All-optical conversion scheme from binary to its MTN form with the help of nonlinear material based tree-net architecture

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In the field of optical computing and parallel information processing, several number systems have been used for different arithmetic and algebraic operations. Therefore an efficient conversion scheme from one number system to another is very important. Modified trinary number (MTN) has already taken a significant role towards carry and borrow free arithmetic operations. In this communication, we propose a tree-net architecture based all optical conversion scheme from binary number to its MTN form. Optical switch using nonlinear material (NLM) plays an important role.
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The inherent massive parallel processing capabilities of light have made optics a strong candidate in the field of computation and information processing[1−6]. Here the traditional carrier of information, i.e. electron, is envisaged to be replaced by photon for devices based on switching and logic. In this case, terahertz (THz) range of operational speed can be achieved. To achieve the parallelism of optics, a suitable number system and an efficient encoding scheme for handling the data are very much essential. Binary number is accepted as the best representing number system in almost all types of existing electronic computers. Such computers are not fit for parallel arithmetic computing due to the use of carry generated binary numbers. Various signed digit number systems such as modified signed-digit (MSD)[7,8], mixed modified signed-digit (MMSD)[9−11], trinary signed-digit (TSD)[12], nonrecoded trinary signed-digit (NTSD)[13], and negabinary signed-digit number system[14,15] have been proposed to reach the goal of carry-borrow free arithmetic operations. In MMSD number system, the numbers (decimal and binary) are represented not only by zero and positive numbers but also by barred numbers. A barred number indicates a number with negative value but with the same radix. The technique of arithmetic operations uses both barred and unbarred numbers to maintain the parallel processing capability[10]. Modified trinary number (MTN) is a particular type of MMSD number. A binary number when expressed in MTN system takes 1 as its most significant digit (except for 0 MTN) where all other digits are either 0 or $\bar{1}$. This is contrast to the negative base number, in which positive and negative digits appear in alternative positions. The MMSD also differs from ternary number (TN) system because 0, 1 and $\bar{1}$ can appear in any position in TN. In our earlier contributions, we exploited the nonlinear material (NLM) based tree-net architecture for designing all optical time division multiplexing[16] and data comparison scheme[17]. In this communication, we propose an all-optical architecture for conversion of binary number to its MTN form using the same NLM based tree structure. Possibilities of its practical implementation are also discussed. Table 1 shows the three input binary numbers and their corresponding MTN forms.

Optical switch, using a NLM, makes it possible to change the direction of outgoing beam (optical signal)[16−22]. Recent researches show that polydiacetylenes (a highly conjugated polymer with very large optical nonlinearities) can show very fast response time (picoseconds response), such response time is hundred times faster than the fastest electronic switching[23,24]. These NLMs are exposed to high intensity laser beam. A Nd:YAG laser with 1.064-μm wavelength is the ideal source to excite such NLMs for switching operation.

The refractive index of some kind of NLMs can be expressed as

$$n = n_0 + n_2 I \cdots , \quad (1)$$

where n_0 is the constant term, n_2 is the coefficient of nonlinear correction term, and I is the intensity of input light beam. Pure silica (SiO_2) glass and carbon disulphide

Table 1. Three Input Binary Numbers and Their Corresponding MTN Forms

Binary Number			Corresponding Modified Trinary Number			
A	B	C	A_3	A_2	A_1	A_0
0	0	0	0	0	0	0
0	0	1	1	$\bar{1}$	$\bar{1}$	$\bar{1}$
0	1	0	1	$\bar{1}$	$\bar{1}$	0
0	1	1	1	$\bar{1}$	0	$\bar{1}$
1	0	0	1	$\bar{1}$	0	0
1	0	1	1	0	$\bar{1}$	$\bar{1}$
1	1	0	1	0	$\bar{1}$	0
1	1	1	1	0	0	$\bar{1}$

