30-GHz millimeter-wave carrier generation with single sideband modulation based on stimulated Brillouin scattering*

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Abstract: A new technique to generate a millimeter (mm)-wave carrier of 32.57 GHz ($f_{LO} = 10.85$ GHz) with single sideband modulation (SSB) for radio-over-fiber (RoF) systems is experimentally demonstrated by using stimulated Brillouin scattering (SBS). The SSB is realized by directly amplifying the +3rd sideband of the modulated optical carrier in the process of SBS. The pump wave is provided through a double Brillouin scattering frequency shifting configuration. The use of the same laser source to generate the pump wave ensures the stability of the mm-wave generation system since the relative frequency shift between them can be eliminated. In addition, the mm-wave carrier obtains an RF power gain of 21 dB with the SBS amplification and a 3-dB bandwidth of 10 kHz.

Key words: radio-over-fiber; millimeter wave generation; stimulated Brillouin scattering; single sideband modulation

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1. Introduction

Due to the explosive demand for high-speed data transmission in wireless communication, millimeter-wave bands could be widely used for broadband wireless access networks in future. Due to its high attenuation in air, using an optical method to generate and transmit a millimeter-wave signal has become the most promising solution to achieve low loss, wide bandwidth and high robustness of its anti-interference ability[1, 2].

Various techniques to generate an mm-wave carrier via the optical method have been investigated, including optical heterodyne of two individual lasers, and direct and external double sideband modulation[3–5]. In order to avoid dispersion-induced power deviation, optical mm-wave generators for single sideband signals are demonstrated[6–8]. However, within these methods, we are still facing the challenge to generate an mm-wave with high efficiency and good frequency stabilities.

In recent years, a new method of selective sideband Brillouin amplification (SSBA) induced by stimulated Brillouin scattering (SBS)[9–11] has been proposed to generate a millimeter-wave carrier[12–15] , which is one of the nonlinear effects in silica-based single-mode fiber (SMF) performing a stable frequency shift of typically 10–11 GHz at the wavelength of 1550 nm. This method seems to be promising to overcome the problems of frequency excursion and dispersion-induced deviation.

In this work, a new technique to generate an mm-wave carrier of 32.57 GHz with single sideband modulation is experimentally demonstrated by using stimulated Brillouin scattering. In our method, the +3rd sideband of the optical carrier modulated by intensive local RF source at 10.85 GHz is directly amplified in the SBS process to realize single sideband modulation. While the pump wave for SBS is obtained through a configuration that performs double Brillouin scattering[16]. The same laser source is used to generate the pump wave, which ensures the stability of the mm-wave generation system since the relative frequency shift between them can be eliminated. In our experiment, a stable mm-wave signal is successfully generated with high efficiency and good performance, which obtains an RF power gain of 21 dB and a rather narrow bandwidth of 10 kHz.

2. Experiment setup

Figure 1(a) shows our experimental setup for demonstration of the new approach to the generation of a millimeter-wave carrier. The whole system mainly comprises four parts: a single tunable laser source (TL), a configuration for generating frequency-shifted light as an SBS pump (lower arm), SBS amplification (upper arm) and a set of measuring devices.

Figure 1(b) presents the transformation of the optical spectrum through the experimental system.

The output of a tunable laser (TL, Agilent 81949A) is divided into two paths with a coupler. The upper optical path (6 dBm) was modulated by a Mach–Zehnder modulator to generate higher harmonic sidebands (up to the order of 6) and was sent into a 25 km SMF. The optical polarization is controlled by a polarization controller (PC). The MZM is driven by a continuous wave source at 10.85 GHz from a vector network analysis (VNA, Agilent 8722ET), which is amplified to 22 dBm with an

