Performance estimation with optical full adder link at 80Gbps data rate

DEVENDRA KUMAR TRIPATHI*
Dept. of Electronics and Communication Engineering, S.I.E.T Allahabad-U.P, India

This article explored performance investigation for all optical full adder link with non return to zero pattern. Accordingly, the sum and carry patterns for applied data inputs verified at 80Gbps data rate, outcome with 12 dB and 15 dB extinction ratio correspondingly. Numerical simulations executed for the key design parameters, depict excellent performance with modulators bias voltage above 2 volts, SOA pump current as 0.2A for sum, 0.1A for carry operation and current injection efficiency as 2, with active length of SOA for range of data rates. This exploration could further aid towards advanced complex computing networks.

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Keywords: All optical networks [AON], Super-fast arithmetic logic unit (SFALU), Ultrafast nonlinear interferometers (UNI), Priodically poled lithium niobate (PPLN), Semiconductor optical amplifier (SOA)

1. Introduction

Signal processing is one of the significant operations in the present era for efficient communication. Accordingly numerous communication techniques have been devised in past in conjunction with their pertinent pros and cons [1]. Presently, owing to rising internet applications there is growing demand of high transmit rate communication networks. This could be a foremost reality with erection of all optical networks (AON). As optical fibre networks endow with abundant benefits and established mode of data transportation, can compete with growing trend of high speed data transportation. This could be feasible if all of the controlling and switching nodes are completely photonic. Photonics can be a significant means of information sharing along with offered matchless speed and inclusive of data package in a signal of zero mass. Further, optical computing techniques can efficiently resolve the restrictions beyond the computational speed and complexity inherent in the electronics computing. So presently there is growing focus towards realization of all-optical binary logic devices. For that semiconductor optical amplifier (SOA) is basic constituent owing to its highly nonlinear characteristics, by exploiting SOA nonlinearity various simple all optical logic (AOLG) circuits realized [2-7].

Accordingly, all optical Boolean inverter logic realized with control and continuous clock pulse appropriately picked, so that SOA is heavily saturated through SOA-based Mach–Zehnder interferometer (SOA-MZI) [8]. Further all optical buffer and OR logic gates based on Mach–Zehnder interferometer structure at 10Gbps data rate was investigated, resulting in Q-factor of 25.94, 11.22 for the buffer and OR gates correspondingly [9]. As well successfully realized for the all optical AND, OR operation at 10Gbps data rate by using cross-gain modulation in semiconductor optical amplifier [10]. Afterward all-optical logic function (AND, XOR), a multiplexer and an encoder realized with SOA-MZI and optical couplers, utilized in the optical tree architecture [11]. All optical NOR logic function with Fabry-Perot (FP) laser chip with two MEMS tunable lasers experimentally evaluated performance at 100Mbps and illustrated good performance (20dB extinction ratio) [12]. Later on optical switching action was demonstrated by an Arrayed Waveguide Gratings (AWG) design. It explored that Bit Error Rate is not affected with number of buffer modules at the higher bit rates [13]. Afterwards to enhance computation speed complex all-optical combinational circuit's desined with semiconductor optical amplifier (SOA) exercising four wave mixing (FWM) with concurrent operations of half-addition and half-subtraction executed with identical input bits successfully [14]. Further using polarization-shift-keying (PolSK) modulation format and semiconductor optical amplifiers optical half adder schematics realized with acceptable performance [15]. Another design of all optical half adder network by means of ultrafast nonlinear interferometers (UNI) and using terahertz optical asymmetric demultiplexer (TOAD) through PPLN waveguide was efficiently realized accompanied by acceptable performance [16-20]. Afterward schematic for the 40Gbps data rate all-optical half-adder, subtractor and the OR logic gate was demonstrated, altogether with SOA and one periodically poled lithium niobate (PPLN) waveguide through SFG and DFG method. It generated the Carry and Borrow outputs with good performance [21-23]. Further a combinational schematic for all optical comparator was proposed and demonstrated successfully for the 20Gbps data rate, resulted with excellent performance metric [24]. Right now most of the previous explorations are restricted near around realization of two bit optical computing combinational networks likewise half optical adder and subtractor configurations, along with limited data rate. Therefore, ultra fast all optical full adder network implementation based on the semiconductor optical amplifier schematic ought to be designed.

Thus, in this vision it explores the performance investigation of ultra fast all optical full adder design with semiconductor optical amplifier. The proposed design is an interferometer structure, leads to ultrafast switching speed as consequence of fast carrier dynamics. Altogether the proposed design offer tremendous benefits as integration and avoids frequent optoelectronic conversions. As well other considerable pros availed with it are the least power consumption, ease in fabrication, cost effective, reliability and compactness. This manuscript is bifurcated as begin with brief introductory part later on the design presentation followed by results and discussion part subsequently the conclusion section in detail.

