Low-cost laser diode pulse generator for quantum information applications

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Abstract. A simple short-pulse generator circuit based on electronic gates is designed for short electric pulse of about 12 ns at Full Width at Half Maximum (FWHM) and 3.6 Volt amplitude for driving a laser diode. Using our circuit with a 780 nm laser diode designed and fabricated for producing short light pulses. The circuit utilizes an AND gate, a XOR gate, and a common function generator, provides a repetition rate from DC up to 1 MHz. The laser pulses were generated and then detected via an avalanche photodiodes (APD). This finding can benefit the field of light-based quantum information including single photon experiments.

1. Introduction

A pulsed laser has been at the center of interests due to its wide range of applications. The ultrashort light pulses are deployed for manufacturing methods which progress materials and product processing. The high-tech devices are fabricated requiring pulsed lasers for patterning and shaping of minuscule features at fast rate [1]. In comparison with a continuous-wave (CW) laser, the collateral damage caused by using a pulsed laser with high intensity for fabrication processes can be precisely controlled. The light pulses are also necessary for time-resolved spectroscopy to investigate the behavior of dynamics of various molecules [2]. In optical communication, the fast laser pulses are needed for test and measurement field [3]. Moreover, the pulsed lasers are employed in medical field, mostly ophthalmology, and shown to carry out clinical successes in the treatment of retinal diseases [4].

There are several techniques for creating laser pulses. Q-switching approach can produce the energetic short light pulses with time duration of nanosecond range and possibly extremely high peak laser power via manipulating intracavity losses [5]. The mode-locking laser involves mode lockers such as active and passive elements to generate the ultrashort light pulse width ranging from tens of femtoseconds to picoseconds [6]. Cavity damping was developed from the Q-switching technique to get rid of some Q-switching limitations [7]. For gain-switched laser pulses, the gain medium is modulated with the pump power at high-speed rate [8]. The gain-switching is often utilized in semiconductor laser diodes and achieves a pulse width of nanoseconds or picoseconds. Other approaches were also demonstrated, such as opto-electronic oscillator [9] and a technique associated with a beat signal provided via two diode lasers with different output frequencies [10].

Currently, quantum information has been intensively studied for its potential applications including quantum key distribution, quantum communication, and quantum computing. Light-based quantum information system has taken single photons as quantum bits and the regular way to produce single photons is to decrease the intensity of a laser beam or in other words the number of photons. This laser beam has to be pulsed at sufficiently narrow pulse width. Here, a low-cost laser diode pulse generator simply based on logic gates is constructed to create short laser pulses for future single-photon quantum experiment. The resulting light pulses are tested to be measured via the avalanche photodiode (APD).

2. Laser pulse generator circuit

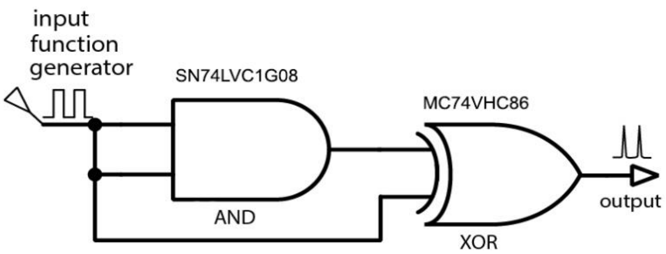

Figure 1. Electrical schematic of the laser pulse generator circuit.

The electrical schematic of the pulse generator circuit is seen in figure 1. The circuit simply utilizes two types of logic gates, the AND gate (SN74LVC1G08) and the XOR gate (MC74VHC86), to achieve short laser pulses. A voltage of 5 V is applied to the Vcc to run both gates. A function generator (GW Instek AFG-2012) basically provides a square wave signal with 500 kHz to the circuit input. Our design uses the AND gate to add a small delay to the signal at the top input leg of the XOR gate. The input signals therefore arrive at the XOR gate at different times (Ch1-yellow and Ch2-blue in figure 2). The output of the XOR gate is high if only the inputs are different (high or low). The brief period of time when both input signals are not identical leads to a pulse on the output of the XOR gate. The repetition rate of the output is therefore double that of the input.

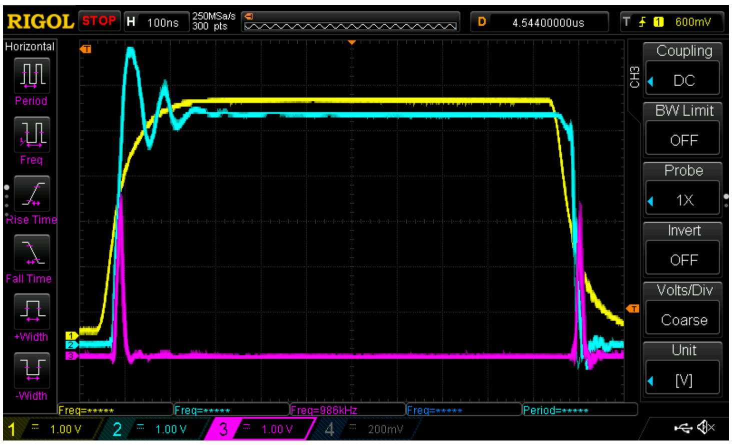

Figure 2. Waveforms of the measured electrical pulse signals (details see text).

