



**A COMPACT AND HIGH GAIN CIRCULARLY
POLARIZED ANTENNA FOR CUBESAT S-BAND
APPLICATION**

by

**ABDUL HALIM LOKMAN
(1630812124)**

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TABLE OF CONTENTS

	PAGE
DECLARATION OF THESIS	i
ACKNOWLEDGMENT	ii
TABLE OF CONTENTS	iii
LIST OF TABLES	vii
LIST OF FIGURES	ix
LIST OF ABBREVIATIONS	xiv
LIST OF SYMBOLS	xv
ABSTRAK	xvi
ABSTRACT	xvii
CHAPTER 1 : INTRODUCTION	1
1.1 Introduction	1
1.2 Problem Statement	2
1.3 Objective	3
1.4 Scope of Work	3
1.5 List of Contributions	4
1.6 Thesis Outline	4
1.6.1 Chapter 1: Introduction	4
1.6.2 Chapter 2: Literature Review	5
1.6.3 Chapter 3: Methodology	5
1.6.4 Chapter 4: Result and Discussion	6
1.6.5 Chapter 5: Conclusion	6
CHAPTER 2 : LITERATURE REVIEW	7
2.1 Introduction	7

2.2	Applications of Pico-satellites	8
2.2.1	Earth and Climate Observation	9
2.2.2	Space Weather Forecasting	11
2.2.3	Space Research	11
2.2.4	Communication System	12
2.3	Requirements for CubeSat Antennas	14
2.3.1	Operating Frequency	15
2.3.2	Circular Polarization	16
2.3.3	Size Compactness/Deployability	19
2.4	Materials for CubeSat Antennas	21
2.4.1	Boards	22
2.4.2	Conventional Metals	22
2.4.3	Films	23
2.4.4	Membranes	24
2.5	Types of CubeSat Antennas	25
2.5.1	Patch Antennas	26
2.5.2	Monopoles/Dipoles	26
2.5.3	Reflector Antennas	27
2.5.4	Reflectarray Antennas	28
2.5.5	Spiral/Helical Antennas	31
2.6	Deployment Mechanism for CubeSat Antennas	33
2.6.1	Tape-spring Model Deployment	34
2.6.2	Umbrella-Like Structure	35
2.6.3	Inflatable Mechanism	36
2.7	Summary	38
CHAPTER 3 : METHODOLOGY		41
3.1	Introduction	41

3.2	Overview of Methodology	42
3.3	Design Specifications	48
3.4	Material Specifications	49
3.5	Antenna Design Procedure	50
3.5.1	Circularly Polarized Antenna	51
3.5.2	Unit Cell	58
3.5.3	Reflectarray Antenna	60
3.5.4	CP Antenna Integrated With AMC Plane	64
3.6	Fabrication Process	65
3.6.1	CP Antenna Using Rogers RO4003C	66
3.6.2	Reflectarray Element Using Kapton Film	67
3.6.3	AMC Plane Using Kapton Film	70
3.7	Measurement Procedure	71
3.7.1	CP Antenna Measurement	71
3.7.2	Reflectarray Antenna Measurement	73
3.7.3	CP Antenna Integrated With AMC Plane Measurement	74
3.8	Deployment Mechanism	75
3.8.1	Reflectarray Deployment Mechanism	76
3.8.2	CP Antenna Integrated With Deployment Mechanism	78
3.9	Summary	79
CHAPTER 4 : RESULT & DISCUSSION		80
4.1	Introduction	80
4.2	Circularly Polarized Antenna	81
4.2.1	Complementary Dipole Antenna	81
4.2.2	Phase Delay Line	82
4.2.3	Printed Complementary Dipole Antenna with Phase Delay Line	84
4.3	Unit Cell	90

4.4	Reflectarray Antenna	92
4.4.1	Impedance and Axial Ratio Bandwidth	92
4.4.2	Gain Performance	94
4.5	CP Antenna with AMC Plane	99
4.5.1	AMC Unit Cell	99
4.5.2	Measured and Simulated Result	100
4.6	Summary	109
	CHAPTER 5 : CONCLUSION	112
5.1	Introduction	112
5.2	Future Works	114
	REFERENCES	116
	APPENDIX A LIST OF PUBLICATIONS	124
	JOURNAL	124
	APPENDIX B LIST OF PUBLICATIONS	125
	CONFERENCE	125

