An All-Optical Frequency Up/Down-Converter Utilizing Stimulated Brillouin Scattering In A Trf And Dcf For Rof Application

N. A. Awang[1,2], H. Ahmad[2], S. F. Norizan[2], M.Z. Zulkifli[2] , Z.A.Ghani[4] and S. W. Harun[3]

[1]Faculty of Science, Art and Heritage, Universiti Tun Hussein Onn Malaysia, 86400 Batu Pahat, Johor, Malaysia.

[2]Photonics Laboratory, Department of Physics, University of Malaya, 50603 Kuala Lumpur, Malaysia

[3]Department of Electrical Engineering, Faculty of Engineering, University of Malaya, 50603 Kuala Lumpur Malaysia

[4]Faculty of Applied Sciences, Universiti Teknologi Mara (UiTM), 40450 Shah Alam, Selangor, Malaysia.

Corresponding email : 1norazura@uthm.edu.my

Abstract

A frequency up and down conversion is proposed based on stimulated Brillouin scattering (SBS) for Radio-over-fiber (RoF) system. Microwave frequency up conversion from 2GHz to 12.5GHz and microwave frequency down conversion from 12.5GHz to 1.8GHz with largest Intermediate Frequency (IF) power of -32dBm is successfully demonstrated. The up conversion is based on the 1st Stokes of Brillouin fiber laser in Truewave reach fiber (TWF) and the down conversion is based on 1st AntiStokes of Brillouin fiber laser in Dispersion compensating fiber (DCF).

Keyword: Stimulated Brillouin scattering (SBS); Radio-over-fiber (RoF); Microwave frequency conversion; Truewave reach fiber (TRF); Dispersion compensating fiber (DCF).

1 INTRODUCTION

The Radio-over-Fiber (Rof) approach in transporting microwave frequencies has drawn increased interest especially due to its cost effectiveness over the single mode fibers which are widely available[1,2]. This approach also offers an advantage over that of the electrical system which has high transmission loss and limited transmission distance. In the case of radio frequency over the optical fiber, the optical signal acts as the carrier that produces a much lower loss thus providing a longer signal transport distance [3]. All-optical frequency up-conversion technique is one of the key technologies for radio-over-fiber (RoF) systems. This technology, which generates RoF signals in optical domain, can achieve a broad bandwidth and reduce the number of expensive microwave components required when techniques including wavelength division multiplexing (WDM) are used to increase the spectral efficiency of the fiber optic channel [4]. Various all-optical frequency up-conversion schemes, using cross gain modulation (XGM) and cross phase modulation (XPM) in a semiconductor optical amplifier (SOA) [5] and SOA Mach-Zehnder interferometer [6], have been reported. These schemes showed a large bandwidth for LO frequency and could achieve an extremely broad bandwidth when WDM was used. They also could reduce the number of expensive components required for WDM-based RoF system if electrical frequency up-conversion technique was used. However, these schemes suffer from a limited IF bandwidth used for subcarrier multiplexing (SCM) since their IF bandwidth depends on carrier lifetime of the SOA. Recently, all-optical frequency up-converter utilizing the FWM effect in an SOA has been reported to have a broad bandwidths with respect to both LO and IF frequencies [7]. As an alternative, a simplification on the system can be achieved by using the up/down conversion technique utilizing the Stimulated Brillouin Scattering (SBS).

In this paper we put forward a simple technique based on SBS for generating microwave photonics signals based on up/down conversion in a 2GHz RoF system using a True wave reach fiber (TWF) for up conversions and a Dispersion compensating fiber (DCF) for down conversions, although there have been earlier reports on SBS observations in these fibers [8,9].

