Journal of Electron Devices, Vol. 11, 2011, pp. 588-595

© JED [ISSN: 1682 -3427]

Journal of Electron Devices
www.jeldev.org

TERAHERTZ ALL-OPTICAL BINARY REGISTER USING D FLIP-FLOP WITH NON-LINEAR MATERIAL: A PROPOSAL

Samir **Sahu**(a)*, Radha Raman **Pal** (b) And Shantanu **Dhar** (c)

(a), (b)Department of Physics and Technophysics, Vidyasagar University, Midnapore – 721102, West Bengal, India
(c)Department of Physics, Jhargram Raj College, Jhargram – 721507, West Bengal, India
* tosamirsahu@gmail.com

Received 22/10/2011, online 26/10/2011

Abstract

All-optical D flip-flops with preset (PR) and clear (CLR) are basic edifice components for the design of terahertz all optical binary register. In this paper, a non-linear material based all-optical switching mechanism is employed here to understand the all-optical D flip-flop with PR and CLR and then it is apply to design ultra fast all optical register. A combination of linear medium (LM) and non-linear medium (NLM) is used to implement the all-optical switch that exploit the blessing features of NLM. This ultra-high speed all-optical D flip-flop can find application in the development of several complex all-optical circuits of enhanced performances. Here we depict an all-optical 3-bit binary register which is the succeeding application of the flip flop. This circuit can elevate to a higher bit different registers. 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. The outputs as well as their complements of these proposed circuits are obtained simultaneously in our scheme.

Key words*:* Nonlinear material, All-optical switch, All-optical logic gate, All-optical flip flop.

I. INTRODUCTION

Facing the explosive growth of the Internet traffic, next generation computation [1-5] and communication [6] will be based on all optical technologies to scale their capacity to the traffic demand. Light has already established itself as a successful signal carrier for information processing over the years primarily due to the advantages of it parallelism, ultra high speed, high bandwidth, no crosstalk, low loss transmission [1-6, 14-15]. Optical devices [3-5, 14] are also lightweight, compact, low expensive to manufacture and more facile with stored data too than the magnetic materials. In view of these gifted features several techniques have been reported to implement various arithmetic [5, 7], algebraic [8], logic [9-11, 14-16] and image operations [12] in optical domain. In the last few years non-linear optical material based all-optical switching mechanism [3-5, 7, 14, 25] proved its validity as one of such promising techniques. This is used to develop various combinational logic circuits [13] as well as sequential logic circuits [3-4, 14] by many scientists and technologists. For examples, all optical registers and its fundamental units, 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 [3-4, 14-16]. In most of these have hybrid structures and so they lacked to reach the desirer speed due to their electronic portion. There are some asynchronous type flip-flops [15] also. An all-optical S-R, S-R with clock, D, J-K and J-K master-slave type flip-flops using non-linear material [3-4] was also reported. The initial output states of the D flip flop, proposed in our previous work [3], cannot be assigned desirably before the application of the optical clock pulses. Here In this proposal, before describing the all optical register, we proposed a scheme for all optical implementation of synchronous D flip-flop with preset and clear using non-linear material as all optical directional switches. The drawback of ordinary D flip flop [3] are overcome here. This modified all optical D flip-flop is applied repeatedly to construct all optical binary parallel register which are awfully essential to store data. Various all-optical registers have been reported [19-23]. They are not as faster as demanded. To gear up the performance speed we implement an all-optical 3-bit register by the consecutive use of the D flip flop with PR and CLR. It is a Parallel-in, Parallel-out (PIPO) type register [17-18]. The outputs of the register can be preset or clear out by the preset and clear input. This circuit can raise to a higher bit other types of registers. As this all optical circuits are purely all-optical in nature, they are 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. 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.

II. ULTRA FAST ALL-OPTICAL SWITCHING BEHAVIOR OF NONLINEAR MATERIAL AND THEIR APPLICATION IN ALL-OPTICAL NOT GATE AS WELL AS AND GATE

The phenomenon photorefractivity [3-5, 24] of some nonlinear optical material is used in nonlinear all-optical intensity switching mechanism. The refractive index [3-5, 14, 24, 26-27] of some nonlinear materials (NLM) such as carbon disulfide, pure silica, potassium dihydrophosphate (KH_2PO_4 (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 (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.

$$n = n_0 + n_1 I \tag{1}$$

II.1 Ultra Fast All-Optical Switching Behavior of 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. 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 (angle of refraction θ_2). The deviation of refractive angle for different incident light intensity I_1 and I_2 is $<ZOY = \Delta\theta_2$. Thus the combination of LM and NLM may act nicely as a directional all-optical switch. This is the unit block of our proposed register circuit.

