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Tunable Brillouin Opto-Electronic Oscillator based on double fiber loop mirror

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Abstract

Brillouin beam generation from a tuned pump laser source with large spectral width using double fiber loop mirror is proposed. Synthesize of a microwave signal using this simple technique is presented. This technique has been verified experimentally using a tunable laser source. The results show the generation of Brillouin beam using pump laser of output Power 15mW, and fiber loop mirror length 6.6 Km. Then the generated Brillouin beam is injected to the second loop to make a tunable Brillouin opto-electronic oscillator. The second loop consists of signal laser source, electro-optic modulator, 2 Km single mode fiber, optical detector and microwave amplifier (the microwave amplifier is introduced to achieve the required gain to start oscillation, as a result of the low allowed input power to the detector used, which is 1 mw in this case). The output oscillation frequency is determined by the difference between the signal frequencies of the generated Brillouin beam and the signal laser source in the second loop.

1. Introduction

Generation of high stabilized microwave signals using optical techniques has received significant attention through the last decade. This is due to the high performance of optical components and very low loss of optical fiber compared to coaxial cables.

The first optical technique used is based on the use of long fiber delay line to stabilize the oscillator [1-3]. The quality factor (Q) in this technique depends on the delay time inside fiber (τ) and the oscillation frequency (*f*). This relation is given by (1) [4].

$$Q = \pi f \tau \qquad (1)$$

This technique requires a very long fiber delay line (in the kilometers range) to satisfy high Q as well as low phase noise. This results in small mode spacing as the free spectral range (FSR) between oscillation modes is the inverse of the delay time in the fiber line as described by (2).

$$FSR = \frac{1}{\tau} \qquad (2)$$

Small FSR requires sharp microwave filter to select only one mode for oscillation which isn't an easy task.
Using Brillouin selective side band amplification technique does not need a microwave filter with high selectivity [5]. There are other techniques that use Brillouin beam to generate microwave signal [6-8].The previous techniques used very long fiber delay line [6], high power laser source [5,7] and signal laser source with very small spectral width [6,8].

Grégoire Pillet et al. proposed a new technique based on a Fiber-Ring Resonator [9-12] and a Dual-Frequency Laser to generate tunable microwave signals within tuning range more than 1 GHz [13]. This technique requires a Pound-Drever-Hall laser stabilization to stabilize one laser line on a resonance of the fiber ring resonator [14,15].

The proposed technique in this paper minimizes the previous drawbacks. Where a microwave signal (up to 3 GHz) has been generated using shorter optical fiber length, pump laser source of wider spectral width and adequate pump power.

The rest of the paper is organized as follows: the generation of Brillouin beam using fiber loop mirror is presented in section 2. Using the generated Brillouin beam in opto-electronic oscillator (OEO) to generate microwave signal has been investigated in section 3. Section 4 is devoted to identify paper's conclusions.

2. Generation of Brillouin beam using fiber loop mirror

To generate Brillouin beam, a coupler is usually used as shown in Figure1. This results from the fact that the generated Brillouin beam is a back scattered process.

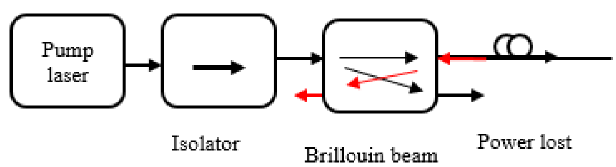

Figure 1. Direct technique to generate Brillouin beam

Using high coupling ratio, the incident power to the fiber increases on the expense of the output Brillouin beam power and vice versa.

On the other hand, if we use a fiber loop mirror configuration as shown in Figure2 all the pump power is utilized without sacrificing the output generated Brillouin beam power. Consequently, low pump power is required for the same optical fiber length is used.

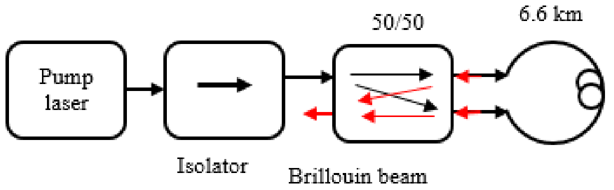

Figure 2. Brillouin beam generation using fiber loop mirror.

Brillouin beam has been generated using fiber loop mirror as shown in Figure.2. The used pump power is 20mW; single mode fiber of 6.6 Km length.

