Chapter 1

INTRODUCTION

This chapter of thesis is giving an introduction of optical devices like optical coupler and splitters, optical switches and optical materials with their design and characterization. “An optical network requires various optical devices such as couplers, splitters and switches to establish communication links among two or more interfaces. Effective and efficient coupling, power splitting and switching of optical signals is necessary in optical processing systems and networks for routing the signals with low losses and power requirements. Main advantage of such all optical devices includes routing of optical data signals without conversion to electrical signals, which makes its independent from data rate and data protocols [2]. The present needs of such all optical devices for telecom applications are high speed LAN management, network redundancy, disaster recovery, access monitoring and for optical hardware sharing. In future, developments in all optical devices shall make possible use of reconfigurable optical networks in this area”.

“It is also expected that devices with high port counts (> 100x100) would be required for routing information in all-optical network. However, the design and fabrication technologies are
supposed to match with the properties of material constituents, while selecting them to perform the desired action in optical domain only. Therefore, these techniques are required to be able to tradeoff between important performance parameters of the devices within the permissible range for their optimal use”.

1.1 INTRODUCTION

“In optical communication systems, information is passed in the form of modulated optical signals from source nodes to destination nodes, which are interconnected by optical fibers. Fiber optic lines offer advantages over other communication media in terms of better bandwidth and reliability. As compared to the traditional copper cables, optical fibers can provide much higher bandwidth, more robust and less susceptible to electromagnetic interferences and other undesirable effects [13]. Therefore use of fiber optic cables over copper wire can provide greater bandwidth over greater distances with reduced data loss and overall expenses for long distance links over time. Fiber optic cables are considerably less vulnerable than metal conductors to unapproved “monitoring”, RF problems, therefore it is suitable for telecommunications systems, digital data links, LANs, and also finds application in illumination, medical and displays uses”.

“An optical telecommunication system demands a variety of devices for initializing, transmitting, switching, amplifying, filtering, and processing optical signals. In a typical optical communication system, coupling and switching systems also including repeaters and regenerators reconnect the spans of optical fibers”. “These systems are used for routing signals to destination and addition/removal of same from the optical fibers. Optical fiber depicts a
waveguide for transportation of optical signal in optical communication networks and thus generated signal needed to switch from one waveguide to other. In analogous way to copper wire based telecommunication system, interconnected fiber optic cables lines are used, which are connected to each other by means of optical couplers and switches located at various places in the systems”.

1.2 OPTICAL DEVICES

“In communication networks, all optical devices such as couplers, splitters and switches have been in use for many applications like routing, multiplexing, signal processing, distributed sensing, and optical logical and control operations. So there is a wide variety of all such optical devices which is using an equally wide range of various technologies, for numerous applications, largely related to telecommunication networks. Different applications require different number of ports, wavelength and polarization dependence and response times. Medical, aerospace, defense and manufacturing industrial applications of all optical devices make them suitable for their value in the global commercial markets”.

1.2.1 Optical Couplers and Splitters

An optical coupler is a device used in optical fiber system in which the optical power from one or more input ports is coupled to one or more output ports. Basic principle of optical coupler is that light entering an input port can be appears at one or more outputs port. As a result power
distribution potentially depending on polarization and wavelength. Optical coupler is a passive device because it is operated in optical domain to combine and split light. Basically, coupler can be fabricated by using either optical fiber or planer optical waveguides using material such as Silica, Silicon Oxynitride, Lithium Niobate, etc.

The figure 1.1 shows a generic structure, which can be used as either as a coupler or as an optical power splitter. In its operation, in a 3dB/equal power splitting operation, the light is divided into two equal parts and appears at output ports 3 and 4. “Similarly, if the light entered from input Port 2, then remaining functions repeat in the same way, although usually one of ports 1 or 2 will be unused if it is desired to act as a Y (or T) coupler. On the other hand if 99% of the input power passes from port 1 to port 3, with only 1% leaving at port 4 the device is described as a 20 dB coupler or tap”.

![Figure 1.1: Generic block of an optical coupler](image)

Such couplers can be fabricated using fusing fibers with thermal processing keeping the cores of fibers with intimate contact to each other. If such coupler is made up of single more fibers, then a physical restriction plays an important role on their performance. That means, combining two or
more inputs of the same optical frequency into one single-polarization output without significant excess losses is not possible.

