PROCEEDINGS OF SPIE

SPIEDigitalLibrary.org/conference-proceedings-of-spie

Design of Excess 3 to BCD code converter using electro-optic effect of Mach-Zehnder Interferometers for efficient data transmission

Santosh Kumar, Chanderkanta , Angela Amphawan

Santosh Kumar, Chanderkanta , Angela Amphawan, "Design of Excess 3 to BCD code converter using electro-optic effect of Mach-Zehnder Interferometers for efficient data transmission," Proc. SPIE 9889, Optical Modelling and Design IV, 98890E (27 April 2016); doi: 10.1117/12.2225720

Event: SPIE Photonics Europe, 2016, Brussels, Belgium

Design of Excess 3 to BCD code converter using electro-optic effect of Mach-Zehnder Interferometers for efficient data transmission

Santosh Kumar[a,], Chanderkanta[a], Angela Amphawan[b]
[a]Photonics Lab, Department of Electronics & Comm. Engineering, DIT University, Dehradun-248009, India
[b]Fulbright Research Fellow, Massachusetts Institute of Technology, 02139 Cambridge, Massachusetts, USA
[b]InterNetWorks Research Laboratory, School of Computing, Universiti Utara Malaysia, 06010 Sintok, Kedah, Malaysia

ABSTRACT

Excess 3 code is one of the most important codes used for efficient data storage and transmission. It is a non-weighted code and also known as self complimenting code. In this paper, a four bit optical Excess 3 to BCD code converter is proposed using electro-optic effect inside lithium-niobate based Mach-Zehnder interferometers (MZIs). The MZI structures have powerful capability to switching an optical input signal to a desired output port. The paper constitutes a mathematical description of the proposed device and thereafter simulation using MATLAB. The study is verified using beam propagation method (BPM).

Keywords: Electro-optic effect; Mach-Zehnder interferometer; Beam Propagation Method, optical computing, Excess 3 code, BCD code.

1. INTRODUCTION

Digital arithmetic plays an imperative role in the design of digital processors, signal processing, and communications to achieve fast computation, less processing time, high system efficiency and data speed [1]. However, as the hunger of high speed data requirement is increasing day by day hence ultra fast computation is also becomes viable. To achieve future requirements, researchers have shown great interest to implement sequential and combinational logic circuits in all optics [2-15] such as full adder [2], multiplier [3], shift registers [4], synchronous up counter [5], encoder [6], comparators [7], and code converters[8]. There are various methods to implement all optical circuits i.e. Micro-electromechanical systems (MEMS) [9], terahertz optical asymmetric de-multiplexer (TOAD) [10], non-linear material (NLM) [11], semiconductor optical amplifier based Mach-zehnder interferometers (SOA-MZI) [12], cross-gain modulation (XGM) effect [13], cross-phase modulation (XPM) effect of SOA based MZI [14], and LiNbO3 based MZI [15]. Here an optical Excess 3 code to BCD converter using electro-optic effect [15] in LiNbO3 based MZI is proposed. $LiNbO_3$ seems to be a promising solution, because of its characteristic features of compact size, thermal stability [16], integration potential [16], re-configurability [17], low latency [17] and low power consumption [17]. Excess 3 codes is self complimentary code and play a significant role in arithmetic operations. It is also used in efficient data storage and transmission [18].

In this paper, an Excess 3 to BCD code converter is designed using electro-optic effect of lithium niobate based MZIs. Section 2 explains the schematic diagram and working of Excess 3 to BCD code converter. Section 3 presents mathematical description of device along with MATLAB simulation results. Section 4 explains the BPM layout with its BPM simulation results. Finally Section 5 comprises the conclusion of work.

2. DESIGN OF EXCESS 3 TO BCD CODE CONVERTER

Conversion circuits are used between two systems if each uses different codes for the same information. A combinational circuit performs this transformation by means of logic gate. K – Map and digital circuit to make excess 3 to BCD code conversion is given in Fig 1. Schematic diagram of proposed device using MZI is shown in Fig 2. Continuous wave (CW) optical signal is launched through the first port of MZI1, MZI2, MZI4, MZI6, MZI8, MZI11, and MZI13. As Excess 3 code is 4 bit code, second output port of MZI1 is equivalent to the B_0bit ($\overline{E}_0$). Second bit B_1 is equivalent to $(E_1 \oplus E_0)$ and available at the second output port of MZI3. Third bit B_2 is equivalent to $(\overline{E}_2\,\overline{E}_1 + \overline{E}_2\,\overline{E}_0 + E_2E_1E_0)$ and available at the combination of first output port of MZI5, MZI7, and MZI10. Fourth bit B_3 is equivalent to $(E_3\,E_2 + E_3E_1E_0)$ and is available at the combination of first output port of MZI12 and MZI15.

Optical Modelling and Design IV, edited by Frank Wyrowski, John T. Sheridan, Youri Meuret, Proc. of SPIE Vol. 9889, 98890E · © 2016 SPIE · CCC code: 0277-786X/16/$18 · doi: 10.1117/12.2225720

