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An all-optical method of developing data communication system with error detection circuit

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ABSTRACT

The basic criterion of data communication is that received data should exactly be the replica of the transmitting data. If any error is introduced in the received data, then data transmission should be stopped immediately. In this article the authors have developed an all-optical method of data communication system with error detection mechanism that works with frequency encoded data. Basic building blocks of the proposed data communication scheme are parity generator and parity checker which are developed from all optical XOR logic gates. Simulation results testify the feasibility of the proposed scheme. These logic gates are developed exploiting nonlinear polarization rotation based frequency conversion and switching character of semiconductor optical amplifiers. The scheme with frequency encoded data, high speed of frequency conversion and polarization switching action of semiconductor optical amplifier offers secure, error free, faster data communication network.

1. Introduction

In communication technology, optical communication makes a strong position due to its most interesting features like less bit error rate, large number of channels, capability of using WDM process etc. But we cannot say that it is totally error free. There may be error due to rapid transmission and crosstalk. So we may get wrong information which is undesirable. To overcome this problem and to detect error an extra bit, called parity bit is added to each binary code word at the most significant bit (MSB) position of the code. This is done for making the number of binary '1' bits in the code even or odd. When the numbers of 1's are even, it is called 'even parity' and, when odd, it is called 'odd parity'. For example, '101011' is of even parity, because it contains four 1's. The ASCII code for the decimal digit '9' is '0111001'. This would require the addition of a '0' in the most significant place to give even parity in the modified word, which is now written as $(9)_{10}$ = '0111001', where '0' is the parity bit. Odd parity means an n-bit input has an odd number of 1's. After generating the parity bit by parity generator, the code word with this bit is transmitted. At the receiving end this parity is checked with the parity checker circuit. Exclusive OR gate is ideal for generating and checking the parity of a given binary number. If the information contains even number of 1's, the EX-OR gate combination produces the output as '0'. Similarly, if the information contains odd number of 1's, the EX-OR gate combination produces the output as '1'.

So many efforts have been made to design error free all-optical data communication systems [1–6]. Roy Chowdhury proposed for developing nonlinear material based intensity encoded parity generator circuit [4]. Dimitriadou et al. proposed intensity encoded quantum dot SOA based parity generator circuit [5]. Roy et al. designed micro-ring resonator-based all-optical logic shifter with intensity encoded data [6]. Chattopadhyay et al. reported polarization encoded all-optical quaternary successor [7], Bhattacharyya et al. proposed all-optical parallel parity generator circuit with the help of semiconductor optical amplifier using polarization as well as intensity encoded data [8]. Awwal et al. developed polarization encoded data processor [9]. Michel et al. proposed unique phase encoded data processor [10]. But it is very difficult to maintain the specific states of polarization of the polarization encoded data, phase of the phase encoded data, and threshold intensities of the intensity encoded data in long haul communication system, and therefore, all these proposed schemes lead to bit error problems. Here in this article we have proposed an all optical method of developing 4-bit parity generator and checker circuits and finally with these two building blocks, an error detecting circuit for long haul communication network is proposed. At the receiving end if the transmitted data is checked as wrong parity, the information transmission is stopped by feed back mechanism of the circuit design. The circuit is working on frequency encoded data.

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Advantage of the proposed scheme is that as the frequency is the fundamental character of a signal, frequency encoded data remain unaltered character throughout the communication, which in turn reduces bit error probability. If any error is introduced in frequency conversion due to some kind of circuit nonlinearity or in anyway then parity checking mechanism further reduces the bit error problem and offers an error free secure data communication system. Here binary state ‘1’ is encoded by optical beam of frequency ‘ν_2’ and state ‘0’ is encoded by the beam of frequency ‘ν_1’. We have organized the paper in some sections and sub-sections. In Section 2, working principles of the basic building blocks i.e. parity generator and parity checker are discussed with the help of theoretical model of the SOA, and then operating points and power levels of the devices are selected from the simulation curves. In Sections 3 and 4, method of developing each block of the error detection circuit is explained. In Section 5, scheme of operation of the whole circuit is explained Section 6 is the discussion part of the paper, and conclusion is drawn in Section 7.

2. Working principle of parity generator and parity checker

The basic building blocks of parity generator and checker are XOR logic gates [11]. Here we propose a unique method of developing all optical XOR gate using SOAs. Two important properties of SOA are exploited to develop the XOR logic gates which are mentioned in Sections 2.1 and 2.2 respectively and theory of the SOA is presented in Section 2.3.

2.1. Nonlinear polarization rotation based frequency conversion by SOA

Semiconductor optical amplifiers show non-linear refractive index variation within the active region due to its gain saturation property [12,13]. Highly intense pump beams modify the optical properties of the SOA. Consequently, the pump beam rotates the state of polarization of the probe beam due to the unequal velocity of the *TE* and *TM* modes of the probe beam.

