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Crosstalk and interference study for multiple segment bus optical clusters

Pritam Das *, T Rameswar Rao and Rana Vijay

Department of Information Technology, HBT College of Science Jaipur, India.

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Abstract

Optical Network on Chip (ONoC) is being researched for integrating no of cores on a single chip or die. As there are some subsisting topologies of optical interconnect for ONoC, multi segment bus (MSB) is one them in which cluster of cores are interconnected in optical domain. Along the signal path of these topologies, signal losses and crosstalk component takes into account. MSB topology results in reduction of signal power and signal to noise ratio also decreases. This paper presents simulation and analysis of a 16 cluster topology. The design of multi segment bus is made by considering the losses due to various fundamental components used in the topology and uniformity of the components while placing them in the design. In design of photonic circuit, system requires micro ring resonators (MRRs) as modulators, and photodetectors with clear cognizance on the resonance behavior of the ring resonator. Inter segment routers (ISRs) couples light at a particular wavelength between two parallel waveguides.

Keywords: Crosstalk; Inter-connects; Optical network on chip; Micro ring resonators; Cluster topology

1. Introduction

In recent years, several topologies inventions have been carried out on network on chip (NoC). These technologies using silicon photonics has emerged as viable solution for energy dissipation due to low power interconnects and high speed data transmission through these optical interconnects. In multi core processors, cluster of cores are made by sets of homogeneous and adjacent cores. Optical interconnection is provided by using planar waveguides assisting bulk data transmission where electrical interconnects is used for intra cluster communication.

Micro ring resonators (MRR) are used as modulator and lasers or photodetector in clusters. These clusters are connected by optical switched connection in 2DFT interconnect in ONoCs [1][2]. Three dimensional multicluster interconnect topology, Corona has been organized in 64 clusters are composed in 256 cores and interconnected using wavelength selective MRR and optical waveguide [3].

2. Related Work

There are several existing topologies related to optical interconnections which are tracked by proposed MSB topology. In these topologies, a laser along with tapered aliment of an off-chip multi wavelength derives conventional optical power, distributing unmodulated lightwaves through a feeder bus to the optical waveguides accommodating as interconnects. Prior wavelength tasks are complete for WDM-predicated connections between all cluster pairs. The number of connections for all-to-all connectivity in N-cluster optical interconnects topology is N C2 × 2 or N (N−1).

* Corresponding author: Pritam Das

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2.1. Dimensional Folded Torus Topology

A distinctive 16-cluster 2DFT topology is demonstrated [1], [4], where the ONoC recognizes intercluster communication over optical waveguides constituting convey matrix (TM) rings, utilizing wavelength-selective MRR based switches, viz., gateway switch (GS), injection switch (IS), network switch (NS) and ejection switch (ES). The GS routes the signal from the source cluster to the unidirectional TM rings, the IS injects the signal from the unidirectional TM ring to the bi-directional TM rings, the NS navigates the signal over the bi-directional TM rings and the ES conclusively routes the signal towards the destination cluster. The communication between clusters is realized by routing modulated signal from the GS of the source cluster into TM rings, where wavelength-concrete MRRs in the non-blocking NSs forward the signal to the ES of the destination cluster. At the ES, the modulated signal is detected to recover the information [5]-[7].

2.2. Corona

Corona is another ONoC entelechy incorporated into a 3D chip interconnecting 256 cores arranged in 64 clusters [2]. For the comparison with the proposed MSB topology, a 16-cluster version of Corona is illustrated in Fig. 1. Each cluster utilizes a dedicated waveguide (bus) originating from itself, through which it receives a fine-tuned set of wavelengths from the remaining clusters through MRRs as modulators [8]; determinately the bus terminates back at the originating cluster composing a broken (incomplete) ring. Corona fortifies dense WDM (DWDM) on a single bus.

In Corona, the no of clusters (N) and no. of waveguides are equal which traverse long serpentine paths through all the clusters; however, the number of wavelengths on a bus (Δ) is (N−1) or 2(N−1) or 5(N−1) for 10/20/50 Gbps inter-cluster speed, respectively.

