Nonlinear Characteristics of an SOA Photonic Frequency Up-converter

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Abstract: We investigate nonlinear distortion characteristics of the photonic up-converter using a semiconductor optical amplifier for multi-frequency signal up-conversion. The third order intermodulation distortions are measured and spurious free dynamic ranges are determined under various conditions.

I. Introduction

Radio-on-fiber (RoF) systems using RF/mm-wave range carriers are attracting much attention for broadband wireless applications such as wireless local area networks and intelligent traffic systems [1-5]. The remote up-conversion scheme is one promising candidate to realize RoF systems, in which baseband or intermediate frequency (IF) signals are optically transmitted from the central station to base stations, and up-converted to desired frequencies at base stations [2]. To realize such base stations, photonic up-conversion techniques based on nonlinear photodiodes (PDs) [3] and Mach-Zehnder modulators (MZM) [4, 5] have been proposed. We also proposed a photonic up-conversion method using cross-gain modulation of the semiconductor optical amplifier (SOA) [6]. Fig. 1 schematically shows the up-conversion process, in which IF signals are modulated into the heterodyne optical LO modes by SOA cross gain modulation, and after photo-detection IF signals are up-converted to the desired frequency band.

The subcarrier multiplexing (SCM) method is very useful for RoF systems since it can merge several applications together [3, 5] and provide frequency sectorization schemes [7], which are important for many wireless applications. For the SCM systems, photonic up-converters should up-convert the data buried in multiple IF frequencies simultaneously. Since any frequency up-converter is based on nonlinear properties of the device used, intermodulation distortion products from multi-channel up-conversion are inevitable, which degrade system performance severely. Consequently, investigation into distortion characteristics of our SOA-based photonic up-converter is necessary.

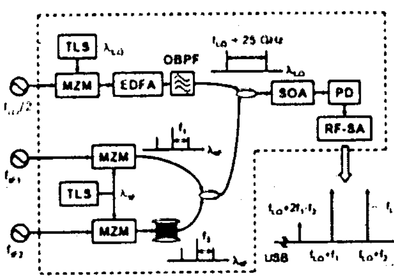


Fig. 1. Experimental setup for the third order distortion measurement. TLS : Tunable Laser Source, OBPF : Optical Bandpass Filter, RF-SA : RF-Spectrum Analyzer, USB : Upper Sideband.

In this paper, we investigate nonlinear

intermodulation distortion properties of the SOA-based photonic up-converter according to different optical LO input powers and IF signal wavelengths. The third order intermodulation distortions are measured for the case of two-tone IF signals, and the resulting spurious free dynamic range (SFDR) is determined.

II. Experiment and Results

Fig. 1 shows the experimental setup used for our investigation. The optical heterodyne LO signals at λ_1 = 1555 nm, having two modes separated by f_{LO} of 25 GHz, were generated by the DSB-SC (Double Sideband – Suppressed Carrier) modulation method [4], for which MZM was modulated by a 12.5 GHz RF signal at the V_π point. For generating IF subcarriers, two MZMs biased at the quadrature point were intensity-modulated independently at 995 MHz (f_1) and 1005 MHz (f_2). The reason for using two modulators is to prevent the influence of the third order intermodulation distortion effects of the modulator itself.

An optical delay line was introduced to prevent coherent beating between two optical IF signals that makes detected signals unstable. Optical sources used in the experiment were tunable external cavity lasers, which did not act as the dominant noise source. As a receiver, we used an HP lightwave converter having 24 dB RF gain at 25 GHz band and 30 pW/Hz$^{1/2}$ noise equivalent power. The influence of PD nonlinearity [3] was eliminated by using a 10 dB optical attenuator before PD, which reduced the received RF power as well as the detected noise floor.

Fig. 2 shows measured RF spectra for IF and up-converted upper sideband (USB) signals before and after photonic up-conversion, respectively. The up-converted USB signals at 25.995 GHz (f_{LO}+f_1) and 26.005 GHz (f_{LO}+f_2) and the third order intermodulation distortion products (IMP3s) at the frequencies of 25.985 GHz (f_{LO}+2f_1-f_2) and 26.015 GHz (f_{LO}+2f_2-f_1) are clearly observed in Fig. 2(b).