The generated Brillouin beam is coupled (10%) to an optical spectrum analyzer (OSA) and the results are shown in Figure.3. The recorded peak power at 1550.03 nm is Brillouin beam where another peak power of -19 dBm has been recorded at wavelength of 1549.942 nm (pump laser beam).

The previous results states that the difference between the pump and the Brillouin wavelengths is 0.088nm which is equivalent to 11 GHz, the Brillouin shift in silica fiber.

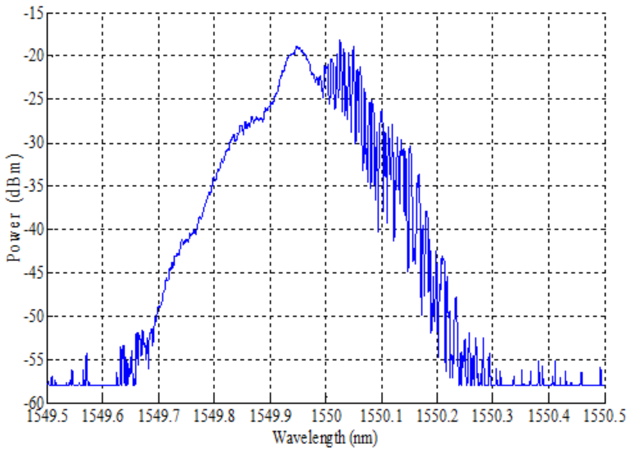

Figure 3. OSA displays the output of the system shown in Figure 2 (Laser Power 20 mW, Fiber loop mirror length 6.6 Km and OSA Resolution 0.07 nm)

The drawback of this experiment is the use of an optical source with large spectral width, this requires higher pump power and it leads to the generation of many Brillouin signals.

We have modified the previous setup to minimize the number of the generated Brillouin signals and to reduce the required pump power.
New Brillouin beam has been generated using two fiber loop mirrors by taking the generated Brillouin signals from the first fiber loop mirror and feed it to semiconductor optical amplifier (SOA). Then another fiber loop mirror is used but with different coupling ratio and feed part of the output back to the first fiber loop mirror. The new setup is shown in Figure 4.

This technique reduces the pump power required to generate Brillouin beam from 20 mw to almost 7 mw. In case of using higher pump power (15 mw) and keeping the same fiber length, the Brillouin beam power increases by about 10 dB as shown in Figure 5.

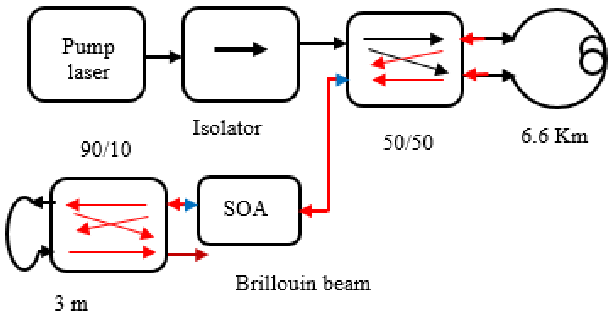

Figure 4. Brillouin beam generation using double fiber loop mirror.

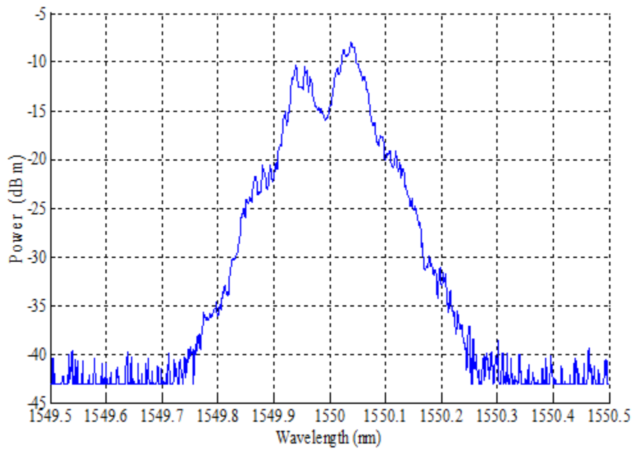

Figure 5. OSA displays the output of the system shown in Figure 4 (Laser Power 15mW, Fiber loop mirror length 6.6 Km and OSA Resolution 0.07 nm)

FSR of the generated Brillouin beam (~30 KHz) is much less than the system resolution. So, only one oscillation mode appears on the screen of OSA.

