Switchable UWB pulse generation using a polarization maintaining fiber Bragg grating as frequency discriminator

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Abstract: We propose and successfully demonstrate a novel approach to optically generate ultrawideband (UWB) pulse with switchable shape and polarity by using a polarization-maintaining fiber Bragg grating (PM-FBG) as frequency discriminator. Depending on the shape of the reflective spectrum of the PM-FBG, the system can function as a first- or second-order differentiator for the generation of Gaussian UWB monocycle or doublet pulses. Consequently, the shape and the polarity of the generated UWB pulse can be switched by simple adjustment of a polarization controller (PC). Gaussian monocycle and doublet pulses were successfully obtained with fractional bandwidths of about 188% and 152%, respectively. Higher-order UWB pulses with spectrum covering from 2.9 GHz to 9.8 GHz have also been obtained through adjustment of the PC.

OCIS codes: (060.0060) Fiber optics and optical communications; (350.4010) Microwaves.

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1. Introduction

Ultrawideband (UWB), which is regulated by the Federal Communications Commission (FCC) for indoor UWB systems operating in the frequency range from 3.1 to 10.6 GHz [1], has recently attracted considerable interests for short-range high-throughput wireless communications and sensor networks due to their intrinsic advantages such as immunity to multipath fading, extremely short time duration, low duty cycle, wide bandwidth, and low power spectral density [1–4]. The generation of UWB pulses in the optical domain provides higher flexibility, which enables the generation of UWB pulses with switchable pulse shapes and polarities. Several approaches have been reported to optically generate UWB pulses showing impressive operation performance [5–22], such as UWB monocycle and doublet generation based on phase modulation to intensity modulation (PM-IM) conversion using an optical frequency discriminator or other devices [4–8], switchable UWB pulse generation using a reconfigurable photonic microwave delay-line filter [9,10], all-fiber UWB pulse generation based on spectral shaping and dispersion-induced frequency-to-time mapping [11–13]. Other techniques for UWB pulse generation based on cross-gain modulation (XGM) in a semiconductor optical amplifier (SOA) [14], a Sagnac-interferometer-based intensity modulator [15], differential group delay devices as well as a SOA [16], and polarization modulation and multichannel frequency discriminator [17] were also reported. The major limitation of most reported approaches is that each scheme can only generate one type of UWB pulse (either Gaussian monocycle or doublet) or different types of UWB pulses with the same polarity. For some applications, such as pulse shape modulation (PSM), it is desirable that both Gaussian monocycle and doublet can be generated in a single system. In pulse polarity modulation (PPM), the polarity of the generated UWB pulses should be switchable. Wang et al ever proposed a technique utilizing a polarization modulator to control the wavelength sweep relative to the slope of the FBG to generate monocycles. Subsequently, they utilize circularly polarized light, a length of polarization-maintaining fiber (post-modulation) and balanced detection to achieve a doublet [22]. But the technique is somewhat complicated.

In this paper, we propose and demonstrate a novel and simple approach to optically generate UWB pulses with switchable shape and polarity by using a phase modulator and a polarization-maintaining fiber Bragg grating (PM-FBG). Depending on the shape of the reflective spectrum of the PM-FBG, the system can act as a first- or a second-order differentiator for the generation of Gaussian UWB monocycle or doublet pulses. Consequently, the shape and the polarity of the generated UWB pulse can be switched by simple adjustment of a polarization controller (PC) without changing the optical carrier. Gaussian monocycle and doublet pulses were successfully obtained with fractional bandwidths of about 188% and 152%, respectively. Higher-order UWB pulses with spectrum covering from 2.9 GHz to 9.8 GHz have been also obtained by adjusting the PC.

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2. Experimental setup and operation principle

Figure 1 shows the schematic diagram of the experimental setup for the proposed UWB pulse generation with switchable shape and polarity. The lightwave from a tunable laser is fed into an optical phase modulator which is driven by an electrical pulse train. The pulse shape is close to Gaussian with an FWHM of about 70 ps. A polarization controller (PC1) is inserted before the modulator to ensure polarization alignment between the laser light and the modulator. The phase-modulated optical signal then passes through a polarizer and another polarization-controller (PC2) before it is introduced to a PM-FBG via an optical circulator. The combination of the polarizer and the PC2 is used to effectively adjust the polarization state of the incident light to the PM-FBG, and consequently change the spectrum reflected from the PM-FBG. The PM-FBG was used to serve as a frequency discriminator and perform PM-IM conversion. The PM–IM converted signal is then detected at a photodetector (PD), and is measured both in the frequency domain using a 40 GHz electronic spectrum analyzer (ESA) and in the time domain using a 40 GHz sampling oscilloscope (OSC).

