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ALL-OPTICAL FEYNMAN GATE USING REFLECTIVE SEMICONDUCTOR OPTICAL AMPLIFIERS AND BINARY TO GRAY CODE CONVERTER

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Abstract

Design and numerical demonstration of all optical Binary to Gray code converters are presented. The basic building block is reflective Semiconductor Optical Amplifier (RSOA) based Feynman gate. The performance of Feynman gate is analyzed by calculating quality factor (QF), Bit error rate (BER), relative eye opening (OP). The effect of Amplified Spontaneous Noise (ASE) is also considered on the QF value. The large eye opening of the Fredkin gate implies efficient operation of the gate. Performance of the code converter is also described in terms of truth table.

1. Introduction

All optical digital processing is highly demanding requirements for next generation communication and computation systems as far as the speed and reliability is concerned. Great efforts in this field of research are necessary for the implementation of systems with ultrafast speed of operation. Optoelectronics or rather all-optical (because the speed of fiber optic components is limited by some electronic components) technologies can give speed beyond electronic bottleneck. Optical amplifiers are replacing electrical regenerators in telecommunication networks. Demand of high-speed internet and merging different dedicated networks in integrated services digital network (ISDN) performances can be improved with the help of optical

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technologies. Optical switching will play a major role in these developments. So various kinds of all optical systems like logic gates [1-3], flip-flops and random access memory [4], arithmetic logic operations [5] etc are proposed in last few years using different kinds of optical switching. RSOA is a versatile gain media and can be utilized for designing all optical logic processors [6-8] and have higher gain at lower injection current compared to ordinary Semiconductor Optical Amplifiers (SOAs) due to its special construction feature with antireflection (AR) coating at one end and highly reflecting(HR) coating on the other end as shown in the figure 1.

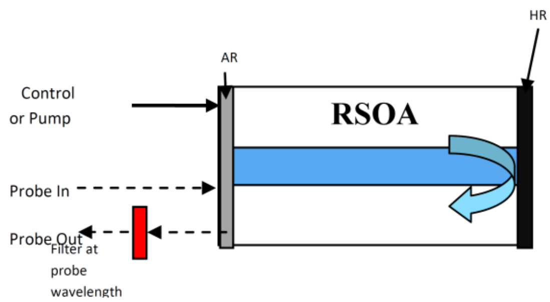


Figure 1. Reflective SOA (RSOA).

Due to this configuration, a signal double passes the RSOA length and gets amplified twice which giving better performance although its waveguide structure is same as ordinary single pass SOA. RSOAs have low noise figure, and high optical gain for low drive current, and can be easily saturated at low optical powers [8]. So all-optical processors shows better performance compared to single pass SOA [2]. In [2], the basic mechanism of the operation of the X-OR gate is cross phase modulation in inter ferometric structure, but in this present communication cross gain modulation (XGM) is modeled to analyzing the performance of the proposed Feynman gate. In [6], the logic processors implemented are complex in structure and RSOAs are only used for wavelength conversion purpose. In [7, 8] RSOAs find application as modulator of the signals for passive optical networks (PON). In this communication for the first time, an RSOA based Feynman gate based on RSOA with simple structure is numerically demonstrated and used to implement code converters from Binary to Gray. Gray code is very important for communication system because it minimizes adjacent decision bit errors [9].

2. Operating Principle of the RSOA Optical Switch and Feynman Gate

The basic mechanism of the working of the Feynman gate is XGM between high intensity pump and low intensity probe signals (Figure.1). When the control signal is absent, the probe signal experiences unsaturated RSOA gain and amplified. This results in high output power. However, in the presence of control signal, the gain of the SOA becomes compressed and the probe signal experiences lower gain. This results in low output.

The compressed or low output is given by,

$$P_1(t) = G(t)P_{in}(t). \tag{1}$$

The uncompressed output is given by,

$$P_2(t) = G_0^2 P_{in}(t). \tag{2}$$

Where $G(t)$ is double pass gain in the presence of control pump, and G_0 is the uncompressed single pass gain. In equations (1) and (2), the facet reflectivity of HR coating is taken $R = 1$. For moderate pump powers $G(t) << G_0$, giving P_2 very low compared to P_1 and very good switching compared to single pass SOA.

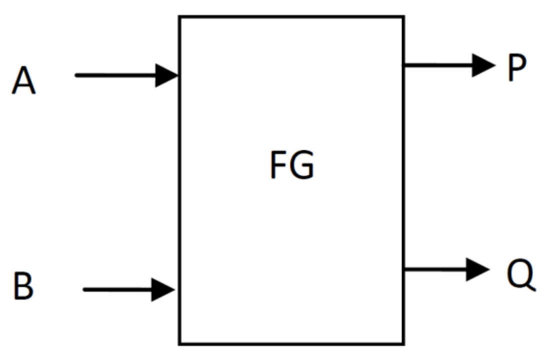


Figure 2. Feynman gate.

