Duobinary RF Envelope Detection in Coherent Optical Millimeter-Wave Systems

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***Abstract*—A novel duobinary RF receiver is proposed and demonstrated based on RF envelope detection for millimeter-wave radio-over-fiber systems. Robust RF downconvertion and duobinary decoding are achieved simultaneously at an RF envelope detector. Duobinary signal delivery over wired and wireless link in coherent single-sideband optical millimeter-wave systems is demonstrated for the first time.**

I. Introduction

FUTURE optical-wireless access networks of combining 60-GHz millimeter-wave (MMW) band and radio-over-fiber (RoF) technologies are providing end users with ultimate bandwidth resources and multiple services through a highly converged infrastructure [1]. Among many modulation formats, duobinary (DB), a three-level signal has shown its unique advantages in achieving high spectral efficiency while maintaining low complexities at transceivers [2]. In our previous work [3], we demonstrated three-level optical DB MMW signal through 5-km single-mode fiber (SMF) and decoded two-level RF signal over 6-ft wireless distance through a double-sideband optical carrier suppressed (DSB-OCS) scheme. However, in order to maintain the three-level DB properties in both optical and wireless domain, we have recently demonstrated a three-level DB signal transmission over wired and wireless link by using single-sideband (SSB) optical MMWs, and also proposed a DB RF receiver based on self-mixing effect to reduce the RF receiver complexity [4]. In this paper, we propose a novel DB RF receiver based on RF envelope detection, which achieves simple and robust operations for RF downconversion and DB decoding at the same time. Besides, different from previous work [4], a coherent single-sideband (SSB) optical MMW generation scheme is used to obtain more stable 60GHz RF carrier. An error-free transmission of 4-Gbps DB signal over 25-km SMF and 4-ft wireless distance is successfully demonstrated with proposed DB RF receiver.

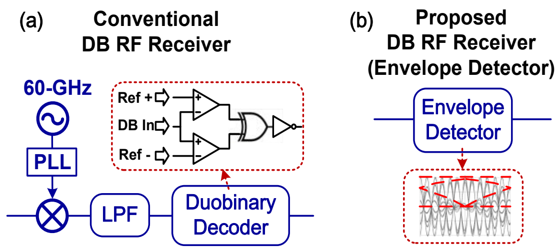

Fig. 2. Comparison between conventional DB RF receiver (a) and proposed DB RF receiver (b). .Inset of (a) shows the procedure of conventional DB decoding. Inset of (b) shows the eye diagram of a RF DB signal and its envelope which represents the decoded binary data.

II. Operating Principles

Figure 1 illustrates the conceptual diagram of a duobinary signal transmission through MMW RoF systems with the proposed envelope detector. Optical DB signal is generated by driving an optical Mach-Zehnder modulator (MZM) biasing at the null point [2]. The three-level DB property is represented in the amplitude and the phase of the optical signal. Single-sideband (SSB) optical MMW upconversion is used to preserve the original DB data in RF domain after photodetection [4], where the SSB means only one of the two optical sidebands carries original DB data, while the other sideband is a pure carrier. At the remote access unit (RAU), a high-speed photodetector (PD) is used to detect the optical MMW signal, where the two optical carriers beat with each other to generate a RF signal carrying the original DB data. After wireless transmission through 60-GHz band, at the subscriber side, instead of using conventional DB RF receiver where a 60GHz local oscillator (LO), a phase-locked loop (PLL), a mixer and a DB decoder are needed; we propose to use just one simple envelope detector to achieve the function of RF downconversion and DB decoding simultaneously. The comparison between conventional DB RF receiver and proposed DB RF receiver is illustrated in Fig. 2. The principle of a DB RF envelope receiver is to capture the envelope information of the received RF DB signal, which achieves RF

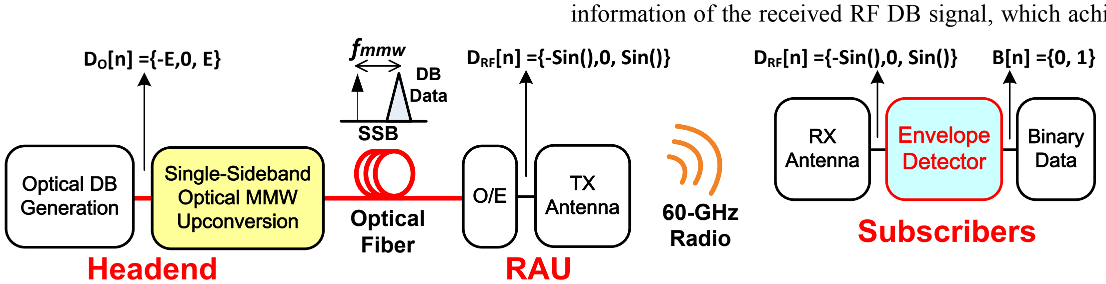

Fig. 1. Block diagram of proposed duobinary RF receiver based on envelope detection for millimeter-wave radio-over-fiber systems.

