# Generation of Ultra-wideband Doublet Pulses Based on Kerr Shutter Using an Elliptically Polarized Beam in Bismuth Oxide-based Nonlinear Optical Fiber

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**Abstract:** We demonstrate a nonlinear signal-processor incorporating a Bismuth-based nonlinear fiber for UWB doublet pulse generation. High quality of doublet pulses is readily generated from the signal-processor based on nonlinear polarization rotation of an elliptically-polarized beam.
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## 1. Introduction

Ultra-wideband (UWB) radio technology has been a highly promising solution for future high-capacity wireless personal-area networks (PANs) [1]. The UWB signal transmission is realized by spreading a small amount of radiated radio frequency power across a very wide frequency band relative to its center frequency. Among two commonly used UWB schemes such as impulse radio UWB (IR-UWB) and orthogonal-frequency-division-multiplexing UWB (OFDM-UWB), the IR-UWB technology, which transmits data via ultrashort temporal pulses, is considered to be more attractive due to its carrier-free modulation and low power consumption, and because it does not require the use of frequency mixers [2]. Despite the various advantages, the IR-UWB technology has the fundamental coverage distance limitation caused by low spectral-power density. As a potential solution, the use of UWB-over-fiber technology, with which the generation, modulation, and distribution of UWB signals are implemented in the optical domain, was proposed, and its feasibility has been successfully demonstrated [3]. The commonly employed UWB waveforms are monocycle- and doublet-shaped as these waveforms possess reduced low-frequency components.

The photonic UWB signal generation techniques can be roughly classified as electro-optic conversion-based and all-optical schemes [3, 4]. The all-optical schemes use a short optical pulse as an input seed, and nonlinear optical media, such as semiconductor optical amplifiers and nonlinear optical fibers, as signal-processing units [4, 5]. One benefit of all-optical schemes is no need for extra electro-optic conversion that makes the whole system complicated. In other words, they do not require high speed electrical pulse generators and high speed electro-optic modulators, since the UWB pulse generation is performed in the optical domain. High-quality IR-UWB signals have been successfully achieved through a variety of schemes that were based on Sagnac-interferometer-based intensity modulation [4], cross-gain modulation effect [5], and cross phase modulation [6].

Recently, Bismuth oxide-based nonlinear fiber (Bi-NLF) has been of high technical interest in the area of nonlinear signal processing due to its ultrahigh Kerr nonlinearity ($\gamma > 1000\ W^{-1}\cdot km^{-1}$), high SBS threshold, and spliceability to silica fibers [7]. Through a range of experimental demonstrations, Bi-NLF has been proved to be a powerful means for high speed all-optical nonlinear signal processing [8].

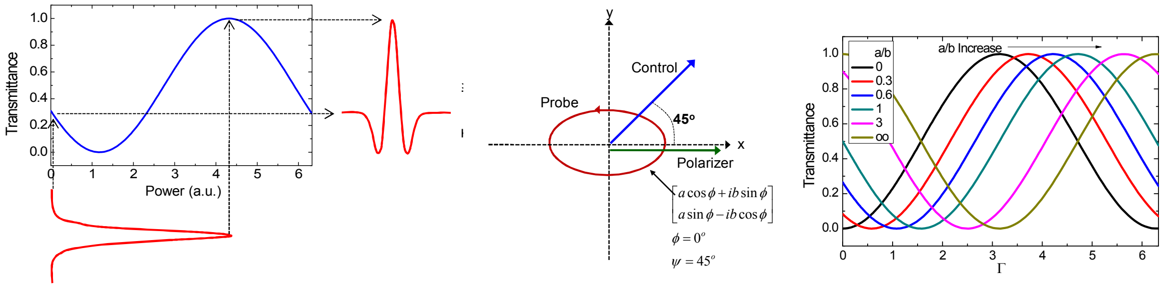
In this paper, we propose and experimentally demonstrate a nonlinear signal processor for UWB doublet pulse generation, which is based on ultra short length of Bi-NLF. The proposed signal processor is based on a Kerr shutter configuration using the nonlinear-polarization-rotation (NPR) principle; however, the processor uses an elliptically polarized probe beam together with a linearly polarized control beam unlike the commonly used Kerr shutters. It is experimentally shown that an ideal transfer function for the successful conversion of input optical Gaussian pulses into doublet pulses can readily be obtained through a 1.3-m-long Bi-NLF-based Kerr shutter. The system performance of the generated UWB doublet pulses was evaluated by propagating them over a 20-km-long non-zero dispersion-shifted fiber (NZ-DSF) link. Error-free transmission is successfully achieved.

