CHAPTER 3

LITERATURE REVIEW

In this chapter, various coupling mechanism have been reviewed, that take place in various optical materials and structures, which make them suitable to fabricate couplers and splitters to perform many optical functions, particularly for photonic networks and integrating optical circuit fabrics. The prevailing emphasis has been given to define effective methods of coupling phenomena and principles, required to perform light transfer task in optical domain only. Various designs and structuring of optical coupling and splitting devices used by past and present researchers are also elaborated in brief. In next chapter, various design and evaluation strategies for realizing MMI based couplers and splitter structures have been elaborated and detailed analysis of their performance have been performed.

3.1 INTRODUCTION

All-optical couplers and splitters in principle are capable of performing the same functions as their electronic counterpart, e.g. guide the signal flow in an optical network as desired and
constitute the basic component of the optical computational systems. With their unique properties of high speed and large capacity, optical couplers have become important components of integrated optics. Driven by these requirements, great progress has been made not only in the structure but also in the materials used for realization of all optical couplers.

An optical coupler is used for channeling light into several different paths and has a wide application in optical communication systems such as in optical LAN. To implement a power splitter, number of structures have been proposed and investigated till date, but none of them have shown the characteristics as desired to split the optical power ideally. Some popular structures are based on tapered waveguides, fused fibers, MMI mechanism, directional coupler and Y–junction waveguides. In waveguide based optical splitters, adjusting the coupling action and shaping techniques results in higher efficiency and low power imbalance.

3.2 POPULAR OPTICAL COUPLING AND POWER SPLITTING PHENOMENA IN OPTICAL WAVEGUIDES

3.2.1 Self-imaging principle in multi-mode structures (MMI Couplers)

The use of light pipes to generate “multiple self–images of symmetric objects has been first suggested by Bryngdahl [29]. The replication of images of random objects in multimode waveguides and fiber interferometers are analogous in nature and have been used to demonstrate 3dB coupler, wavelength filter and crossover strip guides [30-31]. Soldano, Penning, et al. [5, 32-33] has explained the mathematics of self–imaging in uniform index slab waveguides by calculating coupling coefficients and locating multiple images inside the waveguides, which
have been further used to define the phase relation between input, outputs and transition inside the multi-mode interference (MMI) region [34-35]. A MMI (M×N) device is a waveguide, which can support a large number of modes (typically ≥ 3). There are M single-mode input waveguides that are connected to a central structure which is connected to N equally distanced single mode waveguides spaced.

The central structure is known as **coupling region** and its length is called as **coupling length**. The light enters into the central structure and retrieved from it through the input and output waveguides respectively. According to self imaging principle, reproduction of input field profile in single or multiple images placed at regular intervals take places in the direction of propagation of the multimode waveguide. Following theory for formation of self images in multimode waveguides explained here are mainly suggested by L. B. Soldano *et al.* [5, 36].

![Figure 3.1: Reproduction of input field profile in a 2×2 MMI-coupler [36]](image)

As shown in figure 3.1, a self-imaging based 2×2 MMI-coupler can accommodate maximum m lateral modes at a wavelength $\lambda_o$, which can be characterized by mode numbers $v = 0, 1 \ldots (m - 1)$. The relation between the core index $n_c$, the propagation constant $B_v$ and the lateral wave number $k$, can be given by the expression below [36].
\[ k_{sv}^2 + \beta_v^2 = k_0^2 n_r^2 \] ............................................................... (3.1)

Where, \( k_0 = \frac{2\pi}{\lambda_0} \), \( k_{sv} = \frac{(v+1)\pi}{W_M} \)

Where \( W_M \) is the width of the step index multimode waveguide and \( n_r \) and \( n_c \) are the refractive indices of core and cladding region respectively. The “input field profile \( \psi(x, z) \) is assumed to be confined within \( W_M \), including the guided” modes and radiative modes can be expressed as at \( z=0 \):

\[ \psi(x, 0) = \sum_v (c_v \psi_v(x)) \] ............................................................... (3.2)