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(CS_2) also show this type of optical nonlinear feature. Especially for CS_2, the value of n_0 is 1.62 and n_2 is 0.22×10^{-19} m^2/W^2. A laser having the cross section of 1-cm radius and 10-MW power can be focused at a distance of 10 cm if CS_2 is taken as NLM. In practical implementation of such switching mechanism, 1-cm beam radius, 10-MW laser power, and 10-cm focusing distance may apparently be appeared as very large values as we know that all the proposed digital optical devices are built on submicron technology. Here also the proposed system is digital one. The signals are basically digital pulse signal. A pulse of 10-MW power or even in the order of GW can easily be achieved by suitable Q-switching or mode-locking system. A nanosecond or a picosecond pulse can easily satisfy this requirement. Not only a Nd:YAG laser, even an ordinary semiconductor laser can satisfy this need by generating a sub nanosecond pulse, provided it is attached with a suitable Q-switching or mode-locking mechanism. If such a high power pulses are possible to achieve, we can easily come down from the centimeter order range to the micrometer order focusing range, i.e., it can be used in submicron optical technology.

Equation (1) shows that the refractive index of NLM increases with the increase of intensity of the light beam. Hence, the direction of output light is changed with the change of intensity of input beam. This phenomenon is depicted in Fig. 1. Here the system is made of a combination of linear material (LM) and NLM[16−22]. It is assumed that X is the light signal coming from a constant light source (CLS) having the prefixed light intensity I and A is the control signal having a prefixed intensity $2I$. When the light signal X and control signal A both are present, the output light follows OZ_1 direction, i.e., through upper channel according to the above mentioned equation of refractive index (here the total intensity is $3I$). When the signal X is absent but the control signal A is present, the output follows OZ_2 direction, i.e., through intermediate channel (as the total intensity is $2I$ here). When the signal X is present but control signal A is absent, the light will follow OZ_3 direction, i.e., through lower channel (here the total intensity is I). Several architectures have already been proposed, where the refractive index variation of NLM with the intensity of light has been used to design several all-optical switching operations and logic gates[16−22]. In this present communication, we propose an architecture for conversion of binary number to its MTN form which may work in all

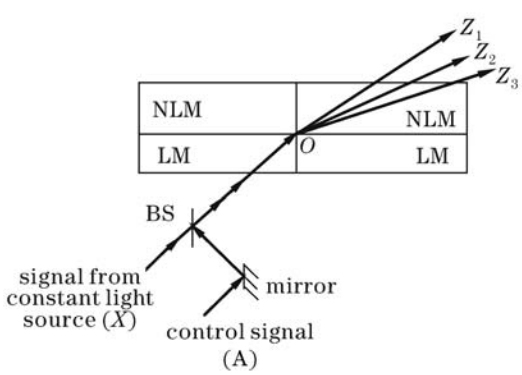

Fig. 1. Nonlinear material based optical switching (BS is the beam splitter).

Table 2. Truth Table of Fig. 1

Control Signal A	Signal from CLS	Output at OZ_1	Output at OZ_3
1	0	0	0
1	1	1	0
0	1	0	1
0	0	0	0

optical domain. The above characteristic of NLM is used for designing a tree structure in all-optical domain which can be helpful for all-optical data conversion scheme. In our present proposal, we will only take the output from upper (OZ_1 direction) and lower channels (OZ_3 direction) of Fig. 1. The nature of the output of Fig. 1 is shown in Table 2. Here 1 indicates the presence of the respective signal and 0 does the same for absence of the signal.

Tree architecture is a multiplying system of single straight path into several distributed branches and subbranch paths[25]. This structure is explained in Fig. 2. Here a light beam MN emitting from a point M breaks into two parts NO and NP. These two beams break again into four parts, i.e., NO to OQ, OR and NP to PS and PT. Proceeding in this way eight output channels could be obtained from a single input light beam. If the situation requires more spatially distributed output channels or terminals then another splitting arrangement is to be inserted in the last output channels.

NLM based switching system, discussed above, can be successfully used to design optical tree architecture (OTA) as shown in Fig. 3. Seven NLM based optical switches s_1, s_2, s_3, s_4, s_5, s_6, and s_7 are to be kept at N, O, P, Q, R, S, and T positions of Fig. 2, respectively. The

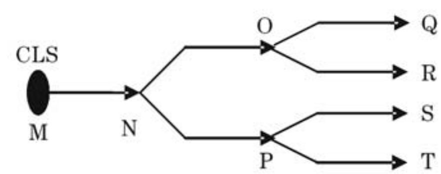

Fig. 2. Optical tree architecture.

