FREQUENCY RECONFIGURABLE LOG-PERIODIC ANTENNA DESIGN

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Specially dedicated to my beloved mom and dad,
Hjh Arapah bte Osman and Hj Ismail bin Baba,
my siblings and family, for their encouragement and support;
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ABSTRACT

The concept of reconfigurable antenna is widely used as additional features of reconfigurable ability for future wireless communication system. There are various configurations of reconfigurable antenna such as monopole, dipole and log-periodic wideband antenna. The integrations of reconfigurable antennas with radio frequency (RF) switches are needed to perform the switchable ability. In this research, a log-periodic antenna (LPA) has been designed to perform a wideband frequency operation by connecting thirteen square-patch antennas using inset feed line technique. Then, the reconfigurable log-periodic antenna (RLPA) is designed by connecting positive-intrinsic-negative (PIN) diodes at every transmission lines with a quarter-wave length radial stub biasing. The representation of real PIN diodes and the locations of biasing circuits in simulation are also included. Three different sub-band frequencies with a bandwidth of 20% (3 - 4, 3.7 - 5, and 4.8 - 6 GHz for each band) are configured from the total of 73% bandwidth (3 to 6 GHz) of the wideband operations by switching ON and OFF of the PIN diode. Other sub-bands or narrow band can also be configured by selecting other group of patches. Validation for the LPA and RLPA is achieved by comparing the simulated and measured radiation patterns. The measured half-power beamwidth (HPBW) for LPA are 62°, 58° and 72° at frequency 3.4 GHz, 4.0 GHz and 5.8 GHz, respectively, while 73°, 67° and 72° for RLPA at the same frequency band. The simulated gain for LPA and RLPA are around 4.9 dB and 5.0 dB respectively, while the measured gain is around 5.5 dBi for LPA and 5.7 dBi for RLPA within a frequency range of 3 – 6 GHz. All the structures have been fabricated and the measurement results show accuracies of 97.5% for return loss, 80.2% for gain and 98.4% for HPBW with the simulation results.

ABSTRAK

Konsep antena boleh-ubah telah digunakan secara meluas sebagai penambahan ciri dalam keupayaan boleh-ubah untuk sistem perhubungan tanpa wayar di masa hadapan. Terdapat pelbagai konfigurasi antena boleh-ubah menggunakan antena jenis jalur lebar seperti antena satu-polar, dwipolar dan log-periodik. Penyepaduan antena dan suis RF diperlukan untuk melaksanakan keupayaan boleh-ubah. Dalam penyelidikan ini sebuah antena log-periodik telah direkabentuk untuk operasi jalur lebar dengan menyambung sebanyak tiga belas antena tampalan segi empat dengan menggunakan teknik kemasukan jalur suapan. Kemudian, Antena Boleh-Ubah Log-Periodik direkabentuk dengan meletakan diod PIN pada setiap jalur penghantaran antena bersama dengan pincangan suku gelombang puntung berjejari. Perwakilan diod PIN yang sebenar dan lokasi litar pincangan dalam proses simulasi juga disertakan dalam projek ini. Tiga sub jalur frekuensi yang berlainan dengan lebar jalur sebanyak 20% (3-4, 3.7-5 dan 4.8-6 GHz bagi setiap jalur) telah dikonfigurasikan dari operasi jalur lebar yang mempunyai 73 % (3 hingga 6 GHz) lebar jalur dengan menukar diod PIN kepada keadaan ON dan OFF. Sub jalur atau jalur sempit yang lain juga boleh diubah dengan memilih kumpulan antena tampalan yang lain. Pengesahan untuk LPA dan RLPA tercapai dengan membandingkan corak sinaran dari hasil simulasi dan pengukuran. Separuh-Kuasa Lebaralur (HPBW) bagi LPA adalah 62°, 58° dan 72° pada frekuensi 3.4 GHz, 4.0 GHz dan 5.8 GHz manakala sebanyak 73°, 67° and 72° bagi RLPA pada julat frekuensi yang sama. Gandaan simulasi untuk LPA dan RLPA adalah masing-masing sekitar 4.9 dB dan 5.0 dB, manakala bagi gandaan pengukuran adalah sekitar 5.5 dBi bagi LPA dan 5.7 dBi bagi RLPA pada julat frekuensi 3-6 GHz. Kesemua struktur telah difabrikasi dan keputusan pengujian mempunyai ketepatan 97.5% bagi kehilangan balikan, 80.2% bagi gandaan dan 98.4% bagi HPBW berbanding keputusan simulasi.