LIST OF TABLES

NO.		PAGE
Table 2.1:	Summary of Pico-satellite applications	14
Table 2.2:	Summary of CubeSat antennas requirements	21
Table 2.3:	Summary of CubeSat antennas materials	24
Table 2.4:	Summary of CubeSat antennas types	33
Table 2.5:	Summary of CubeSat antennas deployment mechanism	37
Table 2.6:	An overview of the different pico-satellite antennas from literature	40
Table 3.1:	Parameter and requirement of the antenna design specification	49
Table 3.2:	Material properties of the substrates	50
Table 3.3:	Design parameter of complementary dipole antenna	52
Table 3.4:	Optimized parameter of CP antenna	55
Table 3.5:	The unit cell dimension parameters	60
Table 3.6:	The reflectarray antenna parameters	63
Table 4.1:	Results of phase and magnitude of the phase delay lines	83
Table 4.2:	Summary result of CP antenna at 2.4 GHz	87
Table 4.3:	Results of reflectarray antenna	95
Table 4.4:	Summary result of reflectarray antenna at 2.4 GHz.	98
Table 4.5:	Comparison between impedance and 3 dB axial ratio bandwidth with varying gap distance at 2.4 GHz	102
Table 4.6:	Performance summary of the proposed antenna with AMC at 2.4 GHz	107

Table 4.7:	Comparison of the proposed antenna performance with recent pico-satellite antennas	111
Table 4.8:	Performance summary of the proposed CP antenna with reflectarray and AMC at 2.4 GHz.	111

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LIST OF FIGURES

NO.		PAGE
Figure 2.1:	A CubeSat with Ka-band reflector antenna for deep space mission (Chahat et al., 2015).	16
Figure 2.2:	CP antenna with phase shifter (a) Front view (b) rear view (Luo et al., 2015a)	18
Figure 2.3:	Compact antenna with symmetrical slit (Nasimuddin et al., 2011).	18
Figure 2.4:	The illustration design of the compact crossed dipole antenna for circular polarization with high impedance resistance (HIS) at back of antenna (Ta et al., 2013)	19
Figure 2.5:	The illustration design of the compact crossed dipole antenna for circular (Vourch & Drysdale, 2014a)	23
Figure 2.6:	Display of the reflectarray antenna model	29
Figure 2.7:	Illustration of spatial phase delay according to (J. Huang, 1995)	29
Figure 2.8:	(a) ISARA CubeSat (Hodges, Radway, et al., 2015) (b) MarCO CubeSat (Hodges, Hoppe, et al., 2015)	31
Figure 2.9:	The “Bull’s Eye” antenna (Vourch & Drysdale, 2014b)	32
Figure 2.10:	The deployable antenna used in PolySat (Heidt et al., 2013)	34
Figure 2.11:	Mechanical deployment (Chahat et al., 2016)	36
Figure 2.12:	A model of the inflatable antenna proposed in (Babuscia et al., 2013; Xu & Guan, 2012)	37
Figure 3.1:	Block diagram of project phases	43
Figure 3.2:	Project flow chart	47
Figure 3.3:	The complementary dipole antenna. (a) Front view (b) Rear view (c) Perspective view	53

Figure 3.4:	Phase delay line.	54
Figure 3.5:	The proposed circularly polarized antenna. (a) Front view (b) Rear view	54
Figure 3.6:	(a) The front view of the AMC unit cell with four triangular slots at each corner of the square shaped patch. (b) The display of unit cell during simulation	59
Figure 3.7:	Reflectarray distribution.	61
Figure 3.8:	Reflectarray antenna illuminates by circularly polarized antenna.	63
Figure 3.9:	Display of proposed 3 x 3 AMC plane	64
Figure 3.10:	Integration of the circularly polarized antenna with AMC plane. (a) Front view (b) Side view	65
Figure 3.11:	Proposed CP antenna (a) before, and (b) after etching process.	66
Figure 3.12:	Fabricated antenna of circularly polarized antenna. (a) Front view (b) Rear view.	67
Figure 3.13:	Printed layout of reflectarray element on an A2-sticker paper.	68
Figure 3.14:	The reflectarray elements on the printed sticker before being sprayed using conductive paint (a) during, and (b) after the sticking process.	68
Figure 3.15:	Spraying the conductive paint.	69
Figure 3.16:	Removal of the unwanted stickers.	69
Figure 3.17:	The reflectarray elements after the removal of the border stickers.	69
Figure 3.18:	The fabricated reflectarray elements.	70
Figure 3.20:	A4-sized sticker as negative element.	70
Figure 3.21:	The fabricated 3 x 3 AMC plane.	71

