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Power-Efficient Photonic BPSK Coded Ultrawideband Signal Generation

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Abstract: We experimentally demonstrate a power-efficient BPSK coded ultrawideband (UWB) signal generator. The 2.5 Gb/s BPSK coded signal is achieved through optical switching based on two intensity modulators driven by complementary microwave signals.

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1. Introduction

Inspired from the unlicensed broad spectrum from 3.1 to 10.6 GHz specified by the Federal Communication Commission (FCC) [1], ultrawideband (UWB)-over-fiber technology, with its desirable advantages of both minor loss in optical fibers and interoperability between indoor wireless personal network and high-speed optical networks, has been studied extensively in recent years [2–7].

Most of the former reports were focused on photonic generation of UWB pulses, especially monocycle and doublet pulses. When optical carrier is located at either linear slope or the quadrature slope of a frequency discriminator, the first and second-order derivative of Gaussian pulses can be generated through phase modulation to intensity modulation (PM-IM) [2]. Moreover, by the means of optical injection, semiconductor-based devices can also generate UWB pulses due to gain modulation and carrier oscillation [3, 4]. However, in view of the worldwide growing thirst for higher power-efficiency, how to generate UWB pulses in a more economical way becomes urgent. It is indicated in [5] that in order to efficiently exploit the spectra and fully utilize the radiated power, UWB pulses in the form of higher-order derivatives of Gaussian pulse are required. Thus, the highlight of the latest research moves to the generation of such power-efficient UWB pulses [6]. Additionally, on the modulation side, on-off-keying (OOK) modulation, as the most traditional encoding method, for power-efficient UWB pulses has been studied recently [5, 7]. But the binary-phase-shift-keying (BPSK) modulation format, with the potential of 3-dB improvement in signal-to-noise ratio (SNR), has not yet gained enough attention [3]. While in this paper, we demonstrate a novel power-efficient UWB pulse generator with two output ports of inverted phases. The phase-coded signal is achieved by optical switching based on two intensity modulators (IM) driven by complementary microwave signals.

2. Principle of generation

Through PM-IM conversion, the symmetric mapping of frequency chirp to intensity change can be fulfilled by locating the optical carrier at the center of the linear slope of a detuned optical filter [2]. Consequently, the phase-modulated signal will be converted into a symmetric monocycle pulse. In the pump-probe scheme using a highly-nonlinear fiber (HNLF), the wavelength of continuous-wave (CW) probe experiences red-shift and blue-shift induced by the rising and falling edge of pump pulse, respectively. Thus, monocycle pulses with inverted polarities can be generated by locating the optical carrier on two opposite linear slopes. On the other hand, if the carrier wavelength moves to either extrema of the linear slope, i.e. the maximum or the minimum transmission point on the linear slope of the transmission function, asymmetric monocycle pulse will be generated by PM-IM conversion instead of symmetric monocycle pulse. Hence, by incoherent summation of two asymmetric monocycle pulses with inverted polarities and one pulse-duration time delay, a FCC-compliant UWB pulse with the potential of efficiently exploiting FCC spectral mask can be attained.

The principle for our scheme is shown in Fig. 1. Instead of using optical filter as the frequency discriminator, an arrayed-waveguide-grating (AWG) with dense channel spacing is utilized as a multichannel frequency discriminator. Probe wavelength λ_1 is located on the maximum transmission point of the linear slope for channel 1 (point A in Fig.

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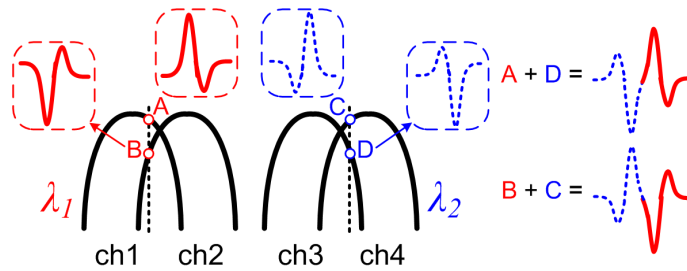


Fig. 1. Principle for the generation of phase-inverted FCC-compliant pulses.

