All optical millimeter-wave signal generation and transmission for radio over fiber (RoF) link

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ABSTRACT

Fiber-based wireless system has become a promising solution as a cost-effective communication and it offers high capacity network with millimeter-wave (mm-wave) signal transmission. The system significantly offers superior possible bandwidths for both fiber and free-space applications. Hence, with the increased capacity as well as wireless mobile network applications particularly at mm-wave signal, radio over fiber (RoF) technology is the utmost option. Nevertheless, when high frequency signal transmission is involved, power fading or dispersion effect limits the performance of RoF link. Therefore, this work proposed a RoF system by integrating remote optical local oscillator (LO) with frequency up-conversion at the base station (BS). All optical mm-wave signals are generated and transmitted for the RoF link. The effects of the changes of fiber loop length, optical power of the continuous wave (CW) optical laser carrier and responsivity value of the p-i-n photodiode (PD) mainly at 40 GHz are investigated and the power fading effects are discussed.

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1. INTRODUCTION

Currently, increasing number of users and requirement of high speed and high date rate exclusively for wireless communication system is undeniable. Therefore, in order to deliver such services over a radio link, a broader spectrum of radio frequency is required. As a result the radio link should use higher frequency carriers due to the spectrum congestion at lower frequencies. Therefore, a lot of research works have been reported and optical mm-wave signal generation has become a leading technique in radio over fiber (RoF) system [1-7]. Mm-wave signal generation techniques that are not only limited in RoF have also been proposed by number of works with different techniques including the use of stabilized mode-locked laser diode [8], employing frequency-quadrupling phase-locked optoelectronic oscillator [9], using a frequency-tunable optoelectronic oscillator [10], polarization multiplexing [2-3], exploiting the nonlinearity of the Mach-Zehnder modulator (MZM) [11] with carrier suppressed frequency eightfold [4], as well as by using the stimulated Brillouin scattering (SBS) [12-14]. In spite of that, RoF offers flexibility to the wireless access networks and ultimately increase the capacity and mobility of optical networks. Integration of optical and wireless networks is a promising technique especially in reducing costs in the access network. Due to the benefits compromises by RoF network specifically in reducing the complexity at the base station and ability of frequency sharing, therefore, in this work the concept of RoF is employed.

Three major RoF system architectures have been reported for commercial in-building wireless deployments [8, 15-16]. They are radio frequency (RF) transmission over fiber, intermediate frequency (IF) transmission over fiber and digitized IF transmission over fiber. The most general configuration is an RF transmission over fiber because it is uncomplicated and more cost-effective in terms of design implementation. Nevertheless, it is vulnerable to fiber chromatic dispersion and power fading effect that affects the transmission distance [17-20] and frequency generation above 40 GHz is still a huge challenge in RoF system. Additionally, power fading effect usually limits the mm-wave RoF system performance mainly during signal transmission through the link [21-24]. Therefore, this work proposes a system that is capable to reduce the dispersion effect that usually limits the mm-wave RoF system performance, in which the frequency up-conversion is done at the base station (BS). The integration between the all optical signal generation based on stimulated Brillouin scattering (SBS) technique and the frequency up-conversion seemed to be more practical by omitting the necessity of local oscillator (LO) at the BS.

This paper presents detail description on the modeling and simulation of LO signal generation at frequency of 40 GHz. The simulation was carried out by considering the important parameters setting that are stated clearly. The simulated system model is discussed in Section 2. Later, the results and performance analysis of the simulation are discussed in Section 3 of this paper by taking into account the effect of changing and varying some of the parameters which are the SBS fiber loop length, the optical carrier power of the CW laser and the effect of different responsivity, R value of the p-i-n PD, particularly at frequency of 40GHz. Finally, conclusion of the modeling and simulation of the signal generation is given in Section 4.

