VISVESVARAYA TECHNOLOGICAL UNIVERSITY

Jnana Sangama, Belagavi – 590018

A Project Report on

"DESIGN AND DEVELOPMENT OF DIFFERENT 3D PRINTED HORN ANTENNAS USING ADVANCED ADDITIVE MANUFACTURING TECHNIQUES"

Submitted in partial fulfilment of the requirement for the award of degree of

BACHELOR OF ENGINEERING
IN
ELECTRONICS AND COMMUNICATION ENGINEERING

Submitted by

J N MOHIT	**(1RR21EC029)**
SPOORTHI B M	**(1RR21EC081)**
SRUSTI MANJU G S	**(1RR21EC082)**
VIVEK C K	**(1RR21EC101)**

Under the guidance of

Dr. DEEPIKA J
Associate Professor
Dept. of ECE

DEPT. OF ELECTRONICS & COMMUNICATION ENGINEERING
RAJARAJESWARI COLLEGE OF ENGINEERING
[Affiliated to VTU, Belagavi, Approved by AICTE, Accredited by NBA & NAAC]
#14, Ramohalli Cross, Mysore Road, Kumbalgodu, Bengaluru-74

2024-2025

RAJARAJESWARI COLLEGE OF ENGINEERING

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#14, Ramohalli Cross, Mysore Road, Kumbalgodu, Bengaluru-74

ELECTRONICS & COMMUNICATION ENGINEERING

CERTIFICATE

This is to certified that the project work entitled **"DESIGN AND DEVELOPMENT OF DIFFERENT 3D PRINTED HORN ANTENNAS USING ADVANCED ADDITIVE MANUFACTURING TECHNIQUES"** is a bonafide work carried out by **J N MOHIT [1RR21EC029], SPOORTHI B M [1RR21EC081], S R U S T I MANJU G S [1RR21EC082], VIVEK C K [1RR21EC101]** in partial fulfilment for the award of **Bachelor of Engineering in Electronics and Communication Engineering** of the **Visvesvaraya Technological University**, **Belagavi** during the year 2024-2025. It is certified that all corrections & suggestions indicated for internal assessment have been incorporated in the report & deposited in the departmental library. The project report has been approved as it satisfies the academic requirements.

Signature of the Guide	Signature of the HOD	Signature of the Principal
Dr. Deepika J	**Dr. Sunitha R**	**Dr. R Balakrishna**
Associate Professor,ECE	Prof. and Head, Dept, of ECE	Principal, RRCE

Name of the Examiners: **Signature with date:**

1.

2.

DECLARATION

We, J N MOHIT (1RR21EC029), SPOORTHI B M (1RR21EC081), SRUSTI MANJU G S (1RR21EC082), VIVEK C K (1RR21EC101) students of 7th semester B.E in Electronics and Communication Engineering, **Rajarajeswari College of Engineering, Bengaluru** hereby declare that the project work entitled **"DESGIN AND DEVELOPMENT OF DIFFERENT 3D PRINTED HORN ANTENNAS USING ADVANCED ADDITUVE MANUFACTURING TECHNIQUES"** submitted to the **Visvesvaraya Technological University** during the academic year 2024-25, is a record of an original work done by us, under the guidance of Dr. Deepika J, Associate Professor, Department of Electronics & Communication Engineering, Rajarajeswari College of Engineering, Bengaluru. This project work is submitted in partial fulfilment of the requirements for the award of the degree of Bachelor of Engineering in Electronics & Communication Engineering. The results embodied in this have not been submitted to any other University or Institute for the award of any degree.

NAME OF THE STUDENTS:

J N MOHIT	**(1RR21EC029)**
SPOORHI BM	**(1RR21EC081)**
SRUSTI MANJU G S	**(1RR21EC082)**
VIVEK C K	**(1RR21EC101)**

DATE:

PLACE: BENGALURU

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ABSTRACT

The horn antenna is an antenna that consists of a flaring metal waveguide shaped like a horn to direct radio waves into a beam. 3D printing is a fast-growing technology for rapid prototyping of mechanical structures at a relatively low cost. This enables quick production and demonstrations of experimental models and measurement results for innovative ideas. In this application note, we describe our experiences fabricating a horn antenna using 3D printing technology. 3D printing a horn antenna can be a great way to prototype and manufacture custom antennas, especially when you need complex geometries or want to quickly iterate on design ideas. However, there are specific considerations that need to be taken into account when 3D printing a horn antenna to ensure it works effectively in its intended frequency range. This trend toward smaller electronic devices makes the three dimensional (3D) antennas very appealing, since they can be designed in a way to use every available space inside the devise.

KEYWORDS: Horn antenna, Double rigid horn antenna, Radio frequency, Radiation pattern, 3D printing**,** Digital Design, Slicing, Stereo lithography.

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LIST OF ACRONYMS

3D - Three Dimensional

PLA - Polylactic Acid

ABS - Acrylonitrile Butadiene Styrene

PETG - Polyethylene Terephthalate Glycol

TPU - Thermoplastic Polyurethane

FDM - Fused Deposition Modeling

SLA - Stereolithography

SLS - Selective Laser Sintering

CAD - Computer-Aided Design

RF - Radio Frequency

IoT - Internet of Things

VSWR - Voltage Standing Wave Ratio

PEC - Perfect Electric Conductor

UAV - Unmanned Aerial Vehicle

UHF - Ultra High Frequency

ML - Machine Learning

AI - Artificial Intelligence

VNA - Vector Network Analyzer

HFSS - High-Frequency Structure Simulator

CHAPTER 1

INTRODUCTION

1.1 OVERVIEW

Introduction to the Design and Development of Different 3D Printed Horn Antennas Using Advanced Additive Manufacturing Techniques

The advent of 3D printing, also known as additive manufacturing, has revolutionized the design and production of complex components, offering unprecedented design flexibility, reduced manufacturing time, and cost efficiency. In the field of antenna design, particularly horn antennas, 3D printing enables the fabrication of geometrically intricate and lightweight structures that were previously difficult or impossible to produce using conventional methods.

Horn antennas are widely used in microwave and millimeter-wave applications for their ability to provide wideband performance, low VSWR (Voltage Standing Wave Ratio), and high directivity. These antennas are often used in radar systems, satellite communications, and in testing environments such as anechoic chambers. Traditional methods of fabricating horn antennas often involve metal machining or casting, which can be expensive, time-consuming, and limited in terms of design complexity.

Advanced additive manufacturing techniques, including Fused Deposition Modeling (FDM), Stereolithography (SLA), and Selective Laser Sintering (SLS), have significantly enhanced the design and production of horn antennas. These methods allow for the creation of highly optimized and customized antenna structures, including intricate internal features and novel geometries that improve performance. Moreover, 3D printing can facilitate the integration of multiple components into a single, unified structure, reducing the overall assembly time and potential for error.

This research focuses on the design, optimization, and development of different types of horn antennas fabricated using advanced 3D printing techniques. By leveraging the flexibility and capabilities of 3D printing, this study aims to explore the potential for improved antenna performance, reduced manufacturing costs, and more efficient production processes.

Key objectives include evaluating the effects of different printing materials, optimization strategies for horn geometry, and performance analysis in real-world scenarios. Through this work, we aim to push the boundaries of horn antenna design while contributing to the evolving field of 3D printed electromagnetic devices.

As the demand for high-performance, low-cost, and rapid prototyping in antenna design increases, 3D printing represents a promising solution that could redefine how horn antennas are developed and deployed in various applications.

1.2 MOTIVATION

Horn antennas are integral components in many high-frequency applications, including satellite communications, radar systems, and electromagnetic testing. However, traditional manufacturing processes often face challenges such as high costs, limited design flexibility, and material waste. The advent of advanced additive manufacturing (AM) techniques has created opportunities to overcome these challenges and unlock new possibilities in antenna design and development. The key motivations for this innovation are outlined below:

Overcoming Limitations of Traditional Manufacturing: Conventional fabrication methods (e.g., milling, casting) restrict the geometric complexity of horn antennas, limiting their design potential.

- **Reducing Production Costs and Time:** Traditional processes involve expensive tooling and extended lead times for prototyping and production.
- **Design Freedom and Customization:** AM techniques support the creation of custom horn antennas tailored to specific requirements, such as frequency range, gain, and beamwidth.
- **Material Versatility:** AM supports a variety of materials, including lightweight polymers, metallic alloys, and composite materials. This allows for the development of antennas that are lighter, more durable, and better suited to extreme environmental conditions.
- **Integration of Multi-Functional Features:** Additive manufacturing facilitates the integration of additional functionalities, such as embedded waveguides, thermal management systems, and RF shielding, into a single component.
- **Sustainability and Material Efficiency:** Unlike subtractive methods, AM uses only the material required for the build, significantly reducing waste.

- **Exploration of Novel Designs:** AM empowers researchers to experiment with unconventional and innovative designs, such as gradient structures or topology-optimized profiles, which were previously impractical.
- **Support for Emerging Applications:** Advanced technologies, such as 5G, IoT, and satellite constellations, demand high-performance antennas with precise characteristics. Additive manufacturing enables the rapid development of antennas to meet these emerging requirements.
- **Scalability and On-Demand Manufacturing:** AM allows on-demand production, reducing the need for inventory storage and enabling localized manufacturing for time-critical applications.
- **Paving the Way for Next-Generation Solutions:** The combination of 3D printing and antenna design fosters innovation in areas like space exploration, unmanned aerial vehicles, and wearable technology. These applications benefit from lightweight, compact, and high-performance antennas, which are made feasible by advanced AM techniques.

1.3 PROBLEM STATEMENT

Horn antennas are critical components in various high-frequency applications, such as satellite communication, radar systems, and wireless networks, where precision and performance are paramount. Traditional manufacturing techniques, such as machining and casting, impose significant limitations on the design flexibility and scalability of these antennas. These methods often lead to high production costs, extended lead times, and material inefficiencies, particularly for complex or custom designs. Moreover, as the demand for antennas with advanced functionalities and optimized performance increases, traditional approaches struggle to accommodate the need for innovative geometries, lightweight materials, and multi-functional integration. In parallel, modern applications like 5G communication, space exploration, and IoT devices require antennas that are not only high-performing but also lightweight, compact, and customizable. The inability of conventional manufacturing processes to address these evolving needs has created a pressing demand for alternative fabrication methods.

1.4 OBJECTIVES

- **Develop Innovative Designs:** Create horn antenna geometries that leverage the design freedom offered by advanced additive manufacturing techniques.
- **Optimize Performance:** Enhance key performance metrics such as gain, bandwidth, and radiation efficiency through novel design approaches.
- **Reduce Production Costs and Time:** Minimize manufacturing expenses and lead times by replacing traditional methods with efficient 3D printing processes.
- **Explore Material Utilization:** Investigate and utilize advanced materials, including lightweight composites and conductive polymers, to improve antenna performance and durability.
- **Enable Customization:** Design and produce horn antennas tailored to specific operational requirements for diverse applications like 5G, satellite communications, and radar systems.
- **Integrate Advanced Functionalities:** Incorporate additional features such as embedded waveguides, multi-material structures, or thermal management solutions within the antennas.
- **Validate Additive Manufacturing Capabilities:** Assess the feasibility, reliability, and reproducibility of 3D-printed horn antennas for commercial and research purposes.
- **Support Sustainability:** Reduce material waste and promote environmentally friendly manufacturing practices by adopting additive techniques**.**
- **Test and Evaluate Designs:** Perform rigorous testing of 3D-printed horn antennas to ensure compliance with performance standards and operational requirements.
- **Advance Industry Applications:** Demonstrate the applicability of 3D-printed horn antennas in cutting-edge fields, including IoT, aerospace, defense, and wireless communication.

1.5 LIMITATIONS

- **Material Constraints**: Limited availability of high-performance conductive materials suitable for additive manufacturing can impact antenna efficiency, particularly at higher frequencies.
- **Surface Finish Quality**: Additive manufacturing often results in rougher surface finishes compared to traditional methods, which can adversely affect antenna performance b

- **Dimensional Accuracy**: Achieving precise tolerances and geometries required for high-frequency horn antennas can be challenging due to limitations in 3D printer resolution and post-processing techniques.
- **Frequency Range Limitations**: The performance of 3D-printed antennas may degrade at very high frequencies (e.g., millimeter-wave) due to material losses and fabrication imperfections.
- **Structural Integrity**: Additive manufacturing may produce components with lower mechanical strength compared to conventionally fabricated antennas, particularly under extreme environmental conditions.
- **Material Costs**: While AM can reduce overall manufacturing costs, specialized materials suitable for antenna applications, such as conductive or high-temperature-resistant polymers, can be expensive.
- **Post-Processing Requirements**: Many 3D-printed antennas require extensive post-processing (e.g., surface polishing, metallization) to meet performance and aesthetic standards, increasing production time and complexity.
- **Scalability Challenges**: Producing large-scale or high-volume horn antennas using additive manufacturing remains challenging due to printer size limitations and slower build rates compared to traditional methods.
- **Lack of Established Standards**: The adoption of 3D printing for antenna manufacturing is still relatively new, and standardized guidelines for design, fabrication, and testing are not fully developed.
- **Environmental Sensitivity**: Some 3D-printed materials may degrade or perform poorly under harsh environmental conditions such as high humidity, extreme temperatures, or UV exposure.

