



**Frequency and Pattern Reconfigurable Dielectric
Resonator Antenna Array**

by

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TABLE OF CONTENTS

	PAGE
DECLARATION OF THESIS	i
ACKNOWLEDGEMENT	ii
TABLE OF CONTENTS	iii
LIST OF TABLES	vii
LIST OF FIGURES	viii
LIST OF ABBREVIATIONS	xiii
LIST OF SYMBOLS	xiv
ABSTRAK	xv
ABSTRACT	xvi
CHAPTER 1 : INTRODUCTION	17
1.1 Introduction	17
1.2 Problem Statement	19
1.3 Objectives	21
1.4 Research Scope	21
1.5 Thesis layout	22
CHAPTER 2 : LITERATURE REVIEW	24
2.1 Introduction	24
2.2 Overview of DRA	24
2.2.1 Reconfigurable antenna	26
2.2.1.1 Frequency Reconfigurable Antenna	27

2.2.1.2	Pattern Reconfigurable Antenna	27
2.2.1.3	Polarization Reconfigurable Antenna	28
2.2.1.4	Compound Reconfigurable Antenna	29
2.2.2	Reconfigurable Dielectric Resonator Antenna	30
2.2.2.1	Frequency Reconfigurable DRA	31
2.2.2.2	Radiation Pattern Reconfigurable DRA	32
2.2.2.3	Polarization Reconfigurable DRA	33
2.2.2.4	Compound Reconfigurable DRA	35
2.3	Switching Methods used in Reconfigurable DRA	36
2.3.1	Pin diode	36
2.3.2	Varactor diode	37
2.3.3	Microelectromechanical system (MEMS)	38
2.4	Feeding methods used in Reconfigurable DRA	38
2.4.1	Microstrip Slot Aperture (MSA) feeding	39
2.4.2	Microstrip line (ML)	40
2.5	Review on existing Reconfigurable DRA	40
CHAPTER 3 : RESEARCH METHODOLOGY		49
3.1	Introduction	49
3.2	Design flow, Tools and Specifications	50
3.2.1	Software for Antenna Modelling	53
3.2.2	Material Specifications	53
3.2.3	Material Specifications	54
3.3	Rectangular DRA without Air Gap	55
3.3.1	Design of Rectangular DRA with Air Gap	56
3.4	Frequency Reconfigurable DRA	57

3.4.1	Frequency Reconfigurable DRA using slot-loaded RF switch	58
3.4.2	Frequency Reconfigurable DRA using TL-loaded RF switch (Lumped Element Equivalent Switch) (Antenna 1)	59
3.4.3	Frequency Reconfigurable DRA using TL-loaded RF switch with QW transformer and Radial Stub (Touchstone Block Switch Representation) (Antenna 2)	61
3.4.4	Working Principle of the Frequency Reconfigurable DRA	63
3.5	Frequency and Pattern Reconfigurable DRA (FP-RDRA)	64
3.5.1	Direct Current (DC) biasing of FP-RDRA	68
3.5.2	Working Principle of FP-RDRA	70
3.6	Fabrication process	72
3.7	Measurement Set-up	75
3.7.1	Reflection Coefficient Measurement	75
3.7.2	Radiation Pattern Measurement	76
3.7.3	Gain measurement	78
CHAPTER 4 : RESULTS AND DISCUSSION		80
4.1	Introduction	80
4.2	Results comparison of Rectangular DRA with/without Air Gap	80
4.2.1	S_{11} result of Rectangular DRA with/without Air Gap	81
4.2.2	Radiation Pattern of Rectangular DRA and Rectangular DRA with air gap	82
4.3	Results of Frequency Reconfigurable DRA	83
4.3.1	Slot loaded RF switch of lumped element	83
4.3.2	Frequency Reconfigurable DRA using TL-loaded RF switch (Lumped Element Equivalent Switch) (Antenna 1)	84
4.3.2.1	Frequency Reconfigurable DRA using TL-loaded RF switch with QW transformer and Radial Stub (Touchstone Block Switch Representation) (Antenna 2)	87
4.4	Results of Frequency and Pattern Reconfigurable DRA (FP-RDRA)	90