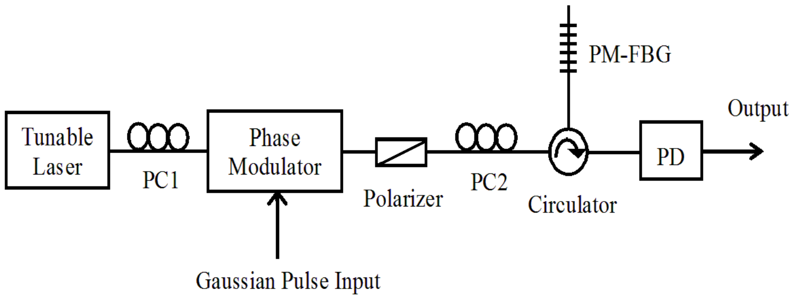


Fig. 1. Experimental setup for the proposed UWB pulse generator using a PM-FBG.

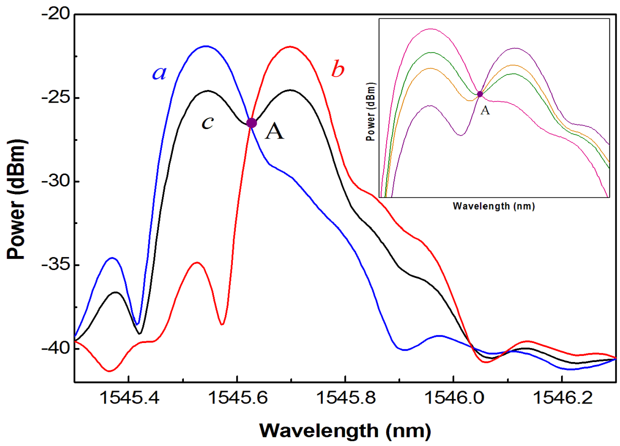


Fig. 2. Reflection spectra of the PM-FBG for different polarization input.

The key component in the proposed system is the PM-FBG. It is known that the reflection spectrum of a PM-FBG depends on the polarization state of the input lightwave [23]. The reflection spectra of the PM-FBG in the experiment for different polarization input are shown in Fig. 2. The blue (*a*) and the red (*b*) curves show the reflection spectra of the PM-FBG when the polarization direction of the incident light is aligned with the fast and slow axis of the PM fiber, respectively. The black curve (*c*) shows the reflection spectrum when the polarization of the input light is aligned at 45° to both the fast and slow axis. The reflection spectra for some other polarization input are shown in the inset of Fig. 2, whose labels are the same with that of curve *a*, *b*, and *c*.

When the carrier wavelength is located at the overlapped point of the reflection spectra, shown as point A in Fig. 2, the reflection rate for the wavelength stays unchanged even

#122751 - $15.00 USD Received 14 Jan 2010; revised 2 Feb 2010; accepted 2 Feb 2010; published 4 Feb 2010

though the spectrum shape changes. Also from Fig. 2, point A can locate at the right linear slope of curve *a*, at the left linear slope of curve *b*, or at the quadrature region of the PM-FBG reflection spectrum by adjustment of the input polarization. These features make PM-FBG a very good candidate to serve as a frequency discriminator and perform phase modulation to intensity modulation conversion in UWB pulse generation. The key point here is that the reflection spectrum of the PM-FBG can be tuned for a fixed wavelength. While in Ref [6], the wavelength was tuned relative to the fixed FBG reflection spectrum. The use of PM-FBG has the advantage of polarity switching compared with the use of a conventional FBG.

When PC2 was adjusted to obtain a reflection spectrum given by curve *a*, a negative monocycle pulse would be generated. When PC2 was adjusted to obtain a reflection spectrum given by curve *b*, a positive monocycle pulse would be generated with the opposite polarity [6]. Similarly, positive and negative doublet pulses can also be generated by adjusting PC2 such that the optical carrier is located at different quadrature slopes of the PM-FBG reflection spectrum. So, depending on the reflection spectrum of the PM-FBG or the state of the PC2, the system can function as a first- or second-order differentiator for the generation of Gaussian UWB pulses, and consequently UWB monocycle or UWB doublet with different polarities can be generated. Therefore, by launching the optical carrier at point A, the proposed system makes it possible to implement two different UWB pulse modulation schemes by simple adjustment of PC2: 1) the pulse shape modulation (PSM) (monocycle-doublet) and 2) the pulse polarity modulation (PPM).

