BRILLOUIN OPTO-ELECTRONIC OSCILLATOR

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ABSTRACT

We demonstrate an all optical Opto-Electronic Oscillator in which the Brillouin selective sideband amplification technique is used to provide a sufficient gain for the oscillator to start and sustain an electro-optic oscillation. Such an oscillator can generate high frequency, high spectral purity, and tunable microwave signals in both optical and electrical domains.

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INTRODUCTION

Opto-Electronic Oscillator,[1,2] OEO, is attractive for generating high spectral purity microwave and millimeter-wave photonic signals for photonic communication systems[3] and Radar systems. It consists of a single mode pump laser and a feedback circuit including an electro-optic amplitude modulator, an optical fiber delay line, an photodetector, an electrical amplifier, and an electrical bandpass filter.

We report in this paper an all optical OEO that completely eliminates the need for electronic components, including the amplifier and the filter. Particularly, a novel technique called Brillouin selective sideband amplification (BSSA) is used to provide the OEO with the necessary gain. In addition, an electro-optic phase modulator can be used to replace the amplitude modulator, thereby eliminating the bias drift problem commonly found in amplitude modulators. We name this novel device a Brillouin Opto-Electronic Oscillator, or Brillouin OEO.

BRILLOUIN OEO CONSTRUCTION AND OPERATION

The construction of a Brillouin OEO is shown in Fig. la. The cw output of the signal laser, laser 1, goes through a modulator, an isolator, and a fiber delay line before being detected by a photodetector. The output of the photodetector is fed into the electrical input port of the modulator. A Brillouin pump laser (also CW), laser 2, is fed into the fiber loop from the opposite end of laser 1 to provide the Brillouin amplifications In particular, this pump beam will induce a moving acoustic grating via the eletrorestrictive effect in the fiber and be scattered by the moving grating into the direction of the signal beam. Due to the Doppler effect, the frequency of the backscattered light will be down shifted by ν_{BS}, as shown in Fig. lb.

The operation mechanism of the Brillouin OEO is as follows: the white noise from the photodetector (thermal noise, shot noise, and RIN noise) will modulate the modulator and generate modulation sideband (also white noise) at the output of the modulator. However, due to the narrow bandwidth of the Brillouin gain (-10 MHz), only the frequency component that coincide with the Brillouin scattering frequency will be amplified by the Brillouin selective sideband amplification process,[3] as shown in Fig. 1c. This amplified sideband will beat with the carrier frequency of laser 1 and produce a beat signal at the output of the detector. This beat signal will in turn drive the modulator to produce a stronger sideband at the beat frequency. Through such positive feedback, the beat signal will get stronger and stronger until the gain saturates. The oscillation power will be clamped at the level corresponding to a unit gain, shown in Fig. 2. Note that this gain satuation also greatly suppresses the spontaneous Brillouin scattering noise and thus avoids the noise problem[6] commonly found in digital Brillouin amplification systems. It is evident from Fig. 1c that the oscillation frequency f_{osc} is:

$$f_{osc} = \upsilon_{BS} + (\upsilon_1 - \upsilon_2), \qquad (1)$$

where υ_{BS} is the Stokes frequency shift of the Brillouin scattering and υ_1 and V_2 are the carrier frequencies of laser 1 and laser 2 respectively.

Because of the narrow gain bandwidth (- 10 MHZ, narrower than most electrical bandpass filters) and the strong gain competition characteristics of the BSSA, no electrical filter is necessary to keep the OEO oscillating at a single mode. The Brillouin amplifier is just like a narrow bandpass filter with gain. The center frequency of this Brillouin gain filter can be tuned easily and quickly by tuning the frequency of laser 1 or laser 2, as indicated in Eq. (l). This will change the oscillation frequency of the OEO and create a widely tunable signal source.

Note that the Brillouin selective sideband amplification process is much more efficient? than any other optical amplification methods because all Brillouin scattering energy from the pump laser goes into the desired weak sideband. Since the strong carrier is not amplified, the saturation of the receiving photodetector can also be avoided.

