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Research article

A novel dual polarization multiplexing RoF system integrating optical fiber and FSO channel with AMI downlink signals

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ABSTRACT

Using dual polarization multiplexing alternate mark inversion (AMI) downlink signals, a novel radio over fiber (RoF) system integrating optical fiber and FSO channel is designed to adapt to applications in mountainous areas and other complex terrain areas. Optical heterodyne technology and self-mixing homodyne detection method are used to realize high sensitivity detection of the received signals after 25.1 km channel (including 1 km single-mode fiber and 100 m free space link) transmission. Moreover, polarization multiplexing technology is introduced to exponentially increase the transmission capacity of downlink signals. This scheme not only can be compatible with traditional optical fiber transmission systems, but also support the wireless optical access application of millimeter wave signals in RoF systems.

1. Introduction

Recently, the development of communication services is becoming more and more mature, but it is difficult to effectively transmitted broadband access signals in some complex terrain areas. Moreover, the traditional information transmission methods in complex terrain areas have some problems, such as large investment and difficulties in construction. Therefore, how to reduce the budget cost and implementation complexity is a hot topic [1]. Free space optical (FSO) communication system can transmit high speed wireless optical signals, reduce the budget cost of the system without optical fibers, especially can be suitable for communication in mountainous area [2]. As we know, the radio over fiber (RoF) communication system has the superiority of large capacity information transmission of optical communication and seamless coverage of wireless access applications [3–6]. In some complex terrain areas, such as mountains and rivers, it is difficult to install communication cables underground, especially for optical fiber cables [7]. Some wireless devices can be used to achieve information transmission in areas where it is not easy to lay optical fiber [8], while wired links are used to communicate between remote areas and cities [9,10]. Hence, a novel RoF system integrating optical Fiber and FSO channel is designed in this paper, and polarization multiplexing technology is also introduced, since it can improve frequency spectrum

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utilization and double transmission capacity [11,12]. Using alternate mark inversion (AMI) coding, positive and negative values can be processed during data processing in electrical domain, which can save application bandwidth of electronic devices [13,14]. Moreover, AMI coding makes it easier to detect and fix errors at the receiver [15]. Hence, AMI coding is introduced in our scheme. Kamal K. Upadhyay and et al. have designed the FSO communication system with AMI coding, wavelength division multiplexing (WDM), and polarization division multiplexing (PDM), and transmission of 160 Gbps data has been realized over 8 km FSO links [16]. R. Chowdhury and et al. have proposed an AMI-PDM-WDM FSO system scheme that can achieve the wireless optical signal transmission of 5 km links [17]. A. Grover and et al. have proposed a polarization shift keying (PolSK) mode division multiplexing (MDM) FSO transmission system. In this system, two 40 Gbps signals are transmitted through 90 km FSO links [18].

In this paper, a novel dual polarization multiplexing RoF system integrating optical fiber and FSO channel with AMI downlink signals is introduced and discussed. The results show that the used system not only can be compatible with traditional optical fiber access network, but also support 20Gbit/s wireless optical signal and 60 GHz mm wave signal downstream transmission.

2. System setup

Fig. 1 shows the transmitter of double-polarization RoF-FSO communication system with AMI coding. The AMI electrical signal generation module consists of pseudo-random bit sequence generator, duobinary precoders, non-return-zero pulse generators, low pass filters and electrical signal delay devices. One 193.1 THz optical carrier is generated by using one continuous wave (CW) $Laser_1$, and the other optical carrier with 193.16 THz frequency is produced through the CW $Laser_2$. The configurated optical frequency interval facilitates the generation of 60 GHz mm wave at the PIN. The polarization beam $splitter_1$ divides the optical signal into two equal orthogonal polarized beams. Two AMI signal generation modules are used to generate 10Gbit/s AMI electrical signal, then driving the dual-arm Mach-Zehnder modulator (MZM) to modulate the two beams of light. One polarized light is formed by combining the polarization beam combiner. The symmetrical 3 dB optical coupler is used to couple the modulated optical carrier with CW_2 (193.16 THz), then transmitted on the 25.1 km channel (integrated 25 km optical fiber and 100 m free space link single channel), as shown in Fig. 2. For the used optical fiber, the signal attenuation value is 0.2 dB/km, and the dispersion is 16.75 ps/nm/km. In FSO links, the transmitter aperture diameter is 5 cm, the receiver aperture diameter is 20 cm, and the beam divergence is 2mard. The atmospheric turbulent follows gamma–gamma (G–G) distribution. In sunny weather, the signal attenuation value is 10 dB/km. Table 1 and Table 2 list the optical fiber and free-space link parameters, respectively.