4.4.1	Non-Steering mode: Reflection Coefficient Analysis	92
4.4.2	Non-Steering mode: Radiation Pattern Analysis	95
4.4.2.1	Pattern (3.5GHz non-Steering)	95
4.4.2.2	Pattern (3.9GHz non-Steering)	96
4.4.2.3	Pattern (4.1GHz non-Steering)	97
4.4.3	Steering mode: Radiation Pattern Reconfiguration	98
4.4.3.1	Steering mode: Reflection Coefficient Analysis	98
4.4.3.2	Steering mode: Radiation Pattern Analysis	100
4.4.4	Summary	103
CHAPTER 5 :	CONCLUSION AND FUTURE WORK	105
5.1	Conclusion	105
5.2	Future Work	107
	REFERENCES	109
	LIST OF PUBLICATIONS	113
	APPENDIX	114

LIST OF TABLES

	PAGE	
Table 2.1	SOTA table	44
Table 3.1	Substrate specifications	54
Table 3.2	Dielectric resonator material specifications	54
Table 3.3	Antenna specifications	55
Table 3.4	Design dimension of rectangular DRA with air gap	57
Table 3.5	Switching condition	64
Table 3.6	Parameter list for FP-RDRA	67
Table 3.7	Configuration for Frequency Reconfiguration	70
Table 3.8	Configuration for Pattern Reconfiguration	72
Table 3.9	Parameter definition of the free space equation	79
Table 4.1	Rectangular DRA without vs with Air Gap	83
Table 4.2	Antenna 1 configuration result	86
Table 4.3	Antenna 2 configuration result	88
Table 4.4	Comparison between antenna 1 and antenna 2 results	89
Table 4.5	Summary of the Frequency and Pattern Reconfigurable Dielectric Resonator Antenna Array results	104

LIST OF FIGURES

		PAGE
Figure 2.1	The cylindrical DRA shape	25
Figure 2.2	The rectangular DRA shape	25
Figure 2.3	Types of reconfigurable antennas	26
Figure 2.4	(a) Structure of the antenna array with PIN diodes, (b) S11 simulation results of the ON and OFF states. (Pan et al., 2020)	27
Figure 2.5	(a) Current distribution in the four operating states at 2.45 GHz, State 1,	28
Figure 2.6	Configuration of the quadpolarization reconfigurable omnidirectional	29
Figure 2.7	Advantages of reconfigurable DRA antenna (Gupta-Kumar,2010)	30
Figure 2.8	Schematic Diagram of the Proposed Reconfigurable dielectric resonator antenna. a) front view, b) back view, c) side view. (Danesh et al., 2016)	31
Figure 2.9	Simulated $ S_{11} $ Results with/ without using DR, a) ON state, b) OFF State. (Danesh et al., 2016)	32
Figure 2.10	(a) Top view for the proposed antenna, (b) The geometry for the proposed antenna bottom view and side view (Khaleel et al., 2018)	33
Figure 2.11	(a) Radiation Pattern for both ports at 2.6 GHz, (b) radiation pattern for both ports at 2.4 GHz (Khaleel et al., 2018)	33

Figure 2.12	Geometry of the Proposed polarization-reconfigurable DRA antenna:	34
Figure 2.13	Simulated radiation patterns of the polarization-reconfigurable DRA at	35
Figure 2.14	Types of switching methods	36
Figure 2.15	Antenna views (a) top view, (b) at side view and (c) at top view (slot area) (Salman et al., 2014)	37
Figure 2.16	Antenna views (a) geometry of dual-wall tunable rectangular DRA, (b) modified sidewall tabs to accommodate varactor diodes (Desjardins et al., 2012)	37
Figure 2.17	Antenna views (a) top view, (b) bottom view (Zohur, Mopidevi, Member, et al., 2013)	38
Figure 2.18	Example of Microstrip Slot Aperture	39
Figure 2.19	A Compact Microstrip Slot Antenna With Novel E-shaped Coupling Aperture (Hoseini Izadi & Mehrparvar, 2010)	39
Figure 2.20	Example of microstrip line	40
Figure 2.21	Microstrip antennas fed by Four-Microstrip port Waveguide Transition with Slot Radiators (Kawase et al., 2012)	40
Figure 3.1	Flowchart of the design	51
Figure 3.2	The DRA design layout (a) Design's dimension, (b) Slot's dimension on the ground, (c) DRA with air gap, (d) Feedline's dimension	56
Figure 3.3	The design with slot-loaded RF switch	58
Figure 3.4	DRA using TL-loaded RF switch (a) front view, (b) back view, (c) side view	60