In order for the Brillouin OEO to oscillate, its open loop gain (defined as the difference of the RF output power from the photodetector and the RF input power to the modulator in dB) must be larger than unity. We measured the open loop gain of a Brillouin OEO described above and the result is shown in

Fig, 2a. It is evident from the data that with a pump power of only 12.23 mw, a small signal gain of more than 20 dB at 5.5 GHz is achieved, more than sufficient for the OEO to start oscillation. As the input gets stronger, the Brillouin gain saturates. In comparison, the open loop gain (actually loss) without Brillouin selective sideband amplification is about -41 dB. The total of 61 dB signal amplification indicates the high efficiency of the Brillouin selective sideband amplification process.

The RF signal gain (the difference between the received RF powers with and without BSSA in dB) versus optical pump power for different input RF power is shown in Fig. 2b. It is evident that a substantial gain of the RF signals can be achieved even when the optical power is much less than the SBS threshold. At high pump powers, the gain saturates. Part of the gain saturation may be due to the photodetector saturation.

Note that the modulator used here can be either an amplitude modulator or a phase modulator. On the other hand, in a conventional OEO only an amplitude modulator can be used. This is because the BSSA can convert a phase modulation into an amplitude modulation.[4] Because no bias is necessary for a phase modulator, the bias drift problem associated with the amplitude modulator is automatically removed.

EXPERIMENTAL DEMONSTRATION

The experimental setup for demonstrating the Brillouin OEO is shown in Fig. 3a and the spectrum diagram showing BSSA and the oscillation frequency is shown in Fig. 3b. This configuration is different from that of Fig. la in that the same laser is used both as the signal and the pump and therefore has the advantage of not having to lock the frequencies of different lasers. However, the drawback is that the oscillation frequency of the OEO is fixed at the Brillouin Stokes frequency without the tunability of a Brillouin OEO having two separate lasers.

In the experiment, an amplitude modulator with a 3-dB bandwidth of 5 GHz and a spool of standard fiber of 12.8 km were used. In this fiber the Brillouin scattering has a Stokes frequency shift of 12.8 GHz for the diode pumped YAG laser used in the experiment. The laser has a wavelength of 1320 nm and an output power of 70 mW. The photodetector has a 3-dB bandwidth of 18 GHz and a saturation power of about 5 mW. The optical power going into the detector without Brillouin amplification is about 1.6 mW and the optical pump power into the optical circulator is 7 mW. The circulator has an insertion loss of 1 dB.

When all the optical components are connected as shown in Fig. 3a, an electro-optic oscillation is immediately observed on an HP 8563E spectrum analyzer. Fig. 4 shows the recorded oscillation spectrum. The measured signal level is about -21 dBm. Taking into account the 10 dB electrode loss of the modulator, the oscillation power at the output of the photodetector is about -1 1dBm. Because the Brillouin gain bandwidth is 10 MHz, but the mode spacing corresponding to the 12.8 km fiber is less than 10 kHz, mode hopping is expected. Such a mode hopping is observed in the experiment. The implementation of double loops[7] in the Brillouin OEO, similar to vernier-type interferometric resonators in a laser,[8] is expected to to eliminate the mode hopping problem.

SUMMARY

A new and improved version of Opto-Electronic Oscillator (OEO) is demonstrated. In this new development, Brillouin amplification is used to provide a sufficient gain for the OEO to start and sustain an electro-optic oscillation, replacing the bulky, expensive, and power consuming high frequency electrical amplifier. Such a replacement also eliminates the flicker noise (1/f noise) associated with high frequency electrical amplifiers, likely resulting an OEO with lower phase noise. In addition, the narrow gain bandwidth of the Brillouin amplification also serves a bandpass filter to replace the bulky electrical filter, making the device more integratable. Furthermore, the oscillation frequency of the Brillouin OEO can be easily tuned over a broad range by simply changing the frequency of the pump laser. Finally, a phase modulator can be used to replace the more expensive and higher loss amplitude modulator, eliminating the instability caused by the bias drift of the amplitude modulator.

