POWER TRANSFER ON MULTIPLE FIBER COUPLERS

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To my dearest father and mother, Bustami and Suarni

Also to my beloved brothers, Eka Nazra, Hardi Nurmansyah,

and my sister, Umi Salmah

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ABSTRACT

Fiber coupler is a great utilization that can be used to split one optical power to the more than two power outputs. Power transfer in fiber coupler depends on not only the geometry arrangement of the waveguides, but also the coupling coefficient. Power transfers between the waveguides are calculated using matrix transfer method. By introducing power input to the one of the waveguides, assuming cross section, power propagation, and fiber axis are held constants, at coupling constant coupling coefficient. It shows that coupling length of NX2, linear order NX3, and triangular NX3 fiber couplers are odd-multiple of $z = \pi / 2\kappa$, $z = \pi / \sqrt{2}\kappa$, and $z = \dfrac{\pi}{2\sqrt{2}\ \kappa}$ respectively. If the coupling coefficient is varied along the coupling region, phase needed to transfer power to the others waveguide changes. The calculation of power transfer has been shown in 3D with variation of coupling coefficient from $0.1\,\mathrm{mm}^{-1}$ to $1.5\,\mathrm{mm}^{-1}$. It describes that the higher the coupling coefficient, the shorter the coupling length or phase that required to transfer power completely to the others waveguides. The good agreement in minimum coupling length or minimum phase of NX2 and NX3 shows that the coupling length of linear order NX3 is larger with a factor $\sqrt{2}$ than the coupling length of NX2. However, the coupling length of triangular order NX3 is shorter with a factor $1/\sqrt{2}$ than the coupling length of NX2 fiber couplers.

ABSTRAK

Gentian pengganding merupakan penggunaan yang boleh digunakan untuk membahagikan satu kuasa optik kepada lebih daripada dua kuasa yang dihasilkan. Penghantaran kuasa dalam gentian pengganding bukan hanya bergantung kepada struktur geometri pemandu gelombang, tetapi juga pekali pengganding. Penghantaran kuasa antara pemandu gelombang dihitung menggunakan cara hantaran matrik. Kuasa masukan hanya di kenakan ke salah satu dari pemandu gelombang. Keratan rentas, pemala perambatan, paksi gentian adalah dianggap malar. Hasil perhitungan telah memperlihatkan bahawa panjang pengganding bagi NX2, susunan linear NX3, dan segitiga NX3 gentian pengganding adalah penggandaan ganjil dari $z = \pi / 2\kappa$, $z = \pi / \sqrt{2}\kappa$, dan $z = \frac{\pi}{2\sqrt{2}\ \kappa}$ masing-masing. Pekali pengganding merupakan parameter yg mempengaruhi hantaran gelombang diantaran pemandu gelombang. Hasil dari pengiraan penghantaran kuasa di tunjukkan dalam 3 dimensi dengan mengubah pekali pengganding dari $0.1\ \mathrm{mm}^{-1}$ to $1.5\ \mathrm{mm}^{-1}$. Iya menunjukkan bahawa semakin tinggi pekali pengganding, semakin pendek panjang pengganding yang di perlukan untuk memindahkan semua kuasa kepada pemandu gelombang yang lain. Panjang pengganding dan fasa yang minimum bagi gentian pengganding susunan linera NX3 lebih besar dengan factor $\sqrt{2}$ dari pada panjang pengganding bagi NX2. Sedangkan panjang pengganding bagi susunan segitiga NX3 lebih pendek dengan faktor $1/\sqrt{2}$ berbanding gentian pengganding NX2.

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LIST OF SYMBOLS

D	-	Dimension
N	-	The number of fiber
dB	-	Decibel
n_1	-	Refractive index of core
n_2	-	Refractive index of cladding
a_m	-	Acceptance angle
θ_C	-	Critical angle
NA	-	Numerical Aparture
V	-	V-parameter
λ	-	Wave length
k	-	Wave number
b	-	Normalized propagation constant
β	-	Propagation constant
V_c	-	Cut-off frequency
E	-	Electric field
z	-	Direction of propagation
κ	-	Coupling coefficient
A	-	Power Amplitude
ψ	-	Scalar wave equation solution
a	-	Core radius
U	-	Normalized lateral phase constant
K	-	Hankel Function
w	-	Normalized attenuation constant
d	-	Separation of fiber axis

P	-	Power Propagation
CR	-	Coupling Ratio
WG	-	Waveguide
L	-	Interaction length
l_C	-	Coupling length

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CHAPTER 1

INTRODUCTION

1.1 Introduction

An optical fiber is a glass/ plastic fiber that carries information in terms of electromagnetic waves over longer distances. Fiber optics have been developed to obtain power losses as small as possible. Single mode fiber is one kind of fiber optics that allows a single mode of light propagating in the core of the fiber. Its tremendous information-carrying capacity and low intrinsic loss have made single-mode fiber the ideal transmission medium for a multitude of applications.

