Coherent Brillouin Interaction Induced Phase Enhancement for Microwave Photonic Signal Processing

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Abstract

Photonic manipulation of the radio frequency (RF) signal phase has the potential to enable wideband microwave phase array antennas and RADARs. Stimulated Brillouin scattering is a promising candidate for RF phase manipulation due to the phase shift associated with its narrowband gain. However, the maximum phase shift that can be generated by SBS is limited by available pump power. Here we propose a phase enhancement technique based on coherent Brillouin interaction between the orthogonal polarization components of SBS gain. We demonstrate a 360º phase shift by tuning the bias voltage, which is three times more than the SBS-induced phase shift at the same Brillouin pump power. The bias-controlled phase shift can be exploited to realize phase array antenna systems for fast scanning applications.

1. Introduction

Controlling the phase of radio frequency (RF) signals has a significant role in signal processing. This task is generally carried out by RF phase shifters. Microwave photonic phase shifters are emerging as an alternative to electronic phase shifters due to their large operational bandwidth, lightweight, phase tunability, and immunity to electromagnetic interference. In general, in a microwave photonic (MWP) system, a RF signal is modulated to an optical carrier to create optical sideband(s), and the RF phase shift is accomplished by altering the phase of the carrier or the sideband(s). RF phase shifters are an integral part of the phase arrayed antennas (PAA) where they require fast and continuously tunable phase over a wide operational bandwidth, to alter the beam profile for different applications such as RADAR, Satellite communication systems, and high-speed network systems [1,2]. There have been many demonstrations of microwave photonic phase shifters where the tunable phase is achieved using different techniques like microresonators [3, 4], fiber Bragg grating [5], cross-phase modulation [6], slow-light in semiconductor optical amplifiers [7], polarization modulation [8], and stimulated Brillouin scattering [9,10,11,12,13]. However, the key bottlenecks encountered by various approaches include limited frequency tunability, insertion loss, and the maximum achievable phase shift. Among the many approaches, stimulated Brillouin scattering (SBS) is a promising choice for realizing a MWP phase shifter because it can offer a gain to the required signal, assisting in overcoming the insertion loss associated with standard phase shifting approaches. The phase introduced by the narrowband Brillouin gain spectrum allows the manipulation of a phase of a single frequency component without affecting nearby frequencies, and phase tunability can be achieved by changing the slope of the Brillouin phase response through tailoring the gain resonance or by scanning the pump frequency through the resonance [9]. In the SBS-based approach, the phase of an RF signal can be manipulated by creating a narrowband Brillouin-gain-based phase shift either on the optical carrier [9,12] or on the sideband[10,11]. However, a full 0º to 360º phase shift is only possible at the expense of a substantial Brillouin gain, which limits the observation of large phase shifts in chip-based devices due to the restricted amount of Brillouin gain available in those platforms. Recent experiments suggest that by employing interferometric methods, the RF phase shift can be tuned up to 360º [13].

In this paper, we propose a phase enhancement technique based on coherent Brillouin interaction between the orthogonal polarization components of SBS gain. We use an analogue of electromagnetically induced absorption (EIA) in the microwave domain to control the RF phase [14,15]. In [14], a narrow absorption profile is realized within the Brillouin gain profile by interfering the out-of-phase orthogonal polarization components of gain resonance. Here we show that the microwave domain analogue of EIA can result in a factor of three enhancement in the SBS-induced phase response, which can be tuned using external bias voltage. By tuning the bias from 2.3 V to 1.9 V, we vary the phase from 120º to 360º while achieving a phase enhancement factor of 3.

2. Experimental setup and Principle

Figure 1 shows the schematic diagram of the experimental setup for realizing the analogue of EIA in the microwave domain. Light from a narrow linewidth laser (ω_c) is split in two arms. The lower arm consists of a z-cut intensity modulator (IM) which generates upper and lower

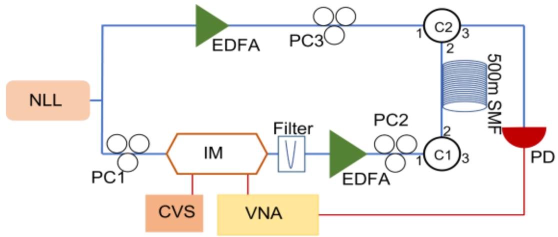

Figure 1: Experimental setup for enhancing Brillouin induced phase shift based on analogue of EIA in the microwave domain.

sidebands using the RF signal from a vector network analyzer (VNA). The upper sideband of the modulator output is filtered out using a narrowband optical filter. The resulting signal, which consists of the lower sideband and the carrier, is amplified using a low-noise erbium-doped fiber amplifier (EDFA). The power distribution in the orthogonal polarization components of the signal is made unequal to create the optical probe using a polarization controller PC2. The light through the upper arm is amplified using a high-power erbium-doped fiber amplifier to act as the Brillouin pump. The pump and probe signals are allowed to counter propagate through 500 m single mode fiber (SMF) through circulators C2 and C1, respectively. The power distribution

