A Novel Approach to Design a Bi-Directional Radio over Fiber SCM/ASK System for Future Generation Networks

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Abstract

Objective: The objective of this research paper is to design a bidirectional radio over fiber by utilizing the effect of stimulated brillouin scattering effect to provide better efficiency of the system. Methods: The core idea is to strengthen upper sideband and suppress lower sideband to realize single sideband suppressed with carrier present signal to provide capabilities for supporting radio over fiber systems. A novel frequency mover is proposed in which a dual directional sub carrier multiplexing is realized by characterizing the effect of stimulated brillouin scattering effect. The parameters are considered including the Bit Error Rate (BER) and Q-factor under acceptable range. Finding: It is found that the proposed approach describes the Sub Carrier Multiplexing (SCM) system along with the Special Broadcasting Scattering (SBS) provides better results than without considering the SBS generated signal over 10 to 40 km distance. The results for the same are compared and the applied technique is selected and the required quality for the optimal performance of the system is reported. Application/ Improvement: This approach can be applied for the future generation networks along with the use of modulated schemes like Quadrature Amplitude Modulator (QAM), Quadrature Phase Shift Keyed (QPSK) etc. Further improvements can be done by dispersion compensation in bidirectional Radio-Over-Fib (ROF).

Keywords: Stimulated Brillouin Scattering (SBS), Radio-Over-Fib (ROF)

1. Introduction

All optical photonics provide the ways to overcome the drawbacks exist in optical communication field. Its advantages consisting of high speed and extended wide area and range which incorporated in various fields such as military, radio-astronomy and radio over fiber systems are intended to provide immunity to interference. Next generation systems require shifting of frequencies to mm-wave region with low false signals and adjustable abilities, which are important and difficult, work with conventional approaches. Photonics can overcome these drawbacks by moving one frequency to more or less frequency. It is also useful to provide single sideband along with carrier, which plays important role in radio over fiber systems. More application areas Such as spectroscopy, quantum measurements and Optics need frequency moving or shifting operations of several Gigahertz. Therefore all optical frequency mover that can work in mm-wave range is required. So far, reported approaches based on acousto-optic has been carried out, however current work incorporating all optical field. It is observed from prior researches that acoustic optic is suffered to low frequency range. Different techniques such as Sagnac loop interferometer and dual drive Mach–Zehnder Modulator (MZM) required 90 degree hybrid coupler which are not all optical and cannot operate at wide frequency ranges. In case of Sagnac loop operations, very low signal to noise is observed and provide false signals which are undesired. Recently, mm-wave generation has been proposed employing dual drive Machzhender modulator to get high signal to noise ratio and maximum shift
of 9GHz has been reported\(^2\). Systems and techniques based on all optics is reported in previous researches, but limited to very less signal to noise ratio\(^{14}\). In best of our survey and knowledge, all these requirements are not solved by any frequency shifter\(^{11,12}\). To fulfill the everlasting needs of internet and data, all optical radio over fiber system is required. RoF provide solution in best possible ways to meet the desire of customer as they could give the wide bandwidth for the communication\(^{14}\). Subcarrier multiplexing is a system to transmit multiple signals in radio frequency region over optical carrier signal\(^{14}\). Other researches related to improvement in this field have also been analyzed\(^{15-22}\). To meet the future demands, all optical SBS generated single sideband and strengthened carrier is needed.

In this paper, all optical stimulated brillouin scattering based new frequency convertor or shifter is introduced for radio over fiber systems. The core idea is to strengthen upper sideband and suppress lower sideband to realize single sideband suppressed with carrier present signal to provide capabilities for supporting radio over fiber systems. This work does not include any electrical module to generate single sideband and enhanced carrier signal for mm-wave generation. Comparison has been made of all optical signal generation and electrical generated signal over radio over fiber systems in terms of performance and error rates. The rest of the paper is organized as follows: the working principle of SBS based single side band with the carrier wave is explained in section 2. The setup of proposed model is described in section 3. Section 4 is followed by results and discussions. Section 5 summarizes the conclusion.

