Optical Shift Register Based on an Optical Flip-flop Memory with a Single Active Element

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Abstract *We present an optical shift register consisting of two serially connected optical flip-flop memories. The concept is demonstrated experimentally using fiber pig-tailed components.*

Introduction

Optical shift registers have received considerable attention since they could be potentially applied in optical packet buffers and serial-to-parallel converters [1-3]. Several approaches have been explored. It is shown in [1-2] that circulating optical shift registers are realized using either fiber buffers or using Sagnac interferometers. Another example given in [3] is based on coupled SEEDS (self-electro-optic effect device) driven by the changes of the driving voltage.

In this paper, we present an optical shift register based on cascaded optical flip-flop memories driven by common optical clock pluses. The flip-flop consists of two ring lasers sharing a single active element [4], which makes the flip-flops easily cascade with each other. The concept is demonstrated at 20 kHz operation speed, which is limited by the 10 *m* long laser cavities formed by the pig-tailed components.

Operation principle

Fig. 1 shows a block diagram of the optical shift-register, which consists of an optical converter in combination with two cascaded optical flip-flop memories. The optical flip-flop memory [4] consists of two coupled ring lasers [4] which are bi-stable in the sense that in each stable state one of the lasers lases while the other is suppressed. The state of the optical flip-flop is thus determined by the wavelength of the dominant laser. Therefore, an optical converter is needed to transform optical data encoded by two binary intensity levels (on and off) into data encoded in two different wavelengths corresponding to the two states of the optical flip-flop. Each optical flip-flop has two input ports and two output ports. The light injected into port 'In1' can not set a new state unless the flip-flop is cleared by a strong external optical pulse injected into port 'In2'. Two flip-flops are cascaded by connecting port 'Out1' of flip-flop 1 with port 'In1' of flip-flop2. Port 'Out2' of each flip-flop is used to output light for monitoring.

The optical shift-register operates in the following fashion. Firstly, the intensity modulated input data are transformed by the optical converter into wavelength encoded data and subsequently injected into port 'In1' of flip-flop1. The two cascaded flip-flops are controlled by clock pulses that are required to clear the flip-flops. A clock pulse is divided into two parts. 50% of the power is delayed while the other 50% of the power is used to clear the state of flip-flop 2 (by injecting via its port 'In2'). The output from flip-flop 1 then sets the new state of flip-flop 2. After this operation, the delayed clock pulse is injected in Port 'In2' of flip-flop 1 and clears its state. The signal encoded in wavelength that outputs from the converter then sets the new state of flip-flop 1. Thus a compete 'shift' function has been realized.

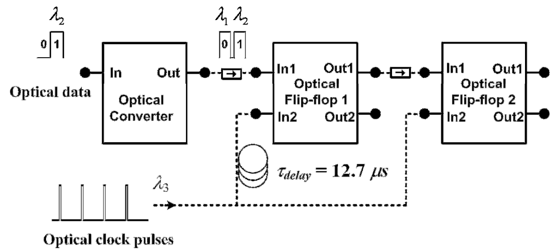

Fig. 1. The schematic of the optical shift register.

Experiment

The optical shift register shown in Fig. 1 is implemented using fiber pig-tailed components. The optical converter consists of a unidirectional ring laser as shown in Fig. 2a. A semiconductor optical amplifier (SOA) injected with 200 mA of current acts as the active element. The Fabry-Perot filter (λ_1 = 1550.92 nm, 3 dB bandwidth 0.20 nm) acts as a wavelength selective element. An isolator enables unidirectional lasing. The optical data to be injected into the ring laser are at a wavelength of 1552.52 nm (λ_2) and have an average power of 3 dBm. If the injected information is a binary '1', half of the injected light is directly coupled to the output port. The other half of the injected light is coupled into the ring cavity by a 50/50 coupler and suppresses the lasing by saturating the SOA. The light that outputs the converter is thus at wavelength λ_2. If no light is injected into the ring laser (a binary '0'), the ring laser remains lasing at wavelength λ_1. In this case, the light that outputs the converter is at wavelength λ_1. Thus data encoded in intensities are transformed by the converter into data encoded in wavelengths.

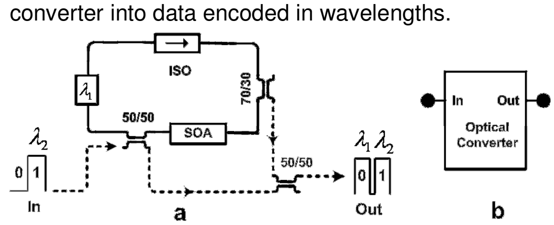

Fig. 2. a: The configuration of the optical converter; b: The icon of the optical converter. ISO: Isolator.