Figure 3.22:	The proposed CP antenna placed on the holder inside the anechoic chamber.	72
Figure 3.23:	(a) Aligning the horn antenna tilt (b) Alignment of the horn antenna with the AUT position using laser (c) Centering of the horn antenna alignment with the center of the AUT	72
Figure 3.24:	Orientation of the horn antenna and the proposed CP antenna. (a) Vertical polarization (b) Horizontal polarization	73
Figure 3.25:	Orientation of the reflectarray antenna (a) 0° elevation (b) 90° elevation	74
Figure 3.26:	(a) Side view of AUT on the bracket holder (b) Setup view of the horn and AUT inside the anechoic chamber.	75
Figure 3.27:	Model of the tape spring mechanism on the (a) reflectarray deployment, and (b) feed deployment.	77
Figure 3.28:	The deployment mechanism of the reflectarray antenna. (a) Stowed (b) Deployed.	77
Figure 3.29:	The deployment mechanism of the CP antenna integrated with AMC plane. (a) Stowed (b) Deployed.	78
Figure 4.1:	Reflection coefficient of the complementary dipole antenna.	82
Figure 4.2:	Normalized radiation pattern of the complementary dipole antenna	82
Figure 4.3:	Simulated results of the phase delay lines. (a) Reflection coefficient (dB) (b) Reflection phase (degree)	83
Figure 4.4:	The result of parametric study. (a) Reflection coefficient (b) Axial ratio	85
Figure 4.5:	The simulated and measured reflection coefficient.	86
Figure 4.6:	The simulated and measured axial ratio	87

Figure 4.7:	Simulated RHCP and LHCP at (a) xz -plane (b) yz -plane	88
Figure 4.8:	(a) Simulated and measured realized gain of CP antenna. (b) Relation between realized gain and reflection coefficient at 2.4 GHz.	89
Figure 4.9:	Measured and simulated RHCP and LHCP of CP antenna.	90
Figure 4.10:	(a) Reflection coefficient (b) Reflection phase	91
Figure 4.11:	Reflection phase of varied unit cell size.	92
Figure 4.12:	Parametric study of different unit cell array sizes (a) Reflection coefficient (b) Axial ratio.	93
Figure 4.13:	Optimized result of gain performance.	94
Figure 4.14:	Simulated and measured reflection coefficient of the reflectarray antenna.	96
Figure 4.15:	Simulated and measured axial ratio.	96
Figure 4.16:	Normalized simulated and measured reflectarray patterns at 2.4 GHz at $\phi = 90^\circ$	97
Figure 4.17:	Normalized simulated and measured RHCP and LHCP of the reflectarray antenna.	97
Figure 4.18:	Parametric study of the gap. (a) Reflection coefficient (b) Axial ratio	101
Figure 4.19:	Comparison between simulated and measured reflection coefficients.	102
Figure 4.20:	Simulated and measured 3 dB axial ratio.	103
Figure 4.21:	Polar plot of normalized simulated and measured gain.	104
Figure 4.22:	Comparison between normalized RHCP and LHCP patterns in simulation. (a) xz -plane (b) yz -plane	105

Figure 4.23: Current distribution at 2.4 GHz. (a) $0^\circ/360^\circ$ (b) 90° (c) 270° (d) 360°

106

Figure 4.24: Comparison between the circularly polarized antenna with and without the AMC plane. (a) Polar gain (b) Reflection coefficient (c) Axial ratio (d) Realized gain (in dBi).