2. THE PROPOSED SYSTEM

The simulation model of optical signal generation based on SBS technique is done by considering the advantages of the nonlinear effect and low input power requirement in SBS. The optical signal is generated as a result of the SBS stokes generation. The optical signal has been generated at four different frequencies; 10 GHz, 20 GHz, 30 GHz and 40 GHz. However, only the generated signal at 40 GHz is discussed. The front-end optical receiver utilizing remote optical local oscillator for RoF system proposed in [21] is referred. The proposed system focuses only on the downlink transmission of the system. Hence, the signal is transmitting from the CS to the BS and finally sent to the end-users wirelessly. The IF block of the system represents the modulated intermediate frequency signal that carries the baseband data. In this work, IF signal is simply generated using direct signal generator. While the LO block as shown in Figure 1 represents the LO signal that will be sending remotely to the BS. This LO signal is generated using SBS technique and will be further explained in this section. The parameters setting of the simulation model can be referred in [21] as tabulated in Table 1. Three key parameters investigated in this study are the CW laser input power, the SBS fiber loop length and the responsivity, R of the p-i-n PD. Power fading for mm-wave signal transmission related to these three parameters with different configurations will be discussed.

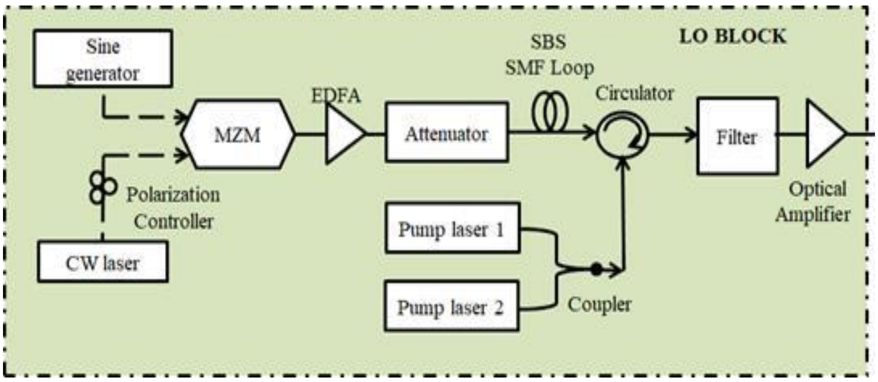

Figure 1. Block diagram of the SBS configuration

The simulated system model consists of an optical input power and an electrical signal with frequency of 10 GHz which was modulated by the Mach–Zehnder modulator (MZM). MZM generates harmonics or sidebands when the modulation takes effect. The optical spectrum consists of several spectral lines spaced by the frequency of 10 GHz. In this work, the sine electrical wave generator with frequency of 10 GHz was chosen since we were only interested with the optical generated frequencies in the range of 10 to 40 GHz. Moreover, it can simplify the computation of the gain in the 10 GHz.

Table 1. Parameters Setting of SBS Simulation Model

Parameters	Values
Bit rate	10 Gbps
Time window	1.28e-0.08 s
Sample rate	640 GHz
Sequence length	128 Bits
Sample per bit	64
Optical Power of CW laser	-30 to 10 dBm
Wavelength frequency of CW laser	1552.52 nm
Linewidth of CW laser	1 MHz
Frequency of Sine Generator, f_{LO}	10 GHz
Frequency of Pump Laser 1 (PL1)	193.09 THz
Frequency of Pump Laser 2 (PL2)	193.11 THz
Responsivity, *R* of the *p-i-n* PD	0.1 to 1.0 A/W
EDFA length	5 m
Optical Fiber Loop Length	1 to 50 km
Dispersion of Optical Fiber	17 ps/nm/km
Attenuation of Optical Fiber	0.2 dB/km
Brillouin Gain, g_B	4.6e-11 m/W

The PL1 and PL2 of the pump lasers used in this circuit model were assigned to wavelength frequencies of 193.09 THz and 193.11 THz respectively. The output spectrum of the coupled signals was then fed to the circulator for the SBS to happen. The output spectrum of the circulator consists of both counter- propagating signals and the amplified modulated signal from the MZM. In an attempt to generate and deliver only the desired frequency signal, hence two types of filters were used during the simulation, which are the inverted rectangle optical filter and the rectangle optical filter. Optical signals obtained from the circulator output port were first filtered by the inverted rectangle optical filter followed by the rectangle optical filter. At frequency of 40 GHz, bandwidth of both inverted and non-inverted rectangular optical filters are set accordingly in order to get only the desired frequency signal. In the setting, the second stoke of both lower and upper sidebands were selected for the generation of the 40 GHz signal. The filtered optical signal was then amplified by an optical amplifier before it was delivered to the receiver through another single-mode fiber (SMF). At the receiver, the optical signal was then detected by a p-i-n PD.

