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Cascaded SOA-EAM Configuration for Millimeter-wave Frequency Up/Down-conversion

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Abstract — We present a novel frequency up/down-converter based on cascaded SOA-EAM configuration for millimeter-wave radio-on-fiber systems. In this scheme, SOA cross-gain modulation is used for frequency up-conversion and EAM nonlinearity is used for frequency down-conversion. Moreover, frequency up/down-conversion is performed with the help of remotely-fed optical heterodyne LO signals, which makes the base station architecture simple and cost-effective.

I. INTRODUCTION

With the rapid progress in wireless communications, broadband radio systems have become one of the main research topics, and millimeter-wave radio-on-fiber systems are widely investigated due to low loss signal transmission and the centralization of expensive equipment [1-9]. These investigations are mainly focused on simple and cost-effective base stations, and EAM transceivers are very attractive for realizing efficient radio-on-fiber systems [1-5]. The EAM has two functionalities of photo-detection and optical modulation, which can eliminate uplink optical sources in bi-directional links. However, when millimeter-wave data signals are simply intensity-modulated by optical components and transmitted via fiber, chromatic dispersion induces signal fading problems after photo-detection [7]. As one solution, optical/optoelectronic frequency up/down-conversion techniques are utilized in radio-on-fiber systems [1-6].

In this paper, we demonstrate a new frequency up/down-conversion method for dispersion insensitive systems, which uses a single cascaded SOA-EAM configuration. The SOA cross-gain modulation and EAM photo-detection are used for frequency up-conversion and the EAM nonlinearity is used for frequency down-conversion. In this configuration, millimeter-wave local oscillator (LO) signals are optically delivered from the central station, and uplink intermediate frequency (IF) optical sources can be shared between up and downlink. Therefore, very simple and cost-effective base stations are possible. In addition, the use of optical IF signals easily allows different services or

wavelength channels. To verify the performance of this frequency up/down-converter, 100 MHz IF signals were frequency up-converted to 60 GHz band at the base station, and 60 GHz band RF signals are frequency down-converted to 150 MHz and returned to the central station.

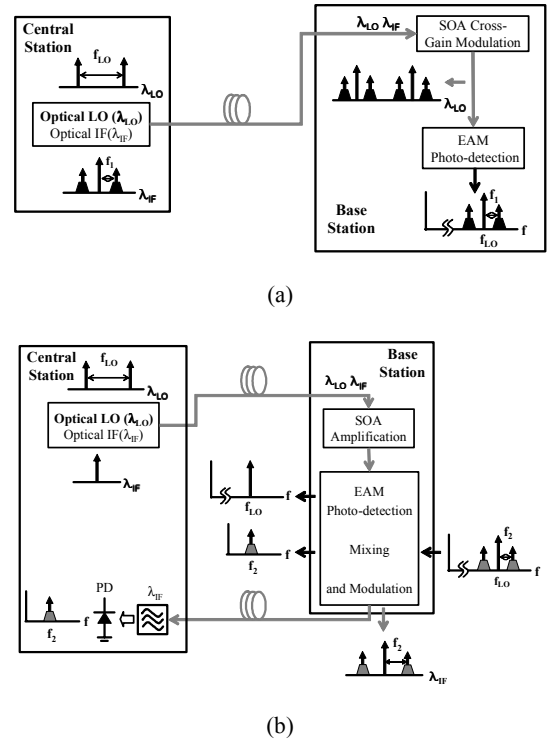


Fig. 1. Basic operation schematic using cascaded SOA-EAM for frequency up-conversion (a) and frequency down-conversion (b).

II. OPERATION PRINCIPLES

Fig. 1 (a) and (b) schematically show the operation principles of frequency up- and down-conversion using SOA-EAM configuration, respectively. When optical LO having two optical modes separated by f_{LO} at λ_{LO} and optical IF at λ_{IF} having two sidebands separated from the

carrier by f_1 are transmitted from the central station and injected into the SOA in the base station, two modes of optical LO are cross-gain modulated by optical IF signals. After photo-detection in EAM, frequency up-converted signals at f_{LO} band can be obtained as square-law beating products. This frequency up-conversion process is essentially same as in SOA-PD configuration reported in [8].