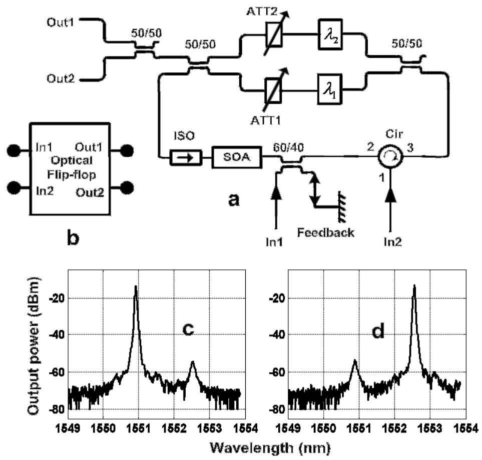

Fig. 3. a: A single optical flip-flop memory; b: The icon of the flip-flop memory; c and d: the experimental results of two stable states. ATT: Attenuator

Each optical flip-flop memory consists of two ring lasers sharing a SOA and a feedback arm as shown in Fig. 3a. The two ring cavities are formed using two 50/50 couplers. A variable attenuator is placed in each ring to balance the cavity loss. The central wavelengths of the Fabry-Perot filter in the ring cavity 1 and 2 are λ_1 and λ_2, respectively. The SOA is biased with 250 mA injection current. It is shown in [4] that the roundtrip conditions of the two ring cavities can not be satisfied simultaneously due to the presence of feedback light which leads to oscillation of the light in the laser cavity. Therefore the system shows bi-stable behaviour in the sense that only one of the two lasers can lase while the other is suppressed (Fig. 3c and 3d). Switching between the two states can take place by injecting external light, at the same central wavelength of the suppressed laser, into port 'In1'. The threshold switching power of the external light is -15.0 dBm in our experiment. The length of the ring cavity is about 10 *m* employing a fiber pig-tailed setup, which leads to a switching time of 5.0 µs.

When the power of the external light is below the threshold value, the system maintains the initial state. In this case, another external light at the wavelength of 1559.30 nm (λ_3) is injected to the port 'In2' with 3.0 dBm optical power. The SOA is deeply saturated so that both lasers are suppressed. In the remainder of this paper, we refer to this process as clearing of the memory. After clearing the flip-flop, light injection via the port 'In2' is stopped and the light injected via the port 'In1' sets the new state of the memory. Thus the flip-flop starts lasing at the wavelength of the light injected via port 'In1'.

The converter combined with two cascaded flip-flops form the optical shift register. Fig. 4 shows how the information of a binary 01010011 signal is shifted. The 20 kHz clock pulses are at wavelength λ_3 and have a 3 dB pulse width of 4.0 µs (Fig. 4a). The intensity encoded input signal operates at the same frequency and is synchronized with the clock pulses. The input signal is firstly transformed into wavelength encoded signal by the converter, and then is injected to port 'In1' of flip-flop 1. The output of the converter, flip-flop 1 and flip-flop 2 are shown in Fig. 4b, 4c and 4d, respectively. In order to show the experimental results explicitly, the three outputs are filtered using a filter with central wavelength λ_2. Hence, a '0' state in Fig. 4c and 4d correspond lasing state at wavelength λ_1 as shown in Fig. 3c. It is shown in Fig. 4 that both flip-flops keep their initial states until they are cleared by the strong clock pulses. This is because the optical power injected in each flip-flop via port 'In1' is below the threshold power and the flip-flops can only be cleared by a well-timed clock pulse injected via port 'In2'. After 4 µs (the duration of the clock pulse), the output of the flip-flop 1 sets the new state of the flip-flop 2. This procedure is repeated for flip-flop 1 using the clock pulse delayed by 12.7 µs. The new state of flip-flop 1 is then set by the output of the converter which leads to the completion of the 'shift' function.

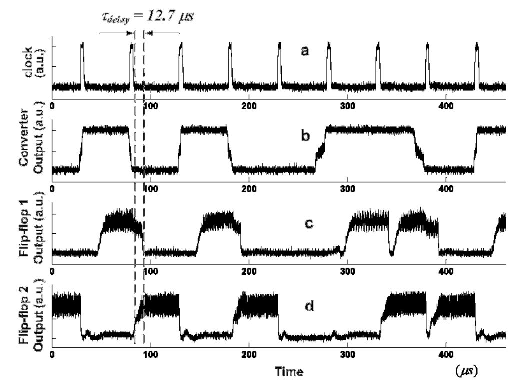

Fig. 4: Experimental results of shifting the information of 01010011. a: the 20 kHz clock pulses. b, c and d show the output of the converter, the flip-flop 1 and the flip-flop 2, which are filtered by the filter with the central wavelength of λ_2 (1552.92 nm), respectively

Conclusions

An optical shift register based on cascaded optical flip-flop memories is demonstrated experimentally. The operation speed is determined by the switching speed of the flip-flop memory. Integration can increase the speed dramatically. Furthermore, the optical shift register shows a novel concept of controlling cascaded optical flip-flop memories. It is worth further investigation of applying this concept to various optical flip-flop memories [5].

References

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