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Radio Frequency Generator Using Four Wave Mixing in Cascaded Nonlinear Semiconductor Optical Amplifiers

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For the last three decades, the phenomenon of four-wave mixing is a significant technique for generation of light at new distinct wavelength. When two distinct laser beams (pump and probe) beat together in a non-linear medium, few modes are increased in the power at same distance from the probe and pump, as a result of four-wave mixing. In this paper, cascading structure of two semiconductor optical amplifiers produces very strong four-wave mixing. This technique is exploited to devise a tunable radio frequency signal generator. The wavelength distance between pump and probe laser beams determines the radio frequency of the generated signal. Using this scheme, it can be observed from the experimental results, that there is an increase of more than 3 dB in signal to noise ratio at 7 Gbits/sec data rate of the 60 GHz generated mm-wave signal. Moreover, the radio frequency can be tuned to hundreds of GHz by varying the distance between the pump and probe signals. This scheme will readily serve as future all optical radars. It is also a key technique for short-range communication systems for military applications. The above scheme can also be monolithically integrated.

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1. Introduction

A radio over fiber (RoF) system with high data rate can achieve the requirements of the next-generation wireless communication system, since in this case the low loss ultra-wide bandwidth provided by the optical fiber can be utilized. Radio-frequency (RF) signal generation and modulation is essential for RoF systems. A number of different schemes are used to generate and modulate RF signals by utilizing a combination of laser direct and external modulation [1] to impart electronic data onto the RF optical carrier, mode locking (ML) in semiconductor lasers [2], cavity enhanced four wave mixing (FWM) in semiconductor ring lasers [3].

In 1974-1975, for the first time four-wave mixing was observed by R.H. Stolen in multimode optical fibers [4]. FWM has become an important research area because of its ability to produce light waves at new wavelengths [5]. Different non-linear optical devices such as optical fibers [5], semiconductor optical amplifiers (SOAs) [6–8] and semiconductor lasers [9–11] have been used to produce the FWM for many different applications. These applications include wavelength conversion, optical multicasting, mm-wave generation, parametric amplification etc.

In this paper, we report, the generation and wide-band modulation of 60 GHz mm-wave optical signals using FWM in the cascaded nonlinear semiconductor optical amplifiers (SOAs). We demonstrate that ordinary intensity modulated (IM) optical data up to 7 Gb/s can be converted into the mm-wave optical carrier, with the mm-wave frequency widely tunable up to hundreds of gigahertz (GHz) and with excellent data quality. The scheme can be used for the downlink [11] in optical transmission for wireless communication systems.

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2. Experimental setup

Figure 1 illustrates the experimental setup. Tunable laser (TL) is used as the pump signal. Agilent optical transmitter (OTx) takes the serial data from arbitrary waveform generator (AWG) and converts it into the optical PRBS sequence. Polarization is maintained

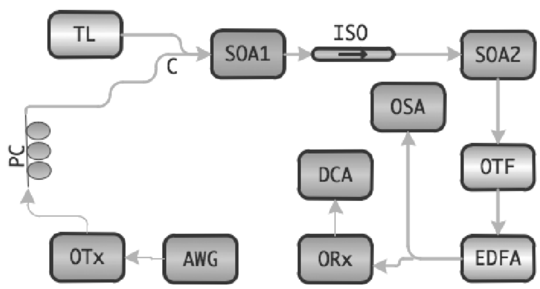

Fig. 1. Illustration of experimental setup.

using polarization controller (PC). Two cascaded semiconductor optical amplifiers SOA1 and SOA2 are used to create strong FWM. An optical isolator is placed in between SOA1 and SOA2 to remove the back reflections. Millimeter-wave signal is filtered using optical tunable filter (OTF). Erbium doped fiber amplifier (EDFA) is used to enhance the power of the signal. The signal is passed to the Aiglent optical spectrum analyzer (OSA) for optical spectrum analysis through coupler. The signal is detected by Agilent optical receiver (ORx) and analyzed using Agilent digital communication analyzer (DCA).

3. Experimental results and discussion

When the strong beam of light at 1547.83 nm from TL and PRBS modulated light from OTX at 1548.31 nm are coupled using optical coupler C and injected into the nonlinear-cascaded SOAs. As a result of beating between two light waves in the nonlinear medium, strong FWM is produced. Thus several equally spaced modes are enhanced in power and locked in phase. Figure 2 demonstrates the optical waveform of the process.