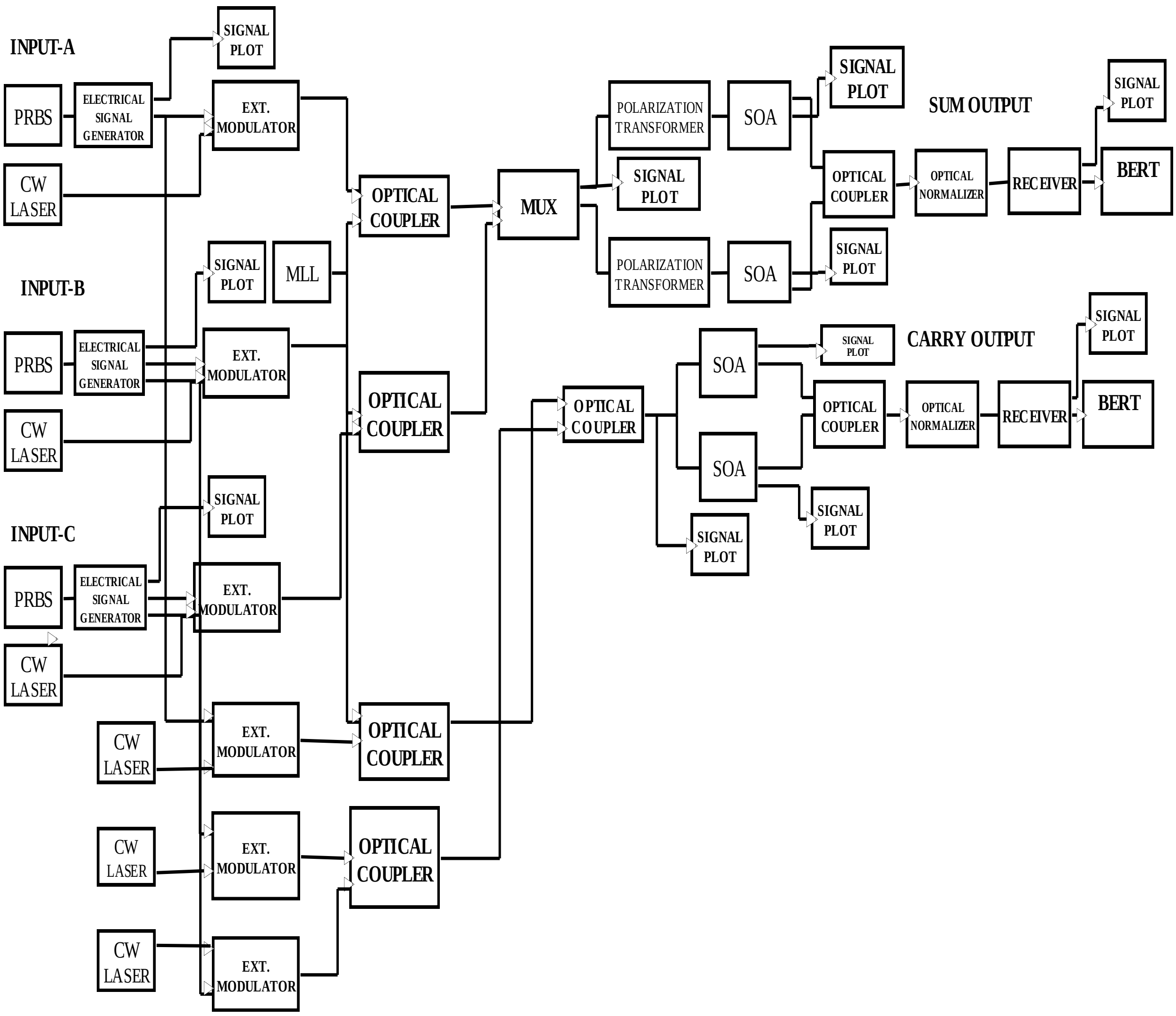

Fig. 1(a). The Full Adder Design

2. The schematic presentation

The combinational circuits are backbone of contemporary digital signal processing units and frequently exercised for optical domain, encouraging for the ultra high speed. Accordingly, all optical full adder schematic is illustrated in the Fig. 1(a). Here three input pulse patterns at the 80 Gbps data rate are generated with PRBS (pseudo random binary signal generators) passed altogether by continuous wave lasers source with peak laser power of 4 watts to excite nonlinear characteristics along with defined pre (5) and post (7) bits used for good accuracy in the results. Accompanied with nonreturn to zero voltage signal generator driven by the raised to cosine driver modulated through the Mach Zehnder modulator. The modulator altogether with wavelength of 1550 nm generated by the continuous wave laser signal with peak power of 4.2w and relative intensity noise(RIN) as -150, modulated probe and the pump signal source (laser) is utilized. Here, the mode locked laser signal (Fig. 1(b)) is the pump source generates the output at the wavelength of 1555 nm at peak power of 10.0 e-5 watts, RIN as -150.

Further the modulated data input-A and mode locked laser narrow pulse coupled with stronger pulse. While other modulated data input-B and data input-C is coupled in other coupler. Now all the coupled data inputs are multiplexed. Now this combined data is split amid the wings of the interferometer accompanied with polarization transformer and semiconductor optical amplifier accordingly to parameters illustrated in the Table 1. Accodingly, optical switching action is feasible by means of a nonlinear interferometer**.** So that one optical signal control switches another optical signal through the nonlinear interaction in the material. The refractive index sensed by each beam relies upon its intensity in addition on the intensity of all the other beams. As well the existence of a strong control pulse transforms the refractive index of the medium and alters the pulse shapes. This nonlinear phenomenon is referred as cross phase modulation accountable for the required sum and carry operations. For the realization off the carry operation another interferometer structure is used accompanied by external modulators with optimized bias voltage to generate the product operation for the applied data input signals as the carry output. Accompanied by, different pump current in the interferometer arm for carry output in order to stimulate nonlinear characteristics. Similarly for sum output the pump current is different than carry output interferometer arm. Subsequently for the signal shaping function the average normalizer power component is used along with receiver and BERT tool used for the necessary performance measurements.

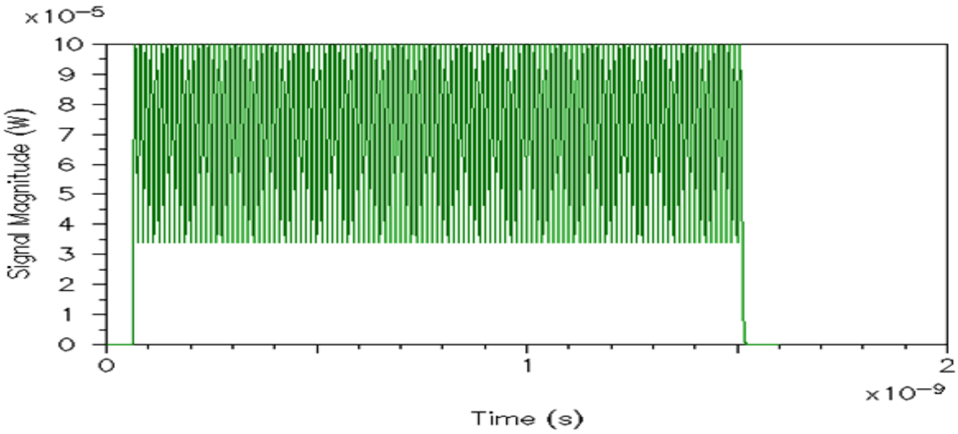

Fig. 1(b). Mode locked laser output

Table 1.

Parameters [SOA]	*Value* *[S_{OUT}/ C_{OUT}]*
Length of active region	5.0e-4
pump current	0.2A
current injection efficiency	2
line width enhancement	7
thickness	8e-8
width	3e-6
reflectivity	0.09/0.01
confinement	0.3/1

3. Results and discussion

For computing full adders is one of the significant modules of any complex combinational logic design. Accordingly, its operation under optical domain for non return to zero formats at 80 Gbps date rate is investigated. The data inputs are taken as data A[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 0 0 1 1 0 0 1 1 0 0 1 1 0 0 0 0 0 0 0], data B[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 0 0 1 1 0 0 0 0 0 0 0 0 0 0 1 1 0 0 1 1 0 0 0 0 0 0 0 0] and data C[0 0 0 0 0 0 0 0 0 0 0 1 1 0 0 0 0 0 0 0 1 1 0 0 0 0 0 0 1 1 0 0 0 0 0 0 0 1 1 0 0 0 0 0 0 0] as illustrated in the Fig. 2 to Fig. 4. The projected optical full adder schematics performance relies upon numerous key constituents. For that selection of key parameters is one of the significant issues. Accordingly, numerical simulation with key factors for the imperative design constraints as the peak laser power, data rate, modulators bias voltage, semiconductor optical amplifiers pump current, active length is evaluated and optimized. Results are demonstrated in the Fig. 5 to Fig. 15.

