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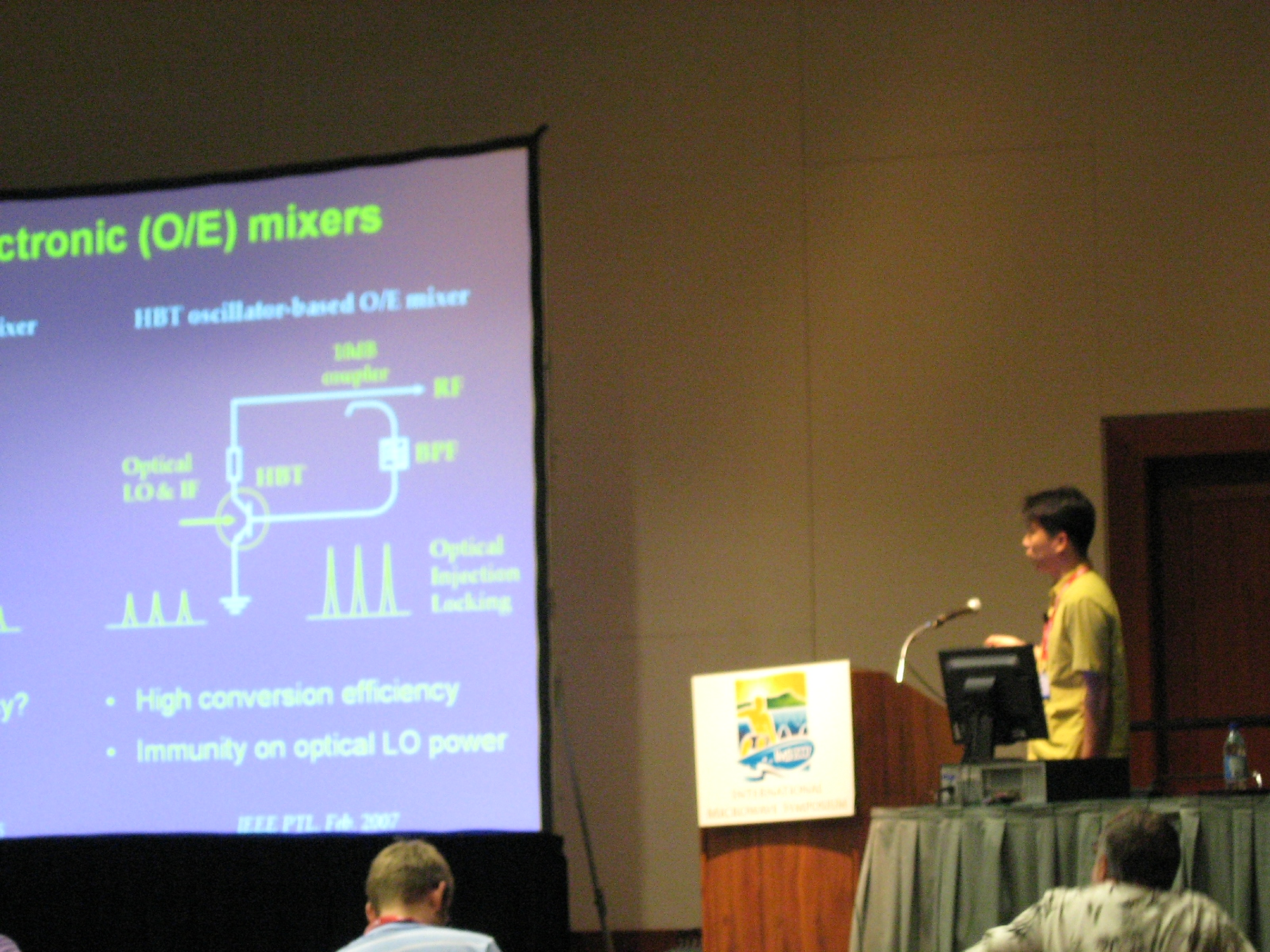
ctronic (O/E) mixers
HBT oscillator-based O/E mixer
10dB coupler
RF
BPF
Optical LO & IF
HBT
Optical Injection Locking
• High conversion efficiency
• Immunity on optical LO power
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Optically Injection-locked Self-oscillating HBT MMIC Optoelectronic Mixer for Bi-directional Fiber-fed Wireless Links

