International Science and Technology Journal
المجلة الدولية للعلوم والتقنية
Published On line in june 2014 on https://www.stcrs.com.ly/istj
تم النشر على موقع المجلة الالكتروني بتاريخ يونيو 2014

ANALYSIS OF OPTICAL SWITCHING ARCHITECTURE Using crossbar architecture based on SMZ

http://www.doi.org/10.62341/istj-vol-1-ma73

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الملخص

تتم معالجة الإشارات الدخله لشبكات الالياف الضوئية في النطاق الضوئي وذلك لتجنب الاختناقات الناتجة من التحويلات البصرية ألالكترونية وتعتبر المُبدلات الضوئية عنصرا مهما في شبكات الالياف الضوئية وخاصاً نوعية تركيب المبدل. في هذه الورقة تم اختيار تركيبة ال crossbar كمُبدل واختيار الماخ زيندر (SMZ) ليكون عنصر التبديل داخل المُبدل الضوئي الرئيسي المختار. فقد تم توضيح المعادلات الرياضية لإشارة الدخل والخرج للماخ زيندر(SMZ) وكذلك معادلتي الخرج للمُبدل الضوئي الرئيسي إحداهما عندما يكون معامل التكبير(G) لجميع SMZ متساوي، والأخرى عندما يكون معامل التكبير(G) مختلف. تم التحقق من التغيرات الخاصة بإشارة الخرج للنموذج الرياضي للمُبدل الضوئي الرئيسي بإستخدام برنامج الماتلاب فوجد ان إشارة الخرج لها سلوك خطي مع التغير الحاصل للمعامل الأقتران(coupling) حيث ان اقل قيمة ل CXT تكون عندما يكون معامل الأقتران(coupling) 0.5, وقد اعطى للمُبدل الضوئي الرئيسي نتيجة جيدة بالنسبة للتحويل الكامل لإشارة الدخل الى المنفذ المطلوب باقل قيمة ل CXT عندما يتم التغير في الطور)

Abstract:

The optical networks need to carry out all the switching and routing in optical domain to avoid the bottleneck imposed by the optoelectronic

conversions. Optical switching is an essential element in the optical networks, in particular; the switches architecture.
In this paper the crossbar switch architecture is presented as proposed switch architecture based on symmetric Mach-Zehnder (SMZ) interferometer configuration as switching elements(SEs). The mathematical expressions for the output of the SMZ is demonstrated in both cases of the input port of the switch (port 1 or port 2), then the mathematical equations for the output of the proposed switch is presented in terms of output electric field and the two output equations for the output port of the proposed switch are presented one if the gain for all SMZSEs are equal and second if the gain is different.
The mathematical modules of the proposed switch are developed to investigate the output power and crosstalk (CXT) against the changes in phase and coupling coefficient parameters by using Matlab software.
The numerical result for the proposed crossbar switch shows the output power has a linear behavior with the change of the coupling coefficient and the CXT at its minimum when coupling coefficient is 0.5.
The proposed switch gave good performance in terms of switching the input data signal to the desired port with low CXT when the phase is changed. The changes in the coupling coefficient value increases the crosstalk of each switching element within the proposed switch and this result of increases in the output power at a certain values of the coupling ratio where the input signal here is power signal (always one) which mean there is always input at the input port of the switch, and this give a drawback to it the proposed switch when the input signal is slow pulse signal.

Introduction

The increase in the use of all new technologies in the communication area such as: internet which is used now to carry voice (voice over IP), and the capability of the electronic devices in the telecommunications, all these need to be sent and received in an appropriate manner, where recent studies shows that the data traffics have been increased over the internet by a rate between 70% and 150% per year since 1997 (Vikrant et al, 2007) thus the existing networks should have the ability to accommodate the increasing of more needs of high capacity. Optical networks recently received considerable attention to address the demand of more capacity in the telecommunication systems for its

high bandwidth, where a single strand of fiber can offer a total bandwidth of 25000 GHz and also providing additional advantages such as low attenuation loss (Maier, 2008).
Optical time division multiplexing (OTDM) is one technique used to mange and make use of the networks bandwidth and by using fast optical switches in high speed OTDM systems the increasing in the reliability and flexibility will be achieved (Schubert *et al*, 2002), where there are different applications, types and sizes of the switches depending on the use of switch in the network.
All-optical switch based on cross-phase modulation (XPM) is one type which found more suitable for the high seed OTDM networks (Toliver et al, 2000) where the Symmetric Mach-Zehnder interferometer (SMZ) based on semiconductor optical amplifier (SOA) one on each of its arm has more advantages than other types of the all-switches due to its compact size, thermal stability and low power control signal (Chiang *et al*, 2006).
There are different uses, applications of the switches and different large switch architectures operate in the large networks to give a good performance to these networks, where the performance of the large switches is depending on the architecture of the switch where some architectures give a high performance as all-optical switches and not for an optoelectronic switches, and also the inter connections crossovers in the switch effect the switch by introducing the crosstalk's (CXT).

Aim

The aim of this paper is to develop a model to analyse a large optical switch architecture based on Symmetric Mach-Zehnder interferometer (SMZ) switch elements.

Optical switches

As the demand for network capacity is growing rapidly, the optical switches should have high speed switching time by providing the switching of the data from the input to output in optical domain, where the bottleneck imposed by the optoelectronic conversions will avoided (Chiang *et al*, 2006).
According to **Ramaswami, Kumar (2002)** the switches are used for different applications where each application requires its own switching time and number of switch ports (for large switches), some of these applications are:

- Provisioning switching of light paths.
- Protection switching.
- Packet switching.
- External modulation.

