A Novel Self-Mixing Duobinary RF Receiver for Millimeter-Wave Radio-over-Fiber Systems

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Abstract: We propose a novel self-mixing duobinary RF receiver structure for 60-GHz radio-over-fiber systems, which simultaneously downconverts and decodes RF duobinary signals at Nyquist limit. Error-free transmission at 4Gb/s over 25-km SMF-28 and 4-ft wireless is demonstrated.

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1. Introduction

Next-generation wireless access technologies at 60-GHz millimeter-wave (MMW) band are providing end users with ultimate bandwidth resources for numerous video-intensive digital network applications. Recently, MMW radio-over-fiber (RoF) has attracted strong research interests for simultaneously delivering very high throughput (VHT) wireless and wired signals over a highly converged fiber-optic physical infrastructure [1]. Among many modulation formats reported so far for MMW RoF applications, duobinary (DB), a simple and unique line coding/modulation technique has shown its advantages in achieving high spectral efficiency and controlling inter-symbol interference (ISI). In the previous work [2], we have demonstrated an end-to-end transmission of three-level (three-level in optical phase domain) optical DB MMW signal through 5-km SMF and decoded two-level DB RF signal over 6-ft wireless distance. Although the two-level DB RF signal enables the use of low-complexity RF receivers at the end users, its bandwidth efficiency is less than three-level DB RF signal which approaches the Nyquist limit [3]. Therefore in this paper, for the first time, we demonstrate DB signal transmission over MMW RoF system by maintaining the three-level properties both in optical and RF domain, which provides higher RF bandwidth efficiency while operating at regular hardware complexity. To realize such a system, we propose a novel self-mixing DB wireless receiver achieving MMW direct downconversion and DB decoding at the same time, which greatly simplifies the structure and reduces the power consumption at the subscriber premise. Based on the proposed scheme, an error-free transmission of 4-Gbps DB signal over 25-km SMF and 4-ft air is successfully demonstrated.

2. Operating Principles

Fig. 1 illustrates the conceptual diagram of duobinary signal transmission through MMW RoF access system with the proposed duobinary receiver. As shown in Fig. 1, in the headend office, the original binary data B[n] is initially precoded (or differential encoded) to avoid complicated decoder at the receiver side and also to avoid error propagation effect. The precoded binary data p[n] = {1, -1} are further encoded to generate three-level electrical DB

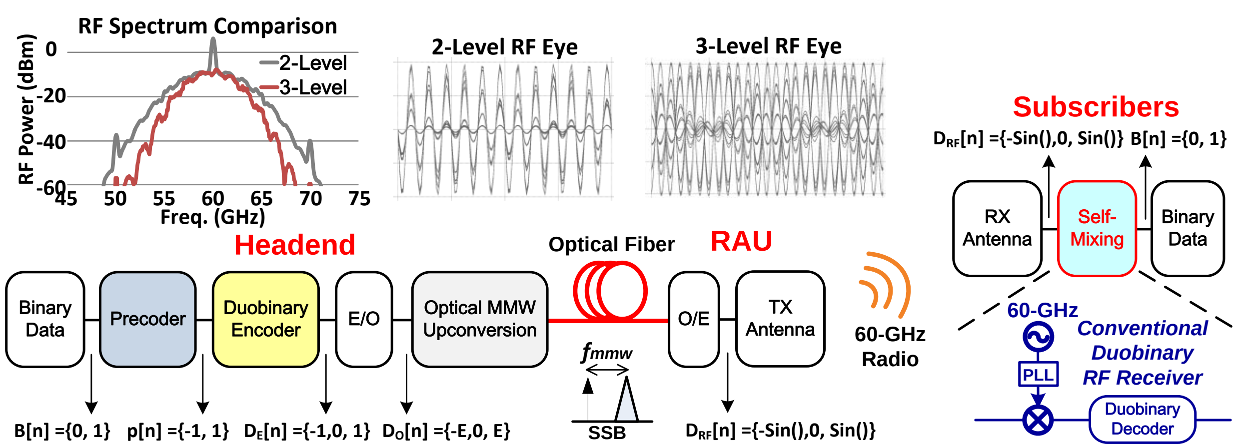

Fig. 1 Conceptual diagram of proposed duobinary receiver based on self-mixing for millimeter-wave radio-over-fiber systems