CHAPTER 2

LITERATURE SURVEY

2.1 BASE PAPERS

SAÚL S. CARVALHO AND RAFAEL F. S. CALDEIRINHA JOÃO R. V. REIS, ARTUR MATEUS, (Senior Member, IEEE). Exploring Design Approaches for 3D Printed Antennas in IEEE, 2024, Volume 12, pp 10718 - 10735

This comprehensive review explores advancements in the design, fabrication and performance evaluation of three-dimensional (3D) printed antennas, across different frequency ranges. Simulation and measurement results are compared to assess antenna performance, considering parameters such as impedance bandwidth, radiation patterns, gain, and efficiency. The findings showcase the significant potential of 3D printing in the development of antennas for wireless communications, terahertz frequencies, transmit array, and multi-beam systems. Various printing techniques are employed to fabricate antennas with complex geometries and optimized performance. Rigorous measurements validate simulation results, addressing challenges related to printing resolution and material selection. This review emphasizes the contributions of 3D printing in antenna engineering, offering customization capabilities, rapid 3D, and improved performance.

STEFANIA DIANA, DANILO BRIZI, CHIARA CIAMPALINI1, GUIDO NENNA, AND AGOSTINOMONORCHIO. A Compact Double-Ridged Horn Antenna for Ultra-Wide Band Microwave Imaging in IEEE,2021,vol 34, pp 134-155

In this paper, we introduce a novel and compact double-ridged horn (DRH) antenna for ultra-wide band microwave imaging. We first develop theoretical considerations useful to derive effective design guidelines and, thus, realizing the antenna model. Afterwards, an electromagnetic numerical solver is employed to study the conceived antenna both in free space and in the presence of a biological load; in both the simulation set-ups, excellent radiating performance are obtained, demonstrating the antenna robustness. Finally, a prototype is fabricated and experimentally measured to validate the final design. The proposed model presents overall dimensions that are 30% smaller with respect to traditional and commercially available DRH antennas (151 mm × 108 mm × 146.6 mm), retaining, at the same time, a significantly large operative band (VSWR >3 over the 1-9 GHz band).

Jason Bjorgaard, Michael Hoyack, Eric Huber, Milad Mirzaee,Yi-Hsiang Chang, and Sima Noghanian. Design and Fabrication of Antennas Using 3D Printing in Electromagnetics Research, 2023,Vol 84,pp 119-134.

Due to a recent growth in three-dimension (3D) printing technology, engineers can fabricate affordable and versatile antennas; however, lossy conductive materials, inadequate antenna terminations, and simplistic designs which do not adequately utilize the available volume continue to limit the capabilities of 3D printed antennas. In this work, the dielectric constants of three polylactic acid (PLA) materials, dielectric PLA, magnetic PLA and conductive PLA, were measured using the coaxial transmission line method, and the results were compared with measurements using the commercially available coaxial probe method. Based on published dielectric constants for solid non-printed PLA, a variety of antenna designs were simulated and fabricated. Each of these antenna designs addressed a certain shortcoming faced by 3D printed antennas. The antennas were designed with a target resonant frequency of 2.45 GHz, an impedance bandwidth of at least 500 MHz, and a gain greater than 1.5 dBi. The three antennas presented here are a fractal bow-tie antenna (FBTA), a spiral antenna, and a Yagi-Uda antenna.

Jana Olivova, Miroslav Popela, Marie Richterova and Eduard Stefl . Multi-Rover Systems for Planetary Exploration. Use of 3D Printing for Horn Antenna Manufacturing in MDPI in 2022, vol 45,pp82-95.

This article describes the manufacturing of a horn antenna using a 3D commercial printer. The horn antenna was chosen for its simplicity and practical versatility. The standardised horn antenna is one of the most widely used antennas in microwave technology. A standardised horn antenna can be connected to standardised waveguides. The horn antenna has been selected so that this antenna can be fabricated by 3D printing and thus obtain the equivalent of a standardised horn antenna. This 3D horn antenna can then be excited by a standardised waveguide. The 3Dprinted horn antenna with metallic layers has very good impedance characteristics, standing wave ratio and radiation patterns that are close to those of a standardised horn antenna. The 3D-based horn antenna is suitable for applications where low antenna weight is required, such as aerospace and satellite technologies. The article also describes a manufacturing procedure for a horn antenna (E-sector horn antenna) that is plated with galvanic layers of silver and gold. The design of the plated horn antenna in the Matlab application using the Antenna Toolbox extension is also described, including 3D printing procedures, post-processing procedures (plating) and practical testing of its functionality. The measured results are compared to simulations of the standardised horn antenna and then analysed.

Z. Khan, H .He, X .Chen, and J. Virkki . "Dipole antennas 3d-printed from conductive thermoplastic filament, " in IEEE Electron. Syst. In teg r. Technol .Conf. in 2020,pp.1–4.

In this paper Fused Deposition Modeling (FDM) of thermoplastics is a flexible and simple 3D printing method. FDM has a variety of adjustable fabrication parameters to modify both the mechanical and electrical properties of the printed structures. However, the use of 3D-printable conductive thermoplastic filaments for electronics manufacturing has so far been quite limited. This type of printing would allow 3D-printed antennas to be efficiently embedded inside 3D-printed structures during the manufacturing process. In this paper, we present prototypes of 3D-printed dipole antennas using a conductive copper-based filament. Despite some initial challenges in the printing process, three types of ultrahigh frequency (UHF) radiofrequency identification (RFID) tag antennas were successfully printed, one of which was a contour pattern and the other two were printed using 100 % antenna patterns. Based on the achieved results, the thickness or printing pattern of the 3D-printed dipole antenna had no major effect on the tag read range. All types of tags showed read ranges of around 0.7-1.1 meters. Further, they were functional throughout the global UHF RFID frequency band (860-960 MHz). These first results are promising, especially when considering the contour type of antenna, which saves a lot of printing material and time.

K. Lomakin, T. Pavlenko, M. Ankenbrand, M. Sippel, J. Ringel, M. Scheetz, T. Klemm, D. Gräf, K. Helmreich, J. Franke, et al., "Evaluation and characterization of 3-d printed pyramid horn antennas utilizing different deposition techniques for conductive material, " in IEEE Trans. Compon. Packag. Manuf. Technol , 2018, vol.8, pp.1998–2006.

This work compares a pyramid horn antenna printed by selective laser sintering (SLS) process from stainless steel powder with a commercially available cast metal horn. Although exhibiting significant surface roughness and lower conductivity, the printed specimen shows almost identical performance as compared to the cast metal reference. The measurement results are analyzed and the impact of surface roughness is attributed to physical relations which can be represented by using an effective, frequency dependent conductivity.

K.V. Hoel,M. Ignatenko, S. Kristoffersen, E. Lier, and D.S. Filipovic,"3-d printed monolithic grin dielectric-loaded double-ridged horn antennas," IEEE Trans. Antennas Propag., vol. 68, pp.533–539,2019.

Monolithic integration of 3-D printed gradient index (GRIN) dielectric loading with a double-ridged rectangular horn standard gain horn (SGH) and its impact on antenna performance are demonstrated. Results show that the GRIN loaded horns improve sidelobe levels (SLLs) and beam symmetry, while maintaining good impedance match and relatively high radiation efficiency over more than an octave bandwidth from 7.5 to 18 GHz. Moreover, they have low weight and show good robustness to fabrication imperfections. This work paves the way for seamless integration of complex wideband antennas in 3-D printed systems such as unmanned aerial vehicles (UAVs).

D. Helena, A. Ramos, T. Varum, and J.N.Matos,"Inexpensive 3d printed radiating horns for customary things in iot scenarios, "in EuropeanConf.AntennasPropag.,pp.1–4,IEEE,2020.

Three-dimensional (3D) printing technology is an area of research that has received great attention in the last decade and it is pointed out by many as the future of manufacturing. 3D printing can be described as an additive process that creates a physical object from a digital model, depositing materials layer by layer. The ability to quickly produce complex structures at a reduced cost and without wasting materials is the main reason why this additive manufacturing technique is increasingly being used instead of conventional manufacturing processes. 3D printing has been applied in several scenarios, including automotive, maritime and construction industry, healthcare, as well as in the antenna research eld. This paper reviews the current state-of-the-art of 3D printed antennas. Firstly, an overview of 3D printing technology is presented and then a vast number of 3D printed antennas, categorized by their construction process, are described. Finally, the main advantages and some of the limitations of using 3Dprinting technology in the construction of Radio

Frequency (RF) structures are presented.

D. Helena, A. Ramos, T. Varum, and J.N. Matos, Evaluation of different materials to design 3D printed horn antennas for Ku-band, in IEEE MTT-S Int. Microw. Symp. Dig., Nov. 2019, pp. 13.

In this paper the evolution of new satellite services in the Ku-band drives the development of new antenna technologies. For systems like this, the high performance and the antenna's cost are critical aspects to consider. 3D printing technology is a possible solution, as it provides both fast and low cost prototyping, while ensuring high precision features. In this article two 3D printed horn antennas are presented. They followed different production approaches in order to evaluate distinct materials. The first prototype was printed with PLA and then covered with copper tape, while the second one was merely printed with a conductive PLA. Although the first one presented better efficiency, the second one achieved better bandwidth. Further, they were functional throughout the global UHF RFID frequency band (860-960 MHz). These first results are promising, especially when considering the contour type of antenna, which saves a lot of printing material and time.

Mrs. Rikita Gohil, 2 Mrs. Niti P. Gupta. Design and analysis of pyramidal Horn antenna in IJCRT,2020, Vol 8, pp 2320-2882

This paper discusses the design of a pyramidal horn antenna with high gain, suppressed side lobes. The horn antenna is widely used in the transmission and reception of RF microwave signals. Horn antennas are extensively used in the fields of T.V. broadcasting, microwave devices and satellite communication. It is usually an assembly of flaring metal, waveguide and antenna. The physical dimensions of pyramidal horn that determine the performance of the antenna. The length, flare angle, aperture diameter of the pyramidal antenna is observed. These dimensions determine the required characteristics such as impedance matching, radiation pattern of the antenna. The antenna gives gain of about 25.5 dB over operating range while delivering 10 GHz bandwidth. Ansoft HFSS 13 software is used to simulate the designed antenna. Pyramidal horn can be designed in a variety of shapes in order to obtain enhanced gain and bandwidth. The designed Pyramidal Horn Antenna is functional for each X-Band application. The horn is supported by a rectangular wave guide.

CHAPTER 3

3.1 TYPES OF ANTENNA

3.1.1 Antenna Types

Different antenna designs serve various applications. Common types include:

- Dipole Antenna: A basic antenna with two conductors, widely used for general-purpose communication.
- Monopole Antenna: A variation of the dipole, often mounted above a ground plane.
- Parabolic Antenna: A high-gain antenna often used in satellite communication, consisting of a parabolic reflector.
- Patch Antenna: A low-profile antenna typically used in wireless communication systems.
- Yagi-Uda Antenna: Directional antenna that is often used in television reception.

3.1.2 Frequency Range

Antennas are designed to work efficiently at certain frequencies. The frequency range determines the size of the antenna, with lower frequencies requiring larger antennas.

Resonant Frequency: The natural frequency at which an antenna radiates efficiently. For example, a half-wavelength dipole antenna is resonant at a frequency where its length is approximately half the wavelength of the signal.

3.1.3 Radiation Pattern

The radiation pattern defines how the antenna radiates energy in different directions. It can be isotropic (radiates uniformly in all directions), directional (focused in specific directions), or omnidirectional (radiates uniformly in a plane).

Beamwidth: The angular width of the main lobe of the radiation pattern.

Side Lobes: Smaller lobes that represent unwanted radiation in other directions.

3.1.4 Gain

Antenna gain refers to the ability of the antenna to focus radiated energy in a particular direction. Higher gain indicates more focused energy, improving range and efficiency in communication systems.

Directivity: A measure of how much power is radiated in the desired direction relative to other directions.

3.1.5 Impedance Matching

For maximum power transfer between an antenna and the transmission line (or feed), the impedance of the antenna must match the impedance of the line (typically 50 ohms).

Standing Wave Ratio (VSWR): A measurement of impedance mismatch. A lower VSWR indicates better matching and more efficient power transmission.

3.1.6 Polarization

Polarization refers to the orientation of the electromagnetic wave's electric field. Common types include:

- Linear Polarization: Electric field oscillates in a single direction.
- Circular Polarization: Electric field rotates in a circular motion.
- Elliptical Polarization: A combination of linear and circular polarization.

