AMC-INTEGRATED RECONFIGURABLE BEAMFORMING ANTENNA BY USING RF MEMS

by

HERWANSYAH BIN LAGO

(1440811249)

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DECLARATION OF THESIS

Author's full name : HERWANSYAH BIN LAGO

Date of birth : 26 AUGUST 1990

Title : AMC-INTEGRATED RECONFIGURABLE BEAMFORMING ANTENNA BY USING RF MEMS

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Specially dedicated to my beloved parents, brothers, sisters, lecturers and friends

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LIST OF SYMBOLS

θ	Theta
Π	Pi
Ω	Ohm
Δ	Variance
ε_{eff}	Effective Permittivity
ε_r	Relative Permittivity
c	Speed of Light
f_r	Resonant Frequency
tanδ	Loss Tangent
λ	Wavelength

LIST OF ABBREVIATIONS

AMC	Artificial Magnetic Conductor
AUT	Antenna Under Test
CST	Computer Simulation Technology
dB	Decibel
DNG	Double Negative
DPS	Double Negative
ENG	Epsilon Negative
FBR	Front to Back Ratio
FET	Field Effect Transistor
FSS	Frequency Selective Surface
EBG	Electromagnetic Band Gap
GHz	Giga Hertz
HPBW	Half Power Beam Width
MEMS	Micro Electro Mechanical System
MHz	Mega Hertz
mm	Millimeter
MNG	Mu-Negative
PEC	Perfect Electric Conductor
PMC	Perfect Magnetic Conductor

RF	Radio Frequency
SAR	Specific Absorption Rate

Antena Pembentukan Alur Boleh Konfigur Bersepadu AMC Menggunakan RF MEMS

ABSTRAK

Tesis ini tertumpu kepada pembangunan kawalan pembentukan alur pada pengalir magnet tiruan (*AMC)* bersepadu dengan antena tampalan menggunakan frekuensi radio (*RF*) *MEMS* berfungsi untuk aplikasi-aplikasi pengesan dan penilaian jarak. Kawalan alur antena sangat bermanfaat dalam pembangunan pesat sistem komunikasi tanpa wayar. Idea utama pengawalan rasuk antena adalah membantu untuk mengurangkan jumlah antena yang diperlukan untuk menguasai satu sudut atau kawasan tertentu manakala pengintegrasian *AMC* adalah membantu untuk mengecilkan saiz antena di samping memperbaiki prestasinya. Tiga reka bentuk antena yang baru telah dicadangkan di dalam tesis ini; antena cetakan dwikutub yang dilipat berbentuk E mengawal pembentuk radiasi dengan menggunakan *AMC* dan *RF MEMS*, pembentuakan radiasi dengan menggunakan parasit dan *RF MEMS* ke atas *AMC* bersepadu dengan antena dwikutub yang dilipat dan kawalan pembentuakan radiasi pada AMC bersepadu bersama antena berbentuk sabit dengan susunan tertentu telah direka dengan menggunakan perisian simulasi 3D. Untuk mengkaji dan mengesahkan keupayaan kawalan dengan menggunakan *RF MEMS* sebagai mekasnisma pensuisan, antena-antena yang disimulasi telah difabrikasi dan diuji. Antena-antena ini adalah usaha yang pertama dalam merealisasikan gabungan antara *RF MEMS* bersama *AMC* yang disatukan dengan antena jenis tampalan. Dua suis dan kemasukan galangan kira-kira 50Ω pada 9.41 GHz telah digunakan pada semua reka bentuk antena yang dicadangkan. Walau bagaimanapun, hanya satu suis diaktifkan dalam satu masa di mana suis yang diaktifkan akan membenarkan arus *RF* melaluinya manakala suis yang dinyahaktifkan akan menyekat arus *RF*. Antena cetakan dwikutub yang dilipat berbentuk E mampu mencapai kawalan pembentukan radiasi sebanyak ±30^{o} dengan galangan jalur lebar yang lebih luas sebanyak 920 MHz. Pengintegrasian parasit ke atas dwikutub yang dilipat telah mencondongkan pembentukan radiasi dan gandaan yang tinggi masing-masing sebanyak ±58^{o} dan 8.08 dB. Di samping itu, gabungan antara satah *AMC* dengan antena berbentuk sabit yang telah disusun dengan susunan tertentu telah mencapai gandaan dan pencondongan bentuk radiasi masing-masing sebanyak 10.5 dB dan 63^{o}. Berdasarkan keupayaan yang telah ditunjuk dan dibincangkan, kesemua antenna ini mempunyai potensi yang besar untuk aplikasi-aplikasi penilai jarak dan pengesan yang pintar.

