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# An optical pulse generation technique using two optical phase modulators and a Fabry-Perot etalon

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## ABSTRACT

In this study, we present simulation studies of an intensity modulation technique to produce an optical pulse train. This technique used two optical phase modulators connected to a Fabry-Perot filter (with a free spectral range of 200 GHz and finesse of 500) connected in series to a fiber. Short RF pulses with a phase difference of 180 degrees induced the optical phase modulators. A digital phase shifter created a 180-degree phase difference between RF signals. In the simulation studies, the technique was investigated in a ring-cavity laser design model at the laser wavelength of 1300 nm. Optical pulses were obtained at a repetition rate of 100 MHz with a pulse width of about 600 ps. It was possible to change the optical pulse parameters by changing the bit sequence configuration and bit-rate of the digital phase shifter. With further improvement in effective control of rapid phase shift between RF signals, the technique can be used in active mode-locking.

**Keywords:** optical pulse generator, phase modulator, phase shift, Fabry-Perot filter

## 1. INTRODUCTION

The production of high-speed optical pulses has taken place in a wide range of applications, from telecommunication[1] to spectroscopy[2], from optical measurements to material processing, from biomedical imaging to physics, chemistry and biology[3,4]. A variety of optical pulse generation methods[4] have been proposed that provide optical pulse generation with different line width and repetition rate. Active mode locking is a widely used method in laser technology and especially in the production of low noise and high stable optical pulses. Besides, active external control can produce optical pulses with flexible technical characteristics and lead to the development of new pulsing techniques[4-6]. For instance, a stretched pulse mode-locked laser source[7], a rational harmonic mode locked laser[8], and an optical frequency comb or a multicarrier light source[9] were various applications based on active mode locking technique.

In this study, an intensity modulation technique was simulated using two optical phase modulators connected in series to a Fabry-Perot etalon to produce an optical pulse train. In the simulation, the technique was investigated in the ring-cavity laser cavity at the wavelength of 1300 nm. <600-ps laser pulses were generated at a repetition rate of 100 MHz.

## 2. MATERIALS AND METHODS

The operating principle of the optical pulse generation technique using two optical phase modulators and an optical filter connected in series can be summarized as follows: (1) First optical phase modulation can spectrally broaden a single frequency or a rather narrow optical band. (2) Depending on the electrical signals inducing the optical phase modulators, the optical band can be further broadened by the second modulation or narrowed by demodulation. For example, if the phase difference between the electrical signals inducing the optical modulators is zero, the second modulation can be achieved, and demodulation can be provided if it is 180 degrees. (3) Only the narrowed optical band can be transmitted through the optical filter with high efficiency, while the broadened optical band cannot be transmitted. Furthermore, an optical pulse train can be obtained by adjusting the first and second modulating signals as a function of time.

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Figure 1 shows a schematic diagram of a laser cavity used in simulation studies. A series of simulation studies were planned to estimate the technical performance of the presented approach for rapid optical pulse generation in a laser cavity. The model was developed in commercially available Optisystem 16.0 (Optiwave, Canada), which provides a powerful simulation and optical computing platform. The laser comprised a unidirectional ring cavity with two optical phase modulators. An optical amplifier was used again element at a wavelength of 1300 nm. A Fabry-Perot etalon with a free spectral range of 200 GHz and finesse of 500 was included in the laser. A 50% tap coupler provided the laser output. The computed laser output was monitored on a 160 GS/s through an optical time domain visualizer, and with an optical spectrum analyzer (at 0.01 nm wavelength resolution) in the optical spectrum domain.

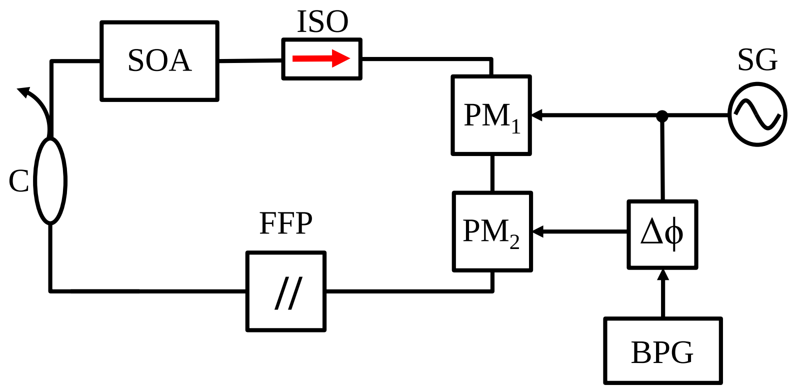


Figure 1. A schematic diagram of a laser cavity. (SOA: semiconductor optical amplifier, IS0: isolator, PM: optical phase modulator, SG: radiofrequency signal generator, BPG: bit pattern generator, $\Delta\phi$: phase shifter, FFP: fiber Fabry Perot etalon, C: coupler)