The block diagram of the Feynman gate (FG) is given in the figure 1. It is a two input two output gate, and the output are given by $P = A.$ and $Q = A$ X-OR B is the building block of proposed Binary to Gray code converter [10].

In the figure 2 below Feynman gate based on RSOA is shown. Here A and B are two pump signals used as input of the gate. A fraction of these signals are used as data signal to the alternative SOAs. The pump and data signals have different wavelengths, 1550 nm and 1555nm. This also confirms that input A and B have different wavelengths. F are the filters at wavelengths corresponding the data signals of RSOA1 and RSOA2. Let us explain the operation of the Feynman Gate using soliton pulses as inputs given by [3]

$$P_{cp}(t) = \sum_{n=1}^{n=N} a_{nA,B} P_{soli} \sec h^2\left(1.763 \frac{(1 - n\chi)}{\tau_{f_{whm}}}\right), \tag{3}$$

where P_{soli} is the soliton peak power. D is the dispersion constant. n_2 is the nonlinear coefficient. λ and c are the wavelength and velocity of light. A_{eff} is the fiber effective area. $\tau_{f_{whm}}$ is the full width half maximum. E_c is the total control pulse energy.

Case 1. When both A and B are low or '0', there are no pump signals (Control) or data signal to both the RSOAs. Therefore, the outputs P and Q are both low, i.e. '0'.

Case 2. When A is low ('0'), and B is high ('1'), there is gain saturation at RSOA2 (gives low gain), and RSOA1 has unsaturated high gain. In this condition, RSOA1 receives data signal but RSOA2 not. Therefore, RSOA1 gives a high output but RSOA2 does not give any light. So the final outputs P is low and Q is high.

Case 3. When A is high ('1'), and B is low ('0'), there is gain saturation at RSOA1(gives low gain), and RSOA2 has unsaturated high gain. In this condition, RSOA2 receives data signal but RSOA1does not. Therefore, RSOA2 gives a high output but RSOA1 does not give any light. Therefore, the final outputs P is low and Q is high again.

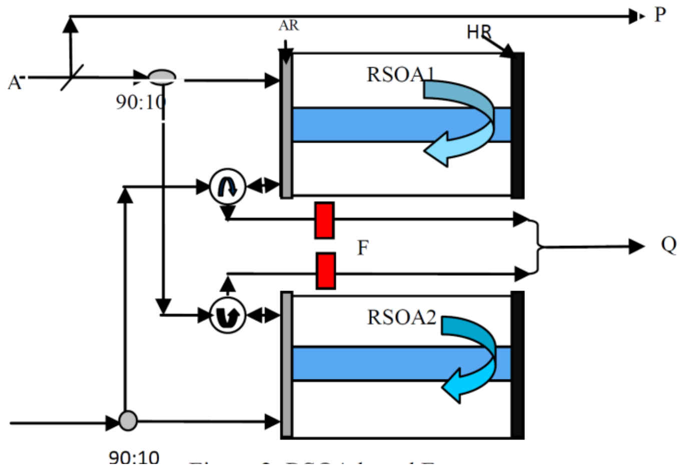


Figure 3. RSOA based Feynman Gate.

Case 4. When both *A* and *B* are high or '1', there are pump signals (Control) and data signal to both the RSOAs. Therefore, the output *P* is high i.e.'1'. Since both the RSOAs receive control signals, there are gain saturations in both the RSOAs. So both RSOA gives low output resulting in low signal intensity at *Q*. Therefore, the above module of figure 2 has truth table of a Feynman gate as shown in Table 1 below.

Table 1. Truth table of a Feynman Gate.

Inputs		Output	
A	*B*	*P*	*Q*
0	0	0	0
0	1	0	1
1	0	1	1
1	1	1	0

3. Operation of Binary to Gray code Converter

The basic building block of the Binary to Gray code converter is the Feynman gate described above. In the figure 3, Binary to Gray code Converter is shown using Feynman gate (FG) as building block. In the table 2, the truth table for binary to Gray code converter is shown.

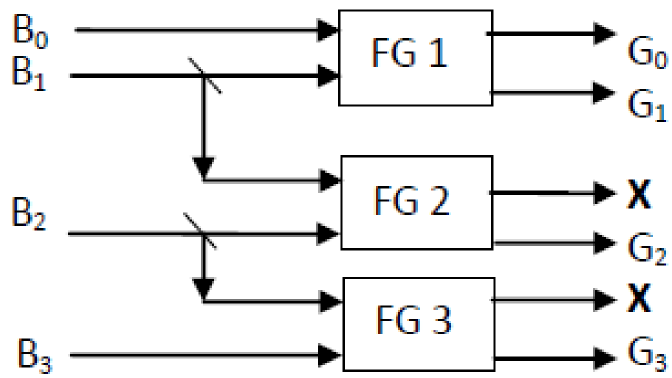


Figure 4. Binary to Gray Code Converter.

