Two Independent Microwave Vector Signals Transmission Based on Single DDMZM Modulation at W band

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***Abstract*—We propose a novel DSP approach, which can simultaneously recover two independent microwave vector signals modulated by a single DDMZM. Experimental verification at the W band presents a high spectral-efficient double-sideband transmission scheme.**

***Keywords*—W band, microwave vector signal, DDMZM modulation, double-sideband, millimeter-wave communication**

I. Introduction

To meet the increasing capacity demand for the upcoming B5G and 6G networks, wireless communication technology is gradually expanding from low-frequency microwave (sub-6GHz) to high-frequency millimeter-wave (MMW) such as W band (75~110 GHz), due to its intrinsic larger available bandwidth. On the other hand, it is quite important and also meaningful to improve the spectral efficiency in a fixed-bandwidth wireless link, which can further increase the overall capacity of MMW communication systems. For this purpose, many outstanding efforts have been made to support simultaneous transmission multiple wireless signals over an identical MMW carrier frequency [1-3]. Utilizing a dual-parallel Mach-Zehnder modulator (MZM), two independent QPSK microwave vector signals carried by an identical carrier frequency at about 2 GHz can be successfully demodulated [1, 2]. Similarly, the cascade of an intensity modulator and a phase modulator can also realize the simultaneous transmission of one QPSK and another 16QAM signals both at 2.5 GHz [3]. However, for all the schemes mentioned above, the modulation of two independent microwave vector signals still relies on one or more costly electro-optic components, whilst a complex and expensive optical coherent receiver is also required at the receiver end. In addition, by occupying another polarization direction, a pure lightwave is delivered from the transmitter to receiver to assist signal recovery in part of above schemes, which will result in potential capacity constraint.

In this paper, we investigate and demonstrate the simultaneous transmission of two independent microwave vector signals with an identical center frequency over up to 80-km SSMF and 3-m wireless at W band (i.e., 92.5 GHz). The optical orthogonal modulation based on a low-cost dual-drive MZM (DDMZM), and the optical heterodyne detection base on one single-end photodetector (PD) as well as the electronic mixing down-conversion are used in this scheme. To recover the two independent QPSK double-sideband (DSB) signals with an overlapping spectrum, a novel DSP approach utilizing RF pilot tone (RFP) phase noise cancellation [4] is proposed and verified. The proposed scheme is not only immune to the power fading induced by chromatic dispersion (CD) during the fiber transmission of DSB signal, but also can double the spectral efficiency for MMW wireless link.

II. Experimental Setup

Figure 1 shows the experimental setup for two independent QPSK microwave vector signals transmission at W band. At the optical transmitter, after symbol mapping, upsampling, RRC filtering with a rolloff of 0.1 and upconversion, two 3-GBd real-valued QPSK microwave vector signals with an identical center frequency of 2.15 GHz (reserving a guard band of 0.5 GHz) can be obtained in the transmitter DSP. It should be noted that two different PRBSs are adopted, and an initial phase of 45 degree is preset for the second QPSK signal to make it different from the first one. Suppose the two QPSK microwave vector signals are expressed as $s_1(t)$ and $s_2(t)$. A simple cross-processing for the two QPSK signals, i.e., $u_1(t) = s_2(t) + s_1(t)$ and $u_2(t) = s_2(t) - s_1(t)$, is adopted to avoid imbalance. Then the obtained $u_1(t)$ and $u_2(t)$ are fed to one 92-GSa/s AWG for digital-to-analog conversion. Subsequently, a low-cost DDMZM biasing at its orthogonal point is used to achieve optical orthogonal modulation, which can modulate $u_1(t)$ and $u_2(t)$ onto two optical carriers that are orthogonal to each other, i.e., $cos\omega_0 t$ and $sin\omega_0 t$. Noting that this modulation scheme can enable high spectral efficiency, since the spectra of the two DSB signals overlap completely. One external cavity laser (ECL1) with the central wavelength of 1552.524 nm, output power of 10 dBm and linewidth of < 100 kHz is used as the input laser. After transmission over 0 ~ 80-km SSMF, the modulated

