# CONVERSION EFFICIENCY OF EAM OPTOELECTRONIC FREQUENCY DOWN-CONVERTERS


**Jun-Hyuk Seo(1), Chang-Soon Choi(2), Young-Shik Kang(3), Yong-Duck Chung(4),**

**Jeha Kim(5), and Woo-Young Choi(6)**

***(1) Department of Electrical and Electronic Engineering, Yonsei University, Seoul, 120-749, Korea, jhseo@yonsei.ac.kr***

***(2) As (1) above, but Email : cschoi@yonsei.ac.kr***

***(3) Electronics and Telecommunications Research Institute, Daejeon, 305-350, Korea, kys63344@etri.re.kr***

***(4) As (3) above, but Email : ydchung@etri.re.kr***

***(5) As (3) above, but Email : jeha@etri.re.kr***

***(6) As (1) above, but Email : wchoi@yonsei.ac.kr***



## ABSTRACT

We analyze the conversion efficiency of an optoelectronic frequency down-converter based on an electroabsorption (EAM) modulator for radio-on-fiber (RoF) uplink applications. The EAM modulator performs the frequency down-conversion of uplink RF signals into optical intermediate frequency (IF) using remotely-fed optical local oscillator (LO) signals. The frequency down-conversion efficiency depends on not only EAM nonlinearity but also optical IF signal powers delivered to the central station. In this paper, we define internal conversion efficiency as the photodetector output power ratio of frequency down-converted signals to EAM-modulating RF signals. Using this definition, we investigate conversion efficiency as functions of EAM bias, optical LO signal power, and optical IF signal power and wavelength, all of which are important design parameters in RoF systems.

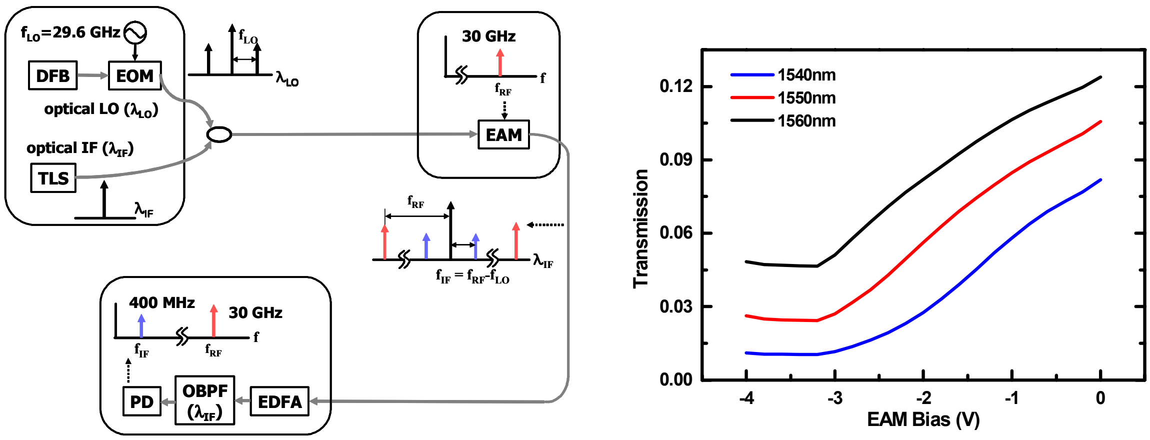

## INTRODUCTION

Radio-on-Fiber (RoF) systems has been investigated very much to realize millimeter-wave wireless systems, because they can support low loss, broadband radio signal transmission, and allow the centralization of expensive equipment and flexible network designs [1-3]. The key issue in RoF systems is simple and cost-effective base station implementation, for which electroabsorption modulator (EAM) based system designs have been widely investigated [2, 3]. Because EAM has dual-function of optical modulation and photodetection, base stations can be achieved with only one optical component. However, the intensity modulation and fiber transmission of uplink millimeter-wave carriers cause dispersion-induced signal fading problems [4]. Therefore, dispersion insensitive transmission methods such as optical single sideband transmission, or optical frequency down-conversion techniques were devised and combined with EAM based RoF links [3, 5]. We also proposed a dispersion insensitive intermediate frequency (IF) transmission method which uses remote frequency down-conversion using EAM nonlinearity [6].

For frequency converters, the conversion efficiency is an essential parameter to design RF systems of base stations. Therefore, in this paper, we investigate the frequency down-conversion efficiency of our proposed EAM frequency down-converter at 30-GHz band. To measure it, we also define internal conversion efficiency to exclude link loss effects that do not influence down-conversion process. Using this definition, we investigate down-conversion efficiency as functions of EAM bias, optical local oscillator (LO) signal power, and optical IF signal power and wavelength, all of which are important system parameters in RoF links.

