Journal of Engineering and Applied Sciences 12 (22): 5924-5928, 2017
ISSN: 1816-949X


# A Stimulated Brillouin Scattering Based Generation of Single Sideband-Suppressed Carrier (SSB-SC) Signal

Usha Thakur and Shaina
Department of Electronics and Communication, Chandigarh University, 140413 Gharaun, Punjab, India

**Abstract:** In this research, a new cost effective wavelength shifter has been proposed. A frequency shifter is demonstrated in this research to realize a shift of signals in the mm-wave region. Proposed technique provides a single sideband signal without the carrier signal due to the stimulated Brillouin scattering in optical fiber. Bandwidth efficiency of double sideband signals is less as compared to SSB-SC signal. The frequency shifter is all optical due to the fact that it uses a optical fiber's performance degrading issue such as SBS as a application. This generation of enhanced carrier power and single sideband is dependent on the Brillouin scattering and principle of gain and loss spectrum of SBS inside optical fiber is used to eliminate the up shifted frequency component and enhance the low shifter frequency component. A single sideband is obtained from SBS phenomenon which is useful in advance modulation formats and requires less bandwidth. It is noteworthy that SSB-SC signal is realized using all optical method and proposed work eliminates the necessary of non optical components such as 90° hybrid couplers. SSB-SC signals are well competent to combat with pulse broadening issues and have potential to work in terahertz frequency. To validate the performance of generated signal, transmission of SSB-SC signal is also presented. Moreover, SSB-SC, SSB with carrier, DSB-SC and DSB with carrier signals are compared in terms of Q-factor at varied link lengths.

**Key words:** SBS (Stimulated Brillouin Scattering), SSB (Single SideBand), DSB (Double SideBand), SMF (Single Mode Fiber), Q-factor, transmission

## INTRODUCTION

The future networks based on fiber optic technologies, intend significantly to boost the capacity or to pack more number of channels in the information transmission. Also data rates for each user should be high as the demand of high speed services increasing day by day (Buchkremer *et al*., 2000). A major and prominently used method is dense wavelength division multiplexing in optical fiber communication systems to augment the capacity of the users in mobile coverage wide area (Minasian *et al*., 2013). With this technology of multichannel transmission in the system, large number of users can be served due to distribution of radio heads. Recent advancement in microwave photonic technology as well as optical polarization multiplexing offers and give rise to the technology called Radio over Fiber (RoF). Near the beginning, existence of telecommunication applications such as Global Systems for Mobile (GSM) and GPRS can support less data rates (Chujo *et al*., 1999; Murata *et al*., 2006). On the other hand, in the today's world, to fulfil the demands of user, high capacity systems are needed, i.e., WiMax and WiMAN that uses capacity up to 1-10 Gbps with broad coverage region (Hisatake *et al*., 2012). However, rising figure of users will enforce boundaries to the information transfer. Solutions include dipping the cell dimension to put up additional users. This refers to as micro or pico-cells concept. The additional method is to employ novel bands of processes since the unlicensed ISM occurrence bands are previously crowded. Now, a lot of developers favour the millimeter-wave (mm-wave) as the novel group of operation. Optical frequency region of 40-90 GHz that offers higher bandwidth (Ogiso *et al*., 2010). Some other problems come into play by utilizing these solutions. More base stations are required if cell size reduces. Increasing the frequency, motivation contributes to additional equipments, fitting and preservation costs. The components that are used in all optical systems are able to combat with the issues in fiber optic transmission. In order to generate the mm-wave, the all optical systems offers wide shift and are well suited for the transmission of high data rates. This all optical method has several advantages are used in military, radio astronomy

**Corresponding Author:** Shaina, Department of Electronics and Communication, Chandigarh University, 140413 Gharaun, Punjab, India

(Frankel and Esman, 1998). Future communication networks need the frequency shifts in the mm wave range as well as the less emergence of spurious signals and more tuning capability, this is find as the tedious task by incorporating conventional mm-wave generation methods.