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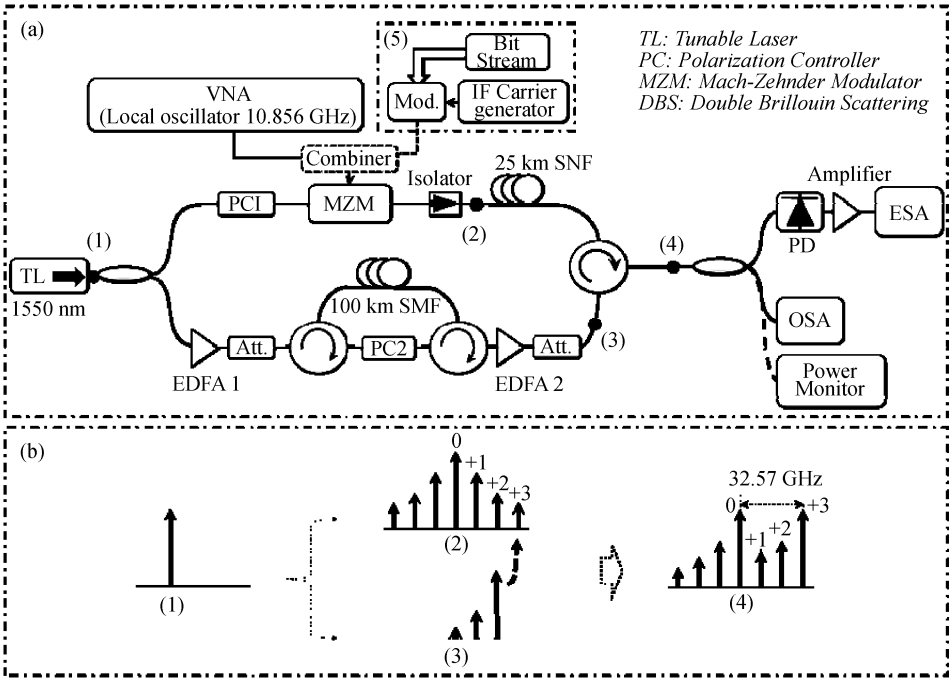

Fig. 1. (a) Schematic diagram of the experimental system. (b) Sketch maps of the optical spectra at corresponding positions marked by 1, 2, 3, 4.

external amplifier. The lower optical path is amplified up to 20 dBm by an EDFA and injected into a configuration made of 100 km SMF and two circulators shown in Fig. 1(A), and then reversely pumped into the 25 km SMF by using another circulator. In the configuration, we insert another PC between the two circulators to investigate the influence of polarization.

The output signal from the last circulator is divided into two optical paths through another coupler. One is detected by a high-speed photodetector (PD, New Focus) with 45-GHz bandwidth and a 40-GHz electronic spectrum analyzer (ESA, Advantest R3182) for characterizing the performance of generated mm-wave signal, while the other is detected by an optical spectrum analyzer (OSA, Advantest Q8384).

3. Results and discussion

We characterize the optical spectrum at different positions (2, 3, 4, as shown in Fig. 1) via OSA and adjust several parameters, such as local oscillating source power, electronic bias of MZM and optical power, to obtain the suitable operating points. Through experiment, we compare the performance of the received signals with and without the SBS process in 25 km SMF by switching on and off the pump wave due to double Brillouin scattering in the lower arm of our experimental system.

Figure 2 shows the output optical spectrum of double Brillouin scattering configuration which induces a 21.7 GHz frequency shift. It indicates that the second Brillouin scattering light (BS2) is larger than the first one (BS1) by over 24 dB. BP denotes the residual Brillouin scattering pump wave out of the configuration. The light is amplified to around 6 dBm via another EDFA and used as the SBS pumping source. During our experiment, we find that optical polarization affects the double Brillouin scattering process obviously. When the first reverse Brillouin scattering light has the same polarization with the pumping source, we get stronger BS2 and higher suppression of BS1.

By switching on and off the pump wave due to double Brillouin scattering occurring in the lower arm, we measure the output spectra of system with SBS amplification (solid line) and without SBS amplification (dotted line), which is shown in Fig. 3.

The result shows that the +3rd sideband is amplified by 13.9 dB and larger than –3rd by over 15 dB. It heterodynes with the main band in the photodiode and generates an mm-wave carrier at 32.57 GHz

Figure 4 presents the spectrum (span of 5 GHz) of the corresponding generated mm-wave carrier with and without the SBS process. It indicates that the mm-wave power with SBS amplification is improved by over 21 dB than that without SBS. The inset in Fig. 4(b) shows a more elaborate spectrum in a span of 500 kHz. The 3-dB bandwidth is 10 kHz, nearly the same as with local RF source according to our measurement.

Compared to those traditional methods, our solution for mm-wave carrier generation has the following advantages.

(1) Stable frequency. The frequency of the local oscillating source is set to 10.8565 GHz and the generated mm-wave carrier exactly at 32.5696 GHz ($f_{\mathrm{mm}} = 3f_{\mathrm{LO}}$) is measured. Moreover, via the ESA, we find that the stability of measured frequency remains the level of ± 10 kHz throughout the experiment for over 6 hours at normal temperature.

(2) Narrower bandwidth. The phase of the optical sideband is highly related to that of the main band. The heterodyning between them could generate a narrow-bandwidth mm-wave carrier. The result shows that the bandwidth is narrowed down to a kHz level as compared to MHz level by heterodyning two individual lasers.

