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IEEE Catalog Number: CFP08MTT
ISBN (CD-ROM): 978-1-4244-1781-0
Library of Congress: 77-645125
ISSN: 0149-645X

WE4D: Microwave Photonic Technologies and Systems

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Fiber-Fed 60-GHz Self-Heterodyne System Using a Self-Oscillating Harmonic Optoelectronic Mixer Based on a CMOS-Compatible APD

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***Abstract* — We demonstrate a fiber-fed 60-GHz self-heterodyne system using a self-oscillating harmonic optoelectronic mixer (SO-HOM) based on a Si avalanche photodetector (APD) fabricated with 0.18 μm standard complementary metal-oxide-semiconductor (CMOS) process. The proposed SO-HOM consists of a CMOS-compatible APD and a feedback electrical loop for self-oscillation. It simultaneously performs photodetection and harmonic optoelectronic frequency up-conversion of photodetected data signals to the 2nd harmonic self-oscillation frequency band. We successfully demonstrate data transmission of 5 MS/s 32 quadrature amplitude modulation signals in a 60-GHz band without any local oscillators operating in millimeter-wave bands.**

***Index Terms* — Avalanche photodetector, CMOS-compatible photodetector, fiber-fed system, optoelectronic mixer, self-heterodyne, self-oscillating mixer, 60-GHz band.**

I. INTRODUCTION

Fiber-fed wireless systems, where broadband data are optically transmitted from a central office to antenna base stations through fiber, have been widely investigated for the next-generation broadband convergence networks [1]. In particular, 60-GHz fiber-fed wireless systems are attracting much research interests since the 60-GHz band provides license-free and wide bandwidth, and fiber-optic data transmission enables coverage extension, which is limited by high free-space loss of 60-GHz signals [2].

Fig. 1 (a) schematically shows a type of conventional fiber-fed 60-GHz system. In the system, the optically transmitted IF data signals are frequency up-converted to the desired 60-GHz band at antenna base stations and the frequency up-converted signals are radiated to mobile terminals. The radiated signals are received and frequency down-converted to IF band for demodulation at mobile terminals. Therefore, the system requires two independent local oscillators (LOs) operating at millimeter-wave (mm-wave) bands for frequency up/down-conversion. Moreover, the LOs should generate stable and low phase-noise signals since phase noise of LOs induces phase errors in demodulating the received data signals. However, it is hard to realize stable oscillators such as phase-locked oscillators (PLOs) in mm-wave bands in a cost-effective manner [3].

We have previously reported a fiber-fed 60-GHz self-heterodyne system based on a CMOS-compatible harmonic optoelectronic mixer [4]. Although the previous scheme successfully demonstrated data transmission in a 60-GHz band with a simple mobile terminal by using a self-heterodyne method, an additional LO was still needed for frequency up-conversion in an antenna base station.

In this work, we propose a self-oscillating harmonic optoelectronic mixer (SO-HOM) for the fiber-fed 60-GHz self-heterodyne system. A CMOS-compatible avalanche photodetector (CMOS-APD) is utilized in the SO-HOM to perform photodetection, harmonic frequency up-conversion, and a feedback electrical loop which generates LO signals by self-oscillation without using an additional LO. With this new configuration, we successfully demonstrate the data transmission of 5 MS/s 32 quadrature amplitude modulation (QAM) in a 60-GHz band.

II. PROPOSED FIBER-FED 60-GHZ SELF-HETERODYNE SYSTEM USING A SO-HOM BASED ON A CMOS-APD

Fig. 1 (b) shows the schematic diagram of the proposed fiber-fed 60-GHz system. As shown in the figure, optical signals modulated by electrical IF data signals in the central office are transmitted to the antenna base station along multi-mode fiber and injected to the SO-HOM oscillating at f_{osc}. The injected optical IF data signals are photodetected by the CMOS-APD in the SO-HOM and frequency up-converted to the 60-GHz band, which corresponds to the 2nd harmonic of f_{osc}, due to the nonlinear characteristic of avalanche multiplication process in CMOS-APD [5]. Therefore, the simple antenna base station can be realized by using the SO-HOM because it can simultaneously perform photodetection and optoelectronic mixing without an additional LO. The frequency up-converted RF and LO signals generated by the SO-HOM are radiated from the antenna base station to the mobile terminal through an antenna. After transmission along the 60-GHz wireless link, they are received by an antenna in the mobile terminal. The received RF and LO signals are self-mixed by a square-law detector, resulting in generation of