1.2.2 Optical Switches

“According to definition, an optical switch enables signals in optical fibers or integrated optical circuits to manage switching from one circuit to another precisely. Photonic switches exploit the nonlinear material properties to perform and controls switching of light, irrespective of how the light itself is switched”. For the more flexibility in the network, theoretically, all optical switches are independent of bit rate and protocols with unlimited scalability [2]. An optical switch directs an optical signal from one or more input ports to one or more output ports. A basic 2×2 optical switch has two possible switching states, popularly termed as Bar and Cross State as shown in the Figure 1.2.

![Figure 1.2: Basic 2×2 switch block with switching states (a) the "bar" state; (b) the "cross" state](image)

“Optical switches call for certain requirements though. As optical switches are usually in operation at all times, this leads to unnecessary power consumption and it is a major cause of significant waste of resources so power consumption in optical switches must be minimized. Other major concern is Scalability, so optical switches are required to be space optimized so that many channels can be accommodated in a relatively small area. Because Almost all the
fabrication methods are bound to have a significant dependence on the size, shape, and structure of the devices, which explains the deep correlation between fiber optic switch design and the physical design of optical fibers”.

“One of the most important applications of optical switches is to provide light paths from any one of the several input nodes to the desired output node”. “A light path [14] is a dedicated connection between two network nodes for an optical signal of fixed wavelength”. For this purpose, the switches are used inside Optical Cross-Connects (OXC)s to dynamically reconfigure them and to support new light paths. “Figure 1.3 shows an opaque network, in which DWDM systems and line terminals are connected through an OXC, which is the base for routing optical signals in the network, while OXC:s dynamically make provisions for and optimize transmission data paths. Optical Add/Drop multiplexers (OADM:s) present in network nodes are capable of inserting (add) or extracting (drop) optical channels (wavelengths) to or from the optical transmission stream [15]. Using an OADM, channels in a multi-wavelength signal can be added to the traffic stream or dropped without any electronic processing”.

![Figure 1.3: The optical cross-connect in the opaque network [2, 14]](image-url)
Figure 1.3 depicts application of wavelength selective switches to add and drop optical signals in a link. Wavelength selective switches can perform this operation in accordance to wavelength of optical signals. In communication networks, network provisioning operation is required, “when new data routes have to be defined or existing routes need to be reconfigured. A network switch should carry out reconfiguration requests over time intervals typically of the order of 1–10ms [2]. In provisioning of lightpaths, switches with port count size of more than 1000 are used inside wavelength cross-connectors to reconfigure them to support new lightpaths”.

![Add-drop applications using wavelength selective switches](image)

**Figure 1.4: Add-drop applications using wavelength selective switches**

All modern computers are based on electronics, wherein the basic building block is an electronic transistor. Therefore computer based on optical technologies, a transistor working optically must replace its electronic counterpart components. Such optical transistors are possible with use of materials that must have a non-linear refractive index profile. Particularly, in such materials, the incoming light intensity affected, when it is transmitted through the material in a manner which is same as in the case of voltage response characteristic of an electronic transistor. These type of optical technology based transistor can also be used generate logical operation optically, which in turn can be clubbed together to form requisite higher level components for central processing unit of a computer. In photonic logic gates such as optical NOT, optical AND, etc., use of
photons (light) in place of electrons perform the required logical operations. Resonators allow energy buildings due to constructive interference; therefore these are suitable candidate to generate photonic logic applications. Photoluminescent chemicals are being is use for investigation of photonic logic at a molecular level. Witlicki et al. [16] have generated logical operations using molecules and Surface Enhanced Raman Scattering (SERS).

1.3 OPTICAL MATERIALS

“Materials which can refract, reflect, transmit, disperse, polarize, detect, and transform electromagnetic radiation in ultra violet, visible or infrared spectral regions are termed as optical materials”. Selection of materials has become an important issue for the purpose of all optical operations in present fiber-optic communication systems which operate in the near-infrared region with low attenuation optical windows (850nm, 1310nm, 1550nm and 1625nm) to avoid possible losses during coupling, splitting and switching action and for their compatibility with the present fabrication technologies.