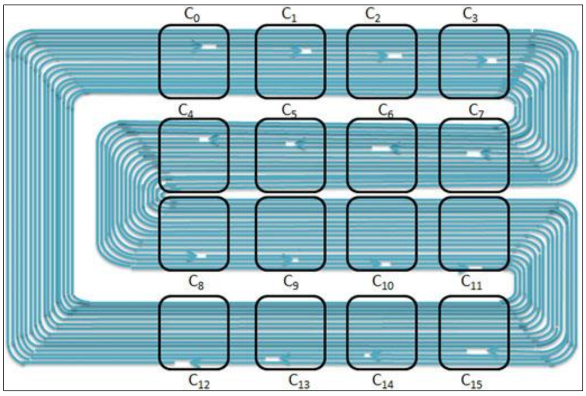

Figure 1 Corona Topology

Geometrical pattern of corona increases waveguide losses and, when DWDM is employed over these waveguides, several MRRs are required on each waveguide to produce high insertion loss and DWDM crosstalk, which degrades BER performance [4].

Single Folded Bus (SFB) based 4 cluster SFB topology using abridged where all clusters share a single folded bus, composed of inner and outer waveguides pass through each cluster. Each cluster utilizes a number of MRRs to modulate lightwaves for different wavelengths on the outer waveguide and another set of MRRs on the inner waveguide to receive the desired WDM channels. [3]

However, nevertheless its simple topology, insertion losses at sizably voluminous number of MRRs and waveguide losses between cluster pairs contribute to astronomically immense signal losses, along with DWDM-induced crosstalk components, which in turn can degrade the BER performance significantly with astronomically immense number of clusters.

3. Methodology

3.1. Micro Ring Resonator

The resonance factor is the main key of silicon photonic technology. To implement a photonic communication and computation circuit, MRR is an important device. Resonators are basically used for oscillating frequency with higher amplitude.

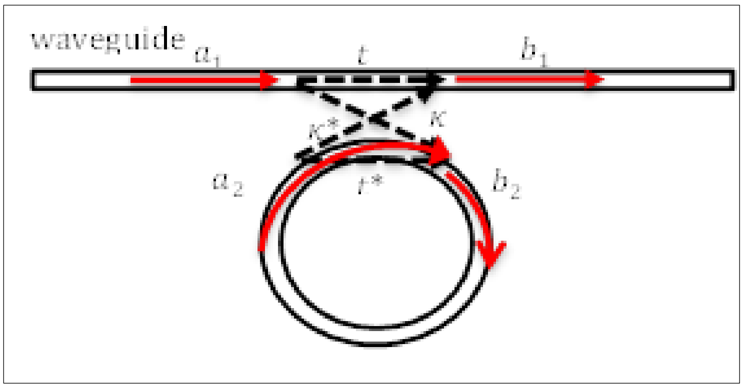

Figure 2 Mirco Ring Resonator

A basic ring resonator consists of an optical waveguide which is looped back on itself, such that a resonance occurs when the optical path length of the resonator is precisely a whole number of wavelengths. Length of an optical waveguide (L) is equal to circumference of coiled waveguide of radius R, it is given by L=$2\pi R$.

Coupling mechanism is accessed by the loop, when the light is given at one end of optical waveguide as it is traversing, near the circular loop, it gets coupled due to less distance as shown in Fig. 2.

While travelling, if no reflection takes place, i.e. input power is equal to output power, then it is described by t and k constants and a unitary matrix:

$$\begin{vmatrix} b_1 \\ b_2 \end{vmatrix} = \begin{vmatrix} t & k \\ k^* & -t^* \end{vmatrix} \begin{vmatrix} a_1 \\ a_2 \end{vmatrix} \text{........ (1)}$$

The lightwave propagating along the MRR (b_2) at can be expressed as

$$a_2 = \alpha e^{j\theta} b_2 \text{ ....(2)}$$

where, t and t^* are the complex conjugate transmission coefficients with main waveguide and MRR respectively, k and k^* are the complex conjugate coupling coefficients between the ring resonator and waveguide, α is the loss, θ is the phase shift encountered by the propagating mode (θ=$2\pi L/\lambda_{eff}$) assuming that the MRR is trained by the law of lossless coupling, one can relate t and k as

$$|t|^2 + |k|^2 = 1 \text{ .... (3)}$$

Using the above expression, i.e., (1) through (3) and $t = |\ t\ | e^{-i\varphi t}$, $|\ t\ |$ is the transmission amplitude and φt is the transmission phase constant along the main waveguide the normalized power with respect to the incident optical power at port 1 can be expressed as

$$\frac{|b_1|^2}{|a_2|^2} = \frac{|t|^2 + \alpha^2 - 2\alpha\,|t|\,cos(\theta + \phi t)}{1 + |t|^2\alpha^2 - 2\alpha\,|t|\,cos(\theta + \phi t)} \text{ .... (4)}$$

