MILLIMETER WAVES GENERATION USING STIMULATED BRILLOUIN SCATTERING

Norizan M. Nawawi and Sevia M. Idrus

Photonic Technology Centre, Faculty of Electrical Engineering,

Universiti Teknologi Malaysia

ABSTRACT The millimeter-wave (mm-wave) range has the highest potential for future data carrier because it is currently uncluttered and can support high data bandwidth. To ease system complexity in such systems there is growing interest in the exploitation of photonic technologies for the distribution of the mm-waves from a central station to a number of base stations via optical fiber links known as fiber-based wireless access scheme using radio-over-fiber (RoF) technology. Several techniques have been proposed for the optical generation of mm-waves such as direct modulation, external modulation, optical heterodyning and so on. However, in this work we proposed and investigate an alternative to above mention methods, which is based on Stimulated Brillouin Scattering (SBS) in an optical fiber. SBS technique was designed and modeled by performing CW laser in a single mode optical fiber (SMF) through optical Mach-Zehnder modulator (MZM) with two pump lasers for amplification purposes. The analysis was done by determination of the generated power depletion. SBS performance with the optical fiber loop length up to 100km was analyzed. It has been shown that SBS power is depends on the fiber loop length which is higher and lower at certain length due to natural properties of the fiber. The simulated design system has shown that the RF carrier generation can be achieved up to 40 GHz

1. INTRODUCTION

Over the past decade there has been substantial progress in the areas of wireless and optical communications. The driving force behind this advancement has been the growing demand for multimedia services, and hence broadband access. Present consumers are no longer interested in the underlying technology; they simply need reliable and cost effective communication systems that can support anytime, anywhere, any media they want. As a result, broadband radio links will become more prevalent in today's communication systems. Furthermore, new wireless subscribers are signing up at an increasing rate demanding more capacity while the radio spectrum is limited. To satisfy this increasing demand, the high capacity of optical networks should be integrated with the flexibility of radio networks. This leads us to the discussion on the fiber-based wireless access scheme using RoF technology.

RoF is an hybrid system that having both a fiber optic link and free-space radio path. Such system is important in a number of applications, including mobile communications, wireless local area networks (LANs), and wireless local loop, etc. However, the growing demand for higher data rates in wireless communication systems requires new frequency bands. RoF system has attracted considerable attention to deliver microwave and millimeter wave signals. It is a system that distributes the radio waveform directly from CS to BS through optical fiber (X. N. Fernando and S. Z. Pinter, 2005). There are some techniques have been proposed for the optical generation of mm-waves, (Lin Chen, Hong Wen, and Shuangchun Wen, 2006). One of the simplest methods is the modulation of continuous-wave (CW) laser light by an external modulator is expensive and there are several problems with the group velocity dispersion of the optical transmission systems. Other methods rely on the optical transport of modulated carriers at intermediate frequencies and optical heterodyne techniques. For the first method the mm-wave signal is generated by upconversion in the base station. This requires a high-quality local oscillator or an optically-supported phase-locked loop in the base station. The second method suffers from phase differences between the two superimposed optical signals. To overcome this phenomenon rather complicated setups have been proposed by (T. Schneider, M. Junker and D. Hannover, 2004).

In a RoF link, laser light is modulated by a radio signal and transported over an optical fiber medium. The laser modulation is analog since the radio-frequency carrier signal is an analog signal. The modulation may occur at the radio signal frequency or at some intermediate frequency if frequency conversion is utilized. The basic configuration of an analog fiber optic link consists of a bi-directional interface containing the analog laser transmitter and photodiode receiver located at a base station or remote antenna unit, paired with an analog laser transmitter and photodiode receiver located at a radio processing unit. One or more optical fibers connect the remote antenna unit to the central processing location.

ROF systems of nowadays, are designed to perform added radio-system functionalities besides transportation and mobility functions. These functions include data modulation, signal processing, and frequency conversion (up and down) (Gliese U., Nielsen T. N., Norskov S., and Stubkjaer K. E., 1998; and Fuster J. M., Marti J., Candelas P., Martinez F.J., Sempere L., 2001).

For a multifunctional ROF system, the required electrical signal at the input of the ROF system depends on the ROF technology and the functionality desired. The electrical signal may be baseband data, modulated IF, or the actual modulated RF signal to be distributed. The electrical signal is used to modulate the optical source. The resulting optical signal is then carried over the optical fiber link to the remote station. Here, the data is converted back into electrical form by the photodetector. The generated electrical signal must meet the specifications required by the wireless application be it GSM, UMTS, wireless LAN or other.