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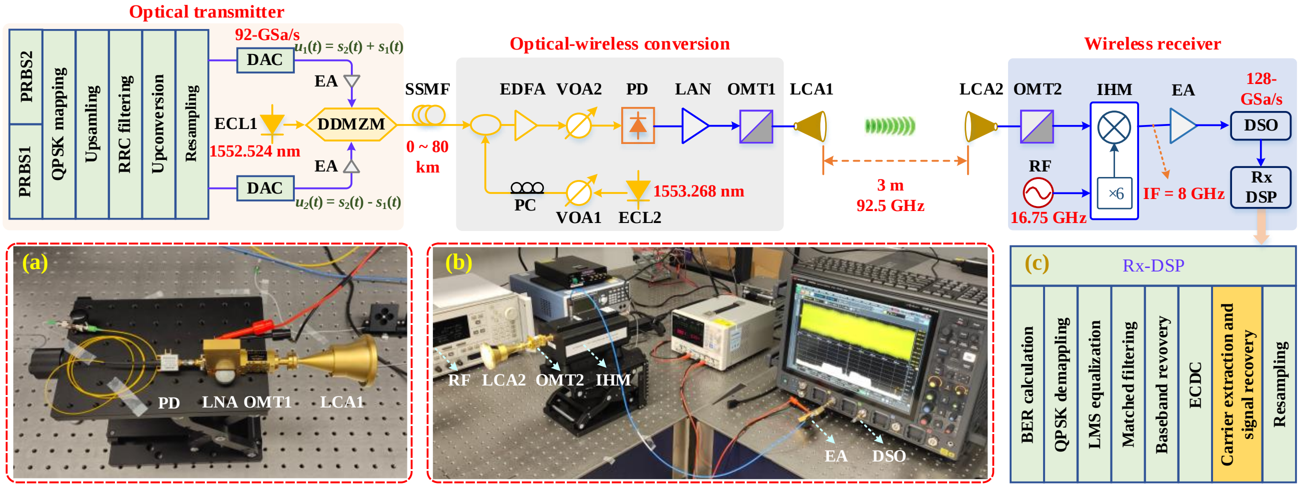

Fig. 1. Experimental setup for two independent QPSK microwave vector signals transmission at W band using one single DDMZM and a novel receiving DSP approach. Photos of (a) W-band optical-wireless conversion unit and (b) wireless receiver. (c) Receiving DSP workflow.

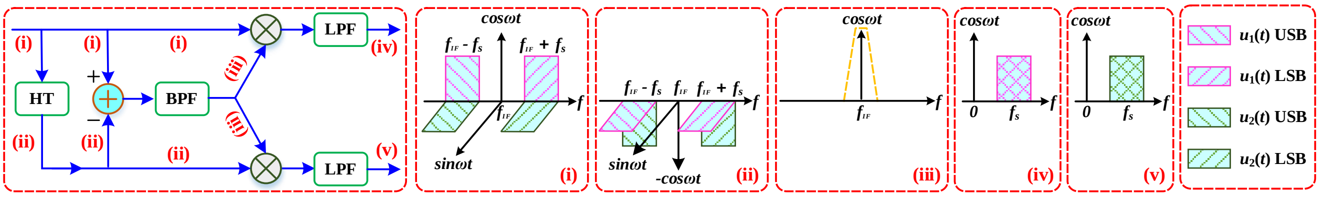

Fig. 2. Proposed carrier extraction and signal recovery approach for two independent microwave vector signals with an identical carrier frequency.

optical dual DSB signal with the form of $u_1(t) + j{\cdot}u_2(t)$, is then coupled with an optical local oscillator (LO) from another ECL (i.e., ECL2) with the central wavelength of 1553.268 nm in optical-wireless conversion module, whose photo is shown in Fig. 1(a). The LO power is controlled at 0 dBm through a variable optical attenuator (VOA1), and one polarization controller (PC) is applied to align its polarization direction with that of signal lightwave. The frequency difference between the two lightwaves is set to 92.5 GHz, thus the W-band MMW at 92.5 GHz can be generated after optical heterodyne detection via a single-end PD with 3-dB bandwidth of 100 GHz. One EDFA and another VOA (i.e., VOA2) are employed, respectively, to amplify the combined lightwaves and adjust the receiving optical power (ROP) before photoelectric conversion. Afterwards, the generated 92.5-GHz MMW signal carrying two independent information is first amplified by a 75~110-GHz low noise amplifier (LNA) with 35-dB gain, and then is fed to the W-band lens corrected antenna (LCA1) through an orthomode transducer (OMT1). Noting that the LCA supports simultaneous delivery of H/V dual-polarized wireless signals. However, only H-polarization is used through OMT in our experiment for concision purpose. After 3-m air transmission, the wireless signal is received by another LCA (i.e., LCA2). Two LCA can offer a total gain of 2×30 dBi, hence the air path loss can be partially compensated.

