Photonic generation of ultrawideband signals based on frequency-dependent gain saturation in a reflective semiconductor optical amplifier

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A novel scheme to generate ultrawideband (UWB) pulses with different polarities is proposed and experimentally demonstrated based on a reflective semiconductor optical amplifier (RSOA). Because the gain saturation in the RSOA is more evident when the injected optical signal has a lower modulation frequency, the RSOA operated at the gain saturation regime can shape a dark or bright return-to-zero pulse to a UWB pulse. An experiment is performed. The fractional bandwidth of the generated UWB pulse is more than 89%. The generated UWB signals with on-off keying format are transmitted in a 20 km single-mode fiber. The power penalty is less than 1.2 dB. Since the RSOA is possibly a key device in wavelength-division multiplexed passive optical networks (WDM-PONs), the proposed optical UWB generator can be used to provide UWB services in a WDM-PON system without significantly increasing the cost.

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With a rich set of features including large capacity, high scalability, service transparency, and enhanced security, wavelength-division multiplexed passive optical networks (WDM-PONs) have drawn considerable interests from academia, industry, and government. For future WDM-PONs, the ability to provide services to both wired and wireless users is needed [1]. Recently, several approaches were reported to distribute ultrawideband (UWB) signals over WDM-PONs since UWB is a power-efficient technology to provide high data-rate wireless services [2–5]. To perform the wireline and wireless convergence without significantly increasing the cost, the optical UWB generator should be constructed based on the mature and wavelength-independent devices in WDM-PONs. However, it is always difficult to do so since the traditional optical UWB generator requires either wavelength selective devices to convert phase modulation to intensity modulation [6,7]; a complex pulse shaper based on microwave photonic filters [8]; an optical spectral shaping followed by frequency-to-time mapping [9]; or nonlinear media with complicated configuration [10]. On the other hand, a reflective semiconductor optical amplifier (RSOA) is considered a key device in WDM-PONs because the information in the downstream signal can be erased due to the gain saturation of the RSOA. Then, the upstream information can remodulate on the reflected optical carrier [11,12].

In this Letter, we propose and demonstrate a novel optical UWB generator based on the frequency dependence of the gain saturation in the RSOA. Because the information-erasing effect is more effective when the input signal has a lower modulation frequency, the RSOA can remove the low-frequency components of a wideband injection signal, while the high-frequency components remain unchanged. As a result, when an optical return-to-zero (RZ) pulse is injected into the RSOA, a UWB pulse would be generated. An experiment is carried out where frequency dependence of the gain saturation in the RSOA is investigated. The generation of the polarity-inversed optical UWB pulses is also confirmed. The UWB pulse train is coded and transmitted through a section of 20 km single-mode fiber (SMF). Electrical spectra, eye diagrams, and receiver sensitivities measurement show that the transmission performance of the generated UWB signals is good.

Figure 1 shows the experimental setup for investigating the performance of the proposed UWB generator. A lightwave from a tunable laser source (TLS, Agilent N7714A) is sent to a Mach–Zehnder modulator (MZM, Fujitsu FTM7938EZ-A), which is operated at the quadrature point. The MZM is driven by a 1.5625 Gb/s pseudorandom binary sequence (PRBS, word length of $2^7 - 1$) RZ signal generated by a pulse pattern generator (PPG, Anritsu MP1763C) with a fixed pattern “1000 0000” to represent one and “0000 0000” to represent zero. The intensity-modulated optical signal is injected into a RSOA (CIP Inc.) via an erbium-doped fiber amplifier (EDFA).

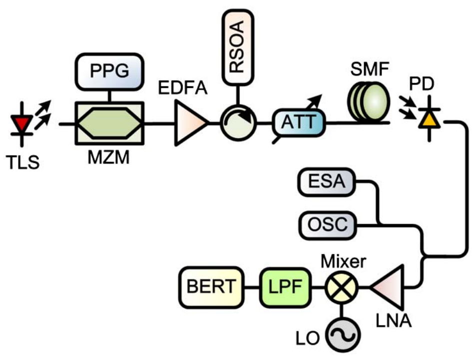

Fig. 1. (Color online) Experiment setup for investigating the performance of the proposed UWB generator. TLS, tunable laser source; MZM, Mach–Zehnder modulator; PPG, pulse pattern generator; EDFA, erbium-doped fiber amplifier; RSOA, reflective semiconductor optical amplifier; ATT, attenuator; SMF, single-mode fiber; PD, photodetector; OSC, oscilloscope; ESA, electrical spectrum analyzer; LNA, low noise amplifier; LO, local oscillator; LPF, low-pass filter; BERT, bit-error-rate tester.