3. PERFORMANCE ANALYSIS AND DISCUSSIONS

This section discusses on the performance of the proposed system particularly in the generation of 40 GHz LO signal. The power fading effects at 40 GHz at different parameters setting of SBS fiber loop length, different optical power of the CW optical laser carrier and responsivity value of the p-i-n PD are discussed and explained. The optical spectrum of the inverted rectangle optical filter and 40 GHz generated RF spectrum detected at the p-i-n PD is depicted in Figure 2. The filtered signal was amplified by an optical amplifier and conveyed to the receiver side. The 40 GHz detected signal was directly sent to the receiver without any filtering since the signal was sent without any harmonics. Through the simulation, it was found that the detected power of the 40 GHz signal was lower than the detected power of lower frequencies. It was proven that the higher the generated frequency, the lower the output power that will be detected.

For the signal transmission mainly for RoF link, the transmission of 40 GHz through the link was observed. By considering the effect of different optical fiber loop lengths, Figure 3 shows the detected output power of 40 GHz generated signal at different optical input power of CW laser in the function of fiber loop length. The SBS fiber loop length was varied between 1 to 50 km and the optical amplifier gain was set to be at 20 dB. While, at the receiver, the responsivity, R of the p-i-n PD was fixed at 0.8 A/W. The detected signal shows more nonlinear at all input power values due to the nonlinearity effects of the SMF especially at higher frequency. The nonlinearity was emerged at about 10 km to 25 km of the optical length before the signal started to decreased slowly. The fiber loop was about 16 km when the output signal was at the peak. With that, the best fiber loop length for the SBS model to generate the optical signal is between 10 km to 25 km with the maximum value at about 16 km. The longer the transmissions distance, the lower the output power at the BS.

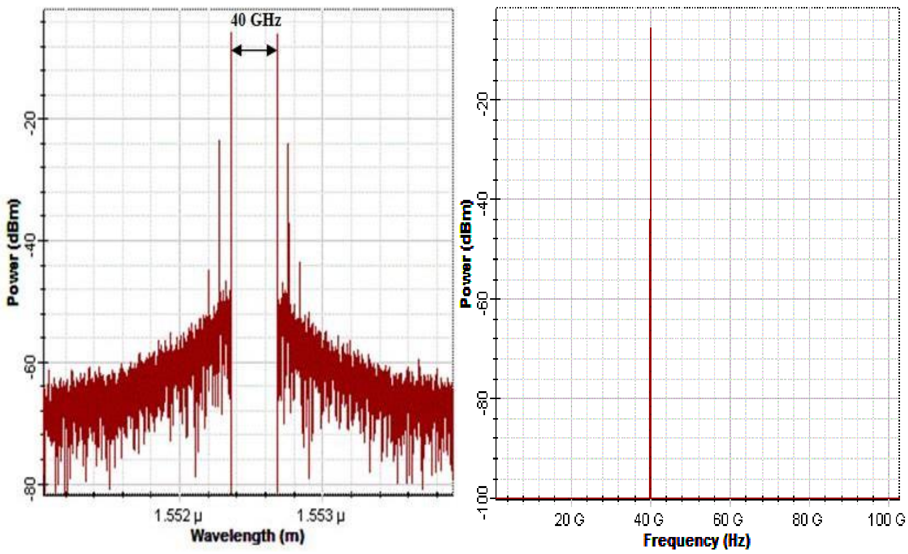

Figure 2. Optical spectrum of the inverted rectangle optical filter at 40 GHz frequency signal (left) and 40 GHz generated RF spectrum detected at the p-i-n PD (right)

