This thesis is dedicated to my dearest grandfather, Lt. Gopal Chandra Das,

my parents, Mr. Dipak Kumar Das and Mrs. Sikha das

and my aunt, Ms. Bina Das

Preface

Antenna arrays are configurations of multiple radiating elements arranged and driven in such a way that their individual electromagnetic fields combine to produce a desired radiation pattern. One of the primary applications of antenna arrays is in Phased Array Antennas (PAAs), where carefully controlling the relative amplitudes and phases of the excitation signals at each element electronically, the combined radiation can be directed, shaped, or enhanced to achieve higher gain, better directivity, and improved overall performance compared to a single-element antenna. Ensuring optimal performance, some of the key design requirements must be met in antenna arrays for PAAs. These include wide bandwidth, minimized mutual coupling between radiating elements, energy-efficient beam steering. Various approaches have been explored to address these requirements; however, several challenges remain. The concerns cover reliability, increased design complexity, larger form factors, and the ease of integrating the technology with the existing antenna systems. The impetus of the thesis is in finding solutions to the critical challenges faced while designing antenna array systems.

The wideband feature in a low-profiled array is achieved by amalgamating two separate techniques, which includes substrate integrate waveguide (SIW) and slotted patch technique. A 64-element wideband planar patch antenna array is developed. An additional feature of incorporating onboard calibration technique using printed calibration lines strategically placed in the same plane as the antennas is developed. A bandwidth of over 7.95% is achieved for the centre element of the array on only $0.03\lambda_0$ thick substrate. The work also addresses a technique to mitigate mutual coupling within a compact array configuration to enhance element isolation. A metasurface superstrate-based technique is presented to sufficiently decouple closely spaced antenna in an array. The technique can reduce mutual coupling in both 1×3 and 1×7 antenna array.

Additionally, an efficient, low-power active beam steering method is proposed for patch antenna arrays for fast beam steering with minimal energy consumption. A transmission phase reconfigurable metasurface placed above the antenna array is tested for beam steering.

Furthermore, the study also includes the design of an integrable, low-power phase reconfiguration mechanism to enable dynamic phase reconfiguration. Fluidic channels are placed between vertically-coupled microstrip structures to achieve a real-time phase tunability by incorporating high dielectric fluid in the channels. The reusability of the design is tested and verified.

DECLARATION

I hereby declare that the thesis *"**Investigation of patch antenna array with enhanced bandwidth, mutual coupling mitigation and active beam steering for phased array application in X-band**"*, being submitted to Department of Physics, Tezpur University, Tezpur, Assam in partial fulfilment for the award of the degree of Doctor of Philosophy in Physics, has previously not formed the basis for the award of any degree, diploma, associateship, fellowship or any other similar title or recognition.

Date: 29-05-2025

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All helps received from various sources have been duly acknowledge. No part of this thesis has been submitted elsewhere for award of any degree.

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"Believe you can and you're halfway there…."

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List of symbols and abbreviation

ω	Angular velocity
λ	Wavelength
ε'	Real part of permittivity
$tan\delta$	Loss tangent
μ	Permeability
Ω	Ohm
k	Wave vector
mm	Millimeter
cm	Centimeter
V	Volt
dB	Decibel
dBi	Decibel relative to isotropic
GHz	Giga Hertz
MHz	Mega Hertz
DNG	Double Negative
T/R	Transmit and Receive
MS	Metasurface superstrate
PSS	Phase Shifting Surface
PIN	Positive-Intrinsic-Negative
FSS	Frequency Selective Surface
RF	Radio Frequency
MEMS	Micro Electro Mechanical Switch

IDC	Inter Digitated Capacitor
MS	Metasurface superstrate
MILSATCOM	Military Satellite Communications
EM	Electromagnetic
NIM	Negative Index Material
SRR	Split Ring Resonator
PEC	Perfect Electric Conductor
PMC	Perfect Magnetic Conductor
VNA	Vector Network Analyser
SMA	Sub Miniature A
PLA	Polylactic acid
NRW	Nicolson Ross Weir
TLM	Transmission Line Model
AUT	Antenna Under Test
PAA	Phased Array Antenna