Where, \( \psi_v \) is the normalized distribution of \( v^{th} \) mode’s modal field. The field excitation coefficient, \( c_v \) and the field profile, \( \psi(x, L) \) at a distance, \( z = L \) can be estimated by following equations.

\[ c_v = \frac{\int \psi(x, 0)(\psi_v(x))dx}{\sqrt{\int \psi_v^2(x)dx}} \] ............................................................... (3.3)

\[ \psi(x, L) = \sum_{v=0}^{m-1} (\psi_v(x)c_v) \exp \left[ j \frac{v(v+2)\pi}{3L_x} L \right] \] ............................................................... (3.4)

Where \( v \) denotes mode number and \( L_x \) denotes beat length for two lowest-order modes. Further, the determination of the shape of \( \psi(y, L) \) and the types of images formed can be determined using mode phase factor as below:
Mode phase factor = \( \exp \left[ j \frac{\phi (v + 2) \pi}{3L} \right] \) ................................................................. (3.5)

Therefore for certain conditions, the field profile at \( \Psi(x, L) \) is a replica of the given input field at \( x=0 \) (\( \Psi(x, 0) \)). Also the field profile at the input (\( \Psi(x, 0) \)) repeats on a regular period basis and produces the single and multiple mirror images.

**For single images:**

After careful examination of equation 3.4, it can be said that (\( \Psi(x, L) \)) is a reflection of (\( \Psi(x, 0) \)), under the condition given below [36].

\[
\exp \left[ j \frac{\phi (v + 2) \pi}{3L} \right] = 1 \text{ or } (-1)^v \................................................................. (3.6)
\]

Therefore, this analysis shows that for all the modes at length L, phase change must be present at a gap in integer multiples of \( 2\pi \). Also, the guided modes can be seen interfering and their relative phases are same as at \( z = 0 \) and the image thus formed is a replica of the input field. The phase changes should be even and odd multiples of \( \pi \) in an alternate fashion. The modes are in phase or antiphase for even and odd modes respectively. When the symmetry is odd,

\[
\psi_v(-x) = \begin{cases} 
\psi_v(x) & \text{for } v \text{ even} \\
-\psi_v(x) & \text{for } v \text{ odd}
\end{cases} \................................................................. (3.7)
\]
An image is produced due to the interference and is mirrored with respect to the plane $x = 0$. Considering that

$$\nu(v+2) = \begin{cases} 
\text{even for } \nu \text{ even} \\
\text{odd for } \nu \text{ odd}
\end{cases} \quad \text{................................................................. (3.8)}$$

Evidently the above two conditions of equation 3.6 are satisfied only when

$$L = p (3L_\pi), \text{ with } p = 0, 1, 2 \quad \text{................................................................. (3.9)}$$

for even and odd values of $p$. Here, the factor $p$ shows that the image formation along the multimode waveguide is periodic in nature. Due to interference, formation of direct as well as mirrored single images of the input field $\psi(x, 0)$ can be seen at distances $z$ that are multiples of the length $(3L_\pi)$ as shown in figure 3.1. Therefore we can say that in bar and cross couplers, we can exploit the direct and mirrored single images, respectively.

**For multiple images:**

At distances given by equation 3.9, both single images and multiple images can be found. At distances $P$, where $P$ is the half-way between the direct and mirrored image positions, the total field is given by Eq. 3.10 [36].

$$\psi\left(x, \frac{P}{2}3L_\pi\right) = \sum_{v=0}^{\infty} c_v \psi_v(x) \exp\left[j\nu(v+2)p\left(\frac{\pi}{2}\right)\right] \quad \text{................................................................. (3.10)}$$
Where, \( L = \frac{p}{2}(3L_\pi) \), with \( p = 1, 3, 5 \)…………………………………………………….. (3.11)

with \( p \) are odd integers. Considering symmetry of mode field and other conditions (3.8), (3.10) can be reproduced as [36].

\[
\psi\left(x, \frac{p}{2}3L_\pi\right) = \sum_{\nu \text{ even}} c_\nu \psi_\nu(x) + \sum_{\nu \text{ odd}} (-j)^\nu c_\nu \psi_\nu(x) = \frac{1+(-j)^p}{2}\psi(x,0) + \frac{1-(-j)^p}{2}\psi(-x,0). \tag{3.12}
\]