3.1.7 Bandwidth

Bandwidth defines the range of frequencies over which the antenna can operate effectively. A broader bandwidth allows the antenna to transmit and receive signals over a wider range of frequencies, essential for applications like broadband communication.

3.1.8 Size and Efficiency

The size of an antenna is often dictated by the wavelength of the signal. Generally, larger antennas are needed for lower frequencies (longer wavelengths).

Efficiency: The effectiveness with which the antenna converts electrical power into radiated power, minimizing losses.

3.2 BLOCK DIAGRAM

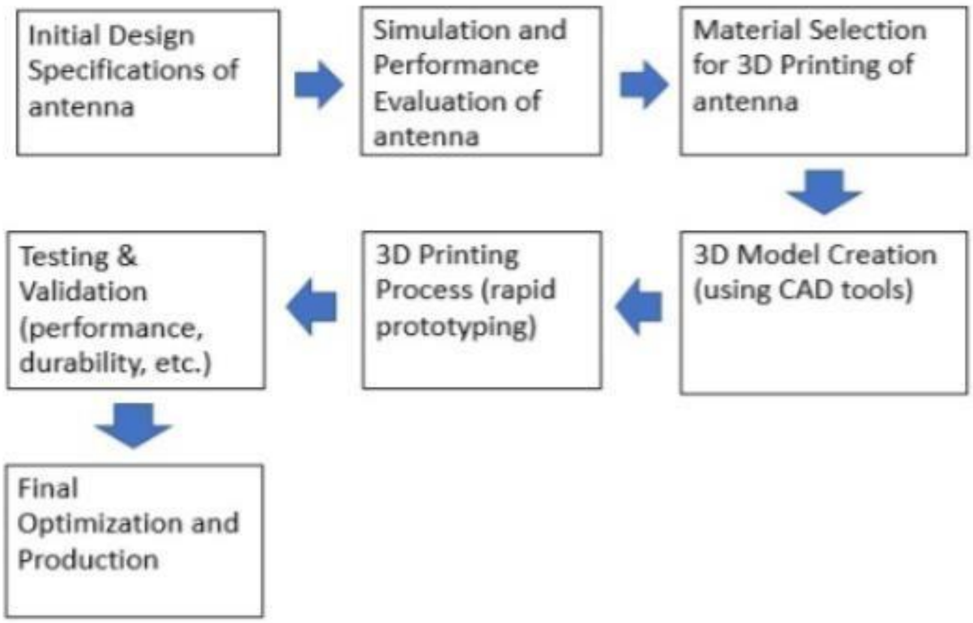


Figure 3.1 Block Diagram

3.3 SOFTWARE USED

COMSOL Multiphysics is a versatile software platform used for simulating and modeling various physical processes in engineering, manufacturing, and scientific research. It provides a comprehensive environment for solving complex, real-world problems through simulation across multiple domains. Here are some key features and aspects of COMSOL:

1. Multiphysics Simulation:

- COMSOL is designed for **multiphysics modeling**, meaning it can couple multiple physical phenomena together in a single simulation. This includes mechanical, electrical, fluid, chemical, and thermal interactions, among others.
- You can model **multi-domain** systems, where different physical effects interact (e.g., heat transfer in a mechanical structure, or fluid flow and electromagnetic fields coupling together).

2. User Interface:

- The user interface of COMSOL is designed to be **intuitive** with drag-and-drop capabilities for creating models, setting up geometries, and defining physics.
- **GUI-based** and **script-based** interfaces are available, allowing both novice users and advanced users to tailor their work according to their needs.

3. Predefined Physics Modules:

- COMSOL comes with a wide variety of **physics interfaces** for different engineering disciplines, including:
  - **Structural Mechanics**: For stress, deformation, and vibration analysis.
  - **Heat Transfer**: For studying temperature distribution and heat exchange.
  - **Fluid Mechanics**: For simulating fluid flow, turbulence, and other related phenomena.
  - **Electromagnetics**: For electrical, magnetic, and electromagnetic simulations.
  - **Chemical Engineering**: For modeling chemical reactions, mass transport, and diffusion.
  - **Acoustics**: For sound wave propagation and noise analysis.
- These modules can be combined to create complex, real-world simulations.

4. Finite Element Method (FEM):

- COMSOL primarily uses the Finite Element Method (FEM) for solving partial differential equations (PDEs) that govern physical phenomena. This allows for detailed, accurate simulations of complex structures and systems.

5. Customization and Scripting:

- COMSOL allows users to further customize their simulations using the COMSOL API (Application Programming Interface). This can be done with Java**,** MATLAB**,** or Python**.**
- The software also supports LiveLink interfaces that allow integration with other platforms like MATLAB for scripting or for use in optimization and automation tasks.

6. Modeling and Solving:

- COMSOL provides a range of solvers for different types of problems, including direct solvers and iterative solvers.
- It also has capabilities for meshing, allowing users to create detailed grids (meshes) for accurate simulation, which is essential for FEM-based simulations.

7. Post-Processing and Visualization:

- COMSOL has strong post-processing tools for visualizing results, including 2D and 3D plots, animations, and contour plots. These tools help users interpret the results in a comprehensible way.
- The software also supports exporting data to other formats for use in presentations or further analysis.

8. Optimization:

- It features advanced optimization tools that can help design or improve a system by adjusting parameters to meet desired performance criteria.

9. Applications and Add-Ons:

- COMSOL offers add-on modules that extend the functionality of the base software, such as CFD (computational fluid dynamics), microwave engineering, battery design, and more.
- COMSOL Application Builder allows users to create custom apps that can be shared with others, facilitating easy access to complex simulations for users who may not be familiar with the full software.

10. Industries and Applications:

- COMSOL is used across a variety of industries, including:
    - Automotive (e.g., structural and thermal analysis of components)
    - Aerospace (e.g., fluid dynamics, material stress, and vibration)
    - Electronics (e.g., electrical and thermal analysis of devices)
    - Energy (e.g., renewable energy systems, heat exchangers)

- Biomedical (e.g., modeling of drug delivery systems, biomechanics)
- Chemical Engineering (e.g., reactor design, mass transport)

Designing of Horn Antenna

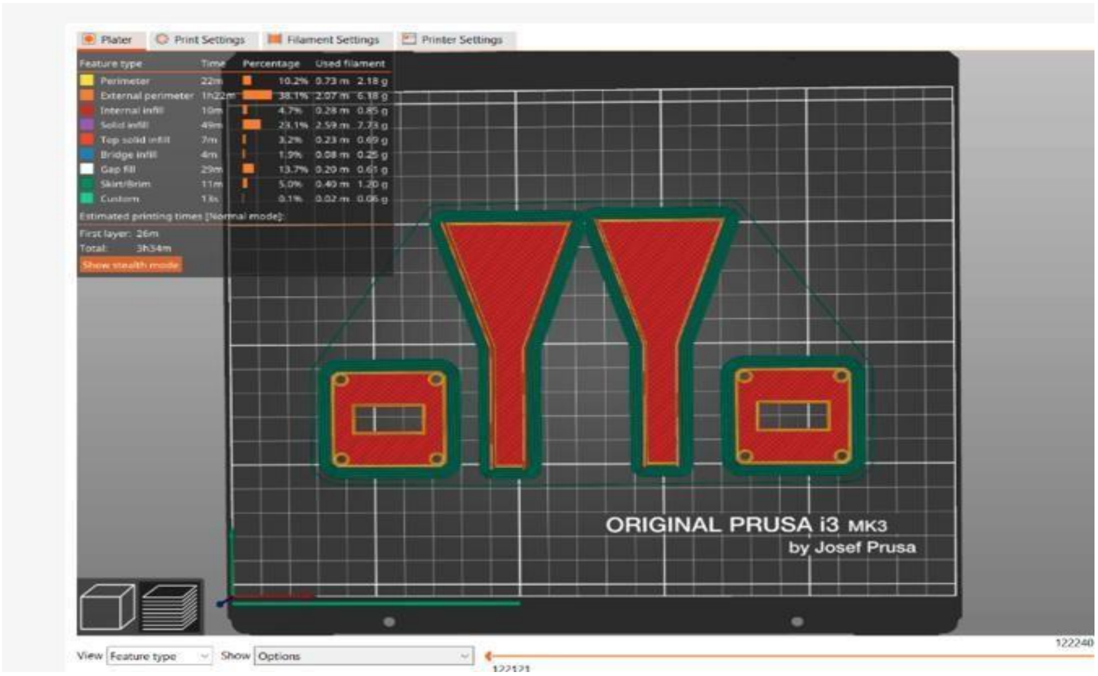


Figure 3.2 Designing of horn antenna

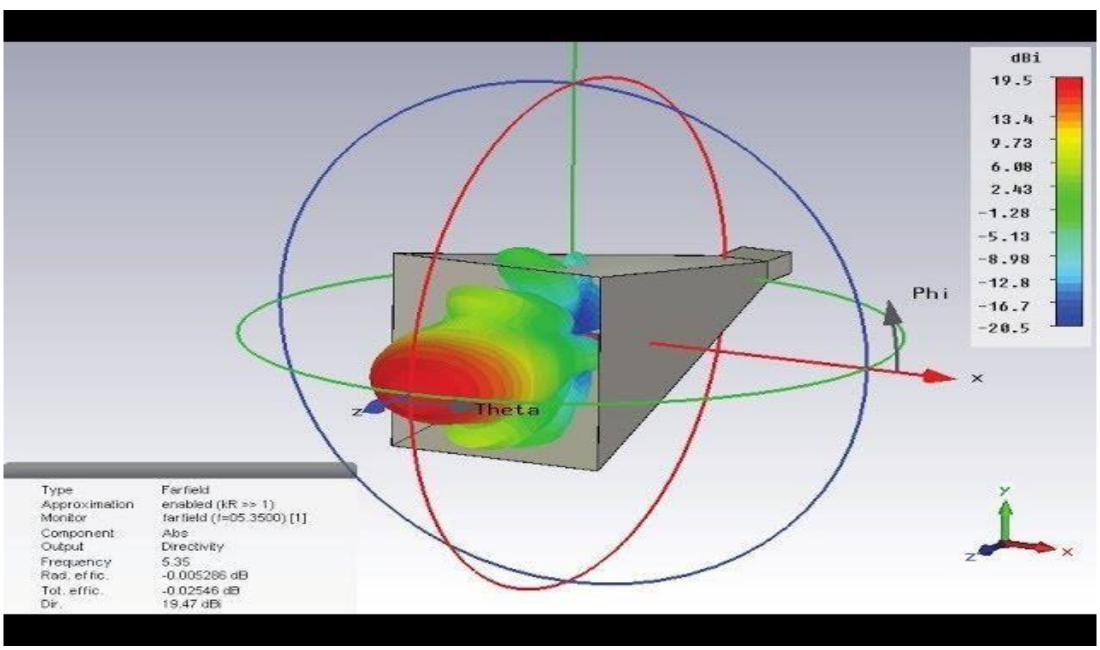


Figure 3.3 Setting up COMSOL

3.4.1 Setting Up COMSOL:

- Open COMSOL Multiphysics and create a new model.
- Choose the RF Module as the physics interface.
- Select the Electromagnetic Waves, Frequency Domain (ewfd) study type.

3.4.2 Geometry Definition:

- The horn antenna's geometry will be defined in 3D space. A simple horn can have a pyramidal shape or a sectoral design. You can also define a rectangular waveguide feeding structure.
- Pyramidal Horn Antenna (Basic Geometry):
  - Start with a rectangular waveguide as the feed.
  - Then taper the walls outward to create a horn shape.
  - You can define a truncated pyramid for the horn.
- To build the geometry:
  - Use the Block feature for the waveguide feed.
  - Use the Cone or Pyramid geometry tools to create the tapered section (horn) that exits from the waveguide.
  - Alternatively, you can create the horn with Revolve or Sweep commands by defining the cross-sectional profile and rotating or sweeping it.
- Typical parameters to consider for the horn include:
  - Waveguide dimensions: width, height, and length.
  - Horn flare angle: the angle at which the horn tapers.
  - Horn aperture dimensions: the width and height at the opening of the horn.

3.4.3 Material Properties:

- Electromagnetic Material: Assign materials like PEC (Perfect Electric Conductor) for the conducting parts, like the waveguide walls and horn.
- Air: For the environment surrounding the antenna, you can assign the material as air or a dielectric material with the appropriate properties (e.g., relative permittivity and permeability).

3.4.4 Boundary Conditions:

- Waveguide Port (Excitation): Use a port to excite the waveguide. For a horn antenna, the port would usually be defined at the waveguide's input, where the electromagnetic wave enters.
- Radiation Boundary (Far-Field): For the antenna's aperture and surrounding space, apply a radiation boundary condition to simulate the wave propagation into free space.
- Perfect Electric Conductor (PEC): Assign PEC boundaries to the inner walls of the waveguide and the horn to ensure they reflect the electromagnetic waves.

