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An all-optical frequency encoded full adder using semiconductor optical amplifiers

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ABSTRACT

Addition of binary data is very important in optical computing and optical signal processing. In this article the author proposes a method of developing all-optical frequency encoded full adder circuit exploiting frequency conversion and polarization switching (PSW) action of semiconductor optical amplifier (SOA). Frequency encoded binary data offer more advantages over conventionally encoded data in terms of less probability of bit errors and greater reliability. Again efficient frequency conversion and faster switching action of SOA makes the scheme attractive.

1. Introduction

Binary adders are of paramount importance in digital and optical computing because different types of arithmetic and logic operation can be performed easily and efficiently with the help of binary adders [1]. Till now so many types of data encoding/decoding techniques have been established, such as spatial encoding [2], intensity encoding [3,4], polarization encoding [5–7], phase encoding etc. [8]. All these existing techniques have their own limitations. In these conversion schemes presence of optical signal is regarded as binary '1' state and absence of optical signal as '0'. But intensity encoded data suffer from attenuation loss problem. Again for long distance communications as the state of polarization may change for several causes, polarization encoded data are not preferable. Similarly all other encoded data have their own limitation. To overcome these shortcomings, the author has established the concept of frequency encoding [9,10]. Advantage of frequency encoding technique is due to fundamental preservative character of the frequency of a wave, which remains unaltered irrespective of absorption, reflection, refraction etc. Again this frequency encoded data can be used in WDM network for long-distance optical signal and data processing. Here the authors propose an all-optical frequency encoded method of binary data addition using frequency conversion and polarization switching (PSW) action of semiconductor optical amplifier (SOA).

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2. Working principles of full adder

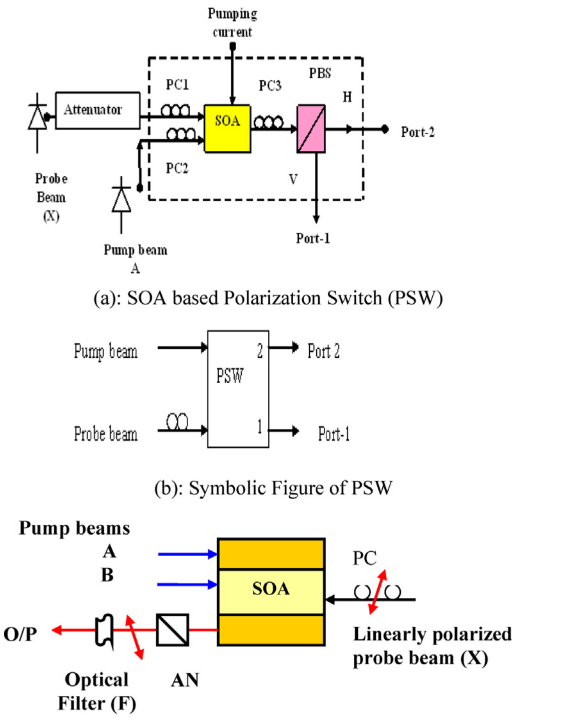
The scheme of SOA based full adder works based on some functionalities of SOA as mentioned below:

2.1. Polarization switch (PSW)

The polarization switch character of SOA is due to its gain saturation property [11,12]. The important feature of PSW is that, in the absence of control (pump) beam '*A*', linearly polarized input probe beam '*X*' appears at the port-1 (vertical component of the probe beam) whereas in the presence of control beam input probe beam appears at the port-2 (horizontal component of the probe beam). Thus with the help of control beam of specific power it is possible to transmit the probe beam from port-1 to port-2. PC1 and PC2, PC3 are the polarization controllers and PBS is the polarization beam splitter which is denoted as optical analyzer 'AN' in Fig. 1(b), symbolic figure of the PSW.

2.2. Frequency conversion by SOA

Frequency conversion by SOA is due to SOP rotation of the probe beam in SOA with the interaction of highly intense pump beam [5,6,9,10]. The frequency conversion scheme is explained in brief with the help of Fig. 1(c). '*X*' is the linearly polarized probe beam and 'AN' is the optical analyzer. In the absence of pump beam '*A*' and '*B*', pass axis of the 'AN' is crossed with respect to the electric field of linearly polarized probe beam '*X*'. Intense pump beams '*A*' and '*B*', combined together introduce nonlinear refractive index difference



(a): SOA based Polarization Switch (PSW)

(b): Symbolic Figure of PSW

(c): Polarization rotation based frequency conversion by SOA

Fig. 1. (a) SOA based polarization switch (PSW). (b) Symbolic figure of PSW. (c) Polarization rotation based frequency conversion by SOA.

between 'TE' and 'TM' modes of the probe beam in the bulk material of SOA, which in turn rotates the SOP of the probe beam, and as a result, a component of electric field of the beam '*P*' passes parallel to pass axis of the 'AN'. In the absence of one pump beam or both, as the pass axis of the 'AN' is crossed with respect to the direction of vibration of '*X*', no light passes through the AN.

3. Scheme of developing full adder

The sum and carry output of frequency encoded full adder is shown in Table 1. Optical circuit of the full adder is shown in Fig. 2.

