Research of all-optical ultra-wideband triplet signal source based on a single semiconductor optical amplifier*

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A novel scheme for all-optical ultra-wideband triplet signal pulse generation based on the cross-gain modulation (XGM) in a single semiconductor optical amplifier (SOA) is demonstrated. In this scheme, only one optical source and one SOA are needed, so the configuration is simple. Due to only one wavelength is included in the generated triplet pulse, no time difference between output signal light and probe light is introduced during the transmission process. By using the software of Optisystem 7.0, the impacts of the input signal width, the optical power and the wavelength of the optical source on the generated triplet pulse are numerically simulated and studied. The results show that the proposed scheme has better triplet signal pulse when the input signal pulse width is larger, and it is insensitive to the wavelength change within a certain range.

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Many photonic approaches for generating ultra-wideband (UWB) signals, such as the cross-gain modulation (XGM)[1] or cross-phase modulation (XPM)[2] in the semiconductor optical amplifier (SOA), and the electro-absorption modulator (EAM)[3], have been reported. A UWB triplet pulse was generated based on four-wave mixing (FWM) in a highly nonlinear fiber (HNLF) and phase modulation to intensity modulation (PM-IM) conversion[4]. Besides, low power UWB pulses were generated based on XPM in HNLF and PM-IM conversion[5]. In Ref.[6], a fiber Bragg grating (FBG) filter was used as a frequency discriminator when generating high-order UWB signals. UWB signals can also be generated by optical arbitrary waveform generation (OAWG)[7-9]. Huang et al[10,11] presented an approach to generate UWB monocycle and doublet pulses by using a nonlinear optical loop mirror. Chang et al[12] presented an approach to generate the UWB doublet pulse based on nonlinear polarization rotation of an elliptically polarized beam. In Ref.[13], all-optical UWB monocycle pulse generating based on cross-absorption modulation (XAM) in an EAM was presented. Besides, a dual-drive modulator was used to generate UWB doublet pulse[14].

With the increase of the differential orders of Gaussian pulses, the energy spectrum gradually shifts from low frequency to high frequency region, which is more in line with the pulse selection criteria of UWB signals[6]. In this paper, we present a novel approach for all-optical generation of UWB triplet pulse based on XGM in an SOA. In this scheme, only one optical source and one SOA are needed, and the output signal light and probe light are coupled into the SOA in opposite directions, hence it is simple and low cost. In addition, there is only one wavelength included in the output triplet pulse, so no time difference between output signal light and probe light is introduced during the transmission process.

Fig.1 shows the operation principle of the all-optical UWB triplet pulse generation. The continuous wave (CW) generated by the laser diode (LD) is split into two beams with the same power. The upper branch is modulated to signal light by Mach-Zehnder modulator (MZM), while the lower branch is used as probe light directly. The signal light and probe light are coupled into a wideband travelling-wave SOA in opposite directions. The probe light is amplified to the maximum at the right side of SOA, whereas signal light is amplified to the maximum at the left side of SOA. At the left side of SOA, signal light is stronger than probe light. Hence, the probe light becomes a polarity-reversed signal pulse due to XGM. The probe light becomes monocycle-like due to the overshoot at its rising edge. Furthermore, oscillation, which occurs on the trailing edge of the positive pulse, forms the negative pulse with smaller amplitude. An attenuator (ATT) is used to adjust the output signal power of the SOA, and

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a time delayer is used to delay the output probe light (about 1 bit pulse width). As a result, the UWB triplet pulse is generated by coupling the output probe light and signal light. The output triplet pulse passes through a Gaussian optical band-pass filter (OBF), which is used to filter the noise. A PIN diode is used to transform the output triplet pulse to electrical signal. The output triplet pulse and its radio frequency (RF) signal can be observed from the oscilloscope (OS) and RF spectrum analyzer.