108

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LIST OF ABBREVIATIONS

AIS	Automatic Identification System
AMC	Artificial Magnetic Conductor
CalPoly	California Polytechnic State University
COTS	Component-off-the-shelf
CP	Circularly polarized
CST	Computer Simulation Technology
CubeSat	Cube Satellite
ENVISAT	Environmental Satellite
ESA	Europe Space Agency
ESAs	Electrically Small Antennas
FCC	Federal Communications Commission
GEO	Geostationary Earth Orbit
GNSS	Global Navigation Satellite System
LEO	Low Earth Orbit
LHCP	Left-handed circularly polarized
LOS	Line of sight
MHz	Mega-hertz
MICROMAS	Micro-sized Microwave Atmospheric Satellite
MIT	Massachusetts Institute of Technology
NASA	National Aeronautic and Space Administration
NTS	Nano-satellite Tracking of Ships
OLFAR	Orbiting Low Frequency Antennas for Radio Astronomy
OPAL	Oxygen Photometry of the Atmospheric Limb
P-POD	Pico-satellite Orbital Deployer
RHCP	Right-handed circularly polarized
STEM	Science, Technology, Engineering, Mathematics
TRMM	Tropical Rainfall Measurement Mission
TT&C	Telemetry, Tracking, and Command
US	United States

LIST OF SYMBOLS

0.5U	Half size of CubeSats
1U	One unit of CubeSat
1.5U	One and half unit of CubeSat
2U	Two unit of CubeSat
3U	Three unit of CubeSat
60U	Six unit of CubeSat
12U	Twelve unit of CubeSat
cm ³	Centimeter cube
CO ₂	Carbon dioxide
dB	decibel
dBi	decibel with isotropic
GHz	Giga-hertz
MHz	Mega-hertz
mm	Millimeter
mm ²	Millimeter square
mm ³	Millimeter cube
UHF	Ultra-High Frequency
VHF	Very-High Frequency

ANTENA POLARISASI MELINGKAR YANG KOMPAK DAN BERGANDAAN TINGGI UNTUK APLIKASI S-BAND CUBESAT

ABSTRAK

Projek ini tertumpu kepada antena kecil dengan gandaan yang tinggi serta pengutuban bulat untuk aplikasi S-band CubeSat. CubeSat dikategorikan sebagai salah satu satelit piko dengan dimensi berukuran $10 \times 10 \times 10 \text{ cm}^3$. Dengan menggunakan komponen komersial, ia mampu mengurangkan kos dan masa pembangunan berbanding satelit komersial bagi segmen kajian angkasa, pemerhatian bumi, perhubungan antara satelit, dan tujuan pendidikan. Disebabkan faktor kekangan saiz dan berat, kebanyakan antena-antena CubeSat disatukan dengan mekanisma pemecahan. Salah satu mekanisma terbaik adalah mekanisma pegas pita. Dalam projek ini, dua jenis antena gandaan tinggi berpolarisasi melingkar direkabentuk bersesuaian dengan saiz CubeSat 1U dan 3U pada frekuensi S-band. Antena bersaiz kecil dan pengutuban bulat telah direka dengan saiz $55 \times 55 \times 0.85 \text{ mm}^3$. Ia beroperasi dengan pekali pantulan sekurang-kurangnya -10 dB , nisbah paksi sekurang-kurangnya 3 dB , dan gandaan sebanyak 3.84 dBi pada 2.4 GHz . Antena ini merambat dengan terkutub bulat tangan kanan (RHCP) pada 0° azimut, dan terkutub bulat tangan kiri (LHCP) pada 180° azimut. Peningkatan gandaan ini perlu ditambahbaik agar sesuai dengan keperluan aplikasi CubeSat untuk perhubungan jarak jauh. Suatu elemen tatasusunan pantul kemudiannya telah direka dengan gandaan sebanyak 10.49 dBi , berserta lebar jalur galangan dan nisbah paksi yang memuaskan, selain merambat pada arah 29° azimut. Walaupun bersaiz lebih besar pada $297 \times 330 \times 0.635 \text{ mm}^3$, dan panjang fokal sebanyak 243 mm , antena ini masih boleh digunapakai dalam CubeSat 3U beserta mekanisma pemecahan, berasaskan konsep pegas pita. Selain daripada itu, suapan tatasusunan pantul ini turut mampu disatukan pada CubeSat dengan mekanisma pemecahan yang berasingan. Rekaan awal antena dengan pengutuban bulat turut disatukan dengan permukaan pengalir magnet buatan (AMC), dan telah menambahbaik gandaan serta pengurangan sinaran terarah songsang. Memandangkan rekaan antena awal tersebut menghasilkan corak sinaran dwiarah, permukaan AMC ini mengurangkan sinaran terarah songsang dan menghasilkan sinaran searah. Dengan dimensi bersaiz $99 \times 99 \times 21.485 \text{ mm}^3$, permukaan AMC tersebut telah meningkatkan gandaan sehingga 7.7 dBi dengan mod RHCP. Selain daripada itu, lebar jalur galangan sebanyak 19.16% dan nisbah paksi 3 dB sebanyak 10.4% telah terhasil pada 2.4 GHz . Disebabkan keperluan jarak sebanyak 20 mm di antara antena dan permukaan AMC, ia telah disatukan dengan mekanisma pemecahan pegas yang mudah di atas CubeSat.

