ALL-OPTICAL BINARY COUNTER BY USING T FLIP-FLOP: AN IMPLEMENTATION

SAMIR SAHU

Department of Physics and Technophysics
Vidyasagar University
Midnapur – 721102
West Bengal, India
tosamirsahu@gmail.com

RADHA RAMAN PAL

Department of Physics and Technophysics
Vidyasagar University
Midnapur – 721102
West Bengal, India
rrpal@mail.vidyasagar.ac.in

SHANTANU DHAR

Department of Physics
Jhargram Raj College
Jhargram – 721507
West Bengal, India
dhar_hit@rediffmail.com

ABSTRACT: All-optical T (Toggle) flip-flop with preset (PR) and clear (CLR) are basic building modules for the development of ultra-high speed all optical binary counter. In this paper, a non-linear material based all-optical switching mechanism is utilized here to realize the all-optical T flip-flop with PR and CLR. A composite slab of linear medium (LM) and non-linear medium (NLM) is used to design the all-optical switch that exploit the attractive features of NLM. These all-optical T flip-flops can find application in the development of several complex all-optical circuits of enhanced performances. Here we demonstrate an all-optical binary 3-bit ripple counter which is nothing but the successive application of the flip flop. This circuit can elevate to a higher bit different counters. As this all optical circuits are purely all-optical in nature, these are very simple as well as very fast. Also the schemes have capacity of cascading.

Keywords: nonlinear material; all-optical logic gate; all-optical flip flop.

1. Introduction

With the increasing data traffic day-by-day, there is a requirement to restrict research problems in a particular region to achieve the reliable, faithful and high speed performances in communication [Mukhopadhyay *et al.* (1988); Chen *et al.* (2011)] and computation [Choudhury and Mukhopadhyay, (2003); Dhar and Sahu, (2008); Sahu *et al.* (2011)]. To deal with the soaring demands, optics has already established its validity in various arithmetic [Choudhury and Mukhopadhyay, (2003)], logic [Pei-Li *et al.* (2008); Dutta and Mukhopadhyay, (2010)], algebraic [Sahu *et al.* (2011)], and image operations [Samanta and Mukhopadhyay, (2007)] in last few years, preliminary because of its promising features of parallel, high speed, high bandwidth non-interfering communications [Mukhopadhyay *et al.* (1988); Sahu and Dhar, (2009)]. These gifted advantages lead us to our dream goal of making the fastest possible computer, specifically, a super fast optical computer that will outperform the fastest possible electronic computer. In this regard, the limitations [Mukhopadhyay *et al.* (1988)] of electronics are familiar. It is expected that in the coming era our dream goal can be achieved by replacing electronics with photonics [Mukhopadhyay *et al.* (1988); Arivouli, (2001)]. In the last few years, non linear material (NLM) based optical switching mechanism [Choudhury and Mukhopadhyay, (2003); Dhar and Sahu, (2008);] has established its validity as one of many promising techniques [Pei-Li *et al.* (2008); Dutta and Mukhopadhyay, (2010)]. This is used to develop various combinational logic circuits [Wang *et al.* (2009)] as well as sequential logic circuits [Wang *et al.* (2010)] by many scientists and technologists. For example, all optical flip-flops are key devices for realizing many functionalities in optical networks, optical computing, especially as all-optical memories for the temporary storage of data.

Several optical flip-flops using different techniques have already been proposed [Dhar and Sahu, (2008); Wang *et al.* (2010)]. An all-optical S-R, S-R with clock, D, J-K and J-K master-slave type flip-flops using non-linear material [Dhar and Sahu, (2008); Sahu and Dhar, (2009)] was also reported. Now, in our present paper we proposed a scheme for all optical implementation of synchronous T flip-flop using non-linear material as all optical switches. As this all optical flip-flop is purely all-optical in nature, it is very simple as well as very fast. The advantageous side of our scheme is that there are two outputs which are complemented to each other. Also the scheme has capacity of cascading. The output of the T flip-flop and its complement are obtained simultaneously in our scheme. The initial state of the flip flop can also be assigned by the inputs PR and CLR.

Binary counters are often required to count events. Existing electronic counter are slow. To gear up the performance speed it is essential to replace existing digital counter by all optical counter. Various all-optical counters have been reported [Wang *et al.* (2009); Wang *et al.* (2010)]. At the end of our present paper we implement an all-optical binary 3-bit counter by the successive use of the T flip flop with PR and CLR. It is a ripple (asynchronous) counter. The outputs of the counter can be erased out by the clear input. This circuit can raise to a higher bit several types of counters. These circuits are key elements for the implementation of a high-speed, all-optical data processing device, which has the potential to outperform its electronic equivalent and constitute a possible new product for our dream goal, optical computer.