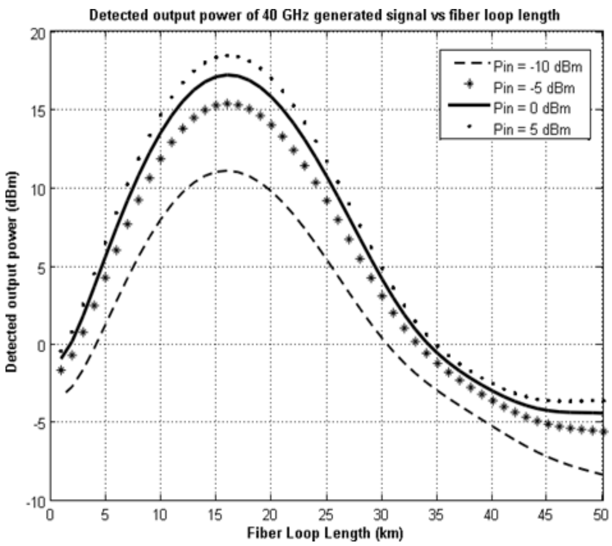

Figure 3. Detected output power of 40 GHz generated signal at different optical input power of CW laser in the function of fiber loop length

Figure 4 shows the detected output power of 40 GHz generated signal at different responsivity in the function of optical carrier power. In the meantime, all the parameters setting are as listed in Table 1 excluding for the SBS fiber loop length which was set at 25 km. The responsivity of the PD was changed to 0.6, 0.8 and 1.0 A/W. The figure exhibits the output power level at three different values of the responsivity of the PD. It was found that the output power level was increased linearly from -30 dBm of input power until it achieved about -10 dBm. Then, the power level was keep on increasing from up to 10 dBm but in a very slow mode such that they were reaching a stable and steady state. As can be seen, the output power has actually decreased at a certain proportion. When 40 GHz signal was generated at 0 dBm of input power, the detected power has decreased to about 34.7%. Furthermore, in the range of -12 dBm to -4 dBm, the output signal almost constant. Therefore, for this SBS setting and configuration, the maximum optical carrier input power that possibly be utilized is about -4 dBm. Higher input power is inefficient as the effect to the output power level is very small and can be neglected. The input power in most devices is controlled at a certain extent. Higher input power might cause damage to the device.

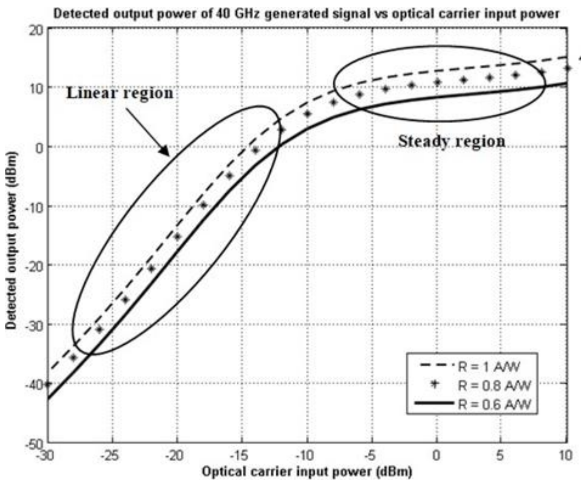

Figure 4. Detected output power of 40 GHz generated signal at different responsivity in the function of optical carrier power

Responsivity value of the photodetector also contributes to an important role during the photodetection of the generated signal. Responsivity and quantum efficiency, are the main characteristics of a PD which contribute to the sensitivity of an optical receiver. It is where the minimum input power is required for the receiver for optimum operation. The SBS fiber loop length is predetermined at 25 km as well as the wavelength of the CW laser still remained at 1552.52 nm. The optical carrier power level is set at -10, -5, 0 and 5 dBm while the optical amplifier gain is retained at 20 dB.