Optical approach or photonics can fulfil the requirements and expel the limitations by shifting operation of frequencies. The all optical approach is also offers the signals that shows better bandwidth efficiency and generate SSB signal with carrier. Generation of bandwidth efficient SSB signal in radio over fiber systems is an important method (Dabbagh and Raweshidy, 2016). There are several more fields that incorporate the all optical frequency shifter such as quantum measurements, spectroscopy and the wide frequency shifters. Due to numerous advantages, all optical mm-wave signal generation in RoF systems is need of a day.

In this research, a frequency shifter is proposed using all optical method in RoF system. The shifter is realized by incorporating the stimulated brillouin scattering that expel the need of any electrical hybrid coupler or components. The main work is to enhance the low frequency component employing gain spectrum and to eliminate up shifted frequency by loss spectrum of SBS. Also modulators used are biased at minimum point to get single sideband after SBS. Achieved advance signal, i.e., bandwidth efficient light signal is further transmitted over optical fiber to test its performance in terms of Q-factor and BER.

**Principle of SBS based frequency down converter:** Architecture is presented to generate the signal that has single sideband and carrier is also eliminated. In order to accomplish the generation of aforementioned signal, a stimulated Brillouin scattering is employed. To realize the SSB signal, two optical modulators are needed and an optical fiber is a root communication medium that introduces SBS. In detail discussion of SBS, it is presented that SBS has two very important phenomenon. Principle of SSB signal generation is that when the low power carrier signal enters in fiber optic, it produces the back scattered light called strokes wave and remaining signal travels to the same direction as it is intended to transmit. A new signal is also coupled to fiber optic from other end called counter direction and this signal is kept at high power. A high power signal delivers its gain to co directional signal as depicted in Fig. 1a and itself experience loss of power. Gain is experienced by the low power signal that is coupled from first intensity modulator and as a result, signal is moved to lower region of frequencies as illustrated in Fig. 1b. Consequently, a

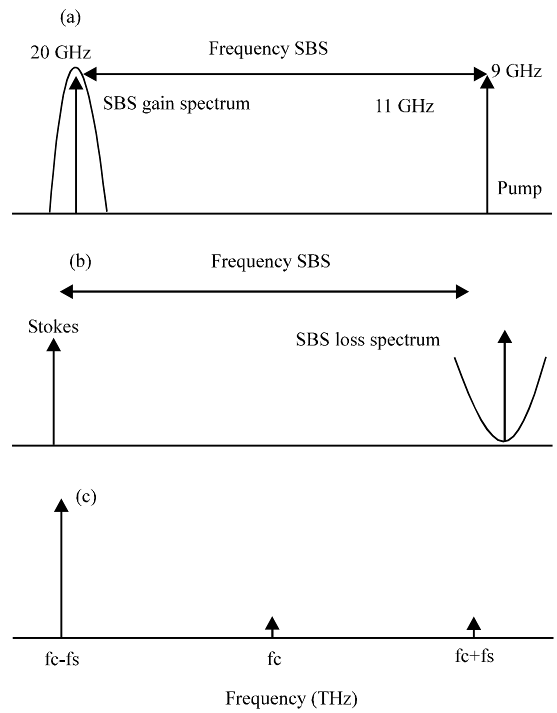


Fig. 1: SBS phenomenon based: a) gain spectrum; b) loss spectrum of strokes and pump waves inside optical fiber and c) output optical spectrum

lower frequency high power sideband is obtained and due to loss spectrum experienced by counter direction signal is eliminated or suppressed as represented in Fig. 1c. The proposed method is useful in numerous applications and has wide tenability range of mm-waves. This method of SBS is attractive and getting more attention due to the advantage that mm-waves shifts can takes place early at low launched powers.

