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Simultaneous All-optical 1's Complement Cum Division-by-two Schemes

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Research Article

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Simultaneous all-optical 1's complement cum division-by-two schemes

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Abstract: Odd and even number detection is an important mathematical operation. Generally when any number divisible by 2 then it is called even number, otherwise it is odd number. Division by 2 can be easily obtained by putting a point before least significant bit (LSB) of any binary number. As an example a number $(27)_{10} = (11011)_2$ when divided by 2 its result will be $(1101.1)_2 = (13.5)_{10}$. Hence when we find the fractional bit as logic-1 we can say that the number is odd, otherwise it is even. This operation can be obtained by using a demultiplexer. Here we have developed an optical circuit which can divide any binary integer number by 2, apart from that its 1's complement can also be obtained from the circuit. Both of the result can be obtained simultaneously. Terahertz optical asymmetric demultiplexer (TOAD) based generally switch assumes a vital part to plan this n-bit circuit. Numerical simulations are done to urge the exhibition of the circuit.

Keywords: Optical signal processing; Optical arithmetic operation; Optical logic.

1. Introduction

Optics shows potential option of electronic calculation as of late. Because of high transfer speed and less information transport necessity, optical information preparing and correspondence become better known [1]. Semiconductor optical intensifier (SOA) makes exchanging activity all the more simple and rapid. Optical sign preparing interferometric switches to construct the upset. Among different switches, TOAD be a solitary arm interferometer. TOAD is capable of deal with information processing about 1Tb/s [2-5]. This switch has quick shift time, low power consumption, low latency and noise. Again this switch has very high nonlinear properties with thermally stabile utilized in correspondence thoroughly [2-4]. The multipliers which are utilizing two diverse plan arrangements come within reach have been designed by Sharma [5]. K. Maji et~al have designed all-optical recurrence encoded AND, OR, and NOT rationale entryways and their presentation re-enacted to affirm their practicality [6]. Huo et al [7] proposed a reconfigurable fotonic filter based on TOAD based switch. Maji et al [8] also proposed a dual control TOAD based 2's complement method in their paper. In their other paper they also proposed XOR gate and binary to gray bit conversion using this interferometric switch [9]. Here we have proposed a plan of n-bit binary division- by-2 circuit using TOAD. Generally when any binary number is divided by 2 one fractional bit appears. If the number is odd, fractional bit is logic-`1' otherwise it is logic-`0'. By dividing different numbers by 2 we see that results can be easily obtained by putting a point before the least significant integer bit of any binary number. As an example if we divide a binary number $(11011101)_2$ by 2, the result will be $(1101110.1)_2$. To play out this activity we have used TOAD primarily based interferometric switch. This all-optical circuit can perform division-by-2 and also its 1's complement simultaneously.

2. Theoretical operation of the switch:

TOAD could be a solitary arm interferometer. It utilizes a SOA that is put unevenly situated in fibre circle. The optical coupler (50:50) is used to join the two end of fibre to form a loop. Here we denote the incoming signal as IS from a CW signal of wavelength λ_1 (generally it is of 1500nm), which divides into two equivalent parts. One is counter clockwise parts and other is clockwise parts. These two sections spread around the circle inverse way to one another and reconsolidate at coupler. Depending upon the segment distinction among clockwise and counter clockwise beats, valuable or damaging obstruction happens. Stage distinction preserves by pertaining beat light emission of wavelength λ_2 from another CW signal (generally 1550nm of wavelength). This signal passes through a Ti:LiNbO3 electro-optic modulator driven by NRZ pulse generator. After that it is amplified by erbium doped fiber amplifier (EDFA) followed by variable optical attenuator (VOA). At every stage polarization of the intense pulse can be controlled by polarization controller (PC). The final signal (CP) mixing can be done by a coupler with the other IP clock wise pulse. Coupler is attached in the fibre circle as demonstrated in Fig.1(a). Data signals and Gaussian signal of full-width half maximum (FWHM) = σ are applied at almost alike point in time. Semiconductor optical amplifier is put unevenly in the fibre circle. The asymmetric distance is $\Delta x = T_{ex}/2$ (T_{ex} is the eccentricity time). Due to this asymmetric counter clockwise and clockwise parts proliferate dissimilar times throughout semiconductor optical amplifier. This timing difference creates different phase between the counter clockwise and clockwise parts. As a result constructive or destructive interference occurs at the input coupler. According light can reach at upper or lower port [3, 4, 10].

$$P_{Upper}(t) = \frac{P_{IS}}{2}\left\{C(t) + C'(t) - 2\sqrt{C(t)\cdot C'(t)}\cdot\cos\left(\Delta\theta\right)\right\} \tag{1}$$

$$P_{Lower}(t) = \frac{P_{IS}}{2}\left\{C(t) + C'(t) + 2\sqrt{C(t)\cdot C'(t)}\cdot\cos\left(\Delta\varphi\right)\right\} \tag{2}$$