“For the fiber optic communication, optical properties of such materials, like refractive index, transparency, spectral dependency, uniformity, strength, hardness, temperature limits, chemical resistivity etc. are determined by microscopic level investigation of interaction between atoms, their electronic configurations and photons. By varying the wavelength of the incident light and other parameters like temperature, pressure and in some cases by applying external electric or magnetic fields on the material, these properties can be altered or controlled. Various actions
such as coupling/switching of light signal takes place inside the device fabric on application of it. This signal is provided by the control module. In each case a reconfiguration of the optical path has to be implemented through the fabric device at that particular input. A coupler in general can be classified by three main aspects viz. the coupling mechanism, the material and the switching structure”.

“A variety of plastic materials have been used for fabricating economically and light also but the uniquely designed optical elements showing high precision. But these plastic materials are susceptible to microscopic defects (result in light scattering), stresses (birefringence) and temperature variations (change in the refractive index). To fabricate lasers, light emitting diodes and photodetectors, many semiconductor compounds like GaAs, GaAlAs, and InGaAsP, etc. have been used. Compositions and architectures in fabrication, it is not possible with inorganic materials, so synthetic organic polymers such as lithium fluoride, calcium fluoride, and potassium bromide, alkali-halide crystals, etc. have replaced natural crystals and to fabricate durable, optically efficient, reliable, and inexpensive photonic and optoelectronic devices”.

1.3.1 Lithium Niobate [LN] - A Perfect Crystal

Lithium Niobate (LN) is a colorless, ferroelectric, insoluble with water. “Due to its extreme versatile nonlinear crystalline nature, it is a suitable candidate for a variety of applications. Lithium Niobate exhibits a large electro-optic, acousto-optic, thermo-optic effects [17], which makes it suitable in modern optics as an integrated optical element like in optical parametric oscillators and integrated waveguides, non-linear optics (SHG or frequency doublers), SAW
filters, etc \[18–19\]. The electro-optic coefficient of LN is well suited for fabricating modulators and switches, which are used in optical communication systems. With use of Lithium Niobate (LN) waveguides, excellent transmission characteristics can be achieved while maintaining a high extinction ratio and low power operation. The property of high intrinsic modulation bandwidth makes LN, a suitable candidate for communication technology. Its high degree of optical uniformity, piezo–electric, photo–elastic properties has been used for various technical developments and fabrication of many active and passive devices, such as transducers, receivers-transmitters, deflectors, generators of non-linear distorted waves, modulator, encoders-decoders and various non-linear elements \[20–22\].

“LN crystal has been doped with different dopants like magnesium oxide, titanium, etc. to generate special effects to be used with specific application such as to make waveguides, SAW filters, etc. LN has a high optical damage threshold, which can be augmented with special dopants such as magnesium. In addition rare-earth ions such as neodymium can be indiffused or doped with LN to create optical sources. Waveguides with LN suitable for optical couplers, splitters, switches and modulators are fabricated with either Ti-indiffusion or annealed proton exchange process. In some cases, where optical leakage needs to be avoided MgO is used to form Mg diffused LN channel waveguide, but it may increase other losses that is not negotiable for fast switching action”.

Diffusion process has been used to fabricate planner lithium niobate waveguides with use photolithography process is used to define masks for selected regions to form channel waveguides. Popular diffused LN waveguides are often produced by the proton-exchanged or
Titanium in diffusion methods. In diffusion of Ti atoms within the LN crystals, increases refraction indexes which allow both TE and TM modes to propagate along the waveguides smoothly. Such waveguides are easy to fabricate and can operate with low temperature. These have been in use for optical communication, signal processing and sensor systems.

1.3.2 Alternate Materials for Optical Coupling And Power Splitting Action

“The coupling of light signals can be achieved either by changing propagating light behavior or alternation in material properties such as refractive index, crystal orientations, etc. Materials possessing piezoelectric, electrostatic or ferromagnetic characteristics have been preferred for developing various all optical devices such as MEMs switches, where switching of light waves is achieved by changing their micro-mirror orientations. The silicon itself is a good choice for integrated optoelectronics applications due to its high refractive index and transparent characteristic at the communications wavelengths [23]”.

Experimental use of electric pumped laser, high-speed modulators and photodetectors had been demonstrated successfully in recent past. Silicon possesses high refractive index contrast and allows formation of submicron waveguides and tight bends for its application for photonic devices. “With progress of silicon technology, Silicon–On–Insulator (SOI) has also immersed as a popular wafer to accommodate the integrated photonic devices and switching circuits. Many III–V group semiconductors, such as GaAs–GaAlAs, are capable of realizing high-speed optical couplers, modulators and switches [24]”.