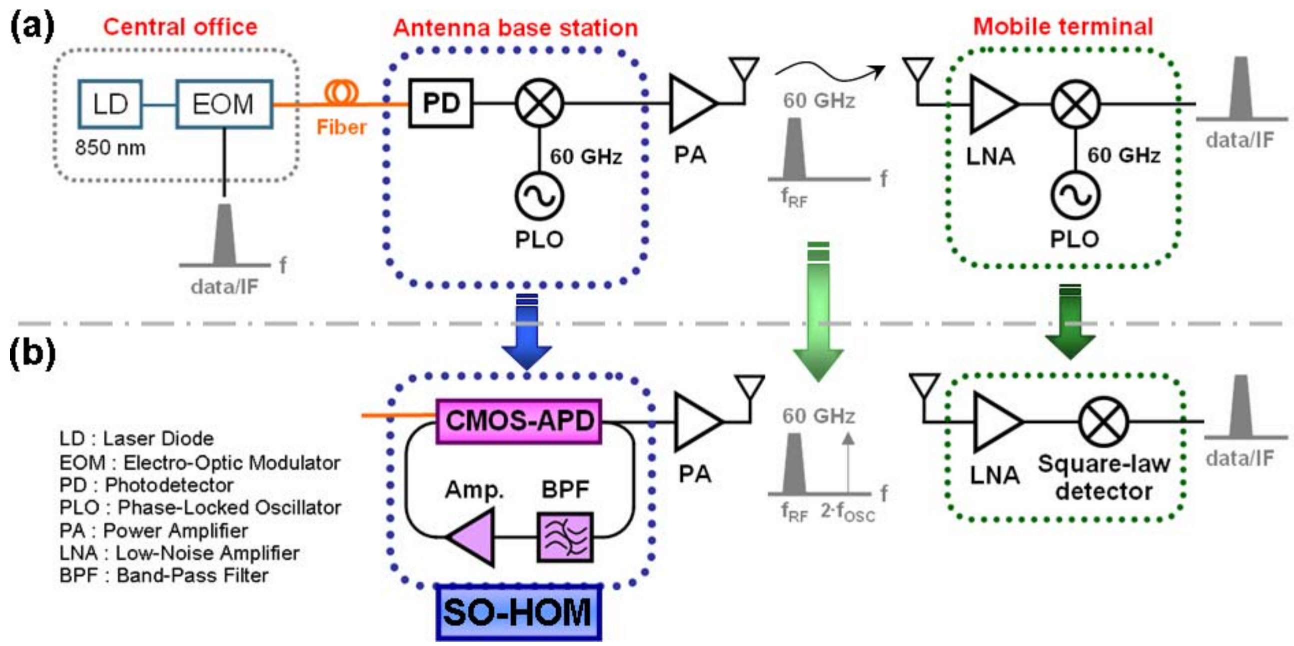

Fig. 1. Configuration of (a) conventional and (b) proposed fiber-fed 60-GHz systems.

frequency down-converted IF data signals. In our scheme, LO signal's phase noise is poor due to free-running oscillation. However, the poor phase noise has no effect on the down-converted IF data signals since frequency down-conversion is performed by self-mixing between phase-correlated RF and LO signals [3].

Fig. 2 describes the architecture of the SO-HOM based on a CMOS-APD. The CMOS-APD was implemented using p^+ source/drain region to n-well junction and each region is connected to the signal pad for realizing the SO-HOM. By applying an electrical feedback loop, which consists of a band-pass filter (BPF) and an amplifier, to the CMOS-APD, the SO-HOM can be realized. For free-running oscillation, the CMOS-APD acts as a capacitor and sufficient amplifier gain is required to compensate the total loss of the electrical feedback loop. The output signal of the SO-HOM is extracted using a 3dB coupler and the oscillation frequency is determined by the BPF. Although the feedback loop was implemented by discrete components in our configuration, the entire SO-HOM can be realized by the single-chip approach with integration of the CMOS-APD and necessary high-speed CMOS circuits.