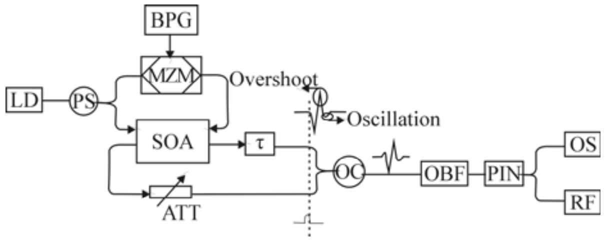
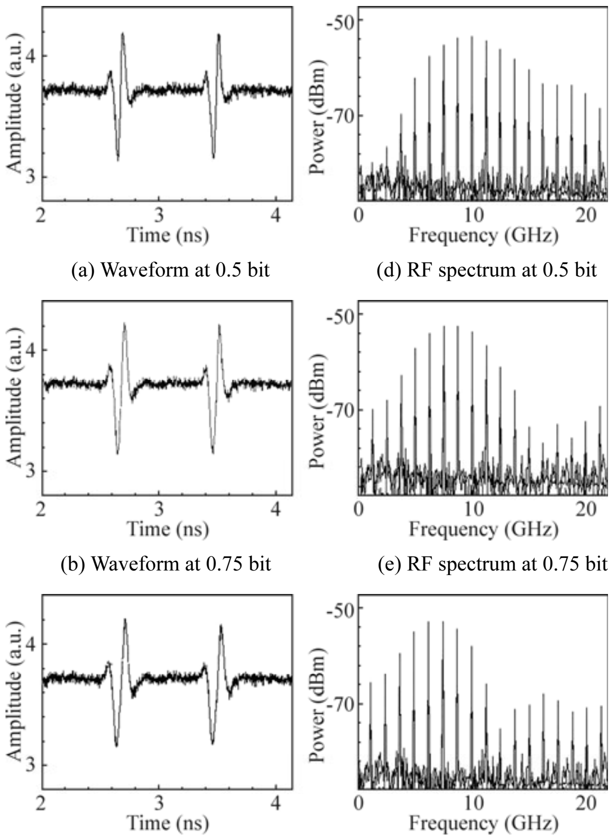


Fig.1 Schematic diagram of the triplet pulse generation based on XGM in SOA

By using the software of Optisystem 7.0, the scheme is proposed to generate ultra-wideband triplet pulse based on a single SOA. In the simulation, the optical power is 2 mW, and its wavelength is 1563.5 nm. The bit sequence generators are set at a fixed pattern “1000 0000 0000 0000” (one “1” per 16 bits) and the bit rate is 10 Gbit/s. The signal pulse width is 1 bit. The active region length of SOA is 600 μm, and its current is 80 mA. The time delay is set as 54 ps. The attenuator is set as 23 dB. The center frequency of the filter is 1563.5 nm and its bandwidth is 0.5 nm.

Fig.2 shows the obtained triplet pulses and their RF spectra, when the input signal pulse widths are 0.5 bit, 0.7 bit and 1 bit, respectively, while keeping other operating parameters constant. From Fig.2(a)-(c), it can be seen that with the increase of input pulse width, the output pulse width of the triplet pulse is also increased, while the average optical power remains relatively unchanged. As shown in Fig.2(d)-(f), when the input signal pulse width is 0.5 bit, the corresponding spectrum is too wide to fit the definition of UWB given by Federal Communications Commission (FCC). While the input signal pulse width is 0.75 bit and 1 bit, the fractional bandwidth of output RF signal is 160% and 155.56%, respectively. As a result, the output triplet pulse is better with larger width of the input signal pulse.

We change the power of probe light by an attenuator while keeping other operating parameters constant. When the attenuations are 0 dB, 3 dB and 6 dB, respectively, the obtained triplet pulses and their RF spectra are shown in Fig.3. From Fig.3(a)-(c), it can be seen that with the decrease of probe light power, the average optical power reduces. The positive pulse has a small increase in amplitude, while the negative pulse increases gradually. Therefore, the generated triplet pulse is asymmetrical. Meanwhile, with the increase of the probe power attenuation, the noise property of signal light is improved. Due to the reduced oscillation pulse power, the output triplet pulse is not obvious. From Fig.3(d)-(f), it can be seen that with the decrease of the probe light power, the fractional bandwidths are 100%, 100% and 120%, respectively. Besides, the corresponding power spectral density increases gradually, and the high-frequency component appears.



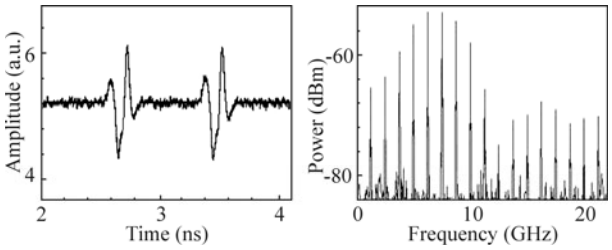
(a) Waveform at 0.5 bit (d) RF spectrum at 0.5 bit

(b) Waveform at 0.75 bit (e) RF spectrum at 0.75 bit

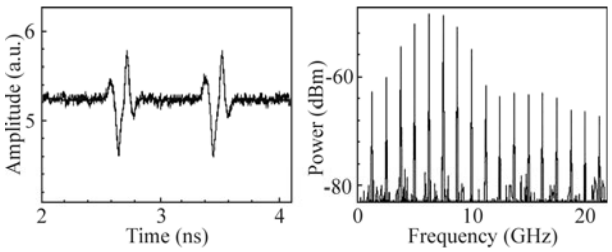
(c) Waveform at 1 bit (f) RF spectrum at 1 bit