These pair of images of the modal field \( \psi(x,0) \), are in quadrature and have the amplitudes \( 1/\sqrt{2} \), at distances \( z = \frac{1}{2}(3L\pi), \frac{3}{2}(3L\pi) \ldots \), as shown in figure 3.1. (2×2) 3–dB couplers can be realized using this phenomenon of two–fold imaging. The use of these single and multiple images in 3db, bar and cross couplers can be summed up as following:

- The coupler is in “bar” state, if the reproduced field at \( L \) is in the phase with the incident filed, i.e. When \( L = 2p \) \((3L_\pi)\).
- The coupler is in “cross” state, if the reproduced field at \( L \) is in antiphase with the incident filed, i.e. When \( L = (2p+1) \) \((3L_\pi)\).
- The coupler is in “3dB” state, if the output filed equals to linear combination of input field and its mirror image in the XZ plane, When \( L = (p+1/2) \) \((3L_\pi)\).

### 3.2.2 Directional coupling

In optical switching networks, a type of coupling device namely the Directional coupler is mostly used. Directional couplers can be used in either way as an intensity modulator or a
switching device. Directional couplers can be classified in various categories depending upon their structuring and operating style, such as switched directional couplers (also known as the reversed-$\Delta\beta$ DC switch) consist of uniform electrodes to generate sufficient coupling caused due to variation in the coupling coefficient with respect to variation in the applied field. In some cases, such directional couplers are also used as signal modulator [37-40]. The structure shown in the figure 3.2 operates on the principle stated here, that means the applied modulating field changes the refractive indices of the adjacent waveguides in an anti-symmetric manner, which then affects the light wave propagation in these two guides (hence the name $\Delta\beta$ directional coupler), the coupling length and the phase matching between them, and finally in turn, affects the power transfer efficiency [41].

![Figure 3.2 Schematic (layout) of $\Delta\beta$ directional coupler](image)

Extensive investigations have been done in the directional of characterization of a Nonlinear Directional Coupler (NLDC) due to their potential applications in fast optical computing and communication systems. Many researchers have proposed interesting application of NLDC based on its power-dependent transmission characteristics [42-43]. The coupling behavior of non linear directional couplers can easily be explained with coupled-mode theory “with weak nonlinear perturbations and sufficient well separated cores [44-45]. The coupling equations for such type of couplers with anomalous dispersion without loss can be expressed” as [46]
\[
\frac{\partial a_j}{\partial z} = -\beta_1 \frac{\partial a_j}{\partial t} + \frac{i}{2} \beta_2 \frac{\partial^2 a_j}{\partial t^2} + iCa_{3-j} + i\gamma |a_j|^2 a_j, \\
\]

(3.13)

Where different parameters used in above equation are as follows;

\[a_j\] = The slowly varying envelope amplitudes of mode fields in waveguide j (j = 1, 2).

\[\beta_1\] and \[\beta_2\] = 1\text{st} and 2\text{nd} order dispersion coefficients.

C = The linear coupling coefficient and

\[\gamma\] = The nonlinear self-coupling coefficient respectively.

### 3.2.3 Y – Junction waveguide coupling

“Y-Branch (Junction) waveguides are important passive devices in optical integrated circuits and have been widely used in power splitters, optical switches, and phase modulators. Typically, a Y-branch optical power splitter consists of a single waveguide splitting symmetrically into two waveguides as shown in figure 3.3, which have been commonly used for analyzing a 1×2 power splitter”.