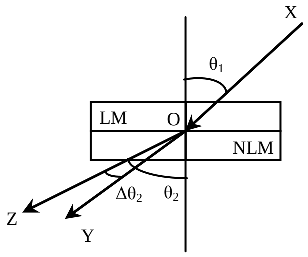


Fig. 1 : Intensity switching of optical nonlinear material

In the expression of refractive index in (1) n_0 is linear term and n_1 is the nonlinear correction term. For carbon disulfide [3-5, 25] (CS_2) $n_0 = 1.63$, $n_1 = 514\times10^{-20}$ m^2/W. and for fused silicon dioxide [3-5, 25] (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.

The logic gates [3-5, 24, 25] 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

Table 1

Estimation of the deviation of pulsed laser light when passing through carbon disulfide (CS_2) and silicon dioxide (SiO_2)

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	

such logic gates can be done by using some femtosecond laser pulses and 1-mm-thick KDP crystal at the pick intensity of 0.6 TW/cm^2 and duration of 60 fs [4-5, 26]. M. Choi et al. show that a single-layer terahertz metamaterial [27] has a peak refractive index of 38.6 while maintaining low losses. It is a broadband, extremely high index of refraction going beyond the limit that is attainable with naturally existing substances, lead sulphide, strontium titanate [27].

II.2 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.

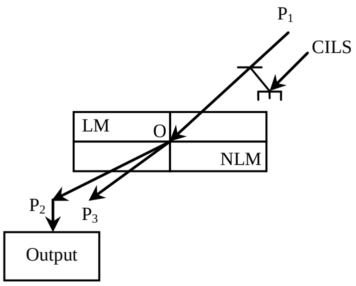
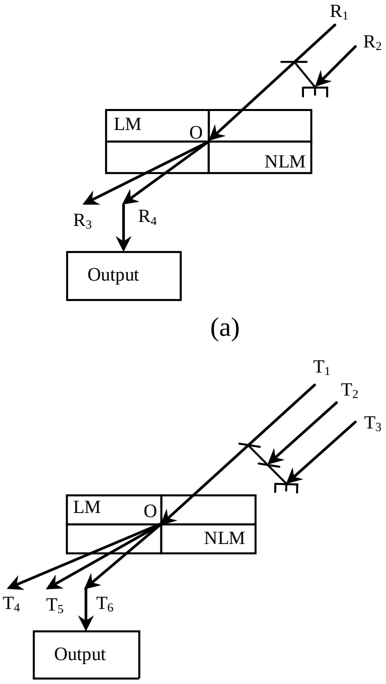


Fig. 2 : All-optical NOT gate

II.3 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.



(a)

(b)

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.

III. ALL-OPTICAL BINARY REGISTER BY D FLIP-FLOP WITH PRESET (PR) AND CLEAR (CLR)

As all-optical D flip-flop with preset (PR) and clear (CLR) are essential implementing components [17-18] to build up terahertz all optical binary register we first describe all-optical D flip-flop with preset (PR) and clear (CLR) and then all optical register.

III.1 All-optical D Flip-Flop With Preset (PR) and Clear (CLR)

Fig. 4 illustrates a clocked all-optical D flip-flop with preset (PR) and clear (CLR) which is the modification of D flip flop proposed in our previous work [3]. The optical clock pulses CLK1 and CLK2 combined together to form CLK and two D inputs are coupled as single D input. The outputs of the D flip-flop are the function of data input D if the clock pulses (CLK) are present (CLK1 = CLK2 = 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 introducing two terminals preset (PR) and clear (CLR) which are shown in Fig 4. We design the D flip-flop with preset and clear replacing the two two-inputs AND gates with two three-inputs AND gates (AG5 and AG6). The preset and clear terminals are connected as the third input of AG5 and AG6 respectively. Now the initial states of the new flip flop can be assigned according to our requirement by the inputs PR and CLR.

