Simulation and Analysis of performance parameters of Optical Power Splitter

[1]Abuhujair Khan, [2]Manisha Chattopadhyay, [3]Aamir Khan, [4]Mayur Kishnani and [5]Rishabh Rizwani,
[1,2,3,4,5]Department of Electronics and Telecommunication, Vivekanand Education Society's Institute of Technology, University of Mumbai, India

Abstract –Optical splitters are gaining more importance from the past few years due to its increased demand in optical networks intended for high data rate communication as bandwidth offered by optical networks are considerably high as compared to other traditional technologies. Performance parameters govern the viability of a power splitter when it is laid down in the network.This paper investigates various performance parameters of the optical power splitter with optimum length and width at different operating wavelength within the 1.525-1.565µmband offering least attenuation.

Keywords – *Optical Power Splitter, Multimode Interference, Photonic Device*

I. INTRODUCTION

The demand for high data rate has resulted in increased research in the field of photonic devices. To fulfil this demand passive optical network needs to be deployed. To further add more effectiveness to the network, optical splitters can be used within the network at power distribution terminals. This will add value to the network as the bandwidth will be shared among many users and cost of the network will be reduced as there will be no need of having different equipment for different user. This will also be beneficial for the service providers.

The power splitter will be employed in passive networks which further adds value to the network as additional power requirement for functioning of network is not required. Various technologies for optical splitter designed have been developed like Y-splitter, fused biconical taper or multi-mode interference-based splitter.

Each one of these techniques employ different structures of waveguide and fabrication process. Though all the different kinds of splitter have their own merits and limitations but the underlying performance parameters related to each of them is same which governs the effectiveness of the splitter.

In this paper wefocused on optical power splitter based on multi-mode interference effect in which interference between different modes propagating inside the waveguide results in splitting of power. Also, design of such splitter is more compact, possess low loss and has large optical bandwidth. The configuration of the splitter can be single input and multiple output ports where the output ports can be 2,4,6,8 and so on. For simplicity we will be focusing on splitter with single input and two output ports i.e. 1X2 configuration. Various performance parameters of this splitter which includes reflection coefficient, transmission coefficient, excess loss, and imbalance will be emphasize in this paper and their deviation from the optimal values of the parameters will be reported.

II. THEORY

Optical coupler takes traffic from input port or connection and directs it, over a fabric, to an output port. An optical couplerworks with light and is used to direct a single wavelength, or perhaps a range of wavelengths, from input port to output port.

All optical coupler can be utilized to disconnect, bypass and reroute fiber optic communications. fiber optic coupler is used for redistribution of optical signals. That means, it can distribute the optical signal (power) from one fiber to two or more fibers depending upon the requirements of the network. On the other hand, the fiber optic coupler is also used for combining the optical power from two or more fibers on to a single fiber. In splitting function, the fiber optic coupler split the input signal in two or more outputs. Such types of couplers are known as *optical splitters*.

An optical splitter is also a passive device, which is used to divide the optical power and transmit to two adjacent fibers. In this paper we deal with the splitter that divides the optical power into two equal parts among the fibers. Also, splitters can be used to divide the incident optical power into unequal powers depending upon the structuring of the splitting section or operating principle. Even a splitter can be made to split the power in such a way, that the split power may appear at one output port and a very small portion is coupled to the other output port.

In the following subsections we will be dealing with the basic operating principle behind the working of optical splitter based on multi-mode interference effect and also looking at some fundamental performance parameter that determines the effectiveness of the splitter.

A. Self-Imaging Principle

Coherent light used to illuminate periodic objects results in self-imaging, it was first depicted over 180 years ago by utilizing interference[1]. Self-focusing waveguides with varying refractive index (graded index) has an ability to produce real images of an object which are periodic in nature. However, it was discovered that in case of uniform slab waveguides it has an ability to produce self-imaging of the input field incident on it[2].

Self-imaging implies that when an input wave is incident inside a waveguide the wave gets distributed in such a way that it repeats itself in a definite distance. The principle can be stated as follows[3]: *Self-imaging is a property of multimode waveguides by which an input field profile is reproduced in single or multiple images at periodic intervals along the propagation direction of the guide.*

Depending on the self-imaging effect there are basically three kinds of image are obtained inside thewaveguide: -

1. Direct Image- possessing same magnitude and phase as that of the original input.
2. Mirrored Image- possessing same magnitude but different phase as that of the original input.
3. Multiple Images- possessing different magnitude and different phase as compared to the original input.

Out of three images mentioned above the multiple images is of concern as it is involved in splitting effect.

