Declaration

I hereby declare that the work presented in this thesis entitled *Studies on Substrate Integrated Coaxial Line Technology (SICL) Based Microwave and Millimeter-Wave Active Circuits* submitted to the Indian Institute of Technology Jodhpur in partial fulfillment of the requirements for the award of the degree of Doctor of Philosophy, is a bonafide record of the research work carried out under the supervision of Dr. Soumava Mukherjee. The contents of this thesis in full or in parts, have not been submitted to, and will not be submitted by me to, any other Institute or University in India or abroad for the award of any degree or diploma.

Saurabh Shukla
P19EE006

Certificate

This is to certify that the thesis titled *Studies on Substrate Integrated Coaxial Line Technology (SICL) Based Microwave and Millimeter-Wave Active Circuits*, submitted by *Saurabh Shukla (P19EE006)* to the Indian Institute of Technology Jodhpur for the award of the degree of *Doctor of Philosophy*, is a bonafide record of the research work done by him under my supervision. To the best of my knowledge, the contents of this report, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma.

Dr. Soumava Mukherjee
Ph.D. Thesis Supervisor

Abstract

Microwave and Millimeter-Wave (mmWave) active circuits are pivotal in modern communication systems, and other emerging technologies. The research work in this thesis is focused on implementing the microwave and millimeter wave active circuits such as bias tee circuits, amplifiers, SPDT switches, oscillators, and mixers. Various circuit technologies have been available to implement active circuits for the past thirty years. Bulky air-filled waveguides and planar circuit technologies such as microstrip, GCPW, and SIW are well-established in microwave and millimeter-wave circuit design. Air-filled waveguides offer lower loss, but they are bulky, while the aforementioned planar technologies provide compact size at the expense of higher loss. In recent decades, a technology known as substrate-integrated coaxial lines (SICL) has emerged as a bridge between coaxial lines and other planar technologies. SICL has gathered considerable attention from microwave and millimeter-wave circuit designers due to its compact size, lower loss, and electromagnetic shielding capabilities. This planar form of the coaxial line structure can be fabricated using printed circuit board (PCB) technologies and can be seamlessly integrated with other planar circuits. In this work, the design of various microwave and millimeter wave active circuits based on SICL technology is presented. The study of RF and DC blocks in the SICL environment, the design of broadband SICL-based bias tee network with butterfly stubs with improved RF isolation, and the innovative approach of interconnecting pads for mounting SMD capacitors are presented. The SICL technology offers a viable solution to integrate SMD components in a low-profile PCB design approach with good insertion loss and isolation. Additionally, the detailed study of designing and implementing an amplifier using SICL technology highlights a novel low-cost PCB-based approach for the mmWave ISM band (23.35- 24.05 GHz). This design also includes the mounting pads for transistors and capacitors and introduces a novel matching network to enhance amplifier gain, demonstrating the potential of SICL technology in high-frequency applications. The study also presents a Ka-Band (27-28.5GHz) SPDT switch for duplexer applications using SICL technology. The switch incorporates an innovative RF isolation network in an asymmetric stripline environment, achieving optimal isolation and performance, as validated by an equivalent circuit model. Further, a high-performance reflection oscillator for Ku-band applications is designed using SICL technology, achieving low phase noise and high output power. Lastly, the research work introduces a compact mmWave downconverter mixer utilizing a SICL-based rat-race coupler, offering cost-effective, compact, and reliable performance with a low conversion loss. This mixer is ideal for high-performance mmWave integrated circuits in communication and radar systems.

This research showcases the viability and effectiveness of SICL technology in various high-frequency applications, providing innovative, cost-efficient solutions for modern communication systems.

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List of Symbols

E	Electric Field Intensity
H	Magnetic Field Intensity
c	Speed of Light in Free Space
k	Wave Number
λ_g	Guided Wavelength
α	Attenuation Constant
β	Phase Constant
γ	Propagation Constant
ε_r	Relative Permittivity of the Dielectric
$\tan\delta$	Loss Tangent of the Dielectric
σ	Electric Conductivity

List of Abbreviations

SICL	Substrate Integrated Coaxial Line
SIW	Substrate Integrated Waveguide
PCB	Printed Circuit Board
SMD	Surface Mount Device
ML	Microstrip Line
GCPW	Grounded Coplanar Waveguide
VNA	Vector Network Analyzer
ADS	Adavance Design System
HFSS	High Frequency Structural Simulator
DGS	Defected Ground Structure
PTH	Plated Through Hole
SPDT	Single Pole Double Through
TDD	Time Division Duplex
NF	Noise Figure
FOM	Figure of Merit
NTN	Non-Terrestial Networks
RL	Return Loss

IL	Insertion Loss
LTCC	Low Temperature Co-fired Ceramic
TE	Transverse Electric
TM	Transverse Magnetic
FDD	Frequency Division Duplex
TEM	Transverse Electromagnetic
FR1	Frequency Range 1
FR2	Frequency Range 2
LNA	Low Noise Amplifier
SMA	Sub-miniature Version A
SNR	Signal to Noise Ratio
IoT	Internet of Things
GSM	Global System for Mobile Communication
MMIC	Monolithic Microwave Integrated Circuit
QF	Quality Factor
RF	Radio Frequency
LO	Local Oscillator
IF	Intermediate Frequency
5G	5th Generation