Table (1) switch applications

Application	switching time required	Number of ports
provisioning	1-10 ms	>1000
Protection switching	1-10 ms	2-1000
Packet switching	1 ns	>100
External modulation	10ps	1

All-optical switches based on the XPM in a SOA in conjunction with interferometric structures such as: Terahertz optical a symmetric demultiplexer (TOADS), ultrafast non-linear interferometers (UNIs) and Mach-Zehnder interferometer (MZI) (Le Minh *et al*, 2006), (Ngah, 2004). A comparison between the different types of the all-optical switching architecture is summarized in table (2).

Table 2 comparison of all-optical switches (source (Ngah, 2004))

Switching device	Switching time	Control pulse energy(pJ)	Noise figure	Integratable
MZI/SMZ	< 1 ps	0.25	6	Yes
TOAD	< 1 ps	0.25	6	Yes
UNI	< 1 ps	0.25	6	No
NOLM	0.6 ps	> 50	Low	No

The interferometer switches based on the SOAs is the most promising (Le Minh *et al*, 2007), suitable devices for the high speed OTDM systems, and from different interferometric types listed above the MZI is the most promising one where it have demonstrated its ability to switch a single channel OTDM by using two SOAs one in each if its arms, at up to 168 Gb/s (Roy, 2007; wang *et al*, 2007).

Symmetric Mach-Zehnder interferometer (SMZ)

The SMZ shown in Figure (1) provides the highest flexibility due to its compact size, thermal stability, low power operation, short and almost square switching window profiles (SW) (Chiang *et al*, 2006; Diez *et al*, 2000; Roy, 2007).

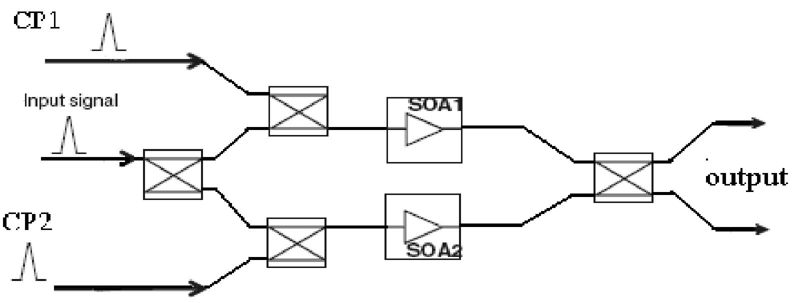

Fig 1. SMZ optical switch (based on: Ghassemlooy, 2006)

And also the co-propagating signal characteristic of the SMZ helps to reduce the crosstalk (CXT) which come from the other signals whiten the switch. The name symmetric comes from the positions of SOAs where they are in the same relative location within the interferometer and they use the same parameters (Ngah, 2004).
Also the SMZ switch can be used to extract a single data channel from the incoming OTDM data stream in the OTDM demultiplexer or as all-optical switch to switch a complete data packet to the desired output as seen in figure (2) (Le Minh *et al*, 2006).

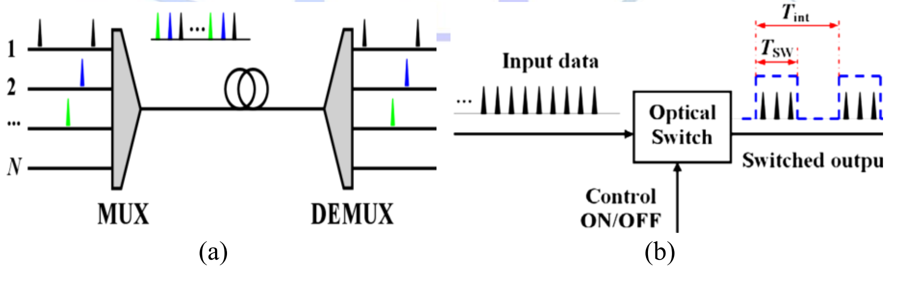

Fig 2. (a) as an OTDM demultiplexer (b) as all-optical switch
(Source; Le Minh *et al*, 2006))

Large switch architectures

Due to the ability of the optical networks to carry a few hundred to few thousand of wavelengths on the optical fiber the need of large switches is obvious to protect and provision these wavelengths. To build a large optical switch with n inputs and n outputs, the interconnection of a number of small switches is required. So, some consideration should be taken when build a large switch such as, number of switches elements needed, number of crossovers because each crossover is a source of losses and crosstalk, longest path, the shortest path and blocking characteristics.