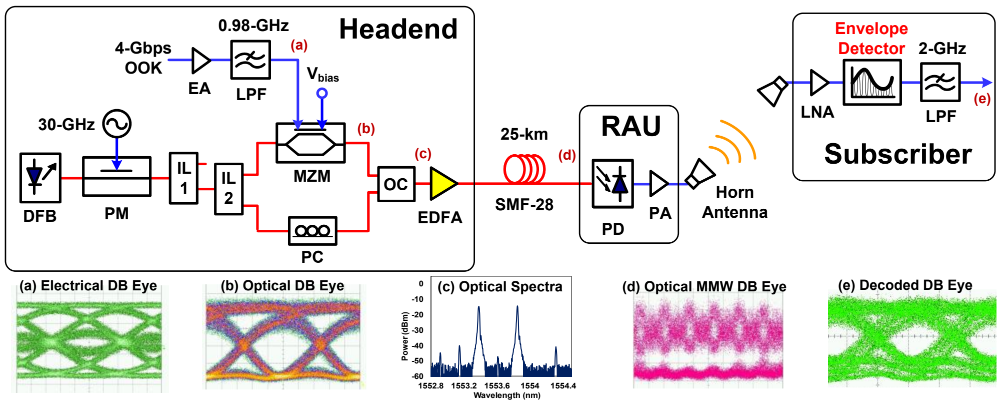

Fig. 3. Experimental setup of DB signal transmission carried on coherent SSB optical MMWs with proposed DB RF envelope receiver.

downconversion without external mixing. Therefore no 60-GHz LO and PLL is needed since carrier phase is not important in this case, which obtains simple and robust operation. Besides, for the DB decoding, different from a conventional DB decoder which is constituted of two comparators with different slicing levels, by which ±1 are decoded as 1, and 0 is decoded as 0 [5]; we found out that the function of an envelope detector is equivalent to decoding ±Sin(RF) into 1, and 0 into 0. Therefore, both RF downconvertion and DB decoding are achieved simultaneously with much simplified receiver design.

III. Experimental Setup and Results

Figure 3 shows the experimental setup of DB MMW RoF signal transmission and demodulation with proposed DB RF envelope receiver. 4-Gb/s optical DB signal was generated in the same way as in [4]. The measured eye diagrams of electrical and optical DB signal are shown in the insets (a) and (b) respectively. However, different from our previous system setup, the SSB optical MMW upconversion was achieved by using two coherent optical carriers instead of two independent lasers [4]. The advantage of coherent optical MMW is that much more stable 60-GHz RF signal (in terms of both frequency and phase) will be generated after the beating between the two optical carriers. In this experiment, the two coherent optical carriers were generated by interleaving (IL) a coherent optical comb, which was obtained by driving a phase modulator at 30-GHz. Then the two carriers were further separated by another IL to achieve SSB DB modulation. After 25-km SMF-28 transmission, the coherent optical MMW signals were directly detected by a PD to generate 60-GHz DB RF signal. The eye diagram of SSB optical MMW carrying DB data is shown in inset (d). Due to the synchronized coherent MMW, the ± sinusoidal 60-GHz RF clock can be seen clearly in the eye diagram, which proved the three-level property of DB signal was maintained in both optical and wireless domain. After wireless transmission by using a pair of horn antenna with 15-dBi gain, the received three-level DB RF signal was then amplified and fed into an envelope detector, where the RF downconversion and DB decoding were achieved simultaneously. The output binary sequence was then sent into bit error rate (BER) tester for BER calculation.

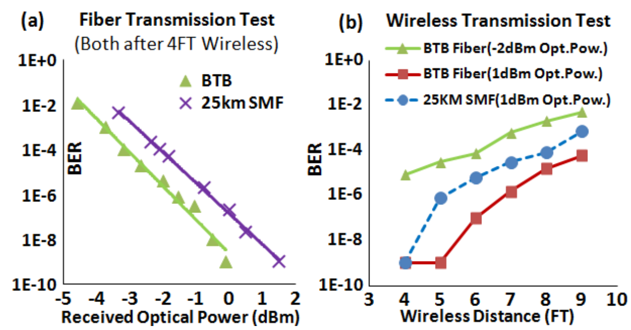

Fig. 4. BER performance of the demodulated DB signals at different received optical power (a) and wireless propagation distance (b).

Figure 4 shows the BER performance of demodulated DB signals at different received optical power as a function of wireless propagation distance with and without 25-km optical fiber transmission. In Fig. 4(a), an error-free transmission (BER lower than $1x10^{-9}$) over 25-km SMF and 4-ft in-building wireless distance was achieved at received optical power of 1dBm. The high received optical power value is due to no optical pre-amplifier being used. As we can see from Fig. 4(b), for the BTB case, with 3-dB increase in received optical power (from -2dBm to 1dBm), the wireless distance can be extended by 3-ft while maintaining the same target BER, which follows Friis transmission equation at short propagation distance.

IV. Conclusion

A novel duobinary RF receiver for MMW RoF systems is proposed and demonstrated. Through envelope detection, RF downconversion and DB decoding are achieved simultaneously, which greatly simplifies the conventional duobinary receiver. DB signal carried on coherent SSB optical MMWs is transmitted through wired and wireless link for the first time.

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