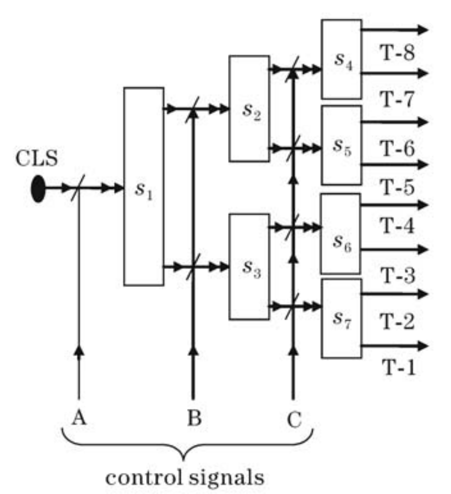

Fig. 3. Optical tree architecture with NLM based optical switch.

operational principle of these switches has already been discussed. These switches control the light in such a manner that, in the absence of control signal (which is also a light beam having some prefixed light intensity), the incident beam coming from constant light source (CLS) emerges through lower channel of the NLM based switch. The presence of control signal changes the light intensity and hence refractive index of the medium. Therefore, the light signal is switched to upper channel of the NLM based switch. Light coming from constant light source is incident on switch s_1 first. The control signal is considered to be as one (1) state when light beam is present with prefixed intensity and zero (0) when light beam is absent. For three control signals A, B, and C there are eight possible combinations 000, 001, 010, 011, 100, 101, 110, and 111. We will first explain the operational principle of proposed optical tree using NLM based optical switches as shown in Fig. 3 in detail.

Case 1: When A = 0, B = 0, and C = 0. The light coming from CLS is incident on switch s_1 first. As here A = 0, the control signal A is absent, which means that only the light beam coming from CLS is present at s_1. As per the switching principle discussed above, the light from CLS emerges through lower channel and falls on switch s_3. Now, at s_3 the control signal B is absent. Hence, the light comes through lower channel of s_3 and falls on switch s_7. Here also the control signal C is absent, which means that light beam coming from CLS finally emerges through the lower channel of s_7 and arrives at T-1 (terminal-1). In this case, light is present only at T-1 and no light is present at other terminals. So T-1 (terminal-1) is in one state and others are in zero state, when A = B = C = 0.

Case 2: When A = 0, B = 0, and C = 1. Light from constant light source is incident on s_1. As A = 0, light beam emerges through lower channel and falls on s_3. At s_3, the control signal B is absent. The beam comes through lower channel of s_3 and falls on s_7. At s_7 , the control signal C is present. Presence of two beams increases the intensity of light and hence the refractive index also. Therefore, the light emerges through upper channel of s_7 and finally reaches T-2 (terminal-2). In this case, light is present only at T-2 and no light is present at other terminals. So T-2 (terminal-2) is in one state and others are in zero state, when A = B = 0, and C = 1.

Case 3: When A = 0, B = 1, and C = 0, light from constant light sources reaches output terminal-3 (T-3).

Case 4: When A = 0, B = 1, and C = 1, the incident light reaches output terminal-4 (T-4).

Case 5: When A = 1, B = 0, and C = 0, the incident light reaches output terminal-5 (T-5).

Case 6: When A = 1, B = 0, and C = 1, the incident light reaches output terminal-6 (T-6).

Case 7: When A = 1, B = 1, and C = 0, the incident light reaches output terminal-7 (T-7).

Case 8: When A = 1, B = 1, and C = 1, the incident light reaches output terminal-8 (T-8).