Fig.2 Waveforms and RF spectra for output triplet pulse at different input signal pulse widths

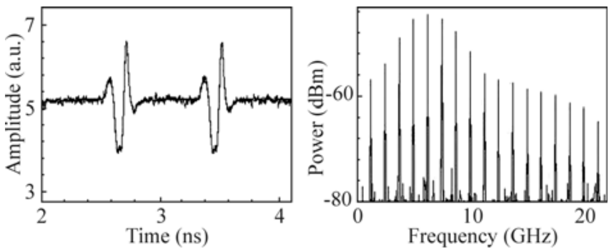
We change the power of signal light by an attenuator while keeping other operating parameters constant. When the attenuations are 0 dB, 3 dB and 6 dB, respectively, the obtained triplet pulses and their RF spectra are shown in Fig.4. From Fig.4(a)-(c), it can be seen that with the decrease of signal light power, the average optical power remains relatively unchanged. When signal power is smaller than probe power, the positive and negative pulses at right side of output triplet pulse are very small. This is because the probe light consumes a large number of carriers, and the probe light cannot be modulated by signal light effectively. Besides, oscillation pulse decreases with the reduced signal power. When the attenuation of signal power is 6 dB, the oscillation pulse is drowned in the noise, which forms doublet pulse. From Fig.4(d)-(f), it can be seen that the fractional bandwidths are 100%, when the attenuations are 0 dB and 3 dB, respectively. However, when the attenuation is 6 dB, the output triplet pulse is influenced by noise heavily, and is not matching the definition of UWB given by FCC.



(a) Waveform with probe attenuation of 0 dB (d) RF spectrum with probe attenuation of 0 dB



(b) Waveform with probe attenuation of 3 dB (e) RF spectrum with probe attenuation of 3 dB

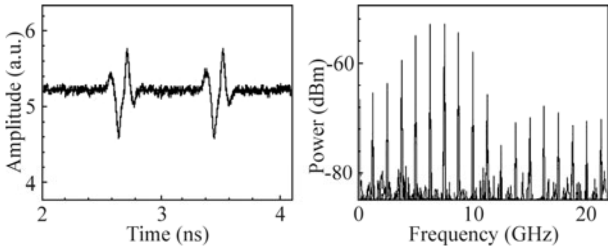


(c) Waveform with probe attenuation of 6 dB (f) RF spectrum with probe attenuation of 6 dB

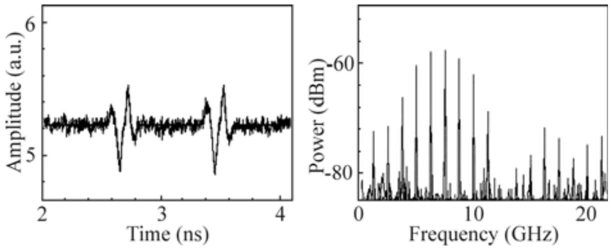
Fig.3 Waveforms and RF spectra for output triplet pulse when probe light with different attenuations

As a result, we can get the best triplet signal when input probe light power is equal to input signal light power by using a power splitter.

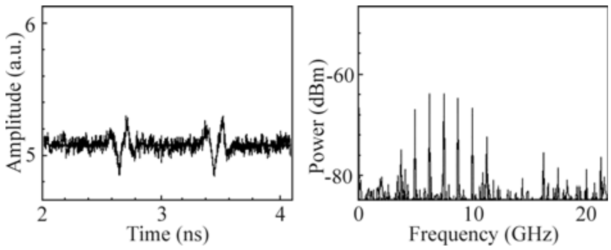
Fig.5 shows the obtained triplet signals and their RF spectra with different light source power values. With the increase of optical source power, the upper pulse amplitude first increases then decreases, while the lower pulse amplitude increases gradually. When the optical source power is too low (-15 dB), the output triplet pulse is drowned in the noise. However, when the optical source power is too high (15 dB), the probe light and the signal light consume a large number of carriers, and the overshoot is not obvious, which leads to signal distortion. Furthermore, it can be seen from Fig.5(f)-(j) that the greater the optical source power is, the less influence the noise has. As a result, while the light source power is between -10 dB and 10 dB, the output UWB signals match the definition of UWB given by FCC well.