2. STIMULATED BRILLOUIN SCATTERING

SBS stands for *Stimulated Brillouin Scattering* and it is a natural problem for high laser power in long fibers. If there is high laser power with a narrow linewidth along the fiber, the SBS effect causes much light to be reflected. This limits the power that can be transmitted and makes the signal noisy. Therefore SBS is an issue for optical transmitters in optical networks and for instruments that test components or systems with long fibers. Such tests can include measuring the power budget of an amplified or unamplified transmission span, or testing Raman amplifier configurations. Fibers exhibiting SBS at power levels of interest to telecommunications are usually at least several kilometers in length, but this depends on the type of fiber.

The origin of SBS lies in the backscattering of signal light by acoustic waves in the optical material, which is weak in short fibers. The backscattered light is shifted to lower optical frequency (higher wavelength) by the Brillouin-shift frequency, which depends on the fiber material. For common single-mode silica fiber, the shift is about 11 GHz (0.09 nm at 1550 nm). The backscattered light in a fiber can then stimulate more of the forward traveling light to be backscattered. When there is enough signal power, the backscattered light can gain more power by this stimulated backscattering than it loses due to fiber attenuation. When the fiber is long enough, the backscattered power keeps increasing along the fiber in an avalanche like process and can take most of the input optical power.

2.1 Principle of SBS

SBS is a nonlinear effect due to the amount of light backscattered and the amount of light transmitted by the fiber does not depend linearly on the power input to the fiber. At low input powers the backscattering is dominated by simple Brillouin and Rayleigh scattering which are linear and differ from each other by the Brillouin shift. But as the power is increased, the Brillouin scattered light is increasingly amplified by the stimulation process. At a power level called the *SBS* threshold, the amount of backscattered light increases very rapidly with increasing input power until it constitutes most of the input light. The transmitted power at the fiber output saturates at a level that barely increases with increased input power. For single-mode fiber, SMF, of lengths above 10 km, the SBS threshold can lie in the range of 6 - 10 dBm. Above this threshold, the insertion loss of the fiber is not independent of input power.

2.2 SBS System Model

Figure 1 illustrates the system block diagram of SBS technique developed in this project. The technique was designed and modeled by performing CW laser in a single mode optical fiber (SMF) through optical Mach-Zehnder modulator (MZM) with two pump lasers for amplification purposes. MZM is nonlinear modulator that capable for generation of sidebands. These sidebands will be amplified by SBS in a fiber loop, whereas the rest will be attenuated due to natural attenuation in the fiber. Electrical generator was used to drive the MZM at certain frequency carrier. Circulator has been selected to circulate the signal from coupler and the output signal of SBS fiber loop. The amplified sidebands are then superimposed in PIN-photodiode which is the easiest way to generate mm-wave.

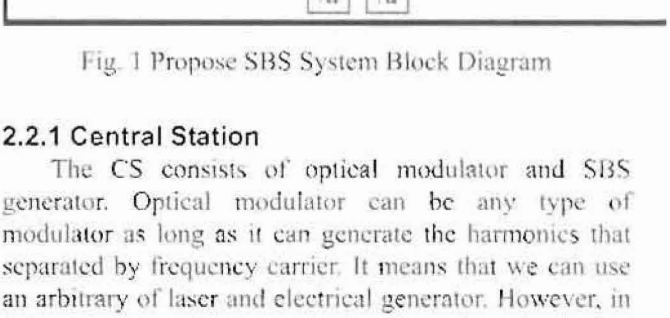


Fig. 1 Propose SBS System Block Diagram

2.2.1 Central Station

The CS consists of optical modulator and SBS generator. Optical modulator can be any type of modulator as long as it can generate the harmonics that separated by frequency carrier. It means that we can use an arbitrary of laser and electrical generator. However, in this particular project, we stated to investigate the design using the CW laser and an intensity modulator (IM).

2.2.2 Optical Modulator

The optical modulator consists of a CW laser, an intensity modulator (IM), an electrical drive signal operating at a frequency, f_m, and the data to be transported. The drive signal is used to sweep the optical frequency of the CW laser resulting in a peak-to-peak optical frequency deviation. To generate an un-modulated microwave or millimeter-wave carrier at the BS, this swept optical signal is fed directly into the SBS fiber loop. Otherwise, the swept optical signal is fed into an IM such as the Mach Zehnder Modulator (MZM), where it is intensity modulated before being distributed by the fiber network. In this case, the signal laser directly generates sidebands of the modulation signal due to its nonlinear characteristic line. These sidebands can be amplified by the SBS in optical fiber.

2.2.3 SBS Generator

The output of optical modulator is fed into the SBS generator where the SBS amplifications and up-conversions were occurred. Pump lasers were used to amplify the selected sidebands produced by MZM by control the frequencies of these pump lasers. The three ports circulator will circulate the signal from port 1 (output from the coupler) into the port 2, and the signal from port 2 into port 3. Using ideal circulator, we can control the insertion loss to be zero and there is no return loss or ideal isolation. The two frequency components from the output of circulator are then be superimposed in photodiode which is one of the easiest way for generating mm-waves.

