4-1

All optical signal up-conversion at K-band using SOA

Y.-K. Seo, C.-S. Choi, and W.-Y. Choi

Department of Electrical and Electronic Engineering, Yonsei University

134, Shinchon-Dong, Sudaemoon-Ku, Seoul, 120-749, Korea

E-mail: west@yonsei.ac.kr

Abstract

We present a novel scheme of up-converting the intermediate frequency (IF) signal with the optical local oscillator (LO) signal at K-band using SOA. The IF signal is generated by the direct modulation of a DFB-laser at 1 GHz. The 25-GHz LO signal is obtained by the DSB-SC (double sideband suppressed optical carrier) modulation of a Mach-Zehnder Modulator (MZM). When these two signals having different wavelengths propagate simultaneously in SOA, signal up-conversion can be observed.

Key Words: All-optical signal up-conversion, SOA

I. Introduction

The fiber-optic transmission of millimeter-wave signals has attracted attention for broadband access radio systems because it allows the centralization of complex equipment at one central office and the simplification of base stations [1-3]. For the increase of the total data traffic capacity, the WDM technique can be introduced to the millimeter-wave-over-fiber transmission. Recently, R. A. Griffin *et al.* demonstrated the millimeter-wave-over-fiber distribution [2] where the WDM data signals having different wavelengths were up-converted to millimeter-wave frequency using one MZM. However, the signal up-conversion using MZM has several problems. First, MZM is inherently sensitive to incident light polarizations. Secondly, it has the insertion loss of about 5 dB. And, its modulation bandwidth will impose the limitation on the accessible frequency range in which the data-signal can be up-converted.

In order to avoid the limitation of signal up-conversion frequency, the all-optical approach is attractive, where optical IF-data signal and LO signal having different wavelengths are utilized. In [4], Tsuchiya and Hoshida presented the IF-data signal up-conversion to the millimeter-wave frequency taking advantage of the nonlinear photo-detection behavior of a high-speed photo-detector (PD). Now that the optical heterodyne methods for the optical generation of high frequency LO signals using a relatively low-speed electrical oscillator are already demonstrated [3, 5], this all-optical approach can avoid the need for high-speed electrical oscillators and high-speed optical modulator in generating LO-signals. The signal up-conversion frequency is limited by the photo-detection bandwidth of a photo-detector but it is usually much wider than that of the optical modulators. The signal conversion efficiency is, however, very low.

In this paper, we present an all-optical signal up-conversion scheme utilizing semiconductor optical amplifier (SOA), which can avoid the incident light polarization problem and compensate optical losses and improve signal conversion efficiency with SOA intrinsic gain. When optical IF-data and LO signals co-propagate

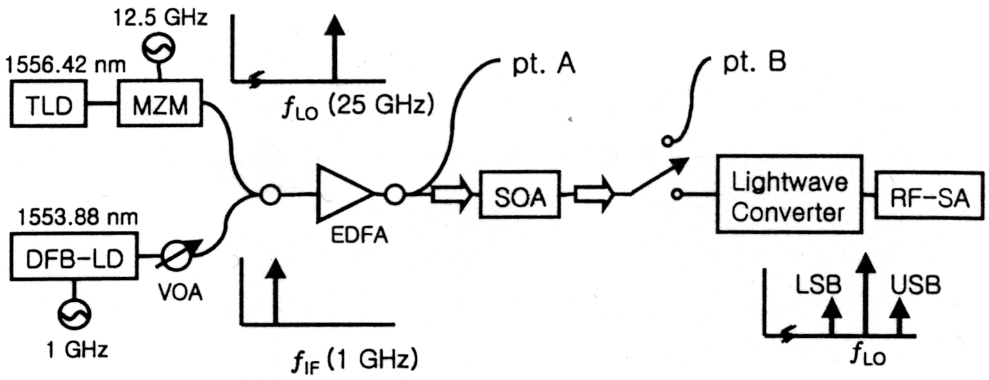

Figure 1: Experimental setup for all-optical signal up-conversion using SOA. LSB and USB mean lower and upper sidebands at f_{LO}-f_{IF} and f_{LO}+f_{IF} respectively.

through SOA, signal up-conversion occurs by the cross-modulation effect of SOA in the optical domain. A previous study demonstrated the signal mixing of two microwave signals of 5 GHz and 6 GHz at different wavelengths in SOA having small signal bandwidth of 9 GHz [6]. In this paper, we show the feasibility of up-converting optical IF-data signal with optical LO signal beyond SOA modulation bandwidth. For the optical generation of LO-signals beyond SOA modulation bandwidth, we employed the MZM DSB-SC modulation technique.

