TECHNICAL DIGEST

2005 International Topical Meeting on MICROWAVE PHOTONICS

MWP 2005

October 12 - 14, 2005
Seoul Olympic Parktel
Seoul, KOREA

www.mwp2005.org

KICS Korean Institute of Communication Sciences

IEEE · IEEE LEOS Lasers & Electro-Optics Society · MTTS · EIC · I·E·E·K

IEEE Catalog No.: 05EX1165 ISBN 89-950043-3-9 93560

Conversion Efficiency Characteristics of Cascaded SOA-EAM Frequency Up/Down-Converters

Jun-Hyuk Seo[1], Chang-Soon Choi[1], Young-Shik Kang[2], Yong-Duck Chung[2], Jeha Kim[2], and Woo-Young Choi[1]

1. Department of Electrical and Electronic Engineering, Yonsei University, Seoul 120-749, Korea.
Tel: +82-2-2123-2874, Fax : +82-2-312-4584, E-mail : wchoi@yonsei.ac.kr
2. Electronics and Telecommunications Research Institute, Daejeon 305-350, Korea.

***Abstract* — We investigate the frequency up- and down-conversion efficiency characteristics of millimeter-wave frequency converters based on cascaded semiconductor optical amplifier (SOA) – electroabsorption modulator (EAM) configuration. We define internal frequency conversion efficiencies and characterize them at 60-GHz as functions of EAM bias, optical LO signal power, and optical IF signal power and wavelength.**

***Index Terms* — Electroabsorption modulator (EAM), frequency conversion, millimeter wave communication, optical mixers, radio-on-fiber system, semiconductor optical amplifier (SOA).**

I. INTRODUCTION

Radio-on-Fiber (RoF) systems are very effective to realize millimeter-wave wireless systems, which need many base stations due to high free space transmission loss of millimeter-wave signals [1-3]. Because RoF systems can support low loss, broadband data transmission and allow centralization of expensive equipment, it is possible to design simple and cost effective base stations. In addition, it is possible to apply optical/optoelectronic techniques for millimeter-wave signal generation and processing to RoF systems, which can improve system performances and reduce base station complexity [1-5]. Especially, the millimeter-wave optical/optoelectronic frequency conversion techniques have been widely investigated for such purposes [1-5]. We have previously proposed frequency up- and down-conversion techniques using semiconductor optical amplifier (SOA) – electroabsorption modulator (EAM) configuration, in which SOA cross-gain modulation and EAM photodetection are used for frequency up-conversion, and EAM nonlinearity for frequency down-conversion [6-7].

For electrical frequency converters, important specifications are frequency conversion efficiency, isolation between RF and LO ports, and intermodulation distortions caused by nonlinearity of frequency converters [8]. Among them, frequency conversion efficiency is essential for RF design of base stations. In this paper, we investigate the frequency up- and down-conversion efficiencies for the SOA-EAM frequency converter. The conventional definition of conversion efficiency is the RF power ratio between input signals and frequency converted output signals. However, it is very difficult to directly apply this definition to our frequency converters because it is difficult to measure exact signal powers related to frequency up/down-conversion due to many optical components used in the scheme. Therefore, we devise a method with which frequency up- and down-conversion efficiencies are estimated, and measure them as functions of EAM bias, optical LO signal power, and optical IF signal power and wavelength.

