Performance Evaluation of Mach Zender Interferometer

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ABSTRACT

This paper evaluates the performance of a Mach Zehnder type of interferometer in optical network switching using MATLAB as the simulator. The function of the switch is to measure the relative phase shift between the two collimated signals from the source. This paper also discusses the effect of the relative delay with respect to time on the two signals and the corresponding effect on the relative phase shift which determines the performance and the efficiency of the switch. The Mach Zender interferometer is particularly a simple device for demonstration of interference by division of amplitude. A light beam is initially split into two parts by the beam splitter. Depending on the relative phase acquired by the beam with efficiency between 0-100 percent. This paper also shows that the relative separation of the devices D1and D2 causes a corresponding change in refractive index which in turn produces a corresponding relative phase change which is responsible for the switching of the device from port 2 to port 4 and port 3. With port 4 having the higher intensity of signal of approximately 98.9% and port 3 having a lower intensity of approximately 1.1%. From the transmittance equation, we can conclude that the interferometer switch has a high performance efficiency 98.9 % respectively.

Keywords: Performance, Evaluation, Mach, Zender, Interferometer

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1. INTRODUCTION

There has been a tremendous increase in the capacity and capability of fiber optic communication networks over the decades. This tremendous achievement in terms of growth has been made possible by the evolution of new optoelectronic technologies that are employed to harness the enormous bandwidth offered by optical fiber technology. Presently there are several systems available that operates at a bit rates of over 100 Gb/s. Optical signal is now a dominant carrier for worldwide information transmission because it has the capability to fulfill the demand of high speed and bandwidth for future networks. Advancement in optical networks has been made possible by the use of Interferometer (Rekha, et al., 2010). The structure of the switch as depicted in figure 1 is a two input 2 x 2 (two input-two output) device. The design consists of two Y-junction 3dB couplers connecting two electronic devices D1 and D2 which are places at a distance relative to each other. The devices D1 and D2 are electronic in origin and are based on the density of charge in the device, which is based on a driving current. The density of charge in the device affects the optical signal propagating through it. The operational behavior of the switch can be described as follows: Incoming optical signal fired from port 1 or port 2 split into the equal part into two arms at coupler 1 which later recombine at the coupler 2 providing a output signal at either port 3 or port 4.

The output signal contain information of the changes that has occurred in the two arms when passing through the devices D1 and D2 which are placed at distances relative to each other. The staggering of D1 and D2 would have imposed some sort of time delay or shift with respect to time which in return would have caused a change refractive index to take place. The change in the refractive index would cause a corresponding phase shift. The change in the refractive index is typically very small nevertheless; its effect on an optical wave propagating a distance much greater than a wavelength of light in the medium can be significant (Saleh and Teich, 1991).

