5 Gbps IR-UWB Signal Generation and Fiber Transmission Based on Optical Pulse Compression

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Abstract: Tunable optical pulse compression is proposed to generate the FCC compliant impulse radio ultra-wideband (IR-UWB) pulses with high speed modulation. Experimental generation and transmission of up to 5 Gbps IR-UWB signals are successfully demonstrated.

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1. Introduction

Ultra-wideband (UWB) technology is widely recognized as a good candidate for wireless short range links, which are limited by the extremely low emission power under the Federal Communications Commission (FCC) regulations [1]. In order to build a seamless wireless access network, UWB over fiber technology is motivated by its capability to enable UWB wireless reach extension. In an UWB over fiber system, photonic generation of FCC compliant UWB pulses with high speed data modulation is of great importance. So far, photonic impulse radio (IR) UWB generation/transmission experiments with 1.025Gbps, 500Mbps and 1.25Gbps on-off keying (OOK) modulation formats have been done by employing pulse doubler [2], fiber Bragg grating [3], response of SOA-integrated sampled grating distributed Bragg reflector (SGDBR) [4], and electrical pulse shaping filtering [5] as optical pulse shapers to generate complex Gaussian-like pulses, which can better fit the FCC mask than monocycle and doublet waveforms [6]. In those schemes, the bit rate is however limited by the repetition frequencies of employed pulse lasers. We have also previously demonstrated OOK and binary phase shift keying (BPSK) modulated IR-UWB generation and transmission [7-9] based on relaxation oscillations from a distributed feedback laser (DFB) [10], up to 3.125 Gbit/s [9]. However, the optical generation scheme is rather simple, faster modulation will need higher electrical speed (>20Gbps) pulse pattern generator (PPG) due to the representation of one UWB bit by using a sequence of several PPG bits. Therefore, in this paper we introduce an optical tunable pulse width scheme to achieve higher bit-rate for next generation UWB over fiber communications with no need for high speed electrical PPG.

In this paper, we propose a novel approach to optically generate a record 5 Gbps OOK modulated FCC compliant UWB pulses based on optical pulse compression. The tunability of an input non-return-to-zero (NRZ) pulse duty cycle has the potential to represent one UWB bit with the use of only a single electrical PPG bit at the symbol rate. Therefore, the generated UWB pulses have a same bit rate as the electrical input NRZ code, resulting in significantly reducing the requirements of the electrical PPG for its generation.

2. Experimental Setup

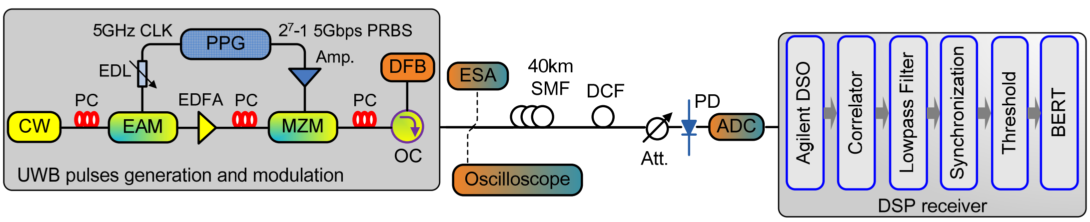

Fig.1 Experiment setup of photonic generation and modulation of 5Gbps UWB signals. CW: continuous-wave laser, EDL: electrical delay line, CLK: clock, PPG: pulse pattern generator, EAM: electro-absorption modulator, MZM: Mach-Zehnder modulator, PC: polarization controller, DCF: dispersion compensation fiber, OC: optical circulator, Att.: attenuator, PD: photodiode, ADC: analog-to-digital converter, ESA: electrical spectrum analyzer.