3.4.5 Meshing:

- The mesh in COMSOL needs to be fine enough to capture the details of the electromagnetic field, especially at the edges and corners of the horn.
- Use finer mesh settings near the waveguide input and the horn aperture to capture the details of the wave propagation and diffraction.

3.4.6 Study Setup:

- Choose the Frequency Domain study for simulation.
- Define the frequency or frequency range of interest (e.g., the operating frequency of the antenna).
- In the Study settings, choose the appropriate solver to solve Maxwell's equations.

3.4.7 Post-Processing (Far-Field Radiation Pattern):

- After the simulation is complete, use Far-Field Calculations to compute and plot the radiation pattern of the horn antenna.
- You can extract the far-field pattern at different angles to visualize the antenna's directional radiation characteristics.

3.4.8 Simulation and Optimization:

- Run the simulation to obtain results such as the S-parameters, radiation pattern, and directivity.
- You can also perform parametric sweeps (e.g., changing the horn flare angle or feed position) to optimize the antenna design.

- Example of Basic Parameters:
  - Waveguide dimensions: 2 cm x 1 cm
  - Flare angle of the horn: 30°
  - Aperture size: 10 cm x 5 cm
  - Operating frequency: 10 GHz
- Tips for Designing Horn Antennas in COMSOL:
  - Horns are often designed to minimize reflections and maximize directivity, so careful attention should be paid to the dimensions and the flare angle.
  - The waveguide feed should match the impedance of the source to avoid reflections.
  - In the optimization step, consider varying parameters like the aperture size, flare angle, and the length of the horn.

3.5 Material used for 3D printing

- Plastics

  - PLA (Polylactic Acid): A biodegradable, easy-to-print material often used for prototypes and low-stress applications. It is made from renewable resources like cornstarch.
  - ABS (Acrylonitrile Butadiene Styrene): Known for its toughness and impact resistance, often used for parts that need to withstand mechanical stress and higher temperatures.
  - PETG (Polyethylene Terephthalate Glycol): Combines the best of PLA and ABS, offering strength, flexibility, and ease of printing, and is resistant to moisture.
  - Nylon (Polyamide): Strong, flexible, and durable, often used for functional parts, gears, and tools.
  - TPU (Thermoplastic Polyurethane): A flexible material used for creating rubber-like parts, such as phone cases, wearables, and seals.

- Resins

  - Standard Resin: Used for high-detail prints in applications like jewelry, dental, and figurines. It offers a smooth surface finish.
  - Tough Resin: Designed to be more durable and resistant to breaking or cracking, used in mechanical parts.

- Flexible Resin: Offers elasticity and can be used to create flexible and soft parts.
- Castable Resin: Used for investment casting processes in industries like jewelry making and dentistry.

➢ Metals

- Stainless Steel: Common in industrial applications, offering strength and corrosion resistance. Often used for parts in aerospace and automotive industries.
- Titanium: Highly durable and lightweight, used for medical implants, aerospace, and automotive parts.
- Aluminum: Lighter than steel but still strong, often used in automotive and aerospace manufacturing.
- Cobalt-Chrome: Known for its biocompatibility and strength, often used in medical implants.

➢ Ceramics

- Ceramic materials are often used in 3D printing for applications such as creating intricate molds, prototypes, or artistic objects. They can be fired to create durable and heat-resistant items.

➢ Composites

- Carbon Fiber Reinforced Plastics: These materials combine plastic with carbon fibers, providing excellent strength and lightweight properties for high-performance applications.
- Glass Fiber Reinforced Plastics: Similar to carbon fiber but with glass fibers, this composite is used for structural parts that need to be light but durable.

➢ Food Materials

- Chocolate: 3D printing with chocolate allows for the creation of intricate edible designs and sculptures.
- Sugar: Similar to chocolate, sugar can be used for creating complex edible designs and decorations.

➢ Bio-based Materials

- Bio-ink: Used in bioprinting for creating tissue and organ prototypes, typically made from proteins or other organic materials.

➢ Concrete

- Large-scale 3D printers use concrete for building structures, such as homes and bridges. The material is extruded in layers to create durable and cost-effective structures.
- These materials are chosen based on the specific requirements of strength, flexibility, thermal properties, and environmental impact.

3.6 Process involved in 3D printing

➢ Designing the Horn Antenna:

- Software: You'll need a CAD (Computer-Aided Design) software like SolidWorks, Autodesk Fusion 360, or open-source software like FreeCAD to design the horn antenna.
- Horn Design Types: The common types of horn antennas include:
- Pyramidal Horn: Shaped like a pyramid and widely used for broadband applications.
- Sectoral Horn: Used for narrow beamwidths and specific directions.
- Conical Horn: A simpler design, often used in higher-frequency applications.
- Dimensions & Parameters: You'll need to consider key parameters such as frequency range, aperture size, flare angle, and the horn's material properties for 3D printing.
- Aperture Size: The larger the aperture, the more efficient the antenna will be at directing the radio waves.
- Flare Angle: Controls how quickly the horn widens as you move away from the aperture. This influences the beamwidth and gain.

➢ Choosing the Material for 3D Printing:

- Material Selection: The material you choose must be non-conductive to avoid interference with the RF signal but may need to have good dielectric properties. Some materials suitable for 3D printing antennas include:

- PLA (Polylactic Acid): An easy-to-use material but not ideal for high-frequency applications.
- ABS (Acrylonitrile Butadiene Styrene): More durable than PLA but still might not provide ideal RF performance.
- PETG (Polyethylene Terephthalate Glycol): A good compromise between strength and ease of printing.
- Conductive Filaments (optional): Some advanced 3D printers use conductive filaments for parts like feeds or support structures, though the main horn itself would likely remain non-conductive.

➢ 3D Printing the Antenna:

- Resolution: Choose a high-resolution setting (around 0.1mm or finer) for detailed designs to ensure accuracy.
- Printing Orientation: Print the antenna in a way that minimizes the need for post-processing. Depending on the geometry, you might print it flat or vertically to avoid warping or structural issues.
- Supports: Some complex horn designs may require supports during the printing process to prevent drooping or failure of overhanging parts.

➢ Post-Processing:

- After printing, the horn may require some post-processing, such as:
- Smoothing: To ensure the antenna surface is as smooth as possible for better signal reflection and transmission.
- Cleaning: Remove any remaining support material and debris from the print.
- For conductive parts like feeds or connectors, you may need to attach or print metal parts separately to ensure proper signal handling.

➢ Testing and Tuning:

- Impedance Matching: Check the impedance of the antenna (typically 50 ohms for most RF applications). You may need to use a Vector Network Analyzer (VNA) to ensure that the antenna is correctly tuned for the desired frequency.

- RF Testing: Use tools like a signal generator and spectrum analyzer to test the antenna's performance in terms of gain, directivity, and beamwidth.

➢ Applications:

- 3D-printed horn antennas are primarily used in experimental setups, research projects, and custom applications where a standard commercial antenna is too costly or unavailable.
- They are particularly useful for applications requiring high-gain, directional radiation patterns, such as satellite communication, radar systems, and wireless testing.

Example Workflow:

Step 1: Design the horn antenna in CAD software.

Step 2: Choose the right material and settings for 3D printing.

Step 3: Print the antenna using your 3D printer.

Step 4: Post-process the printed model

electric vehicles, and more.

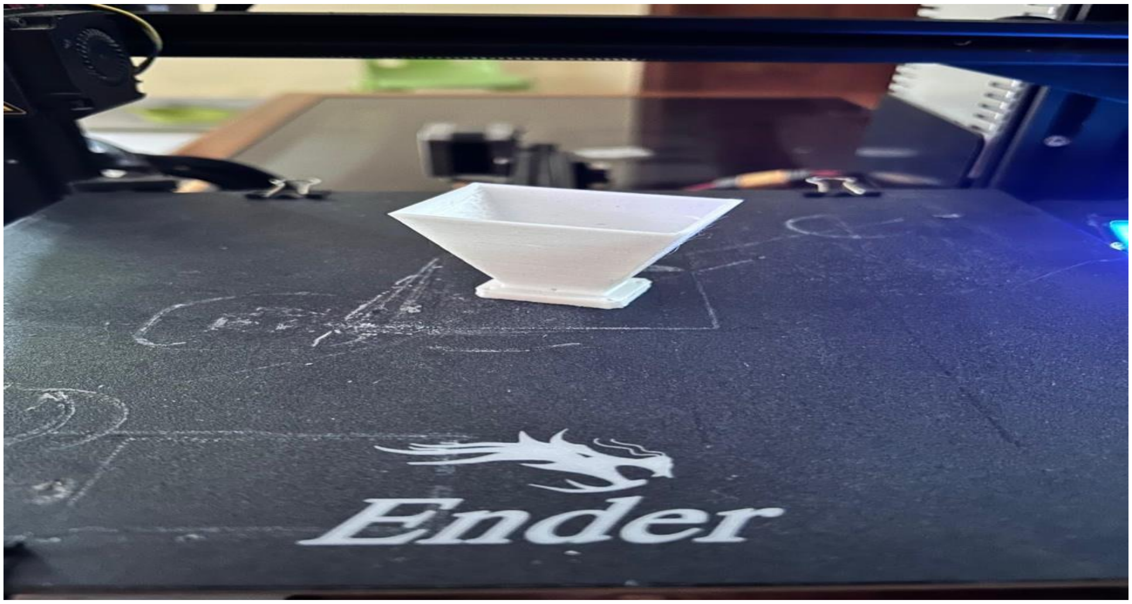


Figure 3.4 SIM800L

- Designing the 3D Model
  - CAD Software: The first step is to create a digital 3D model of the object using Computer-Aided Design (CAD) software (e.g., Comsol Multiphysics, Tinkercad, SolidWorks, Blender).
  - 3D Scanning: Alternatively, a physical object can be scanned using a 3D scanner to create a model.
- Converting to STL or Other File Formats
  - The 3D model is saved in a standard file format, typically STL (Stereolithography) or OBJ. These file formats define the surface geometry of the object.
- Slicing the Model
  - The 3D model is "sliced" into thin horizontal layers using slicing software (e.g., Cura, PrusaSlicer).
  - The slicing software generates G-code or another machine-readable file that contains instructions for the 3D printer on how to build the object layer by layer.
- Preparing the 3D Printer
  - Printer Setup: Ensure the printer's bed is calibrated and the correct print settings are selected, including temperature, layer height, and print speed.
- Printing the Object
  - Additive Process: The printer uses the material (e.g., filament or resin) to build the object layer by layer.
  - For FDM (Fused Deposition Modeling) printers, a heated extruder melts the filament and deposits it onto the build platform.
  - For SLA (Stereolithography) printers, UV light hardens resin layer by layer.
- Post-Processing
  - After printing, the object may require post-processing steps such as:
  - Support Removal: Removing any support structures used during printing.
  - Cleaning: For resin prints, washing the object to remove excess resin.
  - Curing: If using resin, it might need to be further cured under UV light.
  - Sanding and Polishing: Smoothing surfaces and improving the appearance.

➢ Final Inspection and Use

- The printed object is inspected for any defects or inaccuracies. If the object is acceptable, it's ready for use or further assembly.