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FIGURE CAPTIONS

Fig. 1 a) The layout of a Brillouin OEO with a separate Brillouin pump laser. Note that the optical coupler can be replaced by an optical circulator to reduce loss. b) The corresponding spectral diagram showing the Brillouin selective sideband amplification and the oscillation frequency of the Brillouin OEO.

Fig. 2. a) Open loop gain of the Brillouin OEO as a function of RF input power to the modulator. A small-signal open loop gain of 20 dB was obtained with only 2.61 mW optical power in the photodetector. The gain decreases at high input RF power levels. The optical pump power in the experiment is 12.23 mW. b) The gain of RF signals vs. optical pump power for different RF input powers to the modulator. Substantial RF gain was obtained even when the pump power is much lower than the SBS threshold level of 10 mW. Note that the gain saturates at high optical pump powers.

Fig. 3 a) The experimental setup for demonstrating a Brillouin OEO. The termination port of the traveling wave electrode of the modulator is used as the output port of the Brillouin OEO and is connected to a HP 8563E spectrum analyzer. Note that no electrical amplifier and filter are used. b) Spectral diagram illustrating the relationship between the frequency of the laser, the Stockes frequency of the Brillouin scattering, and the oscillation frequency of the Brillouin OEO.

Fig. 4 The observed frequency spectrum of the Brillouin OEO oscillation. The span and the resolution bandwidth of the spectrum analyzer were set at 100 MHz and 300 kHz respectively. Mode hopping is also observed in the experiment.

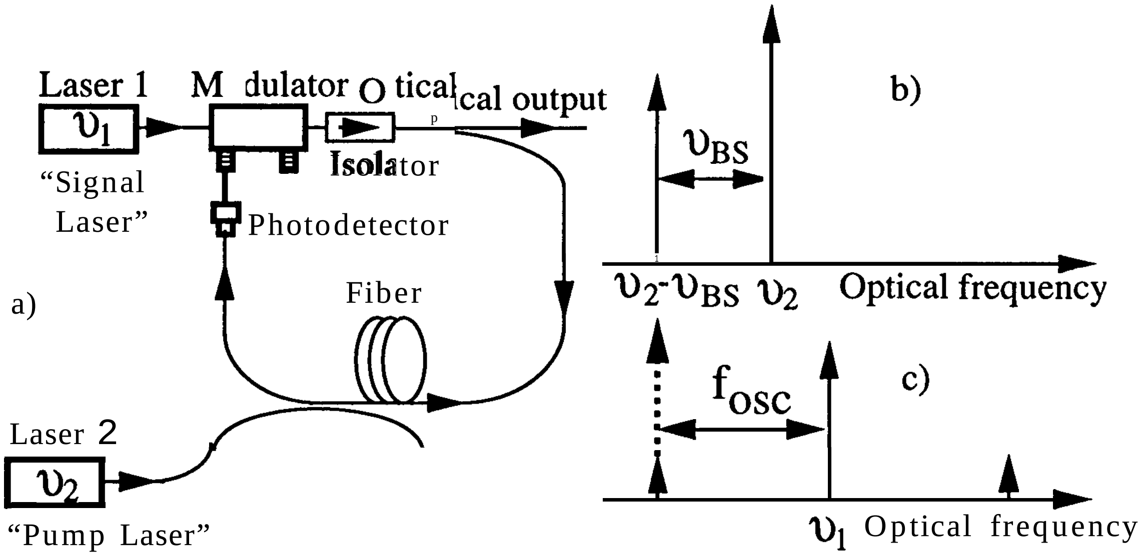

Fig. 1

Yao, "Brillouin Opto-electronic Oscillator"

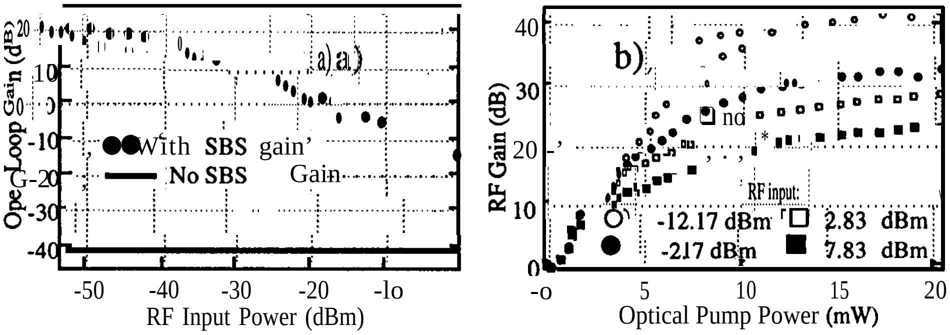

Fig. 2

Yao, "Brillouin opto-electronic oscillator”