Figure 3.5	DRA using TL-loaded RF switch showing arrangement of the components	61
Figure 3.6	DRA using TL-loaded RF switch with QW choke matching (a) front view, (b) back view, (c) side view	62
Figure 3.7	DRA design using TSB in CST	63
Figure 3.8	DRA using parasitic element (a) front view, (b) back view	65
Figure 3.9	Frequency and Pattern Reconfigurable Dielectric Resonator Antenna Array (a) Front view, (b) Bottom view, (c) Side view	66
Figure 3.10	Frequency and Pattern Reconfigurable Dielectric Resonator Antenna Array (Rear view)	66
Figure 3.11	DC biasing operation using RF switches and lumped elements	68
Figure 3.12	Measurement with DC biasing set-up	69
Figure 3.13	Yagi-Uda working principle	71
Figure 3.14	Front view	74
Figure 3.15	Rear view	75
Figure 3.16	S_{11} measurement set-up	76
Figure 3.17	Agilent 2-D PNA Antenna Measurement	77
Figure 3.18	Gain measurement test system	78
Figure 4.1	Parameter sweep results of S_{11} and comparison between DRA with/without Air Gap	81
Figure 4.2	The images from CST software (a) Comparison of radiation pattern in polar form between DRA with and without air gap	82

Figure 4.3	The 3D radiation pattern results (a) without air gap, (b) with air gap	83
Figure 4.4	The S11 comparison between design with and without slot	84
Figure 4.5	Parameter sweep of the length of transmission line	85
Figure 4.6	Return loss for Frequency Reconfigurable DRA using TL-loaded RF switch	86
Figure 4.7	Return loss for Frequency Reconfigurable DRA using TL-loaded RF switch with QW choke matching	88
Figure 4.8	Radiation pattern for Frequency Reconfigurable DRA using TL-loaded RF switch with QW choke matching	89
Figure 4.9	Parameter sweep for parasitic line length at 1111 condition	91
Figure 4.10	Parameter sweep for parasitic line length at 1110 or 1101 condition	91
Figure 4.11	Comparison between simulated and measured result at 1111 switching state	92
Figure 4.12	Comparison between simulated and measured results at 1011 switching state	93
Figure 4.13	Comparison between simulated and measured results at 0011 switching state	94
Figure 4.14	Comparison between simulated co, measured results and simulated cross	95
Figure 4.15	Comparison between simulated co, measured results and simulated cross	96
Figure 4.16	Comparison between simulated co, measured results and simulated cross	97

Figure 4.17	The simulated reflection coefficient during steering mode - 30°,0° and +30°	98
Figure 4.18	The measured reflection coefficient during steering mode - 30°,0° and +30°	99
Figure 4.19	Comparison between simulated co, measured results and simulated cross for 1101 condition	101
Figure 4.20	Comparison between simulated co, measured results and simulated cross for 1110 condition	102

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LIST OF ABBREVIATIONS

DRA	Dielectric Resonator Antenna
CST	Computer Simulation Technology
RPR	Radiation Pattern Reconfigurable
DC	Direct Current
RF	Radio Frequency
S11	S-Parameter 11
dB	Decibel
FR-4	Flame Retardant 4
SMA	SubMiniature version A Connectors
MHz	Megahertz
TSB	Touchstone Block
TL	Transmission Line
GPIB	General Purpose Interface Bus
PNA	Performance Network Analyzer
PT	Power Transmitted
PR	Power Received
AUT	Antenna Under Test
LOS	Line of Sight

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LIST OF SYMBOLS

ϵ_r	Dielectric Constant
f	Frequency
S_{11}	Reflection Coefficient
c	Speed of Light
h	Substrate Height
t	Substrate Thickness