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***Abstract* — 30GHz bi-directional fiber-fed wireless link is realized using an optically injection-locked self-oscillating HBT optoelectronic mixer as a harmonic frequency up- and down-converter. Bi-directional transmissions of 32 QAM data are successfully demonstrated.**

***Index Terms* — InP HBT, optoelectronic mixer, optical injection locking, OIL-SOM, MMIC, fiber-fed wireless link.**

I. INTRODUCTION

The increasing demand for high-speed wireless communication systems has awaken interests for the millimeter-wave band, which can offer wide bandwidth up to several GHz. The wireless communication systems in millimeter-wave band need a large number of antenna base stations (ABSs) due to high transmission loss of millimeter-waves in air. Consequently, there is a need for careful network design that can support simple antenna base station architecture for overall cost reduction. In wireless networks, ABSs need to perform generation of LO (local oscillation) signal, amplification, and frequency conversion between IF (immediate frequency) and RF (radio frequency) bands. However, millimeter-wave components such as phase-locked oscillators, power amplifiers and mixers are as of now very complex and expensive for realizing simple ABS architecture.

The fiber-fed millimeter-wave wireless system utilizing an optoelectronic (O/E) mixer and the optical LO distribution scheme [1]-[6] is an attractive solution for this problem. In this scheme, by using optical fiber as a transmission medium between CS and ABSs, the millimeter-wave LO signals can be generated in CS and distributed to numerous ABSs in the optical domain. In this scheme, the O/E mixer at ABS plays a key role including photo-detection of optical LO and IF signals and frequency up/down conversion of downlink IF and uplink RF signals.

Several types of O/E mixers have been investigated based on photonic [2]-[3] and microwave technologies [4]-[6]. Among them, the InP heterojunction bipolar transistor (HBT)-based Optically Injection-Locked Self-oscillating O/E Mixer (OIL-SOM) has many advantages. The InP HBT inside OIL-SOM offers wide photo-detection bandwidth and high optical responsivity for optically injected LO and IF signals. Also, the self-oscillating of OIL-SOM provides high conversion efficiency independent of injected optical LO power.

Previously, we demonstrated above advantages with a 30GHz OIL-SOM implemented in the hybrid configuration and reported downlink data transmission using the hybrid OIL-SOM as a harmonic O/E up-converter [6]. In this paper, we report 30GHz bi-directional data transmission using MMIC OIL-SOM as a harmonic frequency up/down-converter.

II. PROPOSED SCHEME

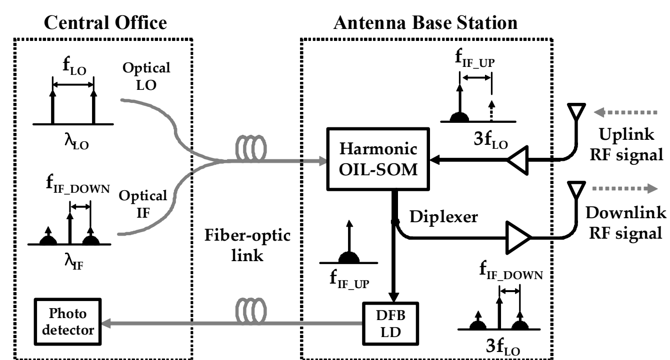

Fig. 1. Schematic diagram of bi-directional fiber-fed wireless system using OIL-SOM as a harmonic frequency up/down converter.