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“Similarly, in photonic crystals, coupling of light signals have been achieved by pump light based alterations in their index-contrast with mechanisms, such as photonic-bandgap shift and defect-mode shift [25–26]. However, with these mechanisms, high pump intensity is usually required. This problem can be overcome by enhancing the optical nonlinearities in such crystals such as using excited-state interelectron transfer method reported recently to perform ultrafast coupling with less power consumption [26]. Polymers, InP/GaAs, Si, etc. have been preferred for fabrication of passive waveguides [27] and phase (carrier) modulators due to their transparent behavior for such applications. A large number of organic materials have also been a preferable choice for performing optical coupling and switching action such as materials possessing LC state over a certain temperature range, through which polarization of the propagating light has been altered using a modulating electric field to fabricate couplers, modulators, switches and splitters [2, 28].”

1.4 MOTIVATION

“As compared to other technologies, the states of the art of fiber-optic communication systems have advanced dramatically with in a very short period of time. For example, in the year of 1992, it has been possible to have a commercial fiber-optic links with a capacity of 2.5 Gb/s. While in next 4 year of time, the commercial market witness a wavelength-division-multiplexed (WDM) systems with the total capacity of 40 Gb/s, which has been again advanced upto 1.6 Tb/second by the beginning of year 2001. While in end of the same year, the prospect of lightwave systems operating at 3.2 Tb/s or more has been in sight. Moreover, several other undersea networks have
been in the construction phase in December 2001. By the end of year 2001, many technical articles and papers claiming the lightwave systems operating at a bit rate of more than 40 Tb/s have been published [1].

In last one decade, the capacity of transoceanic lightwave systems installed worldwide has exploded. A global network covering 250,000 km with a capacity of 2.56 Tb/s (64 WDM channels at 10 Gb/s over 4 fiber pairs) is now fully operational. In optical communication networks, an optical coupler enables signals in optical fibers or integrated optical circuits (IOCs) to be selectively coupled from one path to another or one circuit to another [2]. An Optical Coupler is a unit that actually couples light between fibers and a photonic coupler, which also performs coupling by exploiting nonlinear material properties to steer light [3–4]. Any generic fiber optic data link, transport and provide the optical data through the fiber optic components based systems only. Generally, a fiber optic data link divides in to three basic operations:

![Figure 1.5: An example of E – O – E communication link](image)

- Electrical to optical convertor: to convert an electrical input signal to an optical signal
- Transportation of optical signal/information over an optical fiber
- Back conversion, i.e. optical to electrical conversion at the output port.

The requisite conversion must be achieved in such a way, that original electrical signal remains at the input and output port. However this needs the networks to go through the process of
conversion from electrical to optical and vice versa. Therefore to avoid this conversion need of inserting all optical components is becoming an urgent issue. Optical couplers are important component, which are very much required in using them with optical networks or communication links for their day to day operations and various applications. With the advent of multimedia and scientific computing, there is an exponential growth in bandwidth demand raised by many users possessing the internet connections.

This has certainly impacted for their use in military and in academic communities particularly. Also with advent of wavelength division multiplexing (WDM) technology, the numbers of wavelengths per fiber has also been increased to hundreds or more, whereas the wavelength operates at rates of 10Gbps or higher [2]. Therefore WDM technology based all-optical mesh networks have been in use to adjust the Internet’s ever growing bandwidth demands, as the mesh-in-nature Internet backbones are proven to be much capable in terms of efficiency and reliability [2]. In telecom applications, an optical coupler can be used for selective coupling from one circuit to another in optical fibers or integrated optical circuits (IOCs). In present scenario, electronic coupling is more popular between fiber transponders. Photonic couplers perform this function by physical coupling of light signals among the fibers, however independent of how the light itself is coupled. Hence a certain portion of the optical coupler market is made up of photonic couplers. This proposed research work has also focused on this market demand as well. All-optical coupling devices in principle are capable of performing the same functions as electronic coupling devices, e.g. guide the signal flow in an optical network as desired and constitute the basic component of the optical computational systems.
“The capability of transmitting large amounts of information over long distances at nearly the speed of light and without any significant loss of data or interference has made optical fibers perfect choice to use in modern communication systems. In O–E–O devices, the conversion of optical to electrical and vice versa requires extra power and generates unavoidable extra heat, which put great impact on the device cost, if the conversion has to took place quickly or many times. Besides, it is almost impossible for electronic conversion circuitry to keep pace with very high speed optical data transfer, creating a bottleneck situation and thus decreasing the overall efficiency of optical links and communication channels”.