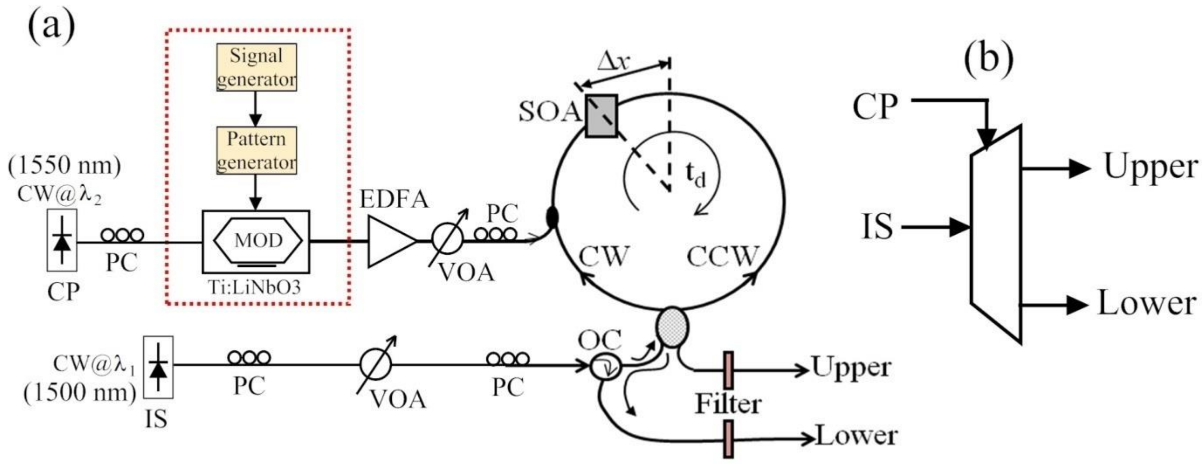


Fig. 1. (a) Optical switch based on TOAD (b) Schematic diagram of TOAD

where, *C(t)* and *C'(t)* measure the SOA gain for clockwise and anticlockwise signal respectively. Between the counter clockwise and clockwise parts creates a phase difference, which is numerically communicated as [11-15],

$$\Delta\theta = -\frac{\alpha}{2}\ln\left\{\frac{C(t)}{C'(t)}\right\} \tag{3}$$

Here linewidth enhanced factor is α. Here we consider that SOA is wavelength independent and its unsaturated gain G_U is [12]

$$G_U = e^{L\left[\Gamma g_d N_c\left(\frac{I\tau_r}{e\omega l L N_c} - 1\right) - \Upsilon\right]} \tag{4}$$

Where g_d = differential gain, Γ = confinement factor, L = active length of SOA, N_c = carrier density at transparency, I = biasing current of SOA, τ_r = recovery time of SOA, e = charge of electron, ω = width of active region of SOA, l = depth of active region of SOA, Υ = SOA internal loss per unit length. When control pulse (CP) is OFF i.e., absence of control pulse, information signal (approaching signal parts CW and CCW) reaches to SOA by dissimilar times. Therefore one of the pulse experience an unsaturated little amplifier acquire G_U. As a result when the pulses recombine at the input coupler i.e. *C(t)* is nearly equal to *C'(t)*. At that point, $\Delta\theta$ is almost equal to 0 and articulation for P_{Upper} is nearly equal to 0 and P_{Lower} is equal to $P_{IS}(t).G_U$. So the input signal is returned back around the source. This returned back pulse can be segregated by a circulator. This circulator is named as optical circulator (OC). When a control pulse is infused into fibre loop, after the time t_s it penetrates SOA and alters its benefit as [11, 12],

$$G(t) = \frac{1}{1 - \left(1 - \frac{1}{G_U}\right) \cdot e^{\left(-\frac{E_{cp}(t)}{E_{sat}}\right)}} \tag{4}$$

$E_{cp}(t)$ is control pulse energy.

When CP is infused into the fibre loop then the gain of SOA decreases rapidly as $G'(t) = e^{f(t)}$ and $f(t)$ can be determined by the ordinary differential equation as [12],

$$\frac{df(t)}{dt} = \frac{\Gamma g_d N_c L\left(\frac{I\tau_r}{e\omega l L N_c} - 1\right) - f(t)}{\tau_r} - \frac{P_{in}(t)}{E_{sat}}\left(e^{f(t)} - 1\right) \tag{5}$$

Then, $\Delta\theta$ is nearly equal to $-\pi$ then the information egress from the upper line i.e. $P_{Upper}(t)$ is equal to 0 and $P_{Lower}(t)$ is not 0, the comparing esteems can be gotten from the conditions (1) and (2), separately. In a short time the gain of SOA recuperates owing to carrier insertion into SOA by recovery time τ_r. The energy of the incoming signal is about one-tenth time less than that of the control pulse, A band pass filter alter ought to be utilized at the yield of TOAD based change to dismiss the CP and pass the IS. The block diagram of a TOAD is appeared in Fig.1(b). For optimum performance of TOAD based interferometic switch must follow the relation: $\sigma < T_{ex} < 0.5T_c < \tau_r < 1.5T_c$, where T_c is the cycle period.

3. Division-by-2 cum 1's complement

In the above section we notice when CP is applied to TOAD, at that point IS is communicated to upper line. At that time, no information is found at the lower line. If control pulse is absent, the IS is coordinated to the lower line and at that time no information is exposed to the upper line. We can plan *n*-bit division-by-2 circuit utilizing n no. of TOADs that is appeared in the Fig.2. In this communication we utilize all the output line (upper and lower) of the TOADs. $(A_nA_{n-1}...A_1A_0)_2$ are n-bit inputs of wavelength λ_1. Upper ports yield all TOADs structures division-by-2 yield as $(D_nD_{n-1}...D_1D_0D_{-1})_2$, where D_{-1} is the fractional part. Likewise $(C_nC_{n-}...C_1C_0)_2$ are the 1's complement, which are taken from lower lines of all TOADs. IP of wavelength λ_2 are supplied from steady light source.