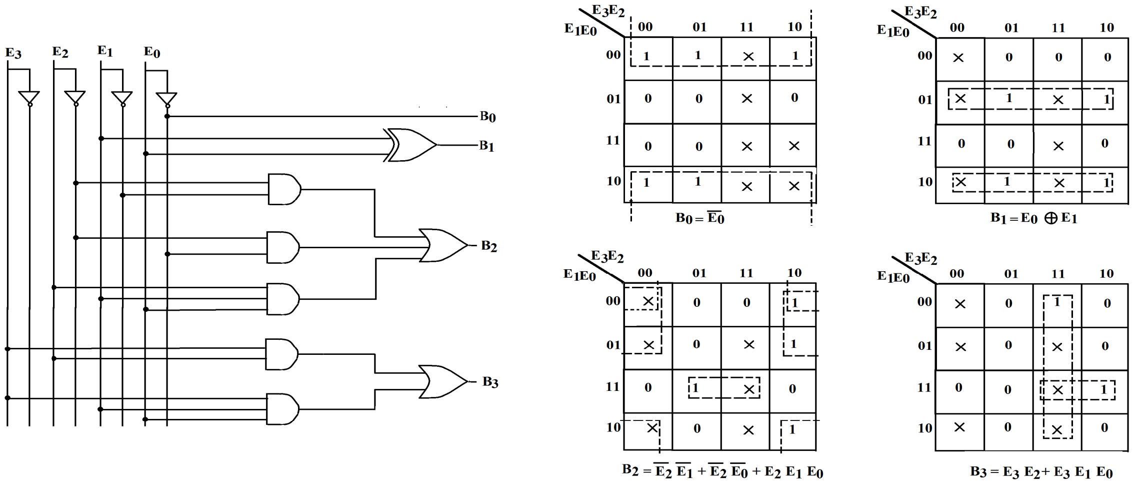

Figure 1: Digital circuit and K-map of Excess 3 to BCD code converter.

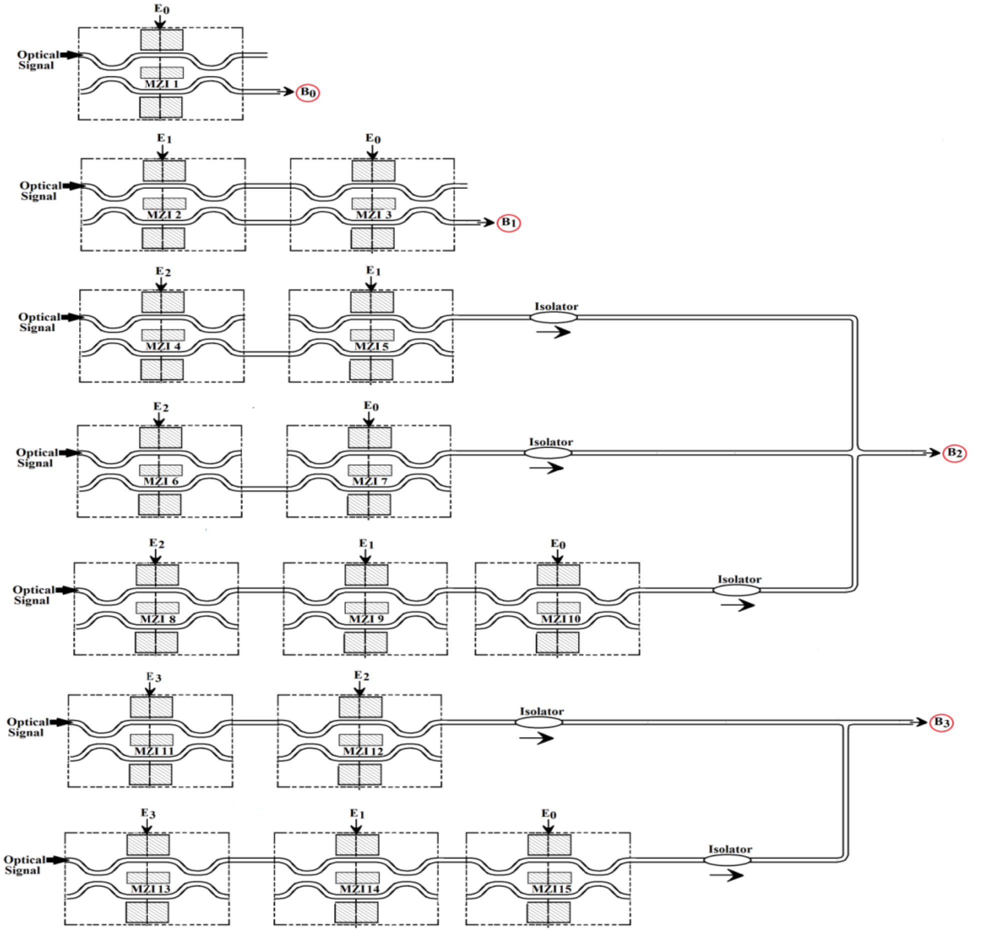

Figure 2: Schematic diagram of excess 3 to BCD code converter using MZIs

3. MATHEMATICAL FORMULATION OF NORMALIZED POWER AT VARIOUS OUTPUT PORTS

P_0, P_1, P_2, P_3 is output power calculated for B_0, B_1, B_2, B_3 respectively. Here $\Delta\emptyset$ is the phase difference occurs in MZI after applying the appropriate voltage V_π.

$$\Delta\emptyset = \frac{2\pi}{\lambda}\,(\Delta n)\,L \tag{1}$$

Where λ = wavelength of light source, L = substantial length of electrode, Δn is change in refractive index occurs due to electro-optic effect. Voltage V_π and Δn can be calculated as,

$$\Delta n = \left(\frac{n^3}{2}\right) rE \tag{2}$$

Here n= refractive index, r = Electro-optic (EO) coefficient of material, and E is electric field.