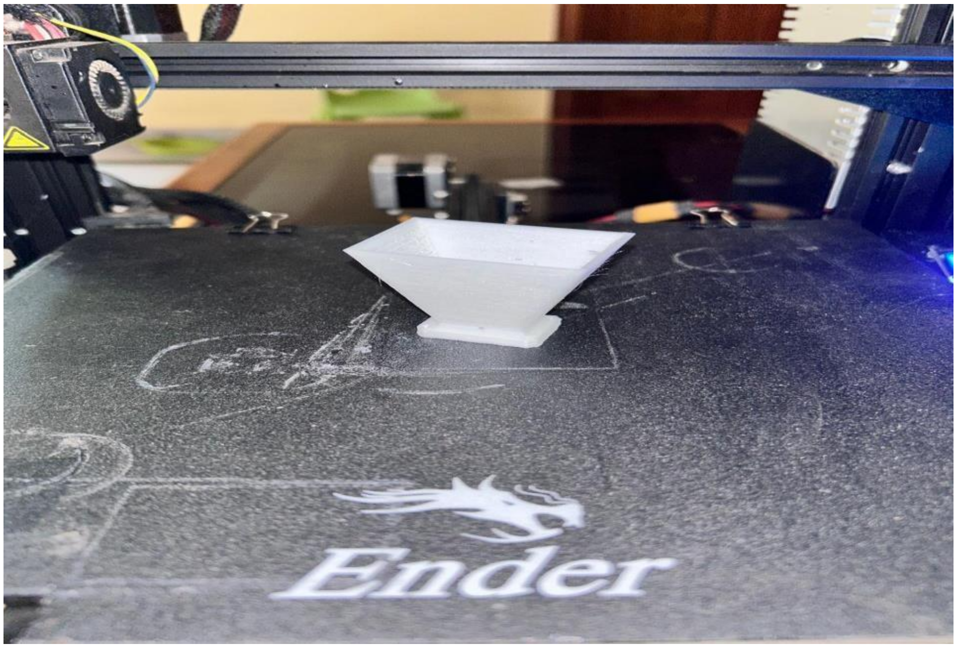


Fig 3.5 Assembly

CHAPTER 4
HARDWARE REQUIRED

4.1 3D PRINTING MACHINE

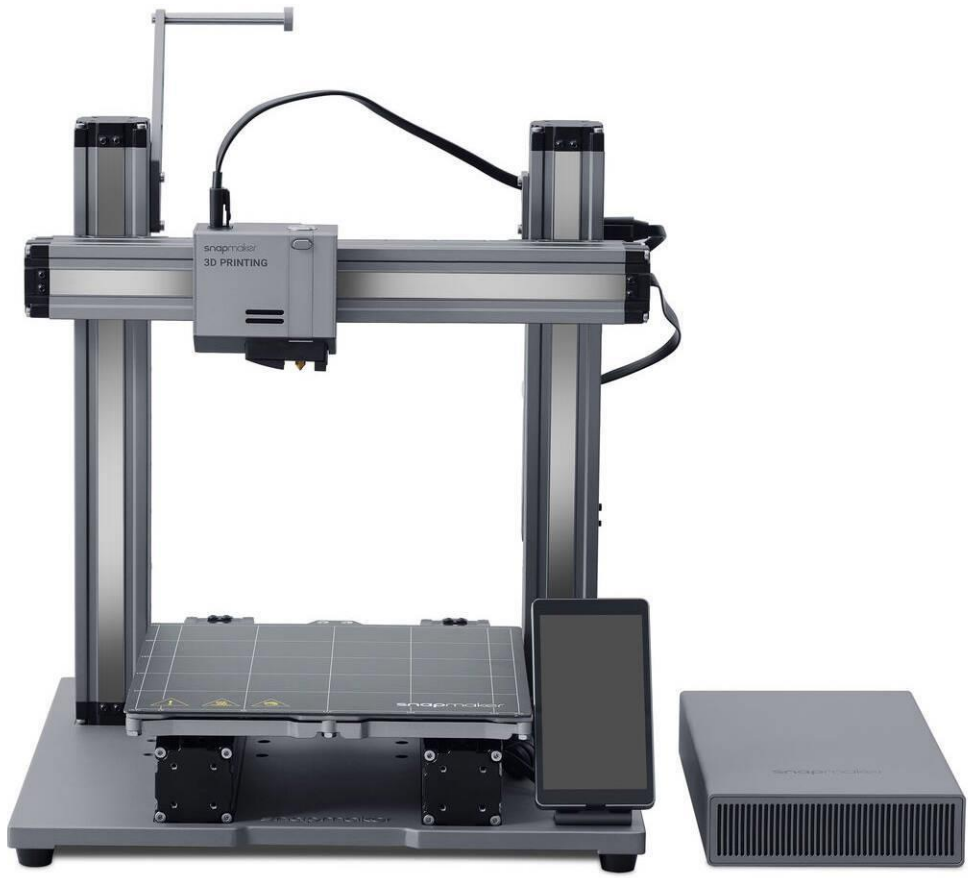


Fig 4.1 3D printing machine

- **Digital Design**: The process begins with a digital model of the object, typically created using 3D modeling software or by scanning an existing object.
- **Slicing**: The model is then "sliced" into thin horizontal layers by specialized software, which prepares the file for the printer.
- **Printing**: The 3D printer reads this sliced data and begins creating the object, layer by layer, using materials such as plastic (PLA, ABS), metal, resin, or even food and living cells.
- **Post-Processing**: After the object is printed, it may require post-processing steps like cleaning, curing (for resin), or finishing (like sanding or painting).

4.2 TYPES OF 3D PRINTERS

- **Fused Deposition Modeling (FDM)**: The most common type, where a filament is heated and extruded through a nozzle to create layers.
- **Stereolithography (SLA)**: Uses ultraviolet light to harden resin layer by layer.
- **Selective Laser Sintering (SLS)**: Uses a laser to sinter powdered material, typically plastic or metal, to form solid objects.
- **Inkjet 3D Printing**: Similar to standard inkjet printing but instead of ink, it uses materials like plastic or resin to create layers.

4.3 APPLICATIONS OF 3D PRINTING

- **Prototyping**: Rapid prototyping allows designers and engineers to quickly create and test models before full-scale production.
- **Manufacturing**: Custom and low-volume production, especially in industries like aerospace, automotive, and medical devices.
- **Healthcare**: Creating customized implants, prosthetics, and models for surgery.
- **Architecture and Construction**: Creating scale models of buildings or even 3D printing actual houses.
- **Art and Fashion**: Artists and designers use 3D printing to create intricate designs, sculptures, and wearable tech.
- **Education**: Used in schools and universities for hands-on learning in STEM fields.

CHAPTER 5
RESULT AND DISCUSSION

5.1 BUILDING THE 3D MODEL

3D printing is a novel prototyping technology, but the model of the horn antenna will be a traditional horn antenna. There are several ways to determine the best dimensions for the horn antenna. The first approach is to calculate the dimensions according to a target frequency using equations. The second approach is to create your model based on an existing design. For example, you can find many antenna reference designs online with different characteristics, and then tune them for your own application or requirements. When creating the models, we can utilize the unique capabilities and advantages of 3D printing. For example, in our demonstration we've added curvature to our model with the objective of reducing ripples in the frequency response.

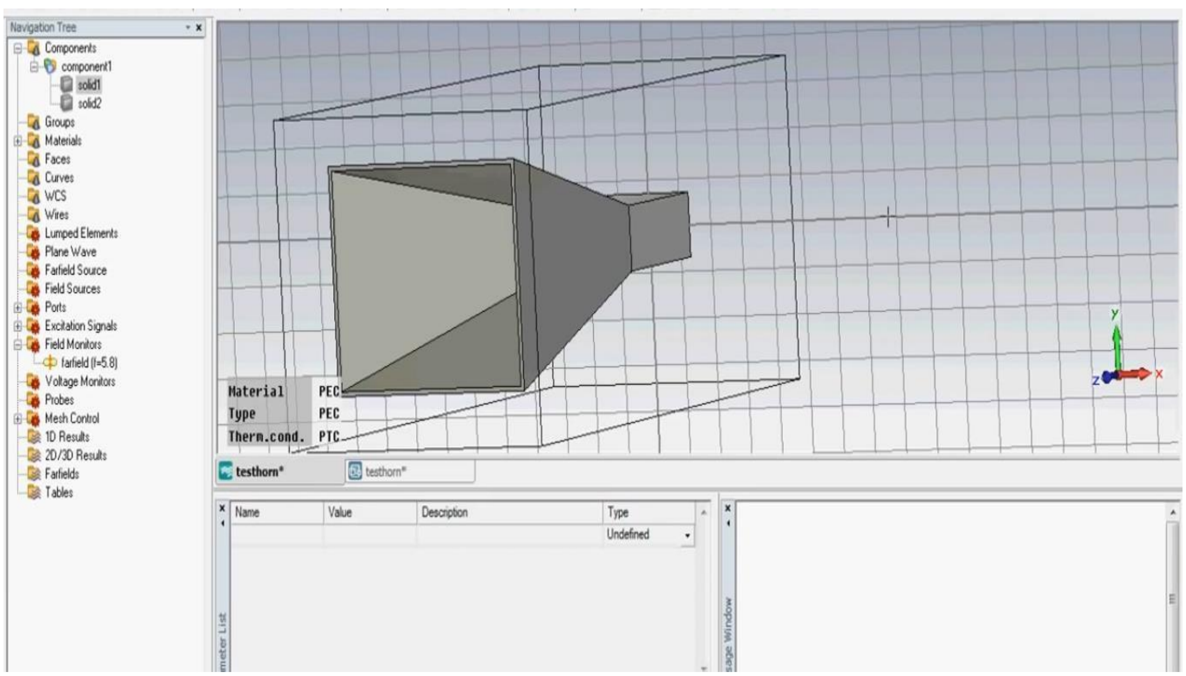


Fig 5.1 3D model

- The following simulation results show the S11, the radiation pattern, and a 3D plot of directivity in turn. The first pair of plots shows a comparison between S11 of a straight, conventional structure (top) and a curved structure (bottom). The smoother transition reduces ripple in the transmitting region by lessening the reflection. Subsequent plots are for the curved horn antenna model. As can be seen in the plots on the following page, the directivity estimated by the simulation is 14.37 dBi.