When the same EAM is modulated by the uplink signals having sidebands separated from the carrier (f_{LO}) by f_2 , frequency down-converted signals at f_2 are generated by the optoelectronic mixing with the photo-detected f_{LO} signals. This optoelectronic mixing occurs due to the EAM nonlinearity as explained in [5]. The frequency down-converted signal at f_2 modulates the optical IF signal (λ_{IF}), which is then transmitted to the central station.

The advantages of this cascaded SOA-EAM frequency converter are as follows. First, dispersion insensitive bi-directional data transmission is possible with simple base station design which does not require expensive high frequency phase-locked oscillators and mixers. Second, SOA provides frequency up-conversion gain [8] which can compensate the EAM insertion loss, which is very helpful for uplink data transmission. In addition, since optical LO signals are separated from optical IF signals, optical LO can be shared among several base stations and WDM techniques can be used for multiplexing optical IF signals to different base stations. Fig. 2 shows the system configuration of bi-directional radio-on-fiber link adopting the SOA-EAM frequency converter.

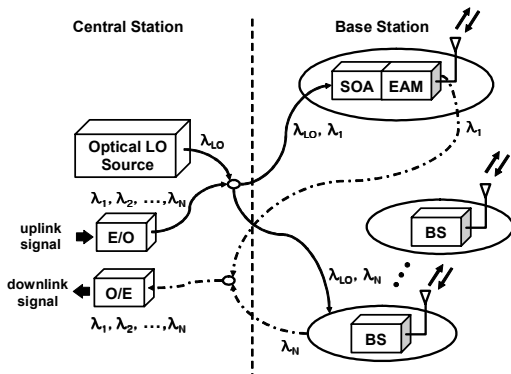
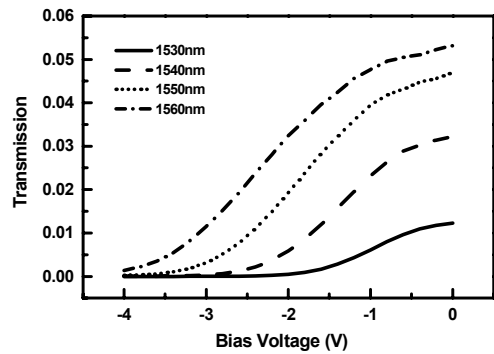


Fig. 2. System schematic with SOA-EAM configuration for the bi-directional radio-on-fiber link.

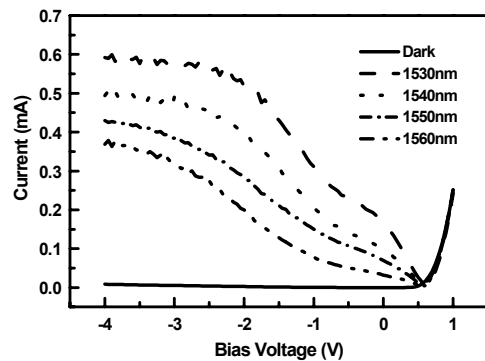
III. EXPERIMENT AND RESULTS

The EAM used in this experiment has a multiple-quantum well structure and is packaged for 60 GHz narrow-band application. Details of EAM characteristics can be found in

[9]. Fig. 3 (a) shows the optical transmission characteristics of the packaged EAM as a function of bias voltages at different input wavelengths. The insertion loss for 0 V bias is about 11 dB at $\lambda=1550$ nm. Fig. 3 (b) shows the photo-current characteristics of the packaged EAM as a function of bias voltages at different input wavelengths. To measure the results, 0 dBm optical power is injected into the EAM. When the EAM is biased at -2 V, the estimated responsivity ranges from 0.2 A/W to 0.5 A/W including insertion loss.