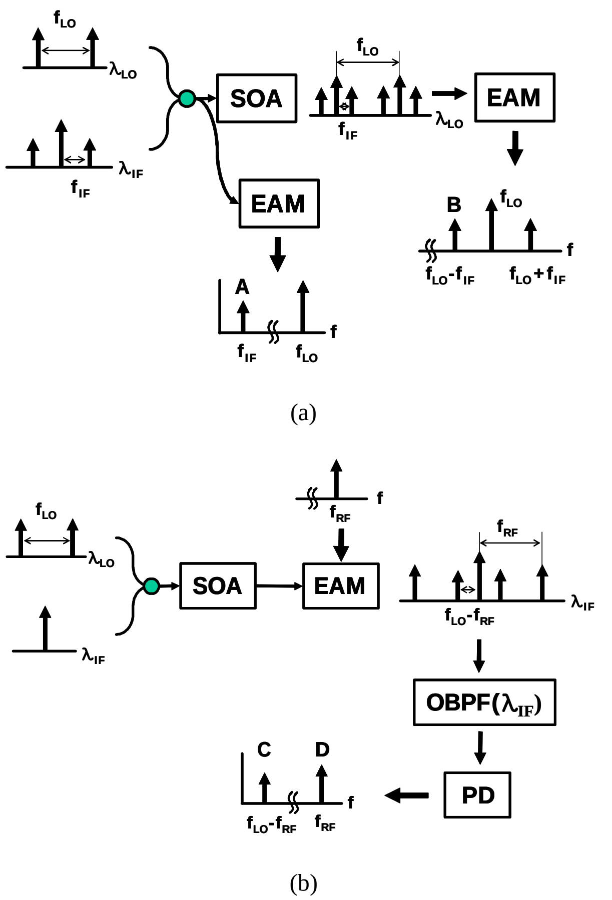


Fig. 1. Simple schematics of frequency up-conversion process (a), and frequency down-conversion process (b). OBPF : Optical BandPass Filter.

ISBN 89-950043-3-9 93560

II. Operation Principles and Definition of Frequency Conversion Efficiency

Fig. 1 (a) and (b) schematically show operation principles of frequency up- and down-conversion, respectively. For frequency up-conversion, both optical heterodyne LO signals (λ_{LO}) to generate f_{LO} and optical IF signals (λ_{IF}) carrying f_{IF} signals are injected into SOA. Inside SOA, two modes of optical heterodyne signals are cross-gain modulated by optical IF signals. After photodetection in EAM of optical LO signals, frequency up-converted signals at f_{LO}-f_{IF} and f_{LO}+f_{IF} are generated as beating products as shown in the fig. 1 (a). Therefore, the frequency up-conversion efficiency (η_{up}) can be defined as the EAM photodetected power ratio of frequency up-converted signals marked as B in Fig. 1 (a) to IF signals before SOA marked as A.

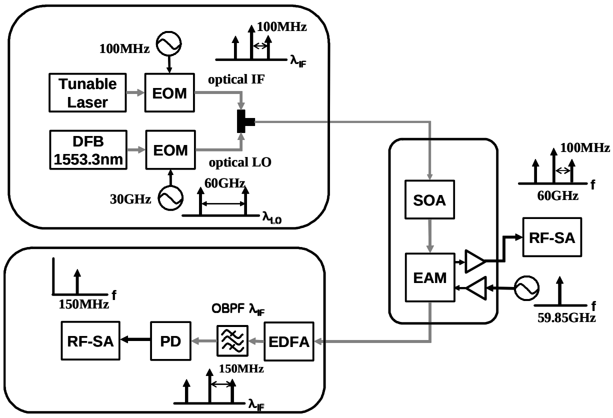
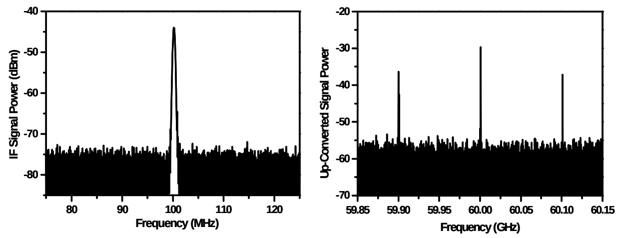


Fig. 2. Experimental setup for frequency up/down-conversion at 60-GHz-band. EOM : Electrooptic Modulator, DFB : Distributed Feedback Laser : RF-SA : RF Spectrum Analyzer, PD : Photodetector, OBPF : Optical BandPass Filter, EDFA : Erbium Doped Fiber Amplifier.

For frequency down-conversion, optical LO signals and optical IF signals are injected into the SOA-EAM configuration. During the photodetection process in EAM, signals having f_{LO} component are generated inside EAM. These signals are frequency mixed with RF signals at f_{RF} externally applied to EAM due to EAM nonlinearity, which results in frequency down-conversion to f_{LO}-f_{RF}. The resulting f_{LO}-f_{RF} signals then modulate optical IF signals at λ_{IF} in the same EAM, thereby frequency down-converted signals can be obtained by the photodetection of optical IF signals as shown in the fig. 1 (b). In this frequency down-conversion process, the frequency down-conversion efficiency (η_{down}) is defined as the photodetected power ratio of frequency down-converted signals marked as C to EAM modulated RF signals marked as D. This definition can eliminate the effects of EAM modulation efficiency and photodetector efficiency of optical IF signals, indicating internal frequency down-conversion efficiency in EAM. The details of frequency conversion characteristics and data transmission results are reported in [6-7].