3.1.1. MRR as Modulator

MRRs with electrically controlled $p-n$ junctions at the base use carrier injection/ depletion effects to design high-speed electro-optic modulators. For binary '0', with zero bias across the $p-n$ junction, the path covered by the lightwave with the MRR circumference length encounters a total phase shift of $\theta + \varphi t$ as shown in Fig. 4. It is manifest from (4) that, when $\theta + \varphi t = 2m\pi$ and $|t| = \alpha$, the output power at port (P_0 at o/p port) goes down close to zero, i.e., the MRR grips whole power for the corresponding wavelength (λ_{res}), there by *writing* a binary '0' on the waveguide (for binary '0' transmission). The governing equation for λ_{res} is given by

$$\theta + \varphi t = \frac{2\pi L}{\lambda_{eff}} = \frac{2\pi L \eta_{eff}}{\lambda_{res}} = 2\pi m \text{ .... (5)}$$

Length is fabricated by transmitting ‘0’, by altering carrier concentration with effective refractive index binary ‘1’ takes effect. This is forward biasing across $p - n$ junction and causes spectral shift in absorption spectrum.

3.1.2. MRR as Photodetector

Ge has direct bandgap origins large absorption coefficients for wavelengths in near infrared region. Therefore, Ge doping can be used in photonic systems. Integrated metal-semiconductor-metal configuration is used to design photodetector for higher speed and sensitivity.

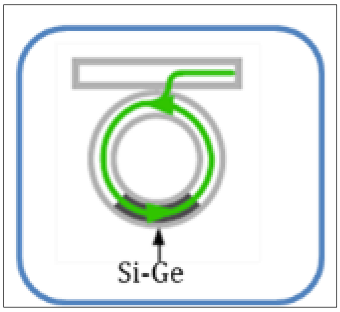

Figure 3 Si-Ge photodetector

Ge is tamper with Silicon ring resonator as shown in Fig. 3.These photodetectors can be interfaced with the broadband silicon waveguides to carry data modulated WDM signal.

3.2. Inter Segment Router (ISR)

The 2 × 2 routing device which based on MRR, as shown in Fig. 2, is called as an inter-segment router (ISR). It couples light at a particular wavelength, selectively between both parallel waveguides. By appropriately altering the values of t_i, k_i and α_{i+1}, we can design wavelength-selective ISRs. These routers are being fixed-tuned to respective wavelengths which does not requires electro-optic tuning and it does not consume power and operate as a set of passive MRR devices.

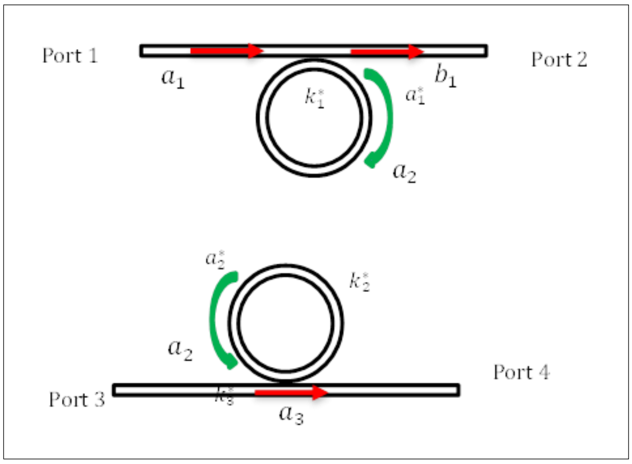

Figure 4 ISR using 2 MRRs

4. MSB topology

MRR is the basic building block to design great speed and low power ONoC. Modulator and demodulator are also made by MRRs. WDM is enabled by wavelength selectivity to increase the bandwidth of interconnections. However, length of waveguide, no. of MRRs and geometry of architecture direct the total crosstalk and optical losses incurred by signal.

4.1. Cluster MSB Topology

Using smaller multiple-segment buses (MSB), where each segment goes through fewer In 4-cluster MSB, two successive rows of clusters (RCs) i.e. RC(0) and RC(1) connected by couple of counter-clockwise (CCW) and clockwise (CW) segmented buses as shown in Fig.5.

