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

by

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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	Massachusets Institute of Technology
NASA	National Aeronautic and Space Administration
NTS	Nano-satellite Tracking of Ships
OLFAR	Orbitting 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 istropic
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 x 10 x 10 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 x 55 x 0.85 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^o azimut, dan terkutub bulat tangan kiri (LHCP) pada 180^o 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 x 330 x 0.635 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 x 99 x 21.485 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 x 10 x 10 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 x 55 x 0.85 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 x 330 x 0.635 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 x 99 x 21.485 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 $10 \times 10 \times 10$ 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 x 10 x 10 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.