(a)



(b)

Fig. 3 (a) Optical transmission characteristics, (b) photo-detection characteristics. To measure the results, 0 dBm optical signal is used.

Fig. 4 shows the experimental setup for frequency up/down-conversion using the SOA-EAM configuration. 60 GHz optical LO signals were generated by modulating a Mach-Zehnder modulator biased at minimum transmission point with a 30 GHz signal. The wavelength of optical LO was 1553.3 nm. For the frequency up-conversion, optical IF signals were produced by modulating another MZ modulator with 100 MHz IF signals. Both optical signals were combined and injected into the cascaded SOA-EAM, producing frequency up-converted signals in 60 GHz band. The SOA was biased at 150 mA, which gave 25 dB optical gain, and output saturation power was 7 dBm.

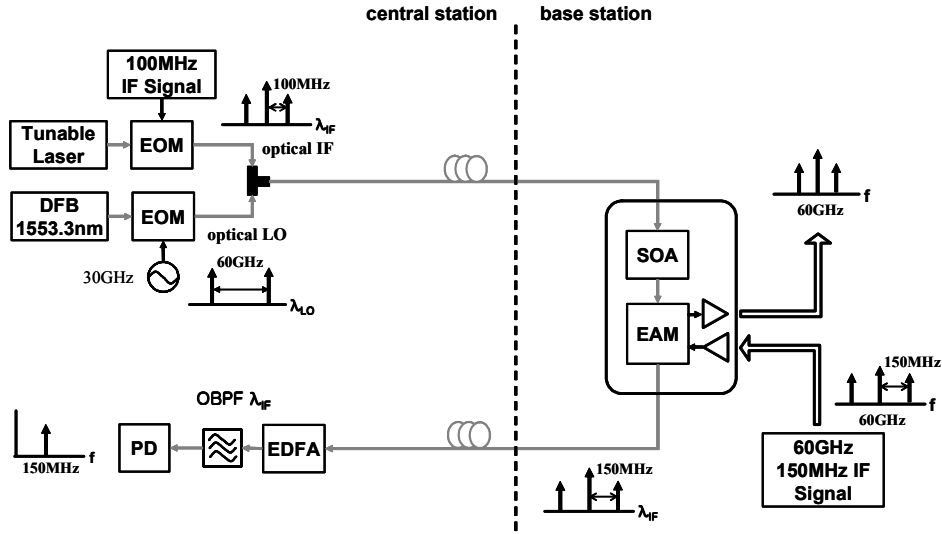


Fig. 4. Experimental setup for frequency up/down-conversion using SOA-EAM configuration. EOM : Electro-Optic Modulator, DFB : Distributed Feedback semiconductor laser, EDFA : Erbium-Doped Fiber Amplifier, OBPF : Optical Bandpass Filter, PD : Photo-Detector.

For the frequency down-conversion, 60 GHz band signals having 150 MHz separated sidebands were used to modulate the same EAM. These signals were optoelectronically mixed with 60 GHz optical LO inside the EAM and down-converted to 150 MHz. At the same time, the optical IF from the central station was modulated by 150 MHz frequency down-converted signals, which were then transmitted to the central station. In the central station, the uplink signals were photo-detected after optical amplification and filtering. All the results were measured at the back-to-back conditions.

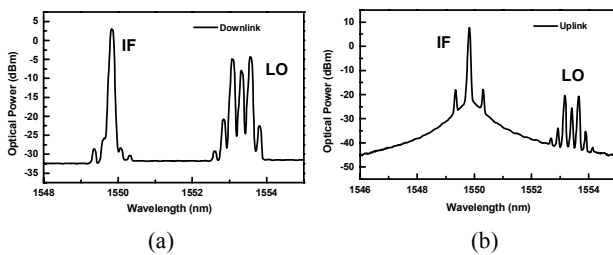


Fig. 5. Optical spectrum of downlink signals (a) and uplink signals (b).