1), and, on the other hand, also located on the minimum transmission point of the linear slope for channel 2 (point B in Fig. 1). Similarly, probe wavelength λ_2 is also located on both maximum and minimum transmission points of the linear slopes for another two adjacent channels with symmetric filtering side as to point A and B (points C and D in Fig. 1). By incoherent summation of channel 1 and 3 with one pulse-duration delay, a power-efficient UWB pulse can be generated. Analogously, combination of channel 2 and 4 will produce an identical power-efficient UWB pulse but with inverted phase.

3. Experiment and Discussion

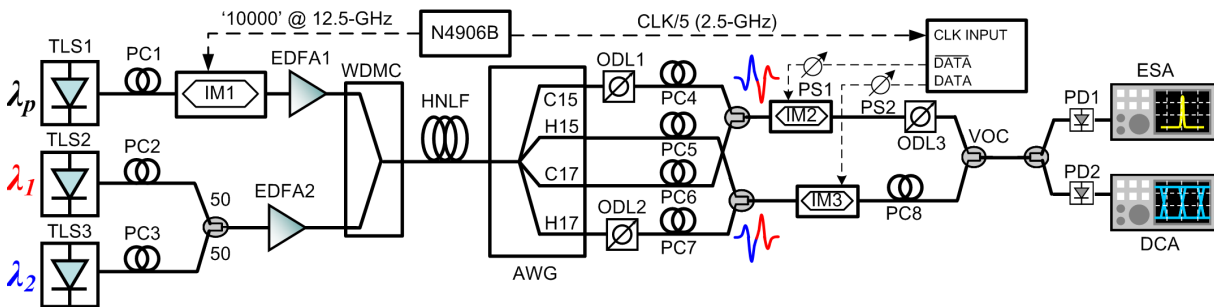


Fig. 2. Experimental setup for the BPSK-coded power-efficient UWB signal generation. IM: intensity modulator, WDMC: WDM coupler, AWG: arrayed-waveguide grating, ODL: optical delay line, PD: photodiode.

The experimental setup is shown in Fig. 2. The pump pulse, sourced from a tunable laser source (TLS) at 1548 nm, was first modulated by an IM driven with the pulse pattern from a pulse pattern generator (PPG), Agilent N4906B, at 12.5 GHz with approximately 80-ps pulse-width and “10000” edited pattern which led to an equivalent repetition rate of 2.5 GHz. It was then amplified to 20.92 dBm by an erbium-doped fiber amplifier (EDFA1). On the other branch, two probe waves, sourced from two TLSs at ITU-WDM wavelengths of channel 17 (191.7 THz) and 15 (191.5 THz), were coupled by a 50:50 coupler and amplified to 16.68 dBm by EDFA2. After combining by WDM coupler (WDMC), the pump and the probes were launched into a 400 m HNLF. An AWG with 3-dB bandwidth of 40 GHz and channel spacing of 50 GHz was inserted after HNLF as a multichannel discriminator and pump light blocker simultaneously. Two optical delay lines (ODLs) in channel ITU-WDM-C15 and H17 were used to gain 160 ps delay relative to channel C17 and H15, respectively. The optimized UWB pulses, fully compliant with FCC mask, were achieved when probe wavelengths were 1563.616 and 1565.422 nm. Two 50:50 couplers were used to combine C15-C17 and H15-H17, respectively. The polarization controllers (PC4-7) were used to align the state of polarization (SOP) of each AWG channel to the transmission axis of the corresponding IM. One pattern generator, synchronized by Agilent N4906B with 2.5 GHz clock repetition rate, drove the IMs with a pattern of 2^7-1 pseudo-random binary sequence (PRBS) from two complementary output data ports. Two phase shifters (PS) were used to adjust the relative time delay between UWB pulse and signal bit slot to guarantee that each UWB pulse was at the center of each slot. ODL3 was inserted after IM2 to satisfy complementary summation of the two branches.