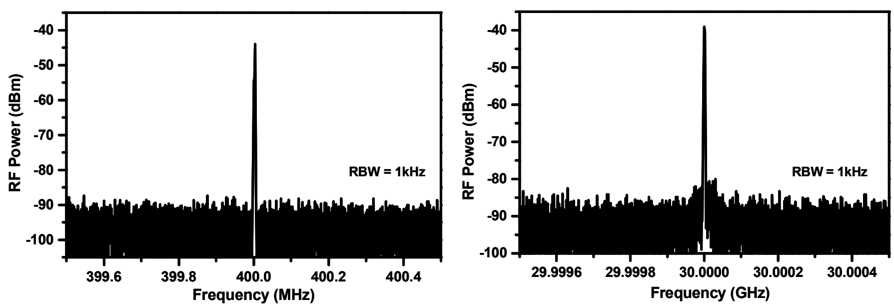
## EXPERIMENTAL SETUP AND CONVERSION EFFICIENCY DEFINITION

Fig. 1 (a) schematically shows the experimental setup and operation principle of the frequency down-conversion. For 29.6-GHz optical LO signals, 8-dBm, 29.6-GHz RF signals modulated a 40-GHz Mach-Zehnder modulator biased at the quadrature point. The wavelength of optical LO was 1553.3-nm. For the optical IF signals, a tunable laser source was used. These two optical signals were combined and injected into EAM, and 29.6-GHz signals were generated by EAM photodetection. The used EAM was designed and packaged for 40-GHz broadband applications [7], and fig. 1 (b) shows the optical transmission characteristics of EAM as a function of applied bias voltages. When 30-GHz RF signals for frequency down-conversion modulated EAM, optoelectronic mixing with photodetected 29.6-GHz signals produced frequency down-converted signals at 400-MHz by EAM nonlinearity, which were then modulated optical IF signals. After the amplification and filtering of optical IF signals, they are photodetected using a 32-GHz broadband photodetector, and 400-MHz frequency down-converted IF signals were generated. During the photodetection process, 30-GHz RF signals were also generated, because 30-GHz signals modulated optical IF signals, too. Fig. 2 (a) and (b) show the example RF spectra of frequency down-converted signals at 400-MHz and photodetected 30-GHz signals, respectively. Input optical LO power was 3-dBm and optical IF power was 0-dBm. The wavelength of optical IF was 1550-nm. With these results, the frequency down-conversion efficiency can be defined as the photodetected signal power ratio of frequency down-converted signals at 400-MHz to 30-GHz RF signals, by which link loss effects on frequency down-converted signals are removed and internal conversion efficiency can be calculated.




(a) (b)

Fig. 1. (a) Experimental setup for frequency down-conversion. DFB : Distributed Feedback Laser, EOM : Electrooptic Modulator, TLS : Tunable Laser Source, EDFA : Erbium-Doped Fiber Amplifier, OBPF : Optical BandPass Filter, PD : Photodetector, (b) Optical transmission characteristics as a function of bias voltage in EAM.




(a) (b)

Fig. 2. (a) Frequency down-converted signal RF spectrum. A 20-dB gain electrical amplifier was used after photodetector. (b) Photodetected RF signals for frequency down-conversion.

**DOWN-CONVERSION EFFICINECY RESULTS**

Fig. 3 shows the dependence of frequency down-conversion efficiency on EAM bias. The power of optical LO was 3-dBm, and optical IF at 1550-nm was 0-dBm. After the RF power measurement of each signal, the gain of an electrical amplifier for 400-MHz signals and the different frequency response of the 32-GHz photodiode were corrected for the efficiency calculation. These corrections were applied to every down-conversion efficiency measurement. As shown in the figure, the conversion efficiency is the highest at around -1.4V, and the dependence of bias voltage is similar to the

EAM modulation efficiency characteristics. Because the frequency down-converted IF signals should modulate optical IF signals, EAM modulation efficiency affects down-conversion efficiency very much in this frequency converter.
Next, we measured down-conversion efficiency as a function of EAM input optical LO power. The power of optical IF at 1550-nm was 0-dBm, and the EAM was biased at -1.4V. The LO signal power is an important parameter for electrical frequency converters, because it determines the performance of frequency converters very much. For this frequency down-converter, optical LO power affects the conversion efficiency greatly. Fig. 4 shows the measured results of frequency down-conversion efficiency. When optical power increases 1-dB, photodetected LO power inside EAM increases 2-dB, which results in the about 2-dB increase of frequency down-converted signal power. However, the change of optical LO power hardly affects 30-GHz signals. Therefore, the slope of frequency down-conversion efficiency according to optical LO power is about two. The conversion efficiency saturation is also observed when optical LO power is larger than -2-dBm.