Optical directional coupler uses single-mode fibers as the waveguides. It has been fabricated and developed for industrial application such as optical switches and tunable filter in telecommunication and device sensor. Fiber couplers may refer as devices that are used to combine and split optical signal in the optical system.

Fiber coupler is an optical directional coupler that consists of two or more fibers arrangement. The most common optical directional coupler is NX2 fiber couplers, where the two waveguides are in parallel arrangement. The NX3 fibers coupler has been also designed using three single-mode fibers as waveguides. they are made by fusion technique. During the fusion process, it is not easy to maintain coupling length of the fiber couplers. Sometimes the coupling length exceeds the desire one and resulting undesired coupling ratio between the waveguides. In order to make it better, and more effective, the study about fiber coupler becomes necessary.

A matrix transfer method is a mathematical theory to calculate power coupling distribution in fiber couplers. This power distribution as a function of coupling ratio can be controlled by adjusting coupling length and coupling coefficient which can be varied along the interaction region. The calculation of power transfer gives important information in coupling region such as power transfer between the waveguides. Then, the coupling length is determined in order to obtain output characteristics due to appropriate application such as splitters, routers, etc.

1.2 Background of Study

Fiber couplers are passive devices in which a wide range of parametric changes occurs during fiber fusion. One of the main phenomena which occurs in optical coupler is the coupling of mode in space. Coupling length and coupling coefficient contribute to power transfer along coupled fiber. In order to explain these phenomena, characteristics of NX2 and NX3 fiber couplers will be studied and makes the fiber couplers more efficiency in coupling length.

Power transfer characteristics among N parallel single mode optical fibers have been investigated using coupled mode theory (Wang *et al*, 2007). The analysis shows that power transfer of N fibers is periodical during coupling among parallel single mode optical fibers. NXN optical directional couplers with a linear array arrangement have been studied by assuming that the coupling coefficient is constant (Pan *et al,* 2000).

In most investigation, the power transfer between the waveguide are investigated when the fibers are in parallel or linear array arrangements and with constant coupling coefficient. However, it is interesting to investigate the power transfer characteristics between the waveguides with different of coupling coefficients.

In this research, coupled mode theory is modified to be a set of matrix transfer equation that it will be used to determine power transfer in NX2 and NX3 single-mode fiber couplers. The coupling length is then analyzed by varying coupling coefficient along the fiber.

1.3 Problem Statement

In order to obtain the desired output characteristics of the fiber coupler, the power transfer will be calculated. Experimentally, it is difficult to maintain the coupling length of fiber couplers due to changes of geometry of fiber during the fiber fusion. The calculation of the power distribution and the coupling length in order to address this condition, the matrix technique is introduced, then becomes important.

1.4 Objectives of Study

The objective of this research is to investigate power transfer in NX2 and NX3 fiber couplers for constant and variable coupling coefficients, and the effect of order placement for obtaining the power output characteristics by using a matrix transfer for power propagation computation. It is modeled in 2D and 3D. The relationship between the coupling length and coupling coefficient is also investigated.

1.5 Scope of Study

This research focuses on the study of power transfer in interaction region of multiple fiber couplers. The calculation of power transfer is done with the assumption that the fiber couplers have constant cross section. The propagation constants and the separation between the waveguides are maintained constant. The calculations are performed under two conditions, both constant, and for variable coupling coefficient. The coupling length is determined to observe the effect of the coupling coefficient to the power transfer characteristic of the fiber couplers. The kind of multiple fiber couplers that will be investigated are NX2 and NX3 of linear and triangular order arrangement.

1.6 Significance of Study

The calculations of power transfer in linear order of MXN fiber couplers have been done with assumption that the coupling coefficient is constant. The calculation with variable coupling coefficient along the fiber will provide a better understanding of power transfer on fiber couplers

1.7 Organization of Thesis report

This thesis described five chapters which is as follows. Chapter 1 is the research framework. This chapter contains some discussion on the introduction to the study, a description to the problem, the objectives of the study, the scope of study, the significance of the study and finally the chapter organization.

Chapter 2 will brief about the theory that support this research that has been done related and used to the study. Chapter 3 will describe a complete calculation on the research methodology. The coupled-mode theory is expand and expressed in term of matrix transfer that it will be used to calculated power transfer in fiber couplers.

Chapter 4 is the result and analysis of the calculation based on Chapter 3. These results are shown in simulation and its analysis which are explained in terms of the relevant theory. Finally, chapter 5 gives the conclusion of this research and the future works.