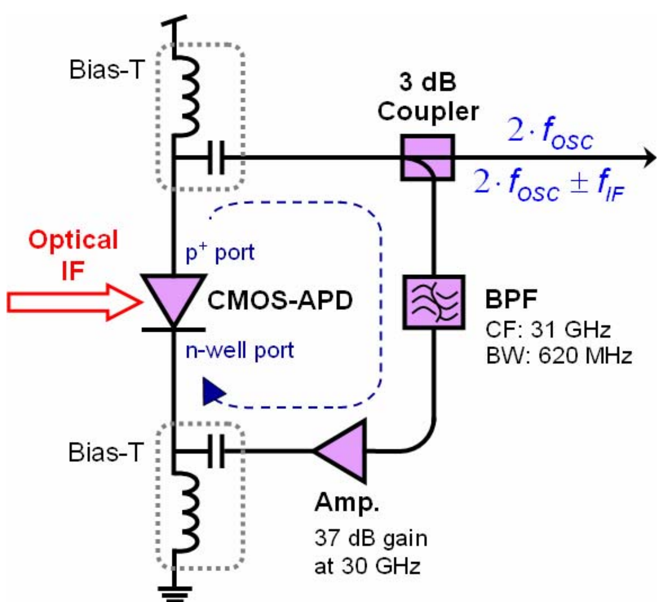

Fig. 2. Schematic diagram of the SO-HOM based on a CMOS-APD.

III. Experimental Results

Downlink data transmission at the 60-GHz band was demonstrated. At the central office, 5 MS/s 32 QAM data signals at 950 MHz band are converted to optical signals using an electro-optic modulator. The generated optical IF data signals are transmitted through 2-m long multi-mode fiber to the antenna base station. Transmitted data signals are photodetected and frequency up-converted to the 60-GHz band by using the SO-HOM at the antenna base station. A 26-dB gain power amplifier was used to compensate the free-space loss in the 60-GHz band. RF spectrum of 2^{nd} harmonic frequency up-converted data signals is shown in Fig. 3 when the input optical power was 1 dBm and the reverse bias voltage of 10.3 V was applied to the CMOS-APD. The spectrum evidently shows frequency up-converted double sideband data signals at 950 MHz (f_{IF}) away from 62.23 GHz ($2 \cdot f_{OSC}$). The inset magnifies the lower sideband (LSB) frequency up-converted data signals. The output signals of the

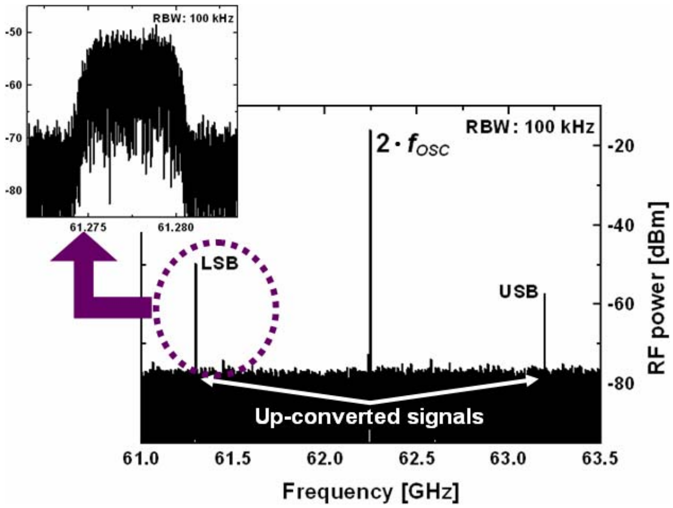

Fig. 3. Spectrum of frequency up-converted signals.

antenna base station are radiated to mobile terminals via 1-m free space using an antenna having 24-dBi gain. The wireless link gain including antennas is about -20 dB. At the mobile terminal, received data and LO signals are amplified by a 36.5-dB gain low-noise amplifier, and then frequency down-converted to IF band by a square-law detector. Fig. 4 shows the spectrum of frequency down-converted data signals. The signal-to-noise ratio (SNR) was about 30 dB at 950 MHz. In order to evaluate the system performance, the frequency down-converted data signals were demodulated by a vector signal analyzer. Fig. 5 shows the constellation and the eye diagram of the demodulated 5 MS/s 32 QAM data signals. The eye was clearly open and the measured error vector magnitude (EVM) was about 1.83 % which corresponds to the 30.7 dB SNR. We believe that this should be sufficient for most wireless applications. To estimate the supported optical link distance between the central office and the antenna base station, we measured EVMs as a function of optical IF power using an optical attenuator. Fig. 6 shows the measurement results. As shown in this figure, the EVM of the downlink data transmission deteriorates from 1.83 % to 7.2 % as optical IF power decreases. The degradation of EVM is simply regarded as the transmission loss in fiber. With a sufficiently high optical power source, the distance of an optical link between the central office and the antenna base station can be expected to reach a few hundred meters.