The polarization beam $splitter_2$ splits the received signal into two distinct signals and sends them to different photodetectors. In positive intrinsic negative (PIN), the millimeter wave signal of 60 GHz is generated after the beat between two light waves that carried different center frequencies. The transmission and reception of millimeter wave signals are realized by two standard horn antennas, and then demodulated by self-mixing homodyne detection method. The received electrical signal is divided into two channels. To match the RF phase information, two adjustable phase shifters and two mixers are used for self-homodyne reception. The self-mixing detection is used to eliminate the need of a local oscillator source and reduce the system cost budget [19]. Two baseband signals are filtered out by using two low pass filters (LPFs). The cut-off frequency value of the used LPF is 0.75 GHz. Two original digital signals are restored by using two 3R regenerators, as shown in Fig. 3. Each used 3R Regenerator has one input port and three output ports. The input port he input port is used to receive the electrical signals after demodulation and filtering. The first output port is the original bit sequence, the second one is the modulated NRZ signal and the last output is a copy of the input signal. These three signals can be connected directly to the bit error ratio (BER) Analyzer, avoiding additional connections between transmitter and the receiver. Fig. 4 shows the simulation system we have built.

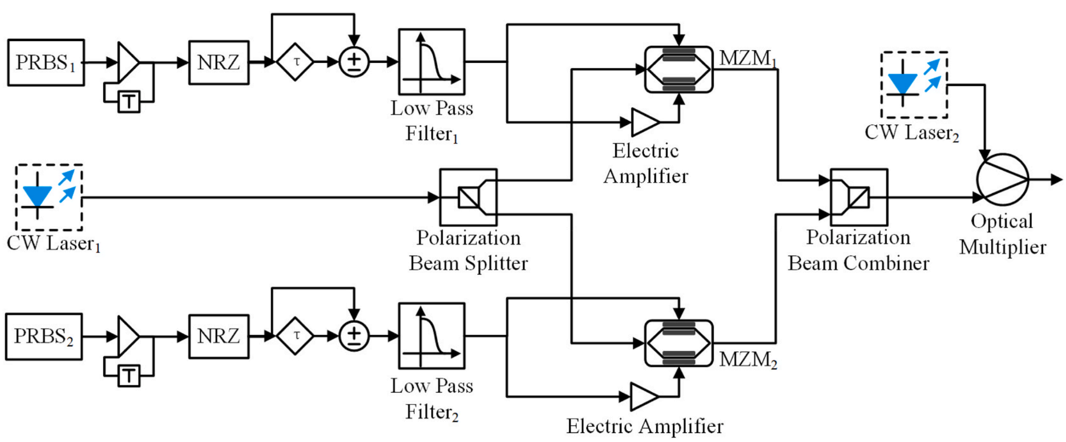

Fig. 1. Transmitter configuration. CW: continuous waves; MZM: Mach-Zehnder modulator; NRZ: Non-Return to Zero; PRBS: Pseudo-Random Bit Sequence.

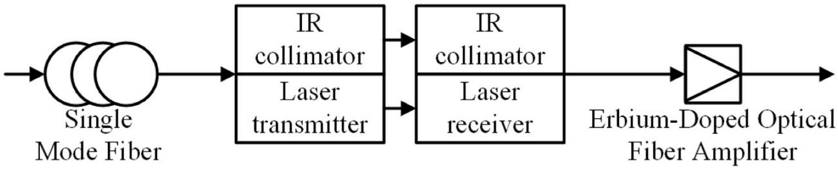

Fig. 2. Channel configuration.

Table 1
Optical fiber parameters.

Parameter	Value
Length	25 km
Attenuation	0.2 dB/km
Dispersion	16.75 ps/nm/km
Dispersion slop	0.075 ps/nm^2/km
Core area	80 μm^2

Table 2
FSO links parameters.

