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30GHz-band Radio-on-fiber downlink data transmission using InP HPT-based MMIC OIL-SOM

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***Abstract* — A 10GHz-band optically injection-locked self-oscillating optoelectronic mixer is implemented with an MMIC HPT oscillator. Using this mixer as a harmonic frequency up-converter, 30GHz radio-on-fiber downlink is realized and 25Mbps 32QAM data are successfully transmitted.**

***Index Terms* — optical injection locking, locking range, optoelectronic mixer, HPT, radio-on-fiber.**

I. INTRODUCTION

The rapid progress in wireless communication technology stimulates interests for millimeter-wave wireless data transmission systems that can support high data rates. In millimeter-wave wireless systems, the cell size should be small and a large number of antenna base stations are required due to the high transmission loss of millimeter-waves in air. Consequently, development of the cost-effective antenna base station is the main issue of research for this system.

The antenna base station performs such functions as generation of LO (local oscillation) signal, frequency conversion between IF (immediate frequency) and RF (Radio frequency) bands, and amplification of RF signals. The biggest obstacle in realizing simple antenna base stations is the millimeter-wave band phase-locked oscillators that are complex and expensive. The fiber-fed millimeter-wave wireless system utilizing an optoelectronic (O/E) mixer and the optical LO distribution scheme [1]-[3] is an attractive solution for this problem. In this scheme, by using optical fiber as a transmission medium between central and antenna base stations, the millimeter-wave LO signals can be generated in central station and distributed to numerous antenna base stations. This method can eliminate the phase-locked millimeter-wave LO generator in antenna base stations and greatly reduces the complexity. The data signals can be transmitted from central to base stations also through optical fiber in the IF domain. In antenna base station, the O/E mixer performs photo-detection of optically transmitted IF/data signals and frequency up-conversion into the desired RF band with help of the optically distributed LO signal.

For O/E mixer, InP heterojunction phototransistor (HPT) O/E mixers [1] and optically injection-locked self-oscillating optoelectronic mixers (OIL-SOMs) [2-3] have been investigated. The InP HPT has the layer structure fully compatible with monolithic microwave integrated circuit (MMIC) technology [4] and, consequently, the system-on-chip solution for the entire base-station is possible. Also, the high optical responsivity of InP HPT-based O/E mixers offer higher O/E conversion efficiency. The OIL-SOM has higher conversion efficiency than simple HPT O/E mixer because the LO power of OIL-SOM depends only on the power of free-running oscillator not on injected optical LO power. Also, by the same reason, the conversion efficiency of OIL-SOM is not sensitive on optically injected optical LO power while the variation of optical LO power directly influences for performance of the HPT O/E mixer.

Previously, we demonstrated the above advantages with a 30GHz OIL-SOM implemented in the hybrid configuration and reported 60GHz-band RoF data transmission using the OIL-SOM as a harmonic O/E up-converter [3]. In this paper, we report an 10GHz OIL-SOM based on MMIC HPT oscillator for 30GHz band RoF data transmission using the OIL-SOM as a harmonic frequency up-converter.

II. SCHEME

Figure 1 schematically shows the 30GHz RoF downlink system using a 10GHz MMIC oscillator as a harmonic O/E frequency up-converter. When the 10GHz optical LO signals generated in central station are injected into a free-running 10GHz oscillator through optical fiber, the free-running oscillator is optically injection-locked by optical LO resulting in phase noise reduction. At the same time, the optical IF signals injected along with optical LO are photo-detected and harmonically frequency up-converted to 30GHz band with help of 10GHz injection-locked LO. The up-converted RF signals are transmitted to mobile terminal through an antenna after amplification and filtering. By using the MMIC OIL-SOM as a harmonic frequency up-converter, the antenna base station can be significantly simplified because the photo-detection, local oscillation and frequency up-conversion can be performed in a single HPT oscillator.

