The Design, manufacturing, and implementation of a K-band pyramidal horn antenna, using additive manufacturing techniques, for optimised gain and directivity

Project Proposal

Student name: Alec Robin Gould
Student number: 16412117
Module code: HPELE81
Supervisor: Prof. Sumbwanyambe Mbuyu
Date: 10 July 2024

Department of Electrical Engineering
School of Engineering
College of Science, Engineering and Technology
University of South Africa

Plagiarism Declaration

1. I know that plagiarism is a serious form of academic dishonesty.
2. I have read the UNISA policy for copyright infringement and plagiarism, am familiar with its contents and have avoided all forms of plagiarism mentioned there. Policy found at https://www.unisa.ac.za/sites/corporate/default/Register-to-study-through-Unisa/Student-policies-&-rules
3. Where I have used the words of others, I have indicated this by the use of quotation marks.
4. I have referenced all quotations and properly acknowledged other ideas borrowed from others.
5. I have not and shall not allow others to plagiarise my work.
6. I declare that this is my own work.

Signature

10/07/2024

Date

Abstract

This project aims to design, manufacture, and optimize a K-band pyramidal horn antenna using advanced additive manufacturing techniques to enhance gain and directivity. Traditional manufacturing methods for high-frequency antennas face limitations in geometries and material usage. This study explores the potential of three-dimensional (3D) printing, particularly Stereolithography (SLA), to overcome these challenges. By integrating electroless and electroplating techniques, the conductive properties necessary for effective antenna performance are achieved. The research employs both computational simulations using Python and Ansys HFSS, and physical experiments to validate the antenna's performance. The results are expected to demonstrate equivalence in electromagnetic performance, reduced material waste, and enhanced design flexibility, contributing to the advancement of antenna technology in high-frequency applications.

Table of contents

List of Figures

List of Tables

List of Abbreviations

3D	Three Dimensional
AM	Additive Manufacturing
PHA	Pyramidal Horn Antenna
RF	Radio Frequency
EM	Electromagnetic
CNC	Computer Numerically Controlled
FDM	Fused Deposition Modeling
SLA	Stereolithography
SLS	Selective Laser Sintering
AC	Alternating Current
DC	Direct Current
AUT	Antenna Under Test
DUT	Device Under Test
VNA	Vector Network Analyser
HFSS	High-Frequency Structure Simulator
FEM	Finite Element Method
MOM	Method of Moments
PPE	Personal Protective Equipment
GA	Genetic Algorithm
PVD	Physical Vapour Deposition

Chapter 1 Introduction

Background

The pyramidal horn antenna (PHA) is the epitome of antenna measurement and characterization antennas. Originating from the pioneering work of Wilmer L. Barrow in the 1930s, the horn has since become a cornerstone in the field of antenna engineering [1]. Its significance lies in its ability to provide a known, stable radiation pattern and gain across a wide frequency range (Bandwidth), making it invaluable for antenna calibration, testing, and research.

Traditionally, horns have been manufactured using conventional techniques such as milling, turning, or casting, which often pose limitations in terms of design complexity, production time, and cost. However, with the advent of additive manufacturing (AM) techniques, new possibilities have emerged for enhancing the design, manufacturing, and implementation processes of antennas [2].

AM, offers the flexibility to fabricate intricate geometries with high precision, opening doors to novel antenna designs that were previously unattainable. By leveraging AM, researchers can explore innovative horn antenna configurations tailored for specific applications, optimizing parameters such as gain, directivity, and bandwidth [3].

Moreover, the use of AM in antenna production holds promise for streamlining manufacturing processes, reducing material waste, saving weight, and ultimately lowering production costs. These advantages not only make antennas more accessible to researchers and engineers but also pave the way for custom-tailored antennas optimized for individual requirements.

In recent years, the K-band frequency range (18 to 26.5 GHz) has gained prominence in various applications, including satellite communications, radar systems, and remote sensing. The demand for high-performance antennas operating in this frequency band has spurred interest in developing antennas optimized specifically for K-band applications [4]. As the signal frequency goes up, the wavelength becomes smaller, hence, the antenna’s physical size becomes smaller, and tolerances become less forgiving.

