Generation of millimetre-wave signals by stimulated Brillouin scattering for radio over fibre systems

T. Schneider, M. Junker and D. Hannover

A new simple method for an all-optical generation of a radio frequency carrier is presented, which is based on stimulated Brillouin scattering (SBS) in an optical fibre and the creation of harmonics by double sideband suppressed carrier modulation. For the setup inexpensive standard components of optical telecommunications can be used.

Introduction: The growing demand for higher data rates in wireless communication systems requires new frequency bands. The millimetre-wave (mm-wave) range has the highest potential here because it is currently uncluttered and can support high data bandwidth [1]. 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 fibre links. Several techniques have been proposed for the optical generation of mm-waves. One of the simplest methods is the modulation of continuous-wave (CW) laser light by an external modulator. However, for higher carrier frequencies the external modulator is expensive and there are several problems with the group velocity dispersion of the optical transmission systems [2]. 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 [1]. The second method suffers from phase differences between the two superimposed optical signals. To overcome this phenomenon rather complicated setups have been proposed [3].

Here we present a very simple method which only uses standard components of optical telecommunications. Our method relies on the generation of sidebands of a CW laser wave by the nonlinearity of an optical modulator. Two of these sidebands are to be amplified by SBS in an optical fibre whereas the rest are to be attenuated. Then these two sidebands are superimposed in a photodiode. Owing to the fact that both sidebands come from the same source there will be no problem with phase noise. Hence, this method has the potential to create very stable mm-waves with low noise.

Experiment: Our experimental setup is shown in Fig. 1. A signal laser generates a CW wave with a wavelength of 1578.6 nm, an optical power of 3.31 dBm and a linewidth of 150 kHz; due to the following polarisation controller the input polarisation into the Mach-Zehnder-Modulator (MZM) is fixed. The MZM is driven by an electrical generator working with a fixed frequency of 10 GHz. The bias voltage, which is applied to the MZM, is high enough that it works in the nonlinear range of its characteristic line. Hence, the signal laser wave is modulated nonlinearly with the frequency of the electrical generator. Therefore, in the optical output spectrum of the MZM a frequency comb with a separation of 10 GHz between the different lines can be found, as shown in inset (a) of Fig. 1. The frequency comb is launched into a standard singlemode fibre (SSMF) with a length of 50.43 km. The combined output signal of the two pump lasers (PL 1 and PL 2) is coupled into the fibre from the other side. The wavelength of each pump laser is adjusted in a manner that it is around 11 GHz higher than one of the frequencies in the comb, as shown in inset (b) of Fig. 1. The power of each pump laser at the fibre input is 6.2 dBm and the linewidths 0.7 and 0.8 MHz, respectively. So it is much lower than the power that is required to generate SBS from the noise in the fibre (around 8.8 dBm for our conditions [4]). Therefore, only the two chosen frequencies of the comb are amplified by SBS due to the counter-propagating pump waves. At the same time, all other frequency components in the comb are attenuated by the fibre attenuation. Because of this, only two strong frequency components can be found at the output of the circulator (inset (c) in Fig. 1). Thus, the device works like a kind of filter that suppresses all unwanted frequencies. The two amplified frequency components are superimposed on a PIN-photodiode. The output current of the PIN follows the fading frequency between the two components. If the first two sidebands are chosen for amplification the fading frequency will be 20 GHz, with the second sidebands it will be 40 GHz and so on (inset (d) in Fig. 1).

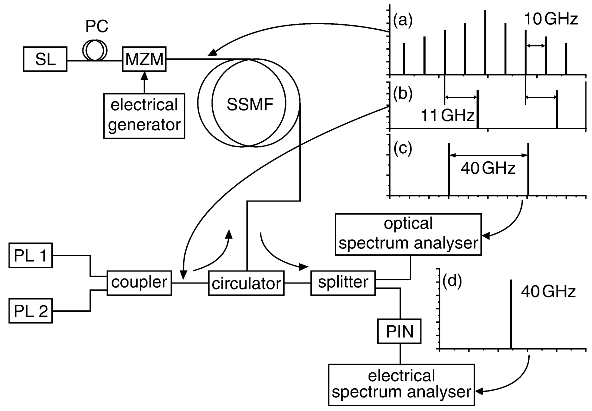

Fig. 1 *Experimental setup*

Insets: Show different spectra at marked locations. Note that output spectrum of the MZM depends on bias voltage applied to it, hence inset (a) is a strong simplification
SL: signal laser; PL: pump laser; PC: polarisation controller; MZM: Mach-Zehnder modulator; SSMF: standard singlemode fibre;
PIN: photodiode