2. All-Optical Switching Behavior of Nonlinear Material

The phenomenon photorefractivity [Arivouli, (2001); Sahu and Dhar, (2009)] of some nonlinear optical material is used in nonlinear all-optical intensity switching mechanism. The photorefractive effect, where the refractive index changes induced by a light field when the crystal is subjected to intense laser radiation, defocusing and scattering of the light, is observed, as a result of an inhomogeneous change in the refractive index. It is also found that these changes still prevail even after the light is switched off, but it could be erased by strong, uniform illumination [Arivouli, (2001)].The refractive index of some nonlinear materials (NLM) such as carbon disulfide, pure silica, potassium dihydrophosphate (KDP) crystal etc. varies linearly with the intensity of the light incident on it. The refractive index (n) of such isotropic dielectric non-crystalline media can be put into an equation as Eq. (1). Here n_0 is the linear term, n_1 is the nonlinear correction term and I is the intensity of the incident light beam on the material.

$$n = n_0 + n_1 I \quad (1)$$

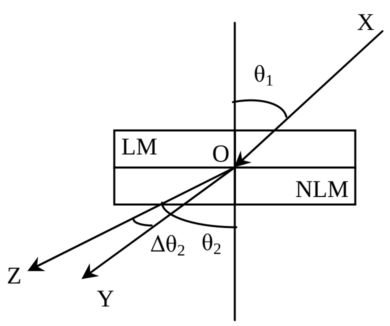

Fig. 1. Intensity switching of optical nonlinear material

We can implement the switching mechanism with such nonlinear material by taking an interface between two media of which one is a linear material (LM), whose refractive index n_0 is independent of the intensity of light and the other is aforesaid NLM. A laser beam, highly intense polarized light, preferably pulse laser of intensity $I_{1,}$ is allowed to incident on the interface from linear to nonlinear part in a particular direction XO (incidence angle θ_1) as depicted in Fig. 1. The refracted beam from the NLM follows the path OZ (angle of refraction θ_2). But when another higher intense laser beam of intensity I_2 ($I_2 > I_1$) is made to incident along XO, after refraction from the NLM the light passes through OY direction. The deviation of refractive angle for different incident light intensity I_1 and I_2 is $\angle ZOY = \Delta\theta_2$. Thus the combination of LM and NLM may act nicely as a directional all-optical switch. This is the unit block of our proposed T flip-flop and binary counter circuit.

In the expression of refractive index in Eq. (1), n_0 is linear term and n_1 is the nonlinear correction term. For carbon disulfide [Samanta and Mukhopadhyay, (2007); Sahu and Dhar, (2009)] (CS_2) $n_0 = 1.63$, $n_1 = 514\times10^{-20}$ m^2/W. and for fused silicon dioxide [Samanta and Mukhopadhyay, (2007); Sahu and Dhar, (2009)] (SiO_2) $n_0 = 1.458$, $n_1 = 2.7\times10^{-20}$ m^2/W. If we use CS_2 and SiO_2 as nonlinear materials and the pulse laser of intensity $I = 2\times10^{18}$ W/m^2 as a source, we can estimate the deviations of light in two cases as given in Table 1.

Table 1. Truth table of Clocked T flip-flop with Preset (PR) and Clear (CLR)

Material	Angle of incidence (θ_1)	Incident light intensity	n (= $n_0 + n_1 I$)	Angle of refraction (θ_2)	Deviation ($\Delta\theta_2 = \theta'_2 - \theta''_2$)
carbon disulfide (CS_2)	45 deg	$I=2\times10^{18}$ W/m^2	11.91	3.404 deg = θ'_2	1.578 deg
	45 deg	2I	22.19	1.827 deg= θ''_2	
silicon di-oxide (SiO_2)	45 deg	$I=2\times10^{18}$ W/m^2	1.512	27.883 deg= θ'_2	1.041 deg
	45 deg	2I	1.566	27.842 deg= θ''_2	

3. All-Optical NOT Gate And AND Gate

The logic gates [Choudhury and Mukhopadhyay, (2003); Dhar and Sahu, (2008); Sahu *et al.* (2011)] are implemented in optics using NLM by taking the presence of light signal as 1 and the absence of it as 0. The implementation of such logic gates can be done by using some femtosecond laser pulses and 1-mm-thick potassium dihydrophosphate (KH_2PO_4 (KDP) crystal at the pick intensity of 0.6 TW/cm^2 and duration of 60 fs [Mironov *et al.* (2009); Sahu and Dhar, (2009)].