Basically, MSB certifies direct single-bus connectivity (SB_{sd}) between an RC-pair i.e. source and destination, say RC(s) and RC(d), by subsequent the rule given by: SBsd connects RC(s)–RC(d), where, s = i[mod($\log_2$ (N)-1)] and d = (i+1)[mod(log2 (N)-1)] and i ∈ {0, 1, . . ., N−1}, with N = number of clusters in a given NoC.

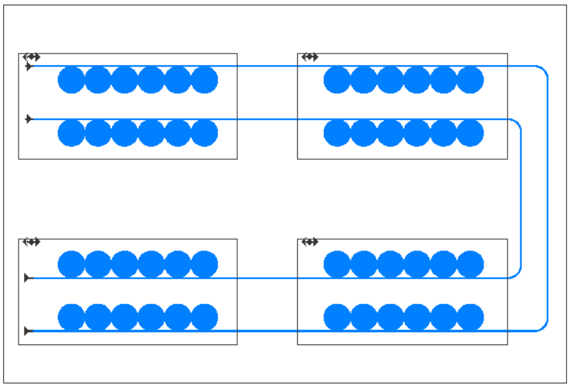

Figure 5 4 Cluster MSB Topology

From a generic viewpoint, for *N*-Cluster MSB topology, the number of waveguides required is *N*/2, however the values of Δ required is 6/12/30 for 10/20/50 Gbps inter-cluster speeds in 4-cluster MSB.

4.2. 16 Cluster MSB Topology

In 16 cluster MSB topology, two adjacent rows are directly connected by a pair of clockwise and anti-clockwise segmented buses and vertically non-adjacent rows are connected through ISRs.

As shown in Figure 6 [1], four rows of clusters are inter connected by using segmented buses, in which adjacent rows are connected by a pair of clockwise and anti-clockwise. i.e RC(0)-RC(1), RC(2)-RC(3), RC(1)-RC(2) and RC(3)-RC(0) are directly connected by segmented bus. These connections ensures direct subsequent rule as explained above.

In Fig. 6, On segmented bus SB_{01} , four clusters in RC(0) i.e. C_{0-3} interconnects with all clusters in RC(1) i.e. C_{4-7}, and C_4 interconnects with C_{5-7}, C_5 communicates with C_6 &C_7 , and finally C_6 communicates with C_7 . So, 4×4+3+2+1 = 22 direct inter-cluster connections are obtained simultaneously. Total 22 × 8 = 176 direct intercluster connections can be obtained on eight segmented waveguides.

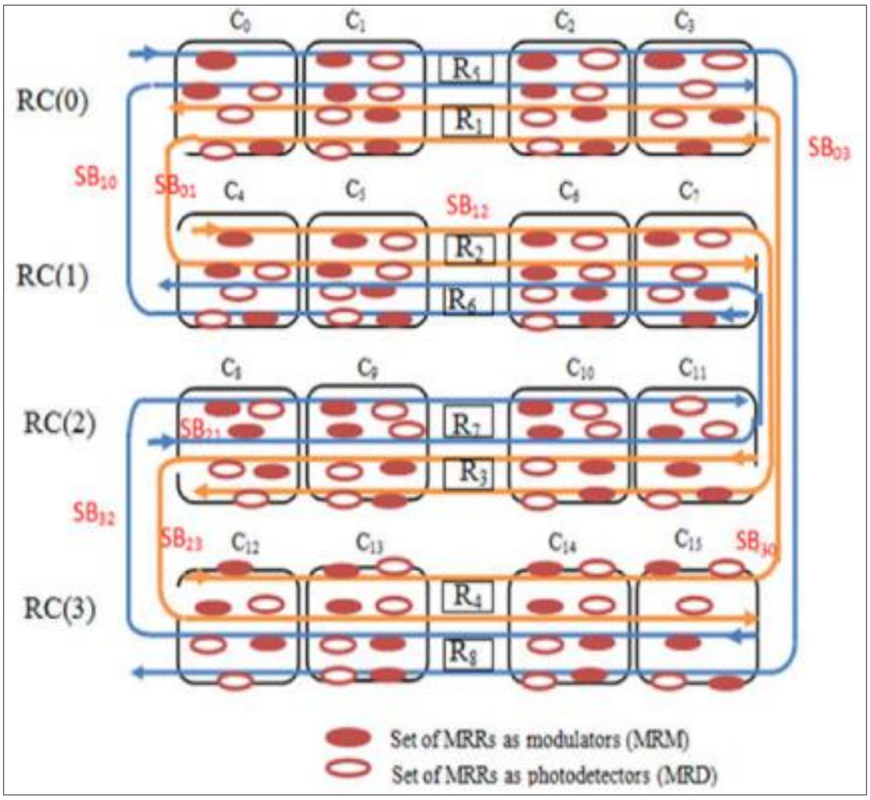

Figure 6 16-Cluster MSB Topology

Now for non-adjacent rows of clusters RC(0)-RC(2) and RC(1)-RC(3), connectivity is shown in following table:

Table 1 Indirect Connectivity

R1	RC(3)-RC(1)	$C_{12\text{-}15} \rightarrow C_{4\text{-}5}$	SB_{30}, SB_{01}
R2	RC(0)-RC(2)	$C_{0\text{-}3} \rightarrow C_{10\text{-}11}$	SB_{01}, SB_{12}
R3	RC(1)-RC(3)	$C_{4\text{-}7} \rightarrow C_{12\text{-}13}$	SB_{10}, SB_{03}
R4	RC(2)-RC(0)	$C_{8\text{-}11} \rightarrow C_{2\text{-}3}$	SB_{23}, SB_{30}
R5	RC(1)-RC(3)	$C_{4\text{-}7} \rightarrow C_{14\text{-}15}$	SB_{12}, SB_{23}
R6	RC(2)-RC(0)	$C_{8\text{-}11} \rightarrow C_{0\text{-}1}$	SB_{21}, SB_{10}
R7	RC(3)-RC(1)	$C_{12\text{-}15} \rightarrow C_{6\text{-}7}$	SB_{32}, SB_{21}
R8	RC(0)-RC(2)	$C_{0\text{-}3} \rightarrow C_{8\text{-}9}$	SB_{30}, SB_{01}

In Fig. 6, all four clusters in RC(3) communicate with two clusters in RC(1), viz., C_4 & C_5 using buses SB_{30} and SB_{01} via the ISR R1 . As these clusters $C_{12\text{-}15}$ do not communicate directly with the clusters C_6 & C_7,because of distance and larger number of MRRs. Instead the clusters $C_{12\text{-}15}$ communicate with the clusters C_6 & C_7 over waveguide segments SB_{32} and SB_{21} using the ISR R7. Therefore it supports all 8 indirect connections using MSB and ISRs. All Eight pairs of waveguides support 8 connections Total 8 × 8 = 64 indirect intercluster connections can be obtained.

Summing up all direct and indirect connections in 16 Clusters MSB Topology provides 176 + 64 = 240 intercluster communication with 22 + 16 = 38 wavelengths. With this, total number of MRRs on a single segmented bus is 60 i.e. 30 modulators and detectors per cluster.so design can achieve load balancing by distributing uniform traffic all over waveguides.

By considering a pair of cluster situated at a distance from each other with intercluster lightwave communication between two cores, each core taken from one of the two given clusters. The lightwave established at the final cluster in presence of crosstalk which is expressed as

$$E_R(t) = \sqrt{(2P_s\,(b_i))}\cos\,(2\pi f_s t + \theta_s + \emptyset_s(t)) + E_{XT}(t)$$

Where, $P_s\,(bi)$ is bit dependent received signal power $b_i \in \{1,0\}$, f_s is signal frequency, θs is initial phase, ϕs is phase noise of the signal component and $E_{XT}(t)$ is accumulated cross talk component and it is given by

$$E_{XT}(t) = \sum_{j=1}^{W} \sqrt{(2P_{xj})}\cos\,(2\pi f_j t + \theta_j + \emptyset_j(t))$$

Where, W is no. of crosstalk components, P_{xj} is received power, f_j is frequency, θ_j is initial phase and $\emptyset_j(t)$ is phase noise.

5. Result and Analysis

Simulation and Implementation of MSB topology is done by using Ansys, which supports to improve quality, reduce time to market and enhance research by offering unique and highly integrated solutions. The proposed design, coming on conclusion that the proposed MSB Cluster Topology design is more efficient and parameters like Insertion Loss and Power Consumption got decreased. Moreover, circuit also achieved better symmetry in the design.

The structure of ISR is designed and simulated in Phoenix. All losses like Bend loss, power loss can be calculated. As shown in Fig. 7., light is given at 1st port of ISR and maximum output is carried out at port 4.its is used for changing path.