At the wireless receiver end, as shown in Fig. 1(b), the received 92.5-GHz MMW signal is fed to an integrated harmonic mixer (IHM) for electronic down-conversion through another OMT (i.e., OMT2). The IHM consists of a ×6 frequency multiplier chain and one mixer in WR10 (75~110 GHz). The input electronic RF sources is set to 16.75 GHz with 6-dBm power, thus an IF signal with the center frequency of around 8 GHz can be obtained after down-conversion. Subsequently, this IF signal is amplified by one electrical amplifier (EA) with the gain of 30 dB, and then is sampled via a 128-GSa/s digital storage oscilloscope (DSO) for offline DSP demodulation. The DSP workflow is shown in Fig. 1 (c). Among them, a critical process is the proposed carrier extraction and signal recovery approach, whose principle is further given in Fig. 2 in detailed. This approach mainly includes two steps, the carrier is firstly extracted by Hilbert superposition, and then signal recovery is realized by RFP-based carrier signal multiplication. The down-converted IF signal $E_{IF}(t)$ is shown as Fig. 2(i), which carries two independent information with an overlapped spectra by a pair of orthogonal IF carriers, i.e., *cosωt* and *sinωt*. Fig. 2(ii) shows its Hilbert transform (HT) form $\hat{E}_{IF}(t)$. Then the carrier in cosine direction can be obtained via $E_c(t)$ = BPF[$E_{IF}(t)$ – $\hat{E}_{IF}(t)$], where BPF represents the band-pass filtering operation, as shown in Fig. 2(iii). Afterwards, utilizing the orthogonality of cosine and sine, two real-valued microwave vector signals can be recovered by $u_1(t) \propto$ LPF[$E_c(t)$ × $E_{IF}(t)$], $u_2(t) \propto$ LPF[$E_c(t)$ × $\hat{E}_{IF}(t)$], where LPF represents the low-pass filtering, which can remove the undesired high-frequency components. It's important to emphasize that, as shown in Fig. 2 (iv) and (v), the recovered signal is the superposition of the upper and lower sidebands (i.e., USB and LSB) of the original DSB signal. Therefore, the CD-induced power fading will undoubtedly appear in fiber transmission case. Noting that the method which filtering out one sideband signal (LSB or USB) first and then applying the RFP approach so as to avoid the above power fading is not feasible, because it will actually cause the constellation superposition between the $u_1(t)$ and $u_2(t)$. Fortunately, the electrical CD compensation (ECDC) based on the form of $u_1(t) + j{\cdot}u_2(t)$, can effectively solve this problem. Finally, the $s_1(t)$ and $s_2(t)$ can be acquired from $u_1(t)$ and $u_2(t)$, and the two independent QPSK signals can be further demodulated through two sets of identical DSP.

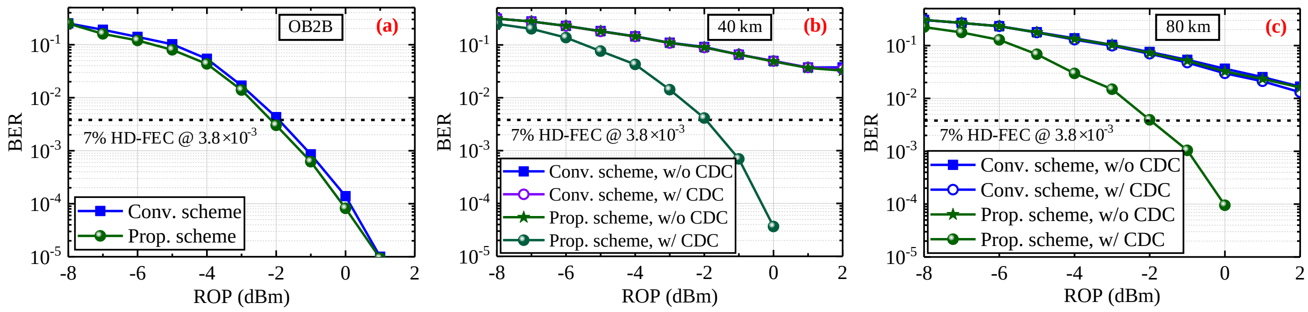

Fig. 3. BER performance comparison for 6 GBd single DSB signal between conventional and proposed schemes over 3-m wireless and different fiber transmission distances. (a) OB2B, (b) 40 km, (c) 80 km.

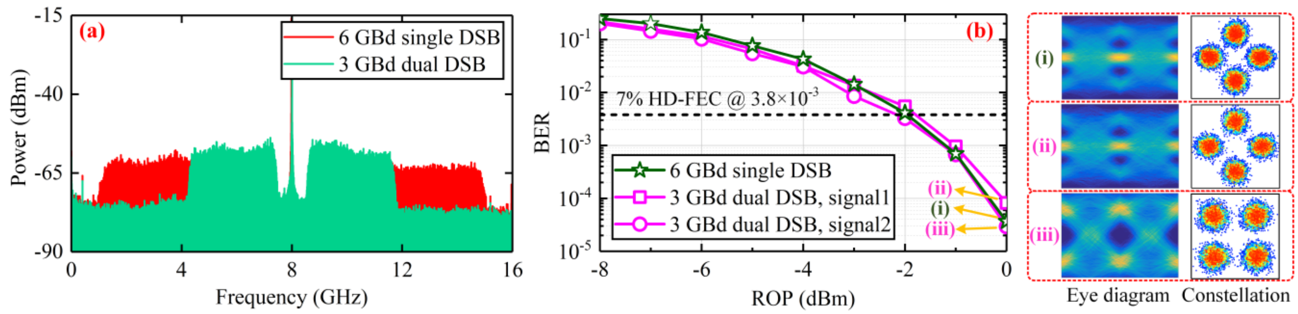

Fig. 4. (a) Measured IF spectra for 6 GBd single DSB and 3 GBd dual DSB cases. (b) BER curves versus ROP for the two different transmission schemes over 3-m wireless and 40-km fiber link. Insets (i) ~ (iii) show the eye and constellation diagrams with the fixed ROP of 0 dBm.

III. RESULTS AND DISCUSSIONS

Firstly, the BER performance comparison for 6 GBd single DSB signal between conventional and proposed schemes over 3-m wireless and three kinds of different fiber transmission distances are shown in Fig. 3. The single QPSK DSB signal is generated by setting $s_2(t)$ to zeros while retaining $s_1(t)$. The RFP phase noise cancellation method is adopted in both schemes. For conventional scheme, signal recovery is achieved by directly extracting the carrier $E_c(t)$ without HT superposition and multiplying it with the original signal $E_{IF}(t)$ only in cosine direction [5]. Instead, the proposed scheme adopts the principle given in Fig. 2(c), in which $s_1(t)$ is recovered jointly by two components in orthogonal directions. Due to the phase shift between the carrier and sideband signal resulting from CD effect [6], the original signal in cosine direction is transferred to two orthogonal directions (cosine and sine) after fiber transmission. Since their powers are exactly complementary, thus the CD-induced power fading can be overcome via a joint ECDC. The results shown in Fig. 3 are consistent with our theoretical analysis. At the optical back-to-back (OB2B) case, the two schemes have similar performance. However, after 40/80-km SSMF transmission, the proposed scheme can effective overcome the CD impact by a joint ECDC, which is impossible for conventional scheme

We further give the performance comparison between 6 GBd single DSB and 3 GBd dual DSB QPSK signals, Fig. 4(a) shows their corresponding spectra. Noting that two independent QPSK signals are completely overlapped in dual DSB case, which can achieve the same transmission rate as that of 6 GBd single DSB case, but the bandwidth is nearly halved. It can be seen from Fig. 4(b) that, similar performance can be achieved in both cases after 40-km SSMF transmission, which can also observed from the eye and constellation diagrams given in insets (i) ~ (iii).

IV. CONCLUSION

We have experimentally demonstrated the simultaneous transmission of two independent microwave vector signals over 3-m wireless and up to 80-km fiber at W band. Two real-value QPSK signals are modulated by one single DDMZM, and demodulated via a novel DSP approach. The proposed scheme can not only effectively overcome the power fading of DSB signal, but also achieve high spectral efficiency for fiber-MMW hybrid transmission links.

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