2 EXPERIMENTAL SETUP

The proposed experimental setup for frequency conversion is shown in Figure 1. The setup comprises of two parts labeled as parts A and B. Part A consists of the tunable laser (TLS) that can be tuned from 1460nm to 1580nm with a linewidth of 0.015nm. For this experiment the TLS is set at 1545nm with an output power of 10.0dBm which acts as the Brillouin Pump (BP). In order to achieve the maximum interaction, the polarization direction of BP is adjusted using the polarization controller (PC). The BP is then connected to Mach-Zehnder modulator (MZM) which is amplitude modulated with a RF frequency of 2GHz from the signal generator (SG). The RF signal of the BP is shown in Figure 2 which illustrates two peaks. One peak represents the 2GHz RF signal and the other represents second harmonics frequency due to the mode hopping that occurs in the tunable laser source. Generally, there are significant insertion losses in a Mach-Zehnder modulator and in this case the measured loss is about 7dB at 1550nm. To compensate for the losses an optical amplifier based on Bismuth based Erbium doped fiber (Bi-EDF) is used to boost up the signal power. This is required to initiate Brillouin scattering. The Bi:EDF is pumped by two 1480nm pump lasers operating at an output power of 50mW.

The total pumped power from both ends is 100mW. The length of the Bi:EDF used is 48.2cm with a dopant concentration of 6300ppm. The amplified spontaneous emission of this fiber-based optical amplifier is about 7.74dBm. The input signal at 1545nm is multiplexed with the pump power at 1480nm using a fused optical fiber wavelength division multiplexer, 1480/1550nm. The signal wavelength is then amplified by the Bismuth based optical amplifier giving at output power of 12dBm which is then taken out from another WDM demultiplex as shown in Figure 1. This signal is connected to port 1 of an optical circulator OC1 which is then emitted at port 2. It then travels into a 10km length of Truewave reach fiber (TWF) (Att: 0.09dB/km, cable cut off: 1171nm, MFD: 8.5µm, CCE: 0µm, clad: 124.9µm, dispersion slope: 0.04 ps/nm2/km for 1550nm) which acts as a nonlinear medium to generate the Brillouin Stokes. The generation of Brillouin Stokes depends on the power of the BP. The BP has to exceed the threshold power of SBS to convert the BP power into the Stokes output [10]. SBS threshold power is defined as in equation 1 [11] below,

$$P_{th} = \frac{21A_{eff}}{g_B L_{eff}}\left(1 + \frac{\Delta v_p}{\Delta v_B}\right) \text{, and} \tag{1}$$

$$L_{eff} = \frac{\left(1 - e^{-\alpha L}\right)}{\alpha} \tag{2}$$

where A_{eff} is the effective core area of the fiber, α is the fiber loss at 1550nm (dB/km), g_B is the peak Brillouin coefficient (g_B=4.5x10-11 m/mW), L_{eff} it the effective interaction length of the fiber, Δv_p is the line width of the pump and Δv_B is the Stokes wave linewidth. In this case the threshold power for TWF is 8.25dBm (A_{eff}=55μm2, L_{eff}=4.32km, Δv_p= 1885.93MHz, Δv_B=78MHz, α=0.20dB/km, L=10km). The BP power at 12dBm after amplification from Bi:EDF optical amplifier thus exceeds the threshold power of SBS for TWF. When the BP is launched into the TWF, the backscattered Brillouin Stokes is generated and rerouted back into OC1 and the spectrum is monitored at port 3 using an optical spectrum analyzer (OSA) which gives a peak power of Brillouin Stokes that is higher than that of BP.

The Brillouin Stokes then enters part B of the setup where it becomes BP1 at 1545.083nm with a peak power of -15dBm. This BP1 is then used to generate another SBS in the DCF. BP1 is launched into part B through port 1 of OC2 and then amplified by Erbium doped fiber (EDF) optical amplifier. The EDF is pumped by a 980nm pump laser operating at an output power of 80mW. The length of the EDF is 5 cm with a large absorption of 11.9 dB/m at 979nm and (Fibercore L-band fiber, DF1500L) with a dopant concentration of 3000ppm. The input signal of 1545.083nm (BP1) is multiplexed with the pump power at 980nm using a fused optical fiber wavelength division multiplexer 980/1550n. The BP1 is amplified by the EDFA and gives a measured output power of 2dBm. Calculating using equation 1, the threshold power to generate the SBS in DCF is approximately 5.56dBm (g_B=1.6x10-11 m/mW [9], A_{eff}=72μm^2, L_{eff}=7.136km, Δv_p=1560.02MHz, Δv_B=78MHz, α=0.02dB/km, L=7.7km), where unfortunately the peak power of BP1 after the amplification by the EDFA is still insufficient to achieve this threshold. Therefore, the Raman Pump (RP) 1440nm is required as a Raman fiber amplifier (RFA) to raise the power of the BP1 signal. The BP1 signal is multiplexed by 1440/1550nm WDM into the 7.7km DCF which is also pumped by a Raman pump with a power of 350mW at 1440nm. The RFA increases the BP1 by about 12dBm in DCF with a peak power of 12.8dBm.