## 2. Operating Principle

In order to produce doublet optical pulses from input Gaussian-shaped optical pulses, an all-optical transfer function, as shown in Fig. 2(a) is essentially required. The transfer function is different from the $\sin^2(\ )$- or $\cos^2(\ )$-shaped ones, which can be easily obtained from the conventional linear-polarization-based Kerr shutter configurations. Let us consider a Kerr shutter where the probe has a right-hand-elliptical (RHE) state of polarization (SOP) and where the polarizer is aligned to the x-axis, as shown in Fig. 2(b). The transmittance $T$ of the Kerr shutter can be calculated as follows [9]:

$$T = a^2 \cos^2(\Gamma/2) + b^2 \sin^2(\Gamma/2) - 2ab\cos(\Gamma/2)\sin(\Gamma/2) \quad (1)$$

where $\Gamma$ is the phase retardation between the slow and fast axes, which is proportional to the control beam power. $a$ and $b$ are coefficients that determine the degree of ellipticity and that have the relation of $\sqrt{a^2+b^2}=1$. Here, $a/b=0$ or $a/b=\infty$ pertains to linear polarization.

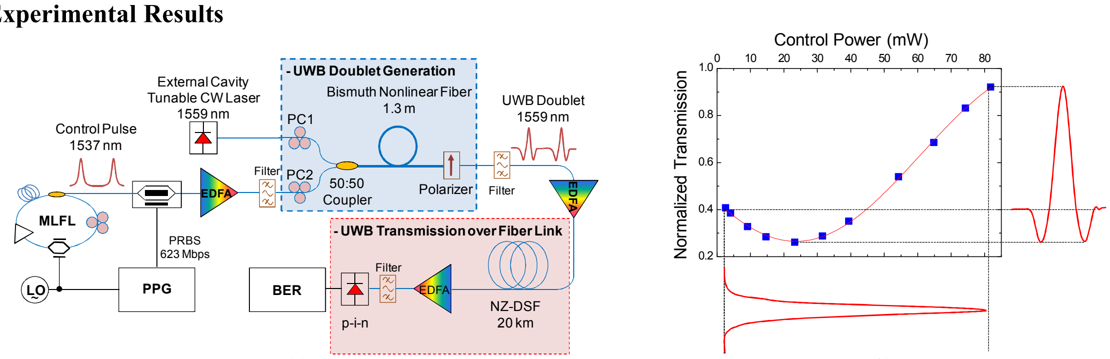



(a) (b) (c)

Fig. 2. (a) Ideal transfer function for the waveform conversion from Gaussian input pulses to doublet pulses. (b) Polarization arrangement: probe beam, RHE SOP; polarizer, x-axis. (c) Calculated transmittance as a function of the ellipticity ratio a/b of the probe beam.

Fig. 2(c) shows the calculated transmittance as a function of the ellipticity ratio $a/b$. It is evident from the graph that the minimum transmission point moves to the righthand side as the $a/b$ ratio increases. From Fig. 2(b) it can be easily inferred that the ideal transfer function, like Fig. 2(a), which is suitable for doublet pulse generation, can be readily produced by controlling the ellipticity ratio $a/b$ of the probe beam. $a/b = 0.66$ was found to lead to the ideal transfer function of Fig. 1(a). The same results can also be obtained in the case where a probe beam with an LHE SOP of $a/b = 1.5$ is used together with a polarizer aligned to the y-axis.

## 3. Experimental Results

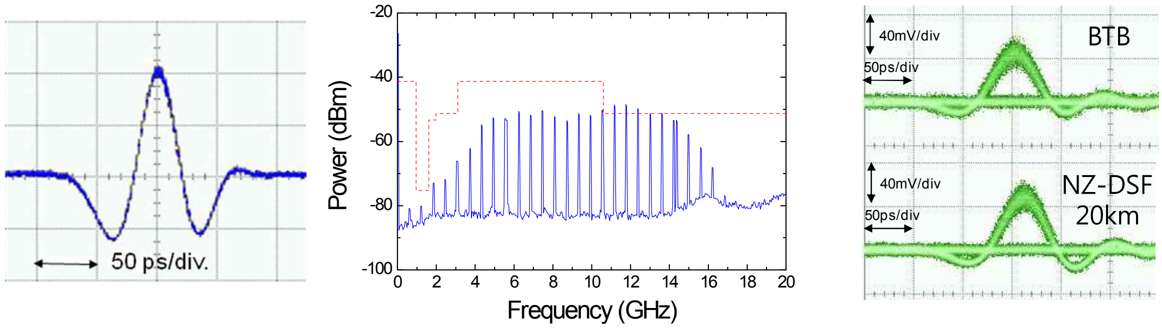



(a) (b)