(a) Waveform with input signal attenuation of 0 dB (d) RF spectrum with input signal attenuation of 0 dB

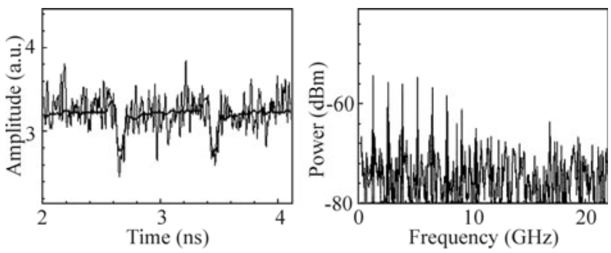


(b) Waveform with input signal attenuation of 3 dB (e) RF spectrum with input signal attenuation of 3 dB

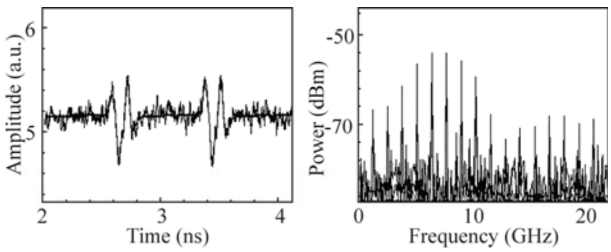


(c) Waveform with input signal attenuation of 6 dB (f) RF spectrum with input signal attenuation of 6 dB

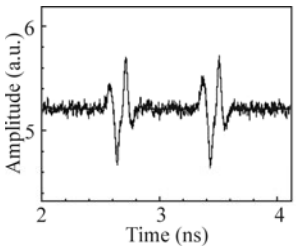
Fig.4 Waveforms and RF spectra for output triplet pulse when input signal light with different attenuations



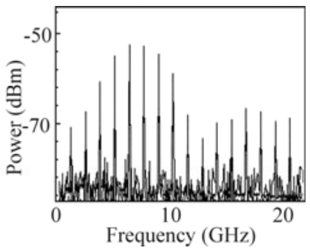
(a) Waveform with light source power of -15 dBm (f) RF spectrum with light source power of -15 dBm



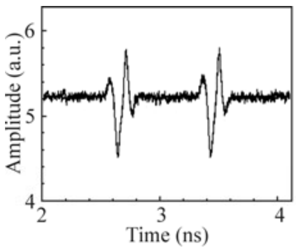
(b) Waveform with light source power of -7.5 dBm (g) RF spectrum with light source power of -7.5 dBm



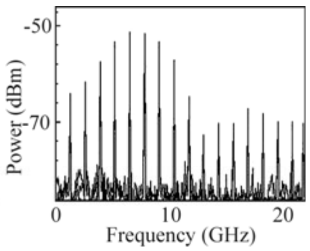
(c) Waveform with light source power of 0 dBm



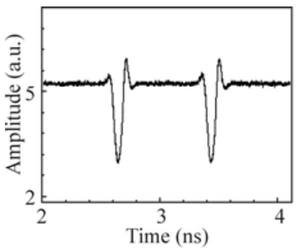
(h) RF spectrum with light source power of 0 dBm



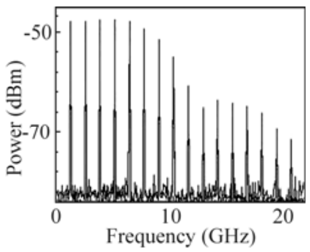
(d) Waveform with light source power of 7.5 dBm



(i) RF spectrum with light source power of 7.5 dBm



(e) Waveform with light source power of 15 dBm



(j) RF spectrum with light source power of 15 dBm

Fig.5 Waveforms and RF spectra for output triplet pulse at different light source power values

Keep all other parameters constant except for the wavelength of the optical source. The simulation results are shown in Fig.6. There is almost no influence on output triplet waveforms when the input wavelength varies from 1552 nm to 1564 nm. Besides, the fractional band widths

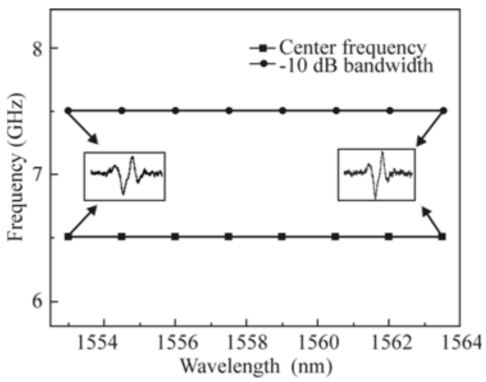


Fig.6 -10 dB bandwidth and center frequency of output pulses at different wavelengths

of the measured triplet pulses are all over 115% which conforms the UWB definition of FCC. Consequently the UWB triplet pulses of our scheme are insensitive to the wavelength change within a certain range.

In this paper, we present a novel scheme for all-optical UWB triplet pulse generation based on XGM in an SOA. By using the software of Optisystem 7.0, the impacts of the input signal width, the optical power and the wavelength of the optical source on the generated triplet pulse are numerically simulated and studied. The simulated results show that our scheme has better triplet signal pulse when the input signal pulse width is greater and is insensitive to the wavelength change within a certain range.

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