B. Modes in Waveguide

Input field travels through the waveguide by different modes supported by the waveguide. Also, the number of modes propagating inside a waveguide depends upon the physical parameters of waveguide such as width and length of the waveguide. The MMI device consists of a large multimode section with an input and output access waveguide. Waveguide modes which results in constructive interference causes a 'self-imaging' phenomenon which is the basic principle of operation of MMI-based devices. Since the excited modes in the MMI section travels with dissimilar phase velocities, they interact with each other resulting in different interference pattern i.e. 'multiple images' which depends upon the position along the waveguide section. Therefore, by choosing optimal waveguide length and width we can obtain suitable interference pattern inside the MMI section. The width of the waveguide affects the amount of interaction different modes in waveguide will have and the length determines the kind of images of the input signal we will be obtaining at the output.

A waveguide can contain a large number of modes that can be classified as guided or unguided modes. In an ideal guide these modes propagate independently of each other.The unguided modes attenuate quickly and does not take part in constructive interference, So, as a result of attenuation of unguided modes only few guided modes are present inside the waveguide which contributes to the constructive interference resulting in self-imaging of the input signal as the modes propagates inside the waveguide.

III. DESIGN OF THE WAVEGUIDE

In the process of designing the MMI splitter the width and length of the core and cladding must be appropriately chosen so that an interference pattern can be observed in which we can distinguish the images of the input wave as it travels through the waveguide. Here, for achieving the optimum values of performance parameters we selected the width of the Port (w) as 4µm and the space between the port (d) as 4µm. Using (2) we calculated the width of the waveguide. After considering the Goos-Haenchen effect [5], effective width of the waveguide, h_e, is calculated as given in (3)[6]. The length of the waveguide, L, is calculated as given in (1). It was found that the fiber produces optimal result when the length of waveguide is 0.933 times the length calculated by (1).[8]

$$L = \frac{n_1 h_e^2}{N \lambda_0} \qquad (1)$$

where, n_1 is the refractive index of core

h_e is apparent width of the waveguide
N is number of output ports
λ_0 is the operating wavelength
L is the length of the waveguide

$$h = N(d + w) \qquad (2)$$

where, N is the number of output ports

d is the spacing between the output ports

$$h_{ev} \cong h_e = h + \left(\frac{\lambda_0}{\pi}\right)\left(\frac{n_2}{n_1}\right)^{2\sigma}(n_1^2 - n_2^2)^{-\frac{1}{2}} \qquad (3)$$

$\sigma = 0, 1$ for TE modes and TM modes respectively

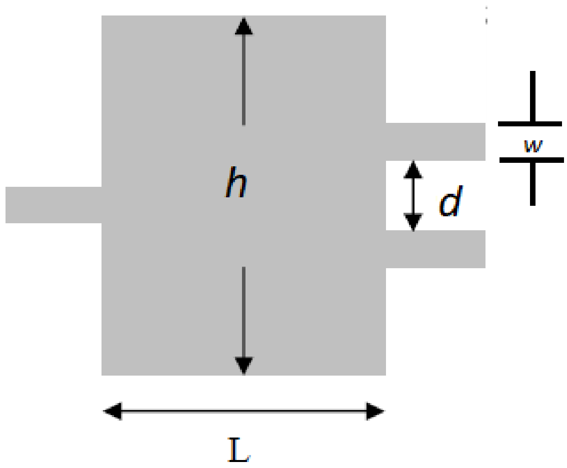

Figure 1: Structure of the waveguide

IV. PERFORMANCE PARAMETERS OF SPLITTER

After designing the waveguide, the main objective of any designer is to optimize it so that it incurs minimum losses. Source of losses can be many like losses due to the imperfect connections amount large on their performance. All important tasks have to be taken care of such as, the light launching from an optical source in to the input port of the splitter and then the perfect transfer of the light from one fiber to other at the output port. In all cases the amount of the light launching from the optical source into the splitter input port largely depends on optical characteristic of both the source and the input fiber.

Intrinsic and extrinsic losses also affect the fiber performance. Intrinsic losses result due to the mismatch in fiber properties while extrinsic the extrinsic losses are caused by techniques used to join the fibers. Therefore, intrinsic losses can be reduced or avoid by matching the fiber characteristics in terms of geometrical and optical properties of the fibers to be connected witheach other. On the other hand, extrinsic losses can be suppressed by proper connecting patterns between the fibers.

Various performance parameters in order to reduce the effect of losses are:

A. Reflection co-efficient

The reflection coefficient at input port is the amount of electric field reflected back at the input. It is given by S – Parameter, S11. The reflection coefficient at input port 1 can be obtained in dB as:

$$Reflection\ Coefficient, R_{11} = 20\log(|S11|)\,dB$$

The reflection co-efficient gives the estimate about the reflection losses occurring inside the fiber. Ideally, the amount of power reflected back at input should be minimum or zero.