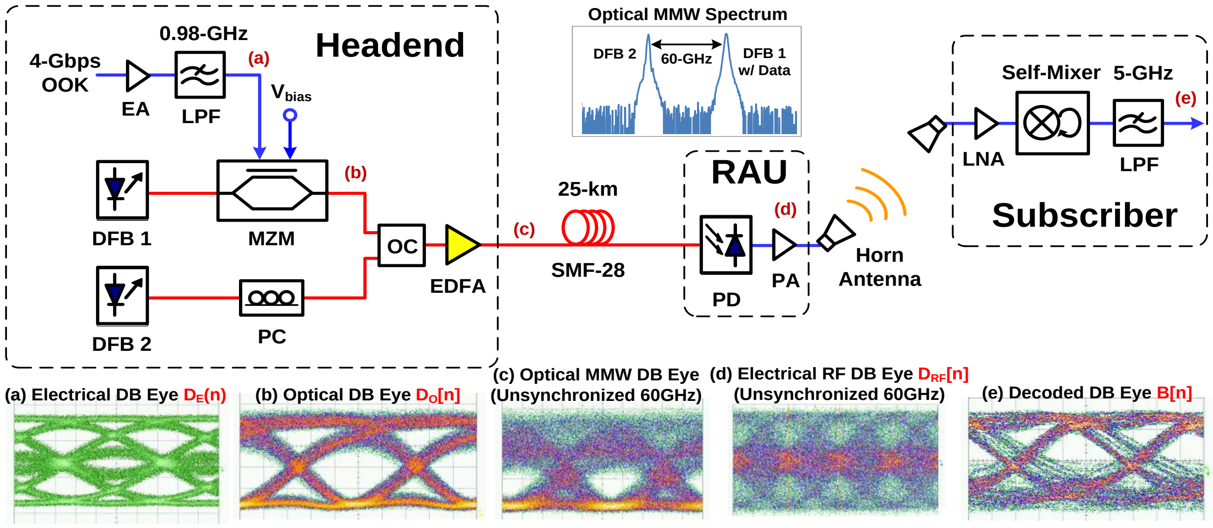

Fig. 2 Proof-of-concept experimental setup of RF duobinary signal downconversion and decoding based on self-mixing

sequence $D_E[n]$ = {-1, 0, 1}. The following electrical to optical (E/O) conversion is responsible for modulating the electrical DB sequence onto an optical carrier by using an optical Mach-Zehnder modulator (MZM) biased at null point. Therefore, the output optical DB signal Do[n] = {-E, 0, E} will exhibit two levels in terms of optical power while preserving three-level nature in optical phase. Comparing with the original binary data d[n], the generated optical DB signal Do[n] requires much less bandwidth while reserving the same data information [2,4]. Besides, the opposite phase between two adjacent one-bits will help to reduce the inter-symbol interference (ISI). At the optical MMW upconversion stage, single-sideband (SSB) optical MMW generation method is needed to convert the three-level optical phase into RF domain, and the beating of SSB optical MMW carriers at the photodetector (PD) in remote antenna unit (RAU) will result in a three-level RF DB signal $D_{RF}[n]$ = {-Sin(RF), 0, Sin(RF)}, which represents the original three-level DB signal $D_E[n]$. This is different from the double-sideband (DSB) scheme used in [2], where the optical phase information were lost after the beating between two modulated carriers, which gives two-level decoded DB RF signal. The comparison of two-level and three-level RF spectra and the corresponding RF eye diagrams are shown in the insets of Fig.1. We can see the improved bandwidth efficiency by maintaining the three-level feature in RF domain. This RF signal is amplified and transmitted out to subscribers through antenna. At the subscriber side, instead of using conventional DB RF receiver where a 60GHz local oscillator, a phase-locked loop (PLL), a mixer and a DB decoder are needed; we propose to use just one simple self-mixer to achieve the function of RF downconversion and DB decoding simultaneously. The principle of a self-mixer is to multiply the incoming RF signal by itself and then low-pass it to obtain the downconverted baseband signal. Since the signal is multiplied by itself, the in-phase mixing condition is always satisfied, which enables stable mixing operation and therefore no PLL and LO are needed. For the DB decoding part, different from the 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 find out that the function of a self-mixer is equivalent to decode ±Sin(RF) into 1, and 0 into 0. Therefore, by feeding a three-level RF DB signal $D_{RF}[n]$ = {-Sin(RF), 0, Sin(RF)} into a self-mixer, the output signal is both downconverted and decoded automatically, which gives the desired binary sequence B[n] = {0, 1}. Therefore, simple and stable RF downconversion and DB decoding are achieved simultaneously based on self-mixing effect.

3. Experimental Setup and Results

Fig. 2 shows the proof-of-concept experimental setup of DB MMW RoF signal transmission and demodulation with proposed DB receiver. In the headend office, a 4-Gbps pseudo-random binary sequence (PRBS) was considered as a precoded bit sequence, and was converted into a three-level electrical DB signal by passing through a Bessel electrical low-pass filter (LPF) with 3dB-bandwidth of 0.98-GHz, which is about 25% of the bit rate [2,4]. To generate optical DB signal, a DFB laser (DFB1) at 1554.18 nm was externally modulated by a $LiNbO_3$ optical MZM, which was driven by the three-level electrical DB signal with a bias voltage (V_{bias}) of 3.2V at its transmission null. The resulting optical DB eye is shown in the inset (b) of Fig. 2, which exhibits two levels in terms of optical power, but actually three levels in optical phase. The other un-modulated DFB laser (DFB2) at the wavelength of 1553.7 nm was coupled with DFB1 by using an optical coupler (OC) in order to achieve SSB optical MMW upconversion.