For the performance evaluation of an optical system key parameter is the extinction ratio(ER) factor. The extinction ratio could be illustrated as the efficiency with that the launched optical power is modulated over the transmission system. Extinction ratio correlates power utilization in transmitting "1" logic level to the power utilization in transmitting a "0" logic level. It is picked as the maximization criterion, described as the ratio of lowest peak output power ($P^{1}{}_{min}$) of "1 to the maximum output peak power ($P_{max}{}^{0}$) of "0" that is in decibel (dB), at the transmit port and defined with equation (1),

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

Numerical simulation of the optical full adder sum operation is same as the exclusive OR operation of three applied input data's, that is [0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 0 0 0 0 1 1 0 0 0 0 1 1 0 0 0 0 1 1 0 0 0 0 0 0 0] EXOR[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 0 0 0 0 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 0 0 0 0 1 1 0 0 0 0 0 0 0] EXOR[0 0 0 0 0 0 0 0 0 0 0 1 1 0 0 0 0 0 0 0 0 0 0 1 1 0 0 0 0 0 0 0 0 0 0 1 1 0 0 0 0 0 0 0 0 0 0 1 1 0 0 0 0 0 0 0]. Consequent S_{OUT} is [0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 0 0 0 0 0 0 1 1 0 0 1 1 0 0 1 1 0 0 0 0 0 0 0] as illustrated in above Fig. 5. Followed by the output carry (C_{OUT}) operation is the binary AND operation over the applied inputs. It will be same as binary logic operation of AB+BC+CA over the applied data inputs. Accordingly the resultant logic operation as [0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 0 0 0 0 0 0 1 1 0 0 1 1 0 0 1 1 0 0 0 0 0 0 0], for that output pattern is illustrated in the Fig. 6. Further Fig. 7 shows optical pattern in one of the SOA arm and after the multiplexer section.

Accordingly, the desired optical performance metric the extinction ratio performance investigated for the sum and carry operation of the full adder design over the single run is illustrated. It showed good performance for the single run (simulation) at 80Gbps data rate, as illustrated with12dB for the sum (S_{OUT}) and approximately 15dB for the carry (C_{OUT}) obtained. The desired full adder operations sum and carry is realized as illustrated in the Figs. 5-6. Aforesaid operation is realized owing to highly nonlinear characteristics of the semiconductor optical amplifier viz the cross phase modulation. When two or more beams of different wavelengths propagate in the nonlinear medium as SOA simultaneously, the SOA medium nonlinearity mediates an interaction among the signals. As the refractive index of SOA active region is inconsistent, relies upon the carrier densities and there will be XPM amid the injected signals. The amplifier gain counters quickly to the variation in the power of the input signal. Thus, numerous results for the performance evaluations are illustrated as follows.

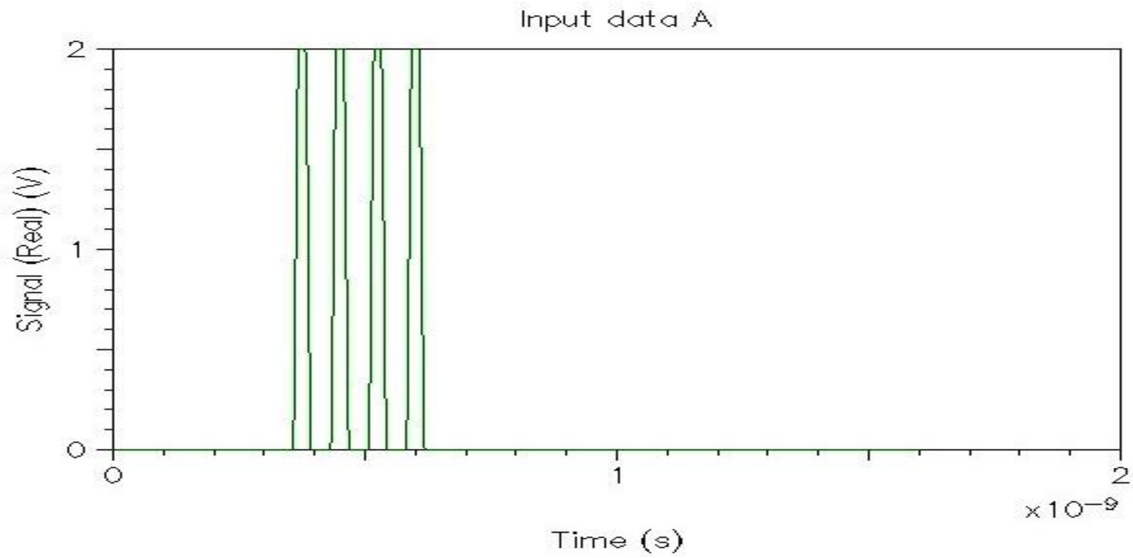

Fig. 2. Input A[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 0 0 0 0 1 1 0 0 0 0 1 1 0 0 0 0 1 1 0 0 0 0 0 0 0]

