All Optical 3-Bit Octal to Binary Code Converter using Micro-Ring Resonator

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Abstract. In the developing field of optical communication, Switching based Micro-Ring Resonator (MRR) is used to design all-optical logic module. The MRR based logical module configured as OR logic gate and 3 – bit octal to binary code converter (OCB) is designed which has less computational errors and uses less digits than hexadecimal and decimal number system. It is widely used in IT application for Linux, android, operating system and Mac for computations. The proposed all optical OR gate and octal to binary code converter is designed for 10 Gbps. Optimum values of MRR length and Coupling coefficient are calculated and obtained values of Quality factor (QF) and Extinction ratio (ER) ensure reasonable performance of the proposed system.

Keywords: Micro-ring resonator, All-optical logic gate, octal to binary code converter

1. Introduction

In the recent field of photonics, researches are undertaken for integrating a photonic and electronic device in a single chip for computation and communication. This process are encouraged by semiconductor optical amplifier (SOA)\[^1\], Mach-Zehnder interferometer (MZI)\[^2\], semiconductor laser amplifier (SLA) loop mirror\[^3\] etc.,. The advantages of the system are parallelism; ultrafast speed and bandwidth have made it possible for next – generation optical networks. Though it has many advantages, lags in terms of aspect ratio which in turn reduces the effective use of chip area. Micro ring resonator is ring waveguide and it work on coupled mechanism \[^4\]. The wave rounds a trip in the ring to produce a phase shift when it is equal to integer times of 2\(\pi\). This produce constructive interference. Ring resonator has many applications such as Switch \[^5\], Modulation \[^6\], Logic gate \[^7\]. Micro ring resonator is used to design and compute all logic gates some of them are AND \[^8\], NAND \[^9\], XOR, XNOR logic gates \[^10\] and Gray code generator \[^11\].

In the proposed system non-linear micro ring resonator is used. The waveguide is tightly confined with the ring. Silicon exhibit strong non-linearity, this leads to Kerr effect. It is also known as quadratic electro-optic effect.

In this paper, 3 bit all-optical binary to gray code converter has been proposed using MRR, configuration with the help of all-optical OR gate. Section II explains the micro ring resonator. Section III explains the design and implementation of OR gate section IV explains about octal to binary code converter. Section V explains the results and discussion.

2. Principle of Micro-Ring Resonator

Micro-ring resonator is the optical device consists of ring waveguide couples with two bus waveguide used in CMOS fabrication technology which is suitable for monolithic application. If the resonator is
made of a non-linear material, it acts as a logic switch. The control pulse generates free carriers in the ring resonator due to the two-photon absorption (TPA) effect [12].

An MRR consists of four ports namely input and add port as input and through and drop port as output port respectively. Due to constructive interference, it acts as a reservoir to accumulate the power at particular wavelength. At resonance condition, the input signal shows high transmission at drop port and low transmission at through port respectively shown in figure 2. Due to change in the refractive index with response to the temperature of the material enable a correct measure of the power-consumption [13]. The function of proposed system of the MRR consists of

1. It is the versatile component posses large spectral range and high wavelength selectivity
2. It consists of small footprint and narrow bandwidth
3. It is attractive due to low power consumption, ultra-fast speed and parallelism of light with enormous bandwidth

The micro-ring resonator consists of four ports namely input and add port as an input and through and drop port as the output with coupling co-efficient of K1 and K2 to couple the light signal into an waveguide is shown in figure 1.The transmission of through and drop port at resonance is shown in figure 2.

![Figure 1](image1.png)

**Figure 1** structure of micro-ring resonator

![Figure 2](image2.png)

**Fig.2** Transmission of output at wavelength (1550.5nm)

### 3. Operation of OR Gate

The input signal A and B are tuned to the resonance which represent the logic bits of 0’s and 1’s. The continuous optical probe signal (0.5mv) is applies to the ring resonator for biasing them. When the absence input signal A and B, there is no signal at the output port. Similarly, when either of the input signal A, B or A and B the output is obtained at through port due to phase shift in the ring resonator. The continuous wave (CW) is used as pumping of optical source to the MRR with the binary input of logic 0’s and 1’s for input A and B respectively. The optical coupler is used to couple both the input
and fed to the micro-ring resonator and the output is determined using signal plot at through and drop port. The resonance wavelength can be calculated as

$$\lambda_{res} = \frac{n_{eff} L}{m}, \quad m = 1, 2, 3 \ldots$$  \hspace{1cm} (1)

Where $\lambda_{res}$ is the resonant wavelength, $L$ is the length of the ring ($L = 2\pi r$), $r$ is the radius of the ring, $m$ is an integer representing the mode number, $n_{eff}$ is the effective refractive index given by

$$n_{eff} = n_0 + n_2 I,$$

where $n_0$ and $n_2$ are linear and non-linear refractive indices and $I$ is intensity of the pump signal. At 1550.5nm, the change in absorption coefficient and the change in refractive index is given as [14]

$$\Delta\alpha = \Delta\alpha_e + \Delta\alpha_h = 8.5 \times 10^{-18}\Delta N_e + 6.0 \times 10^{-18}\Delta N_h$$  \hspace{1cm} (2)

$$\Delta n = \Delta n_e + \Delta n_h = -[8.8 \times 10^{-22}\Delta N_e + 8.5 \times 10^{-18}\Delta N_h^{0.5}]$$  \hspace{1cm} (3)

The electric field of the through and drop port is given as [14]

$$E_t = \frac{[\sqrt{1-k_1} + \sqrt{1-k_2}\exp(\alpha L)\exp^2(j\phi)]}{[1-\sqrt{1-k_1^2}(1-k_2)] \exp(\alpha L)\exp^2(j\phi)} E_{i1}$$  \hspace{1cm} (4)

$$E_d = \frac{[-\sqrt{k_1} + k_2 \exp(\alpha^{-1/2})\exp(j\phi)]}{[1-\sqrt{1-k_1^2}(1-k_2)] \exp(\alpha L)\exp^2(j\phi)} E_{i1}$$  \hspace{1cm} (5)