The bias current applied to the RSOA is 100 mA. The EDFA is used to adjust the power level of the injected signal into the RSOA. Due to the frequency-dependent gain saturation of the RSOA, the lower frequency components in the input signal undergo larger attenuation and therefore an optical on–off keying (OOK) UWB signal is generated. The optical UWB signal is transmitted through a section of 20 km SMF and then converted back into an electrical UWB signal at a photodetector (PD). A local frequency oscillator (LO) at 6.25 GHz followed by a 1.988 GHz low-pass filter (LPF) is employed to down-convert the data signal from around 6.25 GHz to the baseband. At the output of the LPF, the received baseband signal is sent to the bit-error-rate tester (BERT, Anritsu MP1764C) for performance evaluation. The waveforms are observed by a high-speed sampling oscilloscope (Agilent 86100A) and the electrical spectra are measured by an electrical spectrum analyzer (Agilent E4447A).

To investigate the frequency dependence of the gain saturation in the RSOA, we replace the PPG with a tunable microwave source (Agilent E8267D). With the frequency of the microwave signal adjusted from 100 MHz to 12.5 GHz, the extinction ratio, i.e., the ratio of the optical powers of the peak and the valley, of the output signal from the RSOA is recorded. Two different cases are considered. In the first case, the optical power to the RSOA is fixed at 4 dBm and the extinction ratios of the injected signal are different (i.e., 3.7, 6.0, and 10.6 dB). As can be seen from Fig. 2(a), the extinction ratios measured after the RSOA increase with the frequency of the signal, indicating that the gain saturation effect is more remarkable at lower frequency regime. For example, when the extinction ratio of the signal injected to the RSOA is 10.6 dB, the extinction ratio measured after the RSOA is 1.6 dB at 100 MHz, which is increased to 9.33 dB at 5 GHz, almost equal to that of the injected signal. In the second case, the extinction ratio of the injected signal is fixed at 6 dB and the optical powers are varied from −5 to 4 dBm. As shown in Fig. 2(b), the higher the optical power of the injected signal, the lower the extinction ratio measured after the RSOA. For instance, the extinction ratio measured after the RSOA is 2.56 dB at 100 MHz when the optical power of the injected signal is −5 dBm, and is 0.51 dB when the optical power is 4 dBm. The wavelength of the injected signal is also tuned from 1530 to 1564.6 nm, with the extinction ratio of the injected signal fixed at 6 dB, the RF frequency fixed at 500 MHz, and the optical power fixed at 4.5 dBm. The results are almost unchanged, showing that the gain saturation is wavelength independent.

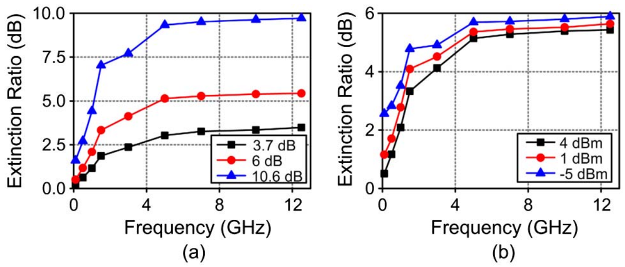

Fig. 2. (Color online) Extinction ratio of the output signal from the RSOA as a function of the frequency of the input signals with (a) different extinction ratios or (b) different optical powers.

When the single frequency signal to the modulator is replaced by a dark or bright RZ pulse train, UWB pulses with different polarities can be generated. Figures 3(a)–3(d) show the waveforms and the electrical spectra of the injected optical dark and bright RZ pulses to the RSOA. The full width at half maximum (FWHM) of the RZ pulse is about 80 ps. Figures 3(e) and 3(f) show the waveform and the electrical spectrum of the UWB pulse generated by the dark RZ pulse. The FWHM of the generated UWB pulse is about 60 ps. The spectrum has a 10 dB bandwidth of 9.66 GHz and a fractional bandwidth of about 90.6%. The waveform and the electrical spectrum of the UWB pulse generated by the bright RZ pulse are shown in Figs. 3(g) and 3(h). The generated UWB pulse has an FWHM of about 62 ps, a 10 dB bandwidth of about 8.48 GHz and a fractional bandwidth of about 89.4%. Since in Figs. 3(f) and 3(h) the low-frequency components below 0.5 GHz are largely attenuated, it is