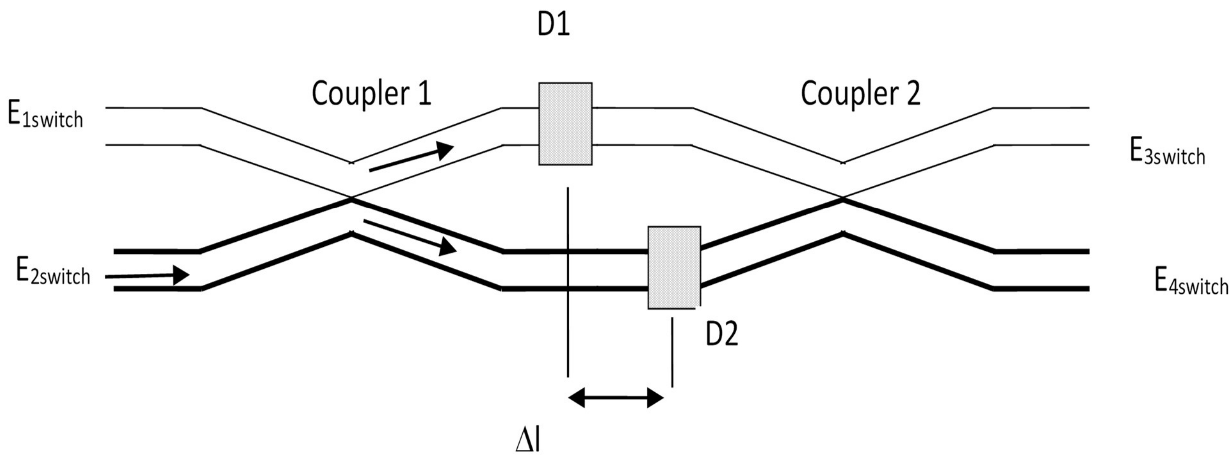

Figure 1.1: Structure of the switch

$$\begin{bmatrix} E_3 \\ E_4 \end{bmatrix} = \sqrt{(1-\gamma)} \begin{bmatrix} (\alpha_{(1,3)})[0] & (\alpha_{(2,3)})[\delta] \\ (\alpha_{(1,4)})[\delta] & (\alpha_{(2,4)})[0] \end{bmatrix} \begin{bmatrix} E_1 \\ E_2 \end{bmatrix}$$ ----------------Equation 1

2.1 Background Consideration

The MATLAB simulator intends to investigate the effect of relative displacement (staggering) of D1 and D2 on the refractive indexes of D1 and D2 and its effect on the relative phase shift between them which is responsible for the switching of the device. The design for the switch is such that the waveguides form the intersection of the inputs, couplers, devices and outputs and serve to guide the fields along.

- The density of charge in D1 and D2 in devices affects the optical signals propagating through them which produce refractive indexes.
- The relative separation of D1 and D2 which impose some sort of relative time delay.
- Assuming data rate of 10 Gb/s

Table 1. Initial simulation parameters

Parameter	Value
L	500×10^{-6}m
K	2×10^{-26} m^3
N_0	3
C	0.15
λ	1.5×10^{-6} m
Refractive index of switch waveguides	1.0
Δl	Such that Δl/c is of the order of a data bit period where c = 3×10^8 ms^{-1}.

2.1 Part1

This part attempts to simulate the Refractive index of D1 and D2 based on the density of charge.

In order to simulate the refractive index of D1 and D2 based on density of charge; there is a need to consider the effect of the relative separation of D1 and D2. The separation (staggering) of the device D1 and D2 will impose some sort of relative shift (delay) with respect to time on the two signals. To implement a delay; the length of the signal was increase with respect to the time (sec) by a factor 1000 while the density of charge (m^3) remains constant. The factor was gotten based on the calculation. Assuming a data rate of 10 Gb/s for the system.

From 10 GB/s we can deduce, 1 bit in 0.1 X 10 E – 9 s

From the data given the time is increasing at the rate of 1.0 E - 13s

Therefore, $\frac{0.1\ X 10\ E-9}{1.0\ X\ 10\ E-13} = 1000$------------------------------- Equation 2

From the above equation we are to increase the length of the signal (data) by 1000 with respect to time.

The length of the signal was increased by 1000 with respect to time; initializing the starting point at 1.05E-10 with a step rate 1E-13.

This was achieved by using the MATLAB command below:

dt1 = (1.05e-10 + 1e-13: 1e-13: 1.05e-10 + (1000*1e-13); to initialize the starting point and also the step rate

dt1_add = 1.0e24*ones (1000, 1); creating of a vector of 1's multiplied by 1 x 10^ (24) with length by 1000.

Increasing the length of the signal will make us have two vectors of unequal length, and is not possible to compare signal of unequal size. Therefore there is a need for a normalization that is making the vectors of equal length with respect to time. The equation for the refractive index based on to density of charge due to D1 and D2 is given below.

$N(t1) = N_0 - CKd(t)$ -------------------------- Refractive index of D1 due to the density of charge.

$N(t2) = N_0 - CKd(t)$ ----------------------- Refractive index of D2 due to the density of charge.

The following subplot was obtained:

- Refractive index (Nt1) of D1 based on the density of charge against time.
- Refractive index (Nt2) of D2 based on the density of charge against time.