A COMPACT AND HIGH GAIN CIRULARLY POLARIZED ANTENNA FOR CUBESAT S-BAND APPLICATION

ABSTRACT

This project focuses on a compact antenna with high gain and circular polarization for S-band CubeSat application. CubeSat is categorized as a type of pico-satellite with a dimension of $10 \times 10 \times 10 \text{ cm}^3$. By utilizing the component-of-the-shelf (COTS), this class of pico-satellite is capable of reducing the development cost and time compared to commercial satellites in segments such as space research, earth observation, inter-satellite communication, and the educational purpose. Due to the CubeSat's size and weight constraints, most of their antennas are integrated with deployment mechanisms. One of the most popular deployable mechanisms used in CubeSats is the tape spring mechanism. In this project, two types of high gain circularly polarized antenna is designed to comply with 1U and 3U CubeSat at S-band frequency. A compact circularly polarized antenna is designed with a size of $55 \times 55 \times 0.85 \text{ mm}^3$. The antenna operates with at least -10 dB of reflection coefficient, at least 3 dB of axial ratio and a gain of 3.84 dBi at 2.4 GHz. The antenna propagates with a right-handed circular polarization (RHCP) at 0° azimuth, and left-handed circular polarization (LHCP) at 180° azimuth. Such gain level needs to be improved for long-range CubeSat communication. A reflectarray is then designed to obtain an improved simulated gain of 10.49 dBi, satisfactory impedance and axial ratio bandwidth, with propagation directed at 29° azimuth. Despite its overall larger size of $297 \times 330 \times 0.635 \text{ mm}^3$, and a focal length of 243 mm, it is still applicable for a 3U CubeSat together with a tape spring based deployment mechanism. Meanwhile, the reflectarray feed is also integrated on the CubeSat with its separate deployment mechanism. The initially designed circularly polarized antenna is also integrated with an artificial magnetic conductor (AMC) plane, which resulted in both gain enhancement and back radiation reduction. Since the initial antenna produces a bidirectional radiation pattern, the AMC plane reduced its back radiation and converting it into a unidirectional pattern. With a dimension of $99 \times 99 \times 21.485 \text{ mm}^3$, the AMC plane increased the gain up to 7.7 dBi with RHCP mode. Besides that, a 19.16 % 10 dB impedance bandwidth and 10.4 % of 3 dB axial ratio bandwidth are achieved at 2.4 GHz. Due to the required gap of 20 mm between antenna and AMC plane, it has been integrated on the CubeSat using a simple spring coil deployment mechanism.