Where $\alpha$ is the overall propagation loss of the ring, $k_1$ and $k_2$ is the propagation constant and $L$ is the length of the ring and the transfer function of the output is written in equation 6,7.

$$T_p = \frac{|E_t|^2}{|E_{i1}|^2}$$  \hspace{1cm} (6)

$$T_d = \frac{|E_d|^2}{|E_{i1}|^2}$$  \hspace{1cm} (7)

Where $E_{i1,2}$, $E_t$ and $E_d$ is the electric field of input, through and drop port respectively and $T_p$ and $T_d$ is the transfer function of through port and drop port. The block diagram, schematic diagram and truth table of OR gate is shown in figure 3,4 and 5 respectively.

Simulation parameters used in the design are mentioned in Table 1.

| S.No | Parameter          | Value      |
|------|--------------------|------------|
| 1    | Wavelength         | 1550.5nm   |
| 2    | CW power           | 5mW        |
| 3    | Length             | 7e^{-6}m   |
| 4    | Coupling coefficient| 0.5       |
| 5    | Power at through port| 1.12mW  |
| 6    | Power at drop port | 0.145mW   |
4. Octal to Binary Converter

In telecommunication, code conversion techniques is used to convert code from one format to other for securing the data while transmission [15]. The proposed octal to binary code converters is
preferred for less computational errors where the word size is divisible by and it can be easily implemented using three bits in binary numbers as ON and OFF switching at 10Gbps. It consists of eight input of logic 1 or 0 from D0 to D7 and output are A, B and C at the output port. When all the input is 0, then no output power at the through port. When either of one signal or both signals becomes 1, then the input power is transmitted via bus waveguide at the through port. The laser source is used to pump the MRR and pseudo random bit generator is used to produce the input of either logic 0 or 1. The external modulator is used to modulate the incoming signal and the coupler is used to couple the input signal. The coupled input is fed to the ring resonator based on which the desired output of A, B and C determined. The schematic diagram for optical octal to binary (O–B) code converter is shown in Condition for the octal to binary converter has the desired output of through port of A, B and C is represented as

1. \[ A = D_1 + D_3 + D_5 + D_7 \]
2. \[ B = D_2 + D_3 + D_6 + D_7 \]
3. \[ C = D_4 + D_5 + D_6 + D_7 \]

The output of (O–B) code converter is designed using OR logic gate so the output of each logic gate is the sum of input signal and it has three output based on different combination of input signal. The flow diagram of the proposed system is shown in figure 6.

![Flow diagram of proposed system](image-url)
SCHEMATIC DIAGRAM OF O-B CONVERTER:

![Schematic Diagram of O-B Converter](image)

Fig. 7 Layout of the all-optical implementation of O-B converter in Rsoft Optsim tool

5. Result and Discussion

The output can be obtained by using different Simulation parameters is shown in table.1 and the relationship between the input and output is numerically analyzed. The output of logic 0 and logic 1 is shown in figure 8a,b and 9a,b respectively.

![Graphs](image)

The extinction ratio is calculated using the maximum power at through port to the minimum power at drop port and the output is 8.87dB

\[
\text{Extinction ratio (dB)} = 10 \times \log_{10} \left( \frac{\text{power level}_1}{\text{power level}_0} \right)
\]  

(8)
The phase shift depends on coupling coefficient and length of the ring resonator is shown in equation 9.

\[ \varphi = \frac{(2\pi * nL)}{\lambda} \]  

(9)

The coupling coefficient \( \alpha \) is used to couple the output power to the ring waveguide. The simulation result shows that the increase in the \( \alpha \) value, the maximum power couples to the ring waveguide hence the output shows minimum power at through port and maximum power at drop port. The optimum value of coupling coefficient is 0.5. This is shown in figure 10.

| OCTAL INPUT(mV) | BINARY OUTPUT (mV) |
|----------------|---------------------|
| D0  | D1  | D2  | D3  | D4  | D5  | D6  | D7  | A   | B   | C   |
| 5   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
| 0   | 5   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 1.12|
| 0   | 0   | 5   | 0   | 0   | 0   | 0   | 0   | 0   | 1.12| 0   |
| 0   | 0   | 0   | 5   | 0   | 0   | 0   | 0   | 1.12| 0   | 1.12|
| 0   | 0   | 0   | 0   | 5   | 0   | 0   | 1.12| 0   | 1.12| 1.12|
| 0   | 0   | 0   | 0   | 0   | 5   | 0   | 1.12| 1.12| 0   | 1.12|
| 0   | 0   | 0   | 0   | 0   | 0   | 5   | 1.12| 1.12| 0   | 1.12|

Fig.10 Relation between coupling coefficient and output power

The length of the MRR is used to shift the output power and the length is directly proportional to phase shift. When length increases as multiple of its value, phase shift occurs at the output port with optimum value of \( 7 \text{e}^{-8} \text{m} \) is shown in figure 11.

Fig.11 Relation between length of MRR and output power
6. Conclusion
All optical OR gate and 3-bit octal to binary code converter have been designed successfully with nonlinear Micro ring resonator using Optsim. The performance metrics have been analyzed at a bit rate of 10Gbps. The Extinction ratio is obtained as 8.87dB and the impact of MRR length and coupling coefficient over the proposed system is analyzed and optimum values are obtained. The octal to binary code converter is used when CPU changes to 32 to 64 bit octal no longer bits are used and efficient for arithmetic operations.

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