Frequency generation tunning in mm-waves is considered to be extremely important such that there is generation of less spurious signal while tunning the shift. The signal power of generated signal can be controlled or regulated by various parameters such as the loop length, launched power and modulation index of intensity modulator. SBS is also used to generate double sidebands and single sidebands. In subcarrier multiplexing, SSB with enhanced carrier signal is needed so that the carrier signal to cater the downstream users and one sideband modulated to serve upstream central unit.

## MATERIALS AND METHODS

**System setup:** In order to realize the bandwidth efficient single sideband suppressed carrier signal, a simulation tool optisystem is used for analysis. In optical

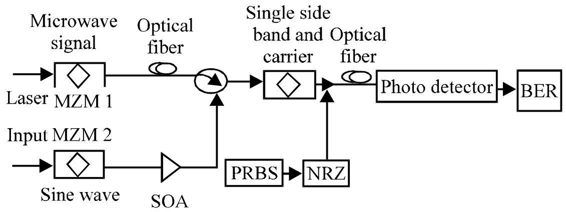


Fig. 2: System setup for single sideband generation and transmission over optical fiber

communication systems, laser is an important component and incorporated in the proposed architecture. Laser is operated in C band and emits the frequency of 193.1 THz. Drive of laser signal is modulated through modulator MZM and sine generator is place to generate RF signals. Modulated signal is suppressed carrier and double sideband signal due the MZM. MZM is biased at minimum point of operation. Two modulators are used and termed as upper MZM 1 and lower MZM 2. A 20 GHz sine generator frequency is provided to MZM 1 at launched power level of 0 dBm. To get a frequency shift, sine wave generator frequency in lower modulator is set to be 9 GHz. It is basically a difference of upper frequency (20 GHz) and Brillouin fixed shift (11 GHz). A semiconductor optical amplifier is low cost and monolithically integrated component for amplification of weak signals. SOA is incorporated in lower modulation process to boost the signal. Lower signal is at launched power (-20 dB), however, SOA amplify this to provide high power signal. Upper modulator signal is coupled to single mode fiber of link length 25 km in co-propagation direction and lower modulator signal is fed from counter direction. Co-propagation directional signal after travelling 8 km show SBS phenomenon, i.e., some part of signal reflected back (stokes wave) and rest move to the same direction in which it was sent by modulator 1. Counter directional signal provide signal power to stokes wave also called gain and after distributing the gain, counter directional signal itself carry the low power. Thus these signals initiate two phenomenon of loss spectrum and gain spectrum. Thus, signal at 193.11 THz due to SBS is suppressed and signal at 193.09 THz is enhanced (Fig. 2).

For the generation of enhanced SBS phenomenon, upper modulator is biased at null point with high extinction ratio and lower modulator is fixed at less ER. Optical circulator are placed to route the signal in n+1 directional port.

After generation of SSB-SC signal, it fed to Mach-Zehnder modulator stage after SBS for further communication and assessment of generated signal in terms of Q-factor and BER. Binary data generation in serial bits is generated from PRBS followed by NRZ pulse format. Modulated signal is transmitted over 100 km SMF. This system is unidirectional so operated in one direction by using frequency 193.09 THz due to SBS. It is received by using PIN photo-detector having 10 nA dark current followed by Bessel electrical filter to remove noises. A 3R regenerator is incorporated to resample retime and re amplify data. BER analyzer connected to regenerator to show eye diagram and also provide Q-factor and error rate.

## RESULTS AND DISCUSSION

For achieving the SBS in bidirectional Single Mode Fiber (SMF), two signals are given to optical fiber in opposite directions as shown in Fig. 3. It represents that signals emerged from two different modulators are carrier less and these carrier less signals are realized with null biased MZMs (Mach-Zehnder Modulators). Figure 3a depicts the optical spectrum of the signal after MZM 1 and (Fig. 3b) represents the signal after lower MZM modulator. These signals are given to optical fiber from opposite direction and due to the SBS effects, it provides single side band. Figure 4 depicts output signal from single mode fiber after the gain and loss spectrum. Single sideband signal at 193.09 THz is reported and also shows loss spectrum at upper frequency. Thus, the SSB-SC (Single Side Band-Suppressed Carrier) signal or also referred as advanced carrier is successfully realized from proposed system architecture.