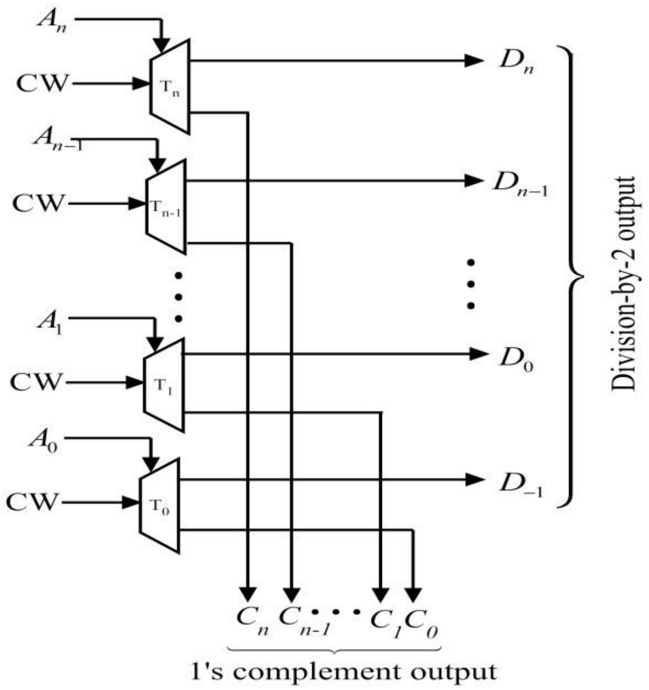


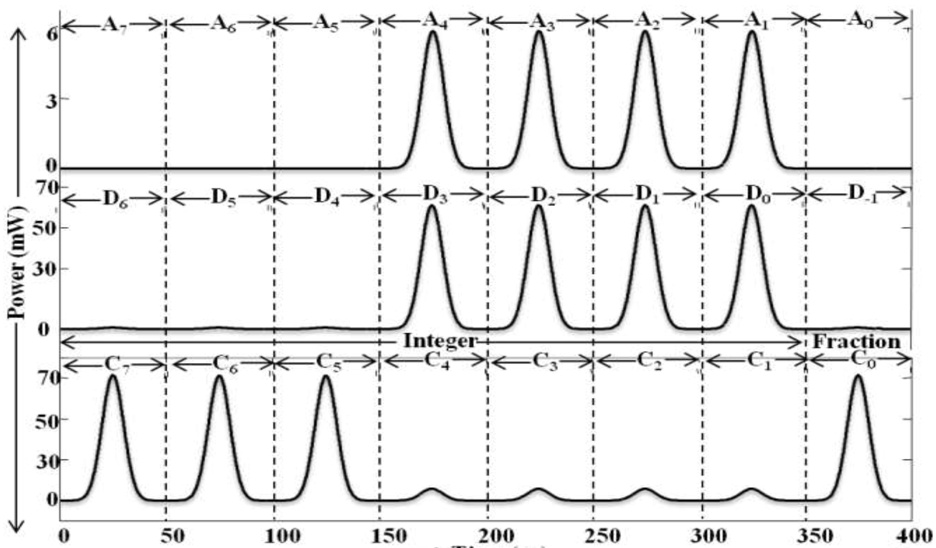
Fig. 2. All-optical division-by-2 cum 1's complement conversion circuit using TOAD. $(A_nA_{n-1}...A_1A_0)_2$ is input number, division-by-2 output is $(D_nD_{n-1}...D_0D_{-1})_2$, where D_{-1} is fractional bit, $(C_nC_{n-1}...C_1C_0)_2$ is 1's complement output.

The activity of the proposed circuit can be seen with any problem. One test set makes the activity clear to each one. Let us consider we have a 4-digit information $(A_3A_2A_1A_0)_2 = (1011)_2$. Now our task is to convert is information to its equivalent to 1's complement and furthermore divide it by 2. These info pieces are given as CP to TOADs (T_0, T_1, T_2 and T_3). At that point as indicated by the exchanging rule of TOAD, CW information of TOADs T_0,

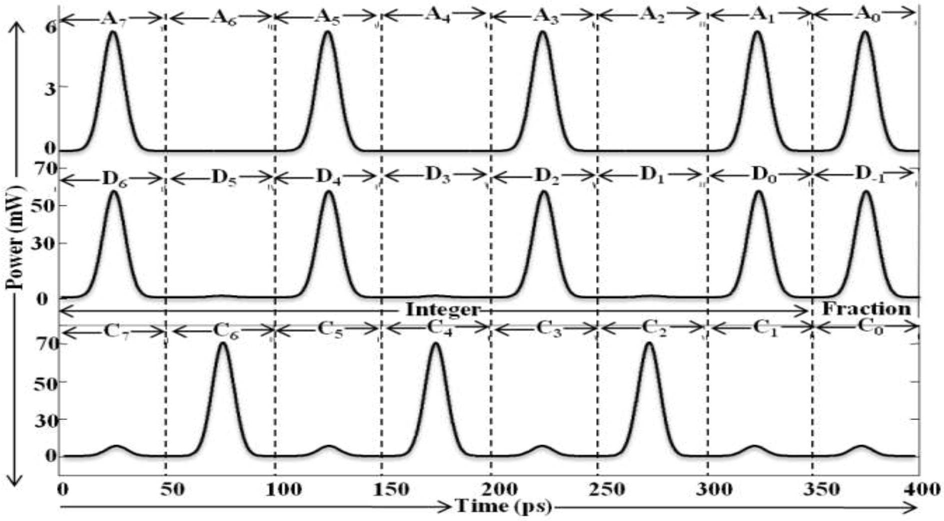
T_1 and T_3 are sent to the upper line. Additionally in TOAD (T_2), information corresponds to the lower line. Henceforth we acquire yields $(D_2D_1D_0D_{-1})_2$ = $(101.1)_2$ and $(C_3C_2C_1C_0)_2$ = $(0100)_2$, which are the division-by-2 what's more, 1's complement of the information parallel information $(1011)_2$ separately.