AMC-Integrated Reconfigurable Beamforming Antenna By Using RF MEMS

ABSTRACT

The research work in this dissertation mainly focuses on the development of reconfigurable beamforming on AMC- integrated patch antenna by using RF MEMS for detection and ranging applications. Reconfigurable-beam antenna is useful in the rapid growth of the wireless communication system. The main idea of reconfigurable-beam antenna is assist to reduce the number of required antenna to cover a specific angle or area while AMC integration helps to miniaturize the antenna size and improving its performance. This thesis proposed three new antenna designs; beam-reconfigurable E-shaped folded printed dipole antenna using metasurface and Radio Frequency (RF) MEMS, AMC-integrated reconfigurable beamforming folded dipole antenna with parasitic and RF MEMS and reconfigurable beamforming on AMC-integrated crescent array antenna that have been designed by using 3D simulator software. To investigate and validate the reconfigurable ability that uses RF MEMS as the switching mechanism, the simulated antennas have been fabricated and measured. These antennas are the first effort in realizing a combination of RF MEMS onto the AMC-integrated patch antenna. Two switches and input impedance approximately 50Ω at 9.41 GHz are applied on all proposed antenna designs. However, only one switch is activated in one time where the activated switch will allow RF current pass through while deactivated switch will block the RF current. The E-shaped folded printed dipole antenna is capable to achieve beam steering ±30° with wider impedance bandwidth of 920 MHz. The integration of parasitic onto folded dipole has awakening the wider beam tilting and high gain of ±58° and 8.08 dB, respectively. Further, the combination of AMC plane and the crescent array antenna has realized a high gain and tilting angle of 10.5 dB and 63º, respectively. With all demonstrated and discussed capabilities, these antennas have big potential in realizing a smart ranging and detection application.

CHAPTER 1

INTRODUCTION

1.1 Introduction

The development of reconfigurable antennas receive much attention to fulfilling different application nowadays. One of the attractive application is an antenna for detection and ranging application. This application system uses the radio wave to determine the range, altitude, and the direction of the speed of an object ("Radar Basics," n.d.). The Radar is popular to be used by several nations during World War II. Nowadays, the used of ranging and detection system are highly diverse due to its capability. Due to the eye limitation especially at night, raining and foggy day, the detection and ranging system is used to locate any moving or motionless object.

Generally, the antenna for ranging and detection applications is operated in specific frequency bands such as L-band, S-band, X-band and etc. Each of the operating band has its own advantages and disadvantages. For example, the lower frequency capable of a longer range detection due to the greater wavelength compare to a higher frequency. However, the antenna which operates in the lower band will be bigger in size. In addition, the higher band is widely used compared to the lower band since it can provide better resolution ("Radar Basics," n.d.). Normally, a waveguide and reflector type antenna is used as the antenna for detection and ranging applications due to their advantageous (Balanis, 2005). Reconfigurable beam pattern antenna can control its beamforming so that the main lobe capable pointing to a particular direction. However, it is nearly impossible to realize the reconfigurable capability especially reconfigurable beam pattern on the waveguide and reflector antenna due their structure itself. In addition, these antennas will have a huge overall dimension with such operating frequencies. A microstrip patch antenna is another type of antenna which is talented to be used for this applications.

A significant number of microstrip antennas have the capability to steer its radiation pattern to more than one direction while maintaining the operating frequency (Aboufoul, Parini, & Chen, 2013; Ahn, Kim, Yoon, & Hwang, 2012). Recently, reconfigurable beam pattern antenna has attracted much attention in numerous applications such as cellular radio system, detection system, and point-to-point propagation. The reconfigurable beam pattern can be realized electronically by using RF switching. However, the RF switch has own limitation on operating frequency, insertion loss, isolation and fabrication complexity (Debogović, Bartolić, & Perruisseau-Carrier, 2014; Pringle et al., 2004; "Radant MEMS," n.d.).