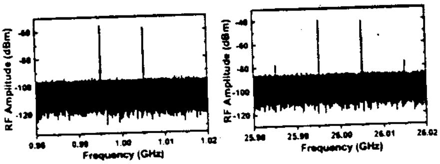


Fig. 2. RF spectra for the IF signals before SOA (a) and up-converted USB RF signals (b). Each LO signal power is -13 dBm at 1555 nm and total IF signal power is -13 dBm at 1545 nm. The resolution bandwidth of two spectra is 3 kHz.

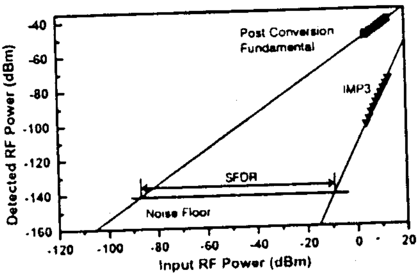


Fig. 3. SFDR measurement example. The SOA input LO signal power is -14 dBm, and IF signal power at 1545 nm is -13 dBm.

For SFDR measurement, we observed powers of the 26.005 GHz (f_{LO} +f_2) USB signal and the IMP3 at 26.015 GHz (f_{LO}+2f_2-f_1). Fig. 3 shows an example of SFDR measurement. Since the RF-spectrum analyzer (HP 8563E) noise display limit is about -130 dBm/Hz at the 25 GHz band, we intentionally enhanced the noise-floor by an electrical amplifier having 17 dB RF gain and 4 dB noise figure for noise floor level measurement. Then, the noise floor level was determined by subtracting amplifier gain from the enhanced noise floor due to the additional amplifier. The measured noise-floor for the case shown in Fig. 3 was -139 dBm/Hz. The SFDR was 76.1 dB-Hz$^{2/3}$.

At first, we measured the dependence of the SFDR on the SOA input optical LO signal power ranging from -20 dBm to -8 dBm. The optical IF signals had in total -13 dBm SOA input power at 1545 nm wavelength. The SOA was biased at 150 mA. Fig. 4 shows the SFDR measurement results. As the LO signal power increases, the SFDR increases monotonically. In order to understand this increase, we show in Fig. 5 the up-converted USB signal power and IMP3 power at 12 dBm input RF power condition as well as the noise floor level. When the LO signal power is low, the increase of USB signal power is larger compared with the increase of the IMP3 power and noise floor. Consequently, the SFDR increases. When the LO signal power is high, the USB signal power is saturated due to the SOA gain saturation [6], and the noise floor level rises as before [8]. The SFDR increases, however, because distortion product powers get reduced very much. We believe that this low distortion is the result of heavily depleted carriers in SOA caused by high SOA input power.

Finally, we measured the SFDR dependence on the input IF signal wavelength. The total SOA input IF signal power was again fixed at -13 dBm, and the IF wavelength was changed within the C-band, which covers the gain bandwidth of SOA biased at 150 mA. The LO signal power was -13 dBm. Fig. 6(a) shows the measured SFDR as a function of the IF signal wavelengths. In this case, the SFDR characteristics are determined by the up-conversion efficiency and the noise floor level. As explained in [6], the up-conversion efficiency is determined by the SOA gain spectrum, and the efficiency is highest at the SOA gain peak wavelength. However, the noise floor change is inversely proportional to the SOA gain spectrum at the saturated SOA so that it has the minimum at the gain peak wavelength [9]. Figure 6(b) shows these characteristics very well. Therefore, the dependence of the SFDR on IF wavelength follows the SOA gain spectrum.

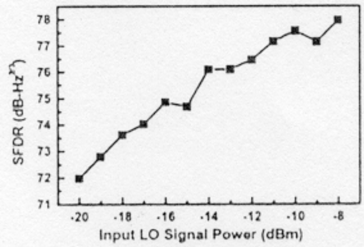


Fig. 4. Dependence of the photonic up-converter SFDR on optical LO signal power.

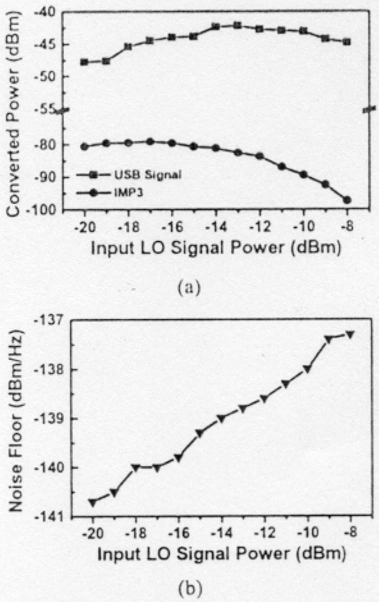
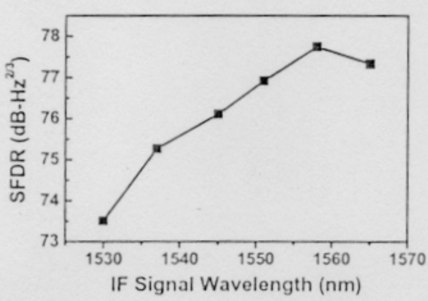