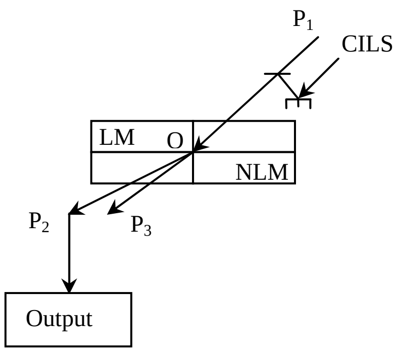

Fig. 2. All-optical NOT gate

3.1 *All optical NOT gate*

To implement an all optical NOT gate using non-linear material a constant intensity pulse laser source (CILS) is used as shown in Fig. (2). It is also called probe beam. Here P_1 is taken as input beam. A detector is placed at P_2 will detect the output beam after refraction. If P_1 is absent, the light will follow a path OP_2 and will be detected by the detector due to presence of CILS. But if P_1 is present, after refraction, the light will follow a path other than OP_2, may be OP_3, and the detector will not detect any light signal. Thus the system acts as optical NOT gate.

3.2 *All Optical AND gate*

The all-optical AND gate using two inputs and three inputs are shown in Fig. 3. The two inputs all-optical AND gate using NLM is shown in Fig. 3(a). Here R_1 and R_2 are two input channels. A detector placed at R_4 gives the output. Now when both the channels carry light signal, the light beam after refraction will detected by the detector at R_4, unless not.

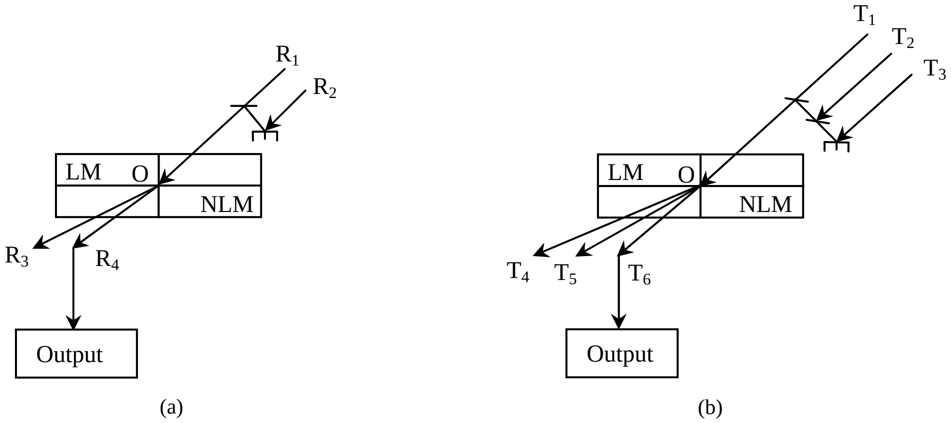

Fig. 3. All-optical AND gate using NLM. (a) two-input AND gate. (b) three-input AND gate

The three inputs all-optical AND gate using NLM is shown in Fig. 3(b). Here T_1, T_2 and T_3 are three input channels. A detector placed at T_6 gives the output. Now when all the channels carry light signal, the light beam after refraction will detected by the detector at T_6, unless not.

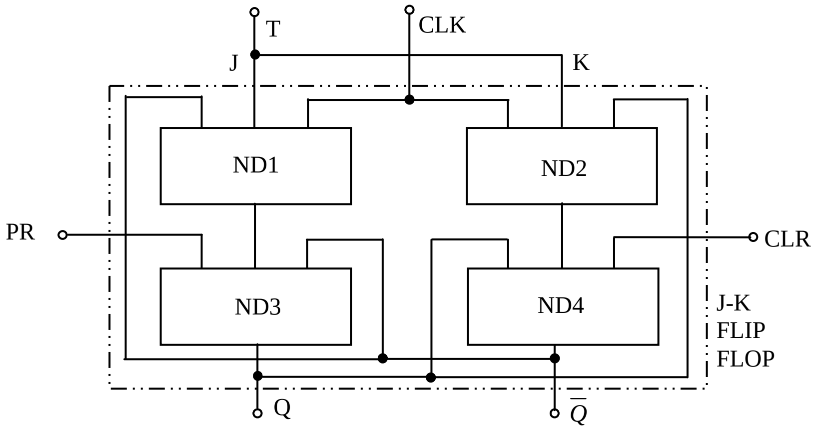

Fig. 4. Electronically addressed T flip-flop with preset and clear

4. Conventional Electronic Flip-Flops

A flip-flop is a device with two stable states. It remains in one of these states until triggered into other. Fig. 4 shows the block diagram of conventional electronic T flip-flop with PR and CLR [Morris Mano, (2000); Jain, (2007)]. The T flip-flop is obtained from a J-K flip-flop with PR and CLR [Sahu and Dhar, (2009)] if both inputs are coupled together as in Fig. 4. The ND1...ND4 are electronically addressed NAND gates. The modified truth tables T flip-flop with PR and CLR are given bellow in Table 2.