3. Experimental results and discussions

To confirm the generation of UWB monocycle and doublet pulses using the mechanism described above, we conducted experiments with the configuration shown in Fig. 1. First, the wavelength of the tunable laser was tuned to 1545.62 nm, which is the wavelength of point A in Fig. 2. Then, through adjustment of the PC2 and without changing the optical carrier, monocycle and doublet pulses were obtained.

Figure 3 shows the waveforms and the spectra of the generated UWB monocycle and doublet pulses. Figures 3(a) and 3(b) respectively show the generated monocycle pulse and its corresponding spectrum, when PC2 was adjusted such that the wavelength is reflected at the left linear slopes of the PM-FBG spectrum shown as the curve *b*. From Figs. 3(a) and 3(b), the monocycle pulse has an FWHM of about 47 ps, the spectrum has a central frequency of 3.94 GHz, and the 10 dB bandwidth is about 7.4 GHz, indicating that the generated UWB monocycle has a fractional bandwidth of about 188%. When PC2 was adjusted such that the wavelength is reflected at the quadrature region of the PM-FBG spectrum, doublet pulses were obtained whose waveform and corresponding spectrum are shown in Figs. 3(c) and 3(d). The doublet has an FWHM of about 62 ps, the spectrum has a central frequency of 5.4 GHz, and the 10 dB bandwidth is about 8.2 GHz, indicating a fractional bandwidth of about 152%.

#122751 - $15.00 USD Received 14 Jan 2010; revised 2 Feb 2010; accepted 2 Feb 2010; published 4 Feb 2010

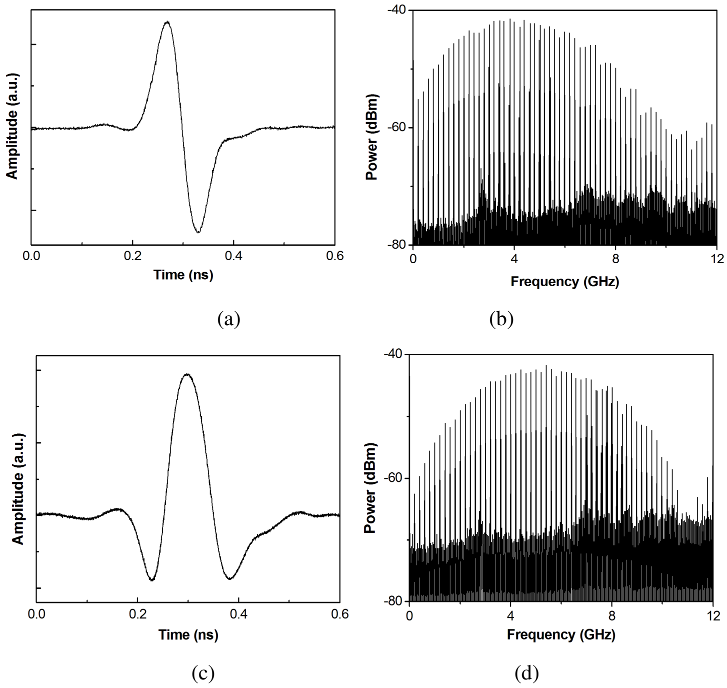


Fig. 3. The waveforms and spectra of the Gaussian UWB pulses obtained at the output. The (a) generated UWB monocycle and (b) corresponding electrical spectrum, and (c) generated UWB doublet and (d) corresponding electrical spectrum.

By adjustment of PC2, the inverted versions of the monocycle and doublet shown in Figs. 3(a) and 3(c) have also been achieved. Figure 4 shows the waveforms of the polarity-inverted monocycle and doublet pulses, the FWHMs of which are 49 and 63 ps, respectively.