The figures below show different types of switches architecture:

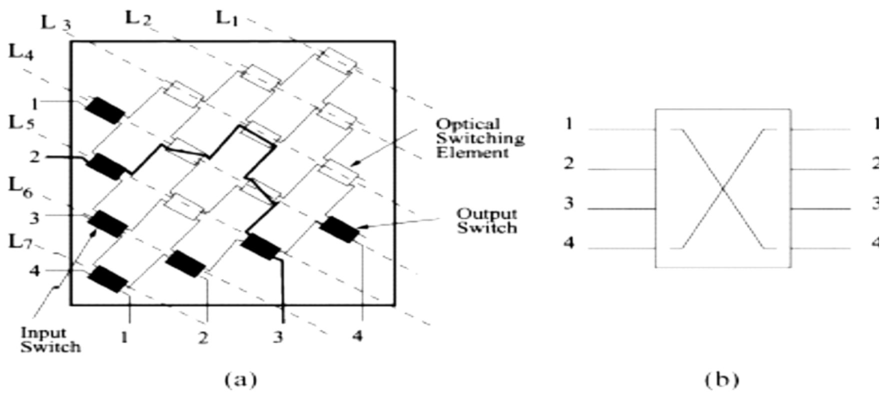

Fig. 3 (a) Crossbar architecture. (b) Symbolic notation. (source; Hamza, Deogun, 2007)

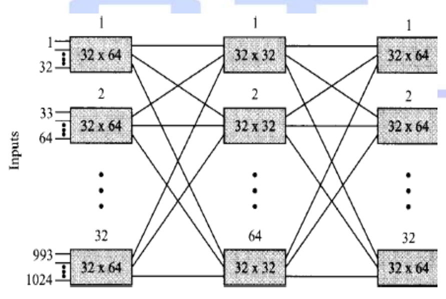

Fig. 4 Clos switch architecture. (source; Shalmany *et al*, 2007)

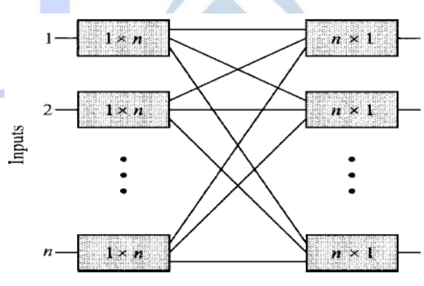

Fig. 5 Spanke switch architecture (source; Ramaswami and Kumar, 2002)

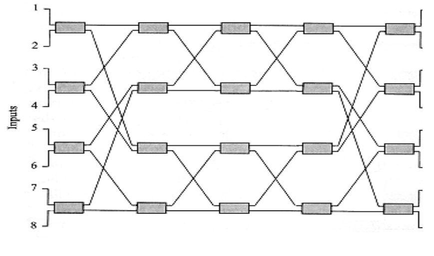

Fig. 6 Benes switch architecture

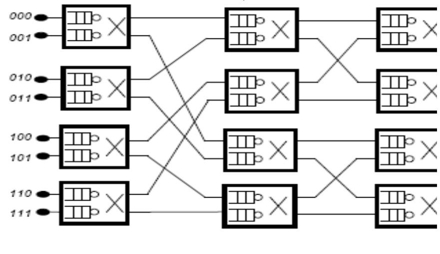

Fig. 8 Banyan switch

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(source; Ramaswami and Kumar, 2002)

(source; Shalmany et al, 2007)

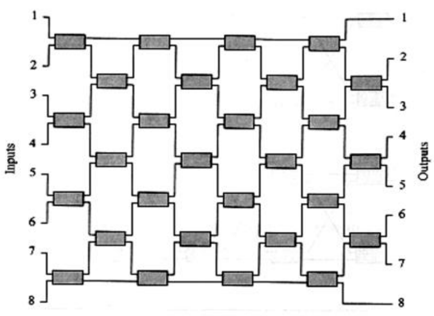

Fig.7 Spanke-Benes architecture
(source; Ramaswami and Kumar, 2002)

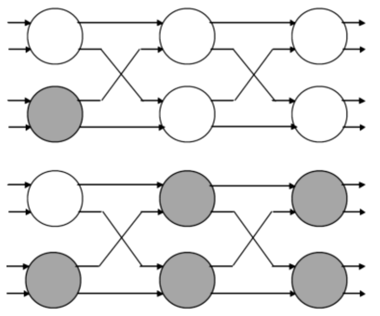

Fig .9 An 8×8 Batcher switch. Dark circles sort address in ascending order, white circles sort in descending order (source; Shalmany *et al*, 2007).

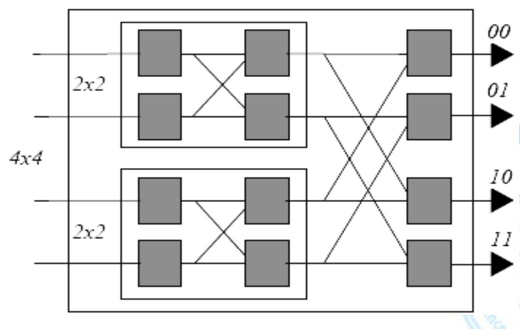

Fig.10 Butterfly Switch
(source; Shalmany et al, 2007)

The next table shows the comparison between the different types of switch architectures.

Table 3 (source, Spanke, 1987; Ramaswami and Kumar, 2002)

Switch type	Blocking type	No. of switching element	Max.loss (Longest path)	Min.loss (Shortest path)
Crossbar	Wide sense nonblocking	n^2	$2n-1$	1
Clos	strict-sense nonblocking	$4\sqrt{2}n^{3/2}-4n$	$5\sqrt{2n}-5$	3

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Switch type	Blocking type	No. of switching element	Max.loss (Longest path)	Min.loss (Shortest path)
Spanke	strict sense nonblocking	$2n$	$2\log_2 n$	$2\log_2 n$
Benes	rearrangeably nonblocking	$(n/2)(2\log_2 n-1)$	$2\log_2 n-1$	$2\log_2 n-1$
Spanke-Benes	rearrangeably nonblocking	$n(n-1)/2$	n	
Banyan	Blocking	$n/2\cdot\log_2 n$	$\log_2 n$	$\log_2 n$
Batcher-Banyan	strict-sense nonblocking	$n(3+\log_2 n)(\log_2 n)/4$	$(\log_2 n+3)$ $\times(\log n)/2$	$(\log_2 n+3)$ $\times(\log n)/2$
Butterfly	Blocking	$n(\log_2 n+1)$	$1+\log_2 n$	$1+\log_2 n$