Fig. 1 schematically shows the 30GHz bi-directional fiber-fed wireless system using 10 GHz MMIC OIL-SOM as a harmonic frequency up/down converter. When 10GHz optical LO signals generated in CS are injected into the free-running MMIC oscillator in ABS, the oscillator is optically injection-locked to optical LO resulting in phase noise reduction. For downlink transmission, the optical IF signals delivered through fiber are photo-detected and harmonically frequency up-converted to 30GHz with the help of phase-locked LO signal. These signals are transmitted to mobile terminals through the antenna. In addition, the uplink RF signals from mobile terminals in 30GHz are received from the antenna and delivered to OIL-SOM through the base terminal of HBT inside oscillator. The uplink RF signals are harmonically frequency down-converted to IF band and optically

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transmitted to CS using direct modulation of a laser diode. The MMIC OIL-SOM simultaneously performs photo-detection, local oscillation and frequency up/down conversion resulting in great simplification of ABSs.

III. DOWNLINK DATA TRANSMISSION

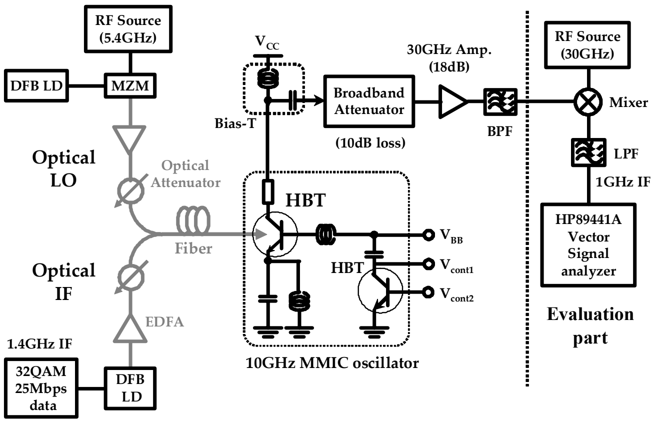

Fig. 2. Experimental setup for 30GHz downlink data transmission using InP HPT-based MMIC OIL-SOM.

Fig. 2 shows the experimental setup for 30GHz downlink data transmission using OIL-SOM. The detailed description for the MMIC oscillator used in our investigation can be found in [7]. 10.8GHz optical LO was generated with the double-sideband suppressed-carrier method [8], in which two optical modes separated by 10.8GHz were generated with a Mach-Zehnder modulator biased at V_π and modulated with 5.4GHz RF signal. When the optical LO was injected into the 10GHz-band free-running oscillator, the oscillator was injection-locked by the optical LO and generated the 3rd harmonic phase-locked LO signals at 32.4GHz. These were measured with a spectrum analyzer after passing through a broadband attenuator and a 30GHz amplifier. A broadband attenuator with 10dB loss was used because the 30GHz amplifier was not impedance-matched in 10GHz band, resulting in unstable operation if used by itself.

Fig. 3 (a) shows the spectrum of optically injection-locked 32.4GHz LO signal when injected optical LO power was 0dBm. This reduction of phase noise by optical injection-locking is clearly demonstrated in Fig. 3 (b) in which the results of single-sideband phase noise measurement are shown for free-running and injection-locked 32.4GHz signals. The advantage of MMIC OIL-SOM compared to hybrid one is the wide locking range, because the MMIC oscillator provides relatively low Q-factor. The measured locking range of MMIC oscillator used in our experiment was about 1.5GHz when the power of optical LO was 6dBm as shown in Fig. 3 (c). The wide locking range is very important because it allows variation of oscillation frequency due to fabrication errors and/or temperature changes.

