



Original research article

All-optical programmable Binary-to-Gray or Gray-to-Binary code converter using TOAD based reversible new multiplexer

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ABSTRACT

Recently, reversible logic gate provides an alternative to overcome many problems in computing technologies as their zero-power dissipation under ideal condition and it is emerged as a promising computing paradigm with applications in low-power CMOS, quantum computing, optical computing and nanotechnology. Optical logic gates become potential component to work at macroscopic (light pulses carry information), or quantum (single photon carries information) levels with high efficiency. This paper proposes a low-power design of all-optical programmable Binary-to-Gray or Gray-to-Binary code converter using reversible new multiplexer in all-optical domain. By Matlab-7.0 the simulation results verify the functionality of both the new multiplexer and programmable code converter as well as reversibility.

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1. Introduction

Reversible logic design became the promising technologies gaining greater interest due to less dissipation of heat and low power consumption [1]. But, energy dissipates due to information loss of irreversible hardware computing [2]. There are number of existing reversible logic gates, n -input n -output logic device with one-to-one mapping, in literature like Feynman (FyG) and Toffoli (TG) gates. The electronic bottlenecks can be overcome by moving towards transparent fiber optic networks and optical information processing, where the transmitted data would remain exclusively in the optical domain without optical-electrical-optical (OEO) conversions [3–11]. Reversible logic gates must have an equal number of inputs and outputs. Then the output rows of the truth table of a reversible gate can be obtained by permutation of the input rows. The present work explores a circuit realization of a low-power design of all-optical programmable Binary-to-Gray or Gray-to-Binary code converter using reversible new multiplexer which is made of SOA-based TOAD [12–16]. TOAD based switch satisfies the requirements for low switching energy and latency as well as stable and cascade ultrafast operations. In digital systems code conversion is a widely used process for reasons such as enhancing security of data, reducing the complexity of arithmetic operations and thereby reducing the hardware required, dropping the level of switching activity leading to more speed of operation and power saving etc.

The paper is prepared as follows: In Section 2, principle and operation of TOAD-based optical switch is discussed. All-optical circuit realization for TOAD switch-based Feynman and Toffoli Gates are described in Section 3. Section 6 discusses

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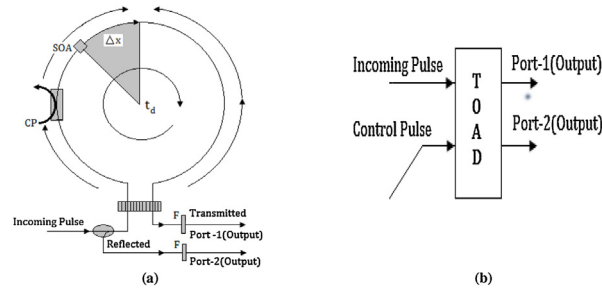


Fig. 1. (a): TOAD-based optical switch. (b): schematic diagram of TOAD-based optical switch.

simulation with Matlab-7 based performance analysis. Finally, conclusions are drawn in Section 7 along with scope of future works.

The reversible logic gate (RLG) TG-based Multiplexer (MUX) and Binary-to-Gray or Gray -to-Binary code converter are proposed in Section 4 and 5 respectively.

2. Principle of TOAD based optical switch

The SOA-based TOAD switches, operationally versatile, are important by their characters of fast switching time, low power consumption, high repetition rate, low latency, noise and jitter tolerance, compactness, high nonlinear properties and thermal stability. These all properties enable their efficient exploitation in a real ultra-high speed optical communications environment [16]. With other buffering solutions they can favorably compete and this highlights their commercial values [17–20]. They can be exploited in more complex all-optical signal processing applications without significantly changing their fundamental architecture [21]. From the last century, TOAD based gate has taken an important role in optical communication and information processing [17–29]. The SOA-based TOAD switches can perform demultiplexing at Tb/s [24]. The TOAD consists of a loop mirror with an additional intraloop 2×2 (ideally 50:50) coupler. The loop contains a control pulse (CP) and a nonlinear element (NLE) that is offset from the loop's midpoint by a distance Δx as shown in Fig. 1(a).

With field $E_{in}(t)$ and angular frequency ω a signal is split in coupler and propagates through the loop in clockwise (cw) and counter clockwise (ccw) direction. At port-1 and port-2, the electrical fields are

$$E_{out,1}(t) = E_{in}(t - t_d) \times e^{-j\omega t_d} \times [d^2 \times \underline{g}_{cw}(t - t_d) - k^2 \times \underline{g}_{ccw}(t - t_d)] \quad (1)$$

$$E_{out,2}(t) = jdkE_{in}(t - t_d) \times e^{-j\omega t_d} \times [\underline{g}_{cw}(t - t_d) + \underline{g}_{ccw}(t - t_d)] \quad (2)$$

Here, t_d is pulse round trip time within the loop as shown in the Fig. 1(a). The coupling ratios k and d indicate the cross and through coupling respectively. The cw signal is amplified by the complex field gain $\underline{g}_{cw}(t)$, while ccw is amplified by the complex field gain $\underline{g}_{ccw}(t)$. The output power at port-1 is

$$\begin{aligned} P_{out,1}(t) &= \frac{P_{in}(t - t_d)}{4} \times \left\{ G_{cw}(t) + G_{ccw}(t) - 2\sqrt{G_{cw}(t) \times G_{ccw}(t)} \times \cos(\Delta\phi) \right\} \\ &= \frac{P_{in}(t - t_d)}{4} \times SW(t) \end{aligned} \quad (3)$$

Here, $SW(t)$ is the transfer function and the phase difference between cw and ccw pulse is defined by $\Delta\phi = (\phi_{cw} - \phi_{ccw})$. The symbols $G_{cw}(t)$, $G_{ccw}(t)$ indicate the respective power gains and relation of the power gain with the field gain is $G = g^2$ and $\Delta\phi = -\frac{\alpha}{2} \times \ln\left(\frac{G_{cw}}{G_{ccw}}\right)$.

Now the power at port-2 is

$$\begin{aligned} P_{out,2}(t) &= \frac{1}{2} E_{out,2}(t) \times E_{out,2}^*(t) = d^2 k^2 \times P_{in}(t - t_d) \times G_{cw} \times \left\{ 1 + \frac{G_{ccw}}{G_{cw}} + 2\sqrt{\frac{G_{ccw}}{G_{cw}}} \times \cos[\Delta\phi] \right\} \\ &= d^2 k^2 \times P_{in}(t - t_d) \times \left\{ G_{cw} + G_{ccw} + 2 \times \sqrt{G_{cw} \times G_{ccw}} \times \cos[\Delta\phi] \right\} \end{aligned} \quad (4)$$

For ideal 50:50 coupler we know $d^2 = k^2 = 1/2$. In the absence of a control signal, data signal (incoming signal) enters the fiber loop, pass through the SOA at different times as they counter-propagate around the loop, and experience the same unsaturated amplifier gain G_0 , recombine at the input coupler i.e. $G_{ccw} = G_{cw}$. This leads to $\Delta\phi = 0$. So expressions are for $P_{out,1}(t) = 0$ and $P_{out,2}(t) = G_0 \times P_{in}$. That is why the data signal is reflected back toward the source. When a control pulse is injected into the loop, it saturates the SOA and changes its index of refraction, the two counter-propagated data signals will experience a differential gain saturation profiles i.e. $G_{ccw} \neq G_{cw}$. Now, $P_{out,1}(t) = \frac{P_{in}(t - t_d)}{4} \times SW(t)$ and $P_{out,2}(t) \approx 0$. Result of

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