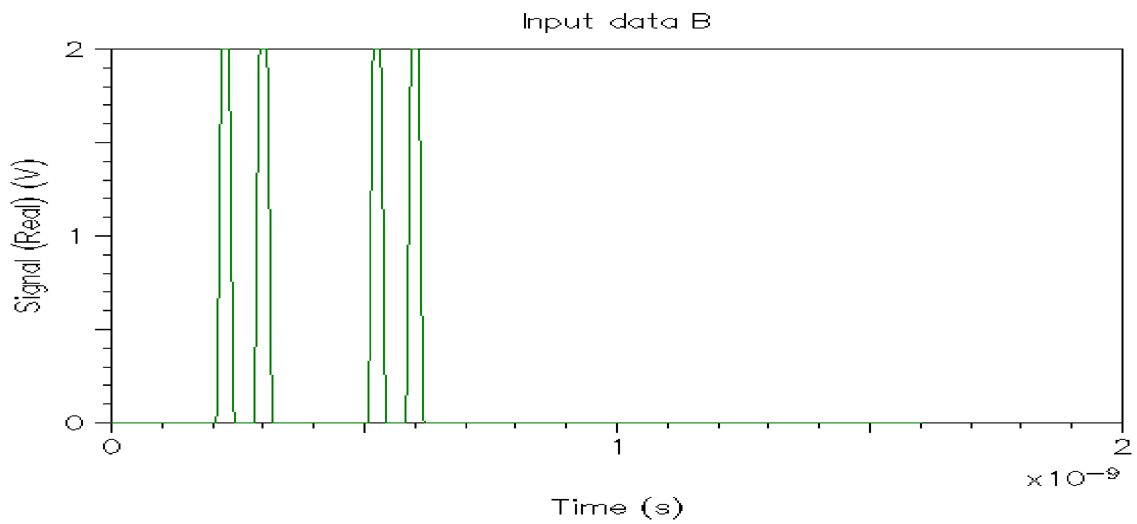

Fig. 3. Input B[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 0 0 0 0 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 0 0 0 0 1 1 0 0 0 0 0 0 0]

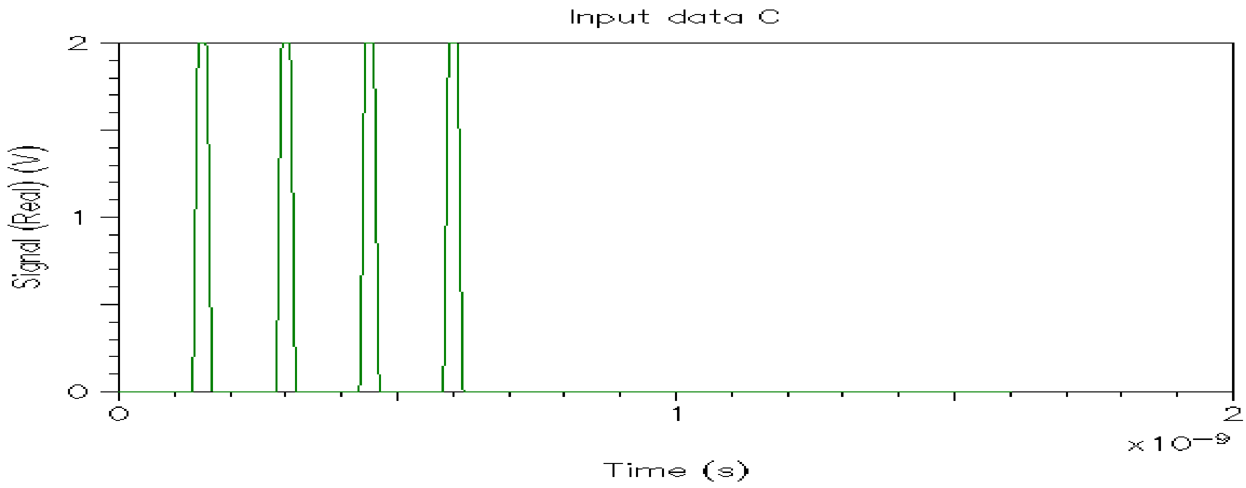

Fig. 4. Input C [0 0 0 0 0 0 0 0 0 0 0 0 1 1 0 0 0 0 0 0 0 0 0 0 1 1 0 0 0 0 0 0 0 0 0 0 1 1 0 0 0 0 0 0 0 0 0 0 1 1 0 0 0 0 0 0 0 0]