An optical polarizer at the output end detects the nonlinear polarization rotation in terms of intensity difference. If the intensities of the pump beams are not sufficiently high, these cannot rotate the state of polarization of the probe beam and no output beam is obtained. Here we use two pump beams as shown in Fig. 1(a). For this case if any one of these pump beams is absent, or both pump beams are absent, then plane of polarization of the probe beam will not be rotated. Using two pump beams at a time it is possible to transmit the probe beam from input to output end.

2.2. Polarization switching of SOA (PSW)

Scheme of the polarization switch is shown in Fig. 1(b). Here the probe beam (having less intensity) and pump beam (having high intensity) are coupled with SOA, and the SOA in turn acts as a switch based on the polarization rotation properties of the probe beam, and that is why it is called Polarization switch (PSW) [14,15]. Using polarization controllers (PC1, PC2) the state of polarization of the probe beam and the output beam of the SOA are controlled.

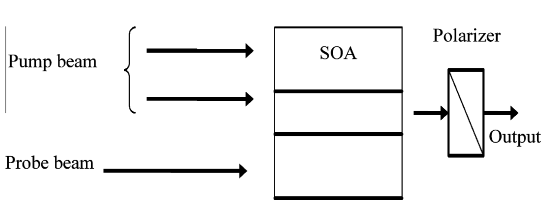

Fig. 1a. Frequency conversion by rotation of SOP of probe beam.

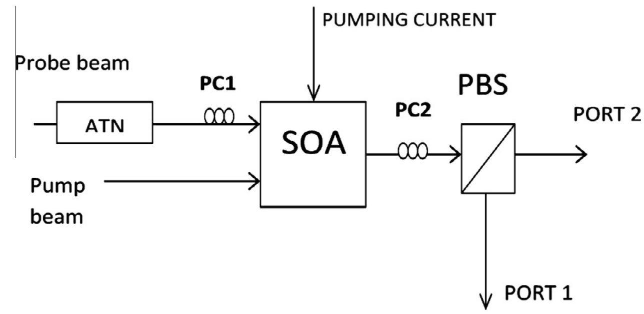

Fig. 1b. SOA acting as a polarization switch.

Here in the absence of pump beam, the probe beam is transmitted to the output port-2 of the polarization beam splitter (PBS) and in the presence of pump beam the probe beam is switched to port-1. Thus controlling the pump beam, one can switch the probe beam from port-1 to port-2 of the PBS and vice versa.

2.3. Theory of the polarization switching and frequency conversion by SOA

The authors now explain the polarization switching action and frequency conversion properties of SOA based on simple rate-equation model of strained bulk SOA as proposed by Dorren et al. [14].

According to this model, optical field ‘$A(z,t)$’ of the input polarized probe beam propagating along ‘Z’ axis as shown in Fig. 1(c) can be decomposed into two mutually perpendicular components along ‘OX’ and ‘OY’ axis which are designated as ‘*TE*’ and ‘*TM*’ mode respectively. These two modes propagate along the SOA independently, and interact with the electrons in the conduction band and light- and heavy-holes in the valance band via gain saturation property of the SOA, and this leads to two different types of transitions with *y*-polarization and *x*-polarization, namely *TM* and *TE* polarization.

If n_c is the number of electrons in the conduction band (controlled by biasing current ‘I’ of the SOA), n_x and n_y are the number of holes participating in *x*- and *y*-transition respectively then

$$n_c(z,t) = n_x(z,t) + n_y(z,t) \tag{1}$$

In an isotropic bulk SOA, there is symmetry between *TE* and *TM* transitions. But in a stained bulk SOA, due to enhancement of light-hole population *TM* transition is favored over *TE* transition and this asymmetry between *TE* and *TM* transition is defined by population imbalance factor ‘f’ which is the ratio of time average value of n_x and n_y, i.e.,

$$f = \frac{\overline{n}_x}{\overline{n}_y} \tag{2.a}$$

and time average value of n_c which is controlled by pumping current I of the SOA as given by

$$\overline{n} = \frac{I}{e}T_1 \quad \text{such that} \quad \overline{n}_x = \frac{\overline{n}f}{1+f} \tag{2.b}$$

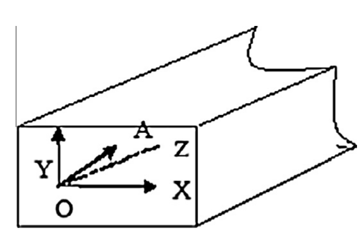

Fig. 1c. Optical field in an SOA.