$$V_\pi = \frac{\lambda}{n^3}\,\frac{1}{r}\frac{d}{L} \tag{3}$$

Here r = EO coefficient of material, d = separation between the electrodes. After applying the appropriate voltage at MZI we can get the desired phase difference at the output. Output power can be calculated by given Eqs. (4-7):

$$P_0 = cos^2\left(\frac{\Delta\emptyset_{MZI1}}{2}\right) \tag{4}$$

$$P_1 = sin^2\left(\frac{\Delta\emptyset_{MZI2}}{2}\right)cos^2\left(\frac{\Delta\emptyset_{MZI3}}{2}\right) + cos^2\left(\frac{\Delta\emptyset_{MZI2}}{2}\right)sin^2\left(\frac{\Delta\emptyset_{MZI3}}{2}\right) \tag{5}$$

$$\begin{aligned}P_2 = {} & cos^2\left(\frac{\Delta\emptyset_{MZI4}}{2}\right)cos^2\left(\frac{\Delta\emptyset_{MZI5}}{2}\right) + cos^2\left(\frac{\Delta\emptyset_{MZI6}}{2}\right)cos^2\left(\frac{\Delta\emptyset_{MZI7}}{2}\right)\\ & + sin^2\left(\frac{\Delta\emptyset_{MZI8}}{2}\right)sin^2\left(\frac{\Delta\emptyset_{MZI9}}{2}\right)sin^2\left(\frac{\Delta\emptyset_{MZI10}}{2}\right)\end{aligned} \tag{6}$$

$$P_3 = sin^2\left(\frac{\Delta\emptyset_{MZI11}}{2}\right)sin^2\left(\frac{\Delta\emptyset_{MZI12}}{2}\right) + sin^2\left(\frac{\Delta\emptyset_{MZI13}}{2}\right)sin^2\left(\frac{\Delta\emptyset_{MZI14}}{2}\right)sin^2\left(\frac{\Delta\emptyset_{MZI15}}{2}\right) \tag{7}$$

Phase difference in MZI can be calculated as:

$$\left.\begin{aligned}
\Delta\emptyset_{MZI1} &= \emptyset_{11} - \emptyset_{12}\\
\Delta\emptyset_{MZI2} &= \emptyset_{21} - \emptyset_{22}\\
\Delta\emptyset_{MZI3} &= \emptyset_{31} - \emptyset_{32}\\
\Delta\emptyset_{MZI4} &= \emptyset_{41} - \emptyset_{42}\\
\Delta\emptyset_{MZI5} &= \emptyset_{51} - \emptyset_{52}\\
\Delta\emptyset_{MZI6} &= \emptyset_{61} - \emptyset_{62}\\
\Delta\emptyset_{MZI7} &= \emptyset_{71} - \emptyset_{72}\\
\Delta\emptyset_{MZI8} &= \emptyset_{81} - \emptyset_{82}\\
\Delta\emptyset_{MZI9} &= \emptyset_{91} - \emptyset_{92}\\
\Delta\emptyset_{MZI10} &= \emptyset_{101} - \emptyset_{102}\\
\Delta\emptyset_{MZI11} &= \emptyset_{111} - \emptyset_{112}\\
\Delta\emptyset_{MZI12} &= \emptyset_{121} - \emptyset_{122}\\
\Delta\emptyset_{MZI13} &= \emptyset_{131} - \emptyset_{132}\\
\Delta\emptyset_{MZI14} &= \emptyset_{141} - \emptyset_{142}\\
\Delta\emptyset_{MZI15} &= \emptyset_{151} - \emptyset_{152}
\end{aligned}\right\} \tag{8}$$

Figure 3(a) to 3(c) shows MATLAB simulation results of excess 3 to BCD code converter for different combinations of $E_3E_2E_1E_0$ as this converter makes 10 input condition starts from 0011 to 1111.

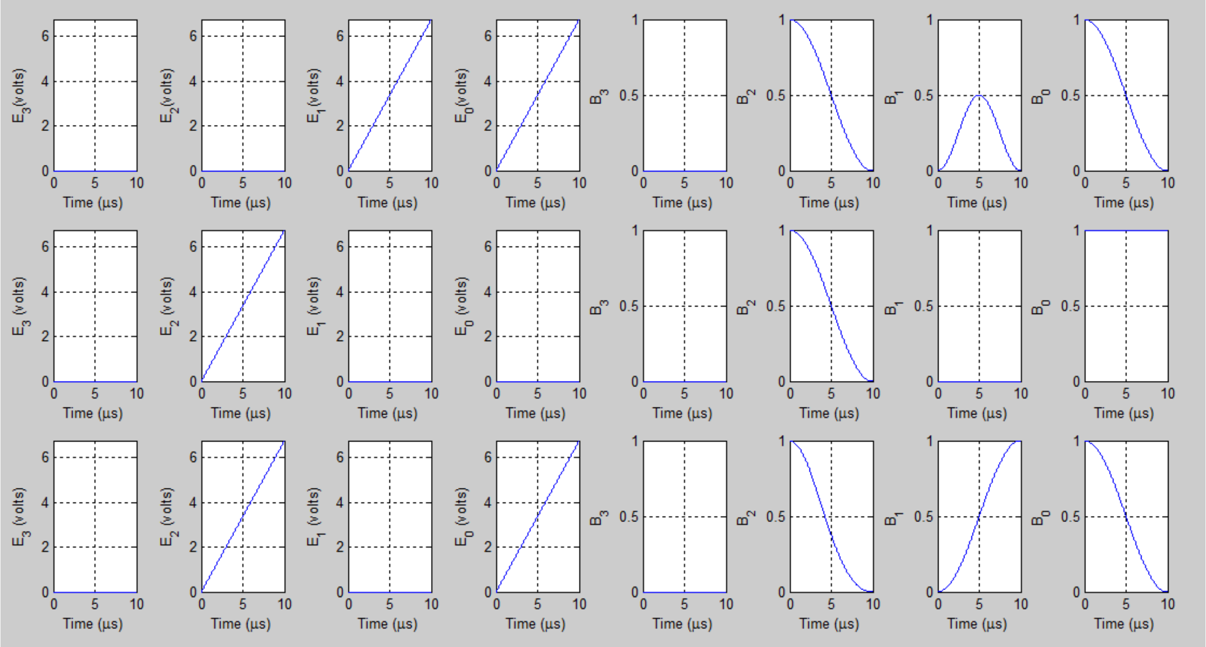

Figure 3(a): MATLAB simulation result of Excess 3 to BCD code converter where E_3 E_2 E_1 E_0 varies from 0011 to 0101.