Now we want to discuss the operation of this clocked all-optical D flip-flop with PR and CLR.

If we assume PR = CLR = 1 the outputs will be the same as the ordinary D flip-flop (first three rows of Table 2).

We know when clock (CLK) is absent (i.e. CLK1 = CLK2 = 0), $D_1 = D_2 = 1$. Now if we take PR = 1 and CLR = 0. As CLR = 1, F_4 must be 0 whatever may be the other two inputs of AG6. As a result $D_6 = \overline{Q} = 1$. Now the three inputs of AG5 are active ($D_1 = \overline{Q}$ = PR = 1) and the output F_3 becomes 1 consequently $D_5 = Q = 0$.

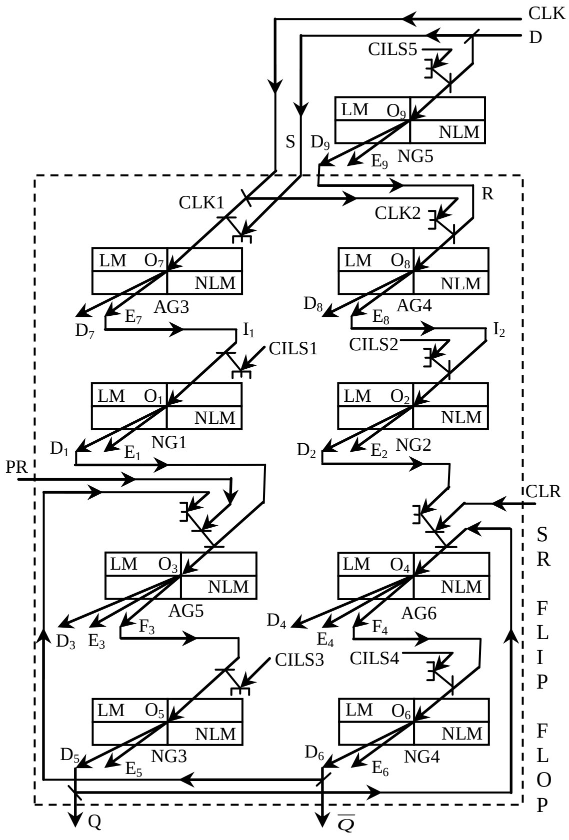


Fig. 4 : All optical D flip flop with preset (PR) and clear (CLR) using NLM as switch

Last of all we consider PR = 0 and CLR = 1 and CLK = 0. Both the path O_1D_1 and O_2D_2 carry light similar to the above case. Then $F_3 = 0$ irrespective of the other inputs of AG5. Due to the probe beam CILS3 one can get light at D_5 terminal i.e. $D_5 = Q = 1$. Now all the three inputs of AG6 become 1 (D_2 = Q = CLR = 1). F_4, the output channel of AG6, will bring light. As the NOT gate NG4 has input $F_4 = 1$, along with probe beam CILS4, $D_6 = \overline{Q} = 0$.

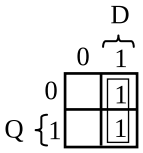
So we can conclude that in D flip-flop we require high PR (= 1) and low CLR (= 0) for clear the flip-flop (i.e. Q = 0 and $\overline{Q}$ = 1) and high CLR (= 1) and low PR (= 0) for preset the flip-flop (i.e. Q = 1 and $\overline{Q}$ = 0) in the absence of CLK. When PR = CLR = 1 i.e. both are high, the flip flop resets or sets according to D when CLK present. The truth table is shown in Table 2. The characteristic equation of D flip flop with PR and CLR is exposed in Fig. 5.

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

Inputs				Outputs		State
CLK	PR	CLR	D	Q_{n+1}	$\overline{Q}_{n+1}$	
0	1	1	d	Q_n	$\overline{Q}_n$	Previous
1	1	1	0	0	1	Reset
1	1	1	1	1	0	Set
0	1	0	d	0	1	Clear
0	0	1	d	1	0	Preset

d = whatever may be the input

In our scheme we use all optical AND and NOT gate in designing the all optical D 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.