Table 2. Truth table of Clocked T flip-flop with Preset (PR) and Clear (CLR)

Inputs					Outputs		State
CLK1 = CLK2	PR	CLR	Q_n	T	Q_{n+1}	$\overline{Q}_{n+1}$	
0	1	1	d	d	Q_n	$\overline{Q}_n$	Previous
1	1	1	0	0 } 0	0 } Q_n	1 } $\overline{Q}_n$	Previous
1	1	1	0	0	1	0	
1	1	1	1	1 } 1	1 } $\overline{Q}_n$	0 } Q_n	Toggle
1	1	1	1	1	0	1	
0	1	0	d	d	0	1	Clear
0	0	1	d	d	1	0	Preset

d = whatever may be the input

5. All Optical T Flip-Flop With Preset (PR) and Clear (CLR)

Now we talk about the fundamental design of the all-optical circuit of the T flip-flop with preset (PR) and clear (CLR) as shown in Fig. 5. Here T is the input and Q and $\overline{Q}$ are the final output states of the T Flip-Flop. There are four all-optical AND gates (AG1, AG2, AG5 and AG6) and four all-optical NOT gates (NG1, NG2, NG3 and NG4) in our proposed circuit. All the four AND gates are three-inputs AND gates. The input T is the constant intensity light source, preferably pulse laser. The T is connected to one of the three inputs of both the AG1 (J) and AG2 (K) respectively. CLK, clock pulse in the form of pulse laser of similar intensity as T, is

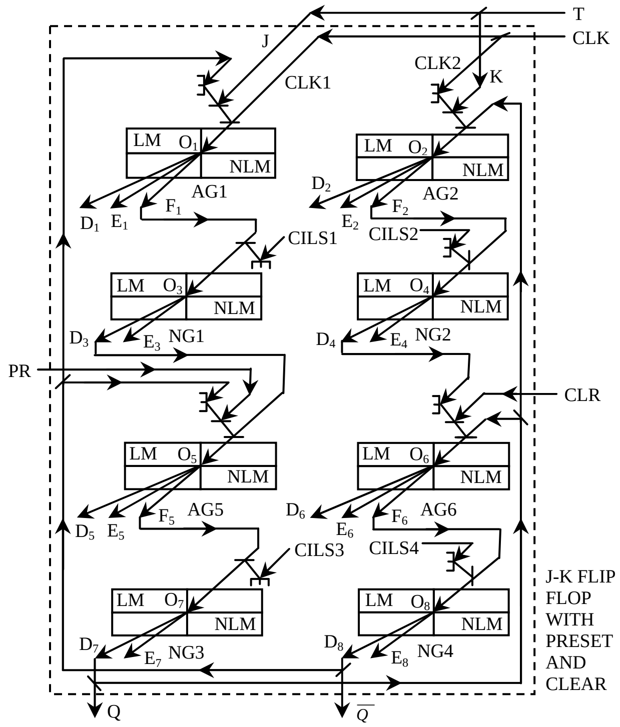

Fig. 5. All-Optical T Flip-Flop with Preset (PR) and Clear (CLR) Using NLM as Switch

divided to CLK1 and CLK2 which are used as second inputs of AG1 and AG2 respectively. Feed backs from $\overline{Q}$ and Q are the third inputs of AG1 and AG2 respectively. F_1 and F_2, the respective outputs of AG1 and AG2, are used as the input of two corresponding NOT gates, NG1 and NG2. Two constant intensity light sources CILS1 and CILS2 preferably pulse laser sources of similar intensity level are fed in the input channels of both the NOT gates NG1 and NG2 respectively as probe beams. The output beams from NG1 (D_3) and NG2 (D_4) are now used as one of the inputs of AG5 and AG6 respectively. $\overline{Q}$ and Q the final output beams are fed to AG5 and AG6 respectively just like AG1 and AG2. The preset (PR) and clear (CLR) inputs are connected to AG5 and AG6 respectively as third input of each. F_5 and F_6 are the outputs of AG5 and AG6 respectively. Now F_5 beam is allowed to incident as the input beam of NG3. A probe beam CILS3 in the form of pulse laser is used for the proper action of NG3. Similarly, F_6 beam is allowed to incident as the input beam along with a probe beam (CILS4) of NOT gate NG4. The output D_7 from NG3 is taken to be the final Q and output D_8 from NG4 is taken to be the final $\overline{Q}$ of the all-optical T flip-flop.