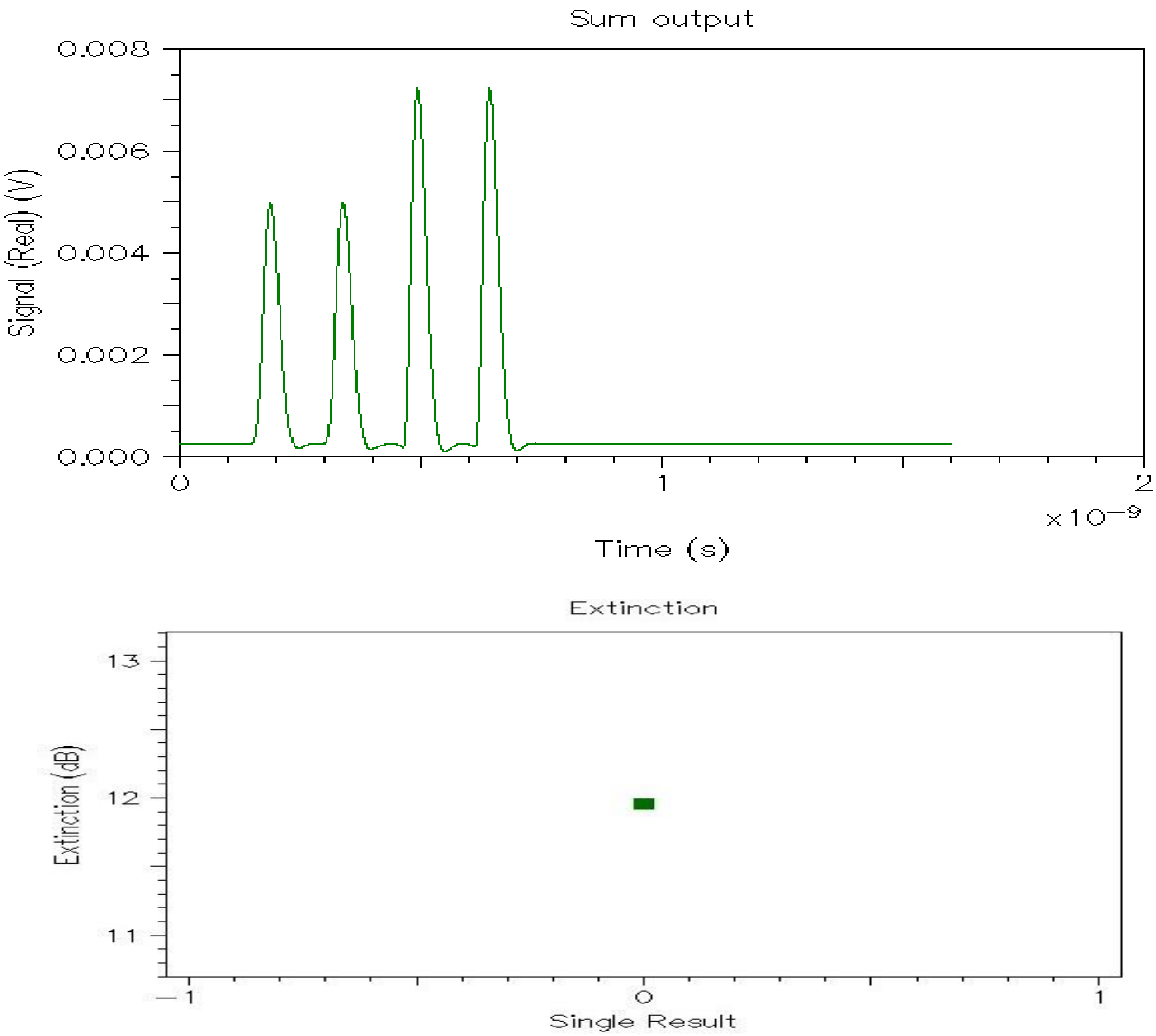

Fig. 5. Full Adder S_{OUT} [data rate 80Gbps] [0 0 0 0 0 0 0 0 0 0 0 1 1 0 0 0 0 1 1 0 0 0 0 0 0 0 0 0 0 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 0 0 0 0 0 0 0 0]

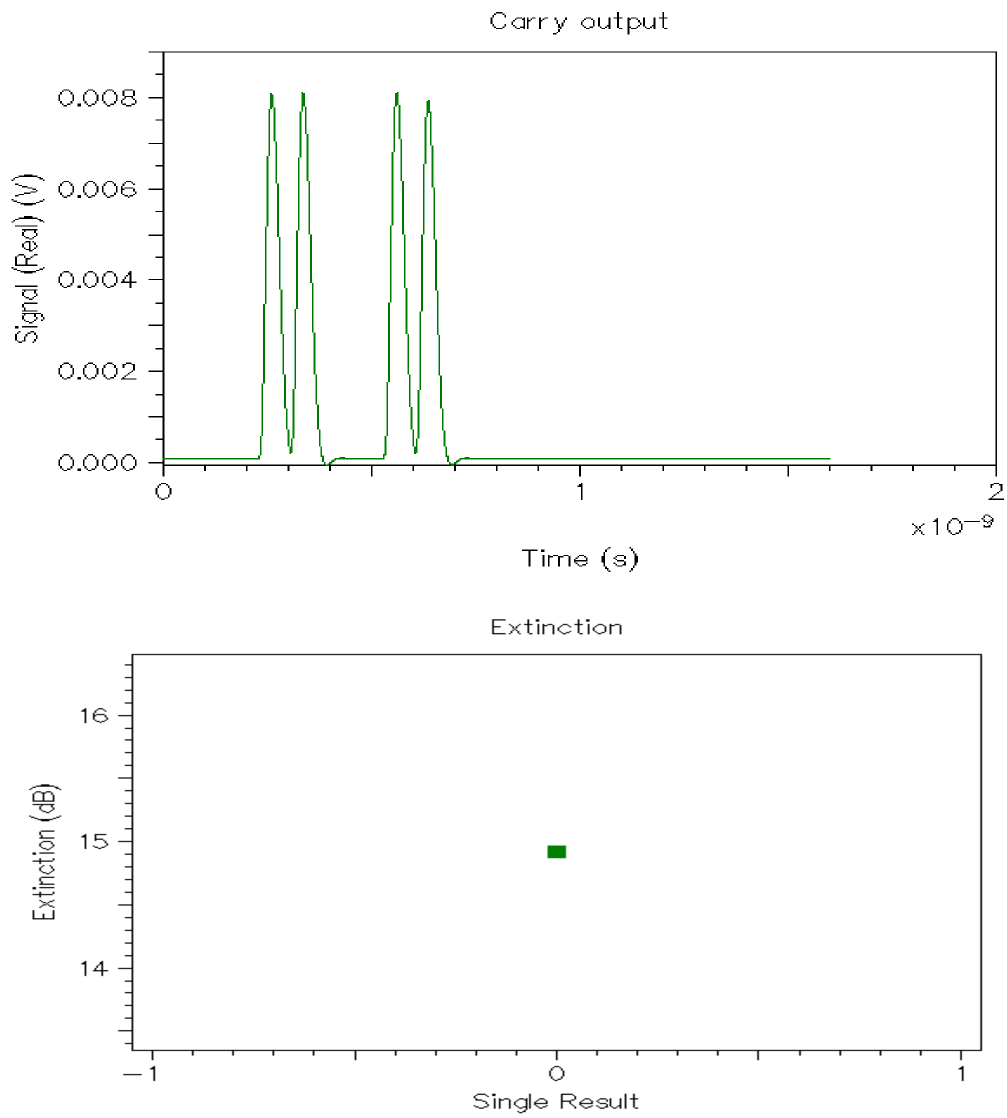

Fig. 6. Full adder [80Gbps data rate] C_{OUT} [0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 0 0 0 0 0 0 0 0 0 0 1 1 0 0 0 0 1 1 0 0 0 0 1 1 0 0 0 0 0 0 0]

