Optics Communications 356 (2015) 123–135

Contents lists available at ScienceDirect

Optics Communications

journal homepage: www.elsevier.com/locate/optcom

Design of optical reconfigurable balanced ternary arithmetic logic unit using MEMS based design

Tanay Chattopadhyay

Mechanical Operation (Stage-II), Kolaghat Thermal Power Station, WBPDCL, Mecheda, Purba Medinipur 721137, West Bengal, India

ARTICLE INFO

Article history:
Received 22 April 2015
Received in revised form
14 June 2015
Accepted 15 July 2015

Keywords:
Multi-valued logic
Balanced ternary logic
Optical logic
Coding
MEMS

ABSTRACT

A new and novel design of microelectromechanical system (MEMS) based optical reconfigurable balanced ternary arithmetic logic unit (radix=3) has been proposed and described in this paper. We can get any logical and arithmetical function from the proposed design without changing the circuit design. Here three logical states have been considered as three wavelengths of light. Binary coded balance ternary digit is used to control micro-mirror. Numerical simulation has been done to get the performance of the circuit.

1. Introduction

RESENT – computer is based on binary (radix=2) number system, but coming generation demand not surly be fulfilled by it only. Hence many researchers have been done to find out the possible alternatives. In radix-2 number system some useful new circuits have been proposed so far such as, optical logic based on nonlinearity effect in Si-waveguides [1,2], directed logic [3–8], nanoplasmonic logic circuits [9,10] etc.

In any numerical system, a large number of digits are necessary to express a given quantity with smaller radix-*R*. A number of *N*–range expressed as $N=R^d$, where d is the necessary number of digits. In binary logic, carry generation during addition is the major problem which reduces the processing speed. Multi-valued logic (radix > 2) (MVL) may be used to ease this problem. The number of logic gates used in *R*-radix system is $R^{(R^n)}$ where n is the number of variables. So higher the radix, the higher the number of logic gates will be. Hence high data storage, less circuit area requirement and high processing speed can be possible in MVL than binary logic system [11,12]. The development of switching circuit theory on MVL system was well proposed during mid and late 1960's. Allen and Givone [13], Haring [14] introduced a minimization algebraic technique for MVL systems. The algebra consists of *n*-logical values and two functions, MAX and MIN [13,15]. Minimization is an important topic in MVL system and researches are still studying to find out new algorithms. Implementation of MVL circuit is a great challenge because of its different distinct logical values. Like binary system it is not confined into two logical values (high and low). Hence it is not so easy to implement in practical. At the early years of 1970's electronic circuit based on threshold ternary (radix=3) logic circuit was first proposed [16,17]. Latter MVL circuits with various devices such as I^2L, ECL, CCD, CMOS, NMOS, MESFET etc have been designed [18–22]. The basic electronic circuits on MVL are based on two types, viz. current mode and voltage mode. At low voltage level MVL circuit fails to give right output logic level. After middle of 1980's optical implementation of MVL system started. As we know photon is the ultimate unit of information with zero mass and high speed, the necessity of computing with light may provides a way out of limitations of computational speed and complexity inherence in electronics computing [23]. At first binary coded ternary logic system was proposed, which was basically binary operation. Here inputs and outputs were binary signals [24]. Then many proposals have been done by means of intensity coded system [25], polarization encoded shadow casting scheme [26–28], fringe shift techniques [29], parallel optical negative binary sign digit system [30–33], mirror symmetrical arithmetic [34], Optoelectronic system [35,36], optical modified signed digit number (MSD) [37–46] frequency encoded system [47], optical modified ternary number (MTN) system [48,49], polarization encoded optical devices [50] respectively. In MVL implementation, intensity coded logical states is a bad choice because intensity loss happens due to absorption and attenuation at different portions of the circuit. In intensity based refractive index variation technology, small fluctuation of

E-mail addresses: tanay2222@rediffmail.com, tanayktpp@gmail.com

http://dx.doi.org/10.1016/j.optcom.2015.07.035
0030-4018/

intensity of the input beams may collapse the total set up. On the other hand pixel arrangement system and shadow casting system will suffer diffraction problem. Polarization encoding technique is a good choice but we have to use polarization maintaining fiber and polarization controller at different portion. Hence circuit cost will high. In phase encoding, different specific phases of the optical beams are encoded as different logical states. But it is very difficult to maintain the constant phase relationship throughout the optical signal processing, specially beyond the coherent length [51]. Similarly the other coding norms may extend some other limitations in wide range data processing. Frequency encoded system is a good choice where different frequencies are considered as different logical states [47,51]. But semiconductor optical amplifier based frequency encoded system [47–51] will cost energy and noise in signal [52]. In this paper different wavelengths of light as different logical states have been chosen. Also circuits using passive optical components have also been proposed. The advantage of this scheme is that all wave lengths are discrete and can be separated easily. Intensity loss at different portion cannot change the logical states. Recently wavelength division multiplexing (WDM) is widely used for routing. Hence wavelength encoding is a good choice and can be used in communication also. So multi logic level using wavelength encoded method may change the computing system with higher radix without much more variation in the existing circuit. The conventional MVL circuit is implemented by binary logic circuits. In that design the binary circuit is placed between a decoder and encoder, shown in Fig. 1(a). Decoder (D) converts MVL signals to its equivalent binary data, which are fed to the binary circuit and finally an encoder (E) circuit converts the binary results into its equivalent MVL signals [53]. But in the proposed design is not based on the conventional type. This circuit has two signal lines, one is data signal and other is control signal. Both of them are of radix-n signals. Control signal is converted to binary equivalent data by a decoder (D), which is used to route the MV data signals to the output. Hence the circuit itself behaves like a traffic signal controlling system. The block diagram of this proposed scheme is shown in Fig. 1(b).