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Frekuensi dan Corak Antena Resonator Dielektrik boleh Dikonfigurasi Semula

ABSTRAK

Dalam beberapa tahun kebelakangan ini, antena boleh dikonfigurasi semula telah digunakan secara meluas dalam pelbagai aplikasi tanpa wayar. Kegunaan antena boleh konfigurasi semula adalah berdasarkan keupayaan reka bentuk yang boleh dikonfigurasi semula. Antena boleh dikonfigurasi semula frekuensi berguna dalam menukarkan jalur kendalian antena seperti dalam rangkaian radio kognitif. Antena corak radiasi boleh dikonfigurasi semula berguna dalam stereng alur untuk meningkatkan gandaan. Sebaliknya, antena boleh konfigurasi semula pengutuban digunakan secara meluas dalam pelbagai sistem antena untuk meningkatkan kapasiti saluran. Penggunaan kebolehkongfigurasi semula menggunakan antena resonator dielektrik (DRA) telah menunjukkan impak yang besar terhadap gandaan. Tesis ini membentangkan reka bentuk dan analisis bagi tatasusunan antena resonator dielektrik frekuensi dan corak yang boleh konfigurasi semula. DRA boleh konfigurasi semula yang telah ada hanya berupaya mengkonfigurasi dari segi frekuensi atau corak sahaja, tetapi tidak kedua-duanya secara serentak. Sekatan terhadap adaptabiliti dan fleksibiliti antena merujuk kepada cabaran dalam mencapai prestasi optimum di pelbagai senario komunikasi yang memerlukan pengoptimuman corak dan frekuensi. Maka, kecekapan spektrum dapat dipertingkatkan dengan reka bentuk antena boleh konfigurasi semula frekuensi dan corak radiasi dalam struktur antena yang sama. Penyelidikan ini bertujuan untuk menggabungkan kedua-dua jenis konfigurasi iaitu, frekuensi dan corak teradiasi ke dalam satu reka bentuk antena. Dari segi konfigurasi semula frekuensi, ia mempunyai tiga frekuensi (4.1 GHz, 3.9 GHz & 3.5 GHz). Talian penghantaran (TL) yang paling panjang akan menghasilkan 3.5 GHz manakala yang terpendek akan menghasilkan 4.1 GHz. Untuk konfigurasi semula corak radiasi, stereng -30° dan $+30^\circ$ hanya berlaku dalam 3.5 GHz. Untuk mengemudi ia melibatkan pensuisan TL parasit. Apabila suis yang berkaitan dihidupkan, DRA parasitik kiri akan diaktifkan, maka corak radiasi akan terarah ke -30° . Mekanisma yang bertentangan berlaku apabila DRA parasitik kanan diaktifkan menggunakan suis pada talian penghantaran parasitic yang berkaitan. Selain daripada itu, frekuensi lain semuanya bukan stereng. Walaupun reka bentuk ini adalah gabungan dua konfigurasi, tetapi ia tetap tidak menjejaskan nilai S_{11} , corak teradiasi, keterarahan, lebar jalur S_{11} dan gandaan. Antena ini menggunakan Rogers sebagai substrat dan kuprum sebagai permukaan bumi. Semua hasil reka bentuk dan simulasi dilakukan menggunakan perisian CST Studio Suite 2019. Berdasarkan keputusan, antena ini menunjukkan bahawa penghasilan frekuensi dengan nilai balikan kehilangan berada di bawah -10 dB. Ia juga menghasilkan gandaan yang sangat baik iaitu lebih daripada 5dBi untuk semua konfigurasi untuk antena jenis ini.