CHAPTER 1 : INTRODUCTION

1.1 Introduction

Pico-satellites are small satellites which are simplified in terms of functionalities, which are normally implemented using conventional satellites. Cube Satellites, or better known as CubeSats, is a type of pico-satellite generally dimensioned at $10 \times 10 \times 10 \text{ cm}^3$, known as a 1U CubeSat (Puig-Suari, Turner, & Ahlgren, 2001). Such CubeSats can be expanded in size in multiples of the 1U size, such as 2U, 3U, 6U, and 12U, and these are rectangular instead of square. They are preferred over conventional satellites due to their power efficiency, space utilization, cost-effectiveness and is an effective tool for the development of Science, Technology, Engineering and Mathematics (STEM) education (Puig-Suari et al., 2001). Due to this reason, several early CubeSats have been deployed in space by either non-profit organizations or universities.

CubeSats generally work in the low earth orbit (LEO) with a distance of 160 to 2000 km from earth, and is applicable for either satellite-to-satellite, or satellite-to-ground base station communication. In terms of frequency, CubeSats have widely used the ultra-high frequency (UHF) band due to its ability for long distance communication (Puig-Suari et al., 2001). Evolution over the years has made the S-band a more popular CubeSat communication frequency (Gao et al., 2009). Moreover, its antenna size is more compatible with the size of the CubeSat due to its smaller electrical length compared to antennas operating in the UHF band frequency. Besides that, the ground station uses the very-high frequency (VHF)/UHF amateur radio bands. Other frequency bands such as X-band, Ku-band, and Ka-band can also be utilized in CubeSats (Lokman et al., 2017).

However, these higher frequency bands are disadvantageous due to their limited propagation distance and limited ability to penetrate through layers of the earth due to their wavelengths. CubeSats are launched together with other conventional satellites before being placed into the LEO orbit. Thus, antennas for CubeSats can be either compact, such as rigid patches fixed on the CubeSat surfaces, or large in size stowed within the CubeSat outer dimension and deployed in the LEO orbit. Both methods need to ensure that the antennas are placed on the CubeSat in the safest position for launch (Nason, Puig-Suari, & Twiggs, 2002).

1.2 Problem Statement

CubeSat antennas need to be designed using low frequencies such as UHF and S-band. Due to the inherently large wavelengths due to the use of these frequencies, their antenna structure are expected to be large (Puig-Suari et al., 2001).

However, this makes the design process challenging due to the limited CubeSat size of $10 \times 10 \times 10 \text{ cm}^3$. Besides that, other considerations include the compatibility of the antenna materials for space applications, and the antenna design's mechanical robustness (Gao et al., 2009).

One of the most effective solution when using an oversized antenna on CubeSats is to implement it using flexible materials and integrate it with a deployable mechanism. Moreover, such antennas and arrays are most likely to offer improved gain compared to compact antennas (Babuscia, Pan, & Seager, 2014; Hodges, Radway, et al., 2015). This enables a quality communication link between CubeSats in LEO orbit with the earth station.

1.3 Objective

This research focuses the development of a deployable antenna capable of satellite communication for CubeSat S-band application. The main objective of the study includes:

- i. To design a high gain circularly polarized antenna compatible for 1U and 3U CubeSat at S-band frequency.
- ii. To implement the antenna using flexible and rigid material to support future integration with deployable mechanisms.
- iii. To fabricate and validate the circularly polarized antennas integrated with reflectarray and artificial magnetic conductor in term of reflection coefficient, axial ratio, and gain.

1.4 Scope of Work

The execution of the project is limit by the scope of work. This research is focuses on CubeSat application and circularly polarized antenna development. Several technologies on CubeSat antennas is explored thoroughly. Upon implementation, some of the design used different type of materials in order to satisfy with the deployment mechanism, and space requirements. An investigation on flexible and rigid material need to be execute. Hence, it has to be with a capability to demonstrate in space, while maintained its flexible and rigid characteristics. Finally yet importantly, project result is the most important aspect. Optimized design of antenna is measured, hence, it will differentiate with simulated result in order to verify the outcome of the project. It is to compare the result of reflection coefficient, axial ratio, and gain of the antenna.

1.5 List of Contributions

There are several contributions for this project, such as a new compact circularly polarized antenna with high gain and wide bandwidth capabilities is designed for pico-satellites application specifically for 1U and 3U CubeSats. The antenna performance is improved with the integration of reflectarray and artificial magnetic conductor plane using a special material of Kapton film that is flexible, thin, and in fact, it follow the space requirement. Hence, the antenna could improve the communication link for the pico-satellites application by utilizing a thin and flexible material that can be integrated with future deployable mechanism.