The FCC-compliant UWB pulses, as shown in Fig. 3(a) and Fig. 3(b), were measured by a digital communication analyzer (DCA). The corresponding electrical spectra, recorded by an electrical spectrum analyzer (ESA), are shown

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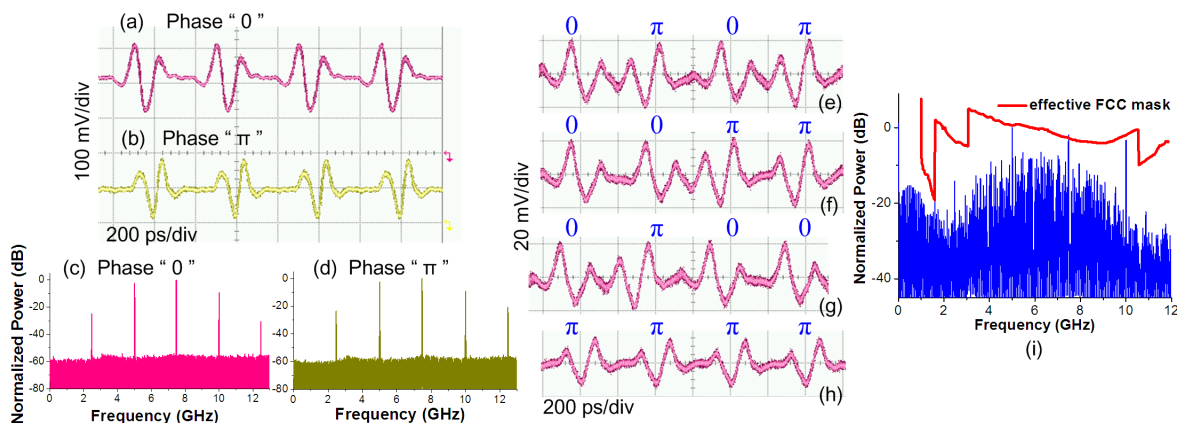


Fig. 3. The waveforms and the corresponding spectra of directly generated UWB pulses with phase (a),(c) “0” and (b),(d) “ π ”; Four phase sequences of the BPSK coded UWB signals: (e) “0 π 0 π ”, (f) “0 0 π π ”, (g) “0 π 0 0”, (h) “ π π π π ” and the measured electrical spectrum (i).

in Fig. 3(c) and Fig. 3(d), respectively. It is observed that the UWB pulses from both output ports are well shaped with almost identical electrical spectra within 3.1 to 10.6 GHz, and both comply with the FCC regulation.

The BPSK coded UWB signal, following a pattern of 2^7-1 PRBS with optical power of -11.2 dBm, was demonstrated with four phase sequences of “0 π 0 π ”, “0 0 π π ”, “0 π 0 0” and “ π π π π ”, as shown in Fig. 3(e-h). The phase sequences are very clear to be identified, although slight distortion is observed due to the nonlinearity of IM. Furthermore, the connection area between sequential UWB signals is not precisely continuous as a result of the incoherent summation of two complementary signals. The above mentioned reasons lead to residual frequency components in low frequency domain (< 2 GHz) as shown in Fig. 3(i). Nonetheless, it can still be fully compliant with the effective FCC spectral mask if the response of the UWB antenna and wireless path were further considered [5]. An optical switch with even faster response and improved linearity can further improve the final results.

4. Conclusion

We have proposed a novel scheme for power-efficient UWB pulses generation, based on cross-phase modulation and PM-IM conversion in HNLF and AWG, respectively. UWB pulses with inverted phases were experimentally demonstrated. Furthermore, 2.5 Gb/s BPSK coded power-efficient UWB signal trains were fulfilled by optical switching two output ports with intensity modulators driven by complementary microwave signals. The electrical spectrum of the BPSK coded power-efficient UWB signal was in good agreement with the FCC regulation.

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