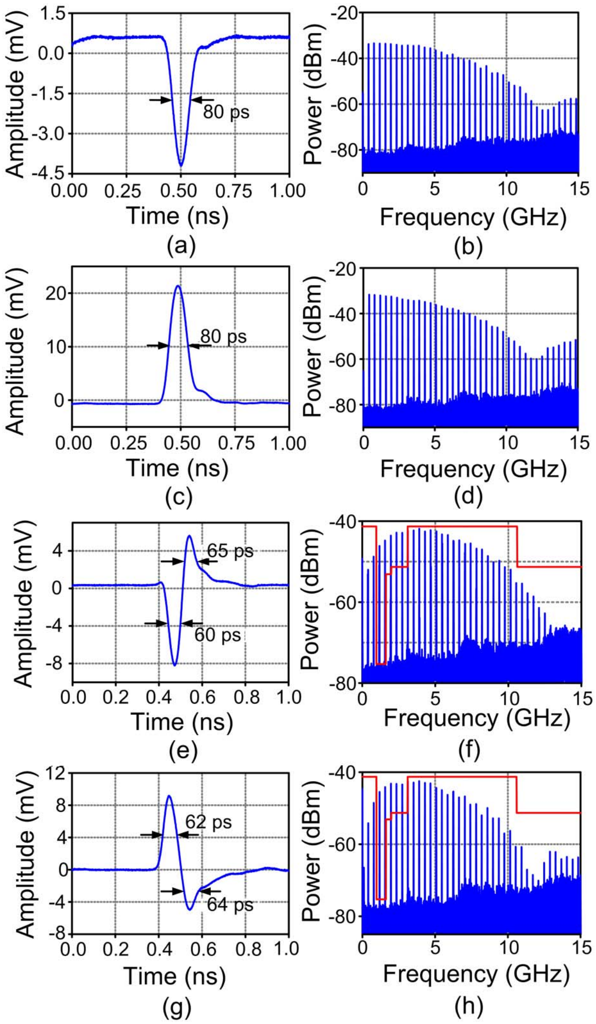

Fig. 3. (Color online) Waveforms and the electrical spectra of the (a) and (b) dark and (c) and (d) bright RZ pulses, and the waveforms and the electrical spectra of the UWB pulses generated by (e) and (f) the dark RZ pulse and (g) and (h) the bright RZ pulse.

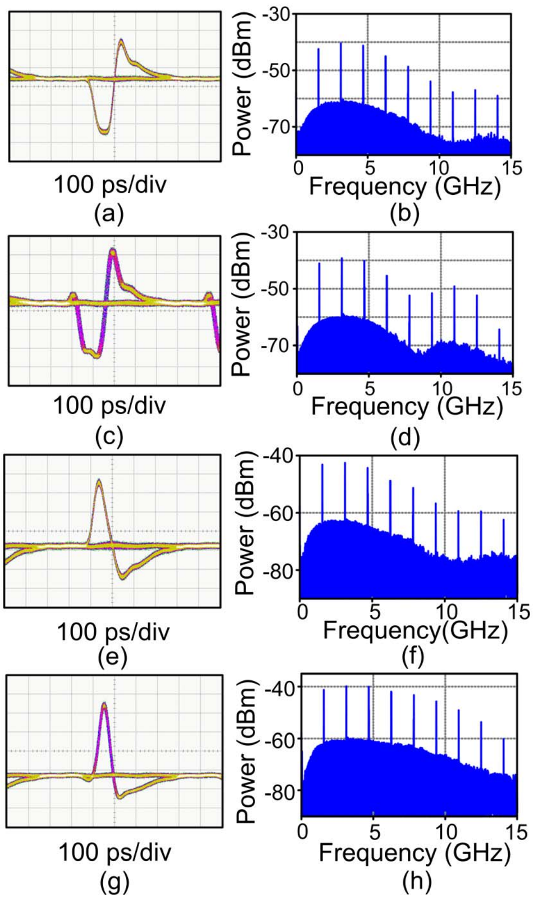

Fig. 4. (Color online) Eye diagrams and electrical spectra of the UWB signals generated by the dark and bright RZ pulse train. (a), (b), (e), and (f) back-to-back, and (c), (d), (g), and (h) after 20 km SMF transmission.

possible to introduce a wired signal with a bandwidth of less than 0.5 GHz to the RSOA. As a result, the provision of both wired service and UWB wireless service on a single wavelength is possible [4]. It should be noted that the generated UWB pulses can be shaped by UWB antennas to fit the FCC spectral mask with a small energy penalty because the fractional bandwidth is very large [8].

To investigate the transmission performance of the generated UWB signals, a UWB-over-fiber link is constructed based on the proposed UWB generator. Figures 4(a)–4(d) show the eye diagrams and electrical spectra of the UWB signals generated by the dark RZ pulse train without and with 20 km SMF transmission. Due to the fiber dispersion, the eye diagram has some degradation after the 20 km SMF transmission. The spectral notch at ~10.9 GHz is shifted to 8.6 GHz. However, error-free transmission can still be obtained. The receiver sensitivity, i.e., the value of the optical power on which the bit error rate of the UWB signal is 10^{-10}, is –5.81 dBm for the back-to-back case, while that for the 20 km SMF transmission is –4.69 dBm, giving a power penalty of 1.12 dB. Similar transmission performance is obtained for the UWB signals generated by the bright RZ pulse train, as shown in Figs. 4(e)–4(h). In this case, the receiver sensitivities for the back-to-back and 20 km SMF transmission are –6.59 and –5.69 dBm, respectively.

In conclusion, a novel approach to generate UWB pulses with different polarities based on the frequency-dependent gain saturation of the RSOA was proposed and demonstrated. The generated UWB signals could be transmitted in a 20 km SMF with a power penalty of less than 1.2 dB. The proposed UWB generator is simple, stable, and wavelength-independent, which may find application in UWB over WDM-PON systems.

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