This study aims to explore the design, manufacturing, and implementation of a K-band PHA using additive manufacturing techniques. By harnessing the capabilities of AM, the goal is to achieve enhanced performance characteristics, including improved gain and directivity, tailored to the unique requirements of K-band applications. Through rigorous experimentation and analysis, this research seeks to contribute to the advancement of antenna technology in the K-band frequency range, opening possibilities for more novel and complex high-frequency research.

Thesis statement

The integration of advanced additive manufacturing techniques can show equivalent electromagnetic performance, but allows for more design flexibility of antenna design, overcoming the limitations of conventional manufacturing processes.

Problem statement

The PHA has long been a staple in antenna measurement and characterization due to its known radiation pattern and gain across a wide frequency range. However, traditional manufacturing methods impose limitations on design complexity, production time, and cost. Additionally, the demand for high-performance antennas in the K-band frequency range has necessitated the development of SGHAs optimized for specific applications, such as radio frequency (RF) lens (dielectric lens) measurements.

Despite advancements in AM techniques, the full potential of AM in enhancing antenna design, manufacturing, and implementation for many applications remains largely untapped. Challenges persist in leveraging AM to achieve optimal results required by K-band applications, while ensuring precision and reproducibility in antenna fabrication.

Therefore, the problem statement of this research is to investigate the design, manufacturing, and implementation of a K-band PHA for optimal directivity using additive manufacturing techniques. This entails addressing key challenges such as optimizing antenna performance characteristics, ensuring compatibility with RF measurement setups, and validating the efficacy of AM for antenna fabrication in the context of RF (K-band) applications. By addressing these challenges, this research aims to contribute to the advancement of antenna technology for RF measurements, enabling more accurate and efficient characterization of electromagnetic (EM) fields in various applications.

Aims and Objectives

Aims:

1. To compare different methods of designing pyramidal horn antennas and evaluate their efficacy.
2. To design a K-band PHA optimized for directivity using additive manufacturing techniques
3. To develop a systematic methodology for the additive manufacturing of PHAs, ensuring precision and reproducibility in fabrication processes.
4. To integrate the fabricated PHA into measurement setups and evaluate its compatibility and performance.
5. To assess the feasibility and effectiveness of additive manufacturing in antenna engineering.

Objectives:

1. Conduct a comprehensive literature review to identify existing PHA designs, additive manufacturing techniques, and standard EM measurement methodologies.
2. Write computer software to design and optimize the geometries of the PHA. Additionally, utilize electromagnetic simulation software to further optimize, tailored for the requirements, considering parameters such as aperture size, flare angle, and material properties.
3. Experimentally validate the performance of the designed PHA prototype through simulations.
4. Implement additive manufacturing techniques to fabricate the PHA prototype, ensuring dimensional accuracy and a smooth surface finish.
5. Evaluate antenna performance through physical measurements.
6. Compare the performance of the additive manufactured PHA with simulations in terms of gain, directivity, and loss.
7. Analyze the results to identify potential improvements in PHA design and additive manufacturing processes for future iterations.
8. Document the findings and insights obtained throughout the research in a comprehensive report, including recommendations for further research and practical applications in RF measurements.

Delimitation

This project will cover the design and optimisation, manufacturing, and electromagnetic performance measurements of the PHA.

There will be no coverage of other measurement techniques, such as mechanical strain measurements, surface roughness measurements, or any other types of evaluation outside of what is required for an antenna. There is sufficient literature around these topics, hence, they will not be covered in detail.

Significance of study

This study is significant from two main fronts. Firstly, creating software to optimize the antenna geometries rather than trial and error (empirical), will save a lot of time and likely yield better performance. Secondly, the study of additive manufacturing techniques in the field of EM may open doors to designs that were previously unobtainable through traditional techniques.

The K-band frequency range, spanning from 18 to 26.5 GHz, has gained significant attention in various applications, including satellite communications, radar systems, and remote sensing. The unique properties of the K-band, such as its high data transmission rates and wide bandwidth, make it suitable for high-capacity communication systems and high-resolution imaging.

Report Outline

Chapter 2 Literature Review: This is a review of previous work relevant to this project.

Chapter 3 Theoretical Background: Fundamental theory and mathematics, that is vital to the understanding of this project.

Chapter 4 Methods and Methodology: Research and experimentation design, with some insight into how collected data shall be analysed.

Chapter 5 Budget: The cost of this project.