Further, the evaluation of realized single sideband-suppressed carrier signal has been done and data from pseudo random bit sequence is modulated on the SSB-SC signal with NRZ and MZM modulator. Modulated signal is fed to transmission single mode fiber of different link lengths. SMF-28 is used for the transmission with attenuation 0.2 dB/km and dispersion 16.75 ps/nm/km. Optical fiber is operated in the C-band due to less losses and scattering effects. All the non-linear effects are considered to realize practical system. Different analysis are carried out to investigate the system such as at different distances with and without amplifier and comparison of SSB-SC, SSB with carrier, DSB-SC, DSB with carrier. Figure 5 depicts the performance of the SSB-SC signal over optical fiber at different link lengths in terms of Q-factor. It is noteworthy that as the distance enlargement takes place, Q-factor reduces due to attenuation and dispersion effects in SMF. It is also evident that the successful transmission of 90 km has been achieved over SMF at 1 Gbps with SSB-SC signal. Data rate 500 Mbps introduces less dispersion and superior results as compared to 1 Gbps rate.

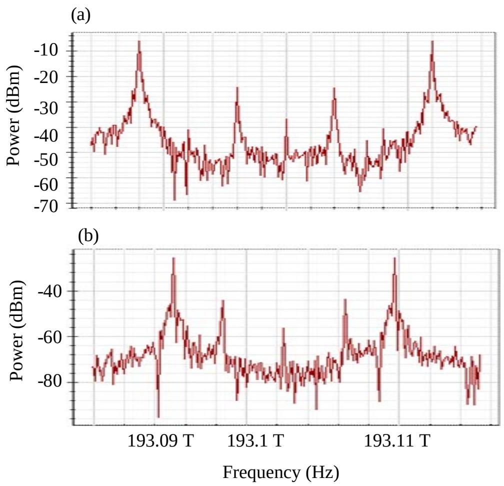


Fig. 3: Optical spectrums of two intensity modulators after: a) MZM 1 and b) MZM 2

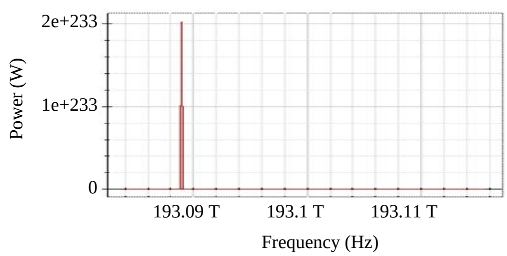


Fig. 4: Single sideband signal after SBS

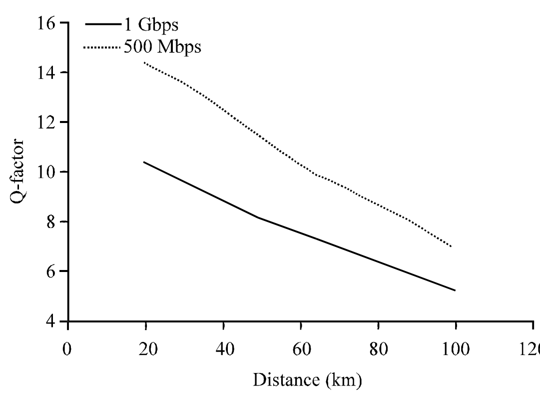


Fig. 5: Distance versus Q-factor of SSB-SC at different data rates

Further, investigation has been done of the system by incorporating semiconductor optical amplifier and without use in the after lower MZM2 signal. Input power of lower signal is kept at minimum (-20 dB), so, as to get maximum amplification from SOA. It is observed that at high launched powers, SOA introduce non-linear effects