1.6 Thesis Outline

The thesis is presented with several chapters. In this section, it will describe the outline of each chapter starting from Chapter 1 until Chapter 5 accordingly.

1.6.1 Chapter 1: Introduction

A detail explanation of the project is explained in this chapter. It includes project introduction, problem statement, objectives, scope of work, and thesis outline. Several problem statements is identified along with objectives that describe the project aims. Meanwhile, scope of work will limit the process of the project from the start until end.

1.6.2 Chapter 2: Literature Review

Several antenna miniaturization techniques are chosen and analyzed based on previous researches to develop a suitable antenna for CubeSat application. New and innovative antenna designs is focused in this research. Flexible materials is used due to the need of integration between antenna and the deployment mechanism. They include materials such as Nylon, Shielded fabric, Kapton film, and Mylar film. Upon investigation, two materials have been chosen as the antenna substrate, Kapton film and Rogers R040030C.

1.6.3 Chapter 3: Methodology

The initial dimensions of the antenna is calculated based on literature. Next, miniaturization techniques, which can be effectively used to design electrically small antennas, are implemented in the antenna. Besides that, such design techniques must also be effective in compacting circularly polarized antenna. Based on the materials and topologies selected in Stage 1, they is designed in the simulator with the materials parameters inserted into the electromagnetic simulator. Besides that, a suitable feeding is chosen to feed the antenna.

The simulation and optimization process of the antennas is performed using CST Microwave Studio (MWS) software, with a focus on circularly polarized antenna with miniaturization technique. Two different methods is employed to develop the antennas. One is using the conventional printed circuit board etching process, while the other is performed using conductive ink spraying procedure on the surface of the substrate.

Upon successful fabrication, these antennas is evaluated experimentally in terms of reflection coefficient, gain, and axial ratio. All measurements is then cross validated with simulations.

1.6.4 Chapter 4: Result and Discussion

In this stage, all simulated and measured results are gathered, analysed and presented. A significant comparison is made between simulated and measured results. Upon several design, various results such as reflection coefficient, axial ratio, and gain is included in each design process. Then, a discussion on each results is elaborated accordingly.

1.6.5 Chapter 5: Conclusion

In this chapter, a brief conclusion summed up whole process of the project especially the design specification and parameter, together with the results. Each design specification contributes to the promising result that has been gathered and compared between simulated and measured. Several methods to improve the design in the near future and possible research work is suggested.

CHAPTER 2 : LITERATURE REVIEW

2.1 Introduction

In general, satellites are structures that capable of transmitting and receiving or relaying signals from space. Due to their location, they are able to provide a wide coverage area with long communication range. The development of the conventional satellites incurred significant amount of financial, time and resources costs.

However, a viable alternative to this is the deployment of pico-satellites such as CubeSats. They cost less, consume less power and allows fast development time, but at the same time, are feasible and robust, similar to conventional satellites. Due to its size and weight, CubeSats are known to be a part of the pico-satellite family. One of the first CubeSats was developed by the California Polytechnic State University (Cal Poly) in collaboration with Stanford University starting 1999 (Puig-Suari et al., 2001) and was first launched in 2002 (Puig-suari, Turner, & J. Twiggs, n.d.).

The Cal Poly's mission was aimed for Stanford University's spacecraft named OPAL as the launcher for the proposed CubeSat (Puig-Suari et al., 2001). CubeSats are satellite structure with a volume of $10 \times 10 \times 10 \text{ cm}^3$ and a mass less than 1 kg as defined by in (Puig-Suari et al., 2001). They are typically made of light weight COTS components (Puig-Suari et al., 2001). This project began with the development of the standard launcher known as the Poly Pico-satellite Orbital Deployer (P-POD).

Besides the CubeSat structure, its theoretical criteria such as the weight and the size of CubeSat must comply to the launcher's specifications to ensure a successful deployment into space (Puig-Suari et al., 2001). Several requirements for the P-POD