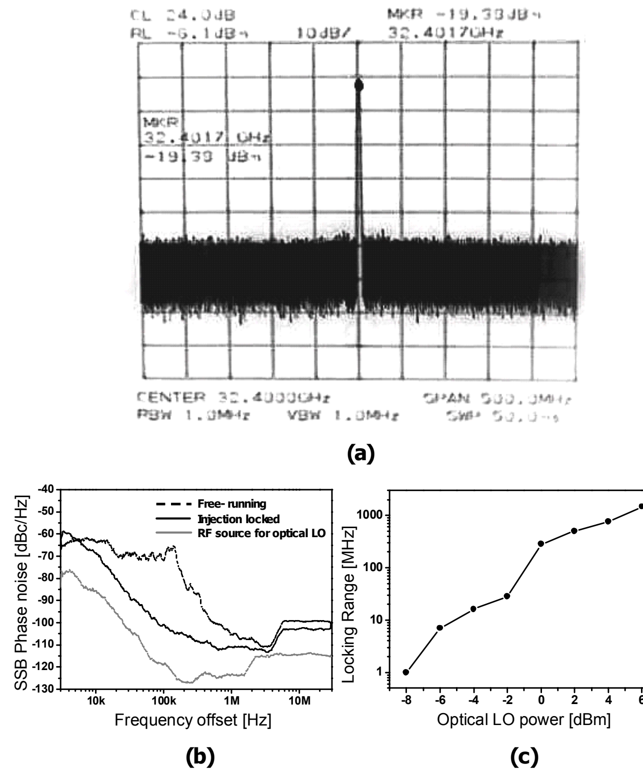

Fig. 3. (a) Spectrum of optically injection-locked 3rd harmonic LO (b) SSB phase noise of 3rd harmonic free-running and injection-locked LO and 5.4GHz RF signal (c) locking ranges of MMIC oscillator as a function of optical LO power.

For downlink data transmission, optical IF signals were generated by direct modulation of DFB LD (distributed feedback laser diode) with 25Mbps 32QAM signals at 1.4GHz IF and injected into OIL-SOM through fiber as shown in Fig. 2. The optical IF signals were firstly photo-detected, amplified and harmonically frequency up-converted to 30GHz-band with the help of injection-locked LO signal as shown in Fig. 4. In practical systems, these RF signals would be radiated to mobile terminal using an antenna. However, we left out the wireless link transmission due to our experimental circumstances.

For evaluation, the up-converted signals were down-converted to 1GHz IF band using an electrical mixer and BPF, and demodulated by a vector signal analyzer (VSA). When both optical LO and IF power were 0dBm, the measured error vector magnitude (EVM) of the demodulated signal was 4.34%, which is sufficient for most wireless applications. The inset of Fig. 5 shows the constellation of demodulated 32QAM signal. The EVMs were measured as a function of incident optical LO powers and the results are shown in Fig. 5. They show that there is an optimum range of optical LO power from 0dBm to 4dBm. When the optical LO power was less than 0dBm, the EVM increased due to phase error increase. On the other hand, when the optical LO power was larger than 4dBm, the EVM increased due to degradation of conversion efficiency caused by the saturation effect of the oscillator under high power optical illumination. Fig. 6 shows the measured EVMs as s function of optical IF power, in which the degradation of EVM by high power optical illumination also can be observed when optical IF power is lager than 2dBm.

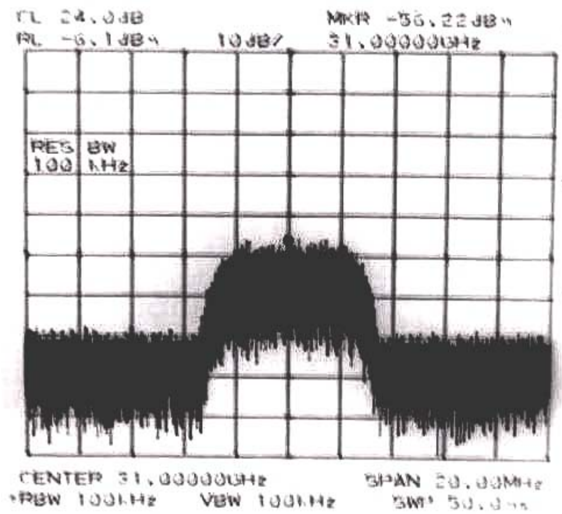

Fig. 4. Spectrum of frequency up-converted 31GHz RF/data signals when both of optical LO and IF powers are 0dBm.