In simulation studies, a radio frequency (RF) sinusoidal signal generator with two half-output induced optical phase modulators. The modulation frequency was set to 8 GHz. One of the outputs of the RF generator directly induced the first modulator, while the other half was connected to a digital phase shifter set to a 180 degrees phase shift. The control input of the phase shifter was attached to a bit pattern generator (BPG), and the phase difference between the RF signals from the output of the RF generator could switch between 0 and 180 degrees by using a series of 1 Volt bit patterns. A user-defined bit sequence generator was coupled to a zero-return (NRZ) pulse generator to simulate a bit pattern generator.

## 3. RESULTS

Figure 2 presents the computed optical spectrum results at 1300 nm before and after phase modulation and phase demodulation, respectively. In this simulation study, the amplitude of the RF signals was set to 2 Volts (before being divided into two), and the phase deviations of the optical phase modulators were $\pi/2$. The calculated modulation index (i.e., modulation depth) was to be 1.57.

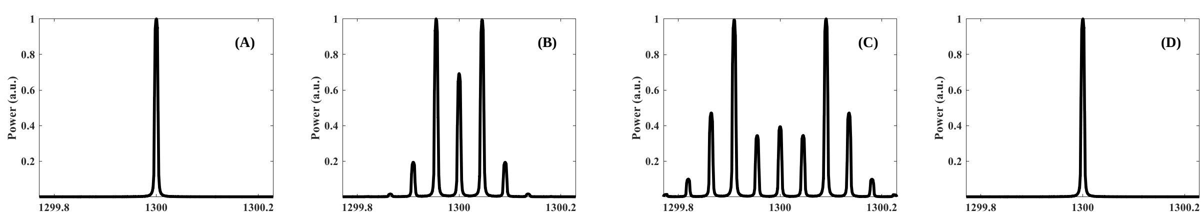


Figure 2. Computed optical spectrum results at 1300 nm before and after phase modulation and phase demodulation. Panel A: A single-mode laser spectrum transmitted to the first phase modulator. Panel B: Broadened optical spectrum with 4 sidebands after first phase modulation. Panel C: Further broadened optical spectrum with 8 sidebands after second phase modulation. Panel D: Narrowed optical spectrum after phase demodulation.

The estimated laser output in the time domain is shown in Figure 3. In this simulation, the BPG provided a bit pattern with a 50 ns pulse-width and 5 MHz repetition rate. The generation of temporally aligned stable optical pulses is apparent. The pulse shapes and parameters (see expanded ROI in Figure 3(b)) reflect great similarities to the bits produced from BPG. Simulations were repeated with different bit pattern parameters to demonstrate the ability of optical pulse technique and phase-shift method in the laser cavity model. Figure 4 shows an example of the results calculated in the time domain of optical pulses at a repetition rate of 100 MHz and a pulse width of approximately 600 ps.

