Optik 124 (2013) 3357–3361

Contents lists available at SciVerse ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

All-optical parallel data and address recovery scheme

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ARTICLE INFO

Article history:
Received 22 May 2012
Accepted 18 October 2012

Keywords:
Terahertz optical asymmetric demultiplexer
Optical switch
Semiconductor optical amplifier
Communication system
Routing

ABSTRACT

In this paper, we have presented a parallel system model to recover data and address based on terahertz optical asymmetric demultiplexer (TOAD)/semiconductor optical amplifier (SOA)-assisted Sagnac gate. The architecture is based on a system which has its input information containing data and address. Here, we first convert the original data into a coded form with the help of input address. Then the coded information is transmitted through the optical routing channel. At the receiver end, the model simultaneously extracts data and address at any point of the routing channel. The operations of the circuits are studied theoretically and analyzed through numerical simulations. The variation of contrast ratio, amplitude modulation, extinction ratio and bit error rate with control pulse energy and switching crosstalk with gain ratio has been thoroughly investigated.

1. Introduction

Development of ultra-fast systems, working beyond the limit of today's electronics, demands sample, effective and cheap all-optical elements for data processing. Various schemes have been proposed in the field of all-optical communications systems [1–6]. There is an ever increasing demand for broad band high speed communication services which in turn demand telecommunication networks having line and switching capacities exceeding those currently available optical time division multiplexed communication systems may be one alternative where high speed demultiplexing is the major requirement. The use of all-optical switching is currently a focus of attention and is an active area of research. Photonic signal elaboration at the optical layer is attractive to perform various computational functionalities, such as packet buffering, bit length conversions, header processing, switching, retiming and reshaping, and overcoming all the speed related electronic limitations. In recent years, a lot of effort has been spent in these fields and all-optical digital processing seems to be one of the most promising technologies to bring increased capacity, flexibility, and scalability to the next generation systems in the optical domain [7–11]. Optical amplifiers have become increasingly important in modern optical communication systems. Semiconductor optical amplifiers (SOAs) are important components for optical networks. On the other hand, potential use of SOA's nonlinearities for all-optical signal processing has led to research in various application fields. One application is demultiplexing of optical time division multiplexed signal using a SOA as a nonlinear element in a short fiber loop, a configuration also known as terahertz optical asymmetric demultiplexer (TOAD) [12] or semiconductor laser amplifier in a loop mirror (SLALOM) [13]. The all-optical TOAD switch has received wide interests in all-optical processing, switching, and demultiplexing in optical network since it has a simple structure, fast response time, and low switching energy. Therefore, all-optical switches emerge as generic devices suitable for the entire routing and processing operation in all-optical network architecture. One key application in optical network node receivers is data and address recovery (DAR). In this present communication, we use a TOAD employing dual-control scheme to achieve a symmetrical, reduces inter-channel crosstalk, and simultaneous data and address recovery scheme in an optical system. The bit error rate is obtained at the receiver end for different control pulse energy by comparing the received data signal with the transmitted data. The proposed all-optical schemes can exhibit its switching speed far above present day electronic circuits.

2. Basic principle of the scheme

Fig. 1 shows the schematic diagram of the proposed all-optical parallel data and address recovery (DAR) scheme. In this proposed routing scheme, at the transmitter end the sequence of input data (D_m) is converted into coded form (C_n and $\bar{C}_n$) with the help of input address (A_{mn}), then they are transmitted in the optical medium. At the receiver end, the model simultaneously extracts input data and address from the coded signal. In this proposed routing scheme, the main code conversion and recover function are implemented by all-optical *XOR* and $\overline{XOR}$ gate. An optical code converter is used to convert the input data (D_m) to another coded form C_n and $\bar{C}_n$. Here the concept of conversion controller i.e., address bits A_{mn} is

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0030-4026/$ – see front matter © 2012 Published by Elsevier GmbH.
http://dx.doi.org/10.1016/j.ijleo.2012.10.017

