

NOVEL DIELECTRIC LOADED RECONFIGURABLE SUBSTRATE INTEGRATED WAVEGUIDE CIRCUITS

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**CENTRE FOR APPLIED RESEARCH IN ELECTRONICS
INDIAN INSTITUTE OF TECHNOLOGY DELHI**

OCTOBER 2022

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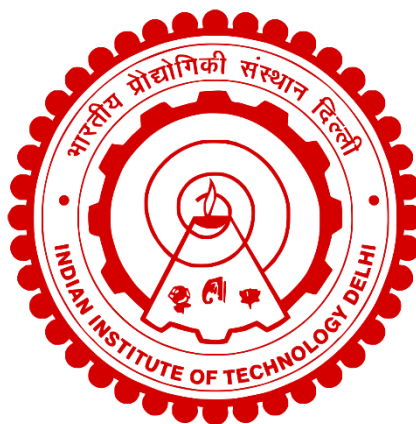
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Submitted

in fulfilment of the requirements of the degree of Doctor of Philosophy

to the



INDIAN INSTITUTE OF TECHNOLOGY DELHI

OCTOBER 2022

DEDICATION

*This dissertation is dedicated to my parents and to my husband for their immense love
and support.*

CERTIFICATE

This is to certify that the work reported in this thesis entitled “**NOVEL DIELECTRIC LOADED RECONFIGURABLE SUBSTRATE INTEGRATED WAVEGUIDE CIRCUITS**” being submitted by **Ms. Sriparna De** 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 our guidance and supervision. 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 she has pursued the prescribed course of research.

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ACKNOWLEDGEMENT

This dissertation would not be possible without the help and support of many people. First, I would like to thank my supervisors, **Prof. Shibhan K. Koul and Dr. Kamal K. Samanta**, for providing me this opportunity to work in the area of Substrate Integrated Waveguide Circuits area at Centre for Applied Research in Electronics (C.A.R.E.), Indian Institute of Technology (I.I.T), Delhi. I would also like to thank my supervisors for providing me the continuous guidance and motivation during my research work. I sincerely thank them for their contributions to my personal and professional growth.

I would also thank **Prof. Ananjan Basu and Prof. Mahesh P. Abegaonkar** for the fruitful technical discussions and for evaluating the progress of my work. I also thank external expert of my research committee, **Dr. Anuj Dhawan** for his suggestions and critical analysis of my work. I appreciate their contributions for reviewing this dissertation and participating in the oral presentation.

I am extremely grateful to **Prof. Dinesh Kalyanasundaram**, Centre of biomedical engineering (CBME), I.I.T Delhi for providing laser cutting fabrication facilities. I would also like to express my sincere thanks to Mr. Vidyasagar (CBME Dept.) from I.I.T Delhi, for their support for fabrication during my work.

I consider myself lucky to be a part of RF and microwave laboratory at Centre for Applied Research in Electronics, I.I.T Delhi. I would like to thank all of my colleagues who made my PhD journey memorable, including Dr. Saurabh Pegwal, Dr. Rajesh Singh, Dr. Robin Kalyan, Dr. Amit Kumar Singh, Dr. Ayushi Barthwal, Dr. Anushruti Jaiswal, Dr. Deepika Sipal, Dr. Kartikeya, Pranav Srivastava, Shakti Singh Chauhan, Dr. Harikesh, Dr. Zamir Ahmad, Somia Sharma, Priyansha Kaurav, Swapna, Rakhi Kumari, Santosh Bhagat, Ashish Jindal, Shilpi, Drishti and Ratul.

I would like to thank Mr. Ashok Pramanik from our lab and other staff members of C.A.R.E. for their support and help rendered during my research work.

I would also like to express my gratitude to all respected faculty members from the C.A.R.E. at I.I.T Delhi, for all of the support that they have given me during my dissertation period.

I would like to thank I.I.T. Delhi for allowing me to use its academic and other recreational facilities throughout my stay in campus and for giving me the financial support through teaching assistantship.

Finally, I would like to thank my family for their steadfast support – particularly my parents, **Mr. Subhas Chandra De** and **Mrs. Pampa De** and my husband, **Rajiv**. They encouraged me at every step by investing their considerable time and never doubted on my ability to complete the task. I needed it the most and I will forever be grateful to them.

Sriparna De

ABSTRACT

A simple, low profile, and cost-effective mechanical tuning technique is proposed in the thesis which is easier to implement in the planar technology of Substrate Integrated Waveguide (SIW). The technique uses dielectric rods which are machined from very easily available substrates/ceramic material in laboratory. The proposed technique is used to design passive reconfigurable circuits in SIW technology which are important building blocks in a transceiver chain like filters, antennas, diplexer, and phase shifters. In the thesis, it is illustrated how the dielectric rods are loaded inside air holes, drilled through the substrate of the SIW circuit at different desired positions. Then they are replaced mechanically with another set of rods having different relative permittivity value. As their relative permittivity changes, the same fabricated circuit becomes reconfigurable, and its frequency response gets shifted to other frequency for the designed filter, antenna, and diplexer. The designed filters show high quality factors (Q-factor) in the range of 102–210.5, lowest insertion loss of <2dB above 10 GHz when compared to available reconfigurable SIW filters, and wide tuning bandwidth in X-band. The cavity based single slot reconfigurable antenna shows almost 9% frequency tunability. Whereas the multi-slot antenna array shows 11.3% tunability in the X-band. An initial investigation on diplexer demonstrates a wide tuning capability with insertion loss (1-1.2 dB) lower than the reported techniques and isolation better than 25 dB in X-band. In case of variable phase shifter, the relative phase shift changes with change in relative permittivity of dielectric rods. It demonstrates highest phase variation range ($0.5^\circ\sim 200^\circ$), finest phase resolution ($0.5\text{-}1^\circ$) among the reported SIW phase shifters with one of the highest Figure-of-Merit of $110^\circ/\text{dB}$, and low insertion loss (1-2 dB). Finally,

a passive beam steering network is also illustrated for the first time using the designed variable phase shifter and antenna array.

There are many advantages of the demonstrated tuning technique. While comparing with active tuning techniques, there is no need for additional DC supply in the proposed technique which automatically eliminates parasitic effects and higher power consumption. This reduces complexity and cost, which increases the reliability and life of a module. In comparison to other passive tuning technique using metallic screws/flaps/posts, dielectric rods show lower electric field disruption. This reduces the insertion loss of any passive reconfigurable SIW circuit loaded with dielectric rods and consequently yields higher Q-factor.

The purpose of the thesis is to design various reconfigurable RF and microwave circuits for the front-end-modules of any high-power radar systems, wireless communication systems or any other transceiver systems for multi-band and multi-channel communication systems. It is mainly focused on the application in advanced point-to-multipoint (P2MP) and point-to-point (P2P) radios (including 5G) and especially for fixed and affordable high-speed internet connection in the hard-to-reach areas, such as small islands and rural areas. The reconfigurable circuits are designed for the Customer Premises Equipment (CPE) which is attached to each user. The prime concern of the complete module is to provide high data rate at a long range with reduced power consumption. It should also ensure that the CPE is affordable and easier to be installed in a remote area where power is limited or non-existent. Same fabricated structure of the circuit can be reconfigured at various frequencies (for filter, diplexer, and antenna) and with variable phase shift (for the phase shifter) with different dielectric rods loading for their application in the transceiver modules of CPEs, making the

inventory management comparatively simple and cheap from the point of view of the network providers in industry.

सार

थीसिस में एक सरल, कम प्रोफ़ाइल और लागत प्रभावी यांत्रिक ट्यूनिंग तकनीक का प्रस्ताव है जो सबस्ट्रेट इंटेग्रेटेड वेवगाइड (एसआईडब्ल्यू) की प्लेनर तकनीक में लागू करना आसान है। इस तकनीक में परावैद्युत छड़ों का उपयोग किया जाता है जो प्रयोगशाला में बहुत आसानी से उपलब्ध सबस्ट्रेट/सिरामिक सामग्री से तैयार की जाती है। प्रस्तावित तकनीक का उपयोग एसआईडब्ल्यू प्रौद्योगिकी में निष्क्रिय पुनः विन्यास योग्य सर्किटों को डिजाइन करने के लिए किया जाता है जो कि फ़िल्टर, एंटीना, डाईप्लेक्सर और फेज शिफ्टर्स जैसे ट्रांसीवर श्रृंखला में महत्वपूर्ण बिल्डिंग ब्लॉक हैं। थीसिस में, यह दिखाया गया है कि एसआईडब्ल्यू सर्किट के विभिन्न वांछित जगहों पर सबस्ट्रेट के माध्यम से छेद किए गए वायु छिद्रों के अंदर परावैद्युत छड़ कैसे डाले जाते हैं। फिर उन्हें यांत्रिक रूप से अलग-अलग सापेक्ष परावैद्युतांक मान वाली छड़ों के दूसरे समूह से बदल दिया जाता है। जैसे-जैसे उनकी सापेक्ष परावैद्युतांक बदलती है, वही निर्मित सर्किट पुनः विन्यास करने योग्य हो जाते हैं, और इसकी आवृत्ति प्रतिक्रिया डिज़ाइन किए गए फ़िल्टर, एंटीना और डाईप्लेक्सर के लिए अन्य आवृत्ति पर स्थानांतरित हो जाती है। डिज़ाइन किए गए फ़िल्टर 102-210.5 की सीमा में उच्च Q-कारक दिखाते हैं, उपलब्ध पुनः कॉन्फ़िगर करने योग्य एसआईडब्ल्यू फ़िल्टर की तुलना में 10 गीगाहर्ट्ज से ऊपर <2 डीबी का सबसे कम प्रविष्टि हानि, और एक्स-बैंड में विस्तृत ट्यूनिंग बैंडविड्थ दिखाते हैं। कैविटी आधारित सिंगल स्लॉट रीकॉन्फ़िगरेबल एंटीना लगभग 9% फ्रीक्वेंसी ट्यूनेबिलिटी दिखाता है। जबकि मल्टी-स्लॉट एंटीना एरे एक्स-बैंड में 11.3% ट्यूनेबिलिटी दिखाता है। डाईप्लेक्सर पर एक प्रारंभिक जांच रिपोर्ट की गई तकनीकों की तुलना में प्रविष्टि हानि (1-1.2 डीबी) के साथ एक विस्तृत ट्यूनिंग क्षमता प्रदर्शित करती है और एक्स-बैंड में आइसोलेसन 25 डीबी से बेहतर है। परिवर्तनीय चरण शिफ्टर के मामले में, सापेक्ष चरण शिफ्ट परावैद्युत छड़ की सापेक्ष पारगम्यता

में परिवर्तन के साथ बदलता है। यह रिपोर्ट किए गए SIW फेज शिफ्टर्स में से उच्चतम फेज वेरिएशन रेंज ($0.5^{\circ}\sim 200^{\circ}$), बेहतरीन फेज रिजोल्यूशन ($0.5\text{-}1^{\circ}$) प्रदर्शित करता है, जिसमें उच्चतम फिगर-ऑफ-मेरिट 110/dB, और कम इंसर्शन लॉस (1-2 डीबी) है। अंत में, एक निष्क्रिय बीम स्टीयरिंग नेटवर्क को पहली बार डिज़ाइन किए गए चर चरण शिफ्टर और एंटीना सरणी का उपयोग करके भी चित्रित किया गया है।

प्रदर्शित ट्यूनिंग तकनीक के कई फायदे हैं। सक्रिय ट्यूनिंग तकनीकों के साथ तुलना करते समय, प्रस्तावित तकनीक में अतिरिक्त डीसी स्रोत की कोई आवश्यकता नहीं है जिसके कारण परजीवी प्रभाव और उच्च बिजली की खपत जैसे समस्याएं नहीं होती हैं। यह जटिलता और लागत को कम करता है, जो एक मॉड्यूल की विश्वसनीयता और जीवन को बढ़ाता है। धातु के स्कू/फ्लैप्स/पोस्ट का उपयोग करने वाली अन्य निष्क्रिय ट्यूनिंग तकनीक की तुलना में, परावैद्युत छड़ विद्युत क्षेत्र में कम व्यवधान दिखाती है। यह परावैद्युत छड़ से लोड किए गए किसी भी निष्क्रिय पुनः विन्यास करने योग्य एसआईडब्ल्यू सर्किट के प्रविष्टि हानि को कम करता है और इसके परिणामस्वरूप उच्च Q-कारक प्राप्त होता है।

थीसिस का उद्देश्य मल्टी-बैंड और मल्टी-चैनल संचार प्रणालियों के लिए किसी भी उच्च-शक्ति रडार सिस्टम, वायरलेस संचार प्रणाली या किसी अन्य ट्रांसीवर सिस्टम के फ्रंट-एंड-मॉड्यूल के लिए विभिन्न पुनः विन्यास करने योग्य आरएफ और माइक्रोवेव सर्किट डिजाइन करना है। यह मुख्य रूप से उन्नत पॉइंट-टू-मल्टीपॉइंट (P2MP) और पॉइंट-टू-पॉइंट (P2P) रेडियो (5G सहित) और विशेष रूप से दूर दराज क्षेत्रों (जैसे छोटे द्वीप और ग्रामीण क्षेत्र) में स्थायी और सस्ती काफी तेज इंटरनेट कनेक्शन पर केंद्रित है। पुनः विन्यास करने योग्य सर्किट ग्राहक परिसर उपकरण (सीपीई) के लिए डिज़ाइन किए गए हैं जो प्रत्येक उपयोगकर्ता से जुड़े हुए हैं। पूरे

मॉड्यूल की मुख्य चिंता कम बिजली की खपत के साथ लंबी दूरी पर उच्च डेटा दर प्रदान करना है। इसे यह भी सुनिश्चित करना चाहिए कि सीपीई सस्ती हो और दूरस्थ क्षेत्र में स्थापित करना आसान हो जहां बिजली सीमित या न के बराबर हो। सीपीई के ट्रांसीवर मॉड्यूल में जरूरत के हिसाब से सर्किट के एक ही बनाए हुए ढांचे को विभिन्न आवृत्तियों (फिल्टर, डिप्लेक्सर, और एंटीना के लिए) और परिवर्तनीय फेज शिफ्ट (फेज शिफ्टर के लिए) के लिए अलग-अलग परावैद्युत छड़ डाल कर पुनः विन्यास किया जा सकता है। इससे इन्वेंट्री को संभालना काफी आसान बन जाता है और उद्योग में नेटवर्क प्रदाताओं के दृष्टिकोण से प्रबंधन अपेक्षाकृत सरल और सस्ता हो जाता है।

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LIST OF ABBREVIATIONS

BPF	Band Pass Filter
BW	Bandwidth
dB	Decibel
FBW	Fractional Bandwidth
GHz	Gigahertz
HMSIW	Half Mode Substrate Integrated Waveguide
HFSS	High Frequency Structure Simulator
MHz	Megahertz
LTCC	Low Temperature Co-fired Ceramic
MEMS	Micro Electro Mechanical System
SIW	Substrate Integrated Waveguide