Figures (11) and (12) shows the longest and shortest path for the different types of switch architectures where as seen the Batcher Banyan switch has a greater shortest and longest path over other types, and the next architectures are depending on the needed size of the switch (n) where for $n \leq 32$ the architectures are Cantor and Crossbar switches, and for $n > 32$ the Cantor and Clos architecture will chosen (Shalmany *et al*, 2007).

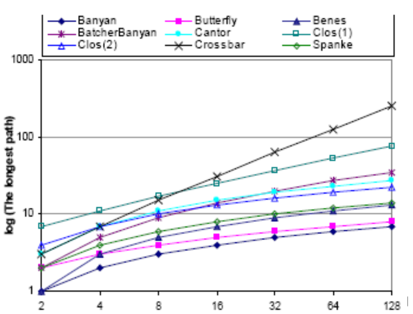

Fig .11 Longest path as a function of n

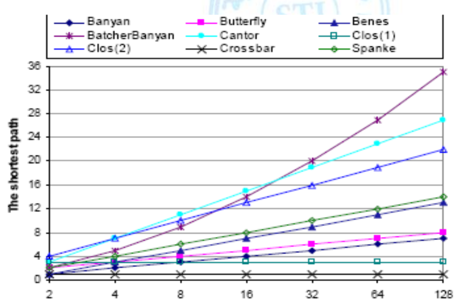

Fig.12 Shortest path as a function of n

Crossbar switch architecture based on SMZ

Crossbar switch is one of the widely used switch architectures in the optical switching systems due to its easy routing algorithm and it's a nonblocking characteristic, and it will handle the data traffic efficiently because it is a wide sense nonblocking (Rahman *et al*, 2007).

In this architecture I use the SMZ as switching element (SMZSE) due to its advantages over other switches, the electric fields of the output data signals from both output ports of the SMZ in presence of the control signal CP1 are given as (Ngah, 2004):

$$E_{out,1} = E_{out}^{UA}(\pi) + E_{out}^{LA}(\pi) \tag{1}$$

$$E_{out,2} = E_{out}^{UA}(3\pi/2) + E_{out}^{LA}(\pi/2) \tag{2}$$

The second control signal CP2 which is delayed by a switching window time delay T_{delay} with respect to CP1 and injected into the interferometer via C3 just after the data signal, so the SOA2 will saturated which resulting in the same phase shift of the upper interferometer arm and then the effect of CP1is cancelled, thus the switch will return to the balance state and switch back to port 4 (Ghassemlooy *et al*, 2006; Le Minh *et al*, 2007). And from the above mechanism, the SMZ switching time is controlled by the optical excitation process to switch between the output ports (Ghassemlooy *et al*, 2006).
The gains of the data signal at the output of both SOAs at the temporal point ($G_1(t)$ and $G_2(t)$) are respectively given as (Ngah, 2004; Ghassemlooy *et al*, 2006):

$$G_1(t) = \exp\left[\int_0^{L_{SOA}} \Gamma.g\left(z, t + \frac{z}{V_g}\right) dz\right] \tag{3}$$

$$G_2(t) = \exp\left[\int_0^{L_{SOA}} \Gamma.g\left(z, t + T_{delay} + \frac{z}{V_g}\right) dz\right] \tag{4}$$

Where Γ is the confinement factor, g represented the differential gain of the data and control signals, L is the active region of the SOAs, t is the time at which the temporal point of the signal inters the SOA, z/V_g is the time increment in the z direction, and V_g is the group velocity of the control signal (Le Minh *et al*, 2007; Ghassemlooy *et al*, 2006).

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The both electric fields $E_{out,1}$ and $E_{out,2} = 0.5\,E_{in}$ and the electric fields at output ports of the SMZ ($E_{out,1}$ and $E_{out,2}$) in terms of the relative G and ϕ of the incident fields within the upper and lower arms are given by(Ngah, 2004):

$$\begin{pmatrix} E_{out,1}(t) \\ E_{out,2}(t) \end{pmatrix} = \begin{pmatrix} (1-\alpha)^{1/2} & j\alpha^{1/2} \\ j\alpha^{1/2} & (1-\alpha)^{1/2} \end{pmatrix} \times \begin{pmatrix} E_{out}^{UA}(t) \\ E_{out}^{LA}(t) \end{pmatrix} \tag{5}$$