2.2 Part2

This part tends to simulate the relative phase change between signal propagating through D1 and D2 (this is appropriate for switching applications such as this).

$$\Delta\phi(t) = \frac{2\pi L \Delta N(t)}{\lambda}$$ ------------------------ Equation 3

for relative phase change between D1 and D2

$\Delta N(t) = N(t1) - N(t2)$ represents the difference in refractive index between D1 and D2.

The plot of the change in phase in (radians) against time in seconds (t) is sub plotted.

3. RESULTS

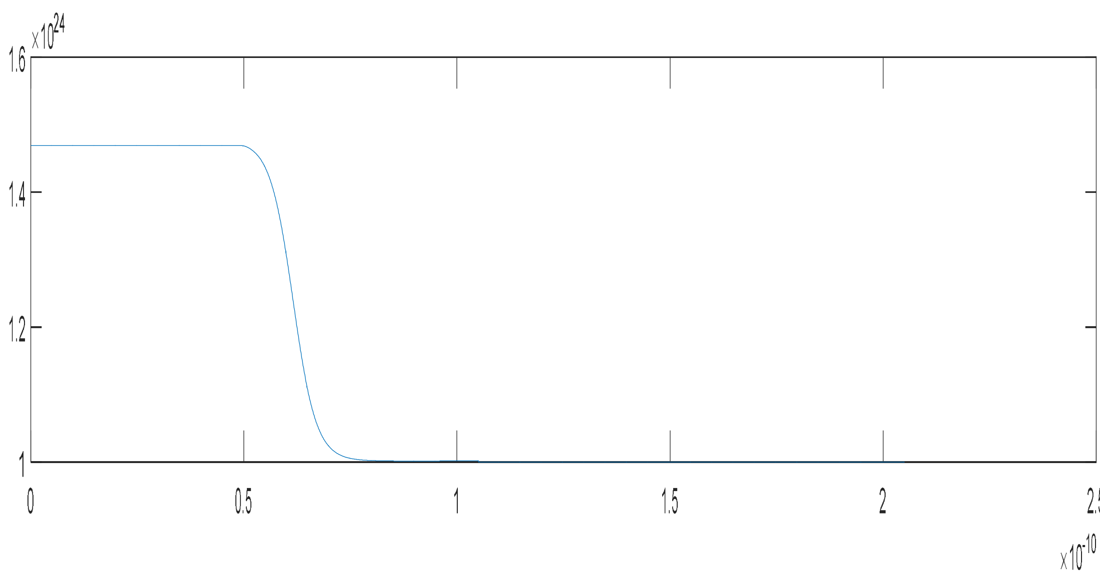

Figure 3.1: Density of charge D1 against time

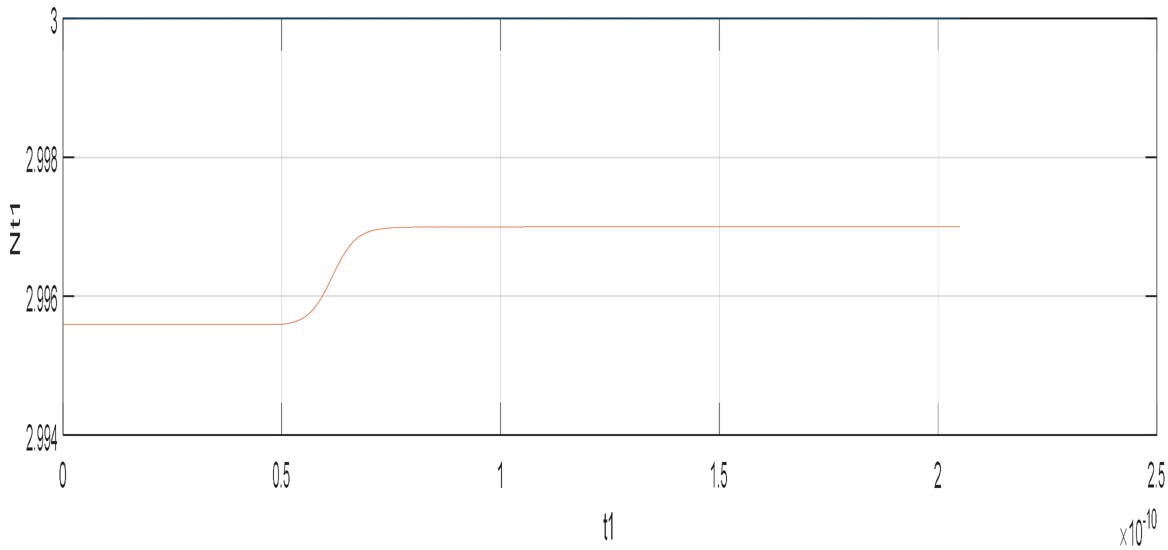

Figure 3.2: Plot of refractive (Nt1) index against time

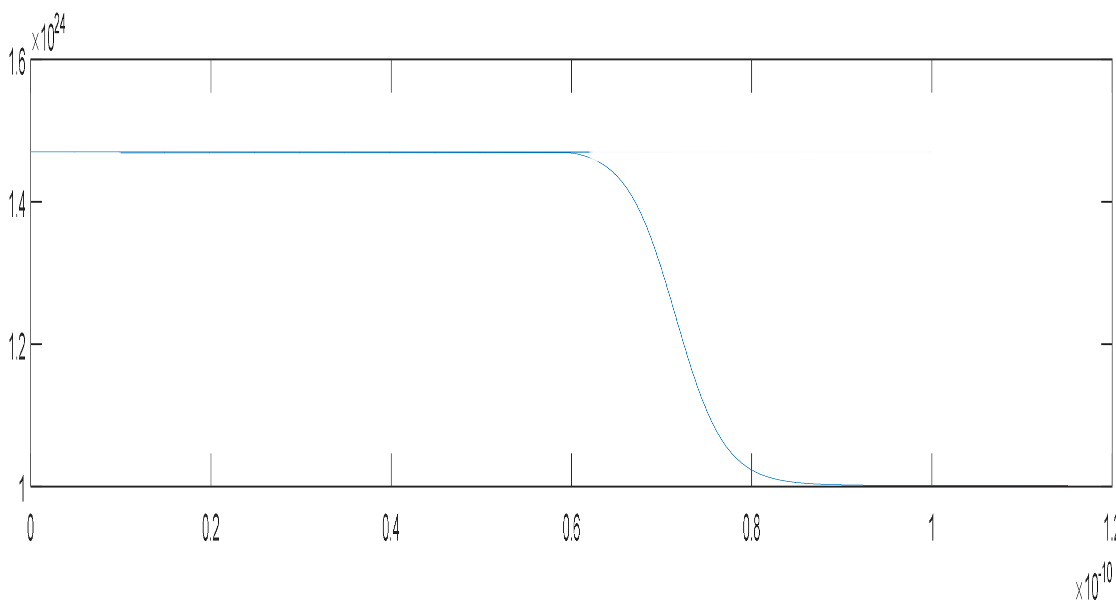

Figure 3.3: Density of charge D2 against time

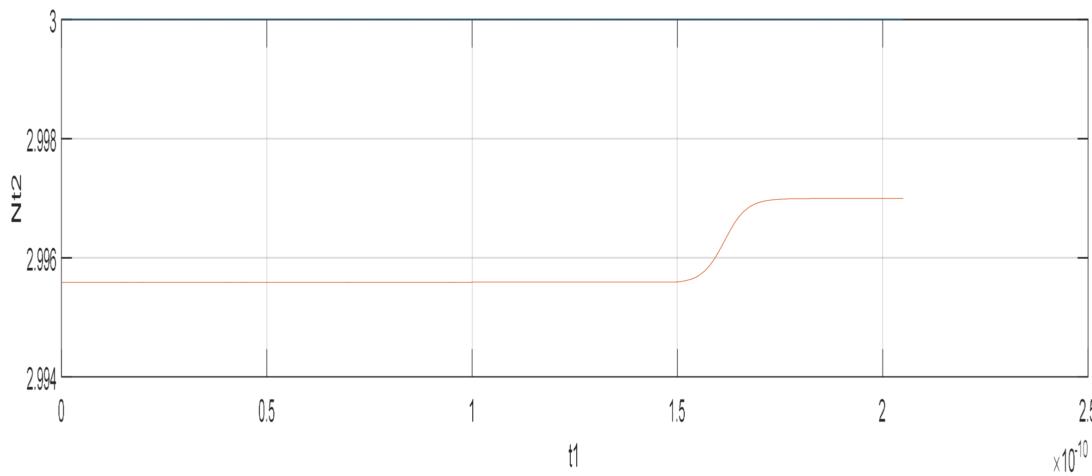

Figure 3.4: Plot of refractive (Nt2) index against time

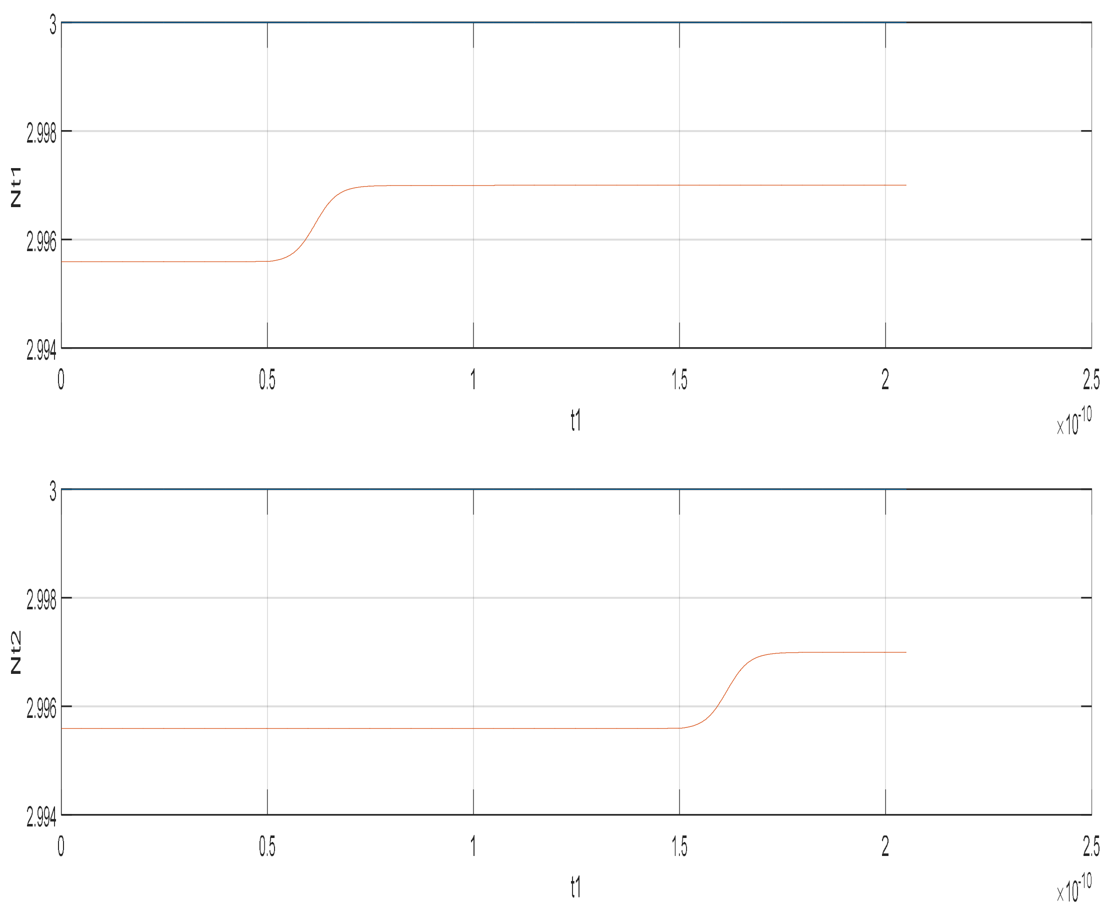

Figure 3.5: A sub plot of refractive (Nt1) and (Nt2) against time

3.1 Analysis

Refractive index of D1 and D2 based on the density of charge

From the plot the refractive indexes for D1 and D2 have similar characteristic in terms of the shape. But the difference is based on the relative distance between with respect to time. The signals will come together and add up constructively or destructively at coupler 2. The way the two signals add up depends on the phase shit imposed on them by the various paths they travelled through.