“The guidance of the signals in all – optical domain improves the efficiency of a communication system exponentially. The processing of signals in all – optical domain is still a futuristic technology. In view of major advantages such as small size, greater density, high speed, and negligible thermal effects as compared to electronic computers, all-optical computers might be economically viable. With advent of WDM technology, more number of wavelengths per fiber (≥ 100) can be accommodated with each wavelength operating at the rate of 10 Gbps or higher. Internet’s ever increasing bandwidth demands fueling research in optical mesh networks field and due to the mesh-in-nature of internet is regarded more sustainable and capacity-efficient. Thus optical switching technology has effectively opened up entirely new horizons of very high speed communication links. An optical coupler capacitate signals in optical fibers or integrated optical circuits to be selectively coupled from one circuit to another, which is basic underlying principle of optical network applications. The electronic coupling between fiber transponders is prevalent in majority of installed systems, and is invariably hampered by the bottleneck situation mentioned above. All optical coupling devices are the system that performs and controls
switching of light, unconstrained of how the light itself is switched. Our research has served the same lines. It is expected to have more research towards proposing new coupling architectures in optical domain to serve commercial applications in future”.

1.5 MARKET PERSPECTIVE OF THE PROPOSED RESEARCH MOTIVE

In optical circuits, all optical coupling and switching components are the key devices. Recently use of multimode interference (MMI) based all optical couplers, which operates in accordance to the self-imaging effect, are rapidly gaining popularity due to their numerous advantages. These advantages are basically their compact size, low operation and their large fabrication tolerance. Various materials have been preferred for fabrication of such couplers such as Lithium Niobate, Indium Phosphate (InP), silica (SiO₂) and gallium arsenic (GaAs) due to their capability of achieving best coupling.

Variety of thermo-optic and electro-optic devices based on single mode SOI (Silicon on insulator) waveguide exhibiting the low propagation losses of the order of – 0.1dB/cm has been demonstrated by wet-etching method in past [3]. High bandwidth optical coupling devices can also offer scalable solution to provide necessary bandwidth for their use in present Internet systems, while maintaining the network cost and complexity at lower end. Such Optical-coupler systems can broadly be categorized into two classes: Opaque and Transparent Optical-coupler systems. While specific requirements for optical-coupling systems may differ from carrier to carrier, following characteristics are common for all [2–6]:
Scalable to gain high capacity and tremendous growth.

To support transport services using the Bandwidth granularity.

Perfect protection services to meet customer’s demands.

To monitor bit-error rates (BERs) for service-level verification.

Exclusive economics, covering the initial and the operating cost.

As compared to the traditional SONET/SDH systems, both type of (opaque and transparent) all optical coupling devices can help carriers to fulfill above requirements.

1.5.1 Performance issues

For ultra fast communication uses, various performance parameters of all optical couplers and power splitters need to take care such as propagation losses, required on-chip area coverage, loss uniformity, tolerance range, operating wavelengths and the power requirements. Requirements of these parameters differ in terms of operating principles, their structures and the applications, where these devices are to be fit. “For sophisticated telecom and internet applications, such devices with losses better than 3–5dB is highly desirable, to keep interferences at minimum levels. Most of the performance parameters of these devices depend on their structure, working principle and the material used”.

For example, waveguide based couplers such as MZI, MMI and Y-shaped waveguiding structure, etc. with overall losses of 2 – 3dB and loss imbalance levels below to – 10dB are useful for integrated optics [7]. “In case of MZI structure based devices, the operating optical bandwidth is an important issue to cover wider wavelength range for various applications like in
optical cross-connection and (OXC) and add-drop multiplexers (OADM) [7]. “Therefore the coupling structure for consuming less power, need attention in this regard, which can be done with some modification in basic structures such as use of MMI waveguides, but that too may lead to higher complexity and on-chip area [8–9]. In order to have suppressed cross talk (CT) levels, thermo-optic and electro-optic Y-shaped waveguides based coupling and switching structures such as DOS, has been proved as an excellent choice, due to their unique property of low polarization dependent losses and wide wavelength operations but at the expense of higher driving voltage requirements [10–12]. In past, conventional Y–junction DOS structures have been modified to suppress CT levels using wide branch angle, tapering the output waveguides, etc. Therefore, adopting few modifications, even conventional Y–junction DOS structure can be used to perform coupling and power splitting functions with reduced losses, CT levels with low power (voltage, in case of EO–switches) requirements, while maintaining the smaller area coverage”.