Chapter 6 Project Plan: The timeline to which the certain phases of the project are expected to be completed by.

Chapter 7 Summary: The condensed version of this report.

Chapter 2 Literature Review

Pyramidal horn antennas

The horn antenna is, fundamentally, a transition from the waveguide impedance to free-space impedance using the gradual flaring of the waveguide to selectively radiate power in a given direction. The shape of the flare, length and angle of the taper can have a significant effect on the electromagnetic properties [5], [6].

Pyramidal horn antennas serve as fundamental components in the field of antenna engineering, facilitating the transition from a coaxial cable to waveguide to antenna topology. Their simple yet effective design enables stable radiation patterns and consistent gain across a wide frequency range [5].

Plausibility of Additive Manufacturing in Antenna Engineering

The conventional techniques for producing antennas have mostly depended on subtractive procedures including computer numerically controlled (CNC) machining, moulding (casting), and etching. Zhang [7] covers designing for manufacturing and assembly (DFMA), and optimizing these processes for a horn antenna, and displays the complexity around machining. Karincic, et al. [8] covers a straight-forward technique on chemical etching for patch antennas. This, however, is not plausible with horn antennas.

Although these techniques work well, they can result in significant labour costs, excessive material waste, heavy final parts, and restricted design complexity. With layer-by-layer building made feasible by AM, complex geometries and structures that were previously difficult or impossible to create may now be created, ushering in a paradigm change. Ponfoort and Nullmeier [9], provide statistics on these benefits of AM. One being reducing propeller blade material costs by 30-70%.

Several studies have demonstrated the successful application of AM in antenna engineering. For instance, research by Yao, et al. [10] presented the development of a 3D-printed Ka-band horn antenna with performance metrics comparable to traditionally manufactured counterparts, comparing the use of copper tape, and conductive paint (for surface conductivity). Similarly, there are other studies showing success using other methods of 3D printing, and various techniques to achieve surface conductivity [11], [12], [13], [14]. It has also been shown by Garcia et al. [15] that surface roughness can have a bearing on the antenna performance, however, the negative effects were quite small.

The general procedure is as follows, and will be covered in the next sub-section:

1. 3D print the part.
2. Surface treatment of part.
3. Metal plating of part.

Additive manufacturing

Additive manufacturing has emerged as a promising technique for fabricating complex geometries with high precision. In the context of antenna engineering, AM offers unique advantages for prototyping and producing customized antenna designs with improved performance characteristics.

3D printing

3D printing has taken the world by storm; every day there are improvements and new possibilities. This section covers the most available (and popular) types of 3D printing.

Selective Laser Sintering (SLS)

SLS printing uses a laser to selectively sinter a thermoplastic polymer power, after which a new fine layer of powder will be laid to sinter further [16]. This powder is typically a composite material, where selective laser melting (SLM) printing is used for metallic parts.

See **Figure 1** [17].

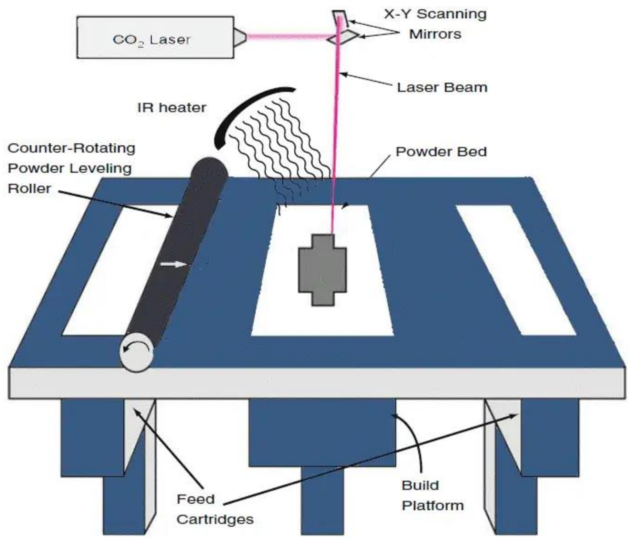


Figure 1: SLS process overview.

This process is inherently dangerous, due to the use of lasers. Personal protective equipment (PPE) is required.