5.2 ANNEX STIMULATED RESULTS

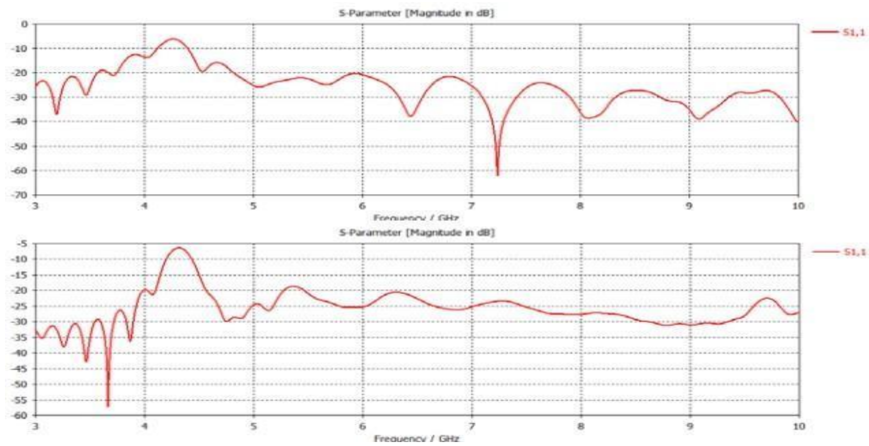


Fig 5.2 Annex stimulated results

5.3 RADIATION PATTERN

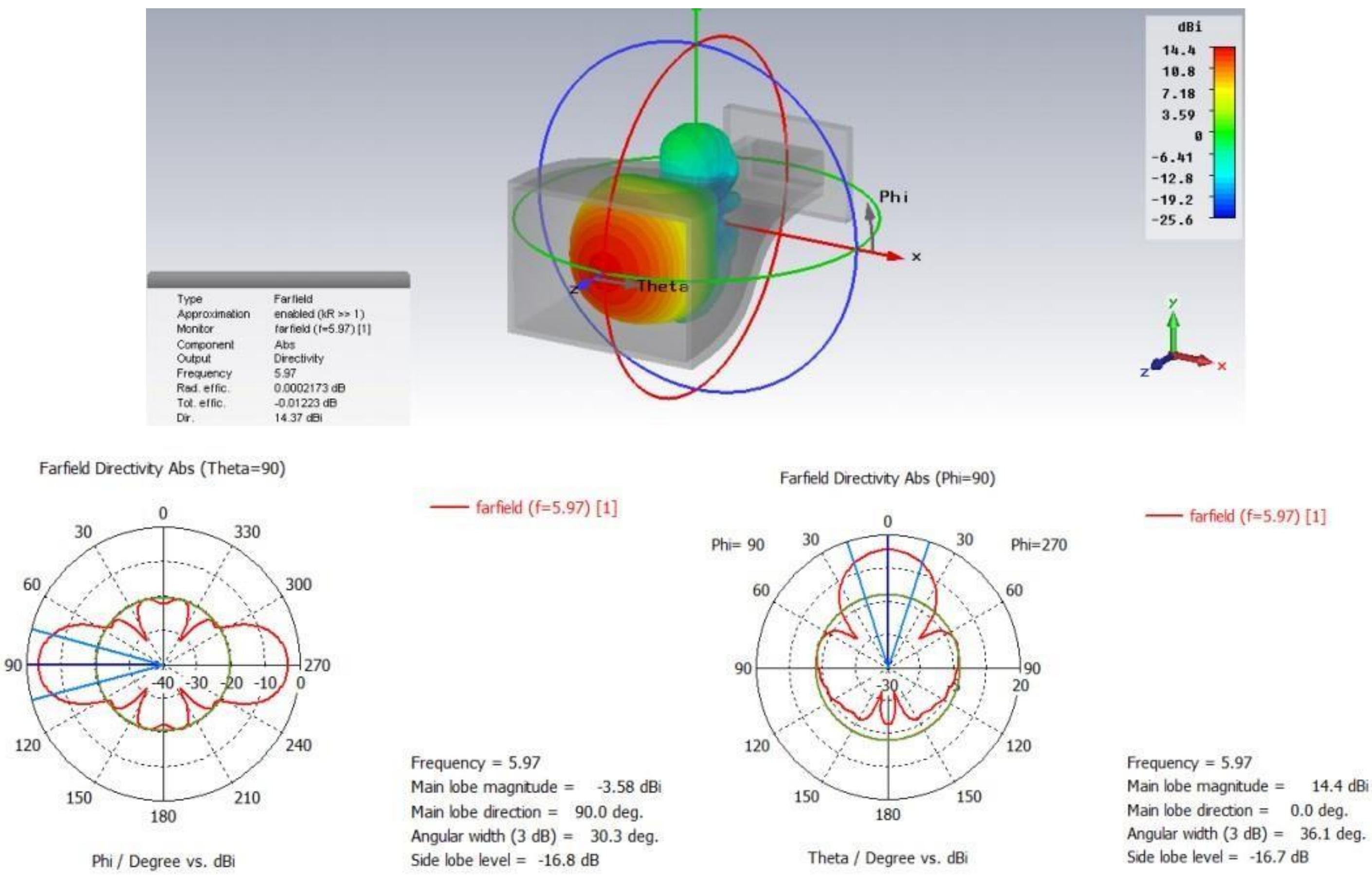


Fig 5.3 Radiation pattern

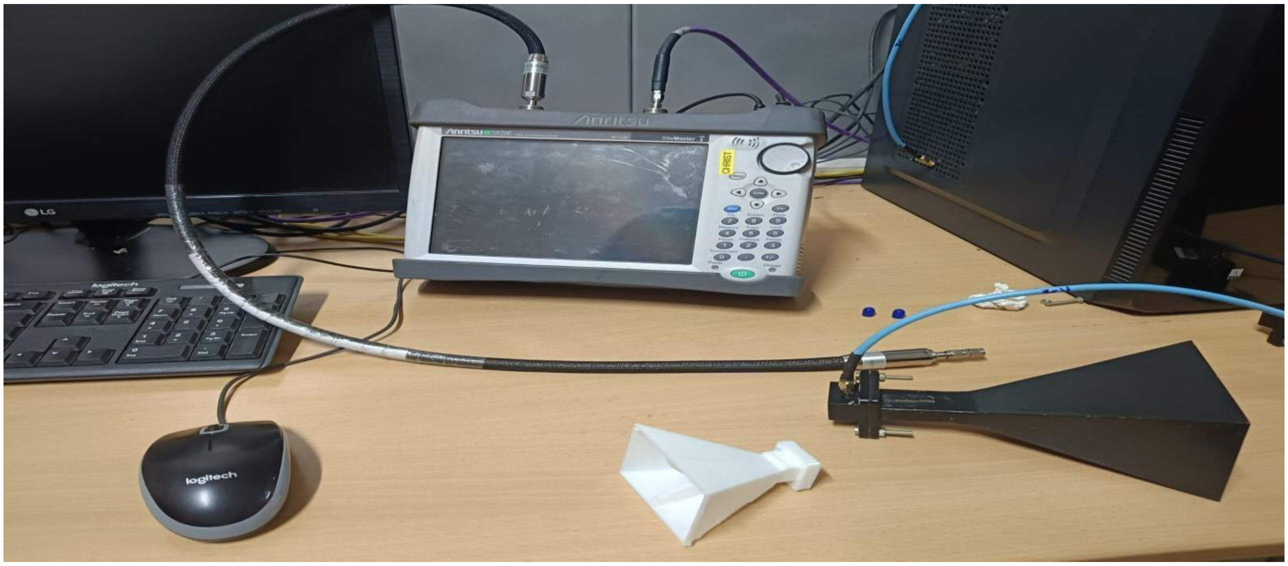


Fig 5.4 Vector network analyzer

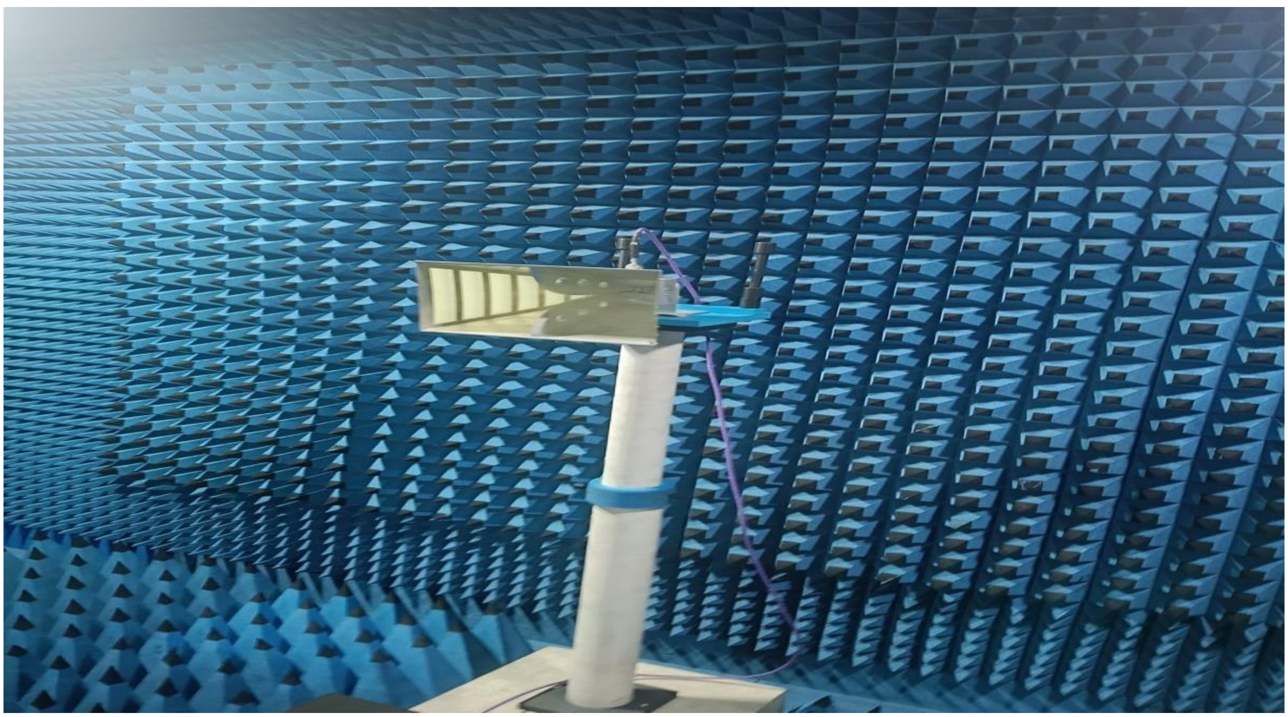


Fig 5.5 Annex chamber

Fig 5.6 Annex chamber receiver

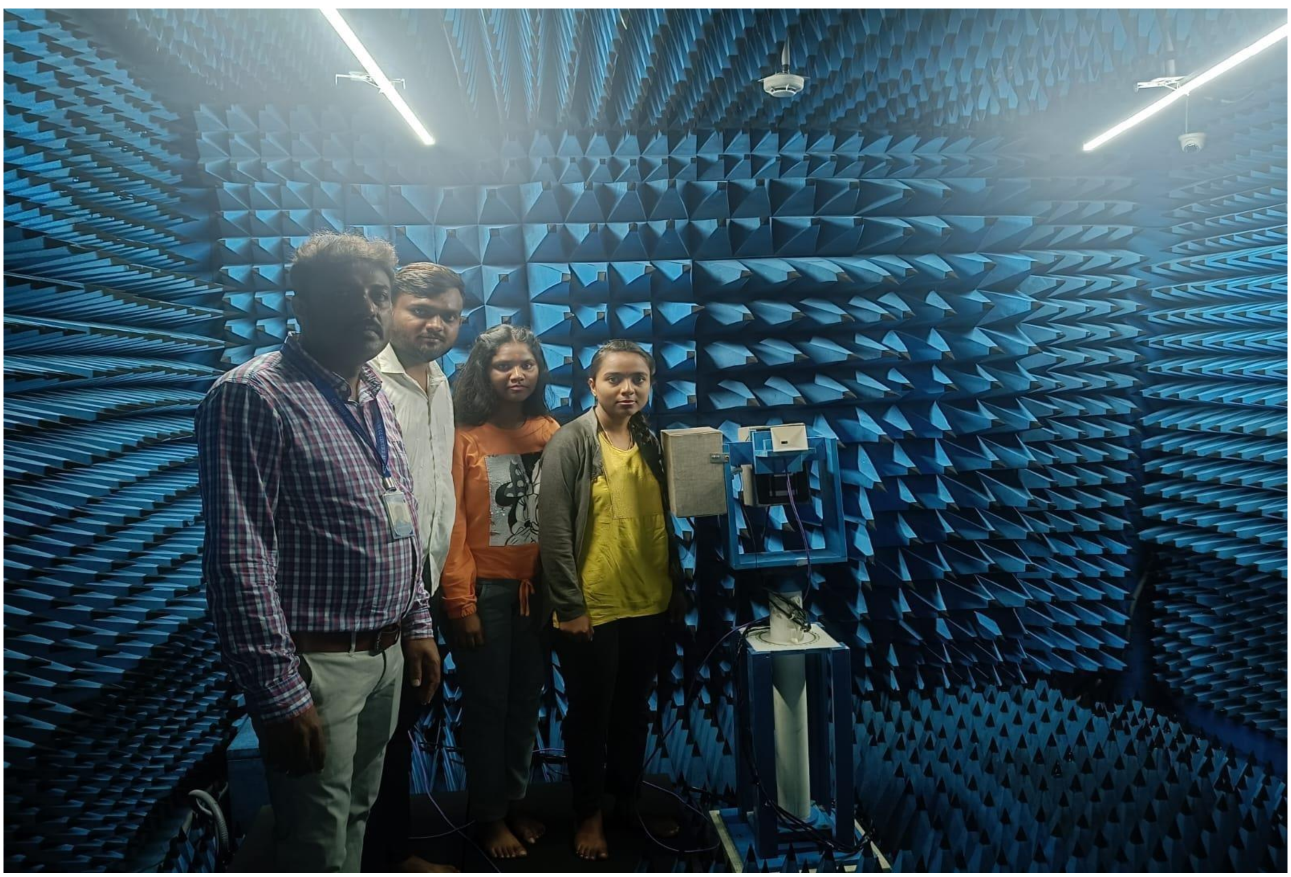


Fig 5.7 Annex chamber transmitter

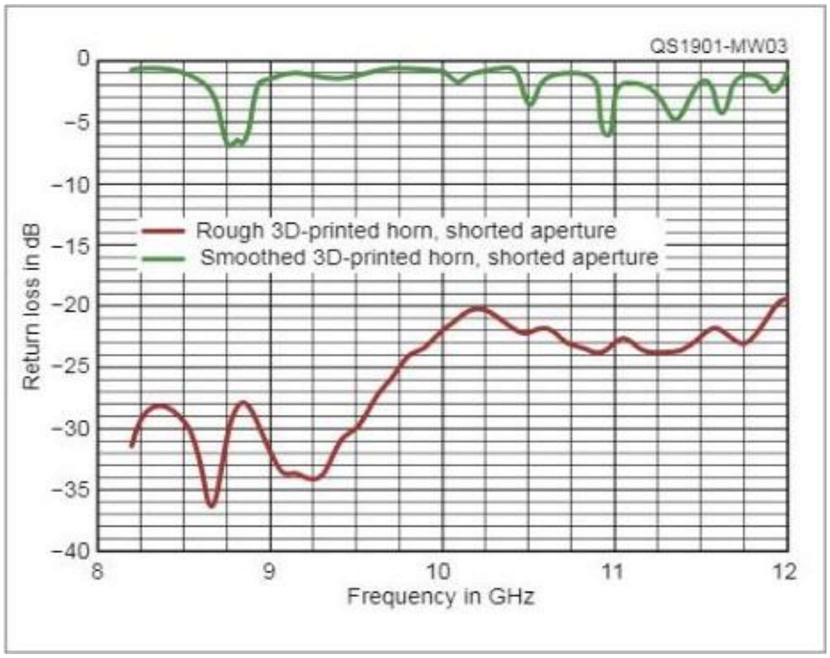


Fig 5.8 — Measured gain of 3D-printed horn antennas for frequenOles from

2 to 40 GHz, showing performance comparable to commercial metal horns.

5.4 Pre-Testing with VSWR

I devised a simple bench test to prove this theory and to pre-test antennas. This is an excellent way to verify your antenna prints. We often check for low VSWR because we all know this indicates a good antenna, but this assumes your antenna's internal losses are low. Paradoxically, even a bad lossy antenna has great VSWR.To look for loss within an antenna, you need the opposite approach. The return loss from a short circuit coax is close to zero (infinite VSWR), and the same is true for a good horn antenna when its aperture is shorted**.**

5.5 A Less Toxic Approach

At Microwave Update 2018, Michelle Thompson, W5NYV, showed some 3D-printed antennas smoothed with a paint-on two-part epoxy coating. I tried "XTC-3D" from smooth-on. com, and it worked well for printed antennas from 2 to 18 GHz. Some pre-sanding before application removes large high spots from rough surfaces, and post-sanding is required to remove the high gloss from the finished surface. The cured shiny surface looks great but will not accept the metallized paint until lightly sanded. In horns from 18 to 40 GHz, the plastic features were just too small for the relatively thick coating.

