

ANTENNA DESIGN FOR CUBESAT APPLICATIONS

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INDIAN INSTITUTE OF TECHNOLOGY DELHI
NOVEMBER 2024**

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ANTENNA DESIGN FOR CUBESAT APPLICATIONS

by

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Centre for Applied Research in Electronics

Submitted

in fulfilment of the requirements of the degree of

Doctor of Philosophy

to the



**INDIAN INSTITUTE OF TECHNOLOGY DELHI
NOVEMBER 2024**

CERTIFICATE

This is to certify that the work reported in this thesis entitled “**ANTENNA DESIGN FOR CUBESAT APPLICATIONS**”, being submitted by **Mr. Ratul De** for the award of the degree of **Doctor of Philosophy** to the Centre for Applied Research in Electronics, Indian Institute of Technology Delhi, New Delhi, India, is a record of original bonafide research work carried out by him under our guidance and supervision.

Mr. Ratul De has fulfilled the requirements for the submission of this thesis, which to our knowledge has reached the requisite standard. The results contained in this thesis have not been submitted in part or full, to any other university or institute for the award of any degree or diploma.

We certify that he has pursued the prescribed course of research.



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ACKNOWLEDGEMENT

First and foremost, I would like to express my deepest sense of gratitude and indebtedness to my supervisors, **Prof. Mahesh P. Abegaonkar** and **Prof. Ananjan Basu**, who provided me the wonderful opportunity to carry out my doctoral research under their guidance. I consider myself immensely fortunate to work and learn under their supervision and am short of words to express my gratitude and thankfulness towards them.

Prof. Mahesh P Abegaonkar allowed me to work on the interesting and tremendously exciting topic of SmallSat Antennas, which defined my professional profile. Simultaneously, he constantly stood by my side and never abandoned me during my Ph.D., owing to his unwavering support, unending inspiration, never-ending hope, enormous experience, creative ideas, and widespread knowledge, all of which contributed significantly to this thesis.

I would like to convey my sincere gratitude to **Prof. Ananjan Basu** for all of the extensive talks that occurred throughout the process of developing my proposal and completing the thesis. He allowed me to exercise complete academic freedom, which contributed to the conception of publishable results in a short period of time. His assessments of the work's novelty were generally accurate. He provided me with space to pursue all of my creative endeavors.

I would like to thank **Prof. Shibani K Koul** who has always acted as a father figure for me. He has always uplifted me and inspired me to think big. It was truly an once-in-a-lifetime opportunity to get in touch with him during my Ph.D. He is, and always will be, a source of inspiration for me.

I am indebted to my SRC members, **Prof. Monika Aggrawal**, **Prof. Manav Bhatnagar**, and **Prof. Kirti Dhawaj**, for their unwavering support and insightful ideas during my project. I am thankful to **Mr. Ashoke Pramanik** for helping me with the fabrication. I would like to thank **Dr. Vigyaneshu Mishra** for various advice and fruitful discussions. I am immensely grateful to the Ministry of Human Resource Department

(MHRD) for providing financial support to me during my Ph.D. Additionally, I would like to express my gratitude to the Science and Engineering Research Board (SERB) for providing me with the necessary funding to attend and present my work at International symposium on Antennas and Propagation. I am thankful to Mr. Bijoy Philip for teaching me how to create an effective journal paper from scratch.

I extend my special thanks to Ms. Shilpi Singh for her support, companionship, and arguments over various diverse topics which made my Ph.D journey smooth, enjoyable, and memorable. I would like to convey my heartfelt gratitude to all of my microwave Group colleagues Dristi Singhal, Dr. Somia Sharma, Dr. Shakti Singh Chauhan, Dr. Pranav Shrivastava, Dr. Sriparna De, Dr. Priyansha Kaurav, Iqram Haidar, Rupa Laller, Tanvi Agarwal, and Vijoyutri Paul for their unwavering assistance, support, and encouragement throughout my Ph.D. study. It is really difficult to mention all the people who contributed directly or indirectly to this accomplishment.

I will always be grateful to my mother Mrs. Jayanti De, father Mr. Mrinmoy De, sister Mrs. Rakhi De, brother Mr. Mridul De and my niece Sweety and Trisha for their unwavering support throughout my life. Their perseverance and sacrifices have shaped me into the person I am today. They have supported me unconditionally and continually throughout my life, showering me with love, care, motivation, and blessings. Without their encouragement and support, our endeavour would not have been possible.

Finally, I offer my humble homage to The Almighty God, whose kindness and blessings have enabled me to complete this academic undertaking.

New Delhi
November 2024



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ABSTRACT

The emergence of CubeSats/SmallSats began a miniaturization revolution in the satellite industry nearly twenty years ago. Only a handful of people could have predicted their capabilities at the time, and today, these Small Satellites are changing the world in a completely different way. They have established themselves as a viable science platform. The mass of the SmallSat family usually is less than 500 kg. Mini, Micro, Nano, Pico and Femtosatellites form the SmallSat family. CubeSats are a special subset of the SmallSat family which falls under nano and picosatellite mass category. They are small satellites with a useful volume of $10\text{ cm} \times 10\text{ cm} \times 10\text{ cm}$ and a mass of approximately 1 kg, often made of commercially available off-the-shelf components. Small satellites can reduce the mass and cost of any space mission significantly and allow fast and frequent access to space in an affordable manner. Small satellites can play very important role in science missions, Earth observation, Tele-communications, weather forecasting, navigation, technology demonstrations, and education.

Antennas are among the most important sub-systems of any satellite. They are the eyes and ears of the satellite. The types of antennas used for CubeSats missions depend on the application, mission objective, frequency of operation, etc. Broadly CubeSat antennas can be classified as Low gain antennas (LGA, gain $< 8\text{dBi}$), Medium gain antennas (MGA, gain $< 25\text{dBi}$), and high gain antennas (HGA, gain $> 25\text{dBi}$). Medium to high gain antennas are used for data transfer whereas low gain omni-directional antennas are used for Telemetry, Tracking, and Command (TT&C) applications. Moreover, CubeSat allows various onboard scientific instruments, such as spectrometer, and these instruments sometimes need integrated antenna system to function. Given the space constraints posed by the small satellite platform, designing high performing antennas is a challenge.

This thesis explores various kinds of innovative antennas for small satellites, starting from X band to THz applications. In small satellites, components are very closely packed because of space constraints, and hence EMI could be a significant problem. In the first work, a compact, high gain substrate integrated waveguide (SIW) based antenna is proposed which is suitable for integration with various other circuit components. This antenna, by virtue of design, reduces mutual coupling among various closely packed components. Array of this element is also demonstrated for high gain applications.

One deployable Fabry-Perot Cavity antenna is proposed which is suitable for X-band data transfer. This work introduces the concept of spatially separated superstrate area excitation in FPC antennas. This concept is validated and applied to increase the gain and the axial ratio bandwidth of a conventional narrowband circularly polarized source patch antenna. The antenna's design leverages independent control of polarization at different frequencies, resulting in a large overall bandwidth. The fabricated prototype antenna provides right hand circular polarization. The antenna is simple, lightweight, easily integrable with CubeSat body, and useful for X-Band data downlink. Integration of this antenna with the metallic body of a 1U CubeSat also demonstrated. A deployment method is proposed for this antenna that results in a very small stowage volume.

CubeSats and other small satellites have natural grounds and they can be utilized for antenna designs. One such possibility is explored by designing a surface wave antenna. The development of a high-gain, wideband, end-fire, mm-wave surface wave launcher is proposed. The design primarily consists of three parts, viz: a Grounded Co-Planar Waveguide (GCPW) feed, a phase equalization section, and a dielectric wedge wave transformer with extended ground which is basically CubeSat chassis. The wave excited by GCPW feed is first converted into a plane wave over a wide aperture by phase-equalization section. The dielectric wedge section efficiently transmits the generated surface wave into the extended ground over a very wide frequency range, which propagates along and finally radiates from the ground edge. This launcher can be mounted on any large metallic ground directly.

Towards the end, antenna for CubeSat based THz spectroscopy application is explored. A Fabry-Perot Cavity (FPC) antenna is proposed for Tera-Hertz (THz) CubeSat spectroscopy instruments. The proposed antenna is a three layer metallic structure consisting of a matching layer, a cavity layer, and a Partially Reflecting Surface (PRS) layer. The antenna is linearly polarized, provides wide BW, and high gain.

सार

क्यूबसैट/स्मॉलसैट के उद्भव ने लगभग बीस साल पहले उपग्रह उद्योग में लघुकरण क्रांति शुरू की। उस समय केवल कुछ मुट्ठी भर लोग ही उनकी क्षमताओं का अनुमान लगा सकते थे और आज, ये छोटे उपग्रह दुनिया को बिल्कुल अलग तरीके से बदल रहे हैं। उन्होंने खुद को एक व्यवहार्य विज्ञान मंच के रूप में स्थापित किया है। स्मॉलसैट परिवार का द्रव्यमान आमतौर पर 500 किलोग्राम से कम होता है। मिनी, माइक्रो, नैनो, पिको और फेमटोसैटेलाइट्स स्मॉलसैट परिवार बनाते हैं। क्यूबसैट स्मॉलसैट परिवार का एक विशेष उपसमूह है जो नैनो और पिकोसैटेलाइट द्रव्यमान श्रेणी के अंतर्गत आता है। वे 10 सेमी × 10 सेमी × 10 सेमी की उपयोगी मात्रा और लगभग 1 किलो वजन वाले छोटे उपग्रह हैं, जो अक्सर व्यावसायिक रूप से उपलब्ध ऑफ-द-शेल्फ घटकों से बने होते हैं। छोटे उपग्रह किसी भी अंतरिक्ष मिशन के द्रव्यमान और लागत को काफी कम कर सकते हैं और किफायती तरीके से अंतरिक्ष तक तेजी से और लगातार पहुंच की अनुमति दे सकते हैं। छोटे उपग्रह विज्ञान मिशन, पृथ्वी अवलोकन, दूरसंचार, मौसम पूर्वानुमान, नेविगेशन, प्रौद्योगिकी प्रदर्शन और शिक्षा में बहुत महत्वपूर्ण भूमिका निभा सकते हैं।

एंटेना किसी भी उपग्रह की सबसे महत्वपूर्ण उप-प्रणालियों में से एक हैं। वे उपग्रह की आंखें और कान हैं। क्यूबसैट मिशनों के लिए उपयोग किए जाने वाले एंटेना के प्रकार अनुप्रयोग, मिशन उद्देश्य, संचालन की आवृत्ति आदि पर निर्भर करते हैं। मोटे तौर पर क्यूबसैट एंटेना को कम लाभ वाले एंटेना (एलजीए, लाभ <8dBi), मध्यम लाभ वाले एंटेना (एमजीए, लाभ <25dBi) के रूप में वर्गीकृत किया जा सकता है। , और उच्च लाभ एंटेना (HGA, लाभ > 25dBi)। मध्यम से उच्च लाभ वाले एंटेना का उपयोग डेटा ट्रांसफर के लिए किया जाता है जबकि कम लाभ वाले सर्वदिशात्मक एंटेना का उपयोग टेलीमेट्री, ट्रैकिंग और कमांड (टीटी एंड सी) अनुप्रयोगों के लिए किया जाता है। इसके अलावा, क्यूबसैट स्पेक्ट्रोमीटर जैसे विभिन्न ऑनबोर्ड वैज्ञानिक उपकरणों की अनुमति देता है, और इन उपकरणों को कार्य करने के लिए कभी-कभी एकीकृत एंटीना प्रणाली की आवश्यकता होती है। छोटे उपग्रह प्लेटफॉर्म द्वारा उत्पन्न स्थान की कमी को देखते हुए, उच्च प्रदर्शन वाले एंटेना को डिज़ाइन करना एक चुनौती है।

यह थीसिस छोटे उपग्रहों के लिए एक्स बैंड से लेकर टीएचजेड अनुप्रयोगों तक विभिन्न प्रकार के नवीन एंटेना की खोज करती है। छोटे उपग्रहों में, स्थान की कमी के कारण घटकों को बहुत बारीकी से पैक किया जाता है, और इसलिए ईएमआई एक महत्वपूर्ण समस्या हो सकती है। पहले काम में, एक कॉम्पैक्ट, उच्च लाभ सबस्ट्रेट इंटीग्रेटेड वेवगाइड (एसआईडब्ल्यू) आधारित एंटीना प्रस्तावित है जो विभिन्न अन्य सर्किट घटकों के साथ एकीकरण के लिए उपयुक्त है। यह एंटीना, डिज़ाइन के आधार पर, विभिन्न बारीकी से पैक किए गए घटकों के बीच आपसी युग्मन को कम करता है। उच्च लाभ अनुप्रयोगों के लिए इस तत्व की सरणी का भी प्रदर्शन किया जाता है।

एक तैनाती योग्य फैब्री-पेरोट कैविटी एंटीना प्रस्तावित है जो एक्स-बैंड डेटा ट्रांसफर के लिए उपयुक्त है। यह कार्य एफपीसी एंटेना में स्थानिक रूप से अलग किए गए सुपरस्ट्रेट क्षेत्र उत्तेजना की अवधारणा का परिचय देता है। इस अवधारणा को पारंपरिक नैरोबैंड गोलाकार ध्रुवीकृत स्रोत पैच एंटीना के लाभ और अक्षीय अनुपात बैंडविड्थ को बढ़ाने के लिए मान्य और लागू किया गया है। एन्टेना का डिज़ाइन विभिन्न आवृत्तियों पर ध्रुवीकरण के स्वतंत्र नियंत्रण का लाभ उठाता है, जिसके परिणामस्वरूप एक बड़ी समग्र बैंडविड्थ प्राप्त होती है। निर्मित प्रोटोटाइप एंटीना दाहिने हाथ का गोलाकार ध्रुवीकरण प्रदान करता है। एंटीना सरल, हल्का, क्यूबसैट बॉडी के साथ आसानी से एकीकृत होने वाला और एक्स-बैंड डेटा डाउनलैंक के लिए उपयोगी है। 1यू क्यूबसैट की धात्विक बॉडी के साथ इस एंटीना के एकीकरण का भी प्रदर्शन किया गया। इस एंटीना के लिए एक परिनियोजन विधि प्रस्तावित है जिसके परिणामस्वरूप भंडारण की मात्रा बहुत कम हो जाती है।

क्यूबसैट और अन्य छोटे उपग्रहों में प्राकृतिक आधार होते हैं और उनका उपयोग एंटीना डिज़ाइन के लिए किया जा सकता है। सतह तरंग एंटीना को डिज़ाइन करके ऐसी एक संभावना का पता लगाया गया है। एक हाई-गेन, वाइडबैंड, एंड-फायर, एमएम-वेव सरफेस वेव लॉन्चर का विकास प्रस्तावित है। डिज़ाइन में मुख्य रूप से तीन भाग होते हैं, जैसे: एक ग्राउंडेड को-प्लानर वेवगाइड (GCPW) फ़ीड, एक चरण इकलाइज़ेशन अनुभाग, और विस्तारित ग्राउंड के साथ एक ढांकता हुआ वेव ट्रांसफार्मर जो मूल रूप से क्यूबसैट चेसिस है। GCPW फ़ीड द्वारा उत्तेजित तरंग को पहले चरण-समीकरण अनुभाग द्वारा एक विस्तृत एपर्चर पर एक समतल तरंग में परिवर्तित किया जाता है। डाइइलेक्ट्रिक वेव सेक्शन उत्पन्न सतह तरंग को बहुत व्यापक आवृत्ति रेंज में विस्तारित जमीन में कुशलतापूर्वक प्रसारित करता है, जो साथ-साथ फैलता है और अंत में जमीन के किनारे से विकिरण करता है। इस लॉन्चर को किसी भी बड़ी धातु वाली जमीन पर सीधे लगाया जा सकता है।

अंत में, क्यूबसैट आधारित टीएचजेड स्पेक्ट्रोस्कोपी एप्लिकेशन के लिए एंटीना की खोज की गई है। टेरा-हर्ट्ज़ (THz) क्यूबसैट स्पेक्ट्रोस्कोपी उपकरणों के लिए एक फैब्री-पेरोट कैविटी (FPC) एंटीना प्रस्तावित है। प्रस्तावित एंटीना एक तीन परत वाली धातु संरचना है जिसमें एक मिलान परत, एक गुहा परत और एक आंशिक रूप से प्रतिबिंबित सतह (पीआरएस) परत शामिल है। एन्टेना रैखिक रूप से ध्रुवीकृत है, विस्तृत बीडव्थ और उच्च लाभ प्रदान करता है।

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LIST OF ABBREVIATIONS

CubeSat	Cube Satellite
CPW	Coplanar Waveguide
CST	Computer Simulation Technology
dB	Decibel
DGS	Defected Ground Surface
EM	Electromagnetic
EMI	Electromagnetic Interference
FPC	Fabry-Perot Cavity
GHz	Giga Hertz
GND	Ground
MPA	Microstrip Patch Antenna
PEC	Perfect Electric Conductor
PMC	Perfect Magnetic Conductor
PRS	Partially Reflecting Surface
RF	Radio Frequency
SmallSat	Small Satellite
SSSA	Spatially Separated Superstrate Area
SIW	Substrate Integrated Waveguide
SWA	Surface Wave Antenna
THz	Tera Hertz