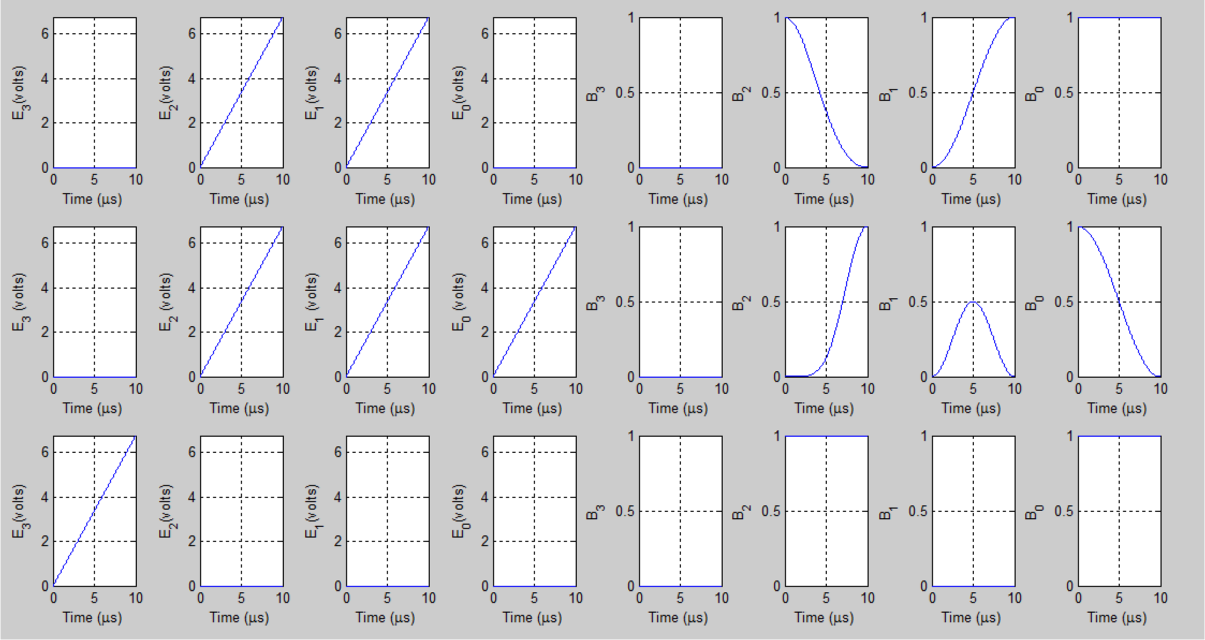

Figure 3(b): MATLAB simulation result of Excess 3 to BCD code converter where E_3 E_2 E_1 E_0 varies from 0110 to 1000

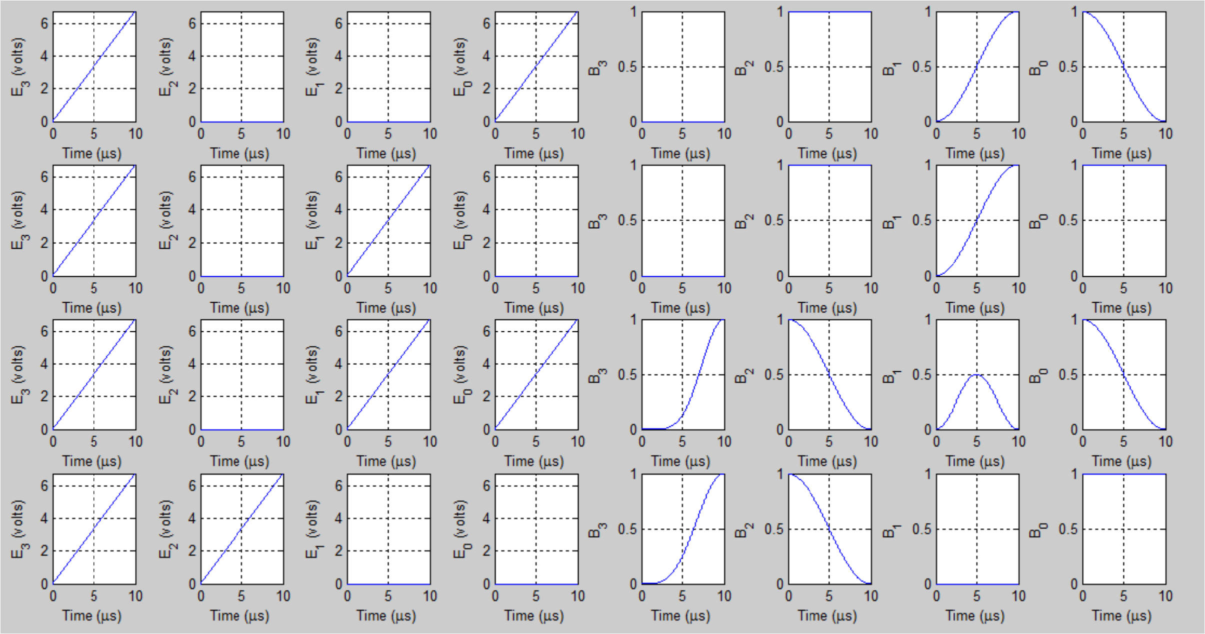

Figure 3(c): MATLAB simulation result of Excess 3 to BCD code converter where E_3 E_2 E_1 E_0 varies from 1001 to 1111

4. DESIGN OF EXCESS 3 TO BCD CODE CONVERTER USING BPM

MZI layout using BPM is shown in Fig. 4. The working principle of code converter is explained in Section 2. Simulation results using BPM is shown in Fig 5. Truth table of Excess 3 to BCD code converter is given in Table 1.