2. **Principle of SBS based Single Side and with Carrier Signal**

All optical frequency shifter structure for generating optical single sideband along with carrier is represented. It is realized on SBS phenomenon from an optical fiber along with two intensity modulators. Stimulated brillouin scattering is very important effect in medium such as optical fiber. Mainly two effects exist in this method. Stimulated brillouin scattering is very important effect in medium such as optical fiber. Mainly two effects exist in this method. When a high power microwave signal is fed into maximum point operated modulator, carrier signals as well as sidebands are generated as shown in Figure 1. High power signal sent to optical fiber, which generate stokes wave in backward direction and rest of the signal to forward direction. Another signal of less power fed to optical fiber from counter direction, which ultimately receives gain from first signal. Brillouin gain is shifted to upper frequency due to brillouin shift introduced by SBS. As a result of this, lower shifted spectrum experience the loss and suppressed as compared to up shifted frequency. The ease of using the SBS makes it acceptable because it can be attained even at low powers. The continuous wave light is split into two signals with the help of an power splitter and both signals fed to peak point biased optical modulator. The output of both the transmitters have carrier along with sidebands. When a high power microwave signal is fed into maximum point operated modulator, a carrier signal as well as sidebands is generated. High power signal sent to optical fiber, which generate stokes wave in backward direction and rest of the signal to forward direction. Another signal of less power fed to optical fiber from counter direction, which ultimately receives gain from first signal as sown in Figure 2. Brillouin gain is shifted to upper frequency due to brillouin shift introduced by SBS. As a result of this, lower shifted spectrum experience the loss and suppressed as compared to up shifted frequency. SBS is all-optical which means that it can operate and be tuned over extremely wide micro-wave and millimeter-wave bandwidths. Benefits of SBS are make it popular because it can be achieved early even at low powers. In this work, the continuous wave light is split into two signals with the help of an power splitter and both signals fed to peak point biased optical modulator. The output of both the transmitters have carrier along with sidebands. The first modulator introduces as top modulator which receive signal from radio frequency and operated at fixed frequency close to required shift. Second modulator is driven by frequency equal to difference between required shift and SBS frequency of optical fiber. Single sideband along with carrier modulation signal after the top and bottom modulator is referred to as the high power microwave signal and another sine wave for the SBS process respectively. The amplitude of upper modulator and other modulator controlled by input launched power as no amplifier is used in this work. Need of amplifier is eliminated by launching required power from laser source. Two optical signals are fed into bidirectional optical fiber in opposite directions to generate stokes wave and amplification of rest of the wave.
Ultimately these signals give rise to two phenomenon of loss signal and gain spectrum. The sideband at lower frequency is experience loss because it transfer its energy to counter propagating signal. Similarly, counter propagating signal experience gain and enhanced along with carrier signal. This represents that frequency of signal up shifted by stimulated scattering of bottom modulator and introduce frequency up shifting operations.

The amplitude of the frequency shifted light can be controlled by the system parameters such as the modulation index and the optical fiber length. This generated signal is required for subcarrier multiplexing. One center frequency is used for downstream and another sideband utilized for upstream data transmission in radio over fiber systems.

3. System Architecture

To initialize the radio over fiber system, carrier along with single sideband is required as sown in system setup 2. For getting this signal two MZM modulators are used operated at peak point. A sine wave generator at frequency 20GHz is used at high power of 10dBm to up shift the spectrum to 193.11GHz from 193.1GHz. Both modulators biased at peak point. So that spectrum includes carrier as well as sidebands. Second modulator is operated at low power 0dBm. A sine wave generator at 9GHz give drive to it. MZM1 signal is fed into optical fiber from one side and MZM2 signal from opposite side. MZM1 signal experience SBS due to its high power and some part of signal reflected back called strokes signal. MZM2 signal experience less SBS due to low power and experience gain from other signal. Now MZM1 signal give gain spectrum to MZM2 wave and experience gain at 193.11 and loss at 193.09THz. To generate more SBS mzm1 is operated at high extinction ratio and for receiving gain mzm2 operated at low extinction ratio. Here both signals are fed into fiber with the help of optical circulator. Optical circulator works on the principle of n+1 formula. Now generated signal due to SBS is given to radio over fiber system to eliminate requirement of electrical coupler and other electrical components. A PRBS is used to generate random bits and give derive to amplitude modulator. Amplitude Modulator implements an analog amplitude modulator which mix data signal with analog wave. This signal is mixed with subcarrier signal and external radio signal and given to MZM for optical conversion. Now signal transmit over optical fiber of 20 Km through optical circulator. This system is bi directional so operated in both directions as shown in Figure 3. In one direction (downstream) by using frequency at 193.1THz and for other direction using up shifted frequency of 193.11 THz due to SBS. A carrier signal 193.1 THz is filtered by fiber brag grating in receiver section of downstream. After reflecting signal from FBG, it is received by using photo detector for radio wave and amplitude demodulator for data signal. A radio frequency analyzer is incorporated to show radio output and bit error rate analyzer for data signal quality. Now, signal at 193.11 THz is transmitted back for upstream communication with help of fiber brag grating. Data is modulated on amplifier sideband and given to optical fiber. At output port of bidirectional fiber, optical frequency is filtered by Bessel filter centered at 193.11THz and bit error test has been done here.
4. Results and Analysis