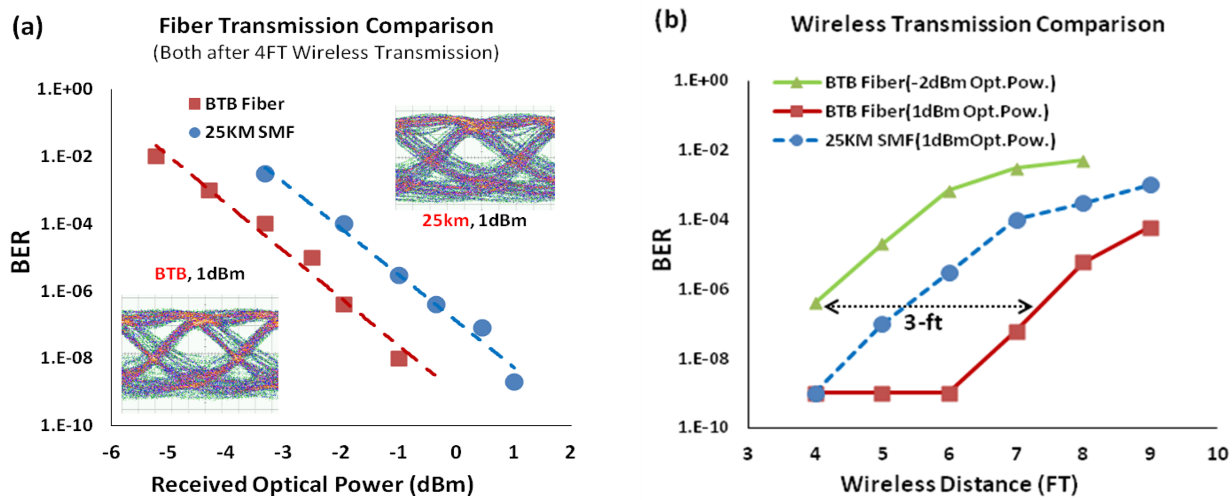

Fig. 3 BER performance of the demodulated DB signals at different received optical power (a) and wireless propagation distance (b) for BTB and 25-km fiber transmission cases.

Note that a polarization controller (PC) was needed to control the polarization state of DFB2 before the coupling to realize most efficient beating between the two optical carriers. After optical power amplification by an EDFA, the optical MMW signals were transmitted through 25-km SMF-28 to RAU, and were directly detected by a 60-GHz photodiode (PD) to generate 60-GHz DB RF signal. The eye diagrams for the optical MMW signal and three-level DB RF signal are shown in inset (c) and (d) of Fig.2, respectively. Since the 60-GHz frequency is generated from the beating between two phase-unlocked lasers, and it could not be synchronized with the scope, we would not able to see the clear 60GHz clock on both eye diagrams as the simulated results shown in the inset of Fig.1. After electrical power amplifier (PA), the three-level DB RF signal was transmitted out through a horn antenna with 15-dBi gain, and received by the other horn antenna with the same parameters. The received three level DB RF signal was then amplified by a low-noise amplifier (LNA), and feed into a self-mixer. After the RF downconversion and DB decoding operation were done within the self-mixer, the output binary sequence was sent into bit error rate (BER) tester for BER calculation.

Fig. 3 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. As shown in Fig. 3(a), error-free transmission (BER lower than 1×10^{-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. There is about 1.5dB optical power penalty after 25-km SMF transmission comparing with back-to-back (BTB) fiber transmission case, which is mainly due to the degenerated phase noise from the two independent lasers after fiber transmission. As Fig. 3(b) indicates, 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. In addition, the insets of (a) show the measured eye diagrams of downconverted DB signal after 4-ft wireless distance at the received optical power of 1dBm with and without 25-km fiber transmission.

4. Conclusions

A novel duobinary receiver for MMW radio-over-fiber systems is proposed and demonstrated. By utilizing the self-mixing effect, the RF downconversion and duobinary decoding is achieved simultaneously, which greatly simplifies the design of duobinary receiver. Based on the proposed scheme, 4-Gb/s DB signal has been successfully transmitted and demodulated over 60-GHz radio-over-fiber system while maintaining the three-level DB properties both in optical and RF domain. Error-free transmission at 10^{-9} is attained after 25-km SMF and 4-ft wireless distance. We believe this proposed duobinary receiver scheme can provide simplified and stabled DB signal demodulation for high spectral efficient MMW radio-over-fiber systems.

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