4. Results and discussion

Numerical simulation with MATLAB has been carried out using different parameters used in simulations and experiment of various papers [15-17]. The estimations of the different boundaries utilized in this reproduction are as per the following: I=400mA, Γ=0.48, g_d = 3.3×10^{-20} m^2, $N_c = 1.0\times10^{24}$ m^{-3}, ω =1.5 μm , l=250 nm , L=1500 μm , Υ =2700 m^{-1}, unsaturated amplifier gain of the SOA (G_U) = 30 dB, acquire recuperation season of the SOA (τ_r) = 50 ps, immersion energy of the SOA (E_{sat}) = 1000 fJ, unconventionality of the circle (T_{ex}) = 15 ps, FWHM of the control pulse (σ) = 3.6 ps, line-width upgrade factor (α) = 6, cycle period (T_C) = 50 ps, and a control pulse energy (E_{cp}) = 100 fJ. The input and output waveforms for six sets of data are given in Fig. 3(a) to 3(f). Parallel input $(A_7A_6A_5A_4A_3A_2A_1A_0)_2$ is given to the circuit as CP of the TOADs T_7 - T_0 individually. Simultaneous outputs are obtained at the O/P ports parallel manner. Hence the O/P $(D_6D_5D_4D_3D_2D_1D_0D_{-1})_2$ check consequences of division-by-2 furthermore, $(C_7C_6C_5C_4C_3C_2C_1C_0)_2$ check the 1s complement activity for the given information. We also plot the gain variation with the used input data for 8-TOAD based interferometric switch in Fig.4.

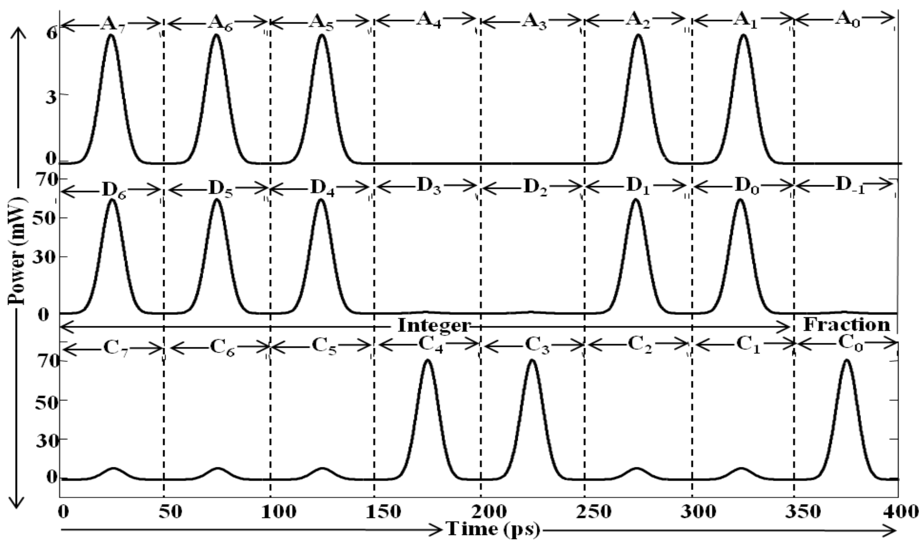


(a)



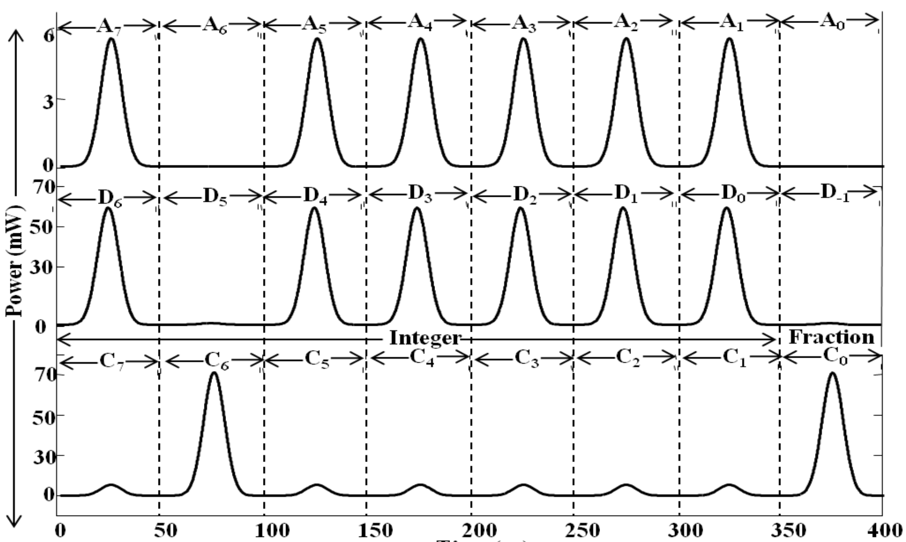
Power (mW)
Time (ps)
Integer
Fraction

(b)