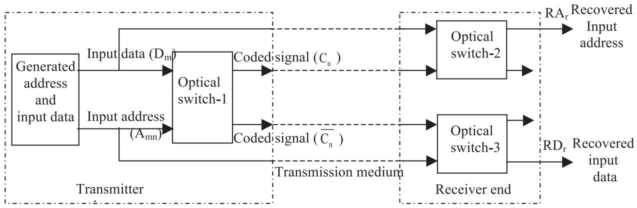

Fig. 1. Block diagram of parallel data and address recovery (DAR) system.

introduced. By processing the input data with A_{mn}, the circuit produces the coded signal. At the receiver end, by processing the coded signal $\bar{C}_n$ with A_{mn}, the scheme generates the recovered data (RD_r) and at the same time by processing the coded signal C_n with D_m, the scheme produces the recovered address (RA_r). The address are generated from the operation $D_m \oplus C_n$. The recovered signals (RA_r and RD_r) are produced by the function $D_m \oplus C_n$ and $\overline{A_{mn} \oplus \bar{C}_n}$ respectively. These are verified by the following example. For example, 8-bit input data having D_m = 10111010 and converted form having C_n = 11010001 (it may be another form), the scheme is verified by

$$A_{mn} \quad \text{(generated input address)}$$
$$= D_m \oplus C_n = [10111010] \oplus [11010001] = [01101011]$$

$$\bar{C}_n = \overline{A_{mn} \oplus D_m} = \overline{[01101011] \oplus [10111010]}$$
$$= \overline{[11010001]} = [00101110]$$

$$RA_r = D_m \oplus C_n = [10111010] \oplus [11010001] = [01101011] = A_{mn}$$

$$RD_r = \overline{A_{mn} \oplus \bar{C}_n} = \overline{[01101011] \oplus [00101110]} = \overline{[01000101]}$$
$$= [10111010] = D_m.$$

Also converted code can be generated using input data and address. These operations are implemented by various SOA-assisted Sagnac switches. Here we use TOAD based optical switch to implement the above scheme for its fast processing speed.

3. TOAD based optical switch

TOAD is an all-optical switch (shown in Fig. 2), which can operate at frequencies in terahertz range [12]. It uses a SOA that is asymmetrically positioned in the fiber loop. The switch is essentially a fiber loop jointed at the base by an optical 50:50 coupler,

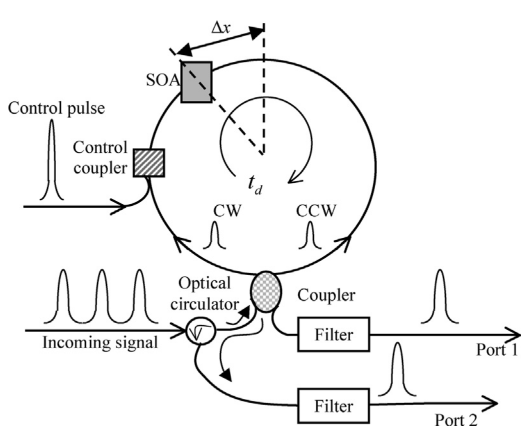

Fig. 2. A TOAD based optical switch with single control pulse (CP), where SOA: semiconductor optical amplifier, CW: clockwise pulse, CCW: counterclockwise pulse, t_d: pulse round trip time, and Δx: asymmetric distance.