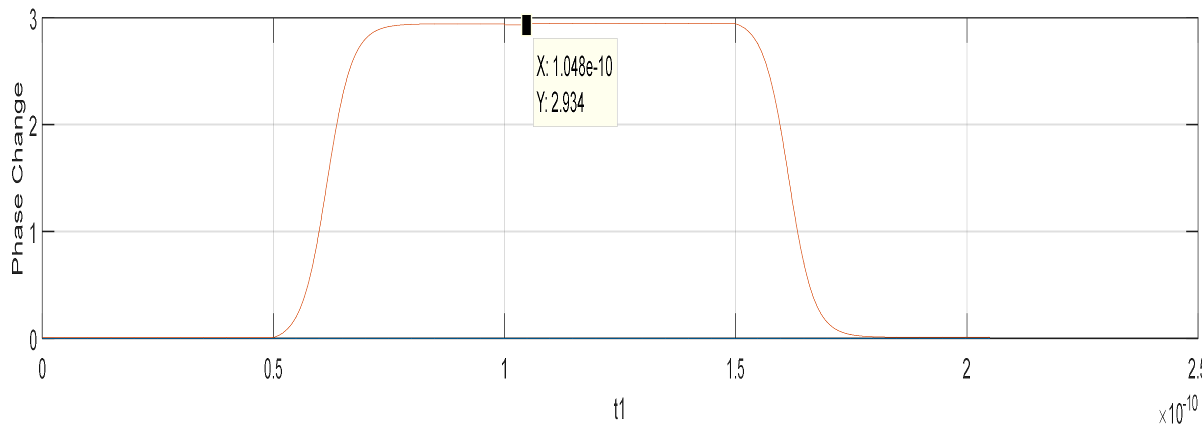

Figure 3.6: Plot of relative phase change against time

The plot of change in refractive index between D1 and D2 gave a flat top Gaussian shape. From the plot the value of the relative phase shit is 2.934 radians. It can be observed from the plot in that the relative displacement of the two devices D1 and D2 created a relative change in refractive with respect to time $N\ (t1) - N\ (t2)$; which in turn created a relative phase change $\Delta\phi(t)$. From the figure 7 relative phase change induced is 2.934 radians. This is approximately $\frac{2.933}{3.142}$ π = 0.94π radians or in degree; $\frac{2.934\ x\ 180}{\pi}$ = 168.54^{0}.

3.2 Discussion

The switch shown depicts in figure 1 is a two input two output device, however it is easier to consider the device in one input two output mode for the analysis purpose. As far as the analysis is concerned then the fundamental equations are those that are used to describe the couplers (coupler 1 and coupler 2) with an additional parameter due to the phase shifter. To justify the switching operation of the device the most logical way is to take into consideration the phase shift imposed by all possible path on the signal from the input port to the output port. The switching operation of the operation of the device can be describe such that the signal input will be split into two halves (in terms of the power) at the coupler 1.The signal travel along different paths. The physical length is the same but the relative displacement of the devices D1

3.2.1 Assumptions:

The optical signal fired in to port 2 only.
There is a relative phase change on D2 with reference to D1.
Path 1. Port 2 straight through coupler 1, through the D2, straight through coupler 2 and out through port 4.
Path 2. Port 2 straight through coupler 1, through D2, cross over at coupler 2 and out through port 3.
Path 3. Port 2 cross over at coupler 1, cross over at coupler 2 and out through port 4.
Path 4. Port 1 cross over at coupler 1, straight through coupler 2 and out through port 3.

Phase shift imposed on a signal when passing straight through a coupler is 0.
Phase shift imposed on a signal when crossing over at coupler is δ.
Phase shift imposed by phase shifter is θ.