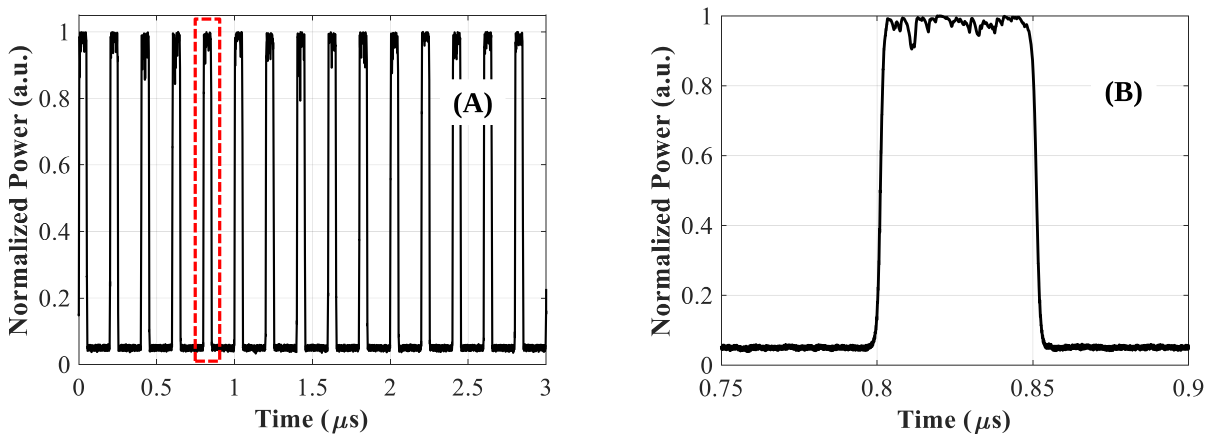


Figure 3. Panel A: Estimated laser output in the time domain of optical pulses at a repetition rate of 5 MHz and a pulse width of approximately 50 ns. Panel B: Expanded region of interest (ROI).

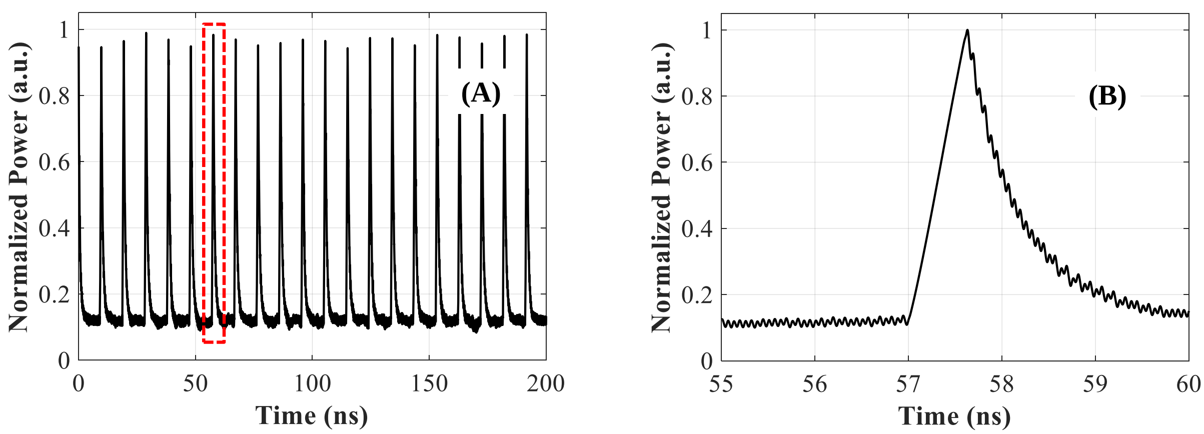


Figure 4. Panel A: Estimated laser output in the time domain of optical pulses at a repetition rate of 100 MHz and a pulse width of approximately 600 ps. Panel B: Expanded region of interest (ROI).

## 4. DISCUSSION AND CONCLUSIONS

This study demonstrated computer simulations of an intensity modulation technique to produce an optical pulse array. The technique uses two optical phase modulators induced by RF signals with a phase difference as a function of time. The modulators apply spectral broadening (phase modulation) and spectral narrowing (phase demodulation) to the single-mode optical wavelength (i.e., the laser wavelength oscillating in the cavity) in order of time-dependent phase change. An optical spectral filter in the cavity model, such as a Fabry-Perot etalon with a free spectral range of 200 GHz and finesse of 500, modulates laser intensity in time.

The calculated results of this simulation study confirm that the presented technique produces fast optical pulses with a picosecond pulse width. However, there are some limitations that the study meets. For example, the simulation does not include either cavity round trip time or harmonics in optical pulse generation. The pulse stability generated by the laser during the mode-locking regime needs further investigation. Besides, the time variation of the phase difference between the RF signals performed using a digital phase shifter can be improved by another method. In this way, optical pulses with narrow pulse line widths can be produced. Finally, all simulation studies should be verified by experimental studies.

Overall, with further improvement in effective control of the rapid phase shift between short RF signals inducing optical phase modulators, the technique may have the potential to be used for active mode-locking.

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