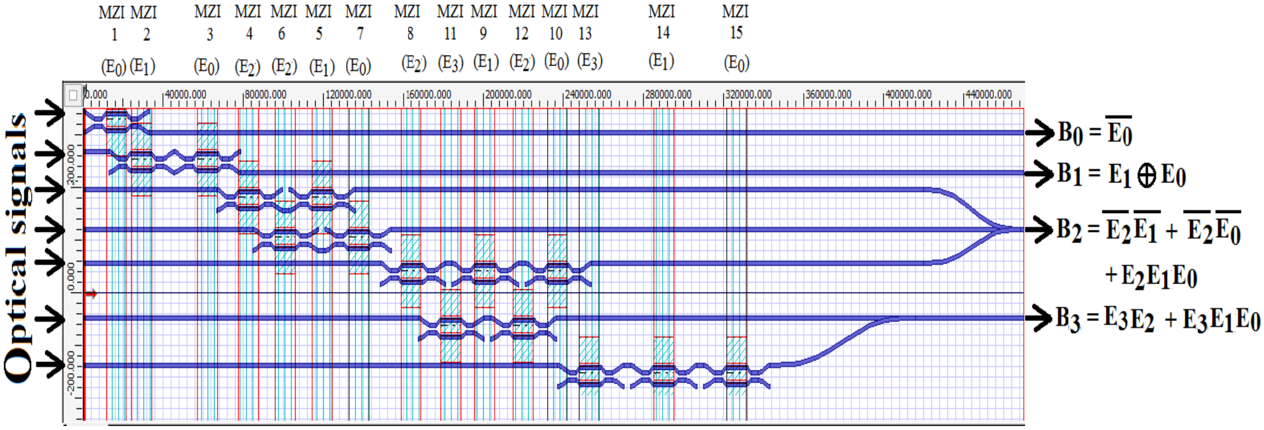

Figure 4: BPM layout of Excess 3 to BCD code converter

Case 1: $E_3 = 0, E_2 = 0, E_1 = 1, E_0 = 1$

The continuous wave (CW) optical signal is incident on the first input port of the MZI1, MZI2, MZI4, MZI6, MZI8, MZI11, and MZI13. As E_0 bit (the control signal of MZI1) is 1, no light emerges from second output port of MZI1 which means $B_0 = 0$ and is equivalent to $\bar{E}_0$. For B_1 bit, E_1 and E_0 work as the control signal of MZI2 and MZI3 respectively. For $E_1 = 1$ output signal appears at the first output port of MZI2 and goes in to the first input port of MZI3, while $E_0 = 1$ then no signal appears at second output port of MZI3. Which means $B_1 = 0$ and equivalent to $(E_1 \oplus E_0)$. B_2 bit is sum of three outputs and will be equivalent to $\overline{E}_2\overline{E}_1 + \overline{E}_2\,\overline{E}_0 + E_2E_1E_0$. For $\overline{E}_2\overline{E}_1$, output appears at the first output port of MZI5. E_2, E_1 works as control signal of MZI4 and MZI5 respectively. If $E_2, E_1 = 0,1$,then output will be 0 at first output port of MZI5. For $\overline{E}_2\overline{E}_0$, output appears at the first output port of MZI7. E_2, E_0 works as control signal of MZI6 and MZI7 respectively. As $E_2, E_0 = 0,1$,output will be 0 at first output port of MZI7. For $E_2E_1E_0$, output appears at the first output port of MZI10. E_2, E_1, E_0 works as control signal of MZI8, MZI9 and MZI10. As E_2, E_1, E_0 are 0, 1, 1 respectively, output will appear 0 at first output port of MZI10. Sum of all these three outputs represent B_2 bit and will be equivalent to 0. Bit B_3 is also combination of two outputs as $E_3E_2 + E_3E_1E_0$. For E_3E_2, output appears at the first output port of MZI12. E_3 works as control signal of MZI11 and E_2 works as control signal of MZI12. While $E_3, E_2 = 0, 0$, output will be 0 at first output port of MZI12. For $E_3E_1E_0$ output appears at the first output port of MZI15. E_3, E_1, E_0 works as control signal of MZI13, MZI14 and MZI15. In this case E_3, E_1 and E_0 is 0,1,1 respectively, output will appear 0 at first port of MZI15. Sum of these two outputs represent B_3 bit and will be equivalent to 0.

Table 1: Truth table of Excess 3 to BCD code converter

	4 Bit Excess 3 information				4 Bit BCD information			
Case	E_3	E_2	E_1	E_0	B_3	B_2	B_1	B_0
1	0	0	1	1	0	0	0	0
2	0	1	0	0	0	0	0	1
3	0	1	0	1	0	0	1	0
4	0	1	1	0	0	0	1	1
5	0	1	1	1	0	1	0	0
6	1	0	0	0	0	1	0	1
7	1	0	0	1	0	1	1	0
8	1	0	1	0	0	1	1	1
9	1	0	1	1	1	0	0	0
10	1	1	0	0	1	0	0	1