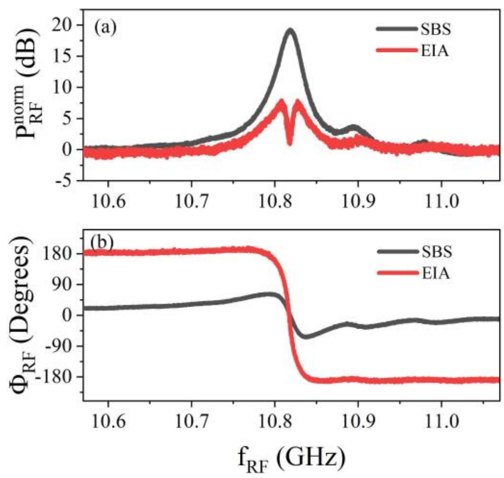

Figure 2: Comparison between the normalized amplitude and phase responses of SBS and analogue of EIA in the microwave domain. (a) Normalized amplitude response, (b) normalized phase response (solid black line represents SBS and the solid red line represents EIA

in orthogonal polarization components of the pump signal is tuned using PC3 so that the Brillouin gain spectrums equalize at the maximum amplitude point [14]. The phase difference between the orthogonal polarization components can be tuned using the bias voltage of the intensity modulator [14,15,16]. When the phase difference at the equal amplitude point is π, it will destructively interfere and results in an absorption profile within the Brillouin gain and characteristic phase response. The bias voltage from this optimum position is tuned both ways, and the amplitude responses and the phase responses are noted.

3. Results and Discussions

Figure 2 shows the normalized amplitude and phase responses of SBS and EIA. We use a maximum SBS gain of ~20 dB (solid black line in Fig. 2a), which results in a maximum phase shift of ~120º (±60º)(solid black line in Fig. 2b). For the same pump power, a narrow band absorption profile is created within the Brillouin gain profile (solid red line in Fig. 2a) when the polarization, as well as the bias, are tuned. The phase shift corresponding to the EIA profile is measured and is shown in Fig. 2b (solid red line). Here we achieved a phase enhancement of a factor of 3 without increasing the pump power.

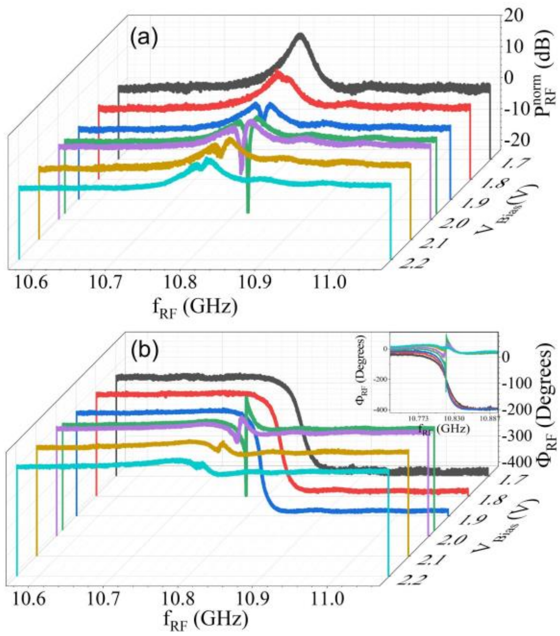

Figure 3: Tuning of amplitude response and phase response of analogue of EIA by changing bias voltage. (a) Different amplitude responses for different bias values. (b) The phase response corresponding to the different bias values. inset shows the zoomed version of phase responses where tunability of phase response with respect to bias voltage is clear.

Figure 3 shows the tunability of the phase response of EIA by changing the bias voltage of IM (V_{Bias}). The amplitude responses of EIA at different bias voltages are shown in Fig. 3a, and the corresponding phase responses are shown in Fig. 3b. The inset in Fig. 3b shows the zoomed version of phase responses at different voltages. As the bias voltages detune from the maximum EIA position (solid green line), the depth of the absorption profile and the phase response change. The inset in Fig. 3b clearly shows the variation of phase response with respect to the bias voltage. We enhanced the phase shift from 120º to 360º while achieving a phase enhancement factor of 3 by adjusting the bias from 2.3 V to 1.9 V, which shows that, this technique can achieve a full 360º phase shift by simply controlling the bias voltage. Phase control using bias voltage can offer fast phase tunability which is crucial for high-performance PAA systems.

6. Conclusion

We have proposed and experimentally demonstrated a new method to enhance the Brillouin-induced phase. The enhanced phase shift can be tuned using external bias voltage. The technique is based on interference-based coherent Brillouin interaction between the orthogonal polarization components of gain. By tuning the bias voltage and the polarization we were able to achieve a 360º phase shift which is 3 times higher than the SBS-induced phase shift at the same Brillouin pump power. The tunable phase shift was realized by simply tuning the bias voltage of the intensity modulator. This tunable 360º phase shift can be exploited to realize microwave photonic phase shifters which are essential components PAA systems.

6. Acknowledgements

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7. References

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