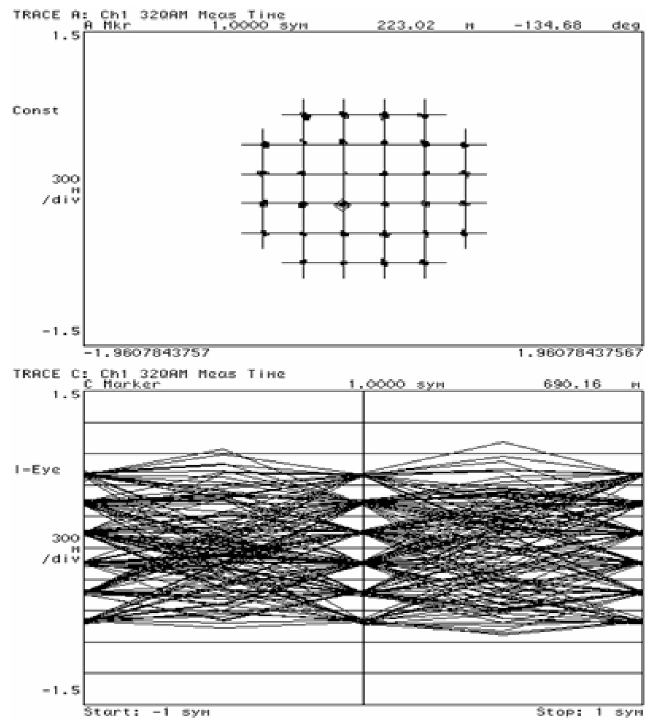

Fig. 5. Constellation and eye diagram of demodulated 5 MS/s 32 QAM data signals.

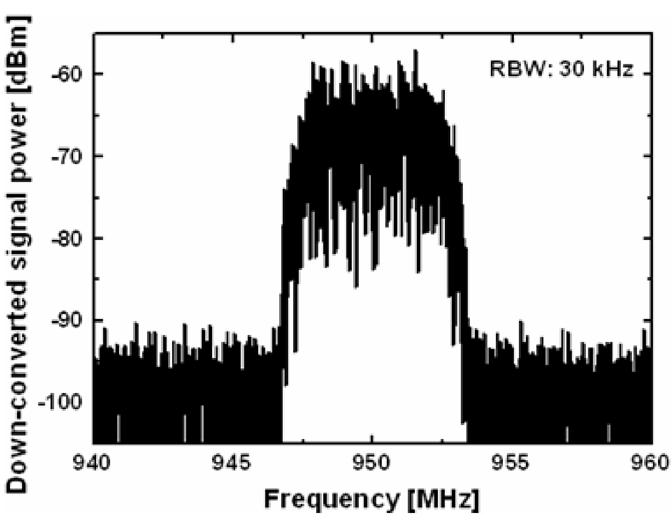

Fig. 4. Spectrum of frequency down-converted signals.

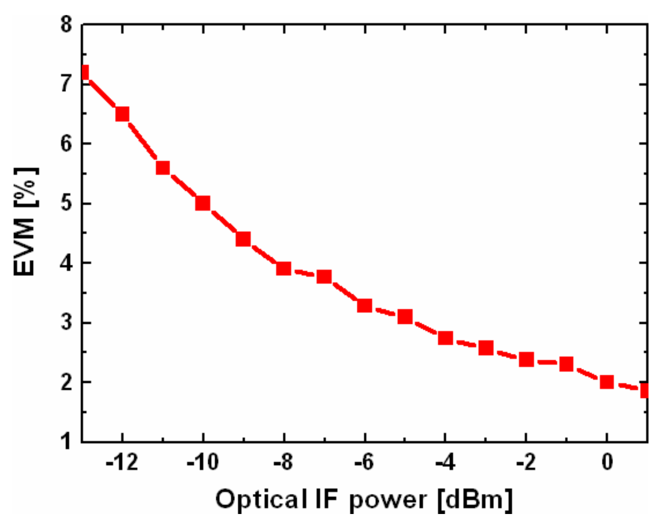

Fig. 6. EVMs as a function of optical IF power.

IV. CONCLUSION

A fiber-fed 60-GHz self-heterodyne system using the SO-HOM is demonstrated. Because the SO-HOM provides oscillation, photodetection, and frequency mixing at the same time, the antenna base station can be substituted by the SO-HOM. In this system, the need to supply PLO signals is eliminated. In order to demonstrate the feasibility of our system, downlink data transmission of 5 MS/s 32 QAM signals in a 60-GHz band is successfully performed with 1.83 % EVM. Although discrete components are used for our present investigation, the single-chip approach with CMOS process should be equally applicable.

ACKNOWLEDGEMENT

We acknowledge that EDA software used in this work was supported by IDEC (IC Design Education Center) of Korea.

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