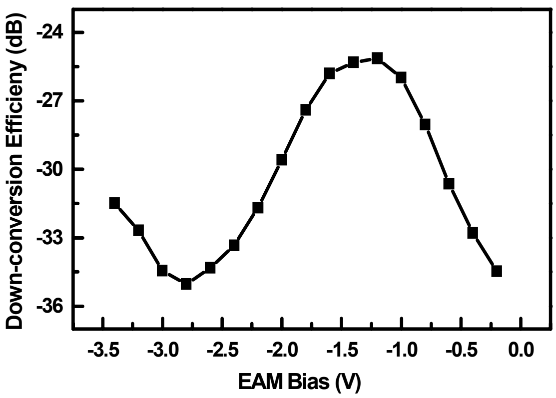



Fig. 3. Down-conversion efficiency as a function of EAM bias voltage.

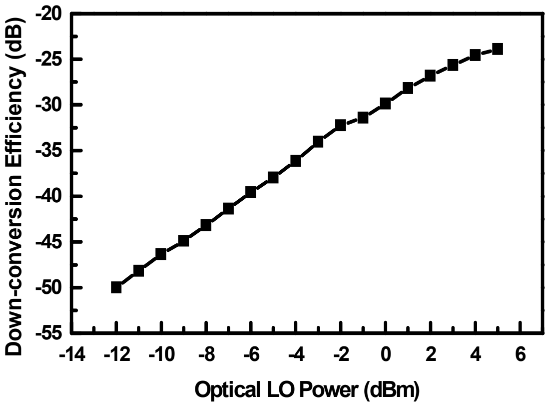
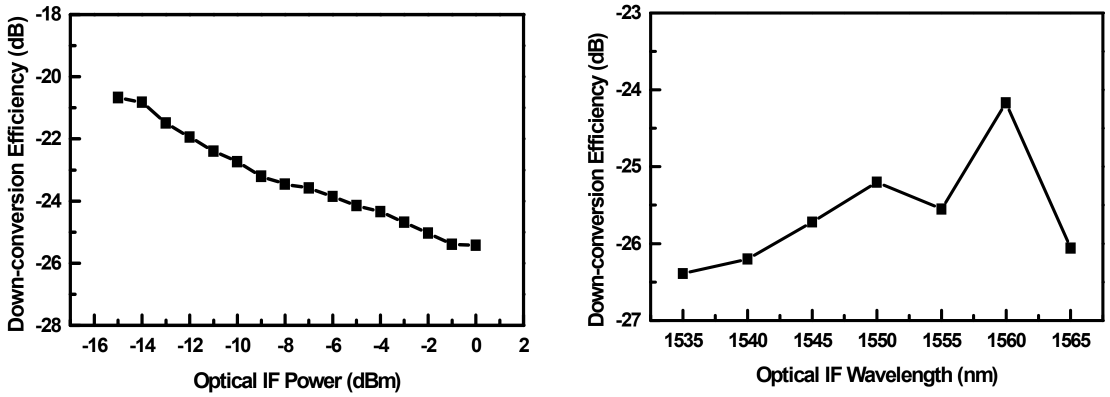



Fig. 4. Down-conversion efficiency as a function of EAM input optical LO signal power.

The dependence of frequency down-conversion efficiency on EAM input optical IF signals was also evaluated. Fig. 5 (a) shows the effects of optical IF power on down-conversion efficiency. For this measurement, the optical LO power was 3-dBm, and optical IF wavelength was 1550-nm. EAM was biased at -1.4V. The frequency down-conversion efficiency was decreased about 5-dB with the increase of optical IF power from -15-dBm to 0-dBm. In fact, the down-conversion efficiency should remain constant because the optical IF power equally affects both frequency down-converted signals and photodetected 30-GHz signals. However, when the optical IF power increased 1-dB, the frequency down-converted signals increased at the rate of about 1.7-dB contrary to the 2-dB increase of 30-GHz RF signals, which makes about 5-dB efficiency change. This is believed due to EAM saturation caused by 3-dBm optical LO power.
Fig. 5 (b) shows the measurement results of down-conversion efficiency as a function of optical IF wavelength. The optical LO and IF power was 3-dBm and 0-dBm, respectively. EAM was biased at -1.4V. The wavelength of optical IF

was changed from 1535-nm to 1565-nm. As shown in the figure, the down-conversion efficiency is changed about 2.5-dB within this optical IF wavelength range. This range is wide enough to adopt this frequency down-converter for the wavelength division multiplexing RoF systems. The results of uplink data transmission using this frequency down-conversion method will be presented in [8], which shows successful data transmission at the wide optical IF wavelength range.




(a) (b)

Fig. 5. Down-conversion efficiency as a function of EAM input optical IF signal power (a), and wavelength (b).

**Conclusion**

We investigated the frequency down-conversion efficiency of an EAM based frequency down-converter for the uplink RoF systems. To exclude the effects of optical components in the experiment that are not related to the frequency down conversion, we defined internal down-conversion efficiency, and measured it as functions of EAM bias, EAM input optical LO power, and optical IF power and wavelength. It was found that EAM should be biased at the voltage of efficient EAM modulation conditions, and optical LO power should be large for the high conversion efficiency. The effects of optical IF power and wavelength were also analyzed, and the wide operation wavelength range of optical IF signals was verified.

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