II. Experiment and Discussion

Figure 1 shows the experimental setup for all-optical signal up-conversion with a polarization-insensitive SOA. IF-data and LO signals co-propagate through SOA and cross-modulate each other in SOA. The LO signal frequency (25 GHz) used in the experiment is much higher than the modulation bandwidth of the commercial SOA. In order to obtain this optical LO signal, we employed a MZM biased at V_π to perform the DSB-SC modulation technique. The MZM was modulated with an electrical oscillator at 12.5 GHz to obtain the LO signal of 25 GHz whose frequency was chosen because of the limited MZM modulation bandwidth available. This limitation can be avoided by utilizing the optical heterodyne method for LO signals. The optical peak powers of +1 and -1 sidebands could become larger than that of the optical carrier by > 10 dB by the proper adjustment of the electrical modulation power.

IF-data signal was produced by the direct modulation of a DFB-LD. 1 GHz IF-data and 25 GHz LO signal having different wavelengths were combined together by using an 1x2 fiber coupler and optically amplified by EDFA before SOA. Each optical power was adjusted by a variable optical attenuator so that the IF-data signal peak power was kept at 0 dBm before SOA in the experiment. Two optical isolators were placed before and after SOA to avoid the undesired optical feedback. No polarization controllers for the SOA input lights were used because a polarization-insensitive SOA was used in the experiment.

Figure 2 shows the optical spectra of the IF-data and LO signal before and after SOA. The IF-data signal wavelength (λ_{IF} = 1553.88 nm) was separated from the LO signal wavelength (λ_{LO} = 1556.42 nm) by about 2.4 nm. From the optical spectrum of the LO signal in Figure 2-(a) (measured at 'pt. A' in Figure 1) one can observe the +1 and -1 sidebands whose peak powers are larger than that of the optical carrier at λ_{LO}. These two sidebands are separated by 25 GHz, which is twice the MZM driving frequency of 12.5 GHz.

Figure 2-(b) (measured at 'pt. B' in Figure 1) shows the optical spectrum of the IF-data and LO signals after SOA having the optical gain of > 5 dB. In the shorter wavelength separated by about 2.4 nm from λ_{IF}, FWM (four-wave mixing) modes between these two signals are observed. The additional sidebands around λ_{LO} are also observed because of FWM between +1 and -1 sidebands of LO signals. The sidebands around λ_{IF}, however, were produced by the cross-modulation with the LO signal at λ_{LO} even though their modulation efficiencies were very low because the LO signal frequency was beyond the SOA gain modulation bandwidth.

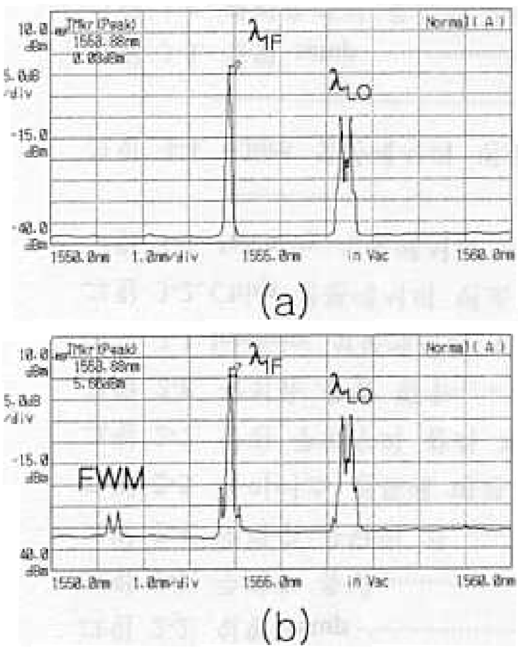

Figure 2: Optical spectra before and after signal up-conversion using SOA.