The full adder circuit comprises two polarization switches PSW1 and PSW2, eight SOA based frequency converters (SOA0, SOA1, SOA2, SOA3 and SOA0/, SOA1/, SOA2/, SOA3/), five numbers of '1 × 2' optical add/drop multiplexers (ADM1,...,ADM5) and four frequency encoded inversion logic gates N_1, N_2, N_3 and N_4 [11]. All five ADMs are tuned to reflect the beam of frequency 'V_1 and these beams are dropped down by their corresponding circulators 'C_r' [13]. Now two frequency-encoded binary data A_i, B_i are to be added with C_{i-1}, the carry beam of the previous stage. Here the carry input beam C_{i-1} is used as the control pump beam of polarization switches PSW1 and PSW2, respectively. Input data 'A_i' and

Table 1
Truth table of full adder.

Input data beams of frequency			SUM	CARRY
C_{i-1}	A_i	B_i	S_i	C_i
υ_1	υ_1	υ_1	υ_1	υ_1
υ_1	υ_1	υ_2	υ_2	υ_1
υ_1	υ_2	υ_1	υ_2	υ_1
υ_1	υ_2	υ_2	υ_1	υ_2
υ_2	υ_1	υ_1	υ_2	υ_1
υ_2	υ_1	υ_2	υ_1	υ_2
υ_2	υ_2	υ_1	υ_1	υ_2
υ_2	υ_2	υ_2	υ_2	υ_2

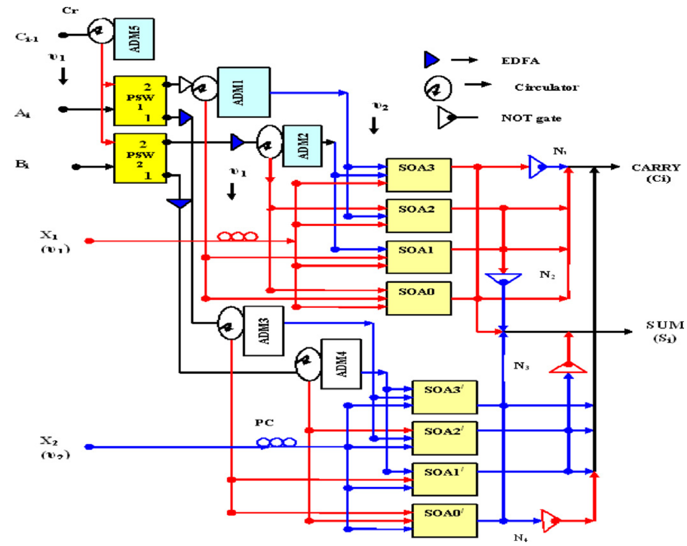


Fig. 2. Frequency encoded all-optical full adder.

'B_i' are used as the probe beam of the polarization switches PSW1 and PSW2, respectively, and in the next stage these are used as the pump beams of the SOA based frequency converters after splitting each beam of specific frequency into two equal parts. Two parts of the beam 'A_i' of frequency υ_1 are used as the pump beams of 'SOA0' 'SOA1'. Similarly, two parts of the beam 'B_i' of frequency 'V_1' are used as the pump beam of SOA0 and SOA2.

When the pump beams 'A_i' and 'B_i' are of frequency 'V_2', then the input beam 'A_i' is injected as the pump beam of 'SOA2' and 'SOA3' whereas two parts of the beam 'B_i' of frequency V_2, are used as the pump beams of SOA1 and SOA3. 'X_1' and 'X_2' are the linearly polarized probe beams of frequency 'V_1' and 'V_2', respectively. Each of it is split up into four equal parts. Four parts of 'X_1' are used as the probe beams of SOA0, SOA1, SOA2 and SOA3, respectively, whereas the four parts of the beam 'X_2' are used as the probe beams of SOA0$^/$, SOA1$^/$, SOA2$^/$ and SOA3$^/$, respectively. Output of each 'SOA' is again split up into two equal parts. One part of output beam of both the SOA1 and SOA3 are converted into the beam of frequency υ_2, and one part of the output beam of SOA0$^/$ and SOA1$^/$ and SOA2$^/$ are converted into the beam of frequency υ_1 using inversion gates. One part of the output beams of SOA0, SOA1, SOA2 of frequency υ_1 and the output beams of SOA1$^/$, SOA2$^/$ and SOA3$^/$ of frequency υ_2 are coupled with the output of N_1 and N_4 to get the Carry result of the full adder. Remaining outputs of SOA0, SOA3 and SOA0$^/$, SOA3$^/$ of respective frequencies υ_1 and υ_2 combined together with the output of N_2 and N_3 to get the Sum result of the full adder. Initially the SOP of each input probe beam is oriented in such a way that output from each 'AN' is zero in the absence of pump beams. Now the operation of full adder is explained with the help of Fig. 2.

3.1. Case-1: Input optical BCD data are the beams of frequency $C_{i-1} = \upsilon_1$, $A_i = \upsilon_1$, $B_i = \upsilon_1$

Now the carry beam 'C_{i-1}' of frequency υ_1 reflects back by ADM5, drops to the circulator-port (Cr) and then serves as the pump beam of polarization switches PSW1 and PSW2, respectively, which in turn switches the amplified probe beams 'A_i' and 'B_i' to the their respective port-2. Then the beams 'A_i' and 'B_i' of frequency 'V_1' reflect back from 'ADM1' and 'ADM2', respectively. Now two split up parts of the beam 'A_i' are used as the pump beams of {SOA0, SOA1} while two split up parts of the beam 'A_i' are used as the pump beams of {SOA0, SOA2}. Now 'SOA0' gets two pump beams and as a consequence both the pump beams of 'SOA0' significantly