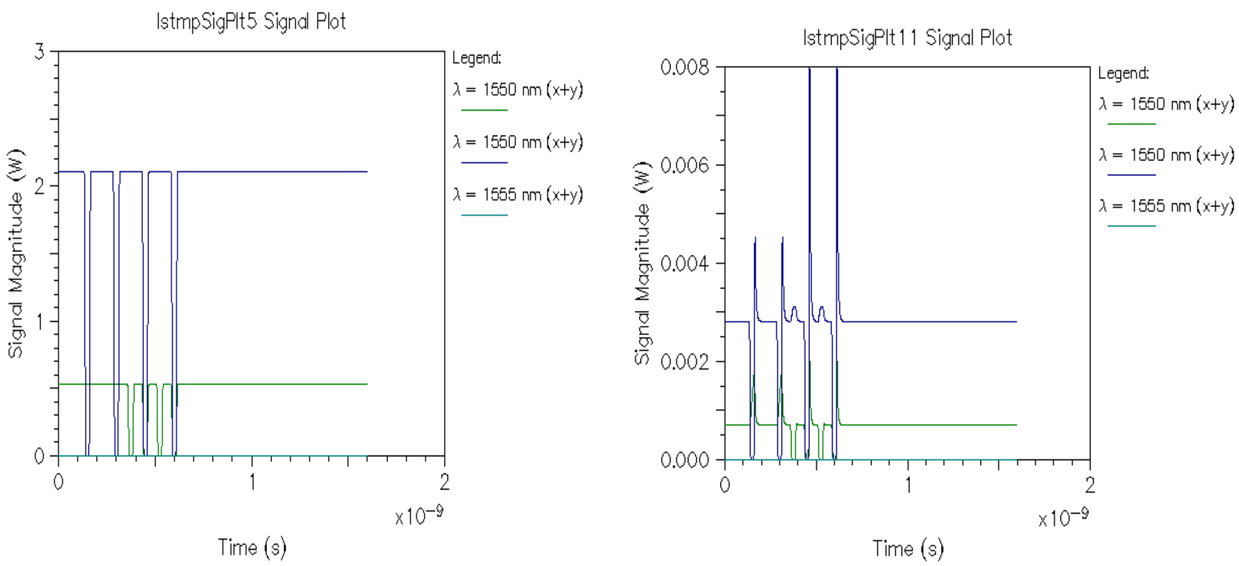

Fig. 7. Output after (a) Multiplexer (b) After SOA-1

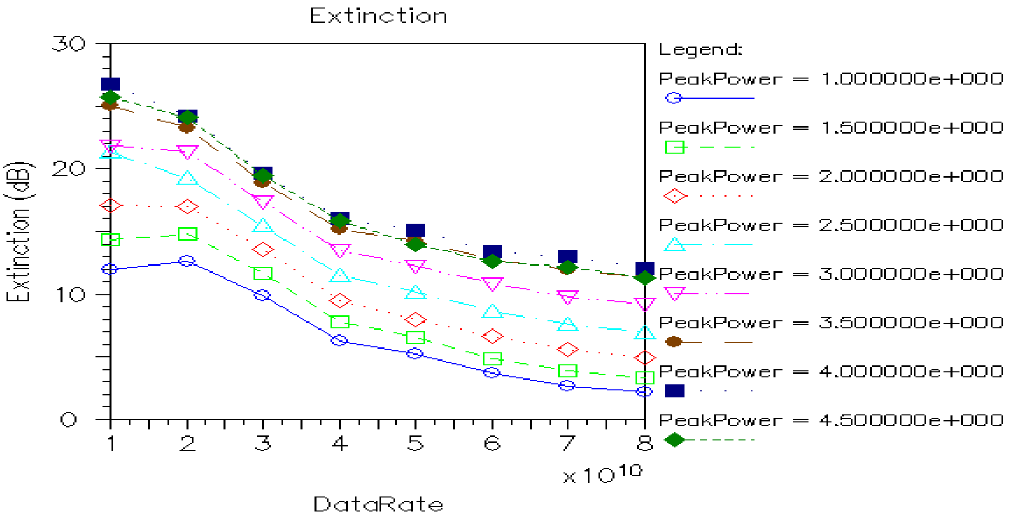

Fig. 8. Extinction vs. data rate vs. probe laser peak power

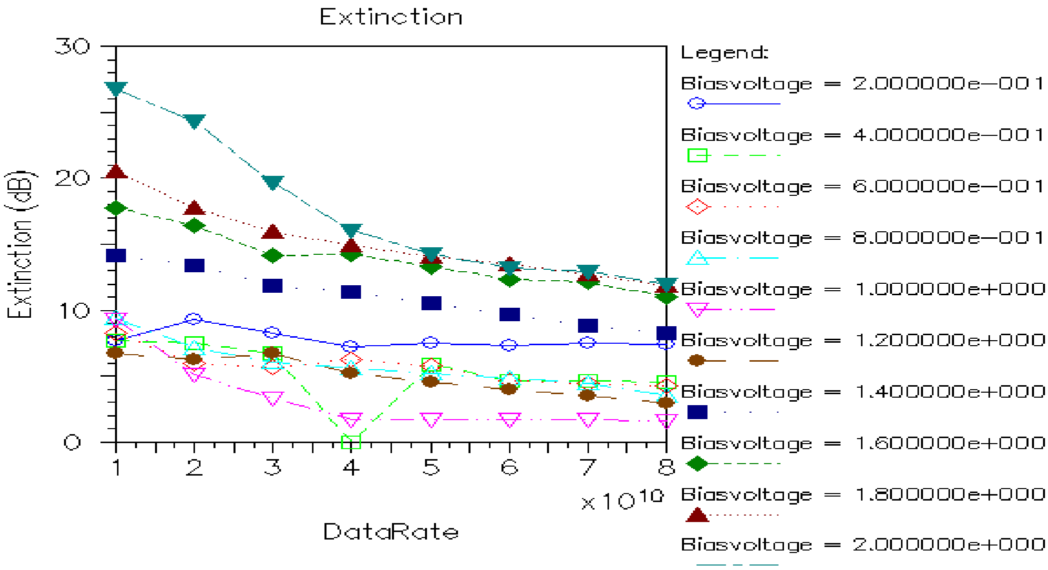

Fig. 9. Bias voltage [sum/carry]