(3) Lower frequency of local oscillator source and high

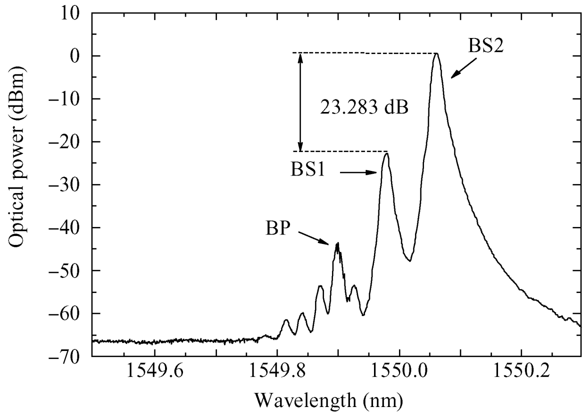

Fig. 2. Spectrum of the light after double Brillouin scattering frequency shifting.

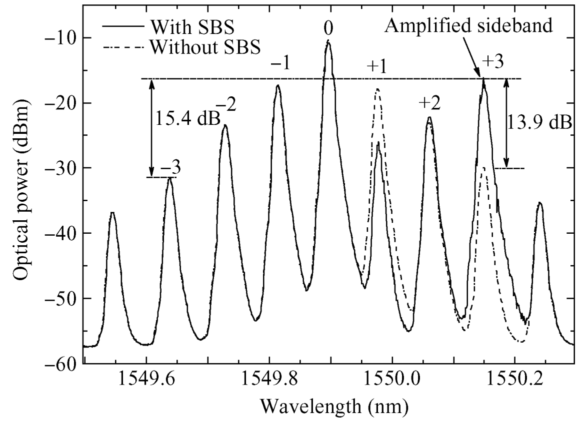

Fig. 3. Spectra with and without stimulated Brillouin scattering (SBS) amplification.

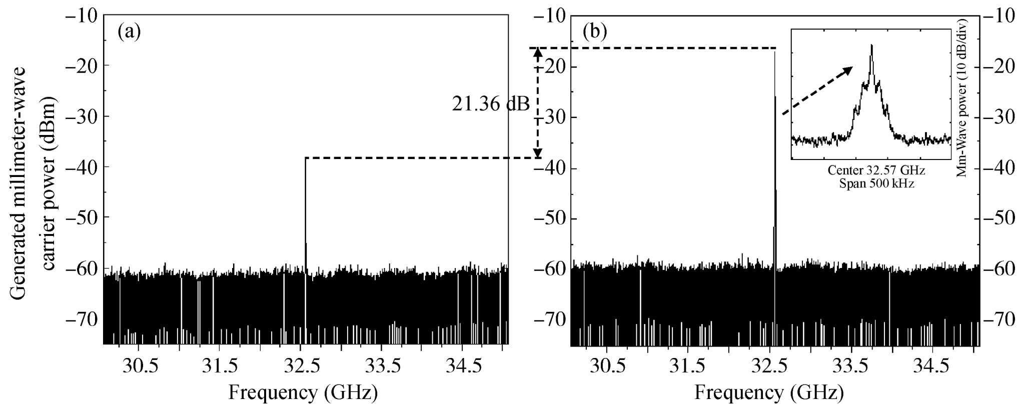

Fig. 4. Spectrum of generated millimeter-wave carrier (a) without SBS amplification and (b) with SBS induced by 6 dBm double Brillouin scattering light pumping in 25 km long SMF.

efficiency. It effectively reduces the systematic cost and improves carrier noise ratio (CNR).

(4) Single sideband modulation. The $+3$rd sideband is larger than –3rd by over 15 dB. It would contribute to avoiding dispersion-induced power penalties.

Furthermore, the square frame marked by “5” in Fig. 1(a) shows a feasible modulating method for application. The data could be modulated onto an intermediate frequency (IF) carrier from the corresponding generator. Then, the signal combines with local oscillator ($f_{\rm LO} = 10.85$ GHz) via a combiner and modulates the light together. After that, the IF signal would be carried on each sideband and its intensity would be lower on higher order sideband. Predictably, the IF signal carried on the main band could be rather strong, as compared with that on +3rd sideband, even after an SBS process.

The self-heterodyning of the main band and +3rd sideband in PD could generate an IF up-converted mm-wave signal, which would be robust against chromatic dispersion.

4. Conclusion

In conclusion, this paper experimentally demonstrates a new technique to generate an mm-wave carrier with single sideband modulation by using SBS. The +3rd sideband of the modulated optical carrier is directly amplified in the process of SBS to realize single sideband modulation. The pump wave of the SBS is provided through double Brillouin scattering. The mm-wave signal at 32.57 GHz is successfully generated with high efficiency and good performance, which has stable frequency and narrow bandwidth (kHz level). In addition, a data-modulating method for practical application is demonstrated.

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