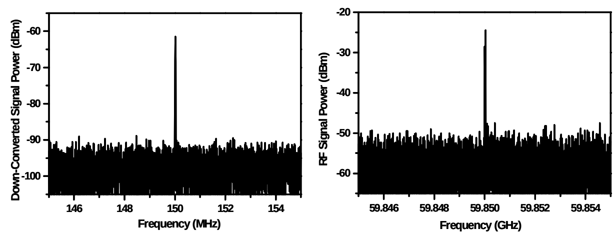
III. Experiments and Results

Fig. 2 shows the experimental setup to measure frequency up/down-converted signals for calculating conversion efficiencies at 60-GHz-band. Optical heterodyne LO signals were generated by modulating a Mach Zehnder modulator biased at minimum transmission point with 30-GHz signals [9]. 100-MHz IF signals for frequency up-conversion modulated another Mach-Zehnder modulator biased at the quadrature point for generating optical IF signals. When these two optical signals were combined and injected into the SOA-EAM configuration, frequency up-converted signals at 59.9-GHz and 60.1-GHz were generated as shown in the fig. 3 (b). The SOA was biased at 150-mA, which provided 25-dB optical gain and 7-dBm output saturation power. The EAM was designed for 60-GHz narrow band operation [10], and biased at -2.5-V. For calculating η_{up}, 100-MHz IF signals are measured using the same EAM as a photodetector before SOA. Fig. 3 (a) shows the measured RF spectrum of 100-MHz signals. Because EAM photodetection response has 16-dB difference between 100-MHz and 60-GHz-band, we corrected this difference to calculate η_{up}. The gain of RF amplifiers was also corrected.



(a) (b)

Fig. 3. RF spectra for frequency up-conversion: (a) IF signals without SOA, (b) frequency up-converted signals. The resolution bandwidth was 300-kHz for (a) and 100-kHz for (b). A 17-dB gain electrical amplifier was used for (b).



(a) (b)

Fig. 4. RF spectra for frequency down-conversion: (a) frequency down-converted signals measured with broadband photodetector, (b) EAM modulated RF signals measured with the same broadband photodetector. The resolution bandwidth was 1-kHz for both. A 20-dB gain electrical amplifier was used for (a), and a 17-dB gain electrical amplifier was used for (b).

For frequency down-conversion, 10-dBm 59.85-GHz signals modulated the EAM, which were then mixed with photodetected 60-GHz LO signals, resulting in optical IF signals modulated with frequency down-converted 150-MHz IF signals. The spectrum of photodetected optical IF signals after optical amplification and bandpass filtering is shown in the fig. 4 (a). When optical IF signals were photodetected, 59.85-GHz RF signals were also generated due to EAM modulation of 59.85-GHz signals as shown in the fig. 4 (b). η_{down} was calculated using these two signals. A broadband photodiode was used to measure both frequency down-converted signals and RF signals, and the 5-dB difference of frequency response between 150-MHz and 59.85-GHz was corrected in calculating $\eta_{down.}$ The gain of RF amplifier was also corrected.

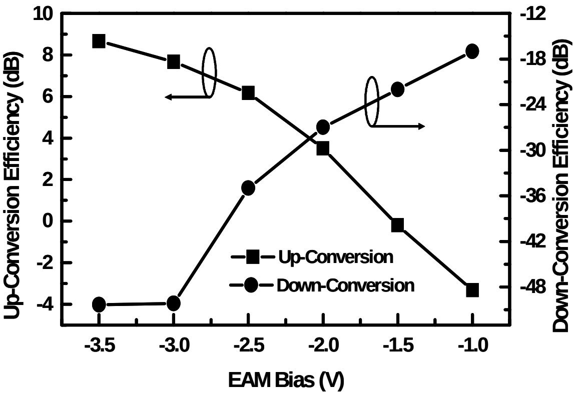
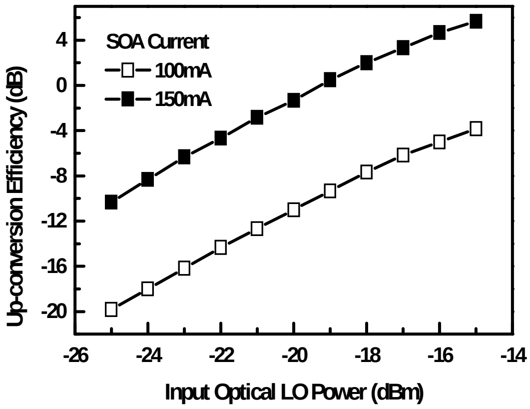


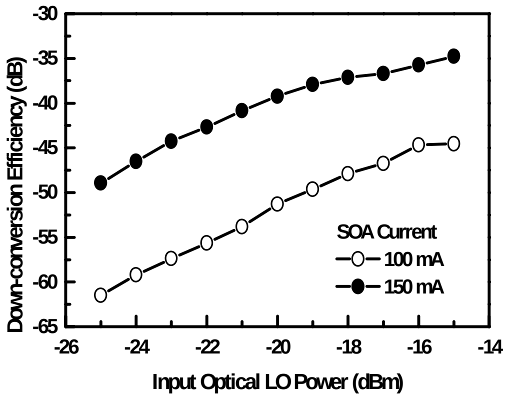
Fig. 5. Dependence of frequency conversion efficiency (η_{up} and η_{down}) on EAM bias conditions.