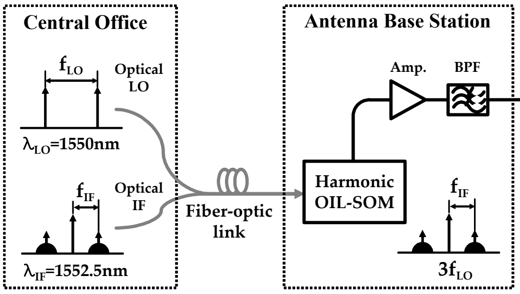

Figure 1 Schematic diagram of MMIC OIL-SOM-based 30GHz RoF downlink systems

III. CHARACTERISTICS OF MMIC OIL-SOM

Figure 2 shows the experimental setup for 30GHz RoF downlink data transmission using the OIL-SOM. Before the data transmission experiment, we first investigated the injection-locking characteristics of MMIC OIL-SOM with the same setup. The detailed description for the MMIC oscillator used in our investigation can be found in [5]. 10.8GHz optical LO was generated with the double-sideband suppressed-carrier method [6], in which two optical modes separated by the desired LO frequency of 10.8GHz were generated with a Mach-Zehnder modulator biased at V_π and 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. The resulting 3rd harmonic injection-locked LO signals at 32.4GHz were measured with a spectrum analyzer after passing through a broadband attenuator and a 30GHz band amplifier. Because the 30GHz amplifier was impedance matched just in the 30GHz band, the impedance mismatch in 10GHz band causes instability in the oscillator. In order to solve this problem, a broadband attenuator having about 10dB loss was inserted between the output oscillator port and the amplifier for impedance matching.

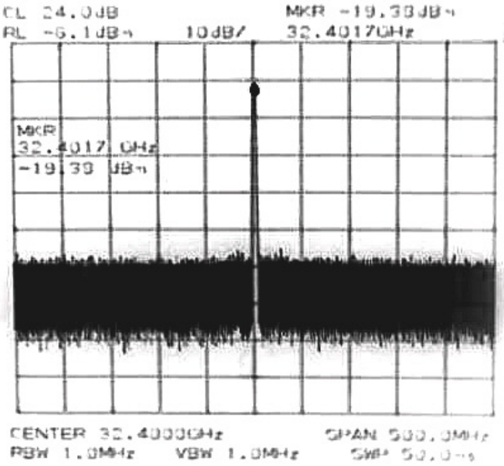

Figure 3 Spectrum of 32.4GHz optically injection locked LO when injected optical LO power is 0dBm

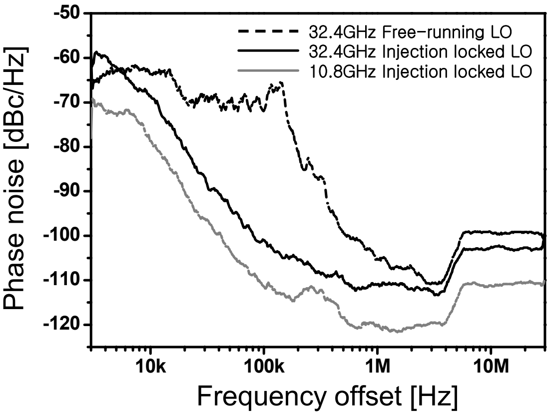

Figure 4 Phase noise of 32.4GHz free-running LO and 32.4GHz and 10.8GHz injection-locked LO

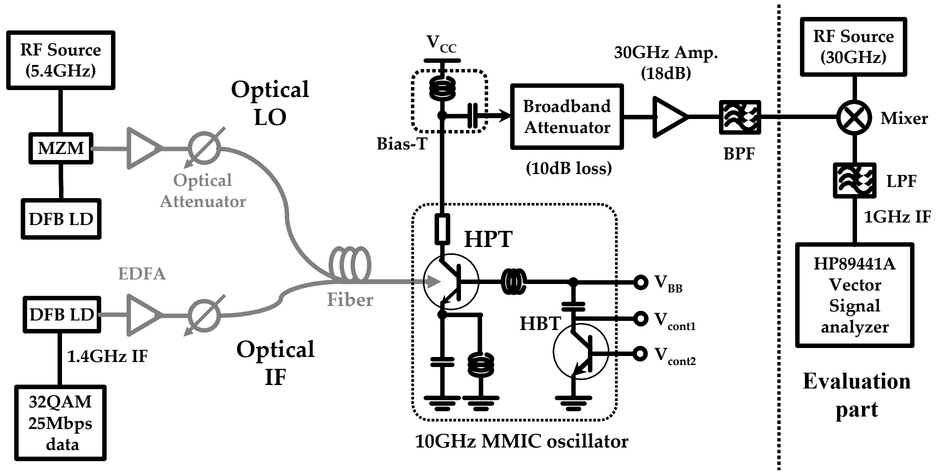

Figure 2 Experimental setup for 30GHz downlink data transmission using InP HPT-based MMIC OIL-SOM