5.6 COMSOL MULTIPHYSICS STIMULATED RESULTS

MATERIAL

- **AIR**

MATERIAL PARAMETERS TABLE 5.4.1

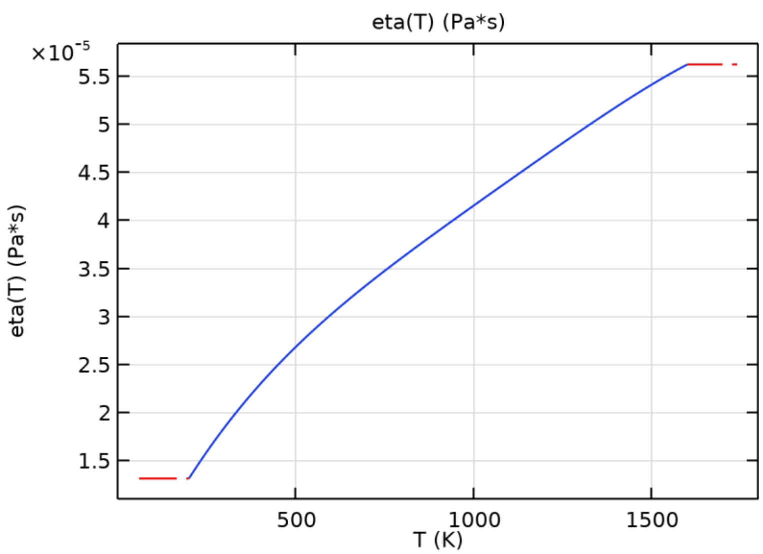
Name	Value	Unit	Property group
Relative permeability	1	1	Basic
Relative permittivity	1	1	Basic
Electrical conductivity	0	S/m	Basic

BASIC TABLE 5.4.2

Description	Value	Unit
Relative permeability	1	1
Relative permittivity	1	1
Electrical conductivity	0	S/m

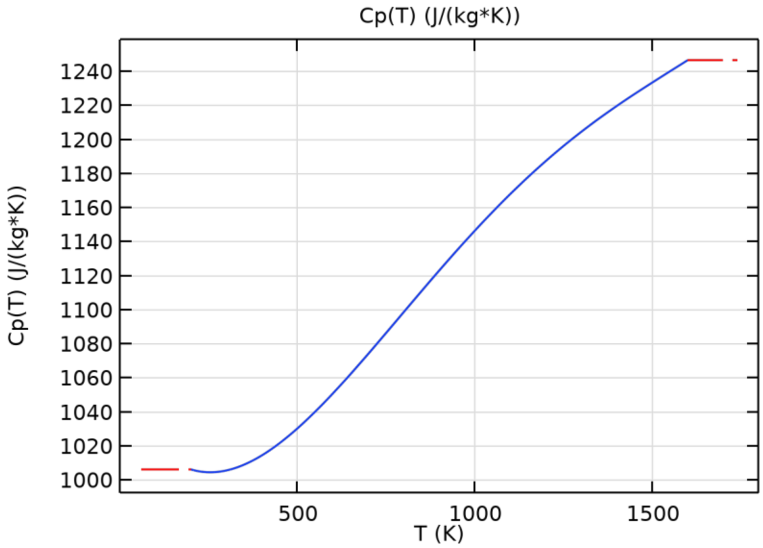
FUNCTIONS TABLE 5.4.3

Function name	Type
eta	Piecewise
Cp	Piecewise
rho	Analytic
k	Piecewise
cs	Analytic
alpha_p	Analytic
muB	Analytic



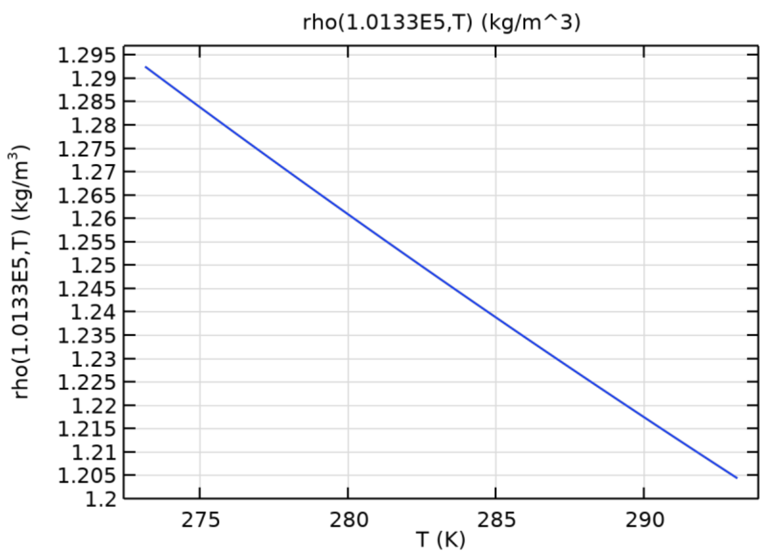
Eta

Fig 5.9 Piecewise 1



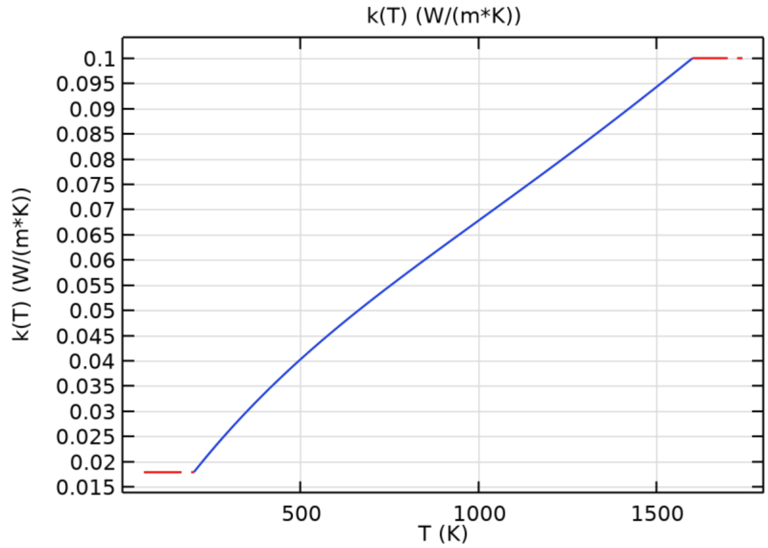
Cp

Fig 5.10 Piecewise 2



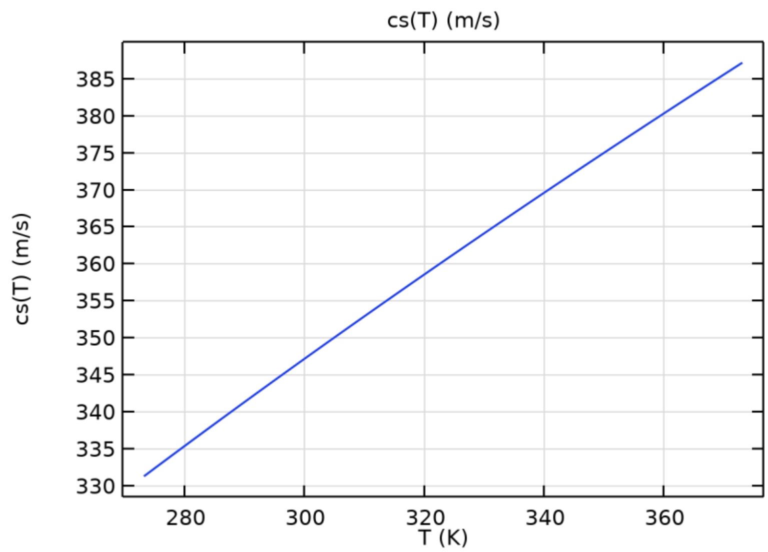
Rho

Fig 5.11 Analytic



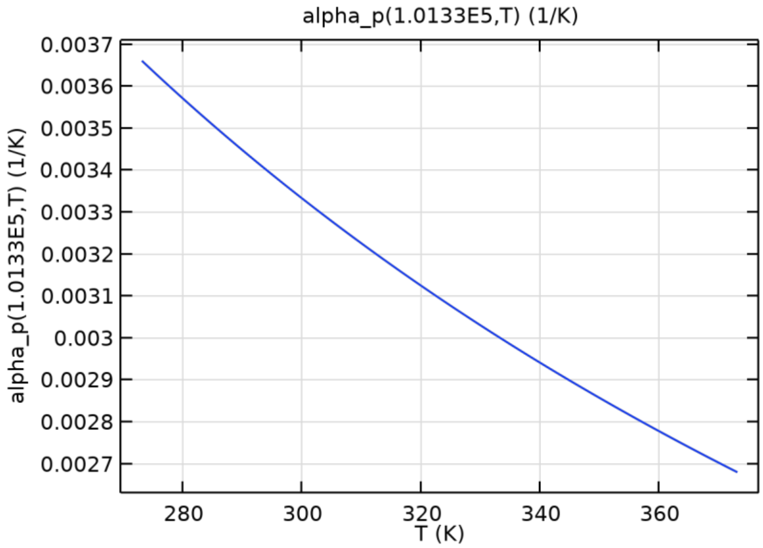
K

Fig 5.12 Piecewise 3



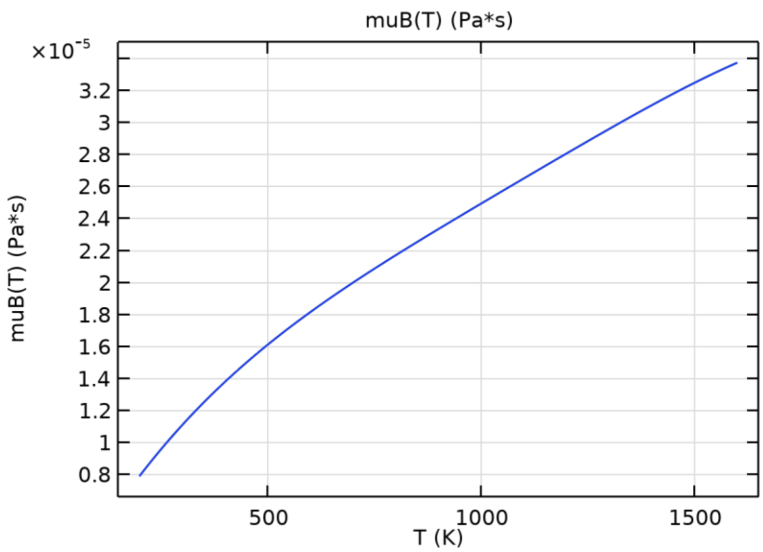
Cs

Fig 5.13 Analytic 2



alpha_p

Fig 5.14 Analytic 3

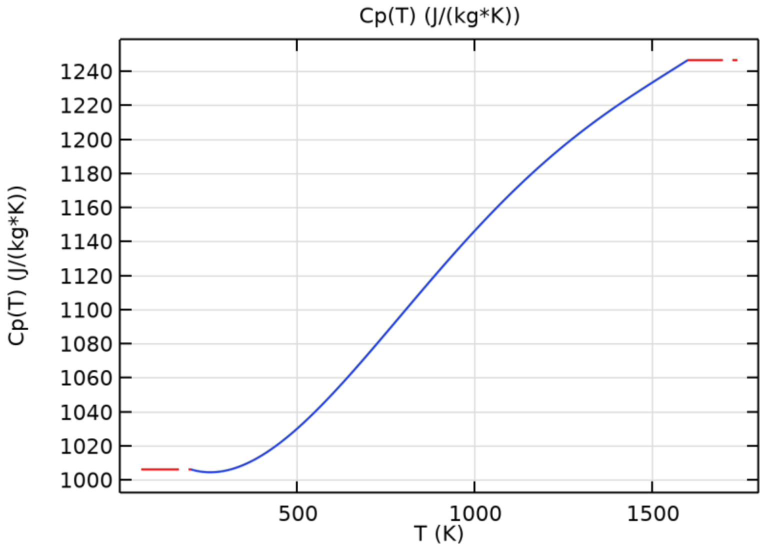


muB

Fig 5.15 Analytic 4

FUNCTIONS TABLE 5.4.4

Function name	Type
Cp	Piecewise



Cp

Fig 5.16 Piecewise 4

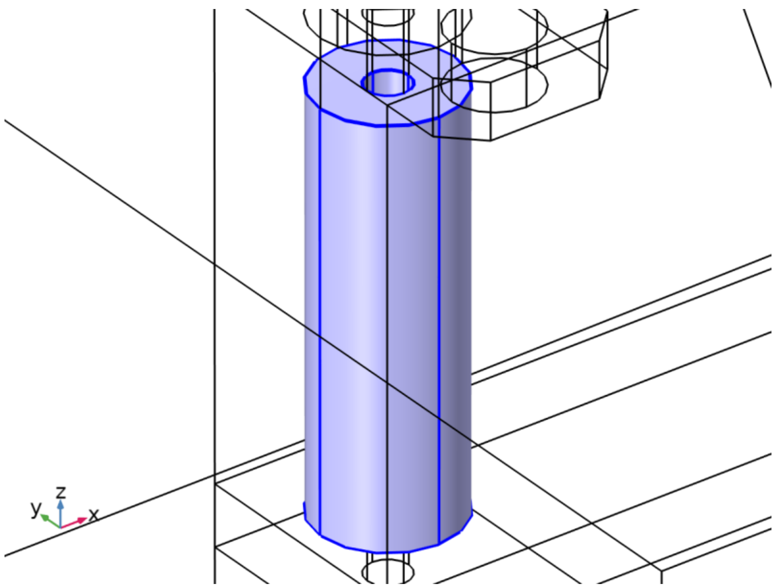


Fig 5.17 Material 2

SELECTION TABLE 5.4.5

Geometric entity level	Domain
Selection	Geometry geom1: Dimension 3: Domain 12

MATERIAL PARAMETERS TABLE 5.4.6

Name	Value	Unit	Property group
Relative permittivity	2.1	1	Basic
Relative permeability	1	1	Basic
Electrical conductivity	0	S/m	Basic