Fig. 5 (a) and (b) show the optical spectra of the downlink and uplink signals, respectively. Fig. 5 (a) was obtained from the optical signals coming out of the SOA, and 1550 nm optical IF and 1553.3 nm optical LO can be seen. Fig. 5 (b) was obtained from the output of the optical bandpass filter (center wavelength of 1550nm) in the central station. As shown in this figure, the optical LO is

suppressed about 30 dB compared with the optical IF and does not affect data signals. The side peaks of the optical IF in figure (a) and (b) are the result of 60 GHz signal modulation in the SOA and EAM, respectively. However, their effects on transmission performance are negligible.

The RF spectra of frequency converted signals were measured to verify the performance of the SOA-EAM frequency converter. Fig. 6 shows the RF spectrum of frequency up-converted signals. For this measurement, -16.3 dBm optical LO and -10 dBm optical IF were injected into the SOA, and 17 dB gain 60 GHz RF amplifier is used after the EAM. As can be seen in the figure, 100 MHz signals optically delivered from the central station are successfully frequency up-converted to 60 GHz band. Fig. 7 shows the 150 MHz RF spectrum of frequency down-converted signals measured at the central station. To measure the spectrum, -15 dBm optical LO and -8 dBm optical IF signals injected into the SOA, and the same 60 GHz RF amplifier is used before EAM modulation. In this case, 60 GHz band RF signals are also successfully down-converted to 150 MHz and transmitted to central station via optical IF signal.

In addition, as a feasibility test, 10 Mbps QPSK data signals were modulated to downlink IF signals and uplink RF signals. After frequency up- and down-conversion, and signal demodulation, the measured error vector magnitude (EVM) was about 3.3 % and 7.4 %, respectively. These measured EVM should be more than sufficient for many applications. From these results, we believe that this SOA-

EAM frequency converter is very useful and sufficient for bi-directional radio-on-fiber systems.

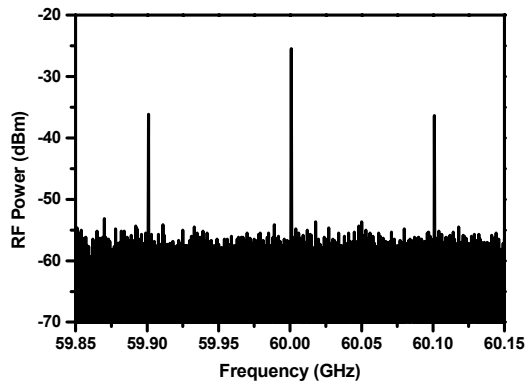


Fig. 6. (a) RF spectrum of frequency up-converted signals at 60 GHz band.

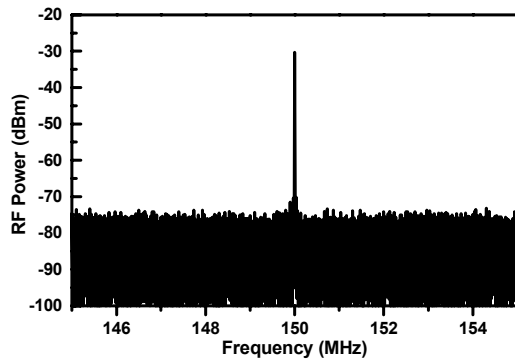


Fig. 7. (a) RF spectrum of frequency down-converted signals at 150 MHz.

IV. CONCLUSION

We demonstrated a novel frequency up/down-converter using cascaded SOA-EAM configuration for bi-directional radio-on-fiber systems. The advantages of this configuration are not only dispersion insensitive data transmission with low frequency IF signals, but also realization of a very simple base station. In addition, optical LO signals can be shared with several base stations and various optical IF signals can be easily adopted. To verify the performance of our frequency converter, 100 MHz IF is optically transmitted to the base station and frequency up-converted to 60 GHz band and 150 MHz IF is down-converted from 60 GHz, and modulates optical IF, which is then transmitted to the central station. In addition, as a feasibility test, 10 Mbps QPSK data signals were transmitted through up and downlink and demodulated successfully.

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