In Figure 5, it shows the detected output power of 10 GHz generated signal at different optical input power of CW laser in the function of responsivity of p-i-n PD. When the input power levels were increased, the output power levels remained constant even though the responsivity values were changed. Moreover, as the responsivity values of the PD are increasing, the detected output power has increased at a certain proportion. Referring to Figure 6, when input power was set at -10 dBm, the output power was extremely increased at about 128.7% as the responsivity changed from 0.1 A/W to 0.2 A/W. Conversely, from 0.2 A/W to 0.3 A/W, the output power was increased at about 32.9%, while from 0.3 A/W to 0.4 A/W, the increment percentage is about 17.6% and so on. It was found that as the responsivity increases, the increment rate is decreasing. Therefore, from the figure, it was proven that the responsivity of a typical p-i-n PD was in the appropriate region which in between 0.6 A/W to 0.9 A/W. The trend shows very small increment in the detected power level within the region. It was expected that the increment remains unchanged as the responsivity increases.

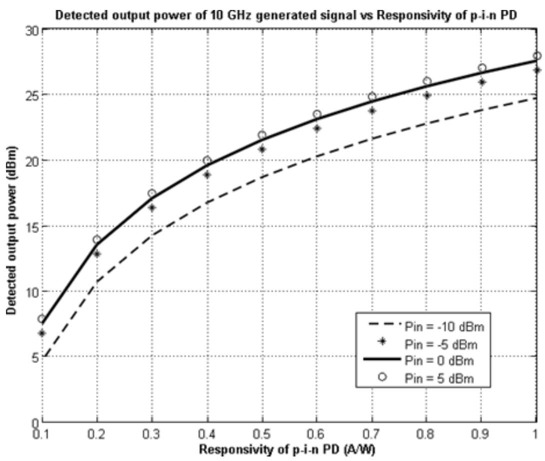

Figure 5. Detected output power of 10 GHz generated signal at different optical input power of CW laser in the function of responsivity of p-i-n PD

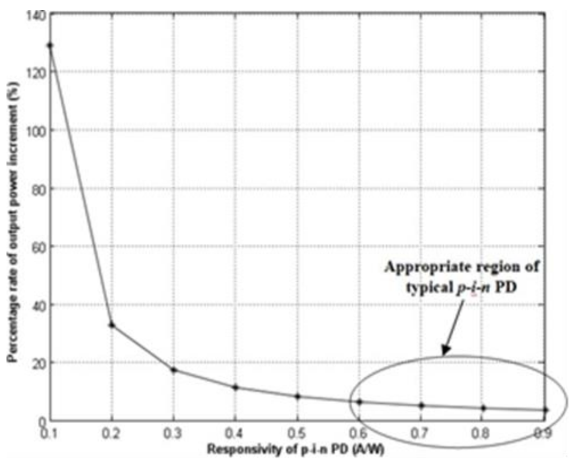

Figure 6. Percentage rate of output power increment at 10 GHz generated signal in the function of responsivity of p-i-n PD

4. CONCLUSION

This paper has presented the simulation model of signal generation based on SBS technique. The simulation was carried out by considering the key parameters setting which were the optical carrier power of the CW laser, the length of the SBS fiber loop and the responsivity, R of the p-i-n PD, particularly at 40 GHz while the other parameters were remained constant. It was found that when high frequency signal transmission is involved, power fading occurred hence, limits the performance of RoF link. For the SBS fiber loop length, the output signal was at the peak which at about 16 km. The optimum fiber loop length that can be used in generating the optical signal based on the SBS technique of the model are in the range of 10 km to 25 km. In addition, at 0 dBm of input power the detected power decreased to about 34.7% when the 40 GHz signals were generated. It was observed that the higher the frequency, the lower the detected output power proportionate to the optical carrier input power. Due to the variation of the responsivity of the p-i-n PD, it was found that as the responsivity increases, the increment rate of detected output power is decreasing. It was proven that the responsivity of a typical p-i-n PD was in the appropriate region that was between 0.6 A/W to 0.9 A/W where the trend exhibited very small increment at the detected power level. Ultimately, it is concluded that all optical signal generation based on SBS technique has been established in mm-wave band by the simulation and optimum configuration setting which was obtained from the simulation has been validated through the experimental demonstration that is not mentioned in this report. The significant of this work shown that the proposed system has simplified the BS by omitting the necessity of the LO at the BS particularly in RoF implementation.

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