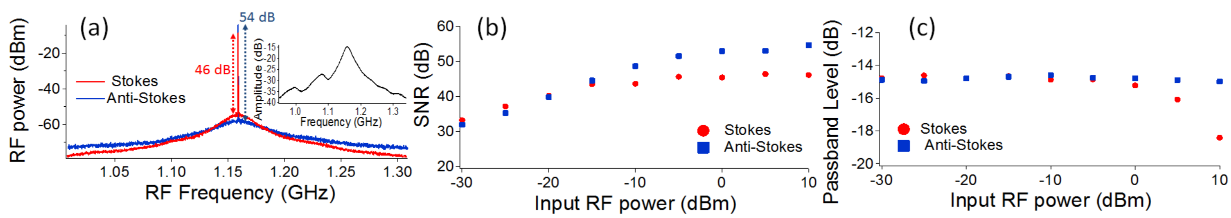

Fig. 2. (a) The measured RF spectra for the filter using the Stokes wave and the anti-Stokes components of SBS at an RF power of 10 dBm. Inset: the filter response. (b) SNR as a function of the input RF power, and (c) passband level as a function of input RF power for the Stokes and the anti-Stokes component.

4. Conclusions

In this paper, we use the anti-Stokes component of SBS to demonstrate a narrowband filter with high selectivity, using phase modulation and low SBS pump powers. This enables the improvement in the critical performance metrics of the filter in terms of SNR and dynamic range while maintaining the passband level, compared with a filter implemented by the Stokes components of SBS. This opens up a path for improved RF system design that can find use in practical systems. This technique is especially promising for on-chip SBS due to the low pump power requirements of this scheme, and is currently under investigation.

5. References

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