ANTENNA WITH METAMATERIAL DESIGN

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To my beloved husband, Hairul Azydy Muhammad Yusuf
for his love, support and understanding
To my lovely son, Muhammad Irfan Raziq (born on 4th May 2007)
for the 9 months of wonderful experienced and lots to come

ACKNOWLEDGEMENTS

I would like to thank the project's supervisor Dr. Mohamad Kamal A. Rahim for his guidance, time and supervision. His ideas, advise and constructive comments have contributed greatly in the overall project progression and in the writing of this report. This acknowledgements also for all the individuals who assist me in their own ways throughout the project's completion.

ABSTRACT

Metamaterial exhibiting negative permittivity and negative permeability in certain frequency range or known as left-handed material (LHM), provides another alternative to the existing right-hand rule. With this theory, it offers a new dimension to the antenna applications as well as optic. The negative refractive index and the convergence of the electromagnetic waves when passing through the metamaterial is good for optical applications. However, this project looks into the effect of metamaterial structure to the conventional antenna and concentrate on proving the existence of the negative index material within certain frequency regions. Also, the relationship between different varies dimensions used affect the frequency response is being emphasized in order to understand further the metamaterial structure and its properties. Knowing that, the structure is optimized to get the left-handed properties in X-band frequency which is around 8GHz-12GHz. Although, the metamaterial structure giving a limited negative range within the X-band, it does agree to the metamaterial theory with the co-existence of both negative permittivity and negative permeability. The theoretical calculation give a reference value to work with, while the simulation via HFSS simulation tools is used to optimized and confirmed to the theoretical result. Then the simulation also being performed on the antenna with metamaterial structure and the effect is observed and analyzed where we can see a frequency shift occurred.

ABSTRAK

Metamaterial menunjukkan permitiviti dan permeabiliti negatif dalam julat frekuensi tertentu. Ia juga dikenali sebagai 'left-handed material (LHM), yang memberikan alternatif lain kepada peraturan tangan kanan sedia ada. Indeks pembiasan negatif dan penumpuan gelombang electromagnet selepas melepasi metamaterial adalah berguna untuk aplikasi optik. Walau bagaimana pun, projek ini melihat kesan struktur metamaterial ke atas antena konvensional dan tumpuan diberikan untuk menunjukkan kewujudan material berindeks negatif dalam kawasan frekuensi tertentu. Hubungkait antara pelbagai variasi dimensi struktur metamaterial dan frekuensi ditekankan dalam projek ini untuk lebih pemahaman terhadap struktur metamaterial dan sifat-sifatnya. Dengan pengetahuan yang diperolehi, struktur metamaterial dioptimumkan untuk memberikan sifat 'tangan-kiri' *(left –hand rule)* dalam frekuensi 'julat-X' (*X-band*) iaitu sekitar 8Ghz -12Ghz. Walaupun struktur metamaterial memberikan nilai frekuensi negatif yang terhad di dalam julat-X, ia tetap mematuhi teori metamaterial dengan kewujudan kedua-dua pemitiviti negatif dan permeabiliti negative. Pengiraan secara teori memberikan nilai rujukan, manakala simulasi menggunakan alat simulasi HFSS membenarkan struktur dioptimumkan dan keputusan teori dipastikan. Proses simulasi juga dilakukan ke atas antena dengan struktur metamaterial dan kesannya diperhatikan dan dianalisa di mana terdapatnya perubahan ke atas nilai frekuensi.

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LIST OF ABBREVIATIONS

HFSS	-	High Frequency Simulator System
LH	-	Left -Handed
LHM	-	Left-Handed Material
PEC	-	Perfect Electric Conductor
PMC	-	Perfect Magnetic Conductor
RHM	-	Right-Handed Material
SRR	-	Split Ring Resonator

LIST OF SYMBOLS

A	-	antenna aperture
c	-	free space velocity of the light
D	-	aperture diameter
f	-	frequency
F	-	filling factor
g	-	gap
h	-	height
l	-	length
n	-	refractive index
s	-	separation
w	-	width
z	-	impedance
ε	-	permittivity
μ.	-	permeability
ω	-	resonance frequency
θ	-	angle
λ	-	wavelength

CHAPTER 1

INTRODUCTION

This chapter consists of the introduction to the metamaterial which includes the definition of the metamaterial, the early theory to the negative index of refraction, and the structure that shows the left-handed properties. Then, follows by the objective and scope of the project which reflect the overall project's content.