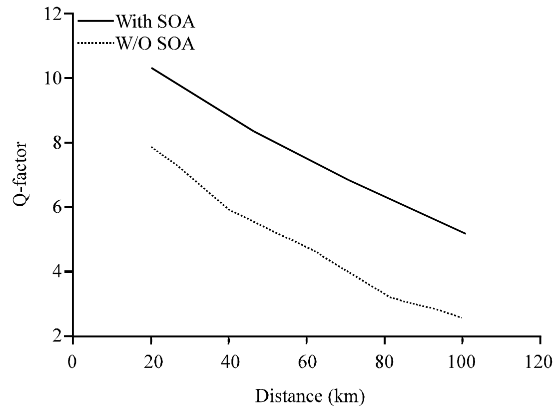


Fig. 6: Distance versus Q-factor with and without SOA

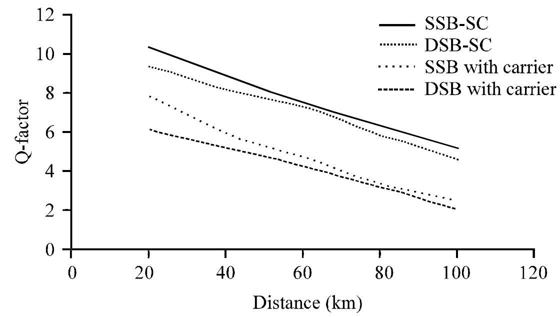


Fig. 7: Comparison of different signals after SBS at varied link lengths

in the system. Thus, degrade the performance of the system. Figure 6 depicts that when signal from lower MZM is fed to optical fiber with SOA, it exhibits better performance. However, without SOA, the generation of SSB-SC is difficult and also degrade the performance in terms of Q-factor.

Figure 7 depicts the performance of different signals after SBS and it is reported that single sideband-suppressed carrier signal transmission prolongs the distance and provides best performance as compared to double sideband-suppressed carrier, single sideband-suppressed carrier, double sideband with carrier signals. SSB-SC signal is comes out to be bandwidth efficient, thus provide better Q-factor. However, SSB with carrier signal is also bandwidth efficient and performance is lag behind SSB-SC signal to some extent. Double sideband with carrier signal is considered bandwidth inefficient and performs worst in this transmission. Figure 8 represents the eye diagram of the signal at 1 Gbps for 90 km distance and performance falls within the acceptable limits of BER ($10^{-9}$).

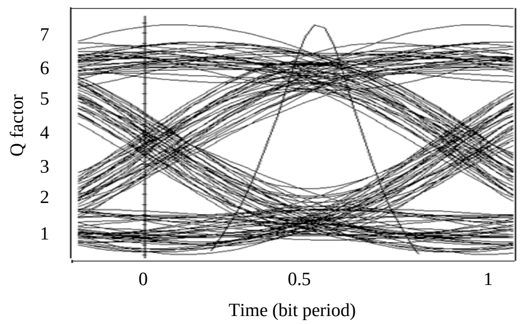


Fig. 8: Eye diagram of the SSB-SC signal after 90 km at 1 Gbps

## CONCLUSION

In this research, a new cost effective wavelength shifter has been proposed. A millimeter range, i.e., 30-300 GHz frequency shifter is demonstrated. All optical SBS generated SSB-SC signal is introduced to offer enhanced efficiency with respect to DSB with carrier signal over optical fiber. System is compared for different distances, with and without SOA amplifier and at different data rates. Results revealed that system act efficiently with SOA amplifier over different distances and at lower data rates due to less dispersion. This generation of enhanced carrier power and single sideband is reliant on the stimulated Brillouin which offers gain and loss spectrum in optical fiber to expel up shifted frequency component and to enhance low frequency component. Moreover, performance of the different signal generated signals form SBS such as SSB-SC, SSB with carrier, DSB-SC and DSB with carrier signal are also investigated in terms of Q-factor over single mode fiber at diverse distances. It is evident that SSB-SC is most bandwidth efficient and exhibits best performance and Q-factor. A single sideband is obtained from SBS phenomenon which is useful in advance modulation formats and requires less bandwidth.

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