Interestingly, the above tree architecture can be successfully used to convert the binary number to its MTN form. For this purpose a special interconnection system (basically a reverse tree structure) is needed. This interconnection can be easily done with beam splitters or mirror-beam splitters combination. The beam splitters used here are not polarizing, reflect and transmit 50% of the incident light for all polarizations. When the light beam falls on the upper surface of the beam splitter it suffers transmission only but when falls on the lower surface of the beam splitter it suffers both transmission and reflection. The optical circuit is shown in Fig. 4. Here the control signals are taken as binary input. The output obtained in the form of a polarized light perpendicular to the plane of paper (•) indicates $\bar{1}$ and the polarized light parallel to the plane of paper (↑), in most significant digit (MSD), indicates 1 and no light signifies 0 state. Here, the input light beams are expected to be an unpolarized one. The MTN outputs (A_3 A_2 A_1 A_0) are obtained through respective polarizer as shown in Fig. 4. A_0 receives light from T-8, T-6, T-4, and T-2 terminals, A_1 receives light from combination of T-7 & T-6 and T-3 & T-2 terminals, A_2 receives light from combination of T-5 & T-4 and T-3 & T-2 terminals, A_3 receives light from combination of T-2, T-3, T-4, T-5, T-6, T-7, and T-8 terminals.

For example, if we take the binary number 110 as the input (meaning A = 1, B = 1, and C = 0), T-7 receives light from constant light source. Hence, in the final outputs A_0 and A_2 get no light, but the polarized light (·) perpendicular to the plane of paper appears in A_1 and the polarized light (↑) parallel to the plane of paper appears in A_3. Therefore, $A_3A_2A_1A_0$ will give the output as $10\bar{1}0$. This is MTN equivalent of binary 110. In this way we can get the conversion of other numbers.

The main advantage of the proposed architecture is that the process is all-optical in nature and bears the inherent advantages of tree structure. The scheme can easily and successfully be extended and implemented for higher number scheme. This can be done by proper incorporation of NLM based optical switches, vertical and horizontal extension of the tree and by suitable branch selection. It is important to note that the predetermined values of the intensities of laser light for control signals, input signals and the constant light source are needed to send the optical signal in desired channels. However, some other parameters are to be taken into account for

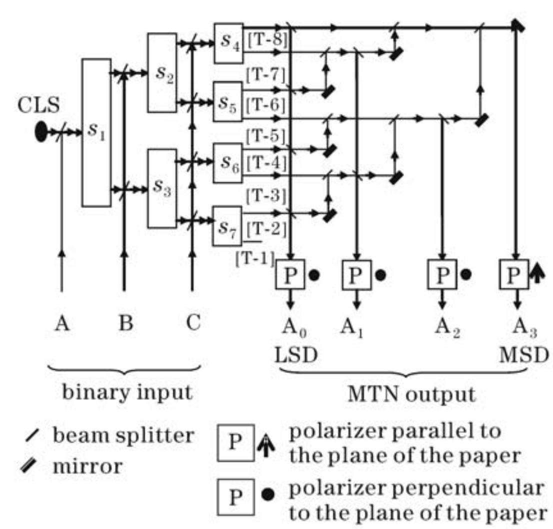

Fig. 4. Optical circuit for binary to MTN conversion scheme.

the implementation of the scheme. The optical efficiency into each output may look problematic for implementation. With the simple assumption of a factor of 2 loss through each beam splitter (which assumes no absorption and no scattering), light into each of the outputs of the system (Fig. 4) can vary depending on the path taken. For example: input of 001, path to A_3 output, goes through 6 beam splitters, thus 2**6 loss due to the beam splitters. Input of the same 001, path to A_0, goes through 1 beam splitter, thus 2**1 loss due to beam splitter. Both paths suffer an additional loss through the final polarizer. But such nonuniformity will not create much trouble in producing the desired optical bits at the output as the whole system is digital one and the MTN output depends only on the presence or absence of light in A_3, A_2, A_1, and A_0 but not on its intensity. To discuss the feasibility on the practical implementation of the whole scheme described above, it may be concluded that for exciting the nonlinear phenomenon of the conventional NLMs a high power laser in the order of MW is necessary. Therefore somebody may think that the system is very much expensive to be implemented physically. The problem of using a very high power laser can be overcome in two ways. In one way, one can develop such NLMs in the domain of organic or organo-metalic compounds where the value of n_2 is normally very high. It needs extensive research. The other way may be more suitable. If Q-switching or mode-locking or the both processes is adopted then one can easily generate high power laser pulses from ordinary solid state lasers, where each pulse may attain the power in the range of MW. As the scheme is a digital system which runs with digital pulses in the input and control stages, so using an ordinary pulsed laser beam (whose power is in the order of watt range) one can exploit the tree-net architecture for implementing the proposed conversion scheme. Our conventional NLMs then can easily respond to implement the above mechanism by using light pulses from the ordinary laser source. To avoid the diffraction limited problems the cell size of NLM should be carefully selected depending on the wavelength used. There is also one more significant advantage of this system. The scheme described in Figs. 3 and 4 can perform parallel conversion of two or more binary data to their respective MTN forms, if different wavelengths are used for different data conversions. Each wavelength will act on its own way and will not disturb others.