Frequency and Pattern Reconfigurable Dielectric Resonator Antenna Array

ABSTRACT

In the past few years, reconfigurable antennas have been widely used in various wireless applications. The use of reconfigurable antennas is based on the reconfigurable capability of the design. Frequency-reconfigurable antenna is useful in changing the operating band of the antenna such in cognitive radio networks. Radiation pattern-reconfigurable antennas are useful in beam steering to improve the reception. On the other hand, polarization-reconfigurable antennas are widely used in multiple antenna systems to improve the channel capacity. The use of reconfigurability using dielectric resonator antenna (DRA) has shown great impact on antenna gain. This thesis presents the design and analysis of a frequency and pattern-reconfigurable dielectric resonator antenna array. Existing reconfigurable DRA either configure in terms of frequency or pattern but unable to control both properties using a single design. The restrictions of antenna's adaptability and flexibility in dynamically adjusting to different communication scenarios where both pattern and frequency optimization are required. Hence, the spectral efficiency could be improved with development of frequency and pattern reconfiguration in same antenna structure. This research aims to combine both types of configurations namely, frequency and radiation pattern into a single antenna design. In terms of frequency reconfiguration, it has three frequencies (4.1 GHz, 3.9 GHz & 3.5 GHz). The highest effective length of transmission line (TL) will produce 3.5 GHz while shortest will produce 4.1 GHz. For pattern reconfiguration, steering of -30° and $+30^\circ$ only occur in 3.5 GHz. For steering, it involves parasitic TL switching. The left parasitic DRA will be activated once the related switch is turned ON, thus the beam pattern could be directed towards -30° . The opposite mechanism occurs when the right parasitic DRA is activated using the switch at the related parasitic transmission line. Apart from this, other frequencies are all non-steering. Although this design is a combination of two configurations but still it does not compromise the S_{11} value, radiation pattern, directivity, S_{11} bandwidth and the gain. This antenna uses Rogers as the substrate and copper as the ground plane. All the design and simulation results are conducted using CST Studio Suite 2019 software. Based on the result, it shows that the antenna produces frequencies of 3.5GHz, 3.9GHz and 4.1GHz with return loss value is under -10 dB. It also produces an excellent gain of more than 5dBi for all the configurations for this type of antennas.

CHAPTER 1 : INTRODUCTION

1.1 Introduction

A reconfigurable antenna is capable of changing the frequency, radiation or polarization in a controlled reversible manner. Reconfigurable antenna consists of three different types which are frequency reconfigurable antenna, polarization reconfigurable antenna and pattern reconfigurable antenna (Bernhard, 2007). The frequency reconfigurable antenna is designed simply to achieve the tuning of the antenna's frequency from narrow band to narrow band or wide band to narrowband and vice versa. With frequency reconfigurable antennas, the antenna can change the operating frequency dynamically. In a situation where a number of communication systems require assembled antenna, a single reconfigurable antenna can replace them. On the other hand, radiation pattern reconfigurable (RPR) antennas can change the radiation pattern of the antenna in desired manner to achieve improved performance (Ahn et al., 2019a).

Specifically, pattern-reconfigurable antenna using dielectric resonator or known as dielectric resonator antenna (DRA) have gained interest due to its capability of steering the beam with improved gain (Shahadan et al., 2017). Most of the existing reconfigurable antenna designs using DRA either configure the antenna in terms of radiation pattern (Ahn et al., 2019a; Shahadan et al., 2017) or frequency (Thomas Apperley, 2014). Therefore, the approach to undertake both types of reconfigurations on single antenna is needed. In (Gulam Nabi Alsath et al., 2012), it is mentioned that two types of reconfigurations are possible with the proposed antenna. However, the results that shown in the work are not promising. The frequency of the antenna does not shift properly when the antenna is tuned and the gain is below 5dBi. Therefore, to implement DC biasing

circuitry by ensuring the reconfigurable DRA to tune both the radiation pattern and frequency might be challenging while maintaining the gain values.

To the best of our knowledge, none of the previous investigations are capable of achieving the following aspects in a single design. Firstly, to design and simulate the frequency and pattern reconfigurable dielectric resonator antenna with improved gain at all tuned frequencies and steered directions. Secondly, to synthesize the switching mechanism of the frequency tuning and beam steering using capacitive loaded switch and RF p-i-n diodes.

This project is proposed to design a combination of frequency reconfigurability pattern reconfigurability using DRA. Hence, this proposed antenna is capable of tuning the frequency and radiation pattern independently while creating minimal effect on the remaining property. The propose reconfigurable DRA can be reconfigured using the aid of RF switches.