Where α is the coupling ratio, $E_{out}^{UA}(t)$ and $E_{out}^{LA}(t)$ are the outputs electric fields from the SOA1and SOA2 respectively, and they given by (based on: Ngah, 2004):

$$E_{out}^{UA}(t) = E_{SOA1,in}^{UA}(t)\,G_1(t).e^{-j\phi_1} \tag{6}$$

$$E_{out}^{LA}(t) = E_{SOA2,in}^{LA}(t)\,G_2(t).e^{-j\phi_2} \tag{7}$$

where $G_1(t).e^{-j\phi_1}$ and $G_2(t).e^{-j\phi_2}$ are the complex gains of the SOA1and SOA2 respectively, $E_{SOA1,in}^{UA}(t)$ and $E_{SOA2,in}^{LA}(t)$ are the input electric fields to both nonlinear elements in each arm (i.e. they are the outputs from C2and C3) (Ngah, 2004).
Because of E_1 and $E_2 = 0.5\,E_{in}$, then by using (6) and (7) in (5) the outputs can be expanded to (Ghassemlooy *et al*, 2006):

$$E_{out,1}(t) = E_{in}(t)\left[(1-\alpha)^{3/2}\,G_1 - \alpha(1-\alpha)^{1/2}G_2\right] \tag{8}$$

$$E_{out,2}(t) = jE_{in}(t)\left[\alpha^{1/2}(1-\alpha)G_1 - \alpha^{1/2}(1-\alpha)G_2\right] \tag{9}$$

The output power from the SMZ switch output ports when the coupling ratio $\alpha = 0.5$ which results of $E_{SOA1,in}^{UA}(t) = E_{SOA2,in}^{LA}(t)$ with $\pi/2$ relative phase difference are given as (Ngah, PhD 2004; Ghassemlooy *et al*, 2006):

$$P_{out,1}(t) = \frac{1}{8}P_{in}(t)\cdot\left[G_1(t) + G_2(t) - 2\sqrt{G_1(t)\cdot G_2(t)\cdot\cos(\Delta\phi)}\right] \tag{10}$$

$$P_{out,2}(t) = \frac{1}{8} P_{in}(t) \cdot \left[G_1(t) + G_2(t) + 2\sqrt{G_1(t) \cdot G_2(t) \cdot \cos(\Delta\phi)} \right] \qquad (11)$$

Where $\Delta\phi = (\phi_1 - \phi_2)$ is the phase different between the data signals propagated in both arms of the SMZ which is related to the gain ratio and the linewidth enhancement factor α_{LEF} and given by (Ghassemlooy and Ngah, 2005):

$$\Delta\varphi = -0.5\alpha_{LEF} \ln(G_1(t) / G_2(t)) \qquad (12)$$

According to Le Minh *et al* (2007); Ghassemlooy *et al* (2006), the width of the SMZ switching window is determined by the T_{delay} between the control signals and thus the switching window given by:

$$SW_i(t) = \frac{1}{8} \left[G_1(t) + G_2(t) - 2\sqrt{G_1(t) G_2(t) \cos(\Delta\phi)} \right] \qquad (13)$$

Where $SW_i(t)$ is the switching window of at both output ports {i = 3, 4}.

The gain of both SOAs in equation (3) and (4) are identical when the T_{delay} is zero, and as reported by (Ghassemlooy and Ngah, 2005) the simulated gain profiles of the data signals propagated through the SOAs is shown in figure (13)

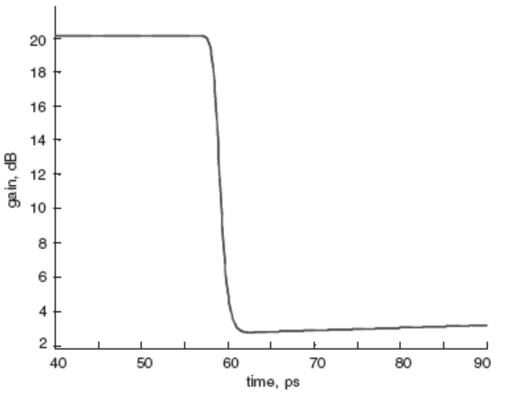

Fig .13 Simulated gain profile when T_{delay} =0
(source; Ghassemlooy and Ngah, 2005)

Then the value of $G_1(t)$ and $G_2(t)$ are substituted in equation (12) and (13) to obtain the output switching window of the SMZ, where at first when the gain of both SOAs are identical there will be no switching window and when T_{delay} is applied the both $G_1(t)$ and $G_2(t)$ have an identical response except the $G_2(t)$ where it is delayed by the amount of T_{delay} (Ngah, 2004). The computing switching windows of the SMZ for T_{delay}=10ps are shown in figure (14).

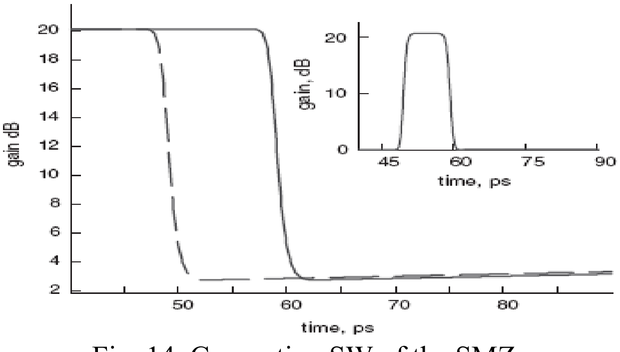

Fig .14 Computing SW of the SMZ
(source: Ghassemlooy and Ngah, 2005)

The crosstalk (CXT) effect the performance of the switches and given by (Ngah, 2004):

$$CXT = 10\log_{10}\left(P_{nt} / P_t\right) \quad (14)$$

where P_{nt} is the output signal power of the non-target channel and P_t is the output signal power of the target channel.

In crossbar architecture the number of switching elements is n^2 2×2 optical switches, so to design 3×3 switch, where $n=3$ the total number of SMZSE in this block are 9 SMZSE (MZ1, MZ2, MZ3, MZ4, MZ5, MZ6, MZ7, MZ8 and MZ9) connected to each other as shown in figure (15).

