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Single-source bidirectional free-space optical communications using reflective SOA-based amplified modulating retro-reflection

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ABSTRACT

A novel amplified modulating retro-reflector (AMRR) based on a reflective semiconductor optical amplifier (RSOA) is proposed and a bidirectional free-space optical communication (FSO) system including both downstream and upstream links is experimentally demonstrated with only a single light source using this AMRR. The RSOA-based AMRR can provide a net gain more than 4 dB and support the modulation bit rate up to 1.25 Gbit/s. The bidirectional FSO transmission performance is evaluated by observing eye diagrams and measuring bit error rate (BER) results of both 10-Gbit/s DPSK downstream and 1.25-Gbit/s OOK upstream signals. The factors that limit the modulation bit rate and transmission quality are analyzed. The power penalties of both links are less than 0.69 dB in the bidirectional FSO system at the BER of 1×10^{-3}.

1. Introduction

Free-space optical communication (FSO) has been considered as a promising technology in response to a growing need for high-speed and tap-proof communication systems to transfer information between mobile and stationary terminals (aircrafts, satellites, and ground platforms, etc.), which exhibits many potential advantages in security, strong anti-jamming ability, high bandwidth, and large available spectrum [1,2]. In the past, several kinds of typical FSO transmissions have been demonstrated between two satellites [3], between the moon and the earth [4], and between an aerobat and a ground terminal [5]. In laboratory conditions, high-speed (gigabit and even terabit) FSO links between two fixed short-distance points have also been implemented by employing multiple-dimensional multiplexing of orbital angular momentum, polarization, and wavelength [6–8].

However, these active FSO systems with high pointing accuracy are often large, heavy, complex, and of high power consumption, which becomes challengeable when the terminals have strict payload and power limits [9]. For such implementations, modulating retro-reflectors (MRRs) have exhibited more competitions. A MRR combines an optical retro-reflector with a modulator to reflect modulated optical signals directly back to the transceiver and shifts most of the power, weight and pointing requirements onto the base station of the FSO systems [10,11]. MRRs have been demonstrated through different ways such as frustrated total internal reflectors [12], electro-optic phase modulators [13], liquid crystal modulators [14,15], and multiple quantum well devices [16,17]. In above schemes, the modulation and reflection elements are all discrete and of large volumes, and the modulation speed is relatively low. As a powerful signal-processing device, reflective semiconductor optical amplifier (RSOA) shows robust performances. An integrated RSOA with pigtail has many advantages such as small volume, lightweight, optical power amplification, and of collinear optical path. Moreover, RSOA can be used as a reflector and a modulator simultaneously, which has been widely demonstrated in wavelength-division multiplexing passive optical networks (WDM-PONs) [18–20]. Therefore, an amplified MRR (AMRR) for FSO systems is possible to be realized by using the RSOA as an amplifier, modulator, and reflector simultaneously, since an amplified, modulated, and retro-reflected light can be obtained when an interrogation light is injected into the RSOA.

In this paper, we propose and experimentally demonstrate, for the first time to our best knowledge, a RSOA-based AMRR and a bidirectional FSO system for 10-Gbit/s downstream differential phase shift keying (DPSK) signal and 1.25-Gbit/s upstream on-off keying (OOK) signal with a single light source using this AMRR. In the bidirectional FSO system, only a single optical carrier is used, which is arranged at the transceiver. The uplink signal is modulated on the reflected optical carrier at the terminal. Eye diagrams and bit error rates (BERs) are measured for both downlink and uplink signals. At the BER of 1×10^{-3}, the power penalties are measured to be 0.69 and 0.47 dB for the 10-

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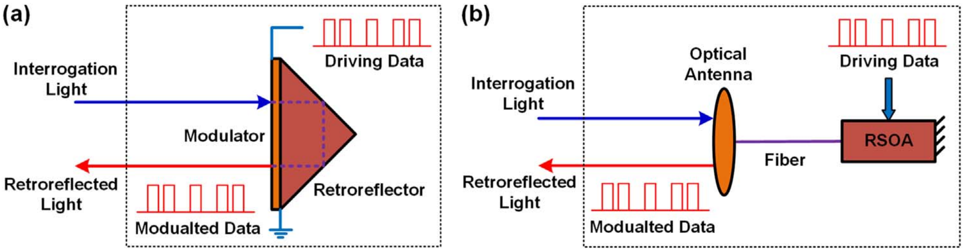

Fig. 1. Schematic configurations of (a) a coventional MRR structure using semicondutor multi-quantum-well modualtor and a corner-cube prism retro-reflector and (b) our proposed RSOA-based AMRR by using the RSOA as the modulator, amplifier, and rectro-reflector simultenously.

Gbit/s downstream DPSK signal and the 1.25-Gbit/s upstream OOK signal.