In our experiment, optical pulse compression is implemented in an electro-absorption modulator (EAM), which has shown good performance in optical signal processing [11, 12]. The experimental setup is shown in Fig.1. A continuous-wave (CW) from a tunable laser is polarization controlled and launched into an EAM, which is driven by a clock from a pulse pattern generator (PPG). Subsequently, a Mach-Zehnder modulator (MZM) biased at quadrature point is used to modulate an amplified pseudo-random binary sequence (PRBS) with a length of 2^7-1 onto the lightwave. An electrical delay line is used to synchronize the PRBS and clock, and an Er-doped fiber amplifier (EDFA) is employed to compensate the absorption and insertion losses of the EAM. Then, the output optical signals from the MZM are injected into a polarization-dependent DFB, and an optical circulator (OC) is used to forward the output signals from the DFB to 40 km single mode fiber (SMF) and matched 6 km dispersion compensation fiber (DCF). The generated signal is analyzed by an electrical spectrum analyzer (ESA) and an oscilloscope. At the receiver side, a digital signal processing (DSP) receiver, which includes correlation, filtering, synchronization and threshold algorithms in the digital domain, is used to demodulate analog-to-digital converted data information and test bit-error-rate (BER) performance.

3. Experimental Results and Discussions

Fig.2(a) displays the optical compressed pulses when a 5 GHz clock with 2 V peak-to-peak voltage is applied to the EAM. We can notice that when the EAM is reversely biased, the output pulse width is compressed and narrower than the original 5 GHz clock. The pulse width at -2 V bias point is narrower than at -1 V, that is to say the duty cycle of the compressed pulse at -2 V is smaller than at -1 V. The optical spectra at -2 V in Fig.2(b) are thus broader than at -1V. As shown in Fig.2(c), the increase of bias voltage will decrease the duty cycle, and however increase the transmission loss. The inset in Fig.2(b) displays the optical spectra of the CW and DFB wavelengths of 1553.47 nm and 1552.56 nm in the experiment.

The generation of a 4-bit UWB pulse train ‘1101’ at a bit rate of 5 Gbps is displayed in Fig.2(d). 2.3 V bias is applied, and the duty cycle in this case is 32.7%, the transmission loss is 19 dB, so an EDFA was needed between the EAM and MZM. When this optical compressed pulse is launched into a a DFB to lock at one of its sidemodes, the modulation at the CW will be transferred to the DFB wavelength, which can be clearly observed in the optical spectra in Fig.2(b), and meanwhile, the wavelength spacing between them determines the time delay. We can see the output pulse at the DFB wavelength in Fig.2d(ii) is composed of an opposite compressed pulse caused by cross gain modulation, and overshooting due to relaxation oscillations in the DFB [5]. By incoherently summing up the intensity of the two short pulses at two wavelengths, a pulse with complex shape in Fig.2d(iii) is thus generated. By this mean, the original NRZ PRBS data sequence is preserved. Therefore, the pulse train in Fig.2d(iii) is also at a bit rate of 5 Gbps.