![Figure 3.3: Layout of a Y-junction waveguiding structure base optical coupler/splitter](image-url)
Multiple Y-branch splitters are often cascading combined into $1 \times 2^N$ optical power splitter where $N$ is cascaded stages. To obtain a short propagation length, the gap between the junction waveguides can be made littler wider in a way, dependence of optical power uniformity on the etch residues and air voids in the gap can be suppressed significantly. However due to inclusion of a wider gap, the performance of the splitter deteriorates. Hence designing of such splitter has to be taken with utmost care to have satisfactory performance including various performance parameters such as insertion and polarization dependent losses and the non-uniformity. Silicon-on-insulator (SOI) substrate based $1 \times 16$ splitter with use of cascaded $1 \times 2$ splitters made up of arc-shaped branching waveguides possessing the uniformity in the measured power better than 0.3 dB at wavelength of 1550 nm has also been reported in recent [47]. Theoretically, a Y-branched waveguiding structure may be lossless, but in practical it is not; as losses do take place inside the structure due to their finite resolution of micro fabrication. As such type of structure requires many sharp corners and their minimum featuring size mismatch with present CMOS technologies, which can be easily detected by design rule checking (DRC) routines. Various fabricating errors for such type of structures may includes peeled off photo resists, swallowed etching in the narrow gaps, errors in oxide cladding deposits, etc. All such errors actually degrade the device performance and lower the yield.

Insertion of two Y-junction waveguides in Mach-Zehnder modulators readily causes the insertion loss of more than 2 dB [48], independent of other type of losses, which arises due to free carrier absorption and on-and-off chip light coupling. That’s why such type of modulators and couplers are less competitive than the modulators based on the III-V electro-optic modulators, which can perform with a fiber to fiber insertion loss of around 5 dB. Therefore such
types of the lossy components are not suitable to build complex and large scale integrated optical circuits. Infect the discontinuity in the waveguiding structures increases the chances of light scattering and back-reflection. Also spectral response of the systems affected badly, if such type of implicit resonant cavities caused by scattered sites.

In recent, many articles have been reported and predicted satisfactory performances of various devices such as splitters in cascaded fashion, 3dB and directional couplers based on photonic crystal, Y-branching waveguides, MMI couplers [49-54]. Among these, a Y-branched coupler has fallen “within the typical design rules of a modern CMOS photonics process and shown low excess loss operation with low wavelength sensitivity with small footprint and lower dimensions. Similarly a Y-junction waveguiding coupling structure made up of circular bends with use of a butt waveguide to overcome the sharp corner problems is reported at [55] with a overall insertion loss, about 1dB, while maintaining the cross-wafer average insertion loss of 0.28 ± 0.02 dB and wavelength insensitive coupling ratio over for its operation for a 80 nm bandwidth” ranging from 1500 nm to 1580 nm.

3.3 REVIEW OF LITERATURE

M. Bachmann, P.A. Besse et al. [32] from Swiss federal institute of technology, Zurich, Switzerland have checked the performance sensitivity of InGaAsP/InP MMI structure based 3dB coupler analytically and experimentally. They have found that such structure can operate for an 80nm to 100nm optical bandwidth to produce expected outputs, while maintaining a excess loss
less than 1dB and 0.2dB power unbalance factor. They have also concluded that the “most critical parameter in the fabrication of the couplers is the MMI section width, which has to be controlled to within ± 0.50μm from its design value in order to achieve an acceptable excess loss” and unbalance.

Due to their large bandwidth and polarization independence these devices have a great potential for application in WDM communication systems. Figure 3.4 shows the sensitivity variation (excess loss and unbalance factor) with respect to width of MMI region for different polarized light inputs at 1530nm.

![Figure 3.4: Sensitivity to MMI section width at 1530nm with (a) TE polarization and (b) TM polarization;](image)

In the year of 1995, L. B. Soldano, E. C. M. Pennings [36] have published their work with IEEE journal of light wave technology, in which they have described MMI structures based optical couplers in details and have shown that such structures “offer superior performance, excellent tolerance to polarization and wavelength variations. They have also concluded that such structures have relaxed fabrication requirements as compared to other structures such as directional couplers, adiabatic X and Y junctions, and diffractive star couplers”. They have also
predicted that such devices are capable of providing a wide range of N×M coupling functions, with insertion losses below 0.5dB, crosstalk figures as low as -30dB and balancing with in 0.2dB, provided restricted (parallel and symmetric) mechanisms are well located and such structures are subjected to reasonably symmetric input fields in order to comply with the selective model excitation requirements.