Q_{n-1} = D (When PR = CLR = CLK=1)

Fig. 5 : Characteristic equation of D flip flop with Preset (PR) and Clear (CLR)

III.2 All Optical Binary Register

The all optical binary registers are consisting of all optical D flip-flops. A 3-bit all optical register is described in Fig. 6, which is composed by three all optical clocked D flip-flop with preset (PR) and clear (CLR) discussed previously (DFF0, DFF1 and DFF2). The flip-flops are cascaded one after another to form the PIPO register. All the PR inputs are connected together to form the preset (PR) of the register. To get the clear (CLR) input of the register we coupled together the three CLR terminals of three D flip flops. The clock input (CLK) is formed by connecting three CLK of DFF0, DFF1 and DFF2. Here D_0 (D input of DFF0), D_1 (D input of DFF1) and D_2 (D-input of DFF2) are the 3 input bits. D_0 is the least significant bit (LSB) and D_1 is the most significant bit (MSB). The outputs are taken from the terminals Q_0 (LSB), Q_1 and Q_2 (MSB). These are taken from Q-outputs of DFF0, DFF1 and DFF2 respectively. The complemented $\overline{Q}$-outputs are left open. One can get complement of stored data from $\overline{Q}_2\overline{Q}_1\overline{Q}_0$. The optical clock pulse is connected to the CLK of the register. As it can store 3 bit binary numbers, this register can store from binary 000 (=0) to 111 (=7). $Q_0Q_1Q_2$ is the 3-bit output of this register.

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

To performing the storing of bits into register we must take PR = CLR = 1. The bits to be stored are applied at the D-inputs of DFF0, DFF1 and DFF2. After the passage of a clock pulse the input bits D_0, D_1 and D_2 are appeared at Q_0, Q_1 and Q_2 through DFF0, DFF1 and DFF2 respectively. Let we want to store 101 (= 5) in this register. The input channels D_0 and D_2 carry light but D_1 dose not. Since PR and CLR are present, the output Q follows the input D in each D flip flop, as Table 2. The output $Q_0Q_1Q_2$ can be clear by turn off light signal momentarily from CLR input. The truth table for 3-bit register is shown in Table 3. We can promote the 3-bit register to n-bit binary register having n-bit binary number storing capacity, with n flip flop. A register with a chain of n D flip flops can store n zeros to 2^n -1 binary numbers.

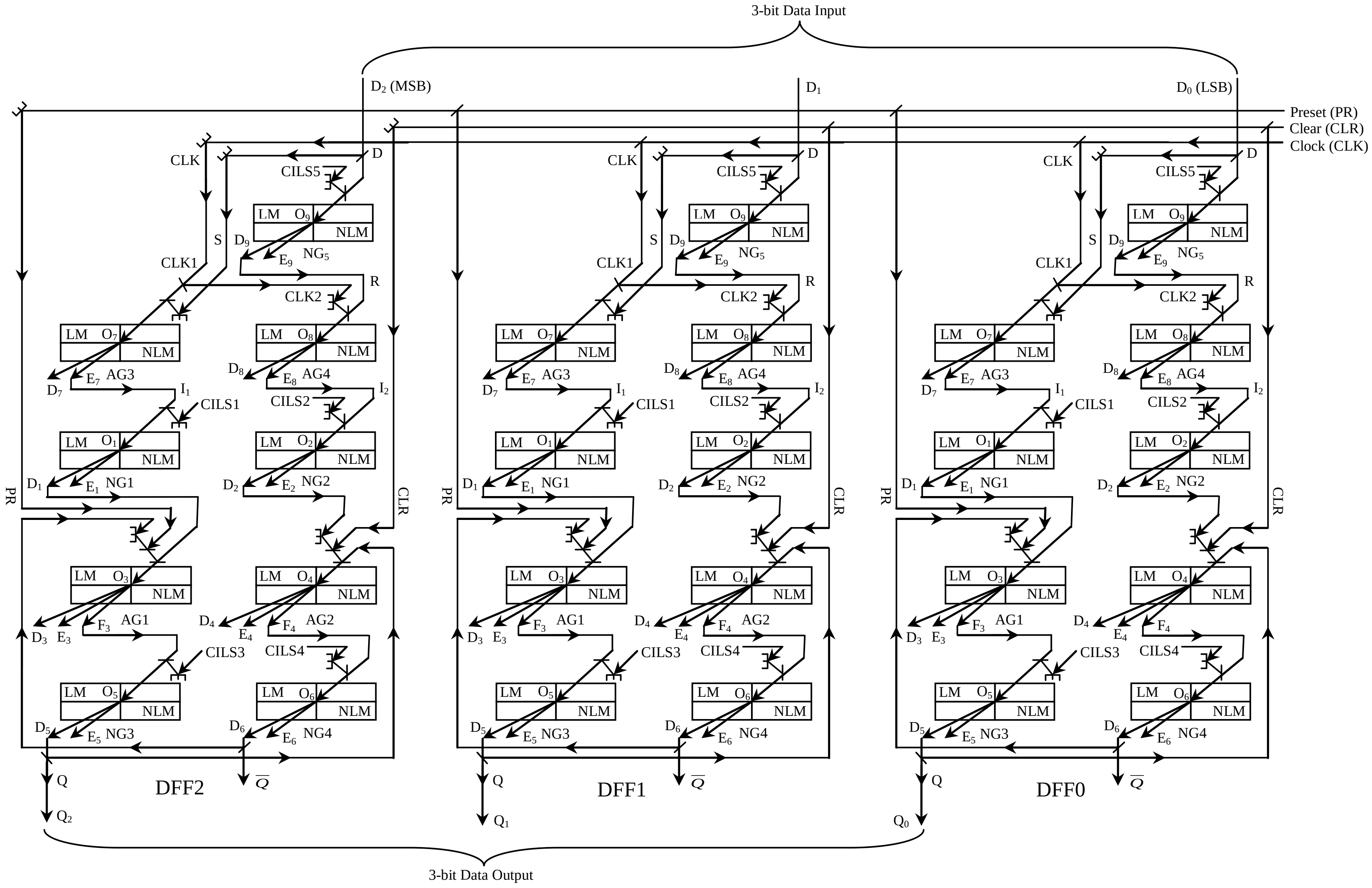


Fig. 6 : All optical 3-bit register using D flip flop

Table 3

Truth table of 3-bit PIPO register using D flip-flop

Inputs						Outputs			State
CLK	PR	CLR	D_2	D_1	D_0	Q_2	Q_1	Q_0	
0	1	1	d	d	d	p Q_2	p Q_1	p Q_0	Previous
1	1	1	0	0	0	0	0	0	Storing
1	1	1	0	0	1	0	0	1	
1	1	1	0	1	0	0	1	0	
1	1	1	0	1	1	0	1	1	
1	1	1	1	0	0	1	0	0	
1	1	1	1	0	1	1	0	1	
1	1	1	1	1	0	1	1	0	
1	1	1	1	0	1	1	0	1	
0	1	0	d	d	d	0	0	0	Clear
0	0	1	d	d	d	1	1	1	Preset

d = whatever may be the input; p = previous state of

IV. CONCLUSION

The proposed technique of all optical implementation of D flip-flop and binary register are very fast (above THz) [2-7, 16, 20, 26-27] as they are 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 other higher order all-optical temporary data storage memories may be developed by cascading the flip-flops. Other different types of registers can be implemented from this PIPO register. Proper findings of non-linear material [25-27] 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.

References

[1] J. Zhang and H. Xu “Optical computation based on nonlinear total reflectional optical switch at the interface,” Pramana. J. Phys. **72**, 547 (2009).

[2] P. Huang, F. Luo, M. Cao, Y. Yang and Y. Feng “Optical interconnecting and switching network system of 5 to 10-Gbps bandwidth for parallel computing,” Proc. SPIE. 5281, 559 (2004).

[3] S. Dhar and S. Sahu “All-optical implementation of S-R, clocked S-R and D flip-flops using nonlinear material,” Opt. Eng. **47**, 065401 (2008).

[4] S. Sahu and S. Dhar “Implementation of clocked J-K, T and J-K Master Slave flip-flops with nonlinear material in All-optical Domain,” Opt. Eng. 48, 075401-1 (2009).

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

[6] D. Hillerkuss et al. “26 Tbit s−1 line-rate super-channel transmission utilizing all-optical fast Fourier transform processing,” Nature Photonics. **5**, 364 (2011).