Let us realize the operation of the clocked T flip-flop with preset (PR) and clear (CLR).

First we consider PR = CLR = 1 i. e. both the inputs are at high state.

Now when the clock pulse beams are inactive i.e. CLK1 = CLK2 = 0, both the outputs F_1 and F_2 of AG1 and AG2 respectively, give 0 whatever may be the other inputs T of the flip-flop. As $F_1 = F_2 = 0$ the light will be present at D_3 and D_4 position due to the probe beams CILS1 and CILS2 respectively. This light is fed in the channel of the inputs of the AND gates AG5 and AG6. Here two possibilities may arise. Possibility 1; if $\overline{Q}_n = 0$ and $Q_n = 1$, then $F_5 = 0$ and $F_6 = 1$ consequently $D_7 = 1$ and $D_6 = 0$, i.e. the Q_{n+1}th state preserve the Q_nth state and $\overline{Q}_{n+1}$th state also preserve the $\overline{Q}_n$th state. Possibility 2; if $\overline{Q}_n = 1$ and $Q_n = 0$, then F_5 gives 1 and F_6 gives 0 consequently D_7 gives 0 and D_8 gives 1, again the Q_{n+1}th state and $\overline{Q}_{n+1}$th state follow the Q_nth state and $\overline{Q}_n$th state respectively.

When CLK1 = CLK2 = 1 (i.e. active part of the clock pulse beam), two circumstances may occur. They are as follow:

Let T is inactive (i.e. J = K = 0). Then there will be no light at both the output terminals F_1 (from AG1) and F_2 (from AG2) irrespective of the other two inputs of AG1 and AG2. The outputs Q and $\overline{Q}$ are latched to their previous state very similar to the aforesaid condition (CLK1 = CLK2 = 0; J, K whatever may be).

Now, we consider the other possible input T = 1. That means J and K both become active. Here two cases may arise, case 1; if $\overline{Q}_n = 1$ and $Q_n = 0$, then $F_1 = 1$ and $F_2 = 0$ therefore, $D_3 = 0$ and $D_4 = 1$. As the output of AND gate gives 0 when any one input is inactive irrespective of the other inputs, there is no light signal present at F_5 (i.e. $F_5 = 0$). As a result the output of NG3 will be 1, i.e. $D_7 = Q_{n+1} = 1$. Now, AG6 has two inputs, one is Q and the other is D_4 and both the input terminals have light signal. Since, $Q = D_4 = 1$, light will follow the path O_6F_6 (i.e. $F_6 = 1$). Then D_8 or $\overline{Q}_{n+1}$ will become 0 as both the input beams F_6 and probe beam CILS4 of NG4 are present. Case 2; if $\overline{Q}_n = 0$ and $Q_n = 1$, $F_1 = 0$ and $F_2 = 1$, as a result D_3 gives 1 and D_4 gives 0. Since, AG6 is an AND gate and $D_4 = 0$ is one input of it, the light will appear at E_6 terminal. So, $F_6 = 0$ and hence $D_8 = 1$ i.e. $\overline{Q}_{n+1} = 1$. Now, AG5 has inputs $D_3 = 1$ and $\overline{Q} = 1$. $F_5 = 1$ and outcome of this is $D_7 = 0$. That means Q_{n+1} state is now become 0. Thus here the circuit always changes state and complement to previous output i.e. if $Q_n = 1$ it switches to $Q_{n+1} = 0$ and vice versa. The truth table is shown in Table 2.

The outputs of the T flip-flop are the function of data inputs T if the clock pulses are present (CLK1 = CLK2 = 1) and preset and clear inputs carry light (PR = CLR = 1). However the output states are assumed arbitrary before the application of light pulses. The initial state of the flip-flop can be assigned by changing the state of the two terminals preset (PR) and clear (CLR).

Now we want to discuss the operation of preset and clear the output of this flip-flop. We know when clock is absent (CLK1 = CLK2 = 0), $D_3 = D_4 = 1$. If we take PR = 1 and CLR = 0, $F_6 = 0$ whatever may be the other two inputs of AG6. As a result $D_8 = \overline{Q} = 1$. Now the three inputs of AG5 are active (i.e. $D_3 = \overline{Q} = PR = 1$) and the output F_5 becomes 1 consequently $D_7 = Q = 0$.