The interaction between the BP1 and DCF creates Stokes and AntiStokes. The AntiStokes is generated through four-wave mixing (FWM) between BP1 and Stokes. This AntiStokes travels backward into EDFA to be amplified to a sufficient power before being analyzed by a spectrum analyzer (SA) and an optical spectrum analyzer (OSA). The signals are measured by an OSA and a SA at port 3 of the OC2. The power signal is split by 90/10 coupler with the 10% leg connected to an OSA and the 90% leg connected to a high speed photodetector. The purpose of connecting the 10% leg to an OSA is to prevent optical damages to the OSA which could be due to the large signal power of 10dBm measured using an optical power meter. In this experiment, a 20GHz high speed photodetector is used for determination of the Brillouin shift which is found to be 10GHz. To observe the frequency spectrum, the SA is connected to a high speed PD. The experimental results of the above measurements are presented and discussed below.

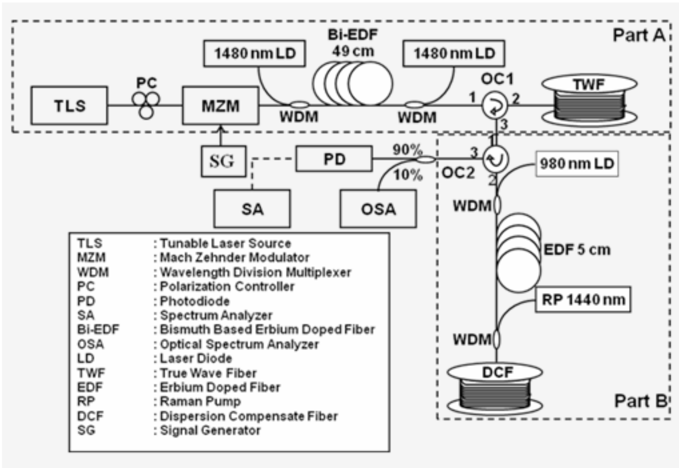


Figure 1 : Schematic diagram for microwave photonics signals conversion based BSB in optical fiber.