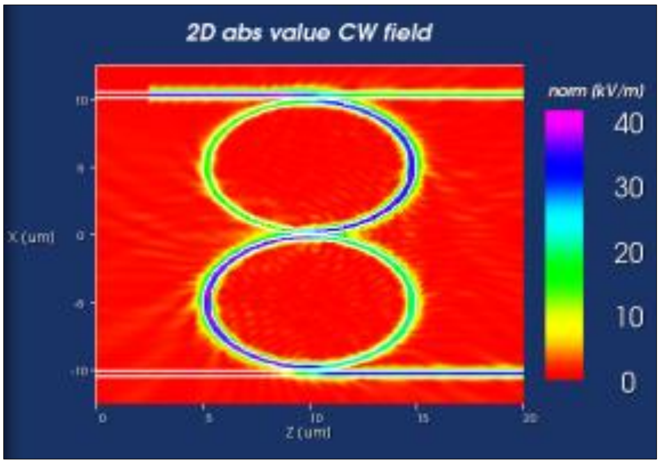

Figure 7 Simulation of ISR

In 4 cluster MSB structure, MRRs are used as modulator and photodetector to improve power efficiency. The maximum transmit power per wavelength needs to be limited within 1.5 mW to prevent any resonance shift in MRRs. Simulation of 4 Cluster is shown in Fig. 8. In that output power is close to input power i.e. 1.5mW.

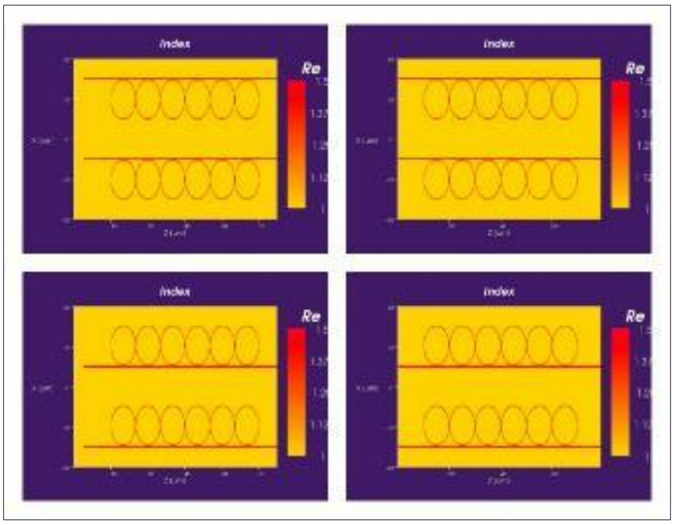

Figure 8 Output of 4 cluster MSB topology

Calculation window is separated as clusters. So result is in 4 parts in 2D as well as 3D Simulation. Data rate is assumed to be 10 Gbps per wavelength. MRR pass-through loss=0.005 dB and ISR loss = 1 dB[1].

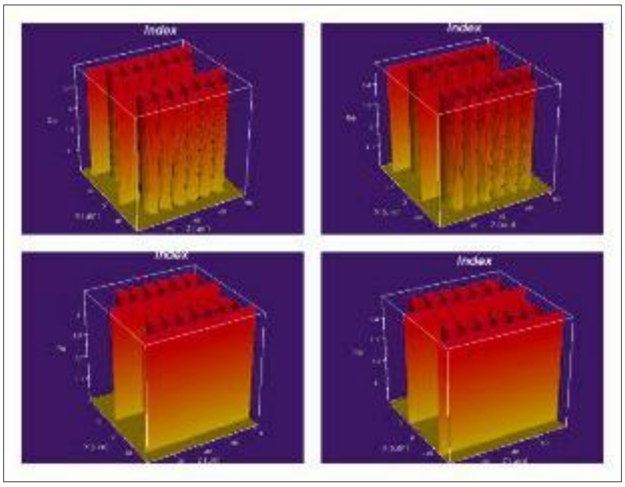

Figure 9 Sectional output of 4 clusters MSB in 3D

6. Conclusion

In comparison to all the design of optical interconnect, the proposed design of MSB topology can be viewed as most symmetric design and give better results in term of less losses and a lower photonic power consumption. The performance optical interconnect topologies in terms of receiver BER for 4-cluster NoCs, by taking into account the impact of various optical losses and crosstalk components improved. Analysis shows that MSB has better performance than the other topologies in respect of achievable BER, while satisfying 1.5mW the upper limit for the launched power in optical buses.

Compliance with ethical standards

Disclosure of conflict of interest

Authors have no conflict of interest.

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