Jinzhong Yu, Hongzhen Wei et al. [78] from “State Key Laboratory on Integrated optoelectronics, Institute of Semiconductors, Chinese Academy of Sciences, Beijing have proposed an integrated multimode interference coupler based on silicon-on-insulator using a thin cladding layers (<1.0μm) on to a SOI waveguide to create large index difference between Si and SiO₂, making them compatible with the VLSI technology”.

With their work, they have also showed that in MMI structure based couplers with tapered waveguides as shown in figure 3.5; great reduction in coupling length can be achieved while keeping uniform output. In later part of their work, a 2x2 MMI-MZI thermo-optical switch is also demonstrated with a switching time less than 20μs, much faster than polymer or silica based thermo-optical switches. Later on, a similar work has been then reported by Jinzhong Yu, Xiaolong Wang et al. from Chinese Academy of Sciences, Beijing, China in the year of 2003
[130], in which they have presented the “design and fabrication of multimode interference (MMI) optical coupler as depicted in figure 3.6, modulator and switch in SOI technology with an extinction ratio of -11.0dB and excess loss of -2.5dB, while a crosstalk of -12.5dB with response time of less than 20ps in case of switch. These works have demonstrated the potential of SOI technology for silicon based optoelectronic devices”.

![Figure 3.6: The schematic structure of the 1x2 symmetric tapered MMI coupler [130]](image)

*Fan Wang, Jianyi Yang et al.* from Zhejiang University, Hangzhou, China [83] have demonstrated working of an optical switch shown in figure 3.7 based on the multimode interference (MMI) coupler “designed and fabricated in polymeric materials. In which the thermo-optic effect of polymers due to their negative to coefficient has been used to make variation in the self-images to realize the switching action with a crosstalk of -20dB with a requirement of 22mW operational power. They have also showed that if the MMI coupler is set with two heaters on its both sides, one can obtain a $2 \times 2$ MMI-based optical switch with less than 4ms switching time, which can find its application in photonic true-time delay networks though it will be blocking” in nature.
Zhiyong Li, Jinzhong Yu et al. From State Key Laboratory on Integrated Optoelectronics, Institute of Semiconductors, Chinese Academy of Sciences, Beijing [131] have elaborated a 3-dB paired interference (PI) optical coupler as shown in figure 3.8. The waveguides are made up of silicon-on-insulator (SOI) with trapezoidal cross section with use of potassium hydroxide (KOH) anisotropic chemical wet etching. They have designed the layout and simulated it by a modified finite-difference beam propagation method (FD-BPM).

As depicted in figures 3.8 and 3.9, theoretically they have achieved fabrication tolerances for its various parameters such as for width, length, and the port distances near about 1, 100, and 1 μm, respectively. The device has worked with a propagation loss of 1.1 dB/cm to achieve smooth interface at the operating wavelength of 1.55 μm. The optical coupler performance has also been showed with a “good uniformity of 0.2 dB and low excess loss of less than 2 dB. Finally they have concluded that in such type of coupler, the output near field images show that the PI-based couplers have large fabrication tolerance and good power uniformity”.

Figure 3.7: MMI optical switch with a channel profile of polymeric materials covered by the heaters [83]
When there is an uncertainty for centre wavelength of the laser source, the wavelength sensitivity of an optical waveguide directional coupler becomes a cause of a problem. Similarly the wavelength sensitive coupler causes problems, if the spectral broadening of the laser when modulated is comparable to the low crosstalk optical bandwidth regime of the coupler. Optical couplers with low crosstalk and broader spectral bandwidth are most suitable for wavelength demultiplexer applications. Keeping the requirements in mind, Indra Januar, Robert J. Feuerstein et al. [132] have designed and have fabricated directional couplers with operating wavelength bans of 1.5µm to 1.65µm and measured their wavelength sensitivities. They have
used 2D diffusion profile and have computed the estimation of various parameters using the effective-index method (EIM). A knowledge of the coupler geometry and fabrication conditions, such as dimensions, tolerances, etc. are sufficient enough to use this method (EIM) to predict the coupler performance in accurate way. They have also fabricated such type of directional coupler using an annealed proton exchange process and measured their wavelength sensitivities.