2. Principle

A MRR structure needs to include the elements that can realize optical retro-reflection and modulation. As shown in Fig. 1(a), in the conventional MRR configuration, the interrogation light is modulated by the driving data sequence using the modulator such as a semiconductor multi-quantum-well modulator. And then, it is reflected by the retro-reflector using such as a corner-cube prism. Since a RSOA can realize the modulation and retro-reflection simultaneously, the MRR function can be utilized using a single RSOA. Fig. 1(b) shows the configuration of our proposed RSOA-based MRR. The interrogation light is collected using an optical antenna and coupled into an optical fiber. And then, the interrogation light is injected into the RSOA, where it is modulated by the driving data and reflected backward to the optical fiber. After coupling from the fiber to the optical antenna, the retro-reflected light is transmitted back to the transceiver from the MRR via free space. Compared with the conventional MRR, our proposed RSOA-based MRR can support higher modulation bit rate, which is up to the level of GHz, and has a small volume. Also, the RSOA has the ability of amplification and the incident interrogation light will be amplified when it is reflected as the retro-reflected light. It means that the RSOA-based MRR is an AMRR.

For an optical carrier, multiple physical quantities can be used for data modulation. According to the used physical quantities, the signals are classified as amplitude-shift keying (ASK), phase-shift keying (PSK), and polarization-shift keying (PolSK) signals, etc. In order to realize high-quality bidirectional transmission using a single light source, the influence between the downstream and upstream signals should be effectively eliminated. Since the amplitude can be kept the same when a PSK signal is modulated on the phase of the optical carrier, the PSK optical signal is expected to be amplitude modulated once more to transmit a ASK signal without crosstalk. The principle is shown in Fig. 2. For the downstream link, DPSK modulation format is selected, which is only modulated on the phase of the optical carrier at the transceiver, and the amplitude of the optical carrier is constant, as shown in Fig. 2(a). When the downstream DPSK optical signal is transmitted to the terminal, one part is used for demodulation, and the other serves as the interrogation light of the RSOA-based AMRR to generate the upstream link. Here, the interrogation light serves as the optical carrier and it is amplitude modulated by the upstream OOK format through the RSOA, as shown in Fig. 2(b). After modulated, the upstream optical signal is amplified and retro-reflected back to the transceiver. As the OOK signal only changes the optical carrier amplitude, which is independent on the carrier phase. Therefore, the existence of the downstream DPSK signal will not affect the modulation and detection of the upstream OOK signal. In this way, a high-quality bidirectional FSO system with a single light source is expected to be realized with low crosstalk using our proposed RSOA-based AMRR.

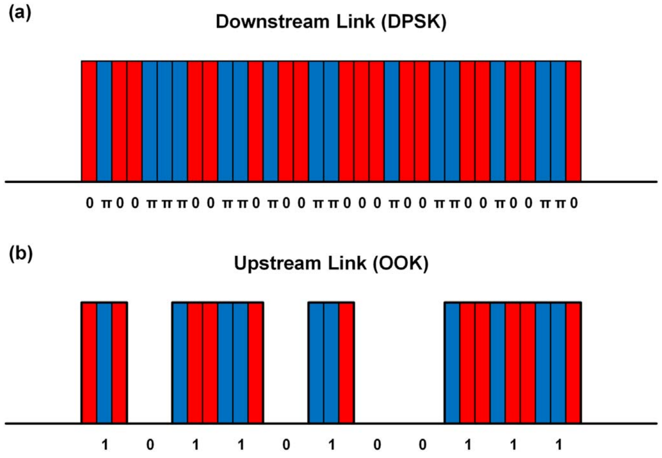

Fig. 2. Principle for choosing the modulation formats of the bidirectional FSO system.

3. Experimental setup

Fig. 3 shows the experimental setup of the proposed bidirectional FSO system with a single light source using the RSOA-based AMRR. The light source is provided by a continuous-wave (CW) tunable laser (Agilent 81940) with a 1.12-dBm power at 1550.0 nm. At the transceiver, it is modulated by a 10-Gbit/s DPSK sequence via a phase modulator and launched into free space through a collimator (Collimator 1, Thorlabs F280FC-1550) whose divergence angle is 0.032°. After 0.5-m transmission, it is coupled back to an optical fiber at the terminal for detection and upstream modulation via another collimator (Collimator 2, Thorlabs A397TM-C), which serves as the optical antenna of the AMRR. Here a relatively short distance is transmitted since we mainly focus on the proof-of-concept demonstration in lab. If high-quality collimation optical systems are used for transmission, the distance has the ability to be effectively enhanced [3]. In our experiment, the field-of-view (FOV) of the RSOA-based AMRR is determined by the acceptance angle of Collimator 2, which is about 34.9°. If larger FOV is required, the conventional way is setting the optical antenna on a servo turntable and the orientation of the optical antenna can be changed by tuning the servo turntable to collect the interrogation light within a wider angle region [21].

At the terminal, the downstream DPSK optical signal is split into two branches. One branch (10% power) is sent into a one-bit delay interferometer for demodulation, where the DPSK signal is converted to a sequence of amplitude modulated signal. The converted signal is detected using a photodetector (PD1), the eye diagram is observed using an oscilloscope, and the BER is measured using a BER tester. The other branch of the downstream optical signal is sent into a RSOA (SOA-RL-OEC-1550) as the interrogation light. The transmission and coupling losses are 2.72 dB, and the optical power injected into the RSOA is −1.60 dBm. The upstream sequence, a 1.25-Gbit/s 2^7-1 pseudorandom binary sequence (PRBS) is modulated via the RSOA with a 55-mA driving current. After being modulated and amplified by the RSOA, the retro-reflected optical signal is measured to be