In optical computing, proper design and simplicity will make a circuit smarter and flexible. Also two important aspects of optical computing are the possibility to integrate large number of devices in a small area and the possibility of cascading a large number of components. Nonlinear elements inside the circuit create noise and heat. In most of all cases the nonlinear properties of light beam have been exploited that requires high intense laser beam as nonlinear refractive index is very low [52]. On the other hand linear optical components are straight forward and very simple to operate.

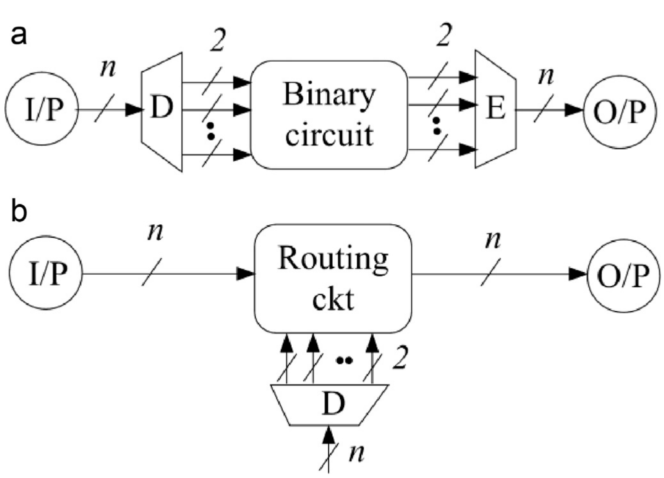

Fig. 1. The concept of multi-valued logic circuit design (a) conventional one, (b) proposed design. I/P: input port, O/P: output port, D: decoder, E: encoder.

In MVL system balanced ternary logic system (radix=3) is very attractive due to its three positive and negative logic values (−1, 0 and 1), which are symmetrical about the logic '0' value. In this literature balanced ternary optical logic unit has been proposed using microelectromechanical system (MEMS) based design. The MEMS based optical switching mechanism is an existing technology in digital communication and WDM systems. By controlling these switches maintained by some rules, we have the provision of release light-paths towards the destination [54]. Also MEMS is very light and suitable for operation in harsh environment of engines and inside nuclear reactors or in space applications [55–58]. It has been proved that MEMS with Si-CMOS enables a new low cost high performance nano-electromechanical device recently [59]. Here I have proposed a novel design of multi valued circuit using MEMS, which is the first proposal using MEMS according to my knowledge. The design is also reconfigurable in nature because we can get all logical expressions and arithmetical functions without changing the circuit design. This is the novelty of this paper. More over the design is wavelength encoded i.e. three different wavelengths of lights are considered as three different logical states.

2. Design concept

A ternary number (radix=3) is an order string of symbol a_i. If a_i are from the set of [−1, 0, 1] it is called balanced ternary (BT) and if its value from the set of [0, 1, 2] it is called ordinary ternary (OT). Any integer (or whole) ternary number can be expressed as $\sum_i a_i \cdot 3^i$. The balanced trit (ternary digit) can be coded into a bit pair as [60],

$$\begin{aligned} -1 &= [0, 1] = \bar{1} \\ 0 &= [0, 0] \\ +1 &= [1, 0] \end{aligned} \tag{1}$$

where the first bit carries the positive value and the second bit carries the negative one [60]. For implementing BT logic unit MEMS based architecture is chosen because firstly mirrors are passive optical components. Secondly it is very commercially available in market and easily fabricated. Thirdly its operation is very simple. In MEMS based design micro mirrors are arranged in an $N \times M$ matrix form. Here mirrors are double reflecting i.e. light can be reflected from both surface of the mirror. Every mirror has two states 'laying' and 'standing'. When they are in 'laying' position, then mirror is not in the optical path. So no refection happens and the light beam passes uninterrupted way. When they are in 'standing' position, then the mirror comes in between the optical path and the light beam is reflected by them to a definite direction. The reflex mirrors are fed with electrical signals through control pad (CP), by which it can be operated from 'laying' to 'standing' position as shown in Fig. 2. Here 'A_1' mirror is a reflex mirror. Here we consider that 'applying electrical signal' to reflex mirror as input '1'. We can write the reflex mirror 'A_1' matrix as,

$$M(A_1) = \begin{pmatrix} A_1 & 1 - A_1 \\ 1 - A_1 & A_1 \end{pmatrix} \tag{2}$$

Here '$M(.)$' is transition matrix, using which can get the output vector ($\mathbf{O}$) from input vector ($\mathbf{I}$) as, $\mathbf{O} = M \cdot \mathbf{I}$. In Fig. 2 there are two optical inputs X and Y. When we do not apply electric filled to the mirror then $A_1 = 0$. So, $M(0) = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}$ i.e. mirror is in 'laying' position and input matrix $\begin{pmatrix} X \\ Y \end{pmatrix}$ interchange at the output as, $\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}\begin{pmatrix} X \\ Y \end{pmatrix} = \begin{pmatrix} Y \\ X \end{pmatrix}$. Here light beam from X and Y can not reflect by