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References

1. H. J. Caulfield, W. T. Rhodes, M. J. Foster, and S. Horvitz, Opt. Commun. **40,** 86 (1981).
2. M. A. Karim and A. A. S. Awal, *Optical Computing: an Introduction* (Wiley, New York, 2003).
3. S. D. Smith, I. Janossy, H. A. Mackenzie, J. G. E. Reid, M. R. Taghizadeh, F. A. P. Tooley, and A. C. Walker, Opt. Eng. **24,** 569 (1985).
4. S. H. Lee, *Nonlinear Optical Processing* (Springer-Verlag, Berlin, 1981).
5. J. N. Roy and S. Mukhopadhyay, Opt. Commun. **119,** 499 (1995).
6. S. Mukhopadhyay and J. N. Roy , Proc. SPIE **1812,** 280 (1992).
7. A. K. Cherri and M. A. Karim, Appl. Opt. **27,** 3824 (1988).
8. S. Zhou, S. Campbell, P. Yeh, and H. K. Liu, Appl. Opt. **34,** 793 (1995).
9. A. K. Datta, S. Mukhopadhyay, and A. Basuray, Opt. Commun. **88,** 87 (1992).
10. S. Mukhopadhyay, A. Basuray, and A. K. Datta, Appl. Opt. **27,** 1375 (1988).
11. A. K. Datta, A. Basuray, and S. Mukhopadhyay, Opt. Lett. **14,** 426 (1989).
12. M. M. Hossain, J. U. Ahmed, and A. A. S. Awwal, Proc. IEEE NAECON **1,** 185 (1993).
13. R. S. Fyath, A. A. W. Alsaffar, and M. S. Alam, Opt. Commun. **230,** 35 (2004).
14. G. Li, L. Liu, L. Shao, and J. Hua, Appl. Opt. **36,** 1011 (1997).
15. G. Li, L. Liu, L. Shao, and Z. Wang, Opt. Lett. **19,** 1337 (1994).
16. J. N. Roy, A. K. Maiti, and S. Mukhopadhyay, Chin. Opt. Lett. **4,** 483 (2006).
17. J. N. Roy, A. K. Maiti, J. Pal, and S. Mukhopadhyay, HIT Transaction on ECCN **1,** 43 (2006).
18. N. Pahari, D. N. Das, and S. Mukhopadhyay, Appl. Opt. **43,** 6147 (2004).
19. K. R. Chowdhury and S. Mukhopadhyay, Opt. Eng. **43,** 132 (2004).
20. K. R. Chowdhury, D. De, and S. Mukhopadhyay, Chin. Phys. Lett. **22,** 1433 (2005).
21. K. R. Chowdhury, P. P. Das, and S. Mukhopadhyay, Opt. Eng. **44,** 035201 (2005).
22. S. Dhar and S. Mukhopadhyay, Opt. Eng. **44,** 065201 (2005).
23. "Recent advances in photonics devices for optical computing" http://science.nasa.gov/headlines/images/nanosecond/thepaper.pdf.
24. R. Q. Torres and M. Thakur, Appl. Phys. Lett. **66,** 1310 (1995).
25. S. Mukhopadhyay, Opt. Commun. **76,** 309 (1990).