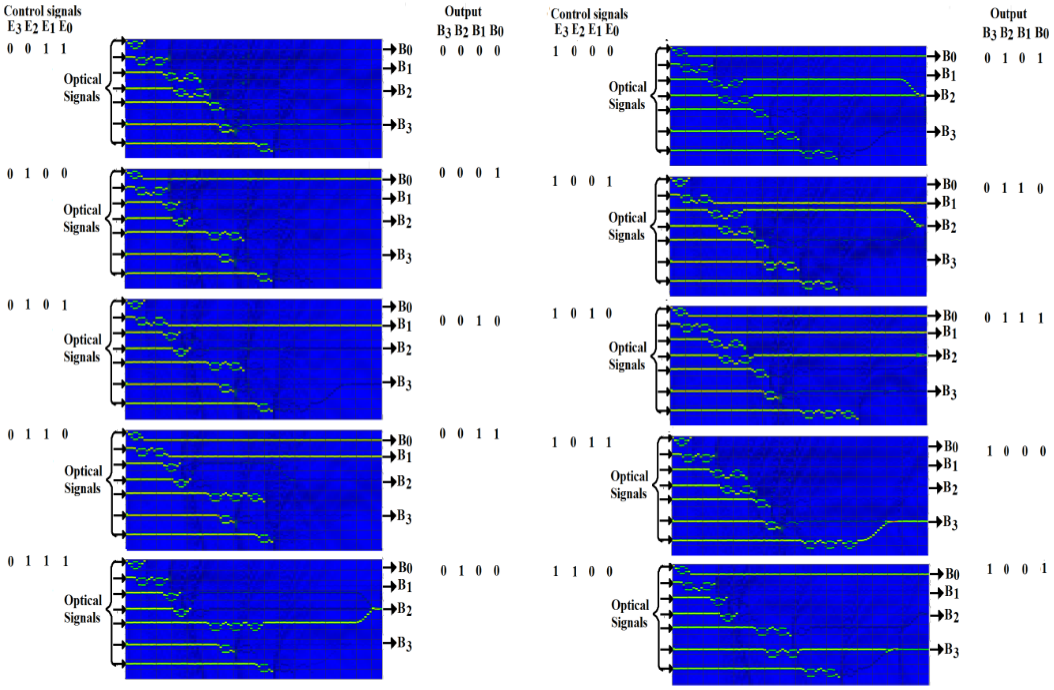

Figure 5: BPM Result of Excess 3 to BCD code converter where $E_3E_2E_1E_0$ varies from 0011 to 1100.

Case 2: $E_3 = 0, E_2 = 1, E_1 = 0, E_0 = 0$

As E_0 bit is 0, the light emerges from the second output port of MZI1 which means B_0 bit is equivalent to 1 $(\bar{E}_0)$. For B_1 bit, if E_1, E_0 is 0, 0 then the no output signal appears at second output port of MZI3, which means $B_1 = 0$. For B_2 bit, as E_2, E_1 is 1, 0 then output $(\bar{E}_2\bar{E}_1)$ will be 0 at first output port of MZI5. Again as E_2, E_0 is 1, 0 then output $(\bar{E}_2\bar{E}_0)$ will be 0 at first output port of MZI7. For $E_2, E_1, E_0 = 1, 0, 0$, output appears 0 at first output port of MZI10.So no signal will reach at the port3 for B_2 bit and it is equivalent to 0. For B_3 bit, as $E_3, E_2 = 0, 1$, no output will be at first output port of MZI12.As $E_{3,}E_1, E_0 = 0{,}0{,}0$, no output appears at the first output port of MZI15 , means no signal will reach at the port4 for B_3 bit and it is equivalent to 0.

Case 3: $E_3 = 0, E_2 = 1, E_1 = 0, E_0 = 1$

As E_0 bit is 1, no light emerges from the second output port of MZI1 which means B_0 bit is 0. For B_1bit, if E_1 is 0, then output signal appears at second output port of MZI2 and goes in to second input port of MZI3. As $E_0 = 1$ then output signal appears at second output port of MZI3, which means $B_1 = 1$. For B_2 bit, as E_2, E_1 is 1, 0 then output $(\bar{E}_2\bar{E}_1)$ will be 0 at first output port of MZI5. Again as E_2, E_0 is 1, 1 then output $(\bar{E}_2\bar{E}_0)$ will be 0 at first output port of MZI7. For $E_2, E_1, E_0 = 1, 0, 1$, output appears 0 at first output port of MZI10. So no signal will reach at the port3 for B_2 bit and it is equivalent to 0. For B_3 bit, as $E_3, E_2 = 0, 1$, no output will be at first output port of MZI12. Again as $E_{3,}E_1, E_0 = 0{,}0{,}1$, no output appears at the first output port of MZI15, means no signal will reach at the port4 for B_3 bit and it is equivalent to 0.

Case 4: $E_3 = 0, E_2 = 1, E_1 = 1, E_0 = 0$

As E_0 bit is 0, light emerges from the second output port of MZI1 which means B_0 is 1. For $E_1 = 1$, the output signal appears at the first output port of MZI2 and goes in to the first input port of MZI3 and while $E_0 = 0$, then signal appears at the second output port of MZI3, which means $B_1 = 1$. For B_2 bit, as E_2 , E_1 is 1, 1 then output $(\bar{E}_2\bar{E}_1)$ will be 0 at first output port of MZI5. Again as E_2 , E_0 is 1, 0 then output $(\bar{E}_2\bar{E}_0)$ will be 0 at first output port of MZI7. For $E_2, E_1, E_0 = 1, 1, 0$ output appears 0 at first output port of MZI10 and no output signal will reach at the port3 for B_2. For B_3 bit, at $E_3 = 0$ and $E_2 = 1$, no output will be at first output port of MZI12. For $E_{3,}E_1, E_0 = 0{,}1{,}0$, no output appears at the first output port of MZI15, means no signal will reach at the port4 for $B_3 = 0$.