which splits the incoming signal into two equal parts that counter propagate around the loop and recombine at the coupler. In almost all TOAD discussed by many authors [14–18], the transmitting mode of the device (output port) is used to take the output signal. But the signal that exits from the input port (reflecting mode) remains unused. In this present communication we have tried to take the output from both the transmitting and reflecting mode of the device [19–22]. The output power at transmitted (*Port 1*) and reflected (*Port 2*) port can be expressed as [13,23–25]:

$$Port \quad 1(t) = \frac{P_{in}(t)}{4} \cdot \{G_{cw}(t) + G_{ccw}(t) - 2\sqrt{G_{cw}(t) \cdot G_{ccw}(t)} \cdot \cos(\Delta\varphi)\} \tag{1}$$

$$Port \quad 2(t) = \frac{P_{in}(t)}{4} \cdot \{G_{cw}(t) + G_{ccw}(t) + 2\sqrt{G_{cw}(t) \cdot G_{ccw}(t)} \cdot \cos(\Delta\varphi)\}, \tag{2}$$

where $G_{cw}(t)$ and $G_{ccw}(t)$ are respectively the power gain exhibited by CW and CCW pulses, $R_G = G_{cw}/G_{ccw}$ $(0 < R_G < 1)$ is the gain ratio of two signal branches. The time dependent phase difference between CW and CCW pulses [13] is

$$\Delta\varphi = \varphi_{cw} - \varphi_{ccw} = -\frac{\alpha}{2} \cdot \ln\left(\frac{G_{cw}(t)}{G_{ccw}(t)}\right), \tag{3}$$

where α is the line-width enhancement factor. In the absence of a control signal, data signals (incoming signal) enter the fiber loop, pass through the SOA at different times as they counter-propagate around the loop, and experience the same unsaturated small amplifier gain G_{ss}, and recombine at the input coupler, i.e., $G_{ccw} = G_{cw}$. Then, $\Delta\varphi = 0$ and expression for $Port$ $1(t) = 0$ and $Port$ $2(t) = P_{in}(t) \cdot G_{ss}$. It shows that data is reflected back toward the source. Here, we consider Gaussian pulse $P_{in}(t) = U_{in}/\tau_0\sqrt{\pi}\exp(-t^2/\tau_0^2)$ as control signal, where U_{in} is the incoming pulse energy and τ_0 is the *full width at half maximum* (*FWHM*) of the incoming pulse. When a control pulse is injected into the loop, it saturates the SOA and changes its index of refraction. The gain of SOA decreases rapidly by the formula [13,23–25]:

$$G(t) = \frac{1}{1 - (1 - (1/G_{ss}))\exp(-E_{cp}(t)/E_{sat})}, \tag{4}$$

where E_{sat} is the saturation energy of the SOA, $G_{ss} = \exp(g_{ss}L)$ is the SOA small signal gain that can be varied by changing its injection current, and $g_{ss} = \Gamma\alpha_N N_0(I/I_0 - 1)$ is the small signal gain coefficient per unit length, Γ is the confinement factor, α_N is the transition cross section, N_0 and I_0 are the carrier density and injection current required for transparency, respectively. $E_{cp}(t) = \int_{\infty}^{t} P_{cp}(t')\,dt'$. Here, we consider control pulse as $P_{cp}(t) = (1/2)E_{cp}[1 + erf(t/\sigma)]$, where $erf(\,)$ is the error function and $E_{cp} = G_{ss}U_{in}$. E_{cp} is the control pulse energy and σ is the full width at half maximum (FWHM) of the control pulse. With these conditions, the SOA gain recover due to injection of carriers can be obtained from the gain recovery formula [13,23–25]:

$$G(t) = G_{ss}\left(\frac{G_f}{G_{ss}}\right)^{\exp(-(t-t_s)/\tau_e)} \qquad when \quad t \geq t_s, \tag{5}$$

where τ_e is the gain recovery time and t_s is the saturation time of SOA. As a result, the two counter-propagation data signal experience a differential gain saturation profiles, i.e., $G_{ccw} \neq G_{cw}$. Therefore, they recombine at the input coupler when $\Delta\varphi \approx \pi$, and then the data exit from the output *Port 1*, i.e., *Port* $1(t) \neq 0$ but *Port* $2(t) \approx 0$; the corresponding value of *Port* $1(t)$ can be obtained from Eq. (1). We consider here that the SOA is polarization independent. A polarization filter may be used at the output to reject the control and pass the incoming pulse. Here we use vertically polarized