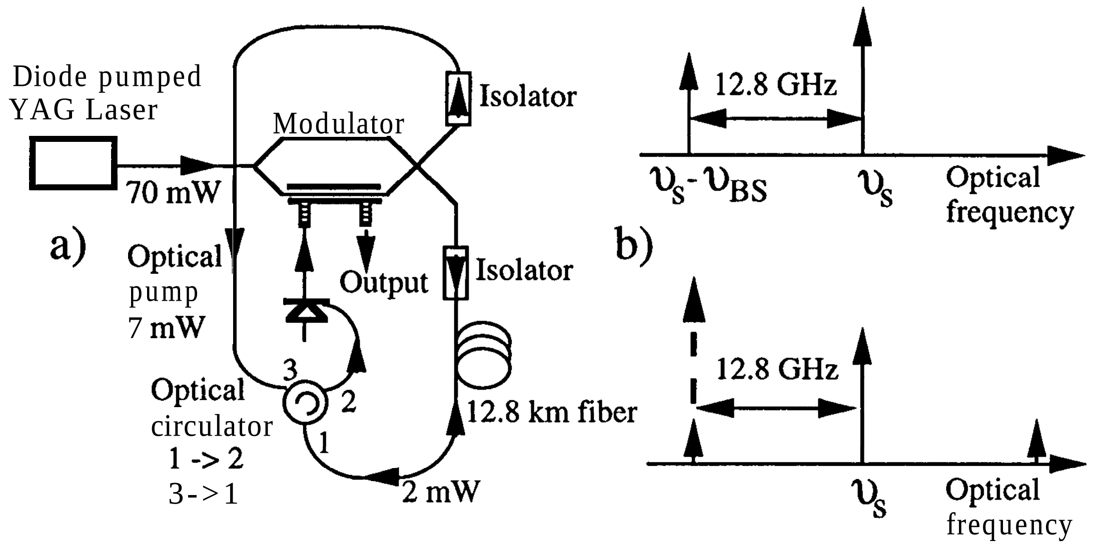

Fig. 3

Yao, "Brillouin Opto-electronic oscillator"

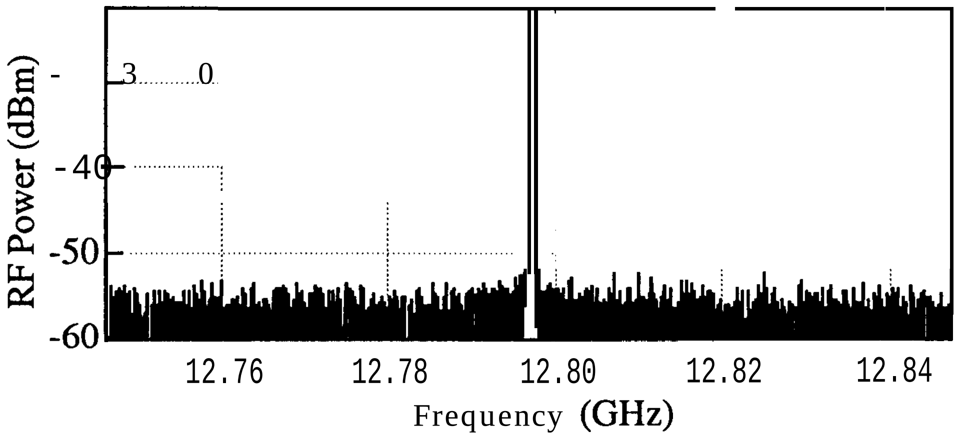

Fig. 4

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