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LIST OF SYMBOLS

f_l	-	Low frequency
f_h	-	High frequency
τ	-	Scaling factor
E	-	Electric field.
H	-	Magnetic field.
h	-	Substrate thickness.
t	-	Copper thickness
wp	-	Width of patch
ε_r	-	Relative permittivity of material.
$tan\ \delta$	-	Tangential loss of material.
dB	-	Decibel
l_f	-	Length of inset fed
l_{tx}	-	Length of transmission line
mm	-	millimeter
R	-	Resistor
L	-	Inductor
C	-	Capacitor

LIST OF ABBREVIATIONS

LPA	-	Log-Periodic Antenna
RLPA	-	Reconfigurable Log-Periodic Antenna
WLAN	-	Wireless Local Area Network
WiMAX	-	Worldwide Interoperability for Microwave Access
UWB	-	Ultra Wide Band
CR	-	Cognitive Radio
VSWR	-	Voltage Standing Wave Ratio
RL	-	Return Loss
BW	-	Bandwidth
BW%	-	Bandwidth Percentage
HPBW	-	Half Power Bandwidth
FR-4	-	Fire Retardant Type 4
mm	-	Millimeter
GHz	-	Gigahertz
THz	-	Terahertz
SMA	-	Sub-Miniature version A
UV	-	Ultra Violet
CST	-	Computer Simulation Technology

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CHAPTER 1

INTRODUCTION

1.1 Introductions

This thesis proposes the design and development of wideband antenna using log-periodic technique. The integration of the antenna with PIN diode switches and lumped elements forms the reconfigurable antenna that enables the antenna to select several sub-bands from a wideband frequency. This work involves the design, fabrication and measurement process of the antenna that has wideband frequency operation with frequency reconfigurability for future wireless communication system such as cognitive radio, radar system and wireless communication network.

This thesis describes the antenna's development including the literature review on the reconfigurable antenna, the simulation design until the fabrication and measurement process. In this first chapter, the brief background of the project is discussed, providing problem statements, objectives, methodology, and scope of work in conducting the research including the project's possible outcome and contributions and also the thesis organization.

1.2 Project Background

The field of wireless communication nowadays has put more emphasis on the field of antenna design. In the early years when radio frequency was discovered, an antenna with a simple design was used as a device to transmit electrical energy or radio wave through the air in all directions. This innovative way of communication to replace wired technology to wireless technology was first introduced by Galileo Marconi when he successfully initiated the first wireless telegraph transmission in 1895 [1]. After that, the development of wireless technology makes leaps and bounds.

Antenna development play a key role in wireless technology since the rapidly increasing number of users in broadcasting, telecommunications, navigation, radar, sensors, military and perhaps for future wireless communication e.g. the cognitive radio [2]. The increasing number of users may lead to congestion of existing spectrum such as Wireless Local Area network (WLAN), Wireless Personal Area Network (WPAN), mobile communication and radio spectrum. Therefore, the development of a reconfigurable antenna is very interesting in the improvement of modern wireless communication system because they enable users to provide a single antenna to be used in many systems.

The advantage of the reconfigurable antenna is they can alter or change the antenna parameters based on their field of operation. The development of a reconfigurable antenna is usually related to the microstrip antenna and their integration with switching circuit. Its advantages include a low fabrication cost, light weight, low profile, conforming, and compatible with integrated circuits devices [3, 4]. Besides, it can be designed at a specific resonant mode to radiate the required frequency bands for the applications of wireless communication systems. However, the new era of wireless communication requires antenna to operate in a wideband range, possesses good radiation and has switchable ability [5, 6].

1.3 Problem Statement

As modern wireless communication systems have developed rapidly in recent years, an antenna as a front component is required to have a wide band, good radiation performances and sometimes switchable ability. To obtain the switchable ability of the antenna, the concept of a reconfigurable antenna was proposed to easily select the frequency from wideband to narrowband. The reconfigurable characteristics of antennas are very valuable for many modern wireless communication and radar system applications, such as object detection, secure communications, multi-frequency communications, vehicle speed tests and so on. Besides, the reconfigurable antenna can also operate within multiple systems by just using a single antenna. For example, a single antenna can be used for both WLAN 2.4 GHz and 5.8 GHz by reconfiguring their dual-band operation.