If we consider PR = 0 and CLR = 1, $F_5 = 0$ irrespective of the other inputs of AG5. Due to the probe beam CILS3 we get light at D_7 terminal i.e. $D_7 = Q = 1$. Now all the three inputs of AG6 become 1 ($D_4 = Q = CLR = 1$). F_6, the output channel of AG6, will carry light. As the NOT gate NG4 has input $F_6 = 1$, along with probe beam CILS4, $D_8 = \overline{Q} = 0$.

So we can conclude that in T flip-flop we need high CLR (=1) for preset the flip-flop (i.e. Q = 1 and $\overline{Q} = 0$) and high PR (=1) for clear the flip-flop (i.e. Q = 0 and $\overline{Q} = 1$). When PR = CLR = 1 i.e. both are high the outputs of the T flip-flop with preset (PR) and clear (CLR) will remain same as T flip-flop without preset (PR) and clear (CLR), shown at the first five rows in Table 2.

In our scheme we use all optical AND and NOT gate in designing the all optical T flip flop. In our design the light beam which is fed back is coming from the output of a NOT gate. Again the concept used here to design the all optical NOT gate has an advantage. When ever the output of a NOT gate is assumed to be at ‘1’ state, the source of that ‘1’ state is a constant intensity pulse laser source (CILS) used as probe beam. So in each feedback arrangement described in our scheme similar intense light beam is fed back. In this way the reduction of intensity by using beam splitter will not affect the non-linear response of the device. The light sources are so chosen that each input beam intensity is in the rang of intensity which is detected as ‘1’ by the detector.

In T flip-flop due to feed back connection a problem may arise. If the active states of the clock pulses CLK1 and CLK2 are so large that they remain 1 (while T = 1) after the output has been complemented, the action of complementation of output will repeat. Then the problem is same as electronic circuits and it is called race-around [Sahu and Dhar, (2009)] problem. Therefore the duration of clock pulse should be chosen critically.

6. All Optical Binary Counter

The all optical binary counters are consisted of all optical T flip-flop. A 3-bit all optical binary counter is depicted in Fig. 6, which is composed by three all optical clocked T flip-flop (T flip flop 0, 1 and 2) with preset (PR) and clear (CLR) discussed earlier. The flip-flops are cascaded one by one to form the ripple counter. All the PR inputs are connected together to form the preset (PR) of the counter. To get the clear (CLR) input of the counter we coupled together the three CLR terminals of three T flip flops. Q_0, the output of the first flip flop is connected to the CLK of the second flip flop and the output Q_1 (from T Flip Flop 1) is inputted to clock of T Flip Flop 2. The complemented outputs $\overline{Q}$ are left open. One can get complement of counted OP from $\overline{Q}_2\overline{Q}_1\overline{Q}_0$. The optical clock pulses (OP) which we want to count are connected to the CLK of the first flip flop. The outputs are taken from the terminals Q_0 (LSB), Q_1 and Q_2 (MSB). 3-bit binary counter can count from binary 000 (=0) to 111 (=7). $Q_0Q_1Q_2$ is the 3-bit output of this counter.

Now we want to realize the operation of the all optical 3-bit binary counter.

To performing the counting $T_0 = T_1 = T_2 = 1$ and PR = CLR = 1 i. e. all the other inputs than clock are at logical ‘1’. That means they carry light signal. The T flip flops, we proposed, are negative edge triggered type flip flops. The optical pulses and the output optical wave forms are illustrated in Fig. 7.

Table 3. Truth table of 3-bit binary counter

No of Optical clock pulses	Inputs		Outputs			State
	$T_0= T_1= T_2$=PR=1	CLR	Q_2	Q_1	Q_0	
0	1	0	0	0	0	Clear
0	1	1	0	0	0	
1	1	1	0	0	1	
2	1	1	0	1	0	
3	1	1	0	1	1	Counting
4	1	1	1	0	0	
5	1	1	1	0	1	
6	1	1	1	1	0	
7	1	1	1	1	1	
8	1	1	0	0	0	Reset

The output Q_0 reverses its state at the negative edge of each optical pulse (OP) because $T_0 = 0$. As Q_0 acts as CLK for T Flip Flop1 and $T_1 = 1$, Q_1 alters at negative edge of each Q_0. Similarly Q_2 is inverted at the negative edge of Q_1. At any instant, the binary number $Q_0Q_1Q_2$ is the number of optical pulses counted till that time. At X the count is 101 = 5. The output $Q_0Q_1Q_2$ will be 000 after counting eight optical pulses. The output $Q_0Q_1Q_2$ can be clear by turn off light signal momentarily from CLR input. The truth table for 3-bit ripple counter is shown in Table 3. We can promote the 3-bit counter to n-bit binary counter with n flip flop having 2^n possible states. A counter with a chain of n flip flops can count up to 2^n -1 optical pulse.