$\delta = \frac{\pi}{2}$ and $\theta = 0.934\,\pi$ radian

Let us assume that relative phase is imposed on D2 with respect to D1 as the reference
Consider the waves output from port 4.
Path 1 the relative phase shifts imposed is 0.934π.
Path 2 $\pi/2$ and $\pi/2 = \pi$.
$1\pi - 0.934\pi = 0.66\,\pi$

$$\frac{0.66 * \pi * 180}{\pi} = 11.86\ degrees$$

From theoretical calculation they are 11.860 out of phase. Therefore the signal will add up partially constructive.
Consider the waves output from port 3.
Path 3 the relative phase shifts is $0.94\pi + \pi/2 = 1.433\pi$
Path 4 $\pi/2$ and $\pi/2 = \pi$.

Adding the two waves means they are 168.54^0 out of phase. This implies that the two signal will add up partially destructive.

3.2.2 Transmittance of switch

With zero radians phase shift the switch switches from port 1 to port 4 and port 2 to port 3 and opposite with π phase shift. Since the value of the relative phase shift is not 0 or π ; then we have to apply the transmittance equation (SHU, 2015) .

From port 2 to port 3

$$T_{2,3} = \cos^2\left(\frac{\Delta\phi}{2}\right)$$

$$T_{2,3} = \cos^2\left(\frac{0.93\pi}{2}\right) = 0.011 = 1.1\%$$

From port 2 to port 4.

$$T_{1,3} = T_{2,4} = 1 - \cos^2\left(\frac{\Delta\phi}{2}\right)$$

Therefore,

$$T_{2,4} = 1 - \cos^2\left(\frac{\Delta\phi}{2}\right)$$

$$T_{2,4} = 1 - \cos^2\left(\frac{0.93\pi}{2}\right) = 0.989 = 98.9\%$$

From the transmittance equation we can see that there was outputs at port 3 and port 4. But port 4 has higher proportion of the signal compare to port. In summary port 4 has approximately 98.9 % and 1.1% in port 3.

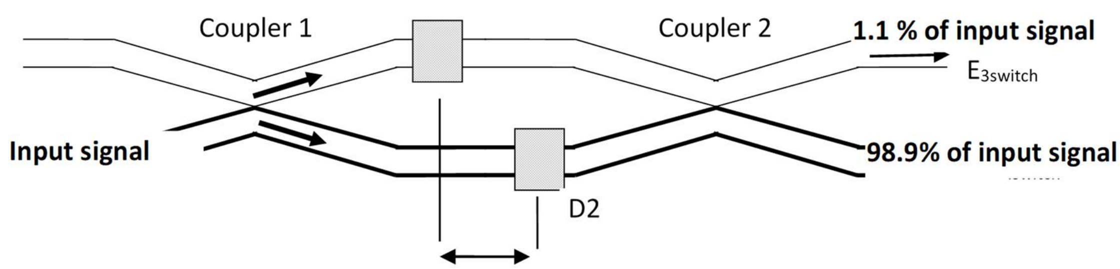

Figure 3.7: Figure showing the efficiency of the signal

4. CONCLUSION

From the result it can be observe that the relative separation (staggering) of the devices D1and D2 causes a change in refractive index ($\Delta N\ (t)$) which produce a corresponding relative phase change $\Delta\phi(t)$ which is responsible for the switching of the device from port 2 to port 4 and port 3. With port 4 having the higher intensity of signal of approximately 98.9% and port 3 having a lower intensity of approximately 1.1%. From the transmittance equation, we can conclude that the switch has a high efficiency (98.9%.)

4.1 Observations

- It can be observed that assuming a data bit rate of 10 GB/s; we increase the length of the signal with respect to time by 1000. This gave impose a relative phase shift 0.934π, this value is very close to π.
- The switch has a very high efficiency.

4.2 Possible Improvement

The switching of the device can be improved by getting a more accurate separation between the devices D1 and D2. Which will in turn give relative phase shift $\Delta\phi(t)$ = π, so that two signal add up absolutely constructively. This mean the output will only come out at port 4.

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