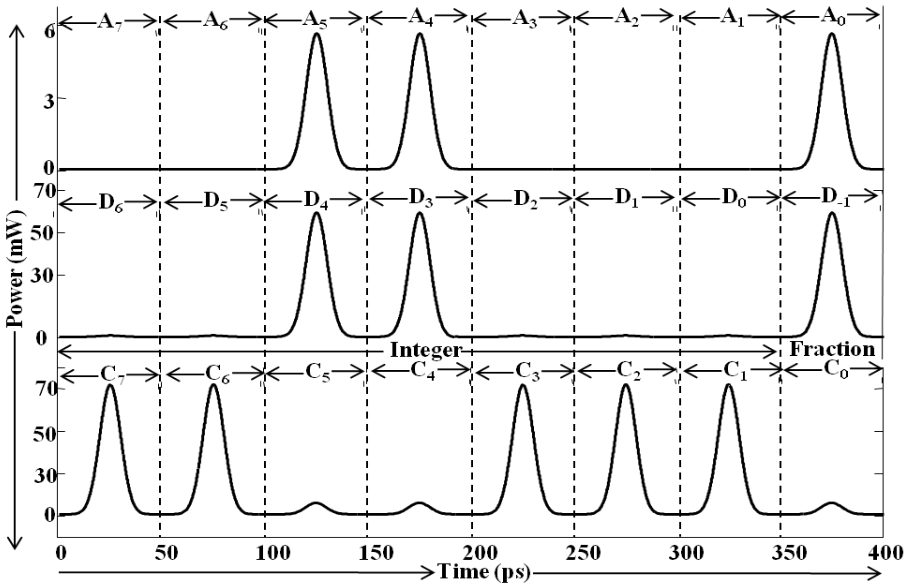
Power (mW)
Time (ps)
Integer
Fraction

(c)

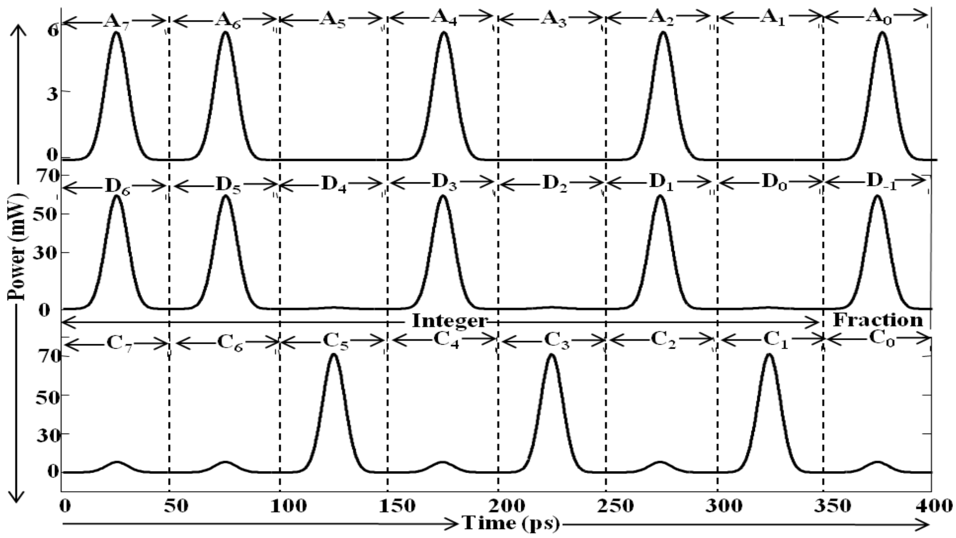


Power (mW)
Time (ps)
Integer
Fraction

(d)



(e)



(f)

Fig. 3. Simulated input and output waveforms, (a) input is $(00011110)_2$, division-by-2 output is $(0001111.0)_2$ and 1's complement output is $(11100001)_2$, (b) input is $(10101011)_2$, division-by-2 output is $(1010101.1)_2$ and 1's complement output is $(01010100)_2$, (c) input is $(11100110)_2$, division-by-2 output is $(1110011.0)_2$ and 1's complement output is $(00011001)_2$, (d) input is $(10111110)_2$, division-by-2 output is $(1011111.0)_2$ and 1's complement output is $(01000001)_2$, (e) input is $(00110001)_2$, division-by-2 output is $(0011000.1)_2$ and 1's complement output is $(11001110)_2$, (f) input is $(11010101)_2$, division-by-2 output is $(1101010.1)_2$ and 1's complement output is $(00101010)_2$.

To quantify our designed, we figure the extinction ratio (ER) as [13],

$$ER(\text{in dB}) = 10\log\left(\frac{P^1_{\min}}{P^0_{\max}}\right) \tag{6}$$

where P^1_{min} and P^0_{max} is the base and most extreme pinnacle force of the '0 states also, '1 states, separately. For superior, ER ought to be at any rate in the request for 8.5 dB. ER value tells that '1 states can be obviously recognized from the '0' states. The circuit performs depend on SOA acquire recuperation and energy of CP.

The effect of the addition recuperation and energy of CP on the ER is delineated in Fig.5. It is observed that ER increments with expanding energy of CP and acquire recuperation time up to a specific worth (~100 fJ and ~100 ps) after which ER is diminished. It is likewise seen from Fig. 5, high addition recuperation time and the energy of CP decreases the ER. This justified by acquire dynamic reaction of SOA. For high addition recuperation time, beat requires more opportunity to recuperate its underlying increase which decreases the ER. The immersion energy lessens with diminish of gain recuperation time for fixed immersion power. That is the reason less energy is needed to soak the SOA.

A fundamental boundary that influences the exhibition of circuit is that the component of the optical pulse. Fig.6 shows the impact of gain recuperation time and input data measurement on the ER. It clarifies that the ER diminishes with diminishing heartbeat measurement and gain recuperation time. This happens because of a proceeding with lopsidedness; all together that the SOA needs more to recuperate its benefit and gives the compulsory alteration of segment. The ER becomes steady once some specified cost of gain recuperation time and heartbeat measurement. A specific ER will be accomplished with less energy for a more limited pulse measurement.