Results: Fig. 2 shows the optical spectrum behind the splitter and the electrical spectrum behind the photodiode, each of which was recorded with the corresponding spectrum analyser. For this measurement the pump lasers have been adjusted so that the two second sidebands have been amplified by SBS in the fibre. As expected, only the two amplified sidebands are present at the output port of the circulator whereas all other frequency components are attenuated in the fibre. The real bandwidth of the sidebands is much lower than one could expect from the Figure. The broad optical spectrum in Fig. 2 results from the rather pure resolution of our optical spectrum analyser (7.23 GHz). The bandwidth of the electrical signal depends on the laser bandwidth and is very narrow. For our setup we measured a 3 dB bandwidth of less than 1 MHz.

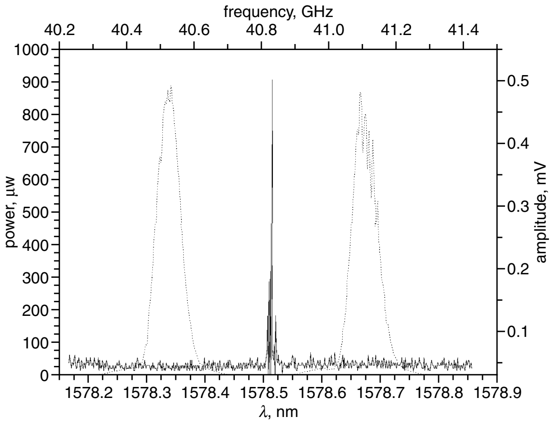

Fig. 2 *Optical (bottom and left) and electrical spectrum (top and right) measured with optical and electrical spectrum analyser*

Output wavelength of two pump lasers has been adjusted so that they amplify two second sidebands of frequency comb
.... optical spectrum
———— electrical spectrum

The wavelength of the two pump lasers can be adjusted with the temperature, hence it is possible to amplify other sidebands of the frequency comb as well. The frequency difference between the sidebands corresponds to the frequency of the mm-wave generated by the photodiode. Fig. 3 shows the optical spectrum for 60, 80 and 100 GHz signals generated with our setup.

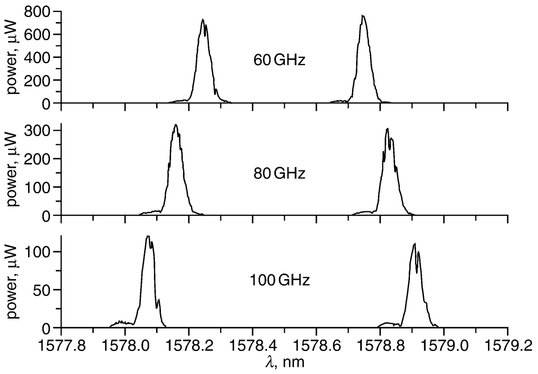

Fig. 3 *Optical spectra measured if two thirds (top), fourths (middle) and fifths (bottom) sidebands amplified by SBS*

Discussion: We have shown a very simple method that has the potential to generate stable mm-waves with low noise. The frequency of the generated wave depends on the frequency of the electrical generator and the wavelength of the pump waves, so with a common control of these values it is easily possible to tune the output frequency of the device. Modulation of the mm-wave with a baseband signal can be done very simply by modulation of the electrical generator, the signal laser or one of the pump lasers. If the natural bandwidth of SBS (around 35 MHz) is not sufficient for applications with a very broad spectrum it can be enhanced by modulation of the pump lasers [5]. The MZM can be saved in the setup if the signal laser is modulated by the electrical generator. 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. Another possibility is the incorporation of a broadband signal laser with sidebands in its output spectrum, for instance a Fabry-Perot laser. In this case the MZM and the electrical generator can be saved. The maximum reachable frequency depends on the bandwidth of the photodetector and can be as high as 330 GHz [6]. If the two pump lasers are located at the base station, the optical fibre in which the SBS takes place can be used for the distribution of the mm-wave signal between control and base station.

In our proof-of-concept experimental setup there are problems with the temperature stability of the lasers we have used. The improvement of the stability and the modulation of the mm-waves will be addressed in future research activities.

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