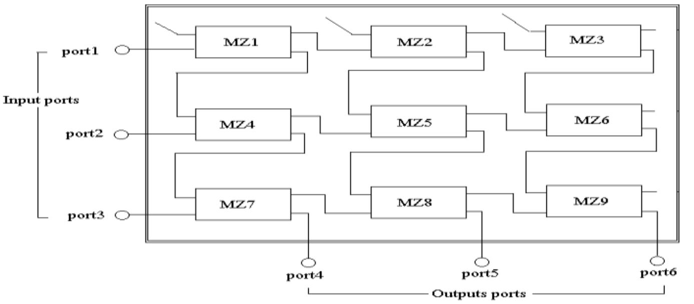

Fig.15 Crossbar architecture switch (based on: Ramaswami and Kumar, 2002)

The shortest path for this architecture is 1 which is through the MZ7, and the longest path is $2n-1$ (Ramaswami and Kumar, 2002). Where in this evaluation the longest path is chosen which is through MZ1, MZ2, MZ3, MZ6 and MZ9 to see the performance of this architecture by using SMZ as switching element and the effects of the change in the coupling ratio and the changing in the phase shifters of the tow semiconductor optical amplifiers (SOA1 and SOA2).
By calculating the output electric fields when the input data signal inters the SMZ from its port 2 it's found:

$$E_{out,3}(t) = jE_{in}(t)\left[\alpha^{1/2}(1-\alpha)G_1 - \alpha^{1/2}(1-\alpha)G_2\right] \quad (15)$$

$$E_{out,4}(t) = -E_{in}(t)\left[\alpha(1-\alpha)^{1/2}G_1 + (1-\alpha)^{3/2}G_2\right] \quad (16)$$

Figure (16) shows the simulated crossbar output signal from port 6 when the electric field input signal E_{in} is $\{0, 1\}$, where ϕ of the SOA1 for the MZ9 changes from 0 to π, and ϕ for SOA2 is π.

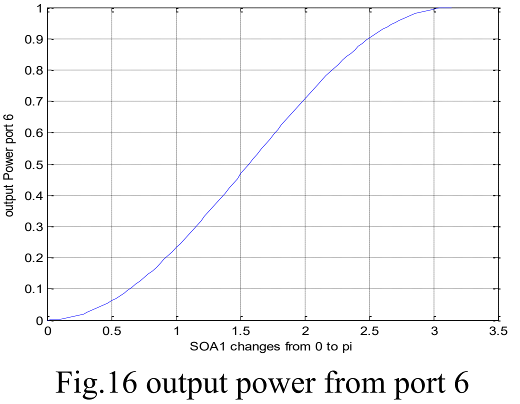

Fig.16 output power from port 6

The electric field of the output data signal for each SMZSE in the proposed crossbar switch if the gain is equal (in simulated module the G1 and G2 are equal to 1) can be given as:
MZ1: the input data signal inters the MZ1 from its port 2 and out from port 3.
MZ2: output from MZ1 will inter MZ2 via its input port 2 and out from port 3.
MZ3: the output from MZ2 will inter the MZ3 via input port 2 and out from port 4.
MZ6: output from MZ3 will inter the MZ6 via port 1and out from the output port 4. MZ9: the MZ6 output will an input to the MZ9 from its port 1 and out from port 4 which is the port 6 for the crossbar switch and given by:

$$E_{in}^{MZ6}(t) = E_{out,4}^{MZ6}(t) \tag{17}$$

$$E_{out,4}^{MZ9}(t) = jE_{in}^{MZ6}(t)\left[\alpha^{1/2}(1-\alpha)G_1 - \alpha^{1/2}(1-\alpha)G_2\right] \tag{18}$$

If the gains is different from one SMZ to another then the gains must be considered, and by take the value of each SOA gain, then the output from MZ9 which is the port 6 of the proposed crossbar switch should be as following:

$$E_{out,4}^{MZ9}(t) = -jE_{in}(t)\begin{bmatrix} \alpha^3(1-\alpha)^{7/2}\begin{pmatrix} G_{1,1}G_{2,1}G_{3,1}G_{6,1}G_{9,1} + G_{1,1}G_{2,1}G_{3,1}G_{6,1}G_{9,2} + G_{1,1}G_{2,1}G_{3,1}G_{6,2}G_{9,1} + \\ G_{1,1}G_{2,1}G_{3,1}G_{6,1}G_{9,2} + G_{1,1}G_{2,2}G_{3,1}G_{6,1}G_{9,1} + G_{1,1}G_{2,2}G_{3,1}G_{6,1}G_{9,2} + \\ G_{1,1}G_{2,2}G_{3,1}G_{6,2}G_{9,1} + G_{1,1}G_{2,2}G_{3,1}G_{6,2}G_{9,2} + G_{1,2}G_{2,1}G_{3,1}G_{6,1}G_{9,1} + \\ G_{1,2}G_{2,1}G_{3,1}G_{6,1}G_{9,2} + G_{1,2}G_{2,1}G_{3,1}G_{6,2}G_{9,1} + G_{1,2}G_{2,1}G_{3,1}G_{6,2}G_{9,2} + \\ G_{1,2}G_{2,2}G_{3,1}G_{6,1}G_{9,1} + G_{1,2}G_{2,2}G_{3,1}G_{6,1}G_{9,2} + G_{1,2}G_{2,2}G_{3,1}G_{6,2}G_{9,1} + \\ G_{1,2}G_{2,2}G_{3,1}G_{6,2}G_{9,2} \end{pmatrix} + \\ \alpha^2(1-\alpha)^{11/2}\begin{pmatrix} G_{1,1}G_{2,1}G_{3,2}G_{6,1}G_{9,1} + G_{1,1}G_{2,1}G_{3,2}G_{6,1}G_{9,2} + G_{1,1}G_{2,1}G_{3,2}G_{6,2}G_{9,1} + \\ G_{1,1}G_{2,1}G_{3,2}G_{6,2}G_{9,2} + G_{1,1}G_{2,2}G_{3,2}G_{6,1}G_{9,1} + G_{1,1}G_{2,2}G_{3,2}G_{6,1}G_{9,2} + \\ G_{1,1}G_{2,2}G_{3,2}G_{6,2}G_{9,1} + G_{1,1}G_{2,2}G_{3,2}G_{6,1}G_{9,2} + G_{1,2}G_{2,1}G_{3,2}G_{6,1}G_{9,1} + \\ G_{1,2}G_{2,1}G_{3,2}G_{6,1}G_{9,2} + G_{1,2}G_{2,1}G_{3,2}G_{6,2}G_{9,1} + G_{1,2}G_{2,1}G_{3,2}G_{6,2}G_{9,2} + \\ G_{1,2}G_{2,2}G_{3,2}G_{6,1}G_{9,1} + G_{1,2}G_{2,2}G_{3,2}G_{6,1}G_{9,2} + G_{1,2}G_{2,2}G_{3,2}G_{6,2}G_{9,1} + \\ G_{1,2}G_{2,2}G_{3,2}G_{6,2}G_{9,2} \end{pmatrix} \end{bmatrix} \tag{19}$$

Where $G_{i,j}$ is the gain of each SOA in the crossbar switch, i is the SE number $\{i=1, 2, \ldots, 9\}$ and j is the number of the SOA within the SE $\{j=1, 2\}$. The output then will be from the output port 6 of the crossbar switch.
Table (4) describe the value of ϕ for each SMZSE where ϕ_1 and ϕ_2 are the phase induced by SOA1 and SOA2 respectively for the chosen path and the output port for each SE.

Table 4 configurations of the SE in the crossbar switch

SMZSE	ϕ_1	ϕ_2	Input port to SE	stat	SE output port
MZ1	0	0	Port 2	Cross	Port 3
MZ2	0	0	Port 2	Cross	Port 3
MZ3	π	0	Port 2	Bar	Port 4
MZ6	0	0	Port 1	Cross	Port 4
MZ9	π	π	Port 1	Cross	Port 4 (port 6 of the proposed switch)

Results

The Matlab software is used as a numerical method to evaluate the proposed crossbar switch architecture based on SMZ model mathematically. The evaluation based on changing in two parameters within the switches, the first parameter is the phase of the SOA1 (ϕ_1) for the MZ9 in the proposed crossbar switch where the other Symmetric Mach Zhender Switching Elements (SMZSEs) are configured as table (4) and the coupling ratio (α) are 0.5 in all couplers, the second parameter is by changing the coupling coefficient (α) for the couplers C1 & C4 for all the SMZSEs, where the phases of all the SOAs are same as configurations of table (4) where these changes act as the effect when the control signals are injected to the SMZSE.

The crosstalk in equation (14) is used to calculate the CXT at the output of the proposed crossbar switch where the output power and crosstalk are calculated against the changes in phase and coupling coefficient.

The gain is 1 dB for all the OSAs inside the proposed crossbar switch and the insertion lose is 0.

1-Effect of SOA phase ϕ delay on output power

The output power of the proposed crossbar switch is investigated against the SOA phase. The value of α is 0.5 which mean the signal intensity divided into two equal intensities E_1^{UA} and E_2^{LA} C1 in each SMZSE within the proposed crossbar switch and then the data signal switched to the configured path (input port 1 and out from port 6).

International Science and Technology Journal
المجلة الدولية للعلوم والتقنية
Published On line in june 2014 on https://www.stcrs.com.ly/istj
تم النشر على موقع المجلة الالكتروني بتاريخ يونيو 2014

The output power from port 6 is shown in figure (17) where the power changes with the different value of ϕ_1 within the MZ9 until the all power switched to port 6 at $\phi_1 = \pi$.

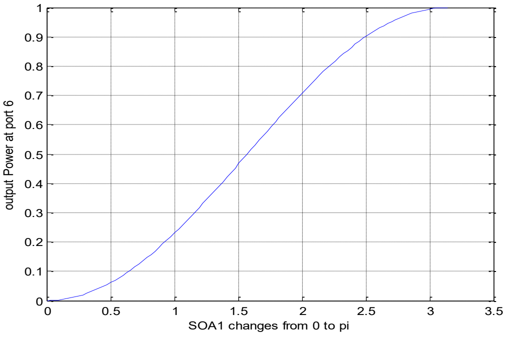

Fig 17 output power port 6 Vs ϕ_1 of MZ9

The relation between the CXT and the changes in the phase is shown in figure (18), where from the figure the value of the CXT reaches its lowest value when $\phi_1 = \pi$ (3.1416).