Case 5: $E_3 = 0, E_2 = 1, E_1 = 1, E_0 = 1$

As E_0 bit is 1, no light emerges from the second output port of MZI1 which means B_0 is 0. For $E_1 = 1$, the output signal appears at the first output port of MZI2 and goes in to the first input port of MZI3 and while $E_0 = 1$, then no signal appears at the second output port of MZI3, which means $B_1 = 0$. For B_2 bit, as E_2, E_1 is 1, 1 then output $(\bar{E}_2\bar{E}_1)$ will be 0 at first output port of MZI5. Again as E_2, E_0 is 1, 1 then output $(\bar{E}_2\bar{E}_0)$ will be 0 at first output port of MZI7. For $E_2, E_1, E_0 = 1, 1, 1$,output appears 1 at first output port of MZI10. So output signal will reach at the port3 for $B_2 = 1$. For B_3 bit, as $E_3 = 0$ and $E_2 = 1$, no output will be at first output port of MZI12. As $E_{3,}E_1, E_0 = 0{,}1{,}1$, no output appears at the first output port of MZI15, means no signal will reach at the port4 and $B_3 = 0$.

Case 6: $E_3 = 1, E_2 = 0, E_1 = 0, E_0 = 0$

As E_0 bit is 0, light emerges from the second output port of MZI1 which means B_0 is 1. For $E_1 = 0$, the output signal appears at the second output port of MZI2 and goes in to the second input port of MZI3 and while $E_0 = 0$, then no signal appears at the second output port of MZI3, which means $B_1 = 0$. For B_2 bit, as E_2, E_1 is 0, 0 then output $(\bar{E}_2\bar{E}_1)$ will be 1 at first output port of MZI5. Again as E_2, E_0 is 0, 0 then output $(\bar{E}_2\bar{E}_0)$ will be 1 at first output port of MZI7. For $E_2, E_1, E_0 = 0, 0, 0$, output appears 0 at first output port of MZI10.So output signal will reach at the port3 from $(\bar{E}_2\bar{E}_1)$ path and from $(\bar{E}_2\bar{E}_0)$ path for $B_2 = 1$. For B_3 bit, as $E_2, E_1 = 1{,}0$, no output will be at first output port of MZI12. As $E_{3,}E_1, E_0 = 1{,}0{,}0$, no output appears at the first output port of MZI15, means no signal will reach at the port4 for $B_3 = 0$.

Case 7: $E_3 = 1, E_2 = 0, E_1 = 0, E_0 = 1$

As E_0 bit is 1, which means B_0 bit is equivalent to 0 $(\bar{E}_0)$. For B_1 bit, as E_1, E_0 is 0, 1 then the output signal appears at second output port of MZI3, which means B_1=1. For B_2 bit, as E_2, E_1 is 0, 0 then output $(\bar{E}_2\bar{E}_1)$ will be 1 at first output port of MZI5. Again as E_2, E_0 is 0, 1 then output $(\bar{E}_2\bar{E}_0)$ will be 0 at first output port of MZI7. For $E_2, E_1, E_0 = 0, 0, 1$, output appears 0 at first output port of MZI10.So signal will reach at the port3 through $(\bar{E}_2\bar{E}_1)$ path and B_2 bit is equivalent to 1. For B_3 bit, as E_3, E_2 is 1, 0, no output will be at first output port of MZI12. As $E_{3,}E_1, E_0 = 1{,}0{,}1$, no output appears at the first output port of MZI15, means no signal will reach at the port4 for B_3 bit and it is equivalent to 0.

Case 8: $E_3 = 1, E_2 = 0, E_1 = 1, E_0 = 0$

As E_0 bit is 0, which means B_0 bit is equivalent to 1 ($\bar{E}_0$). For B_1 bit, as E_1, E_0 is 1, 0 then the output signal appears at second output port of MZI3, which means B_1=1. For B_2 bit, as E_2, E_1 is 0, 1 then output ($\bar{E}_2\bar{E}_1$) will be 0 at first output port of MZI5. Again as E_2, E_0 is 0, 0 then output ($\bar{E}_2\bar{E}_0$) will be 1 at first output port of MZI7. For $E_2, E_1, E_0 = 0, 1, 0$,output appears 0 at first output port of MZI10. So signal will reach at the port3 through ($\bar{E}_2\bar{E}_0$) path and B_2 bit is equivalent to 1. For B_3 bit, as E_3= 1and E_2= 0, no output will be at first output port of MZI12. As $E_{3,}E_1, E_0 = 1,1,0,$ no output appears at the first output port of MZI15, means no signal will reach at the port4 for B_3bit and it is equivalent to 0.

Case 9: $E_3 = 1, E_2 = 0, E_1 = 1, E_0 = 1$

As E_0 bit is 1, which means B_0 bit is equivalent to 0 ($\bar{E}_0$). For B_1 bit, as E_1, E_0 is 1, 1 then no output signal appears at second output port of MZI3, which means B_1=0. For B_2 bit, as E_2, E_1 is 0, 1 then output ($\bar{E}_2\bar{E}_1$) will be 0 at first output port of MZI5. Again as E_2, E_0 is 0, 1 then output ($\bar{E}_2\bar{E}_0$) will be 0 at first output port of MZI7. For $E_2, E_1, E_0 = 0, 1, 1$,output appears 0 at first output port of MZI10. So no signal will reach at the port3 and B_2 bit is equivalent to 0. For B_3 bit, as E_3 = 1and E_2 = 0, no output will be at first output port of MZI12. As $E_{3,}E_1, E_0 = 1,1,1$, output appears at the first output port of MZI15, means signal will reach at the port4 for B_3 bit and it is equivalent to 1.