B. Transmission co-efficient

The transmission coefficient between input port and one of the output port is the amount of electric field from the input port to the output port. It is given by S – Parameter, S21 and S31. The transmitted coefficient between the input port 1 and output port 2 can be obtained in dB as:

$$Transmission\ Coefficient, T_{21} = 20\log(|S21|)\ dB$$
$$Transmission\ Coefficient, T_{21} = 20\log(E2/E1)\ dB$$
$$Transmission\ Coefficient, T_{21} = 10\log(P2/P1)\ dB$$

The transmission coefficient gives the estimate of the splitting ratio. For symmetric splitter the amount of power distributed at both output ports should be equal i.e. the splitting ratio must be 50/50 and for asymmetric fibers the ratio depends upon the requirement of applications. For example, 60/40 ratio means 60% of the power is transmitted to a primary output and 40% to the secondary output.

C. Excess loss

Excess loss is the amount of power lost due to reflection and other material absorption properties and is the ratio of total output power to the total input power. The excess loss can be expressed in dB as:

$$EL = 10\log\frac{P2 + P3}{P1} dB$$

Ideally, it should be such that sum of all power at output port must be same as that of input port which gives the excess loss of 0dB. Excess loss gives the information about the deviation from the ideal state.

D. Imbalance

The amount of imbalance in a splitter is given by the ratio of maximum output power to the minimum output power. It is given in dB by:

$$Imbalance, I = 10\log\left(\frac{min(P_i)}{max(P_i)}\right)\ dB$$

Imbalance results due to the coupling occurring between the output ports due to the gap between them is insufficient. For a symmetric splitter the imbalance should be as minimum as possible, i.e. 0dB.

V. SIMULATION, RESULTS AND ANALYSIS

For analysis purpose GaAs as core material with refractive index of 3.45189744 and GaAs with 10% Al as cladding material with refractive index of 3.36755329 is used. We used GaAs because it has wide direct band gap which reduces losses.

We observed various performance parameters, the electric field pattern, and power flow pattern for the simulated waveguide inthe 1.525-1.565μm band.

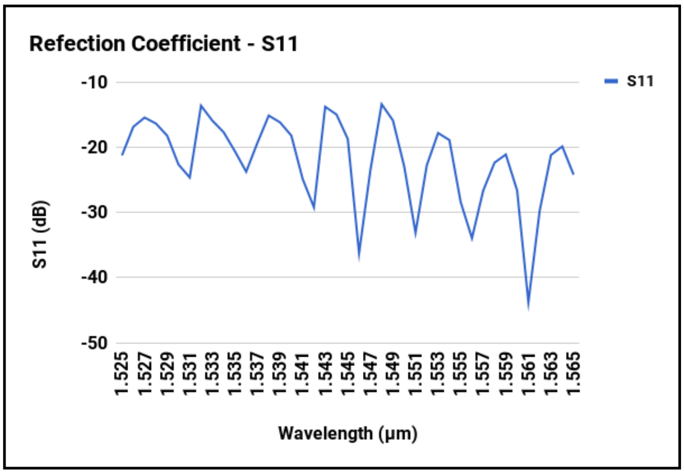

Figure 2: Reflection Coefficient at Port 1 in dB

The reflection coefficient can be observed to be very small when the wavelength is closer to the design wavelength, i.e. 1.55μm.

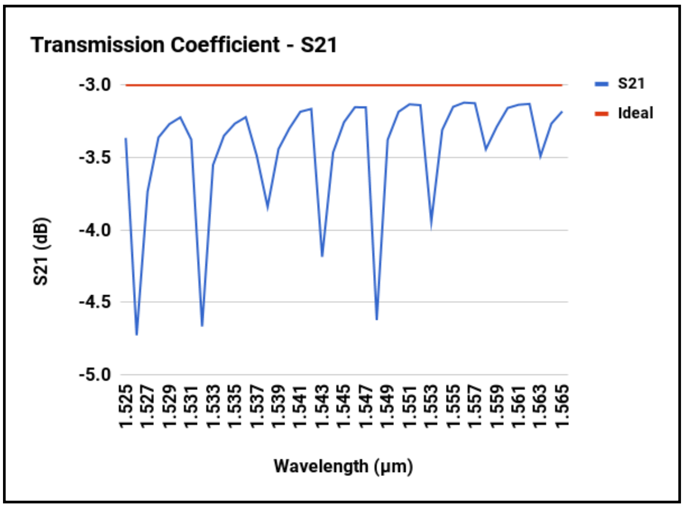

Figure 3: Transmission Coefficient at Port 2 in dB

The symmetric splitter requires that ratio of power at the output ends should be 1:1. In our case for 1X2 power splitter the transmission coefficients S21, S31 should be near the -3dB value. Here the desired results close to the optimum values is obtained at near 1.55μm wavelength which means that at this operating wavelength the power splitter will approximately equally divide the input power.