![Graphs showing power uniformity of the coupler versus tolerances of (a) length, (b) width, and (c) port distance](image)

**Figure 3.10: Power uniformity of the coupler versus tolerances of (a) length, (b) width, and (c) port distance [131]**

It has also been concluded that the computation method is sufficiently used to understand the wavelength sensitivity of the directional coupler, as their calculated results have fallen within the same line as the measured data. Using the same methodology, they have also predicted the response of the wavelength sensitivity for titanium in-diffused Lithium Niobate waveguides.
based directional couplers. In the year of 2004, Y. Wang and W. Wang [65], have concluded that efficient use is possible with a nonlinear coupler, if works with Gaussian pulse then the soliton. Problems like distortion, broadening or narrowing in a nonlinear directional coupler based on soliton are more possible as compared to the Gaussian pulse. They have also investigated the linearly coupled nonlinear Schrödinger equations with use of a new normalized format. With their work, it has been estimated for the first instance that for a non linear coupler, their switching performance and the coupling behavior of pulses depends on the product of the dispersion length and the coupling coefficient. “They have also showed that for a given nonlinear coupler with a Gaussian-like or soliton-like pulse input, switching performance and whether a pulse breaks up or not mainly depend on the input pulse width, not the pulse shape”.

Won-Gyu Lim, Seo-Young et al. from school of Electronics Engineering and Computer Sciences, Korea advanced institute of science and technology, Daejeon, Korea [133] have described a new method for balanced directional coupler structure with lumped elements to solve transmission to receiver leakage problem. In their work, characteristics of the balanced directional coupler have been investigated to conclude insensitiveness of it with variance in the load impedance. A balanced directional coupler have been taken in consideration within their experimental work, comprising of two Wilkinson power dividers and two contra-directional couplers implemented with lumped elements.

The fabricated balanced directional coupler performance at 910 MHz has been found to satisfactory with isolation factor of 58dB and less then 45dB for matched and mismatched load impedance respectively. Y junction waveguiding structures have been used as elementary
devices in many optical communication network applications. Such structures can be used as beam splitters in which the Y junction separates the optical power in two outer waveguides, similarly they can also be used a beam combiner, if their operation is reverse in the direction. Among these beam splitters have been popularly used fundamental building elements in highly dense photonic integrated circuits (PIC) for scaling purposes. These can also be used as optical power dividers, combiners, attenuators, and routers. Splitters are mainly characterized by two factors namely the power uniformity and the excess loss. “The power uniformity is defined as the ratio of the maximum and minimum output powers, and the excess loss is the total loss induced by mode conversion and coupling in beam splitting”.

S. H. Tao, Q. Fang et al. joint collaborator from Institute of Microelectronics, “Singapore and State Key Laboratory on Integrated Opto-Electronics, College of Electronic Science and Engineering, Jilin University, China [52] have described a 1×16 optical power splitter with detailed characterization of splitting angle, uniform outputs, and low excess loss”. “Their (1×16) splitter have comprised of cascaded 1 × 2 splitters (basic schematic is shown in figure 3.11) with arc-shaped branching waveguides fabricated on the silicon-on-insulator (SOI) substrate. The gap between the branching waveguides have been kept widened in a short propagation length such that influences of etch residues and air voids in the gap on the optical power uniformity have been reduced significantly. The measured power uniformity of their proposed 1 × 16 splitter have been found better than 0.3 dB at wavelength of 1550 nm”.

Figure 3.11: (a) Schematic drawing of an arc-shaped Y-junction, (b) microscope picture of the 1×16 splitter, [52]

Figure 3.12: (a) Variation in the insertion losses for the splitter with single input to many output combinations [52]
Table 3.1: Performance indices (uniformity and excess losses) for splitter with single input to many output combinations.