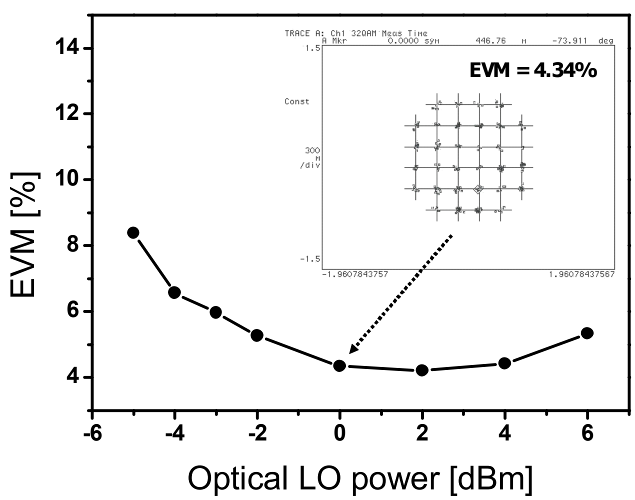

Fig. 5. EVMs as a function of optical LO power when the optical IF power is 0dBm.

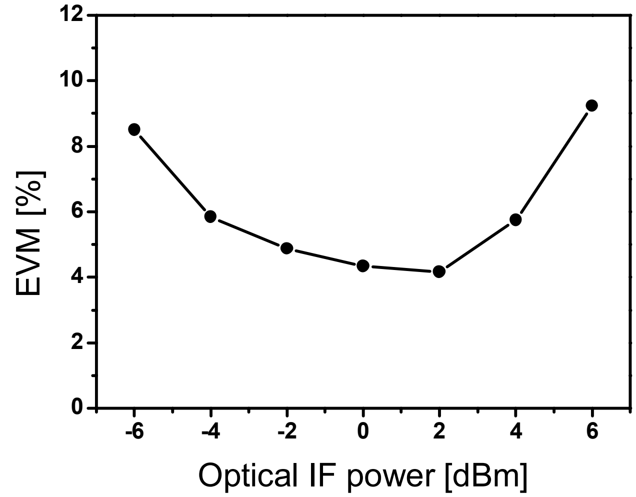

Fig. 6. EVMs as a function of optical IF power when the optical LO power is 0dBm.

IV. Uplink data transmission

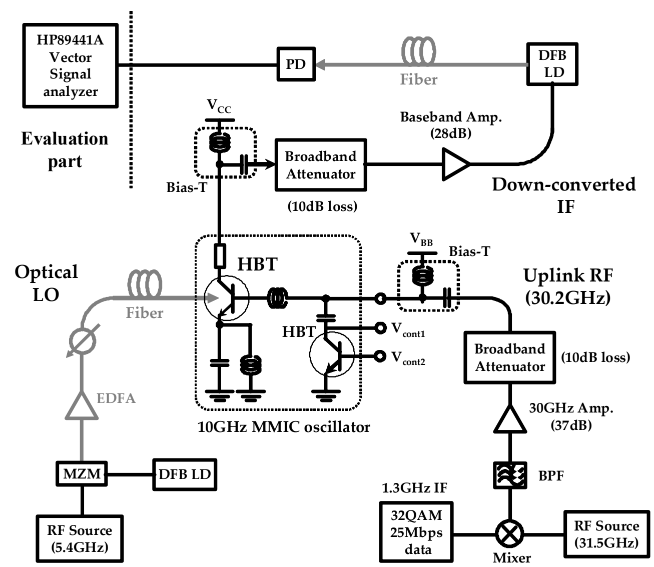

Fig. 7. Experimental setup for 30GHz uplink data transmission using InP HPT-based MMIC OIL-SOM.