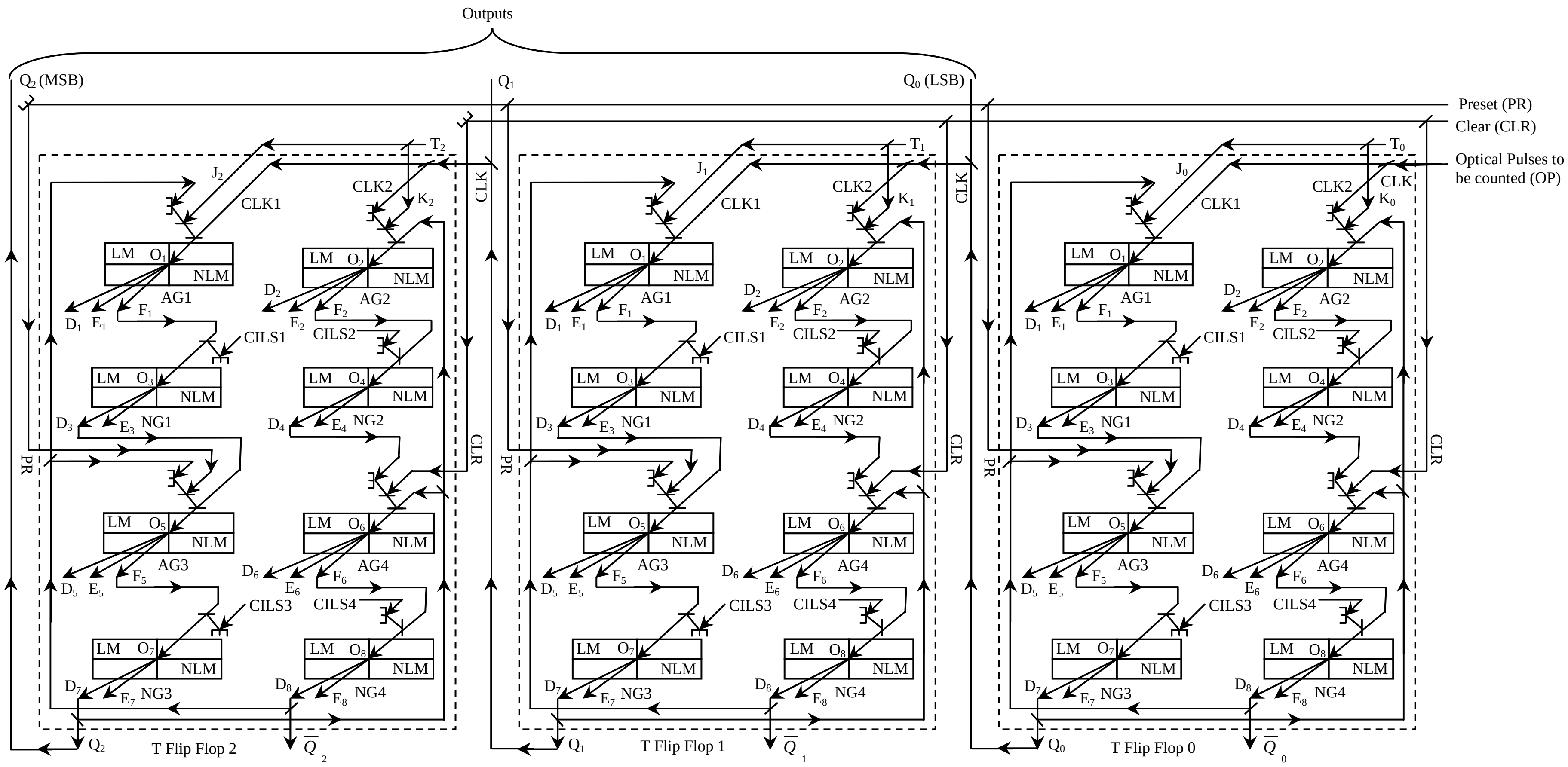

Fig. 6. All Optical 3-bit Binary Counter Using T Flip Flops

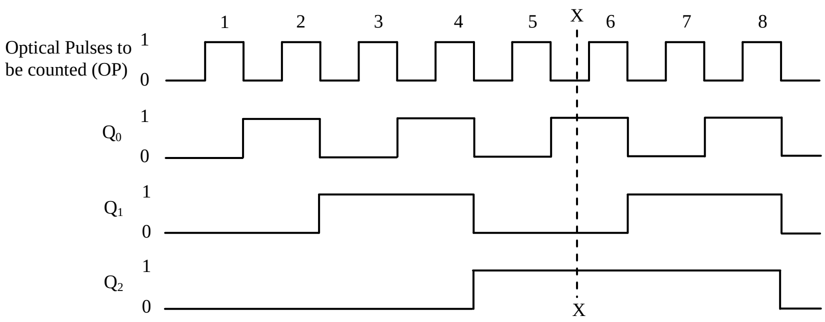

Fig. 7. Waveforms of All-Optical 3-bit binary counter

5. Conclusion

The proposed technique of all optical implementation of T flip-flop and binary counter is very fast (above THz) [Pei-Li *et al.* (2008); Mironov *et al.* (2009); Sahu and Dhar, (2009)] as it is fully all-optical. The light signals which are severally used and the feedback light signals from the outputs are made by mirrors and beam splitters to make the circuits simple. Another important feature is that all-optical temporary data storage memories may be developed by cascading the flip-flops. Other different types of Counter can be implemented from this ripple counter. Proper findings of non-linear material may be a significant issue here. Essentially inputs and constant intensity light source should be chosen properly to function the system accurately. The clock pulse signal should also be selected suitably.

Acknowledgment

The authors want to acknowledge Professor Sourangshu Mukhopadhyay of the University of Burdwan for his valuable suggestions.

References

[1] Arivouli, D. (2001): Fundamentals of optical nonlinear materials, Pramana, **57**(5,6), pp. 871-883.

[2] Chen, C. H.; Matsuo, S.; Nozaki, K.; Shinya, A.; Sato, T.; Kawaguchi, Y.; Sumikura, H.; Notomi, M. (2011): All-optical memory based on injection-locking bistability in photonic crystal lasers, Opt Express. **19**(4) pp. 3387-3395.

[3] Choudhury K. R.; Mukhopadhyay, S. (2003) A new method of binary addition scheme with massive use of non-linear material based system, Chin. Opt. Lett. **1**(4), pp. 132-135.

[4] Dhar, S.; Sahu, S. (2008): All-optical implementation of S-R, clocked S-R and D flip-flops using nonlinear material, Optical Engineering, **47**(6), pp. 065401-6.