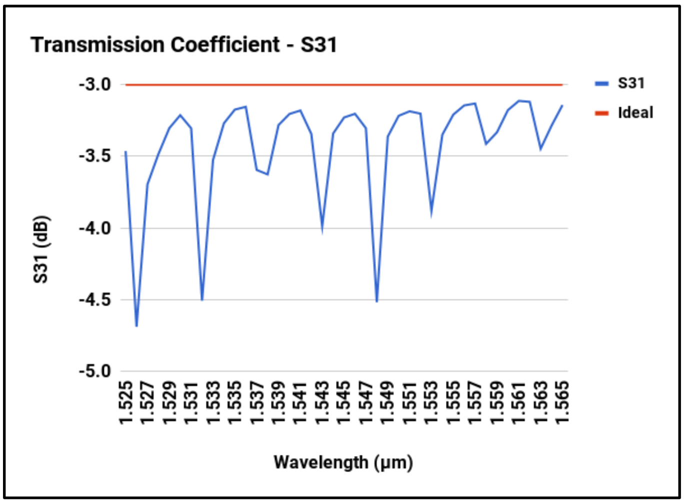

Figure 4: Transmission Coefficient at Port 3 in dB

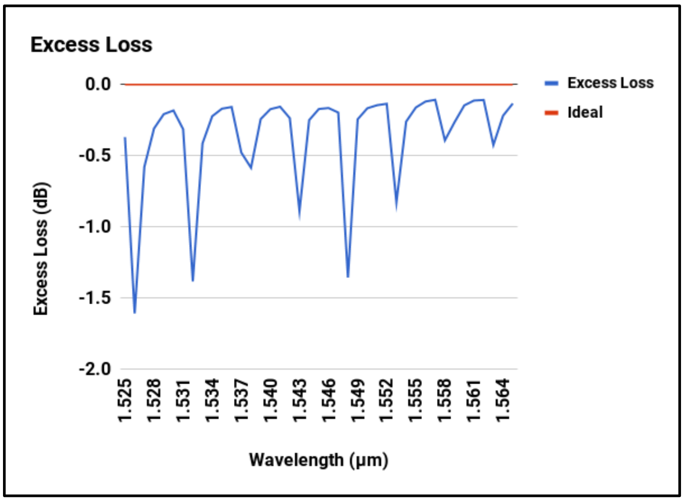

Figure 5: Excess Loss in Waveguide

Carefully designing the splitter may reduce the excess loss but it cannot be totally eliminated as there will be some reflection of the waves happening inside the core region also absorption losses will further aid to presence of the excess loss. So ideal value of 0dB cannot be obtained. However, close to 0dB is obtained at an operating wavelength of 1.55µm.

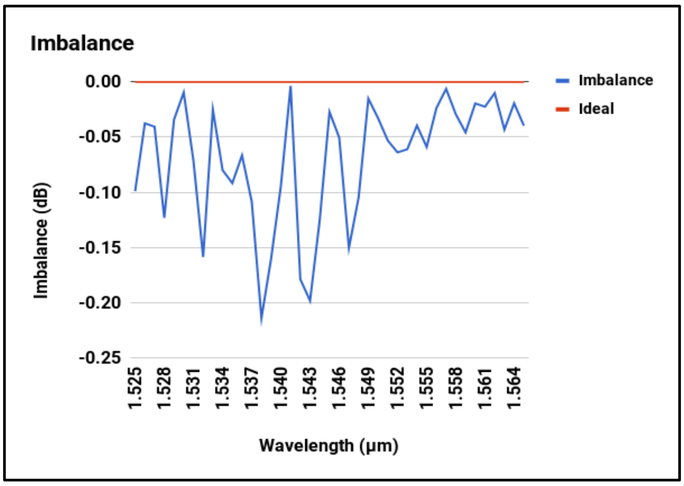

Figure 6: Imbalance at the output ports

Balance among the output ends is of utmost importance for the symmetric power splitter. The ideal value for the imbalance is also 0dB. Here we obtained the near optimum values at wavelength close to 1.55µm.