The +1 and -1 sidebands of the optical LO signal at λ_{LO} were also cross-modulated with the optical IF-data signal at λ_{IF}, which was sufficient enough for the signal up-conversion because the IF-data signal was within SOA gain modulation bandwidth. The results of the cross-modulated sidebands of these +1 and -1 sidebands, however, could not be directly observed in the optical spectrum because of the limited resolution of the optical spectrum analyzer used in the experiment. These cross-modulated results could be also observed with the electrical spectrum analyzer after the photo-detection as shown in Figure 3.

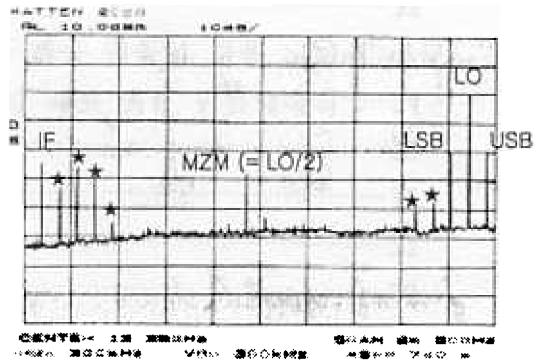

Figure 3: Electrical spectrum after signal up-conversion using SOA.

Figure 3 shows the measured electrical spectrum of the signals after cross-modulated in SOA as shown in Figure 2-(b) and photo-detected with the high-speed PD. One could observe the IF-data_signal frequency at 1 GHz, the MZM driving frequency at 12.5 GHz, and the DSB-SC modulated LO signal frequency at 25 GHz. The lower sideband (LSB) at 24 GHz and the upper sideband (USB) at 26 GHz could be also observed at both sides of LO signal as the result of data signal up-conversion. The other frequency components marked with asterisks are the harmonics produced by the direct modulation of the DFB-LD for the IF-data signal. One interesting point in Figure 3 is that the LSB and USB frequency components have larger powers than the IF-data signal frequency component by about 5 dB. This implies that the up-converted IF-data signal in SOA can have a larger power than IF-data signal because SOA intrinsic gain is directly attributed to the amplified up-converted IF-data signal. Thus, SOA can provide the positive signal conversion efficiency rather than the negative efficiencies that are common in the signal conversion schemes using external optical modulators [2, 7].

The signal up-conversion using SOA has advantages that it is insensitive to the incident light polarizations, is independent of the SOA modulation bandwidth and can have the positive conversion efficiency. However, the overall system noise level increases because SOA provides additional noises as can be seen in Figure 2.

III. Conclusion

We presented an all-optical signal up-conversion scheme using SOA and demonstrated the feasibility of signal up-conversion beyond the SOA modulation bandwidth. We found that this signal up-conversion scheme could avoid the incident light polarization problem and improve the conversion efficiency.

References

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

[2] R. A. Griffin, P. M. Lane, J. J. O'Reilly, "Crosstalk Reduction in an Optical mm-Wave/DWDM Overlay for Radio-Over-Fibre Distribution," in Tech. Dig. *MWP*'99, pp. 131-134, 1999.

[3] L. A. Johansson and A. J. Seeds, "Millimetre-Wave Radio-Over-Fibre Transmission Using an Optical Injection Phase-Lock Loop Source," in Tech. Dig. *Int'l Topical Meeting on Microwave Photonics* (MWP'00), pp. 129-132, 2000.

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

[5] R. -P. Braun, G. Grosskopf, D. Rohde, and F. Schmidt, 'Low-phase-noise millimeter-wave generation at 64 GHz and data transmission using optical sideband injection locking," *IEEE Photon. Technol. Lett.*, vol. 10, no. 5, pp. 728-730, 1998.

[6] W. Shieh, S. X. Yao, G. Lutes, and L. Maleski, "An all-optical microwave mixer with gain," in Tech. Dig. OFC'97, ThG1, pp. 263-264, 1997.

[7] D. S. Shin, G. L. Li, C. K. Sun, S. A. Pappert, K. K. Loi, W. S. C. Chang, and P. K. L. Yu, "Optoelectronic RF Signal Mixing Uisng an Electroabsorption Waveguide as an Integrated Photodetector/Mixer," *IEEE Photon. Technol. Lett.*, vol. 12, no. 2, pp. 193-195, 2000.