In addition, the microstrip antenna also facing the size drawback since its dimension has a close relation with the operating frequency. Nevertheless, there are several techniques have been presented by previous work that can be applied to miniaturize the size of microstrip antenna (Joozdani, Amirhosseini, & Abdolali, 2016; Li & Feresidis, 2014; Malekpoor & Jam, 2013; So, Wong, Luk, & Chan, 2015; M. Yang, Chen, Lau, Qing, & Yin, 2015). Recently, the implementation of engineered material onto the microstrip patch antenna is one of the popular technique to miniaturize the antenna's size (Foroozesh & Shafai, 2006; Rahmadani & Munir, 2011; Yousefi &

Ramahi, 2010). As a result, this will reduce the cost of the antenna for ranging and detection applications. An artificial magnetic conductor is one of the popular engineered material nowadays. The microstrip antenna dimension is determined through the wavelength in the substrate. However, a high permittivity or permeability substrate can be used to reduce the wavelength in the substrate but, there will be a high impedance mismatch which will lead to low efficiency for the miniaturized antenna (Yousefi & Ramahi, 2010). Nonetheless, the Artificial Magnetic Conductor (AMC) is capable of having moderate permittivity or permeability which will achieve a high miniaturization factor while resulting in less impedance mismatch. The aim of this work is to design a reconfigurable beamforming antenna which integrated with engineered material and switching mechanism.

1.2 Problem Statements

The development of the antenna for detection and ranging application is aggressive due to the demand nowadays. To have the bearing, range and position of the object, most of the conventional antenna is mechanically moving (scanning) in a specific direction. However, it is required a large amount of electric power to enable the functionality of the mechanical parts. Besides that, the potential of the antenna to break down due to the mechanical problem such as cracked gear and the jammed motor is very high which resulting frequently maintenance. In addition, most of the conventional waveguide antenna used for detection and ranging applications which determined by its operating frequency can reach up too few feet ($\simeq$ 4 ft) long ("Radar Basics," n.d.). Consequently, it is require a large area to integrate and operate the antenna. Moreover, the conventional antenna used for Radar system is quite heavy ($\simeq$ 25 kg) since it is attached to the mechanical parts.

Referred to all of these constrains, an antenna with the capability to reconfigurable it's beamforming on the azimuth plane is introduced to replace the mechanical parts to cover wider scanning sector with less weight and size. The beam pattern can be electronically controlled by using switching mechanism. The PIN diode and FET are the most habitually to be deployed as the switches to enable the reconfigurability (Ding & Wang, 2013; Pringle et al., 2004). However, both are requiring a complex biasing circuit which will lead to an additional loss especially electronic losses. Moreover, these switches are limited to a lower operating frequency ($\leq$ 6 GHz), low power handling capability and less isolation (Cheng et al., 2009; Debogović et al., 2014). MEMS is a reliable switch which has better performance compared to the PIN diode and FET. Nonetheless, the switching complexity in fabrication is the biggest challenge.

An antenna with a high gain has the capability to work for a longer distance application due to it's propagation behavior. Therefore, a high gain antenna is required for the Radar system since it's one of the most important parameter that will determine the system capability and effectiveness. Therefore, the reconfigurable beamforming antenna with a high gain is needed by the Radar system due to the system requirement to work for a longer distances. However, an antenna which is deploying the RF switch mechanism to achieve the reconfigurability is facing a huge constrain on the gain performance (Petit, Dussopt, & Laheurte, 2006; X. S. Yang, Wang, Wu, & Xiao, 2007). This constrain is occur since each used electronic component have own losses which called electronic losses and must include into the antenna losses. As a result, the antenna losses will increase and then degrading the antenna's performance especially the gain.

One of the conventional technique to improve the antenna's gain performance is through the integration of the full ground plane on the antenna. However, this technique will resulting a narrow tilting angle for the reconfigurable beamforming antenna. Therefore, it is hard to realize a wide tilting angle of beam direction on the reconfigurable beamforming antenna while improving or maintaining the antenna performance. In addition, a narrow tilting angle of the reconfigurable beamforming antenna has limited coverable area compare to the reconfigurable beamforming antenna with a wider beam tilting angle.

1.3 Objectives

The main objective of the study are as follows:

i. To design and analyze an electronically reconfigurable beamforming antenna at the centered frequency of 9.41 GHz.

ii. To realize a high gain of the reconfigurable beam pattern antenna.

iii. To achieve a wide tilting angle of the reconfigurable beamforming antenna.