[7] D. K. Gayen and J. N. Roy “All-optical arithmetic unit with the help of terahertz-optical-asymmetric-demultiplexer-based tree architecture,” Appl. Opt. **47**, 933 (2008).

[8] A. Andreoni, M. Bondani, M.A.C. Potenza, Y.N. Denisyuk and E. Puddu “Boolean algebra operations performed on optical bits by the generation of holographic fields through second-order nonlinear interactions,” Rev. Sci. Instrumn. **72**, 2525 (2001).

[9] M. Xun and J. Sajeev “Quantum-dot all-optical logic in a structured vacuum,” Phys. Rev. A. **84**, 013830 (2011).

[10] A. Meiri and Z. Zalevsky “Nano electro-optical modulator and all-optical logic gate on a silicon chip,” J. Nanophoton. **5**, 051811 (2011).

[11] Q. Xu and M. Lipson “All-optical logic based on silicon micro-ring Resonators,” Opt. Exp. **15**, 924 (2007).

[12] B. Yang, Z. Liu, B. Wang, Y. Zhang and S. Liu “Optical stream-cipher-like system for image encryption based on Michelson interferometer,” Opt. Exp. **19**, 2634 (2011).

[13] P. S. Guilfoyle and W. J. Wiley “Combinational logic based digital optical computing architecture,” Appl. Opt. **27**, 1661 (1988).

[14] N. Pahari and S. Mukhopadhyay “An all optical R-S flip-flop by optical non-linear material,” J. of Opts. **34**, 108 (2005).

[15] A. K. Datta and S. Munshi “Optical implementation of flip-flops using single-LCD panel,” Opt. & Laser Tech. **39**, 2321 (2007).

[16] T. Chattopadhyay "All-optical clocked delay flip-flop using a single terahertz optical asymmetric demultiplexer-based switch: a theoretical study," Appl. Opt. **49**, 5226 (2010).

[17] M. Morris Mano, Digital Logic and Computer Design: Prentice-Hall of India Private Limited, New Delhi, Chap. 1, 6, 7 (2000).

[18] R. P. Jain, Modern Digital Electronics: Tata MaG*raw*-Hill India, New Delhi, Chap 5, (2007).

[19] A.J. Poustie, R.J. Manning and K.J. Blow “All-optical circulating shift register using a semiconductor optical amplifier in a fibre loop mirror,” Electronics Lett. **32**, 1215 (1996).

[20] K. L. Hall, J. P. Donnelly, S. H. Groves, C. I. Fennelly, R. J. Bailey and A. Napoleone “40-Gbit/s all-optical circulating shift register with an inverter,” Opt. Lett**. 22**, 1479 (1997).

[21] A. S. Shcherbakov, E. Tepichin Rodriguez and A. Aguirre Lopez “An all-optical 4-bit register based on a four-order scattering of light by coherent acoustic phonons in single crystals,” Rev. Mex. F´ıs. **50**, 297 (2004).

[22] Tamer A. Moniem, Nabil Abd Rabou and E. M. Saad “Parallel-shift register and binary multiplier using optical hardware components,” Opt. Eng. **47**, 035201 (2008).

[23] E. Lazzeri, G. Berrettini, G. Meloni, A. Bogoni and L. Poti “All-Optical-Bits Shift Register Exploiting a Ring Buffer Based on Semiconductor Optical Amplifier,” Phot. Tech. Lett. IEEE. **23**, 45 (2011).

[24] D. Arivouli “Fundamentals of optical nonlinear materials,” Pramana. J. Phys. **57**, 871 (2001).

[25] D. Samanta and S. Mukhopadhyay “A method of maintaining the intensity level of a polarization encoded light signal,” J. of Phy. Science. **11**, 87 (2007).

[26] S. Mironov. V. Lozhkarev, V. Ginzburg and E. Khazanov “High-efficiency second-hermonic generation of superintense ultrashort laser pulses,” Appl. Opt. **48**, 2051 (2009).

[27] M. Choi, S. H. Lee, Y. Kim, S. B. Kang, J. Shin, M. H. Kwak, K.Y. Kang, Y. H. Lee, N. Park and B. Min “A terahertz metamaterial with unnaturally high refractive index,” Nature. **470**, 369 (2011).