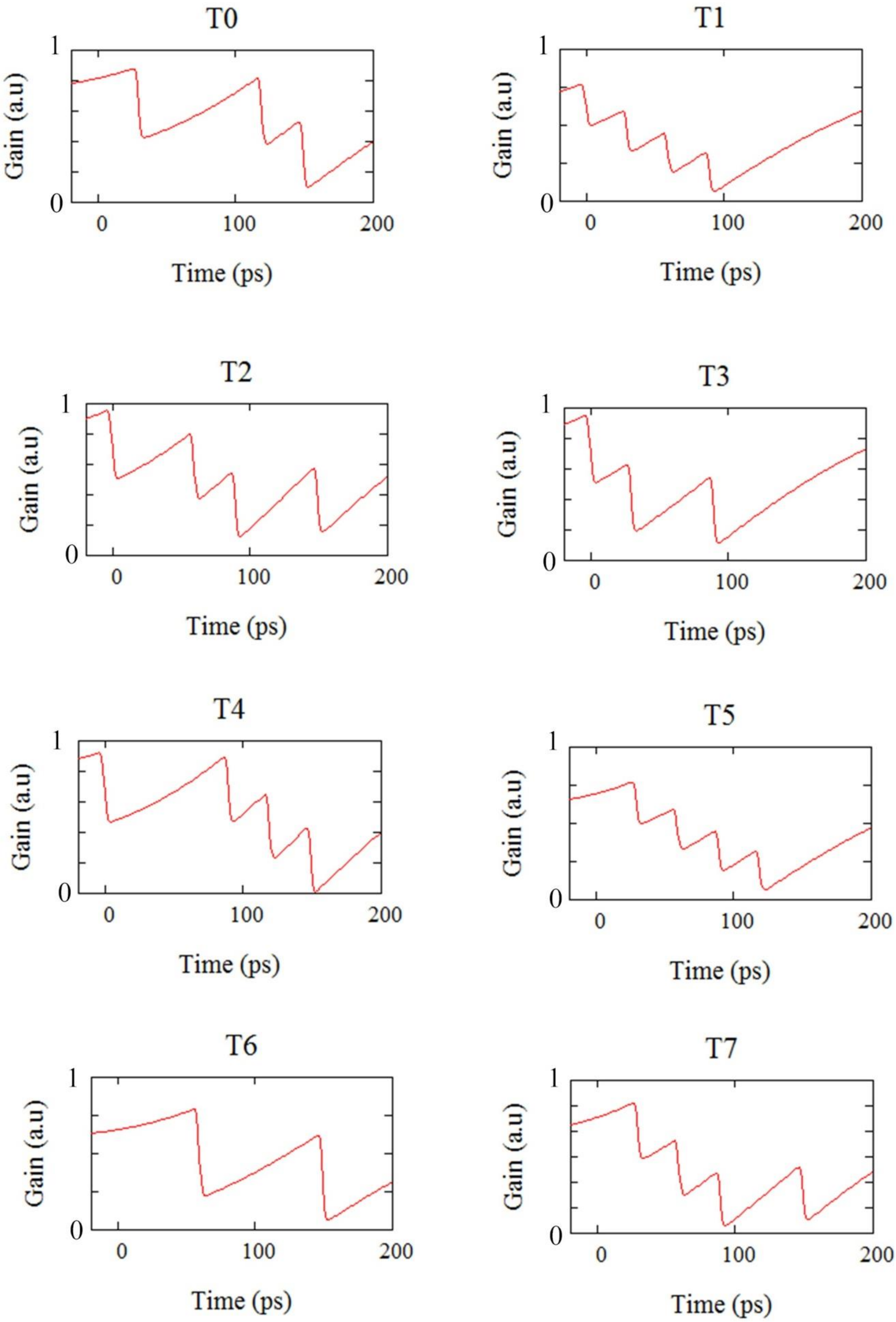


Fig. 4: Simulated gain variation of SOA of TOAD T0 to T7 with used control data pulses.

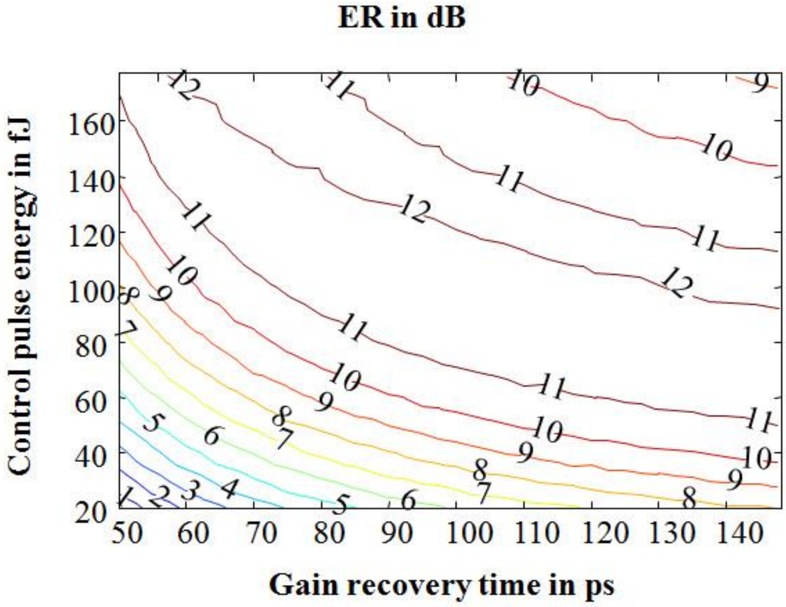


Fig. 5. Variation of ER with gain recovery time and energy of CP at the outputs, while keeping other parameter fixed.