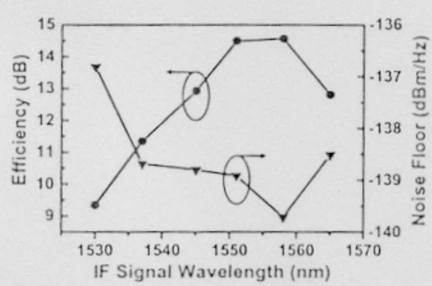
Fig. 5. Converted USB signal and IMP3 powers according to SOA input LO signal power at RF modulation power of 12 dBm (a) and measured noise floors after the lightwave converter (b).

III. Conclusion

We have investigated the nonlinear characteristics of the photonic SOA up-converter using SFDR measurement under various conditions such as optical LO signal powers and IF signal wavelengths. It is found that the SFDR increases with the LO signal power despite the up-conversion efficiency saturation and noise floor increase. We also investigated the dependence of the SFDR on IF signal wavelengths, which follows the SOA gain spectrum. The SFDR larger than 72 dB-Hz$^{2/3}$ was obtained in our investigation. The SFDR of our photonic up-converter is not high compared with that of the conventional 30 GHz band electrical mixers. However, it could be useful in PSK or FSK modulated multi-channel RoF systems.



(a)



(b)

Fig. 6. Dependence of the photonic up-converter SFDR on optical IF signal wavelength (a) and up-conversion efficiencies and noise floor characteristics as a function of the IF signal wavelengths (b).

References

[1] A. J. Seeds, "Microwave Photonics," *IEEE Trans. Microwave Theory and Tech.*, vol. 50, no. 3, pp. 877-887, 2002.

[2] E. Suematsu, and N. Imai, "A Fiber Optic/Millimeter-Wave Radio Transmission Link Using HBT as Direct Photodetector and an Optoelectronic Upconverter," *IEEE Trans. Microwave Theory and Tech.*, vol. 44, no. 1, pp. 133-143, 1996.

[3] M. Tsuchiya, and T. Hoshida, "Nonlinear Photodetection Scheme and Its System Applications to Fiber-Optic Millimeter-Wave Wireless Down-Links," *IEEE Trans. Microwave Theory and Tech.*, vol. 47, no. 7, pp. 1342-1350, 1999.

[4] J. Park, M. S. Shakouri, and K. Y. Lau, "Millimetre-wave Electro-optical upconverter for wireless digital communications," *Electron., Lett.*, vol. 31, no. 13, pp. 1085-1086, 1995.

[5] G. H. Smith, D. Novak, and C. Lim, "A Millimeter-Wave Full-Duplex Fiber-Radio Star-Tree Architecture Incorporating WDM and SCM," *IEEE Photon. Technol. Lett.*, vol. 10, no. 11, pp. 1650-1652, 1998.

[6] Y.-K. Seo, C.-S. Choi, and W.-Y. Choi, "All-optical Signal Up-conversion for Radio-on-fiber Applications Using Cross-gain Modulation in Semiconductor Optical Amplifiers," *IEEE Photon. Technol. Lett.* vol. 14, no. 10, pp. 1448-1450, 2002.

[7] R. B. Waterhouse, D. Novak, A. Nirmalathas, and C. Lim, "Broadband Printed Sectorized Coverage Antennas for Millimeter-Wave Wireless Applications," *IEEE Trans. Antennas and Propagat.*, vol. 50, no. 1, pp. 12-16, 2002.

[8] G. Giuliani, and D. D'Alessandro, "Noise Analysis of Conventional and Gain-clamped Semiconductor Optical Amplifiers," *J. Lightwave Technol.*, vol. 18, no. 9, pp. 1256-1263, 2000.

[9] D. D'Alessandro, G. Giuliani, and S. Donati, "Spectral Gain and Noise Evaluation of SOA and SOA-based Switch Matrix," *IEE Proc.-Optoelectron.*, vol. 148, no. 3, pp. 125-130, 2001.