For the system shown in Figure 4, the value of the output power P_{out} can be estimated for a given pump power P_P by (3).

$$P_{out} = t_1 t_2 P_P \beta \gamma (1 - \alpha) G \qquad (3)$$

Where P_{out} is the output Brillouin power,t_1 *and* $t_2$are the coupling ratios of the first and second couplers, respectively. $P_p$is the pump power, β is the ratio between Brillouin stoke power to the pump power, γ the isolator insertion loss, α the fiber loss and G the SOA gain. The experimental results confirmed this relation.

3. OEO using the generated Brillouin beam from the fiber loop mirror

The proposed setup to generate a tunable opto-electronic oscillator is shown in Figure 6. This setup consists of two main sections; the first one is similar to the setup shown in Figure 4.

The generated Brillouin beam is coupled to the second one which includes: coupler, optical detector, electro-optic modulator, laser source and microwave amplifier. To protect the used photodiode, it is recommended to keep the maximum input power to be less than 1 mW in our case.

Microwave amplifier is inserted to increase the gain of the loop in order to achieve the oscillation conditions.

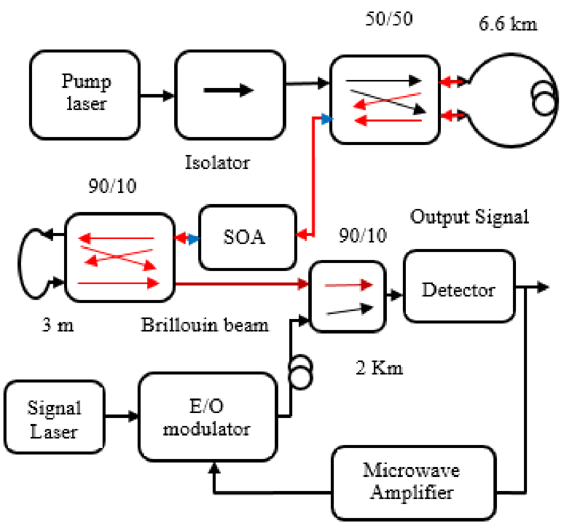

Figure 6. OEO using Brillouin beam generated by two fiber loop mirrors technique.

The generated signal level at 1.164 GHz is -24 dBm as shown in Figure 7. This signal may be tuned within 2.5 GHz range. The tuning is accomplished by controlling the wavelength of either the pump laser or the signal laser.

The frequency range of the output signal is limited by the bandwidth of the used microwave components (the detector and the electro-optic modulator)

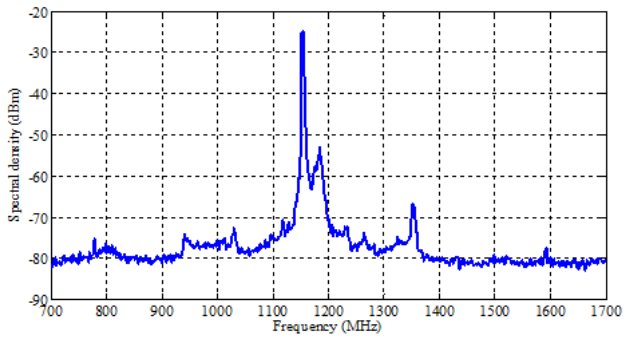

Figure 7. RF spectrum analyzer display (VBW =100 KHz and RBW=1 MHz)

The used laser is a c-band tunable laser source {Agilent 81940A} with variable output power from 4 to 20 mW and linewidth of 100 KHz, the modulator is Mach-Zender modulator (JDSU: 2.5 Gb/s Bias-Free Modulator with Integral Attenuator), the detector is avalanche photodiode (OF3240N-MS-YT), and the results are taken using optical spectrum analyzer (OSA) {Agilent 86143B} and RF spectrum analyzer up to 3GHz (R&S FSP 9k-3G).

4. Conclusion

We report here an implementation of a Brillouin beam generator using a new setup based on using double fiber loop mirror which leads to decreasing the required pump power and fiber length as well. The proposed technique then is introduced to synthesize a tunable microwave signal. The generated microwave signal tuning step dependence on the tuning of the used pump and signal laser sources. The range of the output frequency is limited by the used microwave components.

However, there are two basic items have to be investigated, the first one is the role of the phase locking between the pump laser and signal laser used, the second item is to study the effect of replacing optical fibers used in the proposed system by fiber ring resonators.

5. Acknowledgements

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