Apart from the above observations, it was observed that the performance parameters exhibit periodicity with respect to the wavelength.

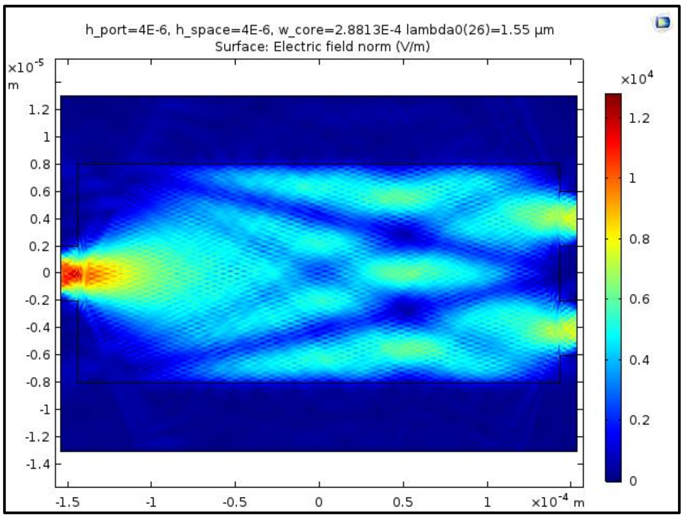

Figure 7: Electric field distribution for port width of 4µm and space between port as 4µm and length of port as 288.13µm at the operation wavelength of 1.55µm

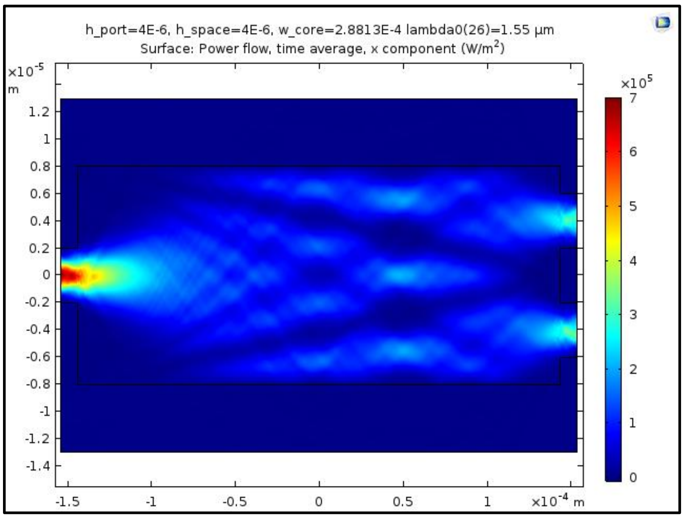

Figure 8: Power flow diagram for port width of 4µm and space between port as 4µm and length of port as 288.13µm at the operation wavelength of 1.55µm

CONCLUSION

Length and width of the splitter was selected so as to get optimum performance parameter. However, the effectiveness of the splitter was measured by varying the operating wavelength from 1.525-1.565µm. Most of the performance parameters is found optimum near the wavelength 1.55µm. It is observed that the performance parameters give optimal results near the design wavelength and the splitter is highly frequency selective. Choosing this wavelength for operating the power splitter in the optical network will certainly give the maximum performance as losses for the splitter will be minimized.

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References

[1] H. F. Talbot, "Facts relating to optical science No. IV," *London, Edinburgh Philosophical Mag., J. Sci., vol. 9,* pp. 401-407, (Dec. 1836).

[2] R. Ulrich. (1975); "Image formation by phase coincidences in optical waveguides", *Optics Communication*. 13(3):259-264.

[3] L.B. Soldano and E.C.M. Pennings (1995); "Optical Multi-Mode Interference Devices Based on Self-Imaging: Principles and Applications", *IEEE Journal of Lightwave Technology*. 13(4): 615-627.

[4] C. Pollock and M. Lipson; "Integrated Photonics"; *Springer Science+Business Media, LLC*: 49-74

[5] Von F. Goos, H. Haenchen (1947); "A new and fundamental attempt at total reflection", *Annalen der Physik. 6. Folge. Band 1*: pp 333-347.

[6] N. S. Kapany and J.J. Burke (1972); "Optical Waveguide", *Academic Press, NY*: 73-80

[7] Abdulaziz M. Al-hetar; "Design and optimization of Optical power splitter based on Multimode Interference for 1.55-µm operation"; *Applied Electromagnetics, 2007. APACE 2007. Asia-Pacific Conference*

[8] Aamir Khan; "Study and Optimization of 1X2 Optical Power Splitter based on Multimode Interference effect"; *ICATE-2018 Conference*