For achieving the SBS, two signals are given to optical fiber in opposite directions as shown in Figure 4. These signals are given to optical fiber from opposite direction and with the help of SBS give single side band enhanced carrier signal.

![Figure 4. System setup for (b) SCM ASK](image)

After optical fiber signal is received and radio frequency analyzed with the help of RF analyzer as shown in Figure 4. Optical signal is modulated by data and radio signal and transmitted over bidirectional optical fiber without using any amplifier. Another data signal received by amplitude demodulator and performance analyzed by Bit Error Rate (BER) analyzer after 20Km. Similarly data is modulated on 193.11 THz and received with the help of optical filter and BER analyzer. The optical spectrum of two intensity modulators namely Machzhender modulator 1 and Machzhender modulator 2 have been shown in Figure 5. After the effect of SBS the lower shifted band is suppressed and the up shifted sideband frequency of 193.11 THz is generated along with the carrier having frequency 193.1. In Figure 6, RF frequency is analyzed at the receiver side to make the system reliable. Comparison has been done between current work and without SBS generated setup in case of subcarrier multiplexing. It has been done for different link distance such as 10Km, 20Km, 30Km and 40 Km for both directions as shown in Figure 7. Graphical representation clearly reveal that system of subcarrier modulation give enhanced output for all optical single sideband and carrier signal for both upstream and downstream. BER diagrams for upstream and downstream with SBS generated signal with Q factor 10.6 and 6.36 is depicted in Figure 8. Table 1 depicts simulation parameters for bidirectional RoF SCM- Amplitude-Shift Keying (ASK) system.

![Figure 5. Optical spectrum of two intensity modulators after (a) Machzhender modulator 1 (b) Machzhender modulator 2 (c) After SBS](image)
Figure 6. Radio frequency at receiver

Figure 7. Graphical representation for (a) with and without SBS for downstream (b) with and without SBS for upstream

Figure 8. Eye diagram at receiver after 20 Km for (a) downstream and (b) upstream

Table 1. Simulation parameters for bi-directional ROF SCM/ASK system

| Parameters          | Values |
|---------------------|--------|
| Laser Frequency     | 193.1THz |
| Data Rate           | 10Gbps |
| RF signal           | 20GHz |
| Gain                | 20 dB |
| Power(EDFA)         | 10 dBm |
| Sequence Length     | 128 bits |
| Sample Per Bit      | 32 |
| Photo detector      | PIN |
| Responsivity        | 0.9A/W |
| Dark current        | 10Na |
| Length              | 20 km |
| Reference Wavelength | 1550 nm |
5. Conclusion

The first ever time a dual directional subcarrier multiplexing is realized using stimulated brillouin scattering. A Novel frequency mover is proposed that can move signal in millimeter range from 30GHz to 300 GHz. All optical SBS generated single sideband along with carrier is introduced to provide better efficiency with respect to conventional radio over fiber systems. It is observed that SCM system with SBS provide better results than without SBS generated signal over 10 to 40 Km distance. This generated more power carrier and single sideband based on the SBS, which provide gain spectrum and loss spectrum in single mode fiber to suppress downshifted sideband and to strengthen up shifted sideband. SBS generation is based on all optical components which eliminates requirement of electrical components in subcarrier multiplexing and give better signal to noise ratio. These generated single sideband along with carrier signals are able to work at even high frequency ranges.

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