

STUDIES ON MICROMACHINED CIRCUITS FOR MICROWAVE TO SUB-THz APPLICATIONS

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**CENTRE FOR APPLIED RESEARCH IN ELECTRONICS
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by

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Centre for Applied Research in Electronics

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DEDICATION

This dissertation is dedicated to my Revered *Gurusatta*, my *Family*, and my
Group-of-Souls.

“Thinking before doing is wisdom. Thinking while doing is awareness, and thinking after doing is foolishness.”

“We should write that which is worth reading about, and it’s even better if we do what is worth writing about.”

— **Pt. Shriram Sharma Acharya**
(20 Sept.1911-02 Jun.1990)
Seer, Philosopher, Scholar, Visionary, Reformer

“Ignorance is the mother of all the evil and all the misery we see.”

— **Swami Vivekananda**
(12 Jan.1863-04Jul.1902)
A spiritual genius of commanding intellect and power

“It does not matter how slowly you go as long as you do not stop.”

— **Confucius**

“Of all the frictional resistances, the one that most retards human movement is ignorance.”

— **Nikola Tesla**

“Education is the kindling of a flame, not the filling of a vessel.”

— **Socrates**
(470BC-399BC)

“Education is the most powerful weapon which you can use to change the world.”

— **Nelson Mandela**

CERTIFICATE

This is to certify that the thesis entitled, “**STUDIES ON MICROMACHINED CIRCUITS FOR MICROWAVE TO SUB-THz APPLICATIONS**”, submitted by **Mr. PRANAV KUMAR SHRIVASTAVA** 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, is a record of bonafide research work carried out by him under our guidance and supervision.

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

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-Pranav Kumar Shrivastava

ABSTRACT

In this thesis, detailed studies are reported on: (a) the design aspects of microwave and mmWave micromachined series and shunt switches; (b) back to back rectangular waveguide to CPW transition for characterization of CPW based series/shunt switches in X- and W-band; (c) CPW to slotline transition based broadband micromachined coupler; (d) realization of 2-Bit reflection type phase shifter (RTPS) utilizing micro-machined shunt switch and coupler; (e) performance improvement of micromachined shunt switch utilizing defected ground structures (DGS); and (f) frequency selective surfaces (FSS) and multiband absorbers for application in mmWave to Sub-THz region.

To start with, analysis and the design of the micromachined switches is carried out. Both types of micromachined switches *viz.* series and shunt are studied with their specific application areas, working frequency ranges in different bands, power handling capacity, and most importantly the fabrication steps for both in-house fabrication as well as following well-established foundry process design rules. The micromachined switches are mainly designed for application in phase shifters, up to *Ka*-band, especially in the frequency range of 8 to 40 GHz. In addition, other micro-machined shunt switches are designed and fabricated at 60 GHz and 75-110 GHz. The topology chosen for the phase shifter design is of reflection type to keep control of size and preferred frequency less than 30GHz. The 2-Bit reflection type phase shifter (RTPS) is designed at 20GHz with bandwidth (BW) of approximately 2GHz. The design of RTPS basically involves design of a micromachined shunt switch and broadband micromachined coupler.

In order to characterize micromachined shunt switches realized in CPW configuration, back-to-back rectangular waveguide to CPW transition is designed, developed, and characterized in both X-band (8GHz-12GHz) and W-band (75GHz-110 GHz). Simulation-based study of the micromachined shunt switches integrated with the transition has also been carried out.

Micromachined shunt switches are next explored with defected ground structure (DGS) in the ground planes of the CPW line. In the case of DGS, the isolation improvement was observed in simulations. The isolation parameter of the shunt switch in the downstate is improved by incorporating DGS structures and further insertion loss performance improvement achieved by the introduction of the secondary switches over DGS. The complete structure observed as a MTM unit cell designed to improve the isolation of a shunt switch and improvement of the insertion loss in the frequency range from 60- 140 GHz.

Lastly, metamaterial structures are studied for application as frequency selective surfaces (FSS) and multiband absorbers in the sub-THz frequency region. A novel FSS structure as a unit cell is designed, fabricated, and characterized in the frequency range from 100- 600GHz. It is observed that simulation results are in good agreement with experimental results. The same structure when studied as an absorber with backside metal (gold) coating shows absorption peaks within the THz range (441GHz to 592GHz).

Wherever possible, the attempt was made to verify the simulated results. In some cases, due to fabrication complexities and limited in house facilities available, only simulation-based studies are reported.

सारांश

प्रस्तुत शोध-प्रबंध में निम्नलिखित प्रकरणों पर, विस्तृत अध्ययन की सूचना दी गई है: (क) माइक्रोवेव और एमएमवेव माइक्रोमशीन श्रृंखला और शंट स्विच की रचना एवं बनाबट पहलू; (ख) एक्स-और डब्ल्यू-बैंड में सीपीडब्ल्यू आधारित श्रृंखला/शंट स्विच के लक्षण वर्णन के लिए सीपीडब्ल्यू संक्रमण के लिए बैक टू बैक आयताकार वेवगाइड; (ग) सीपीडब्ल्यू से स्लॉटलाइन संक्रमण आधारित ब्रॉडबैंड माइक्रोमशीन युग्मक; (घ) माइक्रो-मशीन शंट स्विच और युग्मक का उपयोग करके 2-बिट परावर्तक प्रकार अवस्था परिवर्तक (आरटीपीएस) की प्राप्ति; (ङ) दोषपूर्ण जमीन संरचनाओं (डीजीएस) का उपयोग करने वाले माइक्रोमशीन शंट स्विच के प्रदर्शन में सुधार; और (च) फ्रीक्वेंसी सेलेक्टिव सरफेस (एफएसएस) और मल्टीबैंड अवशोषक मिलीमीटर वेव से उप-टेराहर्ट्ज़ वेव क्षेत्र में अनुप्रयोगों के लिए।

सर्वप्रथम, माइक्रोमशीन किए गए स्विच का विश्लेषण और डिज़ाइन किया जाता है। दोनों प्रकार के माइक्रोमाचिन्ड स्विच अर्थात्; श्रृंखला और शंट का अध्ययन उनके विशिष्ट अनुप्रयोग क्षेत्रों, विभिन्न बैंडों में कार्य आवृत्ति रेंज, शक्ति नियंत्रण की क्षमता, और सबसे महत्वपूर्ण रूप से आंतरिक विरचना के साथ-साथ अच्छी तरह से स्थापित फाउंड्री प्रोसेस डिज़ाइन नियमों का पालन करने के लिए फैब्रिकेशन चरणों के साथ किया जाता है। माइक्रोमाचिन्ड स्विच मुख्य रूप से K_a -बैंड तक, विशेष रूप से 8 से 40 गीगाहर्ट्ज़ की आवृत्ति रेंज में अवस्था परिवर्तक में आवेदन के लिए डिज़ाइन किए गए हैं। इसके अलावा, अन्य सूक्ष्म-मशीनीकृत शंट स्विच 60 GHz और 75-110 GHz पर संरचित और निर्मित किए गए हैं। अवस्था परिवर्तक की संरचना के लिए चुनी गई सांस्थिति 30GHz से कम आकार और पसंदीदा आवृत्ति पर नियंत्रण रखने के लिए परवर्तकीय प्रकार की है। 2-बिट परावर्तक प्रकार अवस्था परिवर्तक (RTPS) को लगभग 2GHz के बैंडविड्थ (BW) के साथ 20GHz पर डिज़ाइन किया गया है। आरटीपीएस की संरचना में मूल रूप से एक माइक्रोमशीन शंट स्विच और ब्रॉडबैंड माइक्रोमशीन युग्मक की संरचना शामिल है।

CPW विन्यास में समझे और जाने गए माइक्रोमशीन शंट स्विच को वर्णित करने के लिए, CPW संक्रमण के लिए बैक-टू-बैक आयताकार वेवगाइड को X-बैंड (8GHz-12GHz) और W-बैंड (75GHz-110 GHz) दोनों में संरचित, विकसित और वर्णित किया गया है। संक्रमण के साथ एकीकृत माइक्रोमशीन शंट स्विच का अभिकलक-तंत्र आधारित अध्ययन भी किया गया है।

CPW लाइन के ग्राउंड प्लेन में त्रुटिपूर्ण ग्राउंड स्ट्रक्चर (DGS) के साथ माइक्रोमशीन शंट स्विच का समन्वेषण किया गया है। डीजीएस के मामले में, अभिकलक-तंत्र-आधारित अध्ययन में विलगता-प्राचल में सुधार देखा गया। निचली-अवस्था में शंट स्विच का विलगता-प्राचल डीजीएस संरचनाओं को शामिल करके और डीजीएस पर द्वितीयक स्विच की शुरूआत से प्राप्त सम्मिलन हानि प्राचल प्रदर्शन सुधार में सुधार किया गया है। एक शंट स्विच के अलगाव में सुधार और 60-140 गीगाहर्ट्ज से आवृत्ति रेंज में सम्मिलन हानि में सुधार के लिए डिजाइन किए गए एमटीएम यूनिट सेल के रूप में पूरी संरचना देखी गई।

अंत में, उप-THz आवृत्ति क्षेत्र में आवृत्ति चयनात्मक सतहों (FSS) और मल्टीबैंड अवशोषक के रूप में अनुप्रयोग के लिए मेटामटेरिअल संरचनाओं का अध्ययन किया जाता है। यूनिट सेल के रूप में एक उपन्यास FSS संरचना को 100- 600GHz की आवृत्ति रेंज में संरचना, निर्मित और विशेषता दी गई है। यह देखा गया है कि अभिकलक-तंत्र आधारित परिणाम प्रयोगात्मक परिणामों के साथ अच्छे समझौते में हैं। पार्श्व सोने की धातु परत के साथ एक अवशोषक के रूप में अध्ययन करने पर समान संरचना THz रेंज (441GHz से 592GHz) के भीतर अवशोषण चोटियों को दर्शाती है।

जहां कहीं भी संभव हुआ, प्रस्तुत शोध-प्रबंध में अभिकलक-तंत्र आधारित परिणामों को सत्यापित करने का पूर्ण प्रयास किया गया। कुछ मामलों में, निर्माण की जटिलताओं और प्रयोगशाला में उपलब्ध सीमित सुविधाओं के कारण, केवल अभिकलक-तंत्र-आधारित अध्ययनों की सूचना दी गयी है।

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“You are like a manuscript, not a completed book. A book has a beginning, a middle, and an end. It is printed by machines in a press and bound as a permanent unit. But you do not know from where you have come or where you will go. You are in search of the beginning and ending pages of life in order to make your manuscript complete.”

-Sri Swami Rama
1925-1996, Indian Sage
In *“path of Fire and light: Vol 2”*