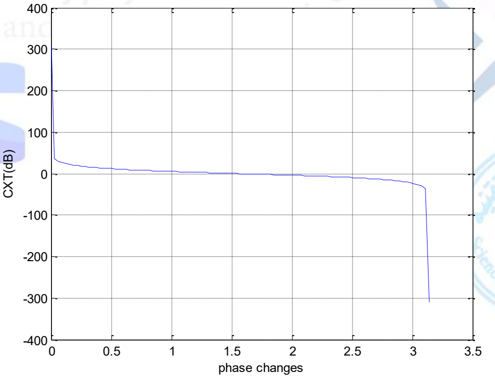

Fig.18 .CXT Vs ϕ_1

2-Effect of Coupling coefficient (α) on output power using equation (18)

The coupling ratio (α) for C1 & C4 in each SMZSE changes from 0 to 0.5, and C2 & C3 are configured to give the output from their desired port (C2 port 4, C3 port 3), the value of ϕ for all SOAs within SMZSEs are configured as table (4).

Figure (19) shows the changes in the output power in port 6 against the change in the value of α . The value of the output power when α = 0.4 where it is 1.1 mw.

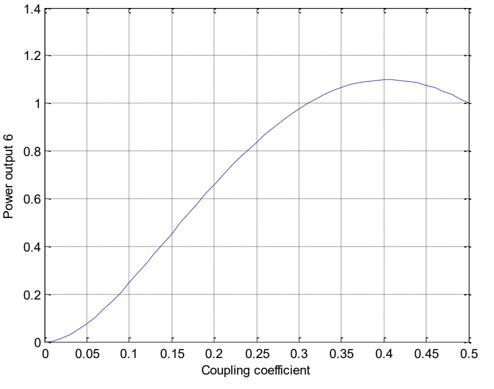

Fig19 output port 6 Vs α

The relation between the CXT and the coupling coefficient for the proposed crossbar switch is shown in figure (20)

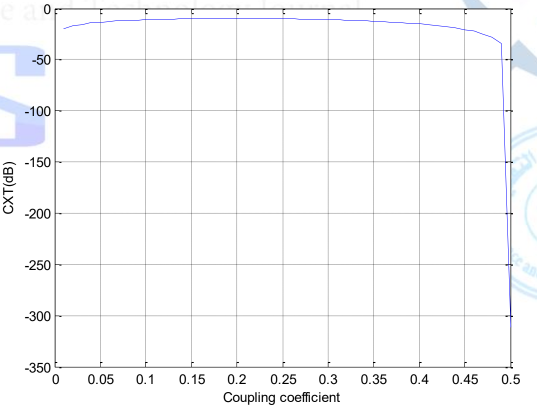

Fig 20 CXT Vs α

Figure (21) shows a schematic diagram for the proposed crossbar switch, where it is divided by times (t_1, t_2, t_3, t_4, t_5) at the output of each stage within the switch.

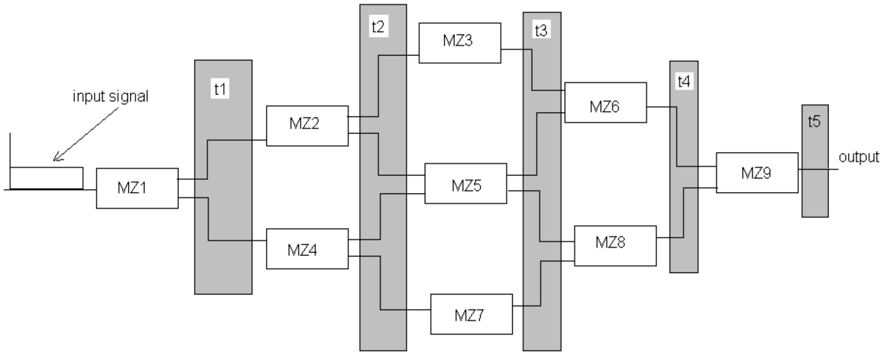

Fig 21 schematic diagram of the proposed switch

Each time is represent the output power at the outputs of the SMZSE which they also available as input power to the next stage.

Conclusion

Optical switches are essential elements to increase the performance of the high-speed optical networks. The architecture of the switches has critical effects on the performance of the switches, so the primary objective of this research is to choose suitable switch architecture and evaluate the output by using a mathematical module.

The crossbar architecture was chosen to be the proposed switch architecture due to its simple interconnection which makes the connection between the elements more easer where it is fabricated with no crossovers, the crossovers increases the crosstalk (CXT) and affect the performance of the switch. The SMZ switch was chosen to be the switch element (SE) of the proposed crossbar switch architecture due to its advantages over other types of optical switches. The mathematical equations for the SMZ and the proposed crossbar switch were presented, the output equation for the proposed crossbar switch were presented in terms of two cases, when the gain of the SOAs is same and when it is different.
The simulation of the mathematical model crossbar switch was carried out by changing in two parameters of the switches: the value of ϕ and the coupling ratio α where ϕ changes from 0 to π and α changes from 0 to 0.5. According to these changes the output power and crosstalk (CXT) were evaluated against the phi and α .

The results show that, the minimum CXT for proposed crossbar switch mathematical model when $\phi_1 = \pi$ was -308.9846 dB, and when α = 0.5 was -311.1330 dB.
The maximum value of CXT for the proposed crossbar switch was -9.7199 dB when the value of α is 0.19, and the output power at α = 0.4 was 1.1mw and decreases to 1mw when α = 0.5 due to the uses of the continues input signal which mean there is always input with the same value at all time at the input port of the switch.

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