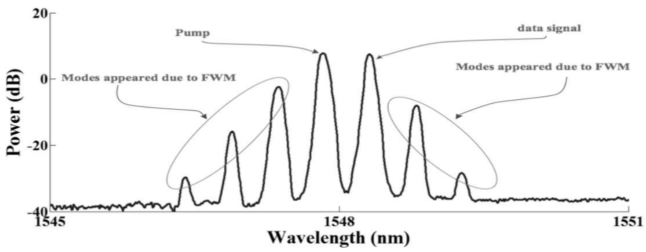

Fig. 2. Optical spectrum of FWM generated using cascaded nonlinear SOAs.

According to traditional mode locking theory the beating between the modes results in a periodical modulation of the optical signal at a frequency equal to the frequency spacing between the modes, as previously demonstrated in [3] indicates remarkable RF tone purity. In Fig. 2 RF frequency of 60 GHz is successfully generated. As a result of fiber dispersion, fading is one of the key issues in the RoF systems. It can be removed using modulation formats such as single sideband (SSB) modulation.

From the optical spectrum (Fig. 2), a pair of modes (such as data signal and adjacent mode on the right side of the main mode) is isolated by adjusting OTF in such a way that both modes have the same power level, as shown in Fig. 3a, creating an optical carrier that is single sideband modulated by the RF or mm-wave, with the RF or mm-wave being in turn amplitude modulated by the data. This signal is labeled as mm_1. In similar manner, another pair of modes mm_2 is also isolated by filtering two adjacent modes on the left hand side of the pump signal as shown in Fig. 3b.

In usual RoF systems, data signal is taken out from the high-frequency carrier through the down-conversion process using a mixer. Nevertheless, ORx directly detects the filtered signal for analysis using DCA. Due to the slow response of ORx compared to the frequency of the mm-wave carrier, the electrical output of the ORx comprises only the base-band data as the carrier is cut off. The respective signal to noise ratio (SNR) of both signals mm_1 and mm_2 is shown in Fig. 4. The signal mm_1 has a better SNR because it comprises the data signal injected into the cascaded nonlinear SOAs. The SNR is > 3 dB for both signals at the data rate of 7 Gb/sec.

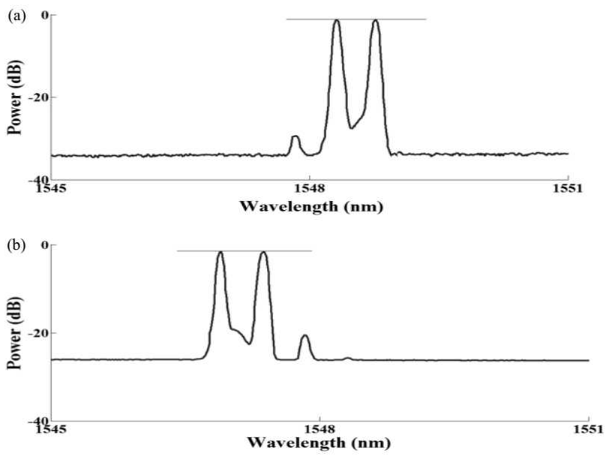

Fig. 3. Generated mm-wave signals (a) mm_1 (b) mm_2.

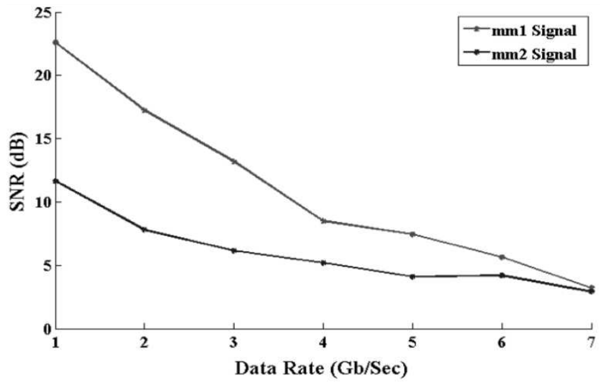

Fig. 4. Measured SNR of generated mm-wave signals.

4. Conclusions

In this paper, we have demonstrated the efficient generation and modulation of 60 GHz mm-wave optical signal using strong FWM in the nonlinear SOAs. Modulated optical data up to 7 Gb/s has been directly converted onto 60 GHz carrier, with excellent data quality. The RF frequency is widely tunable as it depends on the distance between pump and data signal. This scheme can also be monolithically integrated [12].

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