DEVELOPMENT OF NOVEL SLOTTED WAVEGUIDE ANTENNAS FOR MILLIMETER WAVE APPLICATIONS

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by

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CERTIFICATE

This is to certify that the work reported in this thesis entitled **"DEVELOPMENT OF NOVEL SLOTTED WAVEGUIDE ANTENNA FOR MILLIMETER WAVE APPLICATIONS"** being submitted by **Ms. Shilpi Singh** for the award of the degree of **Doctor of Philosophy** to the Indian Institute of Technology Delhi, New Delhi, India, is a record of original bonafide research work carried out by her under my guidance and supervision. The results contained in this thesis have notbeen submitted in part or full, to any other university or institute for the award of any degree or diploma.

I certify that she has pursued the prescribed course of research.

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ABSTRACT

To meet the increasing demand for high data rates, research in millimeter-wave (MMW) frequency ranges, spanning from 30 to 300 GHz, has gained significant attention. Among these, the V-band and W-band are of particular interest due to their diverse applications in wireless communication, imaging, radar, space communication, and security screening. Despite extensive research on leaky wave antennas (LWAs) over several decades, substantial challenges persist in developing high-frequency LWAs suitable for these bands. This research aims to delve into the theoretical foundations, design methodologies, and practical implementations of high frequency V and W-band travelling wave antennas for various applications by focusing on innovative design approaches to enhance performance and fabrication feasibility. The primary objective of this research is to design a high-gain, narrow beamwidth, waveguide based LWA operating in the W-band frequency range. The circularly polarized antenna will be designed into a WR-10 waveguide and will utilize a polarization converter-based architecture to achieve circular polarization. The focus is to maximize efficiency for millimeter-wave applications, ensuring robustness and improving high-frequency communication capabilities. Additionally, this research aims to develop a low-profile dual circularly polarized antenna based on a fully metallic waveguide for satellite communication. A key consideration is ensuring ease of fabrication at W-band frequencies while maintaining scalability to sub-terahertz (THz) frequencies. The proposed design should provide a wideband operating frequency with an axial ratio bandwidth exceeding 10% at the 94 GHz frequency band. Another critical objective is to design and characterize a fixed-frequency beam scanning antenna operating within the 86 GHz - 90 GHz range. This antenna will incorporate a mechanical tuning mechanism within a waveguide-based architecture to enable forward-to-backward beam scanning at a fixed frequency. The design approach will emphasize innovation in waveguide-based beam steering while ensuring ease of fabrication. Finally, this research focuses on designing a fully metallic waveguide-based V-band antenna with circular polarization capabilities. The antenna must exhibit high efficiency, narrow beamwidth, and high gain, while also being robust enough to withstand harsh environmental conditions, making it

suitable for satellite communication. The design should be scalable to both higher and lower frequencies, ensuring versatility in future applications. By addressing these challenges, this research aims to contribute significantly to the advancement of millimeter-wave antenna technology, offering efficient and scalable solutions for high-frequency communication and space applications.

सार

बढ़ती हाई डेटा रेट की मांग को पूरा करने के लिए मिलीमीटर-वेव (MMW) आवृत्ति क्षेत्र, जो 30 से 300 GHz तक फैला हुआ है, में शोध को विशेष महत्व मिला है। इनमें से V-बैंड और W-बैंड विशेष रूप से आकर्षण का केंद्र हैं, क्योंकि इनका उपयोग वायरलेस संचार, इमेजिंग, रडार, अंतरिक्ष संचार और सुरक्षा जांच जैसे विभिन्न अनुप्रयोगों में किया जाता है। हालांकि, लीकी वेव एंटीना (LWA) पर कई दशकों से व्यापक शोध किया गया है, फिर भी इन उच्च-आवृत्ति बैंड्स के लिए उपयुक्त LWA विकसित करने में कई तकनीकी चुनौतियाँ बनी हुई हैं। यह शोध उच्च-आवृत्ति V और W-बैंड ट्रैवलिंग वेव एंटीना के सैद्धांतिक आधार, डिज़ाइन पद्धतियाँ और व्यावहारिक कार्यान्वयन की गहराई से जांच करेगा। साथ ही, इसमें नवोन्मेषी डिज़ाइन दृष्टिकोण अपनाया जाएगा जिससे प्रदर्शन में सुधार हो और निर्माण की प्रक्रिया सुगम बने।

इस शोध का प्राथमिक उद्देश्य एक उच्च-गेन, संकीर्ण बीमविड्थ वाला वेवगाइड आधारित LWA डिज़ाइन करना है, जो W-बैंड (94 GHz) फ़्रीक्वेंसी रेंज में संचालित होगा। इस एंटीना को WR-10 वेवगाइड में डिज़ाइन किया जाएगा और इसमें ध्रुवीकरण कन्वर्टर आधारित संरचना का उपयोग किया जाएगा ताकि वृत्ताकार ध्रुवीकरण प्राप्त किया जा सके। इस शोध का मुख्य फोकस मिलीमीटर-वेव अनुप्रयोगों के लिए दक्षता को अधिकतम करना, मजबूती सुनिश्चित करना और उच्च-आवृत्ति संचार क्षमताओं को बेहतर बनाना है।

इसके अतिरिक्त, यह शोध पूर्णतः धातु वेवगाइड आधारित, कम प्रोफाइल वाले ड्यूल सर्कुलरली पोलराइज़्ड एंटीना के विकास पर केंद्रित है, जो उपग्रह संचार के लिए उपयुक्त होगा। डिज़ाइन में इस बात का विशेष ध्यान रखा जाएगा कि W-बैंड आवृत्तियों पर निर्माण प्रक्रिया आसान हो, साथ ही इसे सब-टेरेहर्ट्ज़ (THz) फ़्रीक्वेंसी तक स्केलेबल बनाया जाए। प्रस्तावित डिज़ाइन को 10% से अधिक एक्सियल रेशियो बैंडविड्थ प्रदान करनी होगी, जिससे यह 94 GHz बैंड में प्रभावी रूप से कार्य कर सके।

इस शोध का एक अन्य महत्वपूर्ण उद्देश्य 86 GHz - 90 GHz फ़्रीक्वेंसी रेंज में फिक्स्ड फ़्रीक्वेंसी बीम स्कैनिंग एंटीना का डिज़ाइन और विश्लेषण करना है। यह एंटीना वेवगाइड आधारित संरचना के भीतर एक यांत्रिक ट्यूनिंग तंत्र को शामिल करेगा, जिससे फॉरवर्ड-टू-बैकवर्ड बीम स्कैनिंग संभव हो सके। डिज़ाइन प्रक्रिया में वेवगाइड आधारित बीम स्टीयरिंग में नवाचार को प्राथमिकता दी

जाएगी, साथ ही निर्माण की सुगमता सुनिश्चित की जाएगी।

अंततः, यह शोध V-बैंड में कार्य करने वाले एक पूर्णतः धातु वेवगाइड आधारित एंटीना के डिज़ाइन पर केंद्रित है, जिसमें वृत्ताकार ध्रुवीकरण की क्षमता होगी। इस एंटीना को उच्च दक्षता, संकीर्ण बीमविड्थ और उच्च गेन प्रदान करने के लिए डिज़ाइन किया जाएगा। इसके साथ ही, इसे कठोर पर्यावरणीय परिस्थितियों का सामना करने के लिए पर्याप्त मजबूत (Robust) बनाया जाएगा, जिससे यह सैटेलाइट संचार के लिए उपयुक्त हो। इस डिज़ाइन को अधिक और कम आवृत्तियों तक स्केलेबल बनाया जाएगा, जिससे यह भविष्य के अनुप्रयोगों में भी उपयोगी रह सके।

यह शोध मिलीमीटर-वेव एंटीना प्रौद्योगिकी को महत्वपूर्ण रूप से आगे बढ़ाने का प्रयास करेगा। यह उच्च-आवृत्ति संचार और अंतरिक्ष अनुप्रयोगों के लिए प्रभावी और बेहतर समाधान प्रदान करेगा, जिससे भविष्य के वायरलेस संचार और सैटेलाइट तकनीकों में सुधार किया जा सके।

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ADS	Advanced Design System
CST	Computer Simulation Technology
TWA	Travelling Wave Antenna
LWA	Leaky Wave Antenna
CP	Circular Polarization
AR	Axial Ratio
dB	Decibel
PC	Polarization Converter
EM	Electromagnetic
EMI	Electromagnetic Interference
FSA	Frequency Scanning Antenna
GHz	Giga Hertz
RHCP	Right Hand Circular Polarization
LHCP	Left Hand Circular Polarization
MS	Microstrip
RGW	Ridge Gap Waveguide
OSB	Open Stop Band
PEC	Perfect Electric Conductor
QTEM	Quasi Transverse Electromagnetic
RCS	Radar Cross Section
RF	Radio Frequency