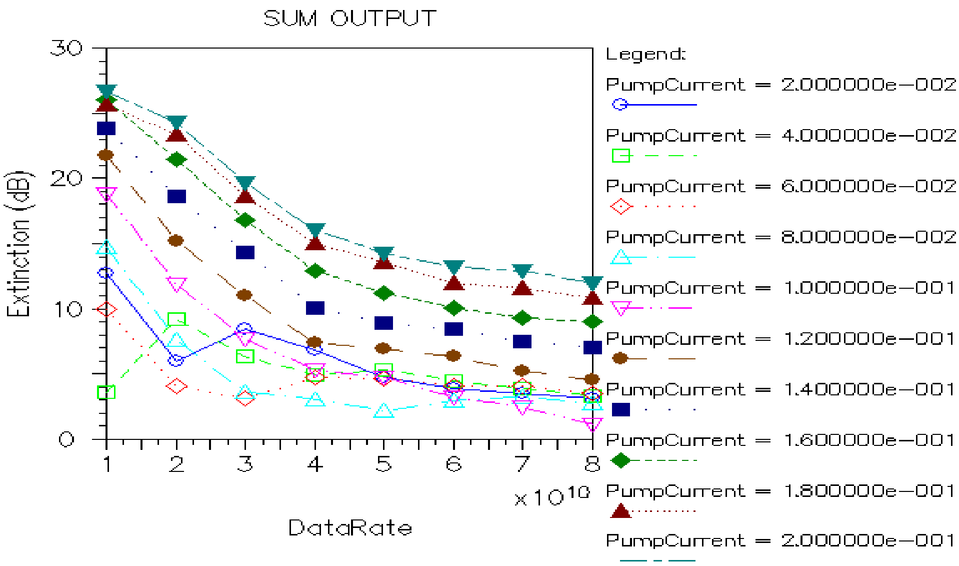

Fig. 10. Extinction vs. data rate vs. pump current

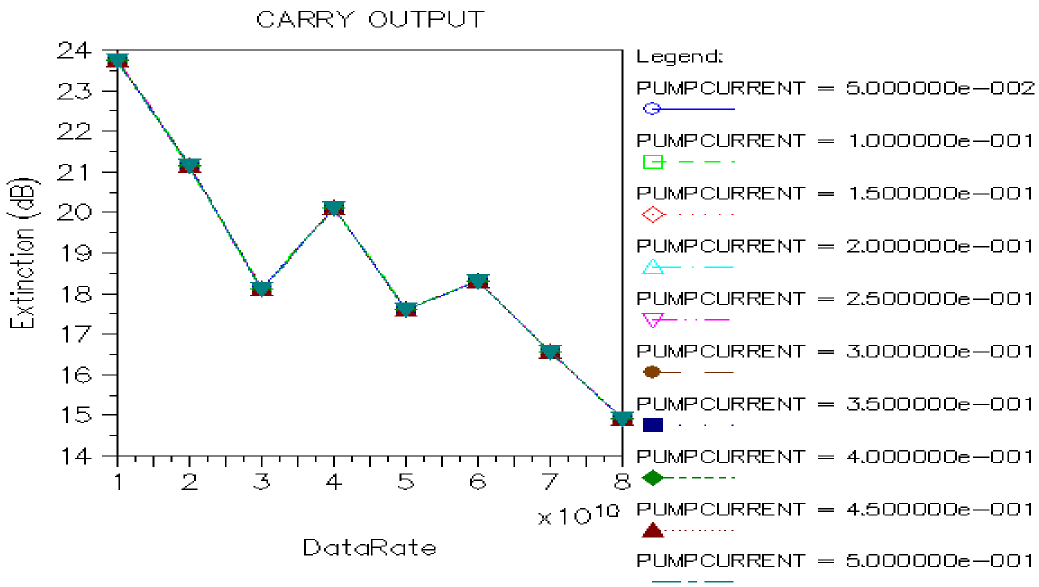

Fig. 11. Extinction vs. data rate vs. pump current

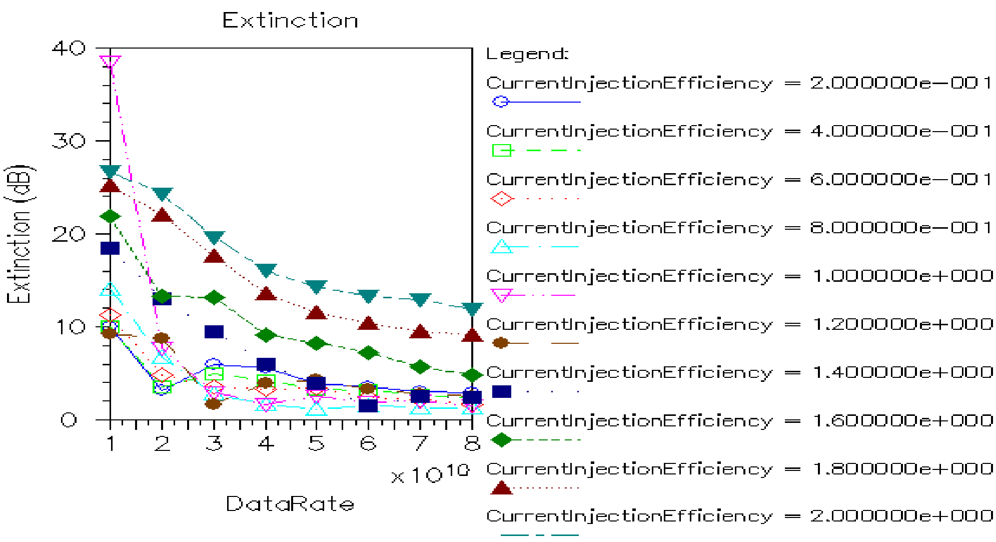

Fig. 12. Bias voltage is same for both [sum/carry]

