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Analytical approach of developing the expression of output of all-optical frequency encoded different logical units and a way-out to implement the logic gates

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ABSTRACT

To implement different all optical logic operations, encoding/decoding of optical signal is a very important issue. Since now there are so many types of optical signal encoding and decoding techniques have been adopted, such as intensity encoding, polarization encoding, phase encoding, symbolic substitution technique etc. All these existing techniques have their own limitations. In this context one may mention the frequency encoding/decoding technique. The basic inherent advantage of frequency encoding technique over all other existing techniques is that as the frequency of a signal is the fundamental character of it, it always preserves its identity throughout the communication of the signal, irrespective of reflection, refraction attenuation etc. Again, different optical signal has different distinct frequency which may be encoded as a distinct state of a logic system to represent the information. Adopting this technique it is possible to implement binary logic system as well as higher order logic system such as tristate logic, quaternary logic system etc. The major advantages of multivalued logic system over Boolean logic system are that in multivalued logic system the states of information is very more and as result information storage capacity is high. Again in multivalued logic system carry free and borrow free operation can be implemented which is less time consuming and therefore speed of operation is very fast. We have already developed methods of implementation of different all-optical frequency encoded logic as well as different optical processor. In this communication we propose an analytical approach to develop the expression of the outputs of frequency encoded different binary logic expression in terms of input frequencies from the stand point of basic laws of reflection, transmission and frequency conversion property of optical devices and of course mention the way-out to implement these logic operations.

1. Introduction

To implement different processors in optical domain, encoding and decoding of optical data is prime issues. Till now several encoding/decoding techniques have been reported for representing the optical information. In this connection intensity encoding, polarization encoding, phase encoding etc. may be mentioned [1–6]. But these coding processes have some inherent problems. In intensity encoding [1–3], presence of optical signal have been encoded as '1' state and absence of optical signal as '0' state. But for long distance communication intensity of optical signal may fall and dropdown below the reference level and for which the '1' state may be treated as '0'of the signal which can lead to the bit error problem. In polarization encoding [3,4], one specific state of polarization of the optical beams is encoded as '0' state and another specific orthogonal state of polarization is treated '1' state. Again, the states of polarization may change for several causes which can also lead to the bit error in information processing. In phase encoding [5,6], one specific phase of the optical beams is encoded as '0' state and another specific phase is treated as 1 state. But it is very difficult to maintain the constant phase relationship throughout the optical signal processing specially beyond the coherent length.

In contrast to those proposals we can mention the frequency encoded technique to implement optical processor and different logic operation [7,8]. It is known that if '1' and '0' logic states are encoded by two different frequencies then one may ensure about the state of a signal during transmission. That is if '0' state is encoded by the frequency 'ν_1' and the '1' state by the other frequency 'ν_2' then 'ν_1' and 'ν_2' will normally remain unaltered through out the transmission of data, whether it suffers from reflection, attenuation, refraction etc. Adopting this frequency encoding/decoding

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technique, we propose an analytical approach to find out the logical expression of the outputs of frequency encoded different logic units in binary states. Here we also present the simulation result of the logical expressions using 'Math CAD-7' software and finally mention the way-out to implement the desired logic operations. We have presented our paper in some sections and sub-sections. In Section 2, we have mentioned the basic building blocks required to perform frequency encoded logic operation, in Section 3 and Sub-sections 3.1 and 3.2 we have developed the logical expression for the outputs of different logic units. In Section 4, we have given simulation results for AND and X-OR logic gates based on the developed logical expression in Section 3. In Section 5, we have presented some functions of SOA devices by means of which the logic operations may be implemented and finally in Section 6, i.e. in discussion part we have mentioned a possible way-out to implement the frequency encoded all optical logic operations exploiting different optical properties of SOA.

2. Basic building blocks for frequency encoded logic operations

Basic building blocks required to implement the frequency encoded optical logic operations are

1. Frequency Mixing Unit (FMU).
2. Frequency Router Unit (FRU).
3. Frequency Converter (FCU).
4. Combiner Unit (CU).
5. Output (O/P).

and this is as shown in Fig. 1.

The function of the Frequency Mixing Unit is to combine the input optical signals (A and B) of respective frequency 'ν_A' and 'ν_B' to generate a third optical beam of frequency '$\nu_C = k_1\nu_A + k_2\nu_B$' where k_1 and k_2 are constant. Depending on the combination of input signal frequencies, frequency of the combined signal will have different values. The function of the Frequency Router is to route different specific frequency to different specific channel by selective reflection and transmission of beam in FR Unit.

Function of the Frequency Converter is to convert a specific beam of frequency 'ν_C' to another appropriate beam of encoded frequency 'ν_1/ν_2' as desired. The conversion of one frequency to another appropriate frequency may be done using proper optical switch and frequency converter.

Different frequency converters are used in different cannels of frequency routers. Optical signals obtaining from all FC Units are combined together in Combiner Unit and finally get the optical signal of desired frequency ν_1/ν_2 (Y) at the final output end.

3. Analytical approach to find the expression of the output of different logic units

Now on the basic of the function of different optical units, we would like to develop the analytical logic expressions of the output of frequency encoded NOT, AND, OR, NAND, NOR and X-OR logic gates which are as indicated in Sub-sections 3.1 and 3.2.

3.1. Analytical approach to find the logic expression of NOT gate

The truth table of frequency encoded NOT logic gate is as shown in Table 1a. Since NOT logic gate is one terminal (A) input gate, therefore, only one beam of specific frequency (ν_1/ν_2) is to be applied at a time and this is to be converted to another appropriate frequency (ν_2/ν_1) to obtain the inversion operation. Here no Frequency Mixing Unit is required. The block diagram of inversion (NOT) logic unit is as shown in Fig. 2 where 'R_1' and 'R_2' are two Frequency Router Units, the reflection coefficient of which are frequency sensitive. 'C1' and 'C2' are two Frequency Converter Units which have different frequency translation factors (T). Outputs of 'C1' and 'C2' are combined together to get the final output (Y).

Let the input beam 'A' is of frequency 'ν_A' and the reflection coefficient of 'R_1' for the frequency 'ν_A' is $r_1 = \frac{(\nu_A-\nu_2)}{(\nu_1-\nu_2)}$ and that of 'R_2' is $r_2 = \frac{(\nu_A-\nu_1)}{(\nu_2-\nu_1)}$.

The frequency translation factor of 'C1' unit is $T_1 = \frac{\nu_2}{\nu_1}$ and that of 'C2' unit is $T_2 = \frac{\nu_1}{\nu_2}$ which are fixed. Now if the input signal be a beam of frequency 'ν_1', i.e. '$\nu_A = \nu_1$' then $r_1 = 1$ and $r_2 = 0$; therefore, the beam of frequency 'ν_1' will be fully reflected back by 'R_1' unit and reach the 'C1' unit from where it will be translated to a beam of frequency $Y(\nu_1) = \nu_1 \cdot T_1 = \nu_2$. On the other hand, if the input signal be a beam of frequency 'ν_2', i.e. '$\nu_A = \nu_2$' then $r_1 = 0$ and $r_2 = 1$; therefore, the beam of frequency 'ν_2' will be transmitted through 'R_1' and fully reflected back by 'R_2' unit and reach the 'C2' unit from where it will be translated to a beam of frequency $Y(\nu_2) = \nu_2 \cdot T_2 = \nu_1$. Thus we can write the logical expression of NOT output as

$$Y(\nu_A) = r_1\nu_1 \cdot T_1 + r_2\nu_2 \cdot T_2 = r_1 \cdot \nu_2 + r_2 \cdot \nu_1 \quad (1)$$

This scheme may be extended to execute tristate inversion logic operation by encoding three frequencies ν_1, ν_2 and ν_0 as 1, $\bar{1}$ and 0 states respectively and selecting reflection coefficient of R_1, R_2 and R_3 units for input beam 'A' of frequency 'ν_A' as $r_1 = \frac{(\nu_A-\nu_2)(\nu_A-\nu_0)}{(\nu_1-\nu_2)(\nu_1-\nu_0)}$, $r_2 = \frac{(\nu_A-\nu_1)(\nu_A-\nu_0)}{(\nu_2-\nu_1)(\nu_2-\nu_0)}$ and $r_3 = \frac{(\nu_A-\nu_1)(\nu_A-\nu_2)}{(\nu_0-\nu_2)(\nu_0-\nu_2)}$ respectively and using three frequency converter units C1, C2 and C3 having respective frequency translation factors $T_1 = \frac{\nu_2}{\nu_1}$, $T_2 = \frac{\nu_1}{\nu_2}$ and $T_3 = 1$. However in this communication we only present the analytical approach to find logical expressions of frequency encoded binary logic units.

Table 1a
Truth table of NOT logic gate.

A	$Y = \bar{A}$
ν_1 (0)	ν_2 (1)
ν_2 (1)	ν_1 (0)

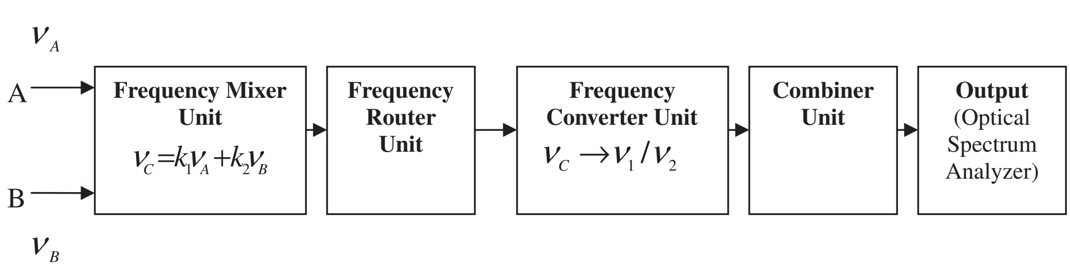

Fig. 1. Block diagram of a basic frequency encoded optical logic Unit.