<table>
<thead>
<tr>
<th>Splitter type</th>
<th>Uniformity (dB)</th>
<th>Excess loss (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1×2</td>
<td>0.07</td>
<td>0.15</td>
</tr>
<tr>
<td>1×4</td>
<td>0.09</td>
<td>0.48</td>
</tr>
<tr>
<td>1×8</td>
<td>0.11</td>
<td>1.28</td>
</tr>
<tr>
<td>1×16</td>
<td>0.27</td>
<td>2.41</td>
</tr>
</tbody>
</table>

The performances of their proposed splitters at wavelength of 1550 nm are summarized in Table 3.1. It can be observed from Table 3.1 and Figure 3.12 (a) that the splitters possess uniformity in outputs. The measured output uniformities have been found to be better than 0.1 dB and 0.3 dB with excess losses of about 0.15 dB and 2.41 dB for 1 × 2 and 1 × 16 splitters respectively. Also the 1 × 16 splitter posses about 0.6 dB excess loss per cascade, if the propagation losses are excluded.

The table 3.1 also indicates that that splitters with more cascaded connections exhibit higher total excess losses as compared to the less cascaded ones. This increase in excess losses have been mainly “caused by the branching arcs with different radii used in different cascades, as the excess loss would not be the same for junctions with different branching arcs”. In summary, the arc-shaped branching waveguides can be utilized to define short and wide gaps to enhance the optical power uniformity significantly.
S. K. Raghuwanshi, V. Kumar et al. from “Department of Electronics Engineering, Indian School of Mines Dhanbad, India [134] have presented the fundamental concept of guided wave for Y-branch structure shown in figure 3.13 suffering from power loss due to branching angle. They have used beam propagation method (BPM) to obtain guided wave characteristics, including power losses for different branching angles. With their work, it has been shown that guided light suffers loss owing to the tapered and separating structure”.

![Figure 3.13: Y-junction waveguide, [134]](image)

C. P. Vardhani and S. Neelima of Photonics research lab, Dept. of Physics, Osmania University, Hyderabad, India have investigated a symmetric Y-branch junction device comprising of S-bend waveguide. In their work, LiTaO₃ based symmetric Y-junction based 1×2 optical power splitter depicted in figure 3.14, instead of a “Zero Gap”, a finite length gap was used to modified the design. The device performance has been observed with deteriorated performance parameters slightly due to the inclusion of such type of gap. They have used BPM to analyze the s-bends waveguides to match optical field in optimum possible way for each Y junction of the splitter.
3.4 CHALLENGES IN OPTICAL COUPLING AND SPLITTING PHENOMENA

In all optical wavelength multiplexing and demultiplexing communication circuits, optical couplers with their multiport connectivity are used for distribution of optical power among the point-to-point and point-to-multipoints connections. However for such application, the optical couplers must be highly insensitive to polarization and should possess higher optical bandwidth. Similarly for optoelectronic integrated circuits (OEICs), the optical couplers have to be designed with lower dimensions and with sufficient fabrication tolerances, which results in lower process cost as well.

Optical coupling devices have been made with small fabrication tolerances and large scale dimensions using various popular structures such as the directional waveguides, the X and Y junction waveguides and the MMI and MZI structures. In symmetric directional couplers, two
fiber cores remain identical to each other. The symmetrical directional couplers can operate for larger bandwidth operation, due to the presence of degenerated modes in identical fiber cores. While in asymmetric directional couplers, the modes are dispersed at a single frequency caused by the unidentical cores. Therefore the asymmetric directional couplers are useful for narrow-band filtering applications [56-58]. However such fiber based narrow band filters can be made to achieve desired filtering profile with satisfactory control for a predefined wavelength range by controlled tuning techniques. Resonant tunneling has been popularly used to realize narrow band pass filters to overcome these issues [59-61]. In this approach, the coupling problems arising in these couplers are reduced by placing a resonator between the identical fiber cores to match the phase at a single frequency so that the proximity effects can be neglected. Detailed studies have been done to reach at a conclusion that if the coupler design is long enough then its coupling length and subjected to a high peak input power, the nonlinear directional couplers exhibits distortion, broadening, or narrowing issues [62-65].