Self-Interference Cancellation for 2×2 MIMO in-band full-duplex radio-over-fiber systems

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Abstract: *A self-interference cancellation (SIC) system based on dual-drive MZMs is proposed for 2×2 MIMO radio-over-fiber systems. Spectrum efficiency and system capacity are significantly promoted by employing SIC system for in-band full-duplex MIMO communications.*
Keywords: *self-interference cancellation, 2×2 MIMO, DD-MZM*

I. Introduction

Recently, the in-band full-duplex (IBFD) transmission have been widely investigated and considered as a promising air interface technique [1]. As for IBFD radio-over-fiber (RoF) systems, downlink (DL) and uplink (UL) radio frequency (RF) signals are simultaneously transmitted and received in the same frequency band between remote antenna units (RAUs) and user ends (UEs), which significantly doubles the spectrum efficiency of wireless system compared to frequency-division duplex (FDD) and time-division duplex (TDD) mode. Moreover, the combination of RoF and multiple-input-multiple-output (MIMO) has the potential to significantly enhance system capacity and reliability, thus representing an attractive trend for next generation mobile access networks [2-3].

However, in IBFD MIMO systems, each receive antenna gets to receive several high-power in-band self-interference (IBSI) signals from transmit antennas located nearby, and these IBSI cannot be removed by preselected band-pass filter. In this case, self-interference cancellation (SIC) systems are investigated to enable IBFD mode. Optical or optical/electrical mixed SIC schemes have been studied in order to overcome the limitation of cancellation bandwidth [4-6]. In our previous work [6], we have proposed a SIC system based on dual-drive Mach-Zehnder Modulator (DDMZM) for single-input-single-output (SISO) IBFD systems and experimentally demonstrated the viability with the available bandwidth range of 0-25GHz.

In this paper, we continue the IBFD research and propose a SIC system for 2×2 MIMO RoF systems. Based on DDMZMs, the SIC system cancels the self-interference from both transmit antenna 1 (Tx1) and transmit antenna 2 (Tx2), and successfully recovers the UL in-band signal from the UE. The results show good UL transmission performance with SIC for the 2×2 MIMO IBFD RoF system.

II. Principle and Architecture

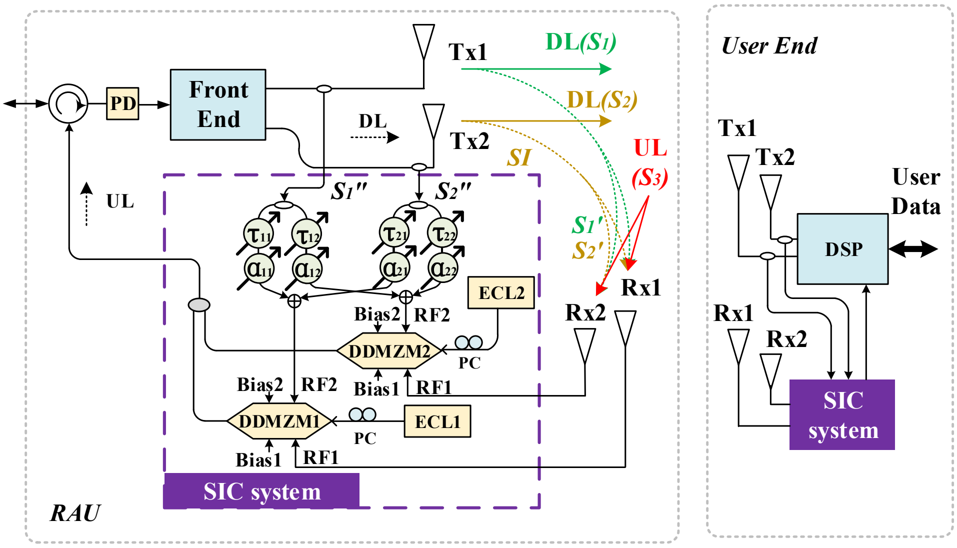

Fig. 1. Architecture of the IBFD system and proposed SIC system.

Figure 1 depicts the architecture of the proposed SIC system and 2×2 MIMO IBFD system. The SIC system has to remove self-interference signals from two adjacent transmit antennas. In RAU, the DL optical signal is demodulated in a photo-detector (PD) and the two DL radio frequency (RF) signals with the same RF carrier frequency are processed in front-end, represented as S_1 and S_2 from Tx1 and Tx2, respectively. S_3 represents the desired UL RF signal, which is the combination of two UL RF signals from two transmit antennas in UE. The processing of UL MIMO signals is conducted in central office (CO), which is not included in our research. The received signal from each receive antenna (Rx1 or Rx2) combines DL SI from Tx1 and Tx2, represented as S_1' and S_2' respectively, and the desired UL signal S_3.

The SIC system in RAU aims to remove S_1' and S_2' and to recover S_3. The two DL signals are tapped into SIC system before transmitting, represented as S_1'' and S_2''. In SIC system, S_1'' and S_2'' undergo splitting, delaying, attenuating, and coupling, then are entered into RF1 ports of the two DDMZMs, as shown in Fig. 1. In this paper, due to the same condition of the two receiving path, we only take Rx1 path as example to study. The condition in Rx2 path only has the difference of optical wavelength generated by ECL with that in Rx1 path. The signal transmitted into RF1 port of DDMZM1 is $S_1'+S_2'+S_3$, while into RF2 port is $\alpha_{11}S_1''(\tau_{11})+\alpha_{21}S_2''(\tau_{21})$. So the optical phase of bottom arm ϕ_1 and up arm ϕ_2 of DDMZM1 are shown in Eq. 1 and Eq. 2, respectively. Bias voltage of bottom arm is V_π and of up arm is 0 to keep the linear E/O modulation bias point.

$$\phi_1 = \frac{\pi}{V_\pi} V_1 = \frac{\pi}{V_\pi}(V_\pi + S_1' + S_2' + S_3). \tag{1}$$

$$\phi_2 = \frac{\pi}{V_\pi} V_2 = \frac{\pi}{V_\pi}(\alpha_{11}S_1''(\tau_{11}) + \alpha_{21}S_2''(\tau_{21})). \tag{2}$$

By precisely-tuned attenuated and delayed, S_1'' turns into $\alpha_{11}S_1''(\tau_{11})$, which is adjusted equal to S_1'. Likewise, S_2'' turns into $\alpha_{21}S_2''(\tau_{21})$, which is adjusted equal to S_2'. So that shown by Eq. 3, the S_1' and S_2' are subtracted and S_3 is remained.

$$E_{out} = E_{in}\cos\frac{\phi_1-\phi_2}{2}e^{j\frac{\phi_1+\phi_2}{2}} = E_{in}\cos\left(\frac{V_\pi}{2}+\frac{\pi}{2V_\pi}S_3\right)e^{j\frac{\phi_1+\phi_2}{2}}. \tag{3}$$

$$P_{out} = P_{in}\cos^2\left(\frac{V_\pi}{2}+\frac{\pi}{2V_\pi}S_3\right). \tag{4}$$

E_{in} is input optical field and P_{in} is input optical power of DDMZM. The bias voltage $V_\pi/2$ is the linear modulation bias point of MZM, set for the best E/O modulation of S_3 in Eq. 4. After optical power detection in PD, the UL signal of interest S_3 is well recovered and treated in CO.

The SIC system is also employed in UE to recover in-band DL signal for realizing IBFD. Without modulation and transmission, recovered DL signal is photo-detected in SIC system and treated in digital signal processing (DSP) module in UE.

III. Simulation Results and Discussion

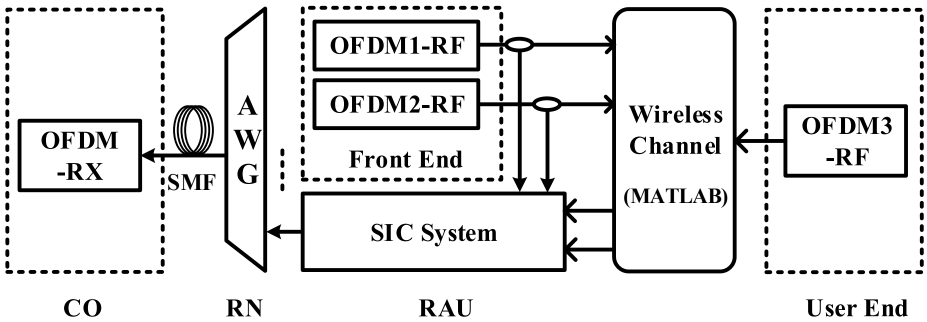

Fig. 2. Simulation architecture of IBFD RoF system

To prove the practicability of this SIC system for 2×2 MIMO IBFD systems, a simulation system is designed and real-time in-band signal transmission is performed over the band of interest, as depicted in Fig. 2. To meet the 3GPP standard [7], 64-QAM OFDM signals over 100-MHz bandwidth in 2.4-GHz wireless band are employed as S_1, S_2 and S_3, which are generated by OFDM1-RF, OFDM2-RF and OFDM3-RF modules, respectively. The wireless channel is simulated by MATLAB and the simulation is conducted by OptiSystem 13.0. For simplicity, only transmission delay, transmission attenuation and additive Gauss white noise (AWGN) are considered in wireless channel simulation. By properly adjusting all the delay and attenuation parameters towards wireless channel response, the self-interference is removed in SIC system. Recovered UL desired signal is transmitted through arrayed waveguide grating (AWG) in remote node (RN) and single mode fiber (SMF), then received in OFDM-RX module in CO. 64-QAM constellation diagrams are plotted and error vector magnitude (EVM) of them are calculated by off-line processing.

Firstly, the comparison of desired UL signal with and without cancellation is observed. The received constellation diagrams are shown in insert (i)-(iii) of Fig. 3. In the case of back-to-back optical transmission and about -3dBm received power, S_3 buried by self-interference cannot be received properly and the EVM is very large shown in insert (ii) of Fig. 3. After enabling the SIC system under the same condition, we can see from insert (iii) that clear 64-QAM constellation diagram is achieved and calculated EVM is only 1.923%, which shows the successful recovery and transmission of desired UL signal S_3. In real IBFD system, due to the variation of environment condition like channel change, the attenuation perameters in SIC system may not be precisely ajusted to the best cancellation condition quickly. So we investigate the ajustment budget of α_{11} and α_{21} shift towards the condition of α_{11} and α_{21} that insert (iii) of Fig. 3 indicates. Received EVM versus the shift of α11 and α21 is plotted in Fig.4. The specified requirement of EVM in the 3GPP standard for 64-QAM is 8% [7], so the simulation results show adjustment budget from -1 to +1.5 dB for both α_{11} and α_{21}. Therefore, this SIC system can support a spot of amplitude shift budget in b-t-b case so that it supports short-term change of system condition.

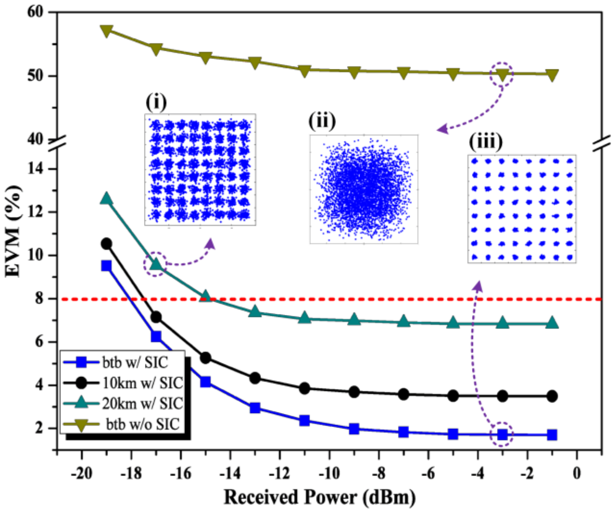

Fig. 3. EVM curves and constellation diagrams

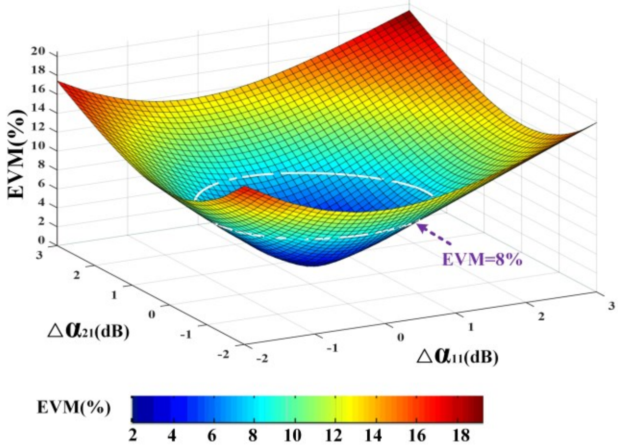

Fig. 4. EVM versus the shift of α11 and α21

Then, the UL EVM performances with difference fiber lengths are evaluated. Figure 3 shows the EVM curves of b-t-b, 10-km and 20-km fiber reach, respectively. The requirements of EVM is 8%, marked as the red dot line in Fig. 3. Insert (i) of Fig. 3 shows the constellation diagram with 9.534%, larger than 8% in 20-km fiber transmission case. The simulation results show that the IBFD system supports 20-km SMF RoF transmission with received power of -15 dBm at least.

IV. Conclusions

In this paper, we propose the SIC system for 2×2 MIMO RoF systems based on DDMZMs. For the first time, SIC is introduced into MIMO systems in which transmission capacity is significantly enlarged than SISO systems. This SIC system can cancel the interference from two adjacent transmit antennas for IBFD communication, which significantly improves spectrum efficiency compared to TDD and FDD.

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