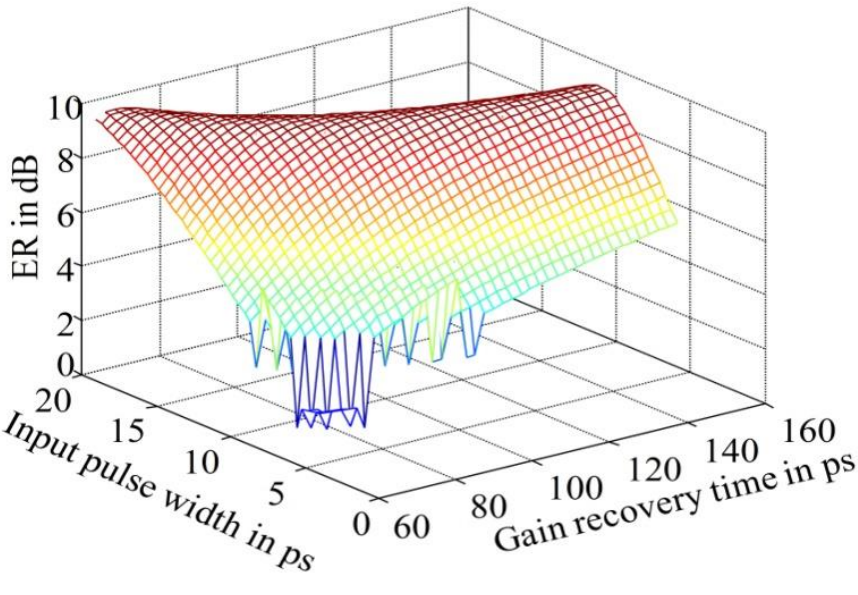


Fig. 6. Variation of ER with pulse width and recovery time at the outputs.

To assess the presentation of the circuit significantly required estimating boundary is contrast ratio (CR). Here, contrast proportion boundary is utilized for the examination. It is the effectiveness through which the communicated optical power is balanced over the correspondence connects. It is picked as an another improvement model, communicated as relationship of the power used in sending a rationale level 'one' to the power used in sending rationale 'zero'. This could be portrayed as the proportion of least O/P peak power of '1' to most extreme O/P peak power of '0' in dB (decibel), defined as

$$CR(\text{in dB}) = 10\log\left(\frac{P_{mean}^{1}}{P_{mean}^{0}}\right) \tag{7}$$

Where, P^1_{mean} and P^0_{mean} is that the standard of the stature force of '1' and '0, respectively. We tend to ascertain the C.R (dB) from condition (7) and it gets 15.62 dB. A significant issue that affects the exhibition of circuit is that the optical pulse width. Fig.7 shows the variety of qualification quantitative connection on pulse broadness and recuperation time. The estimation of CR is about 15.62 dB for the specified little sign increase of approximate twenty dB and the executives pulse energy of about 100 fJ, individually. Figure clarifies that the CR diminishes with diminishing both recuperation time and pulse width. The CR component keeps up consistent once some specified pulse broadness and recuperation time. Henceforth an exact CR esteem gets with less energy for a more limited pulse width. This occurs because of a more limited pulse goes quicker through the SOA upgrading so the fast consumption of transporters and prompting a vessel progress from the lower to the higher immersed acquire values. We tend to thoroughly dole out the value of pulse broadness and gain recuperation time with the goal that the circuit execution is better.

We define amplitude modulation (AM) as

$$AM\,(\text{in dB}) = 10\log\left(\frac{P_{\max}^{1}}{P_{\min}^{1}}\right) \tag{8}$$

where P^1_{max} and P^1_{min} is the greatest and least peak power of the 1-states, separately. Fig. 8 showed the progressions of AM with different energy of CP and gain recuperation time. The AM is tremendously vulnerable to the varieties of gain recuperation time. Notwithstanding, explicit consideration is taken all together that it ought to be a few specific limit in any case design impacts happen at the output of the circuit.

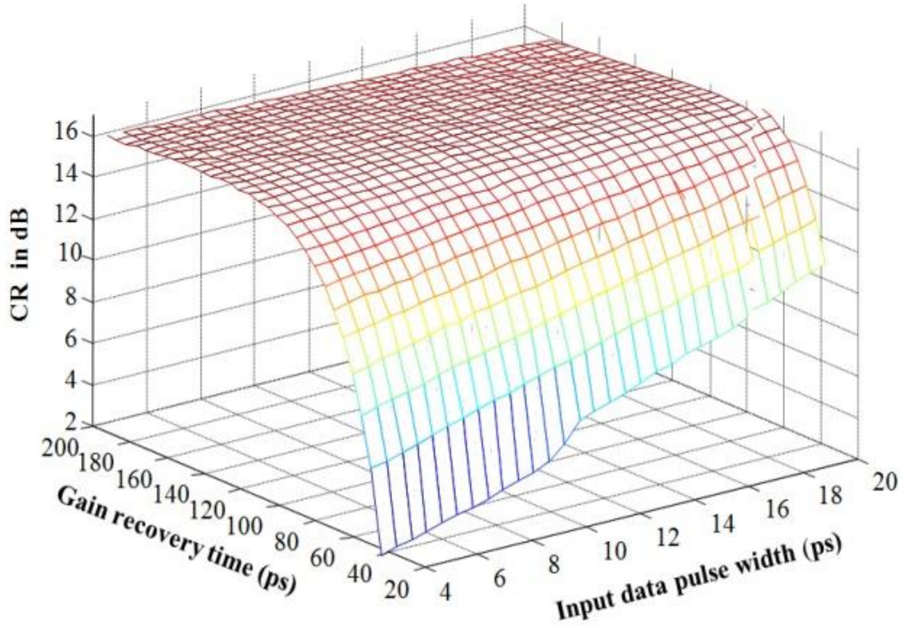


Fig. 7. Variation of CR with pulse width and gain recovery time at the different outputs.

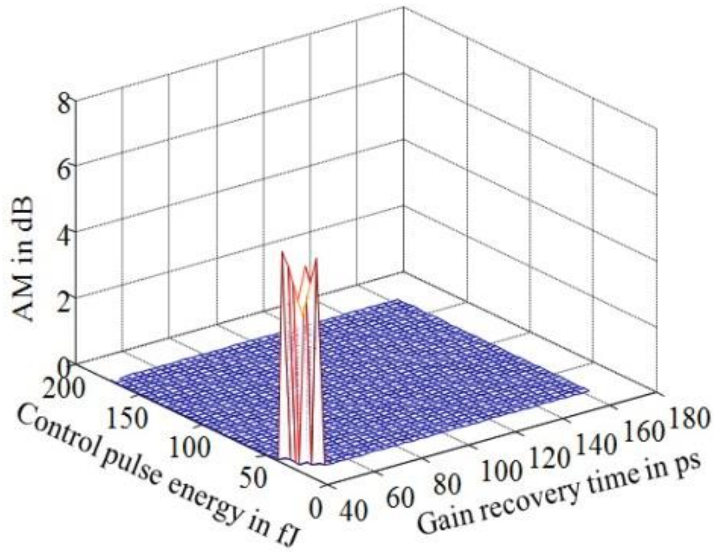


Fig. 8. Variation of AM with gain recovery time and energy of CP and at the different outputs.

Q factor is another performing estimating component of the optical circuit. The *Q* factor can be expressed as,

$$Q = \frac{P^1_{mean} - P^0_{mean}}{\sigma^1_{std} + \sigma^0_{std}} \quad (9)$$

where σ^1_{std} and σ^0_{std} are the standard deviation of the peak power of the 1-states what's more, 0-states, individually. Fig.9 shows the variety of the Q-factor on energy of CP with different the pulse width. From this figure, we see that Q-factor increments with expanding of the pulse width since it requires considerably more an ideal opportunity to travel SOA by the control pulse.

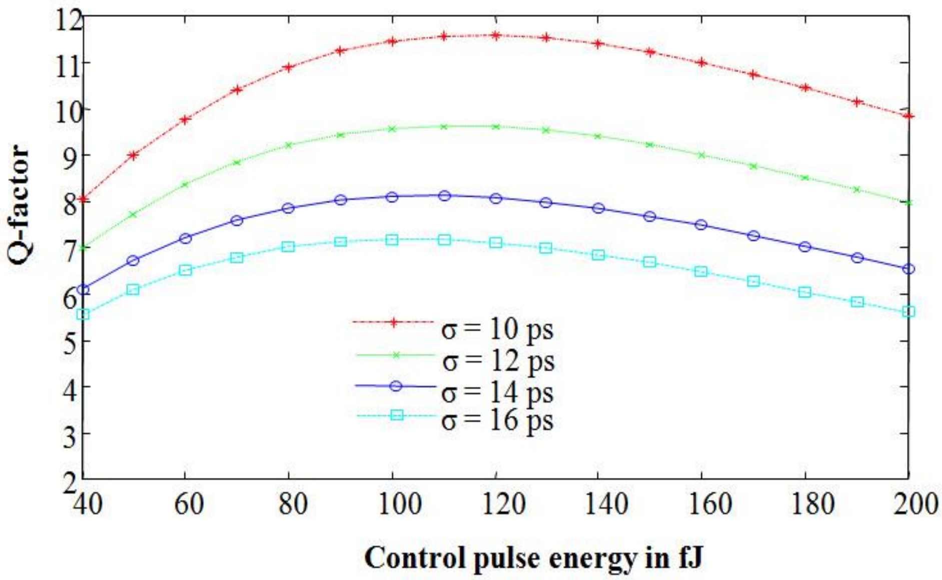


Fig. 9. Variety of Q-factor as a component of energy of CP with various pulse widths at the various O/Ps.

From Figs. 5-9 and their clarifications, we select estimations of the different boundaries as T_{ex} = 30 ps, G_{ss} = 20 dB, α = 6, τ_e = 100 ps, E_{sat} = 1000fJ, E_{cp} = 100 fJ and σ = 12 ps individually, which isn't fixed and stays inside the specified limits. At that point utilizing these qualities all through the recreation, we can get ER = 11.51 dB, CR = 15.62 dB, AM = 0.05 dB, and Q = 8.13 at the O/Ps. To plan n-bit circuit, we require n-no. of TOADs, *n*-inputs. The circuit has 2*n*-quantities of O/Ps, among them *n*-output bits addresses 1's complement results (C_n to C_0) and (*n* - 1) bit represents the integer bits (D_n to D_0) of the division-by-2 output and 1-bit (D_{-1}) for fractional bit.

5. Conclusion

We have proposed and mathematically showed a straightforward plan of synchronous all-optical division by 2 and 1s supplement at 20-Gbit/s utilizing TOADs. The circuit is planned hypothetically and verified through mathematical recreations. Here, by leading mathematical recreation, study precise the necessities for the control pulse energy, acquire recuperation time and information pulse width with the goal that the extinction ratio, contrast ratio, amplitude modulation and Q factor is acceptable. In this proposed plot, the extinction ratio is about 11.51 dB, contrast ration is about 15.62 dB, amplitude modulation is about 0.05 dB, and Q-factor is 8.13 at the O/Ps. The benefit of the designed is all-optical in nature and can be stretched out to n-bit without any problem.

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