Parameter	Value
Length	100 m
Attenuation	10 dB/km
The transmitter aperture diameter	5 cm
The receiver aperture diameter	20 cm
The beam divergence	2mard

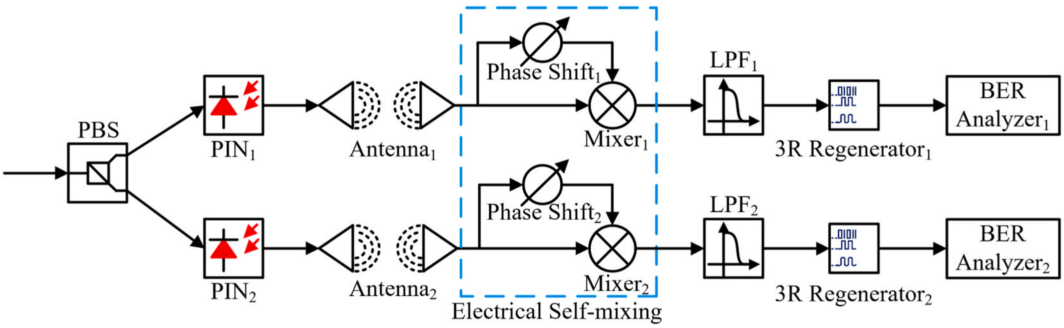

Fig. 3. Receiver configuration. PBS: Polarization Beam Splitter: PIN: Positive Intrinsic Negative; LPF: Low Pass Filter.

3. Results

The detected time domain waveforms of AMI signal$_1$ and signal$_2$ before transmission at the double-polarization RoF-FSO system transmitter are shown in Fig. 5 (a) and (b), respectively. Fig. 5 (c) and (d) show the time-domain waveforms after transmission of AMI signal$_1$ and signal$_2$, respectively. Fig. 6 (a), (b), and (c) show the optical spectra diagrams of different detection positions in Fig. 2. The power values of the received optical signals are reduced, since the dispersion effect of the used fiber and the atmospheric turbulence influence existing in the FSO link. It is clear to see that the values of central wavelength are not changed. Hence, the frequency stability of transmitting and receiving signals is good in this scheme.

Fig. 7 (a) and (b) show the electrical spectrums of the transmitted signal$_1$ and signal$_2$, respectively. Fig. 7 (c) and (d) show the electrical spectrums of the received signal$_1$ and signal$_2$ after polarization demultiplexing respectively. Since the bit rate of the transmitted signals is 10Gbit/s, all the main lobe bandwidth values of the detected electrical spectrums are 10 GHz. The attenuated value of the main lobe peak power is less than the side lobe. The energy of signal is mainly concentrated in the main lobe (0–10 GHz), so the impact is not significant.

The received optical power versus BER of two AMI signals after polarization de-multiplexing is shown in Fig. 8. As the BER is 10^{-9}, at the back-to-back case the received optical power values of AMI signal$_1$ and signal$_2$ are −19.35 dBm and −19 dBm, respectively. After signals are transmitted over 25.1 km channel (including optical fiber and FSO link), the received power values are −17.79 dBm and −17.8 dBm, and the receiver sensitivities are 1.16 dB and 1.45 dB, respectively. The results show that after polarization multiplexing

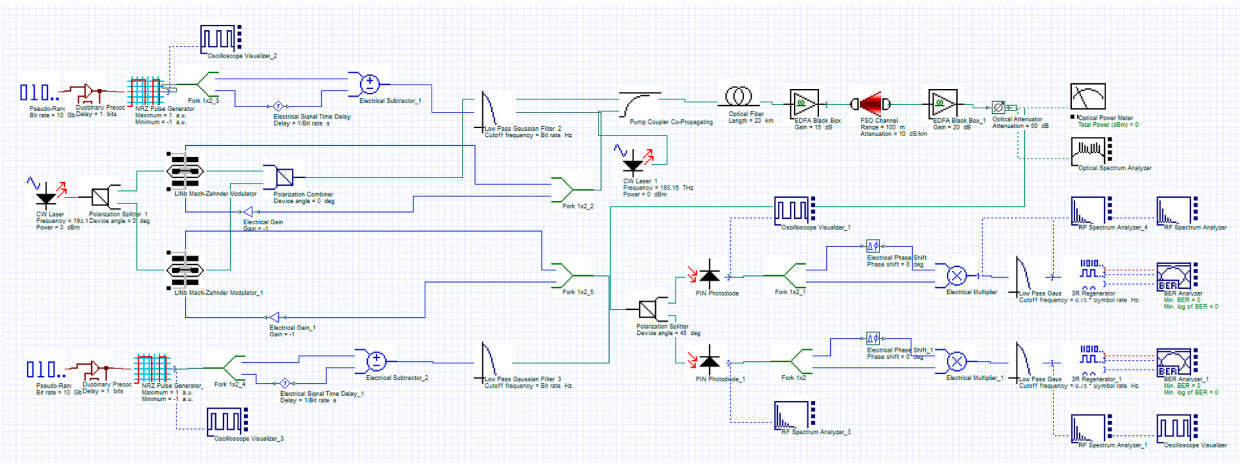

Fig. 4. The image of simulation work.

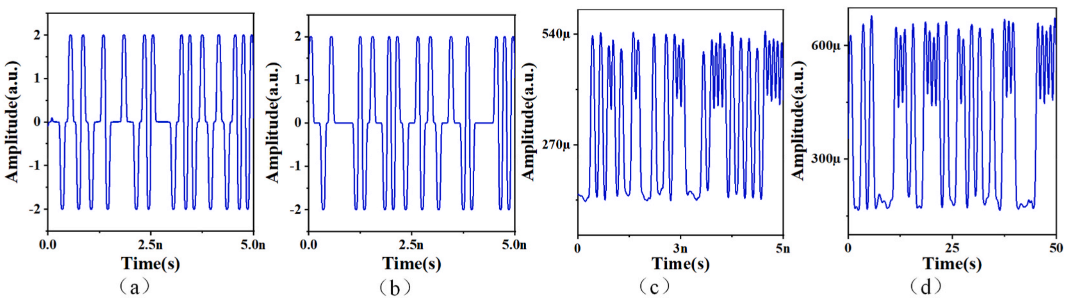

Fig. 5. The time domain waveforms of (a) AMI $signal_1$, (b) AMI $signal_2$ before transmission, (c) AMI $signal_1$ and (d) AMI $signal_2$ after transmission.

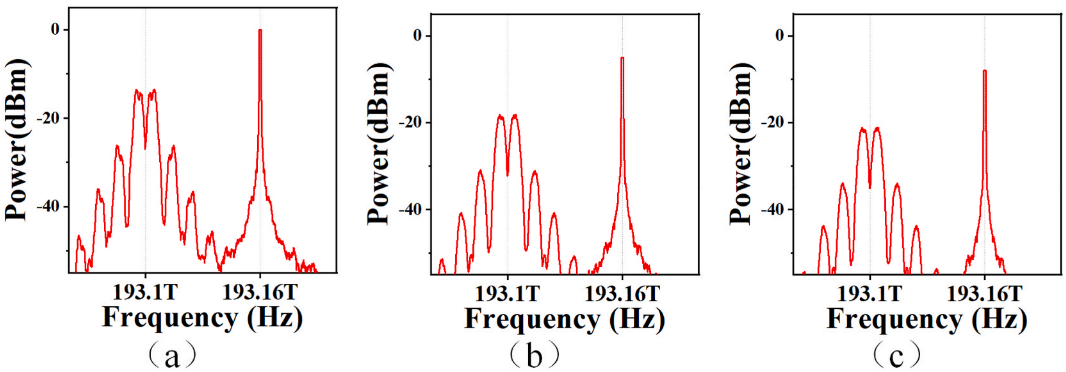

Fig. 6. The optical spectra diagrams of (a) before transmission, (b) after optical fiber transmission and (c) after FSO link transmission.

and de-multiplexing process, there is no significant difference in the reception performance of the two downlink access signals. Although they are transmitted through different polarization direction links, they can be effectively received and restored the original transmitted data signals.

Fig. 9 illustrates the BER curves under different weather conditions. At a BER of 10^{-9}, in sunny weather (the signal attenuation value is 10 dB/km), the received optical power values of both AMIs are −17.75 dBm. In rainy weather (the signal attenuation value is 35 dB/km), the received power values of two signals are −16.91 dBm and −17.05 dBm, respectively, at BER = 10^{-9}. In foggy weather (the signal attenuation is 55 dB/km), at BER = 10^{-9}, the received power values of two signals are −16.22 dBm and −16.28 dBm, respectively. The results show that after polarization multiplexing and demultiplexing the receiver sensitivity values of the two AMI signals are similar. On sunny days, the reception performance of two AMI signals is the best. While on foggy days, the reception performance of two AMI signals is the worst.

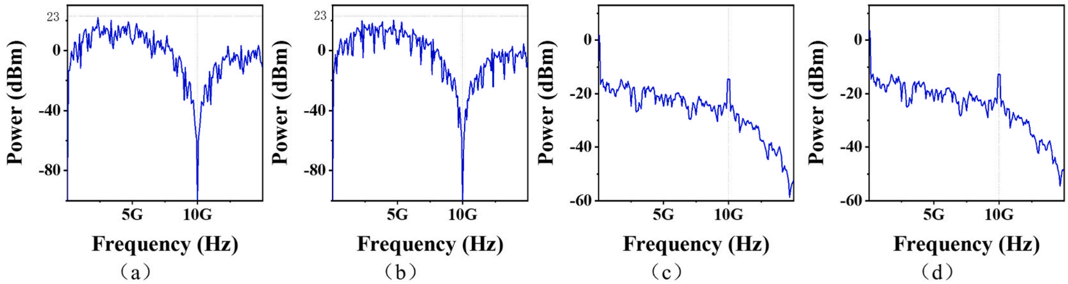

Fig. 7. The electrical spectra diagrams of (a) AMI signal$_1$, (b) AMI signal$_2$ before transmission, and (c) AMI signal$_1$ and (d) AMI signal$_2$ after transmission.

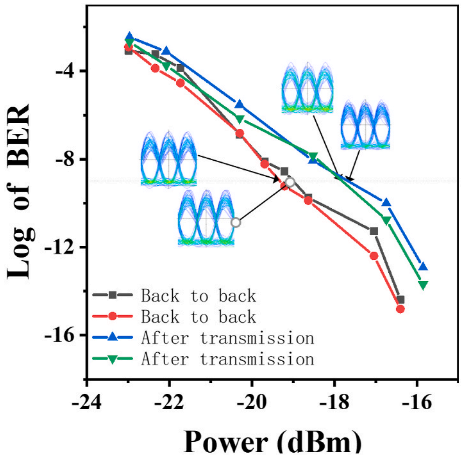

Fig. 8. The curves of received power versus BER and eye diagrams after detecting signals.

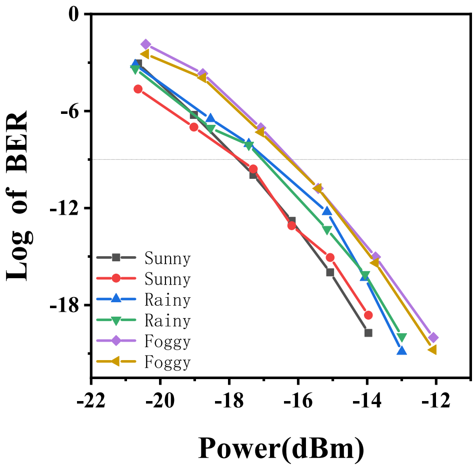

Fig. 9. The curves of received power versus BER under different weather conditions.

4. Conclusion

In this paper, we proposed and designed a novel polarization multiplexing RoF-FSO access system with AMI downstream signals. The results show that this scheme not only can be compatible with traditional optical fiber transmission systems, but also support the wireless optical access application of millimeter wave signals in RoF systems. Hence, this scheme can be applied to mountainous areas and other complex terrain areas, and has a good prospect in the future broadband RoF-FSO access networks.

Data availability statement

Data will be made available on request.

Additional information

No additional information is available for this paper.

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CRediT authorship contribution statement

Yufeng Shao: Writing – review & editing, Writing – original draft, Methodology, Investigation. **Qing Tian:** Writing – review & editing, Writing – original draft, Data curation. **Yaodong Zhu:** Investigation. **Anrong Wang:** Investigation. **Qiming Yang:** Investigation. **Linfang Yi:** Investigation. **Ni Yu:** Investigation. **Chong Li:** Investigation. **Peng Chen:** Investigation. **Yanlin Li:** Investigation. **Shuanfan Liu:** Investigation. **Renjie Zuo:** Investigation. **Jie Yuan:** Investigation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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