1.5.2 Scalability issues

The scalability issues for designing the all–optical networks have been underlined by the current rapid traffic growth rate on carriers’ networks. Today, service providers are talking of new systems which are having the switching capacity in order of several hundred Gbps streams. A large majority of high speed couplers and network circuitry built in recent years have been realized by standard O–E–O converters and high – density ASICs to takes best advantage of opaque coupling technologies.
The high-speed IC technology which is the underlying technology is well researched and thoroughly reviewed by the researchers of IP routers, optical couplers, ATM switches, ultrafast Ethernet switches, and other similar networking products. Today's transparent components are incapable of supporting the same number of input and output ports as those based on electronics. The physical size and the insertion loss limit the cascading of multiple switching elements to create larger fabrics. Thus a large scalable network is still not feasible for transparent optical coupling technology. However, certain technologies allow overcoming this limitation through the integration of multiple optical switches on single chip. Characteristics like service levels, response times etc. directly affect the coupling device performance. A more economic solution can be using polymer waveguide based coupling structures, but they have coupling delays close to hundred of milliseconds.

Lithium Niobate has emerged as a promising candidate for such devices since it offers coupling performance in the order of nanoseconds. Other coupling structure requirements include high power and display sensitivity to polarization-limiting scalability. In this work we target to optimize the performance of the optical couplers and splitters by making the trade–offs between various optical characteristics like polarization dependence, cross talk levels and coupling losses. It has been tried to achieve this by modifying the architectures of these devices as well as carefully modifying their geometrical parameters.

1.6 THESIS ORGANIZATION

In this thesis, various aspects on realization of all optical coupling structures and their use to implement optical power splitters and switching action are described. The studies are focused on
design issues of channel waveguides and optical couplers. The thesis is organized into five chapters. First chapter describe the use of various all optical devices in the latest optical communication systems and networks followed by the second chapter, which elaborate the various types of optical coupling and power splitting structures with their principle in details. We have presented our main research work in chapters 3 and 4 followed by the conclusion and future research work, which shall be carried out in coming times. The study has covered the following aspects of all optical couplers and splitting devices.

- Design -waveguides, all optical couplers based on MMI and Y–junction waveguiding structures
- Characterizations –Detailed evaluation of structures to calculate their propagation loss, coupling and splitting ratio and their response.

**Chapter 1** elaborates the fundamental all optical devices, which have been now became the part and parcel of important optical communication systems and networks with their applications in brief. In **chapter 2**, the review of major coupling technologies has been presented with their structuring, applications and limitations. Later part of the chapter focuses on the type of such architectures and approaches, which are useful to design high order coupling matrixes.

**Chapter 3** describes various popular approaches which had been used for realization of optical coupling and splitting action using common light guiding properties of fibers and waveguides made up of particular optical materials. This chapter also includes a detailed literature survey, reviewed for this work on various optical material properties and different kind of schematics and their principles to achieve efficient coupling/power splitting of light signals, when propagate
through them. Next **chapter 4** reviews basic MMI structure and self-imaging principle and proposes MMI based couplers by defining partial modulation index regions. The coupling structures are simulated for detailed investigation for various performance parameters along with limitation to operating wavelength.

**Chapter 5** explain use of Proton exchanged or titanium in diffused Lithium Niobate substrate based conventional Y-junction waveguiding structures and Silicon on Insulator (SOI) based cross gap coupling structures to realize compact optical power splitters and couplers on a Optimization of designed all optical devices (couplers and power splitters) has been performed to minimize optical losses and power imbalance. Effects of waveguiding shaping and dimensions are also explored in brief. Although each chapter ends with a summary of the literature and the research work carried out, we have also summarized our results with a comparison with previous work done in **Chapter 6**. The future design and development aspect of all optical coupling and power splitting structures have also been enlightened and have been tried to suggest few uncovered areas of our work; with those, research can recall and begin with. In the end, References and appendices are added to explain briefly about the design tools and analyzing methods used within this work.