This project will focus on designing the frequency and pattern reconfigurable DRA array using suitable switching mechanism. The frequency reconfiguration is controlled using the switches located at the transmission line of the antenna while the radiation pattern is controlled using the parasitic DRAs. The operating frequency would be from 3.3 GHz to 4.3 GHz. In term of pattern reconfiguration, the maximum tilt angle should be greater than $\pm 30^\circ$. The antenna design will use Rogers substrate since it offers low loss tangent.

1.2 Problem Statement

In recent decades, demand for wireless communication has become more focused on defining suitable methods and schemes to resolve various issues of wireless transmission, such as interference, energy consumption, noisy atmosphere and shadowing. In such a situation, an antenna's ability to direct the signal to the desired direction and reconfigure its operating frequency can help improve the reception of the signal, save energy and lessen the effect of unwanted interference signals.

Reconfigurable antenna using RPR antenna is an alternative way to reconfigure the beam towards a desired direction that offers simple method using RF switching mechanism. Specifically pattern reconfigurable antenna using dielectric resonator or known as dielectric resonator antenna (DRA) have gained interest due to its capability of steering the beam with improved gain (Shahadan et al., 2017). Most of the existing reconfigurable antenna designs using DRA either configure the antenna in terms of radiation pattern (Ahn et al., 2019a; Shahadan et al., 2017) or frequency (Thomas Apperley, 2014). Therefore, the approach to undertake both types of reconfigurations on single antenna is needed. In (Gulam Nabi Alsath et al., 2012), it is mentioned that two types of reconfiguration is possible with the proposed antenna. However, the results that have shown in the work are not promising. The frequency of the antenna does not shift properly when the antenna is tuned and the gain is below 5dBi. Limited dual reconfigurability could be seen in the existing reconfigurable DRA designs where they typically focus on either reconfiguring the radiation pattern or the operating frequency, but not both simultaneously within a single antenna design. This restricts the antenna's adaptability and flexibility in dynamically adjusting to different communication scenarios where both pattern and frequency optimization are required. Moreover,

previous attempts in dual-reconfigurable antennas using DRAs have shown performance issues. For instance, ineffective frequency shifting and inadequate gain values (below 5 dBi) have been reported, indicating challenges in achieving reliable and consistent performance across all reconfiguration modes. Therefore, the challenges of implementing DC biasing circuitry while ensuring the reconfigurable DRA to tune the radiation pattern, frequency and while maintaining the gain values might be challenging. In summary, the research gap on the need for an innovative approach to reconfigurable antenna design using DRAs, specifically addressing the integration of dual reconfigurability (pattern and frequency) while ensuring reliable performance and overcoming technical challenges observed in previous studies. This research aims to solve the mentioned research gap and the related objectives are given in the following section.

Summarization of problem statements and research gaps are as follows:

- i) Existing Reconfigurable antenna designs using DRA either configure the antenna in terms of radiation pattern (Ahn et al., 2019a) (Shahadan et al., 2017) or frequency (Thomas Apperley, 2014).
- ii) In (Gulam Nabi Alsath et al., 2012), it is mentioned that two types of reconfigurations are possible with the proposed antenna. However, the results that have shown in the work are not promising. The frequency of the antenna does not shift properly when the antenna is tuned and the gain is below 5dBi.

1.3 Objectives

There are three main objectives that need to be achieved in this project, as follows:

- 1) To design and simulate the frequency and pattern reconfigurable dielectric resonator antenna (DRA) array with improved gain at all tuned frequencies and steered directions where the frequency reconfiguration is to be carried out between 3.3 GHz band to 4.3 GHz band while at least 30-degree steering angle to be achieved for pattern reconfiguration.
- 2) To synthesize the switching mechanism of the frequency tuning and beam steering using capacitive loaded switch and RF *p-i-n* diodes to achieve at least three sets of frequencies and three sets of radiation patterns.
- 3) To fabricate and validate the performance of the proposed antenna arrays in terms of frequency reconfigurability and pattern reconfigurability where at least three operating frequencies achieved with gain of 5 dBi and minimum tilt angle of 30 degrees.