Fig. 3. (a) Experimental setup. (b) Experimentally obtained transfer function.

Fig. 3 shows the experimental setup used. An actively-mode-locked fiber laser that can generate ~50-ps-wide soliton pulses at 623 MHz was used. The generated soliton pulses were used as a control beam for a Kerr shutter. The soliton control beam was amplified using erbium-doped fiber amplifiers (EDFAs) and was then combined using a 50:50 coupler together with a continuous-wave (CW) probe beam from an external-cavity tunable laser. The SOP of each beam was adjusted by using a polarization controller (PC) in front of the 50:50 coupler. They were subsequently launched into a 1.3-m-long Bi-NLF. The power levels of the control and probe beams that were coupled into the Bi-NLF were estimated to be ~19 dBm and ~0 dBm, respectively considering the losses of the 50:50 coupler and the splicing point between Bismuth and silica fibers, and their operating wavelengths were 1537 nm and 1559 nm, each. The nonlinear parameter and GVD of the Bi-NLF were ~1000 W/km and -250 ps/nm/km, respectively. A polarizer was connected to the output end of the Bi-NLF and a 1-nm band pass filter was used after the polarizer to filter out the residual control beam components. A novel PC control procedure was used to ensure that the elliptical SOPs of the probe beams would have a specific ellipticity ratio close to $a/b = 0.66$. Further details on the PC control procedure are fully described in Ref. [9]. The generated doublet pulses were propagated over a 20-

km NZ-DSF link to assess their system performance. The $2^7$-1 PRBS pattern-added doublet pulses were produced by modulating control pulses using a $LiNbO_3$ modulator. Fig. 2(b) shows the experimentally measured transfer function at the output of the polarizer. Evidently, a symmetric transfer function as expected in Fig. 2(c) was readily obtained from the proposed signal processor.




(a) (b) (c)

Fig. 3. (a) Measured oscilloscope trace and (b) measured RF spectrum of the generated inverted-doublet pulse. The FCC mask is also shown by a dotted line. (c) Measured eye diagrams after 20-km fiber transmission.

Fig. 3(a) shows the measured oscilloscope trace of the UWB doublet pulse produced and its corresponding measured RF spectrum is shown in Fig. 3(b). The full width at half maximum (FWHM) of the generated pulse was ~47 ps, and the interval of the two negative peaks at both sides was ~79.8 ps. The center frequency and 10 dB bandwidth of the generated UWB doublet pulse were estimated to be ~ 9.7 and ~11 GHz, respectively. Accordingly, the fractional bandwidth was ~113%. Fig. 3(c) shows the measured eye diagram of the PRBS pattern-added doublet pulses transmitted over a 20-km NZ-DSF link together with the back-to-back one. Clear eye opening was observed after 20-km transmission. The subsequent BER measurements showed error-free signal transmission without penalty @ BER=$10^{-9}$.

## 4. Conclusion

We have experimentally demonstrated a Bi-NLF-based nonlinear signal processor for UWB doublet pulse generation. The proposed nonlinear signal processor is based on a Kerr shutter configuration using uses an elliptically polarized probe beam together with a linearly polarized control beam unlike the commonly used Kerr shutters. Since our signal processor is sensitive to the state of polarizations (SOPs) of the input beams, it is believed that the use of ultra short length of Bi-NLF than long length of silica-based nonlinear fiber would be better from a perspective of long term system stability. The system performance of the generated UWB doublet pulses was also assessed by propagating the PRBS pattern-added doublet pulses over a 20-km NZ-DSF link. Based on the obtained results, we can conclude that the proposed Bi-NLF-based UWB doublet pulse generation scheme can be a useful means for IR-UWB-based fiber/wireless-transmission systems.

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