The spectrum of optically injection-locked 32.4GHz LO signal is shown in Figure 3 for 0dBm optical LO power. By optical injection-locking, the phase noise of LO was significantly improved as shown in Figure 4. The phase noise of 32.4GHz 3rd harmonic injection-locked LO is about 10dB higher that that of 10.8GHz fundamental LO because the phase noise of harmonic signal is always higher than the fundamental one [7]. The locking range of MMIC OIL-SOM was quite large compared to a hybrid-type oscillator because the MMIC oscillator has relatively low Q-factor. As shown in Figure 5, the measured locking range of 30GHz band LO was about 5GHz when the supplied power of optical LO was 6dBm, which is three times larger than the locking range of 10GHz band LO. The wide locking range of MMIC OIL-SOM is a big advantage for applications because this can maintain injection locking against the oscillation frequency variation caused by fabrication errors or operating temperature.

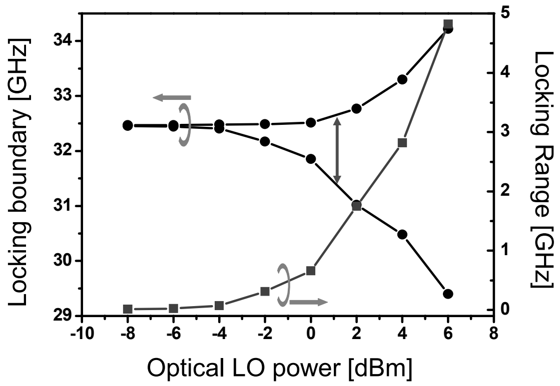

Figure 5 Locking range of MMIC oscillator measured for 32.4GHz 3rd harmonic LO

IV. DOWNLINK DATA TRANSMISSION

For the RoF downlink data transmission, the optical IF signals were generated by direct modulation of DFB LD with 25Mbps 32QAM signals in 1.4GHz IF. The generated optical IF/data signals were optically injected into OIL-SOM along with optical LO as shown in Figure 2. As a result, we could obtain harmonically frequency up-converted RF signals in 31GHz band which was separated from 32.4GHz LO by the amount of IF (1.4GHz). Figure 6 shows the spectrum of 31GHz RF signals when both of optical LO and IF powers were 0dBm. In real systems, these signals would be transmitted to mobile terminals through the antenna. However, in our experiment, the signals were frequency down-converted to 1GHz IF band using an electrical mixer with a BPF for image rejection. The resulting 32QAM signals at 1GHz IF were evaluated by a vector signal analyzer (VSA).

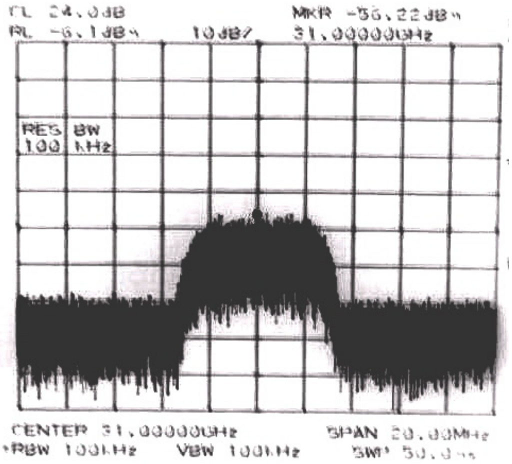

Figure 6 Spectrum of frequency up-converted 31GHz RF/data when both of optical LO and IF powers are 0dBm

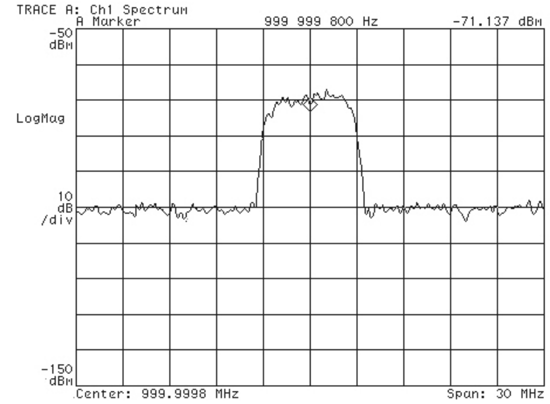

Figure 7 Spectrum of frequency down-converted 1GHz IF signal when both of optical LO and IF powers are 0dBm