1.4 Research Scope

This project will focus on the designing the Frequency and Pattern Reconfigurable Dielectric Resonator Antenna Array using switching mechanism. The operating frequency would be from 3.3 GHz to 4.3 GHz because it covers 5G band. In term of pattern reconfiguration, the maximum tilt angle should be greater than $\pm 30^\circ$. The antenna

design will use Rogers RO4003 C (Lossy) substrate since it offers low loss tangent. In addition, this project is based on hardware and software. CST software will be used to design and simulate for this project. After the fabrication process is complete, the measurement will be done in Anechoic Chamber. The measurement setup inside Anechoic Chamber will have commercialized double-ridge horn antenna as the transmitter while Antenna Under Test (AUT) as the receiver. The distance between both transmitter and receiver is 1m. It is 1m to avoid near-field effects and follow standardization procedure and guidelines such as those from IEEE or American National Standards Institute (ANSI) that recommend specific distances for antenna testing to ensure consistency and comparability of results across different tests and laboratories. One such standard distance is often 1 meter.

1.5 Thesis layout

The thesis is split into five chapters. The current chapter outlines the overall contribution, problems and the objectives of designing Frequency and Pattern Reconfigurable Dielectric Resonator Antenna Array. Chapter 2 describes mainly on types of reconfigurable antenna and DRA. Reason regarding previous researches from journals and websites is enclosed. Chapter 3 explains methodology of the design like flowchart, antenna specifications, antenna simulation procedures and many more. Chapter 4 is mainly on results of the project. The simulated and measured results are compared, discussed and verified with project's objective. Chapter 5 indicates project's summarization and recommendation for future works. The design described in the thesis makes several significant contributions and offers novel aspects in the field of reconfigurable dielectric resonator antennas (DRA). Dual Reconfigurability, one of the primary contributions is combining frequency and radiation pattern reconfigurability into

a single antenna design. Traditionally, reconfigurable antennas often focus on either frequency or pattern reconfiguration separately. By integrating both capabilities, this design offers enhanced versatility and adaptability in wireless communication systems. In Frequency Reconfiguration, the antenna achieves frequency reconfigurability across three distinct frequencies: 4.1 GHz, 3.9 GHz, and 3.5 GHz. This capability is achieved by varying the effective length of the transmission line feeding the DRA. Such frequency agility is particularly beneficial in applications like cognitive radio networks where dynamic spectrum access is essential. Pattern Reconfiguration, the design also incorporates radiation pattern reconfigurability, specifically beam steering, at the 3.5 GHz frequency. Beam steering of -30° and $+30^\circ$ is achieved using parasitic transmission line switching, enabling the antenna to adapt its coverage area dynamically. This feature is crucial for improving reception in mobile and satellite communication systems. In summary, the novelty and contribution of this design lies in its integration of frequency and pattern reconfigurability within a single dielectric resonator antenna array. This innovation expands the capabilities of reconfigurable antennas, offering enhanced flexibility, performance optimization, and adaptability to varying operational requirements in modern wireless communication systems.

CHAPTER 2 : LITERATURE REVIEW

2.1 Introduction

This project proposes to design a multi-mode reconfigurable dielectric resonator antenna which adopts both frequency reconfigurable DRA and pattern reconfigurable DRA. In what follows, the theoretical background of DRA and reconfigurable antenna presented. Next, a critical review is conducted using the existing works to derive the research gap.

2.2 Overview of DRA

DRA is a radio antenna that consists of a block of ceramic material of different shapes. A dielectric resonator can be mounted on a metal surface and ground plane, often used at microwave frequencies. Inside the transmitter circuit, radio waves are introduced into the resonator material and bounce back and forth between the resonator walls, producing standing waves. For radio waves, the walls of the resonator are partly transparent, enabling the radio power to radiate into space (Kao-Cheng Huang, 2008). In several small handheld wireless systems and military millimeter-wave radar equipment, dielectric waveguide antennas are used. The most famous reconfigurable DRA shapes will be cylindrical and rectangular. Compared with a cylindrical DRA, a rectangular DRA provides an additional degree of freedom for antenna design (Tawk-Christodoulou-Husseini,2019). Both shapes are shown in Figure 2.1 and Figure 2.2, respectively.