BASIC TABLE 5.4.7

Description	Value	Unit
Relative permittivity	2.1	1
Relative permeability	1	1
Electrical conductivity	0	S/m

5.6.1 Material 3

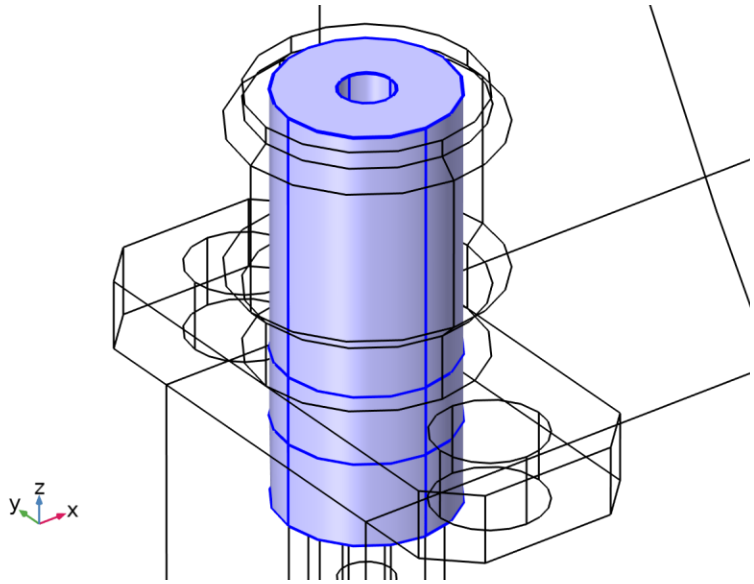


Fig 5.18 Material 3

SELECTION TABLE 5.4.8

Geometric entity level	Domain
Name	Dielectric (SMA Connector, Flange with Two Holes 1)
Selection	Named geom1_pi1_sel3: Geometry geom1: Dimension 3: Domains 13–14

MATERIAL PARAMETERS TABLE 5.4.9

Name	Value	Unit	Property group
Relative permittivity	2.1	1	Basic
Relative permeability	1	1	Basic
Electrical conductivity	0	S/m	Basic

BASIC TABLE 5.4.10

Description	Value	Unit
Relative permittivity	2.1	1
Relative permeability	1	1
Electrical conductivity	0	S/m

5.6.2 Electromagnetic Waves, Frequency Domain

USED PRODUCTS

COMSOL
Multiphysics
RF Module

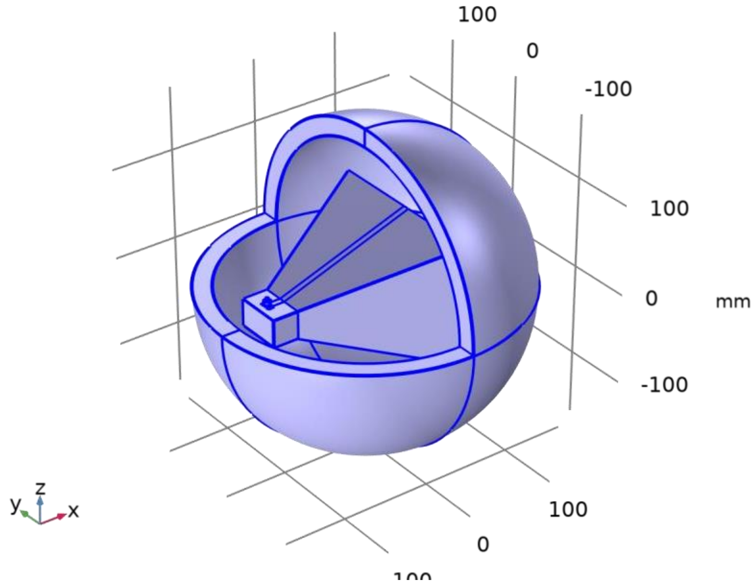


Fig 5.19 Electromagnetic Waves, Frequency Domain

SELECTION TABLE 5.4.11

Geometric entity level	Domain
Selection	Geometry geom1: Dimension 3: All domains

EQUATIONS

$$\nabla \times \mu_r^{-1}(\nabla \times \mathbf{E}) - k_0^2(\epsilon_r - \frac{j\sigma}{\omega\epsilon_0})\mathbf{E} = \mathbf{0}$$

CONCLUSIONS

The adoption of advanced additive manufacturing techniques in the design and development of horn antennas marks a significant advancement in antenna engineering. These techniques enable the fabrication of complex and customized geometries that were previously unattainable using traditional manufacturing methods. The ability to optimize designs for specific performance parameters, such as gain, bandwidth, and beam shaping, positions additive manufacturing as a game-changer in addressing the increasing demands of modern communication and sensing applications. This approach not only enhances the functionality of horn antennas but also reduces production costs and lead times, making it ideal for prototyping and small-batch manufacturing.

Furthermore, additive manufacturing supports the use of a wide range of materials, including lightweight composites and conductive polymers, which contribute to the creation of antennas with superior performance and durability. The ability to integrate multi- functional features, such as embedded waveguides and thermal management systems, further expands the capabilities of 3D-printed horn antennas. These innovations align with the needs of cutting-edge industries such as aerospace, 5G communication, and IoT, where lightweight, compact, and high-performing antenna solutions are crucial.

FUTURE SCOPE

1. **Advanced Material Development**: Research and development of high-performance materials, including conductive polymers, lightweight composites, and metal-infused filaments, will expand the capabilities of additive manufacturing in antenna production. These materials can enable higher frequency operations, improved durability, and enhanced thermal management.
2. **Integration with Emerging Technologies**: Additive manufacturing can be combined with advancements in artificial intelligence (AI) and machine learning (ML) to optimize antenna designs. These technologies can assist in generating innovative geometries and predicting performance outcomes with greater accuracy.
3. **Multi-Material Printing**: Future developments in multi-material 3D printing could allow for the seamless integration of conductive, dielectric, and structural materials in a single manufacturing process. This capability will enable the creation of multifunctional antennas with embedded components like waveguides, sensors, and cooling mechanisms.
4. **Miniaturization for IoT and Wearables**: The demand for compact and lightweight antennas for IoT devices, wearable technology, and biomedical applications presents a significant opportunity for additive manufacturing. 3D printing can facilitate the production of highly customized, miniaturized antennas with precise performance characteristics.
5. **High-Frequency Applications**: As technologies such as 5G and satellite constellations evolve, the need for antennas operating at millimeter-wave and terahertz frequencies will increase. Research into optimizing 3D-printed horn antennas for these high- frequency ranges is a critical area of future exploration.

REFERENCES

[1] A. Modiri, S. Goudreau, A. Rahimi, and K. Kiasaleh, “Review of breast screening: Toward clinical realization of microwave imaging,” Med. Phys., vol. 44, no. 12, pp. e446–e458, 2017.

[2] S. Kwon and S. Lee, “Recent advances in microwave imaging for breast cancer detection,” Int. J. Biomed. Imag., vol. 2016, Dec. 2016, Art. no. 5054912.

[3] M. Persson et al., “Microwave-based stroke diagnosis making global prehospital thrombolytic treatment possible,” IEEE Trans. Biomed. Eng., vol. 61, no. 11, pp. 2806–2817, Nov. 2014.

[4] A. T. Mobashsher, A. M. Abbosh, and Y. Wang, “Microwave system to detect traumatic brain injuries using compact unidirectional antenna and wideband transceiver with verification on realistic head phantom,” IEEE Trans. Microw. Theory Techn., vol. 62, no. 9, pp. 1826–1836, Sep. 2014.

[5] J. Ljungqvist, S. Candefjord, M. Persson, L. Jönsson, T. Skoglund, and M. Elam, “Clinical evaluation of a microwave-based device for detec tion of traumatic intracranial hemorrhage,” J. Neurotrauma, vol. 34, no. 13, pp. 2176–2182, 2017.

[6] S. A. Rezaeieh, K. S. Bialkowski, and A. M. Abbosh, “Microwave system for the early stage detection of congestive heart failure,” IEEE Access, vol. 2, pp. 921–929, 2014.

[7] R. Chandra, H. Zhou, I. Balasingham, and R. M. Narayanan, “On the opportunities and challenges in microwave medical sensing and imaging,” IEEE Trans. Biomed. Eng., vol. 62, no. 7, pp. 1667–1682, Jul. 2015.

[8] M. Mahmud, M. T. Islam, N. Misran, A. F. Almutairi, and M. Cho, “Ultra-wideband (UWB) antenna sensor based microwave breast imaging: A review,” Sensors, vol. 18, no. 9, p. 2951, 2018.

[9] M. A. Aldhaeebi, K. Alzoubi, T. S. Almoneef, S. M. Bamatraf, H. Attia, and O. M Ramahi, “Review of microwaves techniques for breast cancer detection,” Sensors, vol. 20, no. 8, p. 2390, 2020.

[10] D. O’Loughlin, M. O’Halloran, B. M. Moloney, M. Glavin, E. Jones, and M. A. Elahi, “Microwave breast imaging: Clinical advances and remaining challenges,” IEEE Trans. Biomed. Eng., vol. 65, no. 11, pp. 2580–2590, Nov. 2018.

[11] J. Bourqui, M. A. Campbell, T. Williams, and E. C. Fear, “Antenna evaluation for ultra- wideband microwave imaging,” Int. J. Antennas Propag., vol. 2010, May 2010, Art. no. 850149.

[12] W. C. Khor, M. E. Bialkowski, A. Abbosh, N. Seman, and S. Crozier, “An ultra wideband microwave imaging system for breast cancer detection,” IEICE Trans. Commun., vol. 90, no. 9, pp. 2376–2381, 2007.

[13] M. O’Halloran, M. Glavin, and E. Jones, “Rotating antenna microwave imaging system for breast cancer detection,” Progr. Electromagn. Res., vol. 107, pp. 203–217, Aug. 2010.

[14] R. C. Conceicao, M. O’Halloran, M. Glavin, and E. Jones, “Comparison of planar and circular antenna configurations for breast cancer detection using microwave imaging,” Progr. Electromagn. Res., vol. 99, pp. 1–20, Nov. 2009.

[15] A. Fasoula, L. Duchesne, J. D. G. Cano, P. Lawrence, G. Robin, and J.-G. Bernard, “On-site validation of a microwave breast imaging system, before first patient study,” Diagnostics, vol. 8, no. 3, p. 53, 2018.

[16] A. W. Preece, I. Craddock, M. Shere, L. Jones, and H. L. Winton, “MARIA M4: Clinical evaluation of a prototype ultrawideband radar scanner for breast cancer detection,” J. Med. Imag., vol. 3, no. 3, 2016, Art. no. 033502.

[17] N. A. Hassan, M. M. Mohamed, and M. B. Tayel, “Basic evaluation of antennas used in microwave imaging for breast cancer detection,” Comput. Sci. Inf. Technol., vol. 55, pp. 55–63, 2016.

[18] C. A. Balanis, Antenna Theory: Analysis and Design. Hoboken, NJ, USA: Wiley, 2016.

[19] E. Giampietri, D. Brizi, A. Monorchio, and N. Fontana, “Miniaturized antennas design for microwave imaging appli cations,” in Proc. IEEE Int. Symp. Antennas Propag. North American Radio Sci. Meeting, Jul. 2020, pp. 537–538, doi: 10.1109/IEEECONF35879.2020.9329656. 744.

[20] M. Alibakhshikenari et al., “Metamaterial-inspired antenna array for application in microwave breast imaging systems for tumor detection,” IEEE Access, vol. 8, pp. 174667– 174678, 2020, doi: 10.1109/ACCESS.2020.3025672.