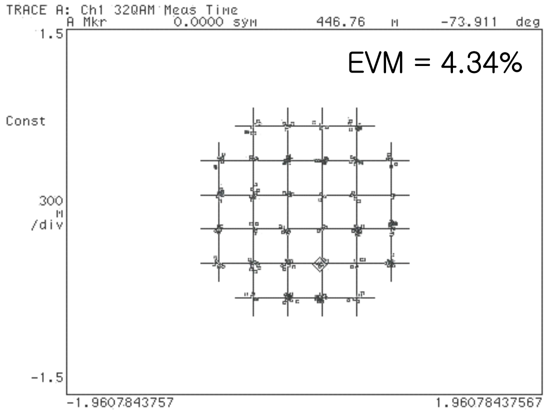

Figure 8 Constellation of demodulated 32QAM signals

Figure 7 shows the spectrum of down-converted IF signals measured with VSA. The signal-to-noise ratio (SNR) was about 30dB. The resulting constellation of demodulated 32QAM signal is shown in Figure 8. The measured error vector magnitude (EVM) was 4.34% when both optical LO and IF powers were 0dBm. The EVMs were measured as a function of incident optical LO and IF powers as shown in Figure 9 and 10, respectively. Figure 9 shows that there is an optimum range of optical LO power from 0dBm to 4dBm. When the optical LO power was reduced below 0dBm, the EVM increased due to the phase error increase. When the optical LO power was over 4dBm, the EVM increased due to the degradation of conversion efficiency caused by the saturation effect of oscillator in high power optical illumination. The saturation effect caused by optical IF also can be seen in Figure 10.

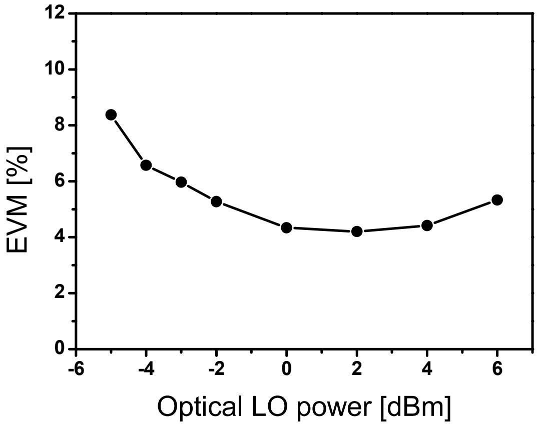

Figure 9 EVMs as a function of optical LO power when the optical IF power is 0dBm

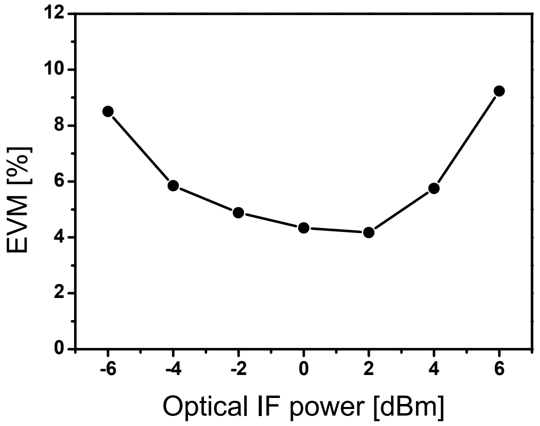

Figure 10 EVMs as a function of optical IF power when the optical LO power is 0dBm

V. CONCLUSION

We implemented a 10GHz band OIL-SOM using a MMIC oscillator based on InP HPT. The MMIC OIL-SOM has a wide locking range and low phase noise characteristics. Using the OIL-SOM as an harmonic optoelectronic frequency up-converter, we successfully demonstrated 30GHz RoF downlink transmission of 25Mbps 32QAM signals. Over the wide range of optical LO powers, low values of EVMs were maintained.

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