Case 10: $E_3 = 1, E_2 = 1, E_1 = 0, E_0 = 0$

As E_0 bit is 0, which means B_0bit is equivalent to 1 ($\bar{E}_0$). For B_1 bit, as E_1, E_0 is 0, 0 then no output signal appears at second output port of MZI3, which means B_1=0. For B_2bit, as E_2, E_1 is 1, 0 then output ($\bar{E}_2\bar{E}_1$) will be 0 at first output port of MZI5. Again as E_2, E_0 is 1, 0 then output ($\bar{E}_2\bar{E}_0$) will be 0 at first output port of MZI7. For $E_2, E_1, E_0 = 1, 0, 0$, output appears 0 at first output port of MZI10. So no signal will reach at the port3 and B_2 bit is equivalent to 0. For B_3 bit, as E_3 = 1and E_2 = 1, output will be at first output port of MZI12. As $E_{3,}E_1, E_0 = 1,1,0,$ no output appears at the first output port of MZI15, means signal will reach at the port4 through E_3E_2 path for B_3bit and it is equivalent to 1.

4. CONCLUSION

Excess 3 to BCD conversion is a prominent code conversion technique and it is very useful for arithmetic operations. This paper explains successful design of Excess 3 to BCD code converter circuit using electro-optic effect of $LiNbO_3$ MZI in BPM along with mathematical description. These results are verified using MATLAB simulations.

ACKNOWLEDGEMENT

This work is supported by the project entitled “Performance study of some WDM optical network components and design of optical switching devices” under the Faculty Research Scheme of DIT University, Dehradun, India (Ref. No.: DITU/R&D/2014/7/ECE) undertaken by Dr. Santosh Kumar.

REFERENCES

[1] Mano, M.M., “Computer Logic Design,” Prentice hall, New Jersey, Ch.4, (1972)

[2] Kumar, A., Kumar, S., Raghuwanshi, S.K., “Implementation of full-adder and full- subtractor based on electro-optic effect in Mach-Zehnder interferometers,” Optics Communications 324, 93-107 (2014).

[3] Kumar, S., Bisht, A., Singh, G., Amphawan, A., “Implementation of 2 bit multiplier based on electro-optic effect in Mach-Zehnder interferometers,” Optical and Quantum Electronics 47, 3667-3688 (2015).

[4] Kumar, S., Raghuwanshi, S.K., Rahman, B.M.A., “Design of universal shift register based on electro-optic effect of LiNbO3 in Mach-Zehnder interferometer for high speed communication,” Optical and Quantum Electronics 47, 3509-3524 (2015).

[5] Kumar, S., Singh, G., Bisht, A., Amphawan, A., "An optical synchronous up counter based on electro-optic effect of lithium niobate based Mach-Zehnder interferometers," Optical and Quantum Electronics 47, 3613-3626 (2015).

[6] Chattopadhyay, T., Roy, J.N., "An all-optical technique for a binary-to-quaternary encoder and a quaternary-to-binary decoder" Journal of Optics A: Pure Applied Optics 11, 075501 (2009).

[7] Kumar, S., Bisht, A., Singh, G., Choudhary, K., Raina, K.K., Amphawan, A.,"Implementation of 1-bit and 2-bit magnitude comparator using mach-zehnder interferometers," Optics communication 357, 127–147 (2015).

[8] Kumar, A., Raghuwanshi, S.K., "Implementation of optical gray code converter and Even parity checker using the electro-optic effect in the Mach-Zehnder interferometer," Optical and Quantum Electronics 47, 2117-2140 (2015).

[9] Fujita, H., "MEMS/MOEMS application to optical communication," Proc. SPIE 4557, 12.442944 (2001).

[10] Chattopadhyay, T., "All-optical cross-bar network architecture using TOAD based interferometric switch and designing of reconfigurable logic unit," Optical Fiber Technology 17, 558-567 (2011).

[11] Chowdhury, K.R., De, D., Mukhopadhyay, S., "Parity checking and generating circuit with nonlinear material in all-optical domain," Chin. Phys. Lett. 22, 1433–1435 (2005).

[12] Kumar, S., Bisht, A., Singh, G., Sharma, S., Amphawan, A., "Proposed new approach to the design of universal logic gates using the electro-optic effect in Mach-Zehnder Interoferometers," Applied Optics 54, 8479-8484 (2015).

[13] Srivastava, V.K., Priye, V., "All-optical 4-bit parity checker design," Optica Applicata 41, 157–164 (2011).

[14] Yow, C.K., Chai, Y.J., Williams, K.A., Penty, R.V., "Enhanced performance of an all- optical parity checker using a single Mach–Zehnder interferometer," OSA Conf. on Laser and Electro-Optic, 765-766 (2003).

[15] Raghuwanshi, S.K., Kumar, A., Kumar, S., "1x4 Signal router using three Mach-Zehnder Interferometers," Optical Engineering 52, 035002(2013).

[16] Wooten, Ed.L., Kissa, K.M., Yan, A.Y., Murphy, E.J., Lafaw, D.A., Hallemeier, P.F., Maack, D., Attanasio, D.V., Fritz, D.J., McBrien, G.J., Bossi, D.E., "A review of lithium niobate modulator for fiber optic communication," IEEE J. Sel. Quant. Electron 6, 69-82 (2000).

[17] Jin, H., Liu, F.M., Xu, P., Xia, J.L., Zhong, M.L., Yuan, Y., Zhou, J.W., Gong, Y.X., Wang, W., Zhu, S.N., "On chip generation and manipulation of entangled photons based on reconfigurable lithium niobate wave guide circuits," Physics Review Letters 113, 103601 (2014).

[18] Sotobayashi, H., Kitayama, K., "All-optical code conversion of 10 Gb/s BPSK codes without wavelength-shift by cross-phase modulation for optical code division multiplexing networks" Proc. IEEE on Optical Fiber Communication 2, 163-165 (2000).