At first, the dependence of frequency conversion efficiencies on EAM bias condition was measured. The power of optical IF signals at 1550-nm and optical LO signals at 1553.3-nm before SOA were -8-dBm and -15-dBm, respectively. As shown in the Fig. 5, η_{up} increases with increasing EAM reverse bias voltages, because photocurrent in EAM increases at high reverse voltages. The dependence of photocurrent in EAM on bias conditions is the contrary of modulation characteristics, so that photocurrent in EAM within this bias range increases with reverse bias voltages. However, η_{down} decreases with increasing EAM reverse bias voltages, because EAM nonlinearity is more pronounced at low reverse voltages.

LO power influences the efficiency of frequency converters. We investigated the dependence of frequency conversion efficiencies on SOA input optical LO power. For this measurement, the optical IF power at 1550-nm was set at -8-dBm, and EAM was biased at -2.5-V. The wavelength of optical LO signals was 1553.3-nm. The results were obtained at two different SOA current levels in order to see the influence of SOA gain on conversion efficiencies. As can be seen in Fig. 6 (a) and (b), both η_{up} and η_{down} increase with optical LO power. For η_{up}, the increase is due to square-law beating power increase with optical LO signals in EAM. η_{down} increases because the photogenerated LO signal power in EAM increases with optical LO power. In both cases, the slight saturation of conversion efficiencies appears at high optical LO power conditions due to the SOA gain saturation. When the SOA bias increases from 100-mA to 150-mA, both frequency conversion efficiencies improve about 10-dB, which corresponds to about 5-dB increase in SOA optical gain.



(a)



(b)

Fig. 6. Frequency up-conversion efficiency (η_{up}) (a), and frequency down-conversion efficiency (η_{down}) (b) as a function of optical LO signal power. Optical LO power was measured in front of SOA.

Finally, conversion efficiencies were measured as functions of optical IF signal power and wavelength. Fig. 7 shows the conversion efficiency dependence on optical IF signal power. The optical LO signal power at 1553.3-nm was -15-dBm, and the wavelength of IF signals was 1550-nm. For frequency up-conversion, the conversion efficiency decreases with increase of optical IF power. This is due to SOA gain saturation, which causes decrease of both cross-gain modulation efficiency and gain that optical LO signals experience. As shown in Fig. 7, the conversion efficiency dependence is very similar to SOA gain saturation characteristics. For frequency down-conversion, the increase of optical IF power leads to the increase of photodetected power of both frequency down-converted signals and RF signals. Therefore, constant conversion efficiency should be maintained. However, at high optical IF power conditions, the frequency down-conversion efficiency is slightly decreased, because the optoelectronic mixing at the EAM starts to saturate faster than RF modulation in EAM.

Fig. 8 show the effects of optical IF wavelength on frequency conversion efficiencies. The wavelength of -8-dBm optical IF was changed from 1540-nm to 1560-nm. As shown in the figure, the frequency up-conversion efficiency is nearly constant over wide optical IF wavelength range. This is because the SOA gain bandwidth near 1550-nm is wide and cross-gain modulation efficiency is saturated with this high optical IF power. On the other hand, the frequency down-conversion efficiency varies about 4-dB. This is because the modulation efficiency and frequency mixing in EAM are changed at different wavelength conditions. These frequency conversion efficiency results show that this SOA-EAM frequency converter has wide operation wavelength range.

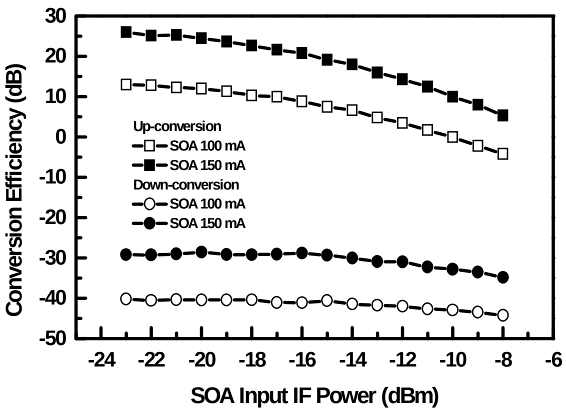


Fig. 7. Frequency conversion efficiencies as a function of SOA input optical IF signal power.