[5] Dutta S.; Mukhopadhyay, S. (2010): An all optical approach of frequency encoded NOT based Latch using semiconductor optical amplifier, J. of optics. **39**(1), pp. 35–41.

[6] Jain, R. P. (2007) *Modern Digital Electronic*, 3rd edn. Tata MaG*raw*-Hill India, New Delhi.

[7] Mironov. S.; Lozhkarev, V.; Ginzburg, V. Khazanov, E. (2009): High-efficiency second-hermonic generation of superintense ultrashort laser pulses, Applied Optics, **48**, pp. 2051.

[8] Morris Mano, M. (2000) *Digital Logic and Computer Design*, 1st edn. Prentice-Hall of India Private Limited, New Delhi.

[9] Mukhopadhyay, S.; Datta, K. A.; Basuray, A. (1988): Optical computating: Researches in this decade, Optics, **17**(4), pp. 94-100.

[10] Pei-Li, L.; De-Xiu, H.; Xin-Liang, Z.; Yang, W. (2008): Single-SOA-Based Ultrahigh-Speed All-Optical Half Subtracter with PolSK Modulated Signals, *C*hin. Phys. Letters, **25**(5), pp. 1705-1709.

[11] Sahu, S.; Dhar, S. (2009): Implementation of clocked J-K and J-K Master Slave flip-flops with nonlinear material in All-optical Domain, Optical Engineering, **48**(7), pp. 075401-7.

[12] Sahu, S.; Pal, R. R.; Dhar, S. (2011): A Novel Method of Implementing Nonlinear Material Based All-Optical Binary Half Subtractor and Full Subtractor System, J. of Electron Devices, **10**, pp. 493-498.

[13] Samanta, D.; Mukhopadhyay, S. (2007): A method of maintaining the intensity level of a polarization encoded light signal, J. of Physical Science, **11**, pp. 87-92.

[14] Wang, J.; Meloni, G.; Berrettini, G.; Potì, L.; Bogoni, A. (2009): All-optical binary counter based on semiconductor optical amplifiers, Opt. Lett., **34**, pp. 3517-3519.

[15] Wang, J.; Meloni, G.; Berrettini, G.; Potì, L.; Bogoni, A. (2010): All-Optical Clocked Flip-Flops and Binary Counting Operation Using SOA-Based SR Latch and Logic Gates, Quan. Electronics: J. of IEEE, **16**(5), pp. 1486-1494.