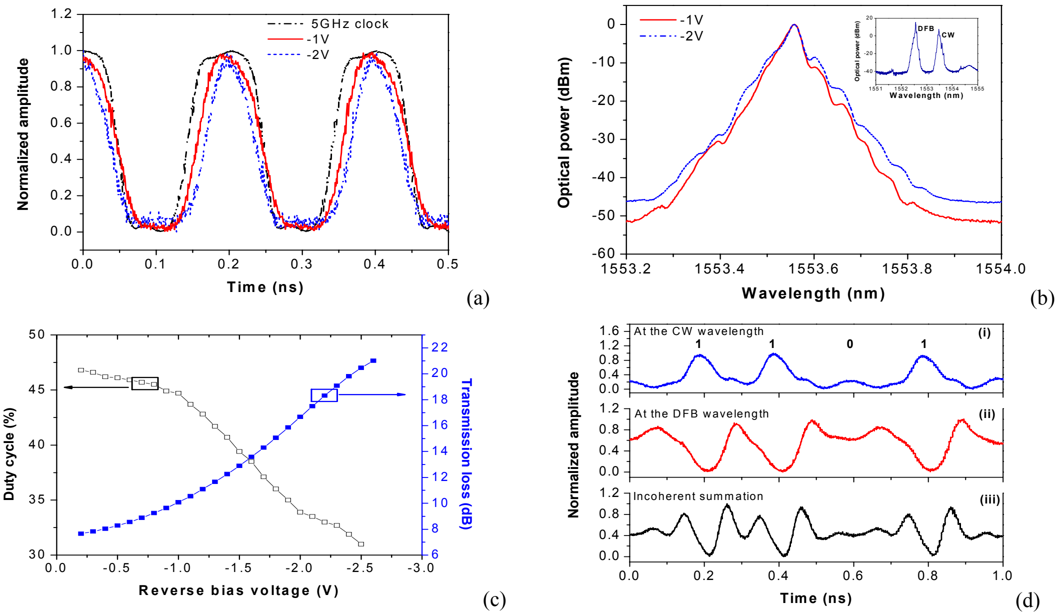

Fig.2 (a) pulse compression in the EAM by changing bias voltage, (b) optical spectra with respect to different bias voltages. The inset shows the wavelengths of the DFB and CW. (c) transmission loss of the EAM and duty cycle of compressed pulse. (d) generation of a UWB pulse train ‘1101’ at a bit rate of 5Gbps. (i) pulses at the output of the MZM, (ii) output pulses from the DFB wavelength, (iii) generated UWB pulses with complex shape.

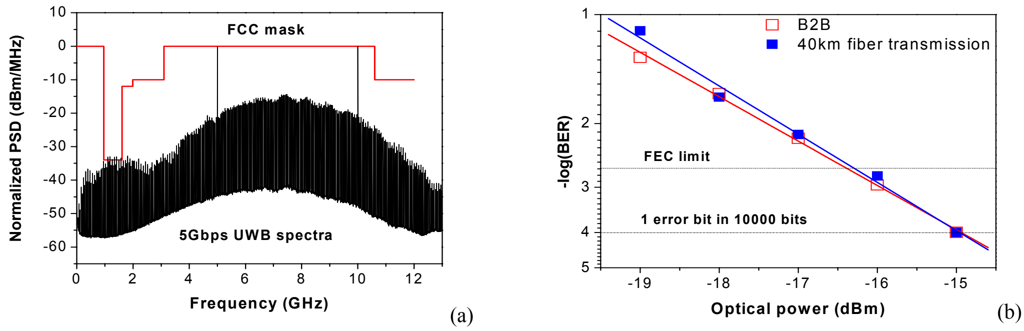

Fig.3 (a) normalized power spectrum density (PSD) of generated 5Gbps UWB signals and FCC mask. (b) BER performance of 5Gbps UWB signals in back-to-back and 40km transmission cases.

In Fig. 3(a) we show the generated UWB frequency spectra with the modulation of a 5 Gbps PRBS. The repetition frequency of 5 GHz validates the 5 Gbps bit rate is successfully generated, and the spectra are fully compliant with the FCC mask. We also experimentally investigate the BER performance for back-to-back (B2B) and 40 km fiber transmission, as shown in Fig.3(b). In the DSP receiver, 10,000 sampled UWB bits are used to analyze bit-for-bit BER performance. We can observe that the penalty between B2B and fiber transmission is negligible and a BER below the forward error correction (FEC) limit is obtained.

4. Conclusions

We have proposed a novel approach to generate UWB pulses with high speed data modulation. In our demonstration, we use an EAM to compress a NRZ pulse, and the tunable pulse compression makes our approach independent on the input NRZ pulse width, and thus makes it promising to generate UWB pulses with high bit rate. In our reported experiment, the FCC compliant UWB signals with 5 Gbps OOK modulations are successfully demonstrated. To the best of our knowledge, 5 Gbps is a record IR-UWB bit rate achieved up to date. This proposed approach has potential application in high speed UWB wireless over optical access networks.

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