IV. CONCLUSION

We measured and investigated the frequency up- and down-conversion efficiencies of SOA-EAM frequency converters for bi-directional RoF systems. For our purpose, we defined frequency up- and down-conversion efficiencies, and measured them as functions of EAM bias, optical LO signal power, and optical IF signal power and wavelength. We found that the EAM bias conditions reversely affect the frequency up- and down-conversion efficiency. It is also found that the high optical LO signal power increases the frequency conversion efficiencies until it is saturated by SOA gain saturation. On the other hand, high optical IF power decreases the frequency conversion efficiency. The dependence on input optical IF wavelength was not too significant in our experimental conditions. We believe that our SOA-EAM frequency converter has enough conversion efficiency for bi-directional data transmission.

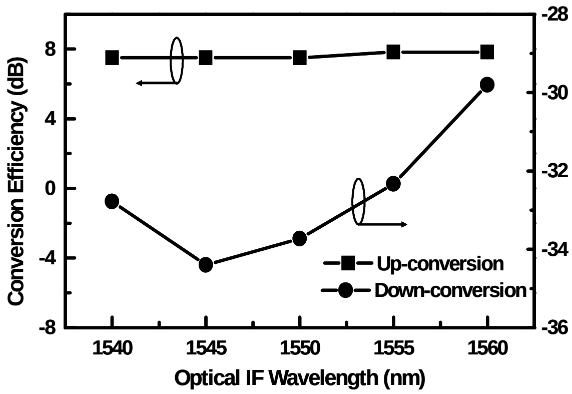


Fig. 8. Frequency conversion efficiencies as a function of SOA input optical IF wavelength.

REFERENCES

[1] H. Ogawa, D. Polifko, and S. Banda, "Millimeter-wave fiber optics systems for personal radio communication," *IEEE Trans. Microw Theory Tech.*, vol. 40, no. 12, pp. 2285-2293, Dec. 1992.

[2] K. Kitayama, A. Stöhr, T. Kuri, R. Heinzelmann, D. Jäger, and Y. Takahashi, "An approach to single optical component antenna base stations for broad-band millimeter-wave fiber-radio access systems," *Trans. Microw Theory Tech.*, vol. 48, no. 12, pp. 2588-2595, Dec. 2000.

[3] A. J. Seeds, "Microwave photonics," *IEEE Trans. Microw Theory Tech.*, vol. 50, no. 3, pp. 877-887, Mar. 2002.

[4] C.-S. Choi, H.-S. Kang, W.-Y. Choi, D.-H. Kim, and K.-S. Seo, "Phototransistors based on InP HEMTs and their application to millimeter-wave radio-on-fiber systems," *IEEE Trans. Microw Theory Tech.*, vol. 53, no. 1, pp. 256-263, Jan. 2005.

[5] T. Kuri, K. Kitayama, and Y. Ogawa, "Fiber-optic millimeter-wave uplink system incorporating remotely fed 60-GHz-band optical pilot tone", *IEEE Trans. Microw Theory Tech*., vol. 47, no. 7, pp. 1332-1337, Jul. 1999.

[6] J.-H. Seo, C.-S. Choi, W.-Y. Choi, Y.-S. Kang, Y.-D. Chung, and J. Kim, "Frequency conversion with cascaded SOA-EAM for bi-directional radio-on-fiber systems," *IEEE International Topical Meeting on Microwave Photonics*, pp. 56-59, 2004.

[7] J.-H. Seo, C.-S. Choi, W.-Y. Choi, Y.-S. Kang, Y.-D. Chung, and J. Kim, "Bi-directional 60 GHz radio-on-fiber systems using cascaded SOA-EAM frequency up/down-converters," will be presented at *IEEE MTT-S 2005 International Microwave Symposium*, 2005.

[8] D. M. Pozar, "Microwave and RF design of wireless systems," *John Wiley and Sons, Inc.* 2001.

[9] J. O'Reilly, and P. Lane, "Remote delivery of video services using mm-waves and optics," *J. Lightwave Technol.*, vol. 12, no. 2, Feb. 1994.

[10] J. Lim, Y.-S. Kang, K.-S. Choi, J.-H. Lee, S.-B. Kim, and J. Kim, "Analysis and characterization of traveling-wave electrode in electroabsorption modulator for radio-on-fiber application", *J. Lightwave Technol.*, vol. 21, no. 12, pp. 3004-3010, Dec. 2003.