The RF switch is important parts in development of reconfigurable antenna as selection devices to makes tunable ability. The modeling of the RF switch in simulation tools with an antenna also important that can give better results when comparing with the fabricated antenna. From the previous research on reconfigurable antenna [7-11], the implementation of real RF switches into the proposed antenna are limited and not included with the simulation of an antenna. Some researchers have used an ideal case to simulate the reconfigurable antenna. This project has propose the development of reconfigurable antenna with integration of real RF switch and its modeling in simulation to give better results when comparing with fabricated antenna.

The development of wideband antenna usually uses a monopole structure [7] because of various advantages: it is low profile, thin and small, has the ability to produce very wide frequencies and possesses an omni-directional pattern. However, by using a monopole structure, there has a difficulty on selection of location to configure from wideband to narrow bands. Therefore, the log-periodic concept is used to perform a wideband operation since it has directional radiation pattern; it also easily selects a narrow band frequency since the log-periodic antenna allows a single patch to radiate at single frequency. The integration of log-periodic antenna with RF switching circuit can make the reconfigurable antenna even better.

1.4 Objective

The main objectives of this project are as follows:

i. Design, simulate and fabricate frequency reconfigurable antenna from wideband range to narrow band range with integration of real PIN diodes and biasing circuits.
ii. Design, simulate and fabricate a wideband antenna using log-periodic technique.
iii. To characterize the antenna parameters in term of input return loss, radiation pattern, half power beam width and gain for both simulation and measurement.

1.5 Scope and Limitation of the Project

The main scopes of this research are:

i. Literature review and previous research study on log-periodic antenna and reconfigurable antenna.
ii. Design, simulate and analyze the log-periodic wideband antenna and reconfigurable log-periodic antenna using CST Microwave Studio Software.
iii. Fabricate and measure the log-periodic antenna and reconfigurable log-periodic antenna. The fabrication part includes soldering the PIN diode and lumped elements.
iv. Analyze and compare the results between simulation and measurement.
v. Journal and thesis documentation.

The limitations of this research are:

i. The range of frequency is limit to 6GHz due to available low cost RF PIN diode from the manufacturers.
ii. There are multiple parameters can be tuned for reconfigurable antenna. However, this research only focuses on frequency reconfigurable from wideband, to narrowband.
iii. The measurements of the antenna are based on available facilities in this university. The anechoic chamber for radiation pattern measurement can only measure from 0° to 180° rotation. Hence, only front lobes of radiation patterns are compared with the simulation.
iv. The switching mechanism of this antenna is using manually by DIP switch to control the PIN diode.

1.6 Organization of the Thesis

This thesis is divided into six chapters that describe all the work done for this project. The first chapter consists of the introduction, project background, problem statement, objectives, scope of study and project contribution. Chapter 2 is literature review that explains literature about the log-periodic antenna and the reconfigurable antenna. The basics of the antenna properties such as radiation pattern, bandwidth, gain and HPBW are presented. The log-periodic concept is introduced and explained to get a wideband operation before integrated with the lumped elements and PIN diodes. Besides, the circuit representation of PIN diode and its biasing circuit have also been explained for reconfigurable purposes. Some overview of previous studies is also presented.

The design process of Log-Periodic Wideband Antenna is presented in Chapter 3. The initial result of single patch antenna and the designing process of the log-periodic wideband antenna are also presented. In order to get an optimum result in term of return loss and bandwidth, a parametric study by varying the adjacent distance between the patches, the length of inset feed line and the scaling factor value are presented. While Chapter 3 discusses the passive antenna, the active antenna that integrated with lumped element is discussed in Chapter 4. In this chapter, the research flow, design methodology and simulation setup of Reconfigurable Log-Periodic Antenna is briefly described. The PIN diode representation and biasing circuit location in RLPA are also presented. This chapter also presents the fabrication and measurement process of the antenna.

The simulated and measured results of the Log-periodic Wideband Antenna and Reconfigurable Log-Periodic Antenna are presented in Chapter 5. The simulated result such as return loss, current distribution, realized gain and radiation pattern is clearly presented. Then, the measurement process is done to validate the simulated results and both results have been compared to each other in terms of return loss, received power and radiation pattern. A discussion of the results is presented clearly. Lastly, the conclusion of the project is presented in Chapter 6. This chapter concludes the findings of the project, some key contribution and provides recommendations for future work.