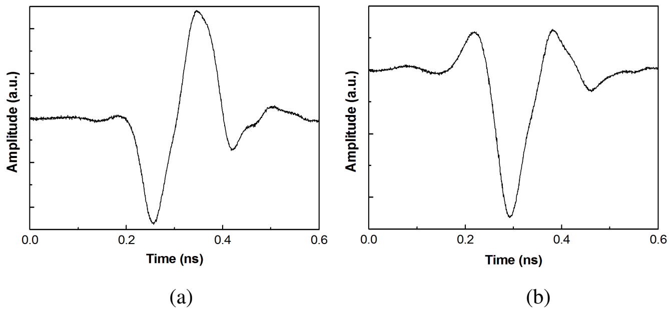
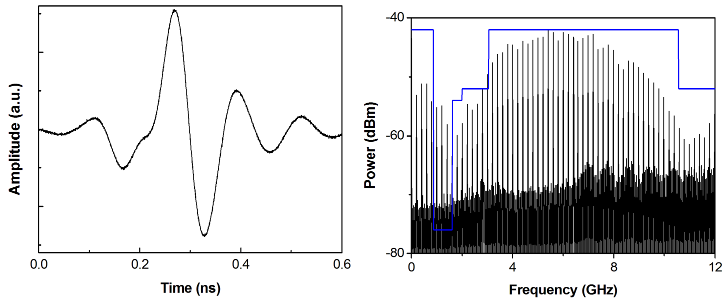


Fig. 4. The inverted version of the pulses shown in Figs. 3(a) and 3(c):(a) Polarity-inverted monocycle pulses. (b) Polarity-inverted doublet pulses.

So, by proper selection of the tunable laser wavelength, both PSM and PPM can be implemented for the proposed scheme because UWB pulses with switchable shape (monocycle-doublet) and polarity can be generated by adjustment of PC2.

When PC2 was adjusted such that the carrier wavelength is located at region other than that mentioned above, the system can function as a higher-order differentiator, and consequently higher-order UWB pulse can be obtained. Figures 5(a) and 5(b) show the generated UWB triplet waveform and its corresponding spectrum respectively. From Fig. 5(a), the pulse has an FWHM of about 42 ps and the waveform is almost the same as that reported in Ref [10], which represents a third-order UWB pulse. The corresponding spectrum has a central frequency of 5.4 GHz and a 10 dB bandwidth of about 6.9 GHz, indicating a fractional bandwidth of about 128%. From Fig. 5(b), the spectrum covers from 2.9 GHz to 9.8 GHz and has a higher performance fitting to the FCC mask (blue line) than that shown in Figs. 3(b) and 3(d).

#122751 - $15.00 USD Received 14 Jan 2010; revised 2 Feb 2010; accepted 2 Feb 2010; published 4 Feb 2010



(a) (b)

Fig. 5. The (a) waveform and (b) corresponding spectrum for higher-order pulses obtained by adjustment of PC2. The blue lines in (b) represent the FCC mask for the corresponding experimental electrical power (black line).

In fact, not only UWB monocycle, doublet, and triplet, but also other higher-order UWB pulses can potentially be generated by appropriately choosing the carrier wavelength and adjusting the polarization controller. This can be shown by from the different reflection spectra shown in Fig. 2.

It should be noted that the polarities of the output light in Fig. 3(a) and Fig. 4(a) have been confirmed to be orthogonal. Consequently, pulse polarity modulation can be implemented because a positive monocycle in one polarization and a negative monocycle in the other polarization can be generated by adjustment of a PC for the scheme. Obviously, UWB pulses with different shapes have been generated in the same configuration, allowing the possibility of implementing PSM. Furthermore, high speed switching of the waveform could be obtained, since fast electronically-controlled waveplates are available. So, the proposed UWB pulse generator has the potential for applications in the high-speed UWB communications and radar systems employing PPM or PSM schemes.

4. Conclusion

In conclusion, we have proposed and experimentally demonstrated a novel and simple approach to optically generate UWB pulses with switchable shape and polarity by using a phase modulator and a polarization-maintaining fiber Bragg grating. Depending on the shape of the reflective spectrum of the PM-FBG, the system can function as a first-, second-, or higher-order differentiator for the generation of Gaussian UWB monocycle, doublet, and higher-order pulses. The shape and the polarity of the generated UWB pulse can be switched by simple adjustment of a PC without changing the optical carrier. Gaussian monocycle, doublet, and higher-order pulses were successfully obtained with fractional bandwidths of about 188%, 152%, and 128% respectively. Thus, by launching the optical carrier at the overlapped point of different reflection spectra of the PM-FBG, UWB pulses with different shapes and polarities can be generated, allowing the possibility of implementing PSM and PPM in the same configuration.

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