As shown in figure 2, our circuit generates an electrical pulse with the duration and amplitude measured to be 12 ns and 3.6 V, respectively (Ch3- violet). The repetition rate was detected to be 1 MHz as expected. It was also found that the difference in the length of the input wires connected to the XOR gate also caused the delay and thus affected the pulse width.

3. Laser operation

The electrical pulses from the circuit were then exploited to pump the 780-nm laser diode (Thorlabs: L780P010) to obtain the laser pulses. The electrical amplitude was well above the operating voltage of the laser diode (1.8 V). The intensity of the pulsed laser had to be reduced for producing the single photons and this can be fulfilled via using a combination of optical elements such as a neutral density (ND) filter, linear polarizer (LP), half-wave plate (HWP), and a polarization beam splitter cube (PBS) (figure 3). The intensity of the laser can be adjusted to the single photon source by rotating the HWP. We used a homemade single photon counter module to measure single photons originated from our pulsed laser system. The counter module comprises the avalanche photodiode (APD) and its power supply circuit and the cooling circuit used for decreasing the temperature of the APD to -14 °C to eliminate the thermal noises. An example of the output of the APD is shown in figure 4. The photon signal pulses appear as the narrow peaks when the pulsed laser is operated. The repetition rate of photon signal pulses, few MHz, is far different from that of the fundamental dark counts arising from the counting module, which is in the scale of kHz.

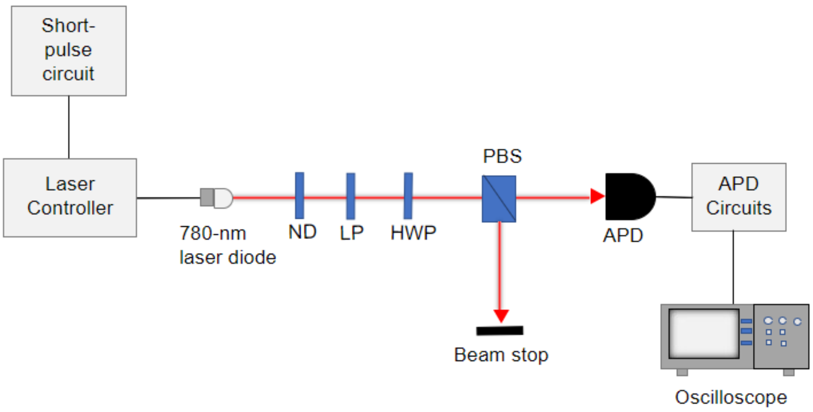

Figure 3. Experimental setup for single photon generation and detection. Short-pulse circuit as shown in figure 1, home-made laser controller for driving the laser, 780-nm laser diode as a single photon source, ND is a neutral density filter, LP is a linear polarizer, HWP is a half-wave plate, PBS is a polarization beam splitter cube, and APD is an avalanche photodiode. Details please see text.

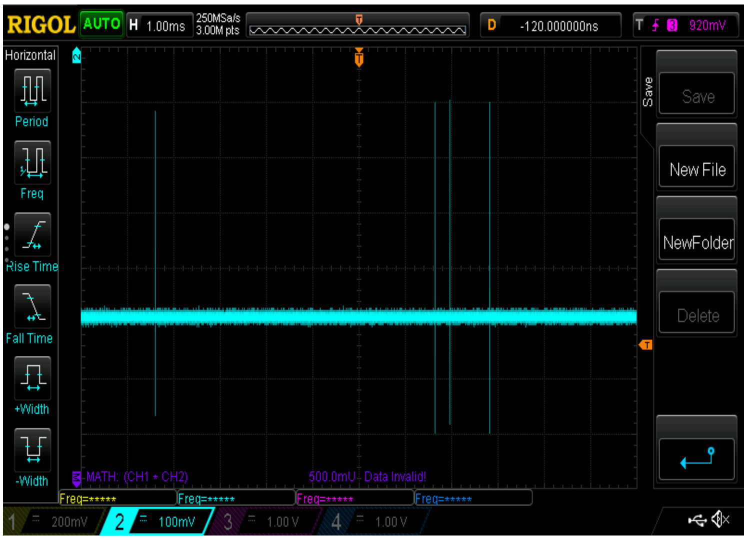

Figure 4. Output signal detected by the APD in the time histogram.

4. Conclusion

The simple short-pulse circuit has been designed and constructed. It comprises of two logic gates, i.e. AND gate and XOR gate. The circuit was used as a pulsed laser diode driver. The laser was then emitted as a single-photon source using weak coherent pulse configuration. These single photons were checked with a homemade single-photon counting module. This short-pulse circuit is aimed to utilize for single photon experiments in the near future.

Acknowledgments

We gratefully acknowledge the support from the research unit grant from Faculty of Science and Burapha University (RU01/2563). SB acknowledges the support from Faculty of Science, Burapha University (SC-NO2/2563).

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