1.4 Scope of Work

Reconfigurable beam pattern antennas integrated on metamaterials represent the innovation in antenna design that changed from the classical form of antennas to fit for numerous applications. The scope of this thesis is demonstrated and labelled in blue box as in Figure 1.1.

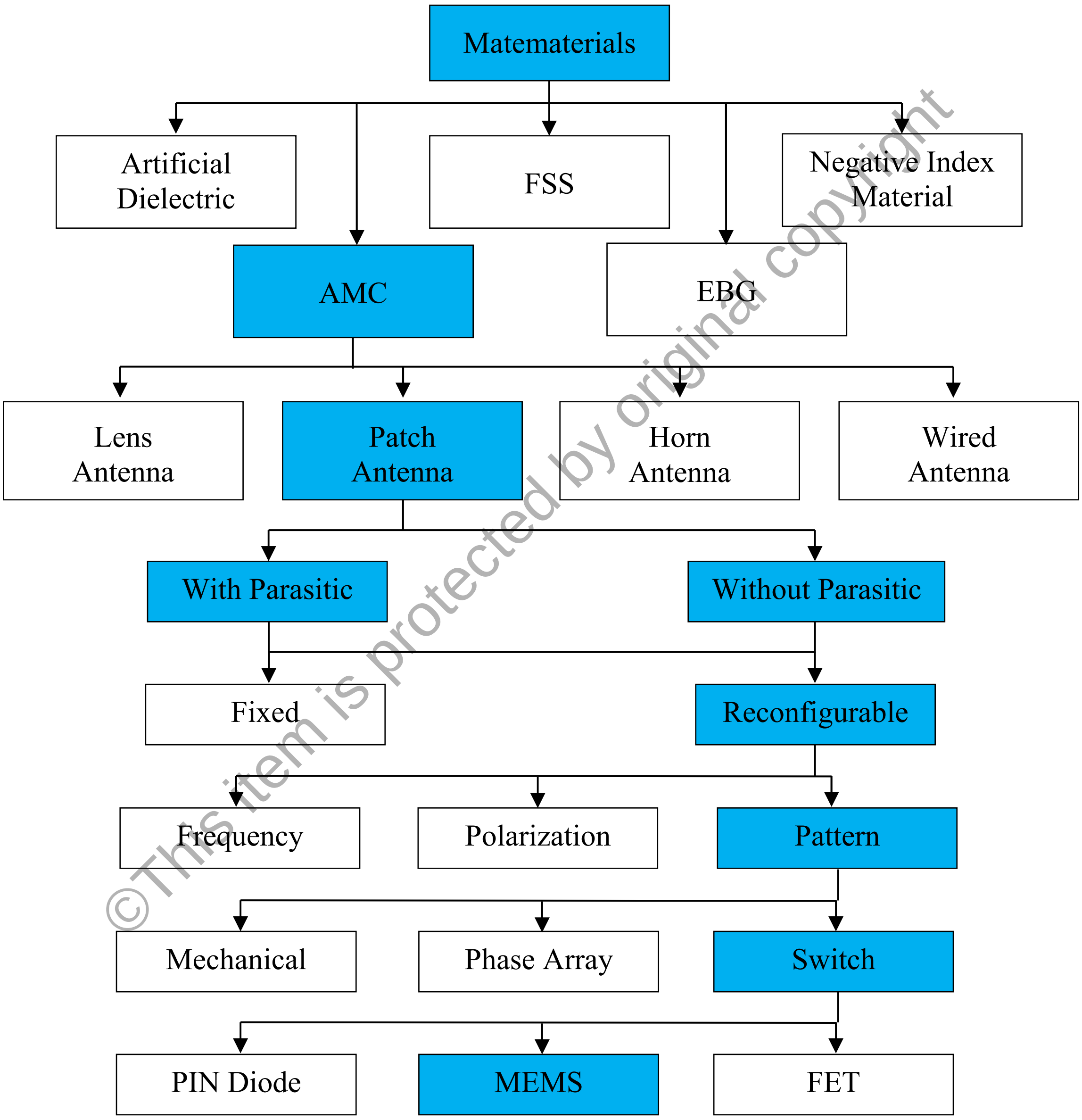

Figure 1.1: Scope of work block diagram.