Logically, the binary number $B_3 B_2 B_1 B_0$ and its Gray code version $G_3 G_2 G_1 G_0$ is related by $G_0 = B_0$, $G_1 = B_0$ (X-OR) B_1, $G_2 = B_1$ (X-OR) B_2 and $G_2 = B_2$ (X-OR) B_3 is clear from the truth table 2. So the binary to Gray code converter can be easily realized by Feynman Gates (FG1 to FG3) as shown in the figure 3. In the figure 3, the output of the Feynman gates marked with 'X' are not used.

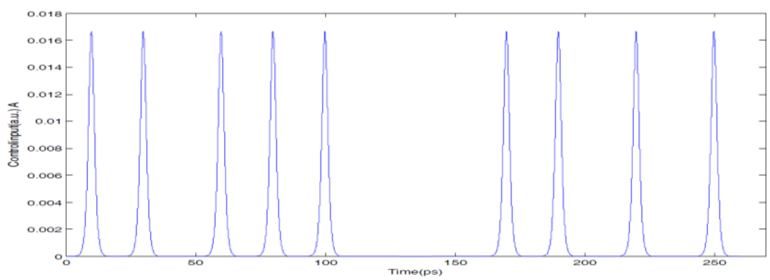
Table 2. Truth table for binary to Gray code converter.

Binary Coded Number				Gray Coded Number			
B_3	B_2	B_1	B_0	G_3	G_2	G_1	G_0
0	0	0	0	0	0	0	0
0	0	0	1	0	0	0	1
0	0	1	0	0	0	1	1
0	0	1	1	0	0	1	0
0	1	0	0	0	1	1	0
0	1	0	1	0	1	1	1
0	1	1	0	0	1	0	1
0	1	1	1	0	1	0	0
1	0	0	0	1	1	0	0
1	0	0	1	1	1	0	1
1	0	1	0	1	1	1	1
1	0	1	1	1	1	1	0
1	1	0	0	1	0	1	0
1	1	0	1	1	0	1	1
1	1	1	0	1	0	0	1
1	1	1	1	1	0	0	0

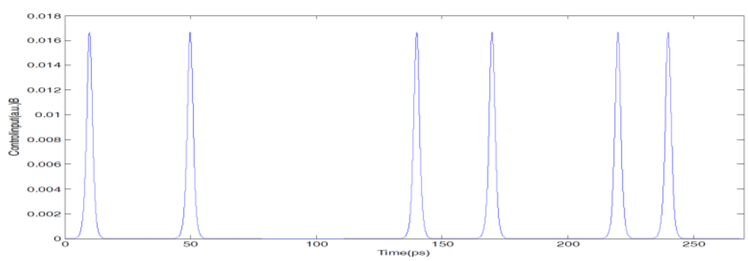
4. Simulations and Results of Operations

Equations (1) and (2) along with the gain expressions given in [3] are used to simulate the proposed Feynman Gate and the binary to Gray code converters. In the figure 4, the input A and B of the Feynman gate and outputs P and Q of the same is shown. The powers shown in the Figure 4 are in mW. Figure 5 shows pseudo eye diagram (PED) of the Q output of the Feynman Gate. An eye opening of nearly 87% is calculated from the figure 6. The quality factor (QF) of the Feynman gate is investigated for amplified spontaneous noise(ase) performance using the relations [1,2], $QF = 10\log[(P_1 - P_0)/(S_1 - S_0)]$, and $P_{ase} = n_{sp}(G-1)hc\,B/\lambda$, where

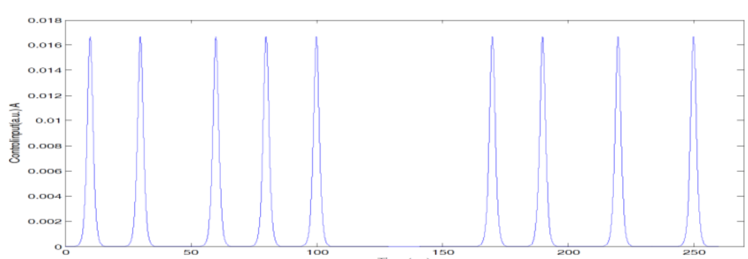
$P_1(P_0)$ and $S_1(S_0)$ are average peak powers and standard deviations of high (low) states of the Q output of Feynman gate, n_{sp} is amplified spontaneous noise parameter, G is the unsaturated RSOA gain, h, the Planck's const, c is velocity of light in free space, B is the band width and λ is the wavelength of the optical signal. A quality factor more than 73 is calculated using the outputs powers of the bit stream Q shown in the figure 4(d). The parameters used in this simulation are same as used in [2].