Stereolithography (SLA)

Stereolithography (SLA) 3D printing is an additive manufacturing process that utilizes a vat of liquid photopolymer resin cured by a UV laser to create solid parts. The UV laser selectively cures the resin layer by layer, following the design specified by a digital 3D model. As each layer is cured, the build platform moves incrementally to allow the next layer of liquid resin to be solidified. This process continues until the entire part is completed. SLA 3D printing is known for its high precision and ability to produce intricate details, making it suitable for applications requiring smooth surface finishes and fine geometries [18].

See **Figure 2** [19].

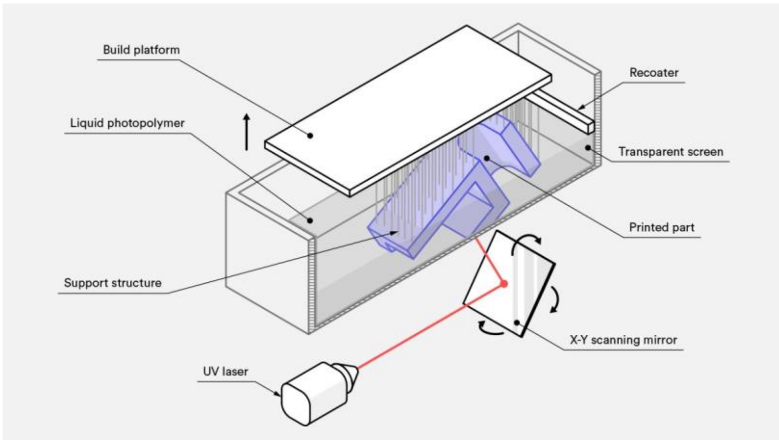


Figure 2: SLA process overview.

Fused Deposition Modeling (FDM)

Fused Deposition Modeling (FDM) 3D printing is an additive manufacturing process that builds objects layer by layer using a thermoplastic filament. The filament is fed through a heated nozzle, where it is melted and extruded onto the build platform. The nozzle moves according to the digital 3D model, depositing the melted material in precise locations to form each layer. Once a layer is completed, the platform lowers, and the next layer is deposited on top of the previous one. This process continues until the entire object is constructed. FDM is widely used for its versatility, cost-effectiveness, and ability to produce durable parts with a range of materials, making it popular for both prototyping and end-use applications [20].

See **Figure 3** [21].

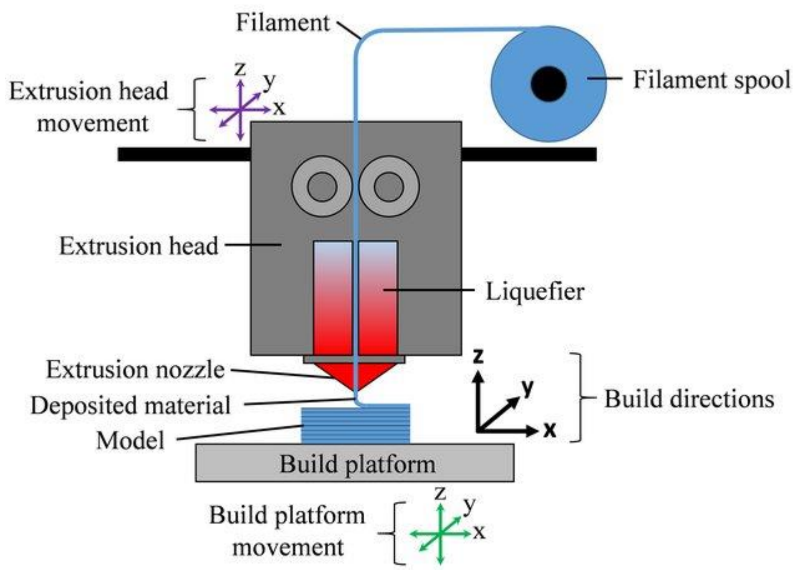


Figure 3: FDM process overview.

See **Table 1** for a summary of the pros and cons of the different 3D printing technologies [22].

Table 1: Comparison of 3D printing technologies.