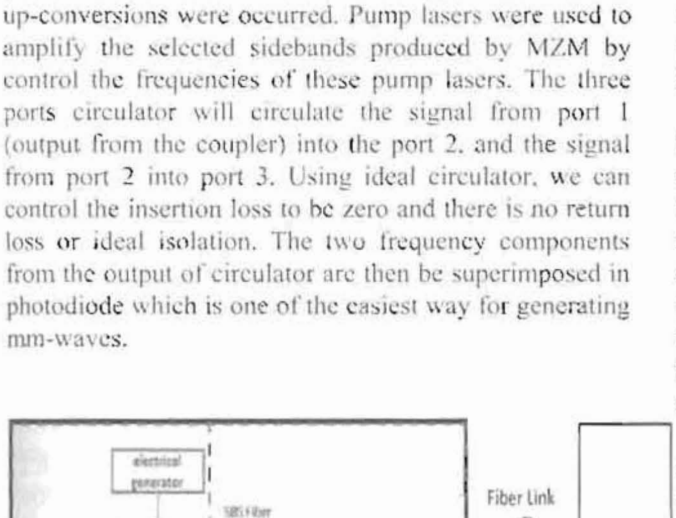


Fig. 2 SBS System Integrated With ROF Link.

3. RESULTS AND DISCUSSION

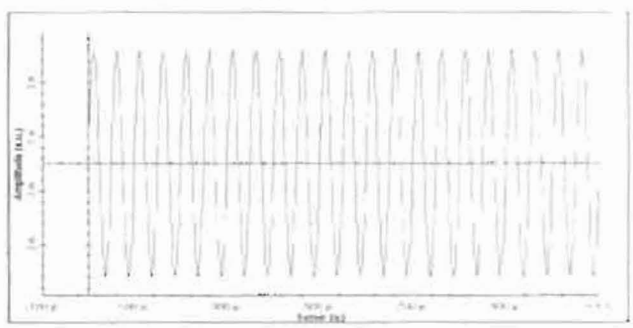
The generation of mm-waves for RoF system using SBS technique shown in Figure 1 was model and simulated using a commercial optical system simulator by Optiwave. The MZM is driven by the electrical sine generator in analog domain working with a fixed frequency: f_{RF} = 10 GHz. A 0.5 dBm light wave emitted from continuous wave (CW) laser at 1550 nm from a narrowband linewidth of 1 MHz is modulated by MZM. The voltage that is applied on the MZM is high enough so that the laser wave is modulated nonlinearly with the frequency of the electrical generator. Several optical sidebands separated by f_{RF} from the optical carrier are generated by MZM nonlinearity. These signals are injected into up to 100 km long of standard single mode optical fiber (SSMF) loop.

The pump source generates a combined output signal of two pump lasers. This pump source is injected into SSMF via an optical circulator and propagates at the opposite direction of the modulated signals. The wavelength of each pump laser is adjusted in the manner of 11GHz higher than one of the frequencies in the modulated signal. The power of signal wave is controlled by an EDFA. SBS relies on the generation of sidebands of CW laser by nonlinear modulation these two sidebands will be amplified by SBS in an optical fiber, whereas the rest will be attenuated due to natural attenuation in the fiber. The millimeter-wave band output signal is detected by a photodiode (PD).

The frequency of the millimeter-wave depends on the RF of the electrical generator and on the sidebands that were chosen for amplification. The generated millimeter-wave has the frequency of $f_{mm}=2nf$, with n as the number of the sideband used and f as the RF of the electrical generator. With f= 10 GHz, millimeter-waves with frequencies of 20, 40, 60, . . . GHz are possible. If the frequency of the generator is f = 5 GHz, output frequencies of 10, 20, 30, . . . GHz can be produced, and so on.

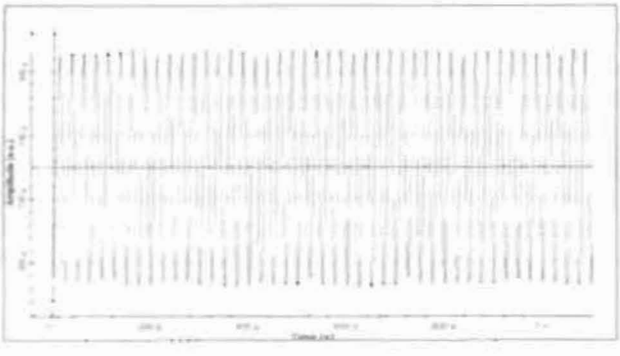
Figure 3 presents the signals pattern of the first and second stokes with 10 GHz modulation at 0.5 dBm light wave for 50 km SSMF loop length, measured after PD in time domain. Oscilloscope visualizer was used to display the time plot of the generated electrical signal. Bandpass rectangular filter (BPF) is used to centre of the desired stoke components results in electrical signals of regular intensity patterns. It is clear that the only difference between signal patterns at 20 GHz and 40 GHz (apart from frequency) is the amplitude (a.u). The amplitude of higher stokes was decreased from 4 mV to about 350μm. This confirms that apart from the fundamental frequency, the higher order stokes may also be used to transmit data.

RF 20 GHz (Rectangular BPF 1.5*Bit Bate Hz)



(a)

RF 40 GHz (Rectangular BPF 1.5*Bit Bate Hz)



(b)

Fig. 3 The signals pattern with 10 GHz modulation at 0.5 dBm light wave for 50 km SSMF loop length. (a) The 20 GHz bandpass filtered electrical signal in time domain; (b) The 40 GHz bandpass filtered electrical signal in time domain.

Figure 4 represents the performance analysis when varies the SSMF loop length within range 1 km until 100km with optical amplifier. In term of power intensities, the amplifier was boosted up the power up to 0dBm at 20km for the first stoke. As can be seen, the first stokes has higher intensity compared to second stoke. It also shows that the SBS effect was started occur at 10 km and then will degraded the power intensities in longer fiber.

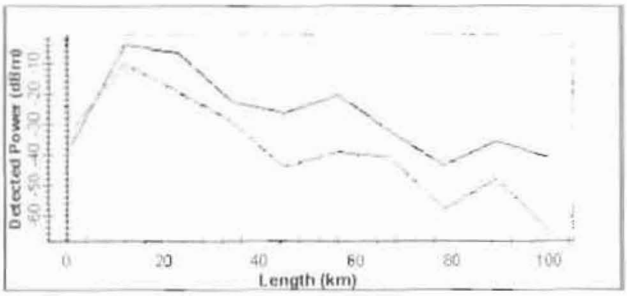


Fig 4 Comparing intensities of first and second stokes generated by sine generator with amplifier.

CONCLUSION

Stimulated Brillouin Scattering (SBS) is a nonlinear effect in an optical fiber due to the amount of light backscattered, and the amount of light transmitted by the fiber, does not depend linearly on the power input to the fiber. In this paper, SBS is used as a method for the tunable generation of mm-waves for RoF. We have demonstrated the generation of mm-waves for RoF system using SBS in SSMF. The proposed technique is necessary for any electrical generator frequency other than 10 GHz. Simulation results have demonstrated that the designed SBS technique for RoF system has a potential to generate high mm-waves. A 0.5 dBm of light wave is carried by 10 GHz RF signal were successfully generated up to 40 GHz millimeter-wave band corresponding to the 2^{nd} stokes. Test the design using an arbitrary wave generator for optimum power performance may be a future work for this paper.

REFERENCES

X. N. Fernando and S. Z. Pinter. "Radio over Fiber for Broadband Wireless Access", *Department of Electrical and Computer Engineering, Ryerson University, Toronto, Canada*, 2005.

Lin Chen, Hong Wen, and Shuangchun Wen, "A Radio-Over-Fiber System with a Novel Scheme for Millimeter-Wave Generation and Wavelength Reuse for Up-Link Connection" *IEEE Photonics Technology Letters*, Vol. 18, No. 19, October 1, 2006.

T. Schneider, M. Junker and D. Hannover, "Generation of millimetre-wave signals by stimulated Brillouin scattering for radio over fibre systems", Vol. 40, Nov. 2004.

Gliese U., Nielsen T. N., Norskov S., and Stubkjaer K. E. : "Multifunction Fibre-Optic Microwave Links Based on Remote Heterodyne Detection": IEEE Trans. On Microwave theory and Techniques, Vol. 46, No. 5, May 1998.

Fuster J. M., Marti J., Candelas P., Martinez F.J., Sempere L., "Optical Generation of Electrical Modulation Formats", in *Proceedings of the 27th European Conference on Optical Communication 2001 (ECOC'01)*, Amsterdam, Sept. 30 - Oct. 4, 2001, pp 536-537.

Stephen Z. Pinter and Xavier N. Fernand, "Fiber-Wireless Solution for Broadband Multimedia Access", *IEEE Canadian Review - Summer 2005*, pp. 6-9, 2005.

Norizan M. Nawawi received B.E.E. and M.E.E. both from UTM in 2007 and 2008 respectively. She joint Universiti Malaysia Perlis as a lecturer in July 2008. Her main research area is related to optical fiber communication technology.

Sevia M. Idrus is the Deputy Director of the Photonics Technology Centre, Universiti Teknologi Malaysia. She received B.E.E and M.Eng. both from the UTM. She obtained her PhD in Optical Communication System from University Of Warwick in 2004. Her main research areas are optoelectronic devices, radio over fiber system, optical transceiver design and optical wireless communication.