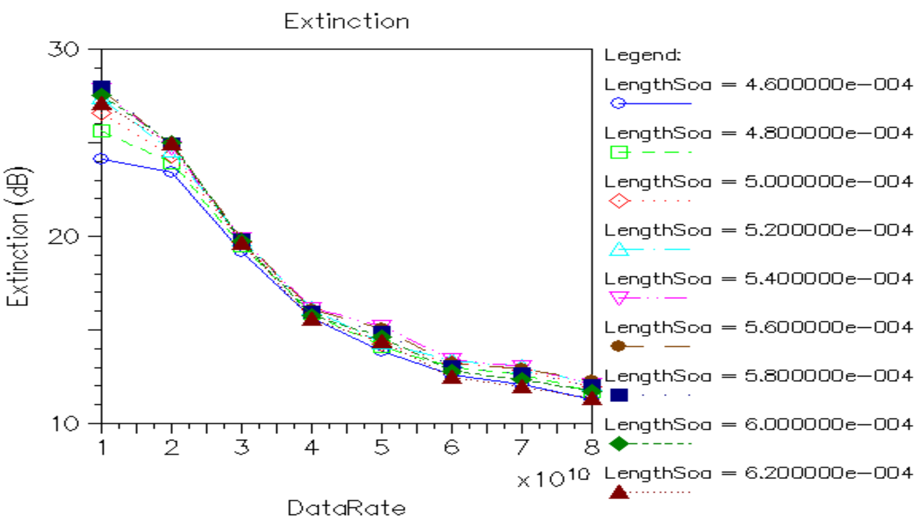

Fig. 13. Extinction vs. data rate vs. Length of SOA

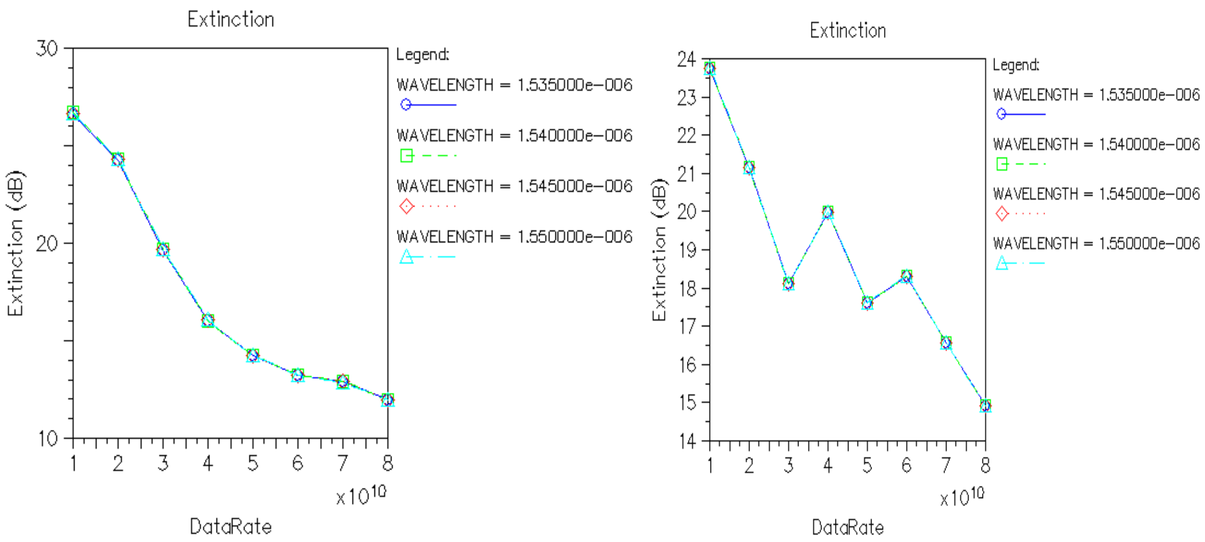

Fig. 14. Full Adder Extinction vs. data rate wavelength (a) Sum (b) Carry

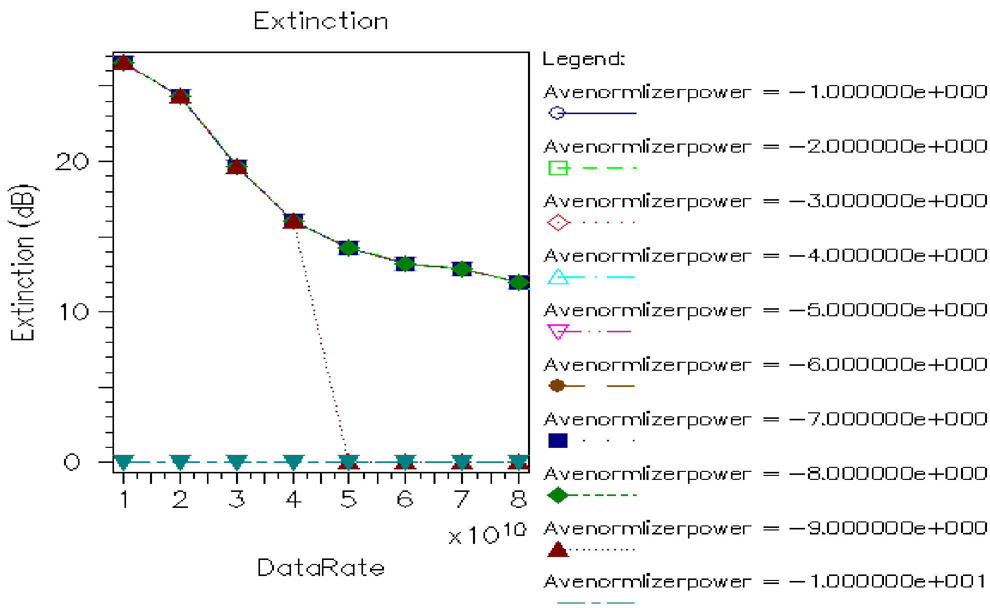

Fig. 15. Extinction vs. data rate vs. Average normalizer power

For performance evaluation of the optical full adder the laser source [probe source] is as well one of the key ingredients of any schematic. For that the performance is investigated over the range of laser source's peak power with variation of data rate as against extinction ratio factor is illustrated in the Fig. 8. It depicts that for the peak power greater than 3watts of the laser source the performance (ER >10dB) is good enough.

The optical modulator is also another key constituent of the optical full adder design. Numerical investigations for the bias voltage of optical modulator on the full adders performance is evaluated with range of data rates and for that the extinction ratio performance illustrated in the Fig. 9. Result depicts optimum performance with extinction ratio varying from 30dB to 15dB over the data rate variation of 10 to 80Gbps for the 2volts bias voltage. As well it depicts that bias voltage is another significant performance metric with system.

The semiconductor optical amplifier is yet another key constituent of optical logic schematic, for that the pump current is one of its vital parameter. Accordingly, the output performance(ER) for the sum operation is evaluated, over the variation of the data rate 10Gbps to 80Gbps vs. the semiconductor optical amplifiers pump current and Extinction Ratio as illustrated in the Fig. 10. It depicts very good performance(ER>10dB) for the pump current over 0.16A, demonstrates that extinction rely upon the pump current. It must be aptly picked for the optimum design performance.

Fig. 11 illustrates evaluated performance for the output carry operation with the design over range of data rates as against the pump current of the SOA. Result depicts that there is decline in the extinction factor over the rise in the data rate. Nevertheless it depicts very good performance(ER>15dB) over the variation of parameters, as the pump current and data rates.

Fig. 12 depicts performance evaluation for the current injection efficiency of SOA as against variation of the data rate for the extinction ratio. It showed that for the current injection efficiency parameter of 2 and demonstrates good performance metric yielding extinction ratio greater than 15dB over the range of the data rates. While executing performance evaluation the active length of semiconductor optical amplifiers variation as against the data rate for the extinction factor is numerically simulated over the range of data rates. Fig. 13 showed well acceptable performance over the range of active length of SOA, depicts that performance as well rely upon the semi conductor optical amplifier active length. Fig. 15 shows performance for the extinction ratio vs. the data rate vs. the average normalizer power for the full adder design. It showed that performance as well rely upon the average normalizer power. Thus, for the optimum performance the average normalizer power should be appropriately selected. Fig. 14 illustrates the optical full adder's performance evaluation over the range of wavelengths and against the variation of data rates, for the extinction factor consequent sum and the carry operations. Results in the plot depict very good extinction ratio performance over the range of data rates.

4. Conclusion

The combinational circuits are the persistent need for modern digital signal processing units. Accordingly, all optical schematics will play significant role for the ultra high-speed optical computing networks. Correspondingly optical full adder network has been designed and its performance successfully realized at 80 Gbps data rate. Required output sum and carry operation patterns have been verified followed by the resultant extinction ratio of 10dB and 15dB respectively. Furthermore, investigations depict key design constituent and design parameter must be appropriately picked in order to extract optimum design performance. Accompanied by the benefits of the illustrated configuration are easy of integration, simpler design, low power consumption, higher data rate operation, shuns recurrent optoelectronic conversions. As a consequence this exploration could be a further aid towards upcoming complex optical computing systems.

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*Corresponding author: dekt@rediffmail.com