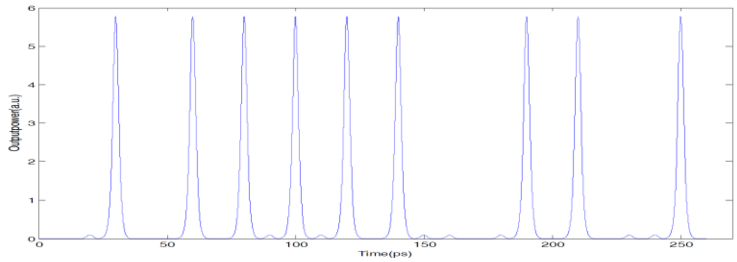
(a) $A = 110111000110101$.



(b) $B = 101000010100110$.



(c) Output $P = A$.



(d) Output $Q = A$ X-OR B.

Figure 5. (a). Input Bit Stream for *A*, (b). Input bit stream for B, (c). Output beat stream for Output P, (d). Output bit stream for Output *Q*.

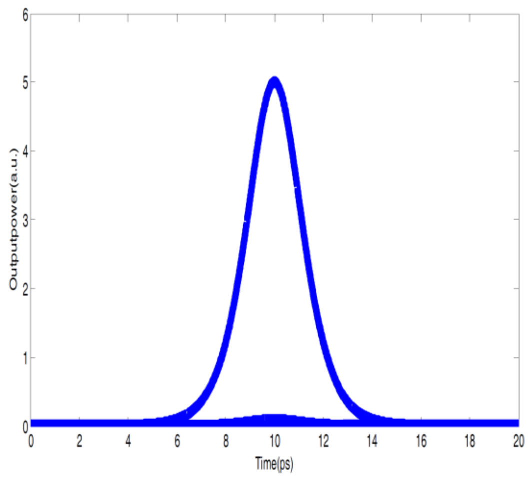


Figure 6. Pseudo Eye Diagram.

The variation of QF with nsp is shown in the figure 7. It shows that for high injection current (high unsaturated gain), there is decrease in quality factor with n_{sp}. *H* is because for high injection current, gain is high and ASE noise becomes significant causing significant patterning effect in the '0' state of the circuit. The bit error rate (BER) is defined by complementary error function (erfc) as [2], Bit Error Rate = 0.5 erfc(QF/√2), and because of high QF value (more than 73), nearly errors transmission is possible.

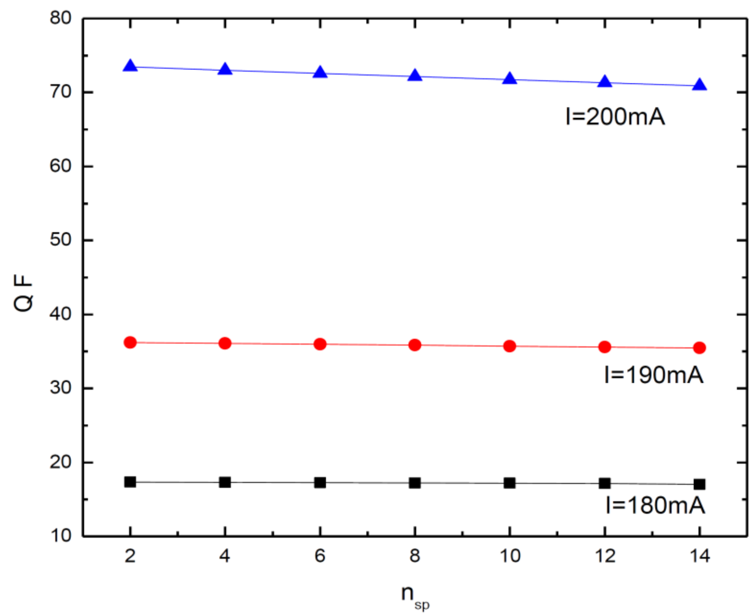


Figure 7. Variation of QF with nsp.

As an application of the Feynman gate we have proposed Binary to Gray code converter shown in the figure 3. The operation of the converter is shown in the figure 8. Similar results of operation of the code converter is also expected since it is based on the proposed Feynman gate.

5. Conclusions

All optical Feynman gate using RSOA is proposed and numerically demonstrated by Matlab. The logic gate uses soliton pulses as input bit stream. Using Feynman gate All-optical Binary to Gray code converter is proposed, the details simulation of which may be our future communications. High quality factor, low bit error rate and large eye opening ensure efficient performance of the gate and code converter also.

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