3D printing technology	SLS	SLA	FDM
Build volume	>36litres	>8litres	>50litres
Build speed	<50mm/h	<50mm/h	>50mm/h
Build resolution	Micrometer	Micrometer	Millimeter
Surface roughness	<50 microns	<5 microns	< 200 microns
Ease of use	Requires some skill	Requires some skill	Beginner friendly
Comsumerised	Not yet	Yes	Yes
Safety	Moderately safe, requires PPE	Moderately safe, requires PPE	Safe
Printer cost	$$$ (>R100,000)	$$ (>R5,000)	$ (>R3,000)
Material cost	$$$ (>R2000 per kg)	$$ (>R600 per kg)	$ (>R250 per kg)

Metal plating

This is the process of additively metalising an object. There are many techniques for this, some of which shall be discussed in the coming sub-sections

Electroplating

Electroplating involves depositing a metal layer onto a part by using an electric current. The part is immersed in a solution containing metal ions, and an electric current causes these ions to adhere to the part’s surface. This technique is valued for its ability to produce uniform and thick metal coatings, enhancing the part's conductivity and wear resistance. Common metals used in electroplating include copper, nickel, and gold. See **Table 2** for a generic process [13], [23].

Table 2: Electroplating process.

<table>
<tr><th colspan="3">Process table</th></tr>
<tr><td rowspan="3">Surface prep</td><td>Surface smoothing</td><td>Remove as much surface deviation as the application requires</td></tr>
<tr><td>Surface cleaning</td><td>Remove dust particles and degrease thoroughly</td></tr>
<tr><td>Conductive layer application</td><td>Copper, graphite, silver paint application to make the non-conductive part become conductive. Uniform thin layer is compulsory</td></tr>
<tr><td>Electroplating</td><td>Plating bath</td><td>Metal ions attach themselves to conductive surface due to potential difference introduced by power supply</td></tr>
<tr><td rowspan="2">Post processing</td><td>Cleaning</td><td>Remove all residue of plating bath. Rinse in deionized water, then a high purity alcohol</td></tr>
<tr><td>Polishing</td><td>Optional based on results</td></tr>
</table>

Electroless Plating

Electroless plating, or autocatalytic deposition, does not require an external electric current. Instead, a chemical reduction reaction deposits the metal onto the part. This method is beneficial for coating parts with complex geometries, as it provides a uniform metal layer regardless of the part's shape. Electroless plating is often used for applying nickel or copper coatings and can be followed by an additional electroplating step for enhanced properties. See **Table 3** for a generic process [24], [25], [26], [27].

Table 3: Electroless plating process.

Process table		
Surface prep	Surface smoothing	Remove as much surface deviation as the application requires
	Surface cleaning	Remove dust particles and degrease thoroughly
	Surface etching	Chemically (or physically) etch the part to create nano pores.
	Surface sensitization	Deposition of metallic ions on the surface of the non-conductive part with-in the surface pores
	Surface Activation	Deposition of a catalytic metal that “attracted” to the sensitized surface, and is “attractive” to the plating material
Electroless plating	Plating bath	Metal ions attach themselves to non-conductive surface due to potential difference in activated part and plating bath chemistry
Post processing	Electroplating	Optional step to thicken metal layer, or change surface metal, etc.
	Cleaning	Remove all residue of plating bath. Rinse in deionized water, then a high purity alcohol

Physical Vapour Deposition

Physical Vapor Deposition (PVD) is a vacuum-based process where metal is vaporized and then deposited onto the 3D printed part. This method is ideal for producing thin, hard coatings with excellent adhesion and high resistance to wear and corrosion. PVD is commonly used for decorative finishes and functional coatings, such as those required in aerospace and medical applications. See **Table 4** for a generic process [28], [29].

Table 4: PVD process.

Process table		
Surface prep	Surface smoothing	Remove as much surface deviation as the application requires
	Surface cleaning	Remove dust particles and degrease thoroughly
PVD	Vacuum	Place part under sufficient vacuum
	Metallic vapour	Introduce metallic vapour, the metal will fall out of suspension onto the surface.
Post processing	Electroplating	Optional step to thicken metal layer, or change surface metal, etc.
	Cleaning	Remove all residue of plating bath. Rinse in deionized water, then a high purity alcohol

Chapter 3 Theoretical Background

Pyramidal Horn Antennas

The theoretical background of this study delves into the fundamental concepts and techniques essential for understanding the optimization of K-band horn antennas. The objective is to provide a comprehensive overview of traditional and modern design methodologies, highlighting the advancements and theoretical underpinnings that drive optimal horