I dedicate this work to my loving parents

Mr. Lokamohan Saikia

And

Late Pranati Hazarika

DECLARATION BY THE CANDIDATE

I hereby declare that the thesis entitled "**Gel sub-wavelength resonator embedded flexible meta-structure absorbers for microwave X-band applications**", being submitted to the **School of Sciences**, **Tezpur University**, in partial fulfilment for the award of the **Doctor of Philosophy** in Physics, is a record of original work carried out by me at the Department of Physics, Tezpur University, Assam, India, under the supervision of Prof. Nidhi S. Bhattacharyya. All sources of assistance have been duly acknowledged. I also declare that neither this work as a whole nor a part of it has been submitted to any other University or institute for any degree, diploma, associateship, fellowship or any other similar title or recognition.

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All helps received from various sources have been duly acknowledged.

No part of this thesis has been submitted elsewhere for award of any other degree.

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This is to certify that the thesis entitled "**Gel sub-wavelength resonator embedded flexible meta-structure absorbers for microwave X-band applications**", being submitted by **Ms. Sanghamitra Saikia** to Tezpur University in the Department of Physics under the School of Sciences in requirement partial fulfilment for the award of the degree of Doctor of Philosophy in Physics has been examined by us on April 02, 2024 and found to be satisfactory.

The committee recommends for the award of the degree **Doctor of Philosophy**.

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"***Alone, we can do so little; together, we can do so much***." - Helen Keller

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Preface

Microwave absorbers have found irreplaceable applications in wireless communication since its first implementation in World War II. Miniaturization of wireless communication technology has led to placement of wireless and electronic devices in close proximity resulting in enormously undesirable and uncontrolled electromagnetic wave (EM) radiations causing malfunctions of the components. A need for lightweight, thin, flexible, absorbers is necessary to obtain an electromagnetic interference free environment. Meta-structure absorbers (MSAs) are an effective replacement to volumetric broadband conventional absorbers with the advantages of flexibility and low thickness similar to 2D structured metamaterial absorbers (MMAs) and outstand MMAs in terms of performance bandwidth and ease of fabrication.

Gel is chosen here as the lossy dielectric material to develop the resonating periodic structures embedded in low dielectric matrix to design and construct flexible, planar meta-structure absorbers operating in the microwave X-band range. Slime, a water based gel and ionic DES gel are used to develop the resonating structures, while silicone-rubber is used as flexible matrix. Symmetrical resonator shapes are taken for polarization angle independent absorption performance. The absorbers are designed and optimized to obtain a wide >90% absorption bandwidth in the operating band. A thin cover of environmentally inert matrix is placed on the top of the developed structure to protect it from damages and make the MSAs more robust. The absorbers are kept planar with a thickness of $\sim\lambda/10$ for convenience of mounting on any surfaces.

The developed gel based MSAs are tested for antenna isolation, RCS reduction and revertibility usages.

Optically transparent DES gel MSA is developed by using optically transparent urethane rubber as matrix. The conventional PEC reflecting back is replaced by copper mesh to obtain a standalone MSA tile (15×15 cm^2). The fabricated transparent absorber is found to effectively low the RCS of solar panels without much effecting its performance.

Keywords: Flexible, polarization insensitive, wide band, meta-structure absorber, slime, deep eutectic solvent gel, urethane rubber, revertibility, radar cross section reduction, antenna isolation, camouflaging solar panel.

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List of abbreviations and symbols

MSA	Meta-structure absorber
EM	Electromagnetic
2D	Two dimensional
3D	Three dimensional
IL	Ionic liquid
EMI	Electromagnetic Interference
RCS	Radar cross section
RCSR	Radar cross section reduction
E	Electric field
H	Magnetic field
TGA	Thermo Galvanometric Analysis
TE	Transverse Electric
TM	Transverse Magnetic
VNA	Vector Network Analyzer
CST	Computer simulation technique
TRL	Trough Reflection Line
GHz	Gigahertz
DES	Deep eutectic solvent
BW	Bandwidth
RF	Resonant frequency
RL	Reflection loss
4FS	Four-fold symmetry
6FS	Six-fold symmetry
OT	Optically transparent
Cu	Copper
f	Frequency
λ	Wave length

ε_a	Permittivity
ε_a'	Real part of complex permittivity
ε_a''	Imaginary part of complex permittivity
ε_0	free space permittivity= $8.86 \times 10^{-12} Fm^{-1}$
μ_a	Permeability
μ_a'	Real part of complex permeability
μ_a''	Imaginary part of complex permeability
μ_0	free space permeability= $4\pi \times 10^{-7} Hm^{-1}$
ω	Angular frequency
θ	Theta
φ	Phi
π	Pi
$tan\delta_e$	Dielectric loss tangent
dB	Decibel
Z	Impedance of free space
Z_a	Impedance of absorber
σ	Conductivity
ρ	Density
℃	Degree Celsius
S_{11}	Scattering parameter (reflection)
S_{21}	Scattering parameter (transmission)
A_ω	Absorption magnitude
R_ω	Reflection co-efficient
T_ω	Transmission co-efficient
mm	Millimeter
nm	Nanometer
MPa	Mega Pascal
g	Gram
h	Hour/Hours
wt. %	Weight percentage