1.1 Introduction to Metamaterial

Metamaterials are artificial materials synthesized by embedding specific inclusions, for example, periodic structures, in host media. Some of these materials demonstrate the property of either negative permittivity or permeability. If both happen at the same time, then the composite exhibits an effective negative index of refraction and is referred to as left-handed metamaterials. The name was given because the electric field, magnetic field and the wave vector formed a left-handed system.

According to Valerie Browning and Stu Wolf of Defense Advanced Research Project Agency (DARPA), metamaterial can be defined as a new class of ordered composites that exhibit exceptional properties not readily observed in nature. These properties arise from qualitatively new response functions that are not observed in the

constituent materials and is the result from the inclusion of artificially fabricated, extrinsic, low dimensional inhomogeneties.

The electric and magnetic properties of materials are determined by two important material parameters, dielectric permittivity, ε and magnetic permeability, μ. Together the permeability and the permittivity, determine the response of the material to the electromagnetic radiation. Generally, ε and μ are both positive in ordinary materials. While ε could be negative in some materials (for instance, ε posses negative values below the plasma frequency of metals), no natural materials with negative μ are known. However, for certain structures, which are called left-handed materials (LHM), both the effective permittivity, ε_{eff} and permeability, μ_{eff} possess negative values. In such materials the index of refraction, n, is less than zero, and therefore, phase and group velocity of an electromagnetic wave can propagate in opposite directions such that the direction of propagation is reversed with respect to the direction of energy flow [1].

The idea of metamaterial or negative index of refraction was first proposed theoretically in 1968 by V.G.Veselago. This metamaterial exhibits a negative permittivity and permeability or also known as left –handed material (LHM). Veselago also predicted that the LHMs exhibit anti-parallel nature in electromagnetic wave propagation and Poynting vectors. This is opposed the conventional materials which normally carry electromagnetic wave energy in the same direction as they propagate. With this theory, it provides another alternative and open the possibility for wider exploration in the area that previously cannot be reached using the right hand rules properties.

The negative permittivity is easily obtained by an array of metallic wires and was theorized in 1996. It was shown that the structure is having a plasma frequency in the microwave regime. Because of its low plasma frequency, this structure can produce an effective negative permittivity at microwave frequencies while suffering relatively small losses. JB Pendry also theorized the structure of negative permeability which is

established in 1999 with split ring resonator (SRR) structure [20]. The first negative index medium was developed when both of these structures were combined and it was shown that the negative index of refraction is existed in the region where both the real parts of the electric permittivity and magnetic permeability were simultaneously negative. Typically, in a structure composed of SRRs and strip wires

1.2 Objective Of The Project

Conventional antenna often limits the application of the antenna since they are governed by the 'right-hand rule' which determine how electromagnetic wave should behave. Metamaterial offers an alternative solution to widen the antenna applications using the 'left-hand rule'. The unique properties of metamaterial enable the enhancement of the conventional antenna, thus open more opportunities for better antenna design. This project will emphasize on obtaining the metamaterial structure with optimized parameters for negative index behaviour in which both permittivity and permeability co-exist simultaneously in the required frequency region.

The main objectives of this project are:

i) To design and simulate the metamaterial structure

ii) To incorporate metamaterial structure in the antenna design

1.3 Scope Of The Project

The scope of the project will includes the study of metamaterial which will be emphasized on the negative refractive index or left-handed material (LHM) and the metamaterial structure which cover the conventional LHM. Another is to design the metamaterial structure by using the theoretical method to find the optimized structure, to compare the design parameter and to see the effect of varies structure dimensions on the

frequency response. Finally to perform a simulation on the designed structure using High Frequency Simulator System (HFSS) and analyze the result obtained.

1.4 Summary

The introduction of metamaterials described on the early finding of the metamaterials from the theory to the realization of the metamaterial properties and structures. Knowing the fundamental concept and information of the metamaterial, the objective and scope are defined to ensure that the overall studies are within the required field.