Fig. 7 shows the experimental setup for uplink data transmission. For generation of 30GHz-band uplink RF signals, 25Mbps 32QAM signals with 1.3GHz IF were frequency up-converted to 30GHz-band using an electrical mixer and 31.5GHz electrical LO signal. After passing through BPF, amplifier and broadband attenuator, 30.2GHz RF signals were injected into the base terminal of HBT oscillator. The broadband attenuator was attached at both collector and base terminals of HBT oscillator for impedance matching in 10GHz-band, resulting in SNR degradation of about 20dB. The uplink RF signals injected to OIL-SOM were harmonically frequency down-converted to 1GHz IF-band as shown in Fig. 8. For uplink optical transmission, the frequency down-converted signals directly modulated a DFB LD and the resulting optical signal was measured by a photo-detector. The link loss of the uplink optical transmission was about 10dB.

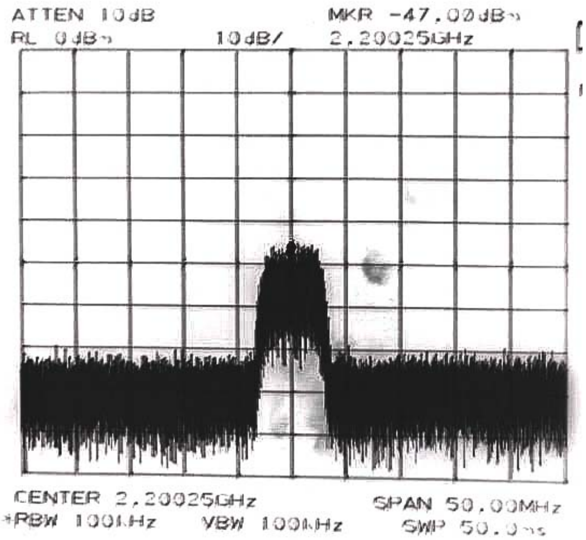

Fig. 8. Spectrum of frequency down-converted IF/data signals when optical LO and electrical IF powers are 0dBm and -2dBm, separately.

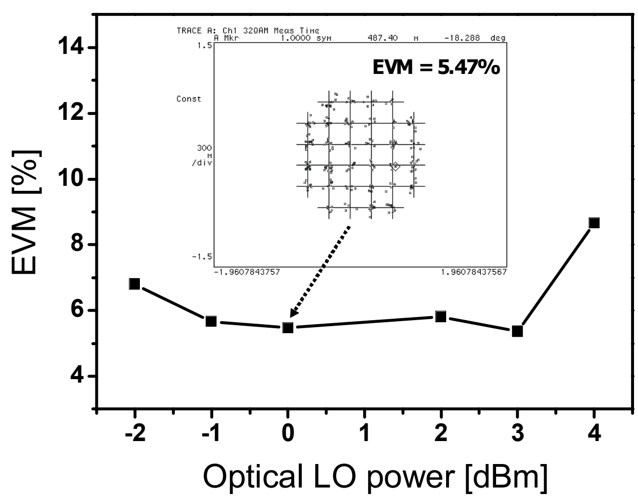

Fig. 9. EVMs as a function of optical LO power when the incident RF power is -2dBm.

After uplink optical transmission, IF signals were measured by VSA for evaluation. The EVMs measured as a function of optical LO power are shown in Fig. 9. The results show that there is an optimum range of optical LO power from -1dBm to 3dBm. The inset of Fig. 8 shows the constellation of demodulated 32QAM signal when the injected optical LO and electrical RF powers were 0dBm and -2dBm, respectively, in which the EVM was 5.47%. The resulting EVM values for uplink transmission are relatively larger than those for downlink due to lower SNR. It is because down-conversion efficiency of OIL-SOM is lower than up-conversion efficiency.

V. Conclusion

The 10GHz InP MMIC OIL-SOM was used as a harmonic optoelectronic up/down-converter and 30GHz fiber-fed wireless links were successfully demonstrated for bi-directional transmission of 25Mbps 32QAM signals.

Acknowledgement

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