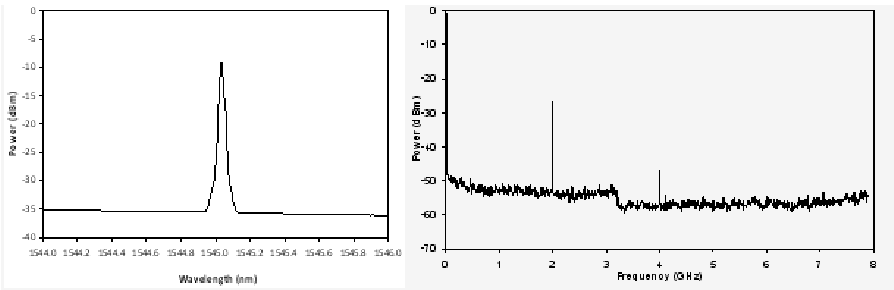


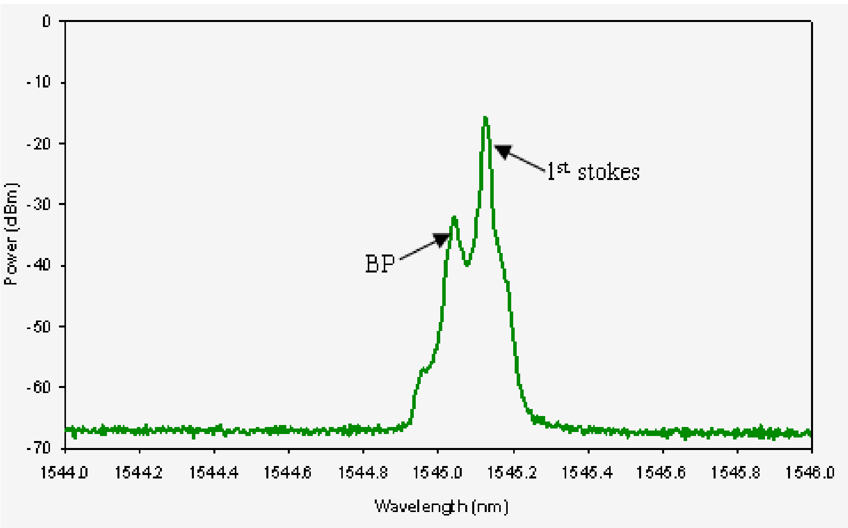
Figure 2 : The input signal and RF input spectrum for the BP pump.

3 RESULTS AND DISCUSSION

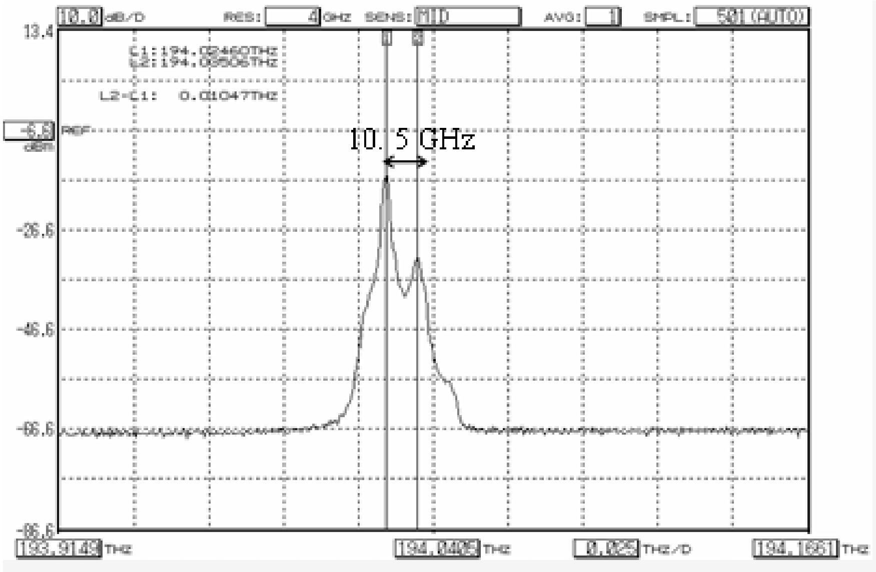
The results of the experimental section are presented in this section. In the Brillouin scattering process, the BP generates backscattered Stokes light through interaction with the acoustic wave. The power of Stokes light increases rapidly as the pump power increases. In the TWF, when the BP power of 12dBm exceeds the SBS threshold power of 8.25dBm, most of it is converted into 1st Stokes light as shown in Figure 3(a). The frequency of 1st Stoke light is downshifted by a given amount that corresponds with the acoustic phonon frequency, v_B which is called the Brillouin frequency shift. It can be described by the following equation 3 [10];

$$f_B = \frac{2nv_L}{\lambda} \tag{3}$$

where n is the refractive index of the core, v_L is the velocity of the acoustic wave in the fiber which is related to the elastic properties of the fiber medium. In this case, the value of Brillouin frequency shift for TWF is 11.3GHz (n=1.47, v_L=5.97x103, λ=1545nm). However, the Brillouin frequency shift of TWF from the measurement is 10.5GHz as shown in Figure 3(b). This is due to the different dopant concentrations of the fiber as reported by T. Horiguchi [12]. Therefore, it is necessary to know the dopant concentration dependence of the Brillouin frequency shift, but the specification of the optical fiber does not indicate the dopant concentration of TWF. Based on the Brillouin frequency shift measurement, the application in microwave photonics signal up conversion can be used when the BP is launched with RF frequency (f_{RF}) of 2GHz. The intermediate frequency (IF) of the signal ($f_{IF} = f_b + f_{RF}$=10.5+2) is 12.5GHz as is shown in Figure 4. However, the 12.5GHz signal disappears from the graph because of the limitation of the spectrum analyzer where the maximum range of the spectrum analyzer is 7.9 GHz. In this part, the 1st Stokes of the Brillouin fiber laser with an intermediate frequency of 12.5GHz operates as BP1.



(a)



(b)

Figure 3 : (a) The Brillouin spectrum of TWF (b) The Brillouin frequency shift of TWF.

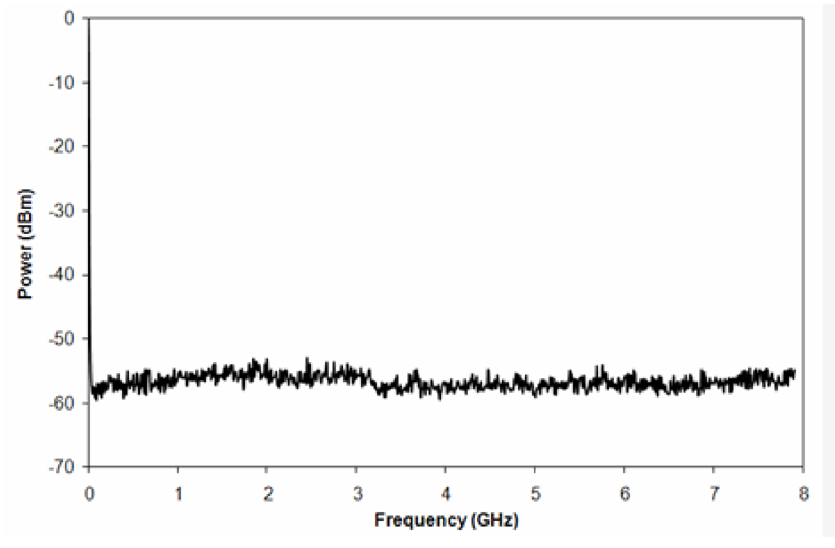
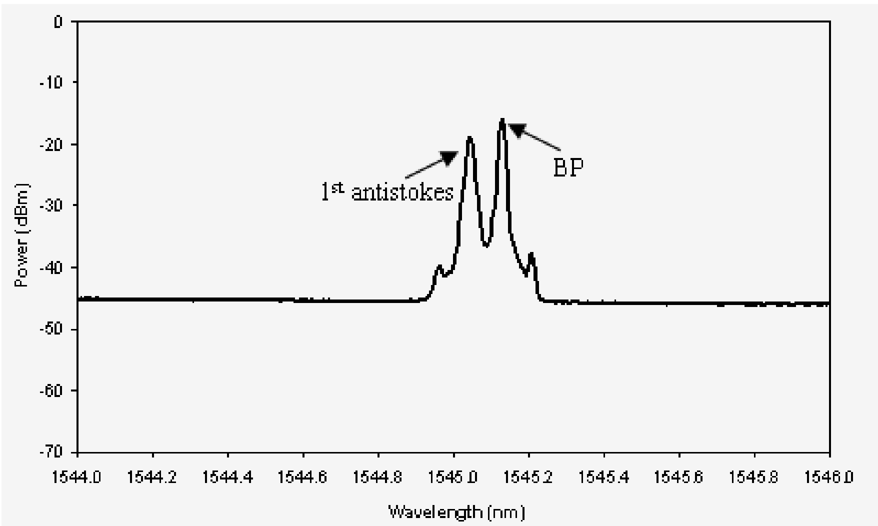
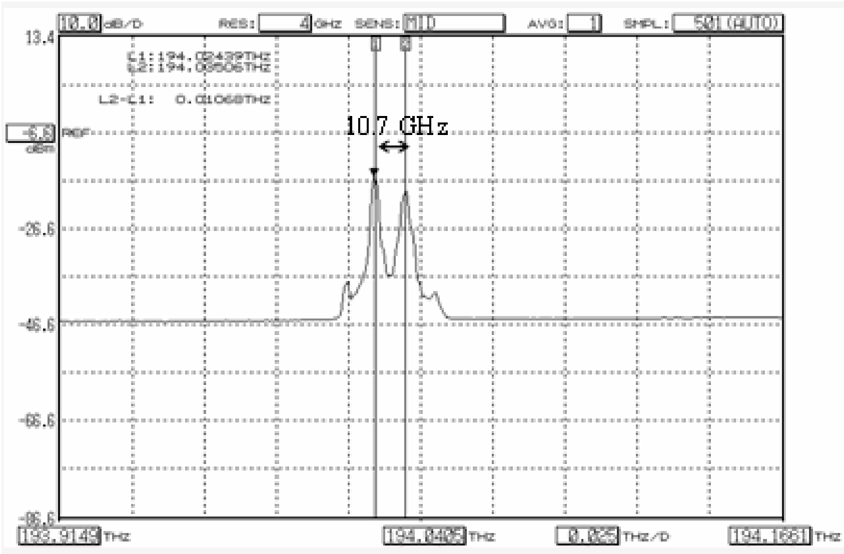


Figure 4 : The frequency spectrum of Brillouin fiber laser from SA of TWF.

This BP1 is used for generating the AntiStokes in part B where the DCF acts as the nonlinear medium. In this part, the threshold power of DCF is 5.56dBm which is less than BP1 power (12.8dBm), so, the Antistokes can be generated as shown in Figure 5(a). Another characteristic that should be of consideration in this experiment is the Brillouin frequency shift. Based on equation 2, the calculation of Brillouin frequency shift for DCF yields 11.4GHz (n=1.48, v_L=5.97x10^3, λ=1545nm) which is different from the SA measurement of 10.7GHz as is shown in Figure 5(b). As explained earlier this could be due to the dopant concentration in the fiber. Different fiber types will have different Brillouin frequency shifts. In order to generate the microwave down conversion, the BP1 with RF signal at 12.5GHz is needed to convert the signal (BP1) to 1st AntiStokes with an intermediate frequency ($f_{IF} = f_{RF}$-f_b = 12.5GHz-10.7GHz) of 1.8GHz with peak power at 32dBm as shown in Figure 6. The experimental results show that microwave photonics signal can be up and down-converted successfully by the two-frequency Brillouin laser. In our knowledge, this two-frequency Brillouin laser technique is first time demonstrated when the other technique from Y. Shen [13] is used ring configuration to generate the Brillouin laser in SMF for up and down converter application.



(a)



(b)

Figure 5 : (a) The brillouin spectrum of DCF (b) The Brillouin frequency shift of DCF

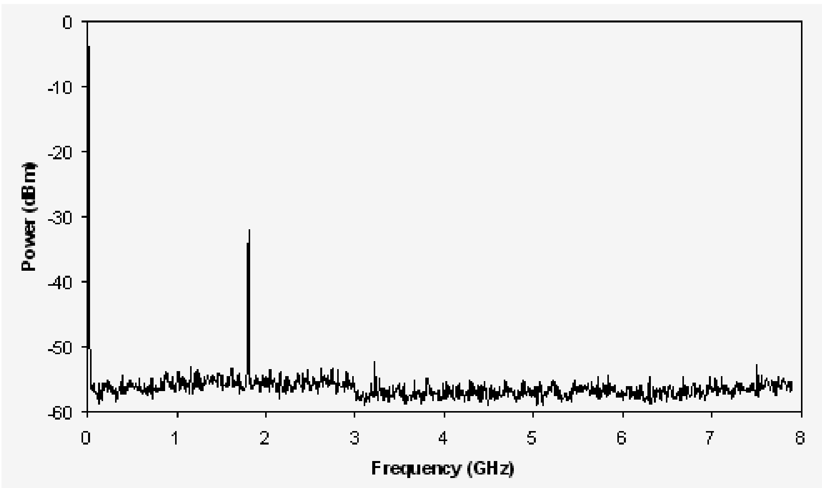


Figure 6 : The frequency conversion of DCF from SA.

4 CONCLUSION

The generation of frequency conversion for microwave photonics signal up and down conversion is realized using the Brillouin fiber laser based on SBS. A 2 GHz RF band signals is used to up convert the signal to 12.5 GHz (IF band signal) and the 12.5 GHz is used as RF band signal for down conversion to 1.8 GHz (IF bands signals) as demonstrated experimentally. This technique has potential applications in the area of radio over fiber (RoF) systems.

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