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Original research article

An optical implementation method for symmetric MSD number

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ABSTRACT

Symmetric modified signed-digit (MSD) number is much advantageous over other numbers. It can implement optical addition operation in one step without carry delay which will much affect the efficiency of numerical operation in computer system. However, study on how to obtain symmetric MSD (SMSD) number has been little concerned. Based on the mapping relations between common MSD number and SMSD number, conversion rules are presented. Following the rules, the optical paths of the converters to implement the conversion are designed. Combining the converters, the optical path of the general converter that can be used to implement the conversion from common MSD number to SMSD number is presented. Simulation results show that the method and the optical path of the converter are correct. They can be used to effectively convert MSD number into the corresponding SMSD number.

1. Introduction

Compared with traditional electronic counterpart, optical computer has many advantages brought by the physical properties of light. These advantages include high speed [1], high parallelism [2,3], multi-values and low-energy consumption and so on. To take use of these advantages, more and more researchers have set their focuses on optical computers. However, most of them follow the ideas that the electronic counterpart has experienced. And many of them are limited to theories, simulations of optical computing or optical components. For example, Zaghloul presented a complete all-optical-processing polarizer-based binary-logic system with which logic gate and processor can be implemented [4–6]. Ghosh et al. put forward trinary flip-flops and trinary arithmetic and logic unit (TALU) using savart plate and spatial light modulator in multivalued logic [7]. Chattopadhyay et al. found Galois Field (GF) algebraic expressions for multivalued logic, developed GF (4) adder multi-valued logic circuits in all optical domain in 2009 [8]. And they used non-linear material-based interferometirc switches to design a converter which can transform 3-bit binary number to equivalent single-digit QSD (quaternary-signed digit) [9]. Esmaeili et al. presented a systematic method to design arithmetic unit using efficient Photonic crystal (PhC) NOT gate [10].

Different from the traditional research mentioned above, Jin et al. proposed the concept of ternary optical computer (TOC) which applies two Orthogonal polarizations of light and dark state to express information [11]. Based on the theory of TOC, a thousand-data-bits experimental system was successfully constructed. And many interesting research results have

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beeen obtained [12–17]. According to the progress of the study on TOC, it has been a computation experimental system which is efficient in logical operation. However it is very inefficient in numerical calculation because of lacking of effectively adder. To promote it to the application field in numerical calculation, a lot of research attempts have been done and much progress has been obtained [12,16–18]. One of the most impressive studies is a SMSD number based adder solution which was proposed by Song et al. [18]. In the study, they found the advantages of a new number system, SMSD number system is very suitable for the three-valued binary computer system TOC. Using SMSD number, they designed an optical adder which can implement addition operation in one-step without carry delay. This is an interesting result. It might highly improve the efficiency of addition and potentially be used in TOC. Though SMSD number consists of three symbols that MSD number system includes or SMSD number can be obtained from common MSD number. Their study fails to discuss how to obtain SMSD number from common MSD number. It could not use the advantages if SMSD number cannot be efficiently obtained.

To solve this issue, a SMSD number conversion method is put forward. Meanwhile, the optical path of the converter together with its converting modules for SMSD number are designed. Analysis and simulation results show that the SMSD number conversion method is correct and the optical path of the converter is effective.

2. Related works

2.1. Modified signed-digit number

In 1961, Avizienis proposed MSD number system for the first time [19]. Later, Draker et al. introduced MSD number system into optical computer [20]. In normal binary system, there are only two symbols, 0 and 1. Different from that of binary system MSD number system is a redundant number system. There are three symbols in the system. And the symbol set of MSD is $\{\bar{1}, 0, 1\}$, in which $\bar{1}$ denotes number -1. Obviously, due to the redundant characteristic, a number may have several representations in MSD system. To any decimal number X, it can be expressed in MSD system as follows:

$$X = \sum x_i \cdot 2^i \tag{1}$$

where x_i belongs to the symbol set $\{\bar{1}, 0, 1\}$, and $\bar{1}$ denotes number -1. 2^i shows that MSD is still a binary system, a three-valued binary system. This means MSD number system is a redundant number system. In this system, a number can be expressed in different forms. For example, number 6 and -6 can be represented as the following different forms.

$$(6)_{10} = (110)_{MSD} = (1\bar{1}10)_{MSD} = (10\bar{1}0)_{MSD}$$

$$(-6)_{10} = (\bar{1}\bar{1}1)_{MSD} = (\bar{1}1\bar{1}0)_{MSD} = (\bar{1}010)_{MSD}.$$

From the above example, it is easy to find that the MSD number system has the following characteristics:

- The opposite of a MSD number can be obtained with NOT operation on each bit of number.
- If the highest bit is negative, the MSD number is negative, and vice versa.
- MSD is a redundant number system, a number in this number system can be expressed in different forms.

Considering the real application requirement of the TOC, we use MSD number system as the foundation for discussion.

2.2. SMSD number

In the addition operation, one of the biggest obstacles affecting the parallelism is the carry delay caused by the uncertainty of carry propagation. In exceptional circumstance, carry propagation can pass from the lowest bit to the highest one. The reason causing carry propagation is that there are consecutive 1 or $\bar{1}$ in both operands. For example, if two operands are 11110 and 10111 or some others like these, carry propagation will occur in the addition. As MSD number system is a redundant system, any number can be encoded with different forms without changing its value. Using this feature, a number with consecutive 1 or $\bar{1}$ can be eliminated via recodification. The recoded MSD number without consecutive 1 and $\bar{1}$ is called SMSD number. If both augend and addend are SMSD numbers, carry propagation does not happen in the process of addition. Cherri et al. put forward SMSD number and presented the recoding rules from the MSD numbers as Table 1 shows [21]. It is easy to notice from Table 1 that four bits of MSD number can produce one bit SMSD number. Assume $A_iA_{i-1}A_{i-2}A_{i-3}$ represent four sequential bits of a MSD number, Z_i is the one-bit SMSD number after the recodification. Where d represents any values of the symbol set of $\{\bar{1}, 0, 1\}$ in the MSD number system.

2.3. One-step MSD addition

As a special type of MSD number, SMSD number has its advantage in the addition operation. Application the advantages of SMSD number, Song et al. put forward the architecture of a no-carry-propagation one-step optical adder [18]. This is an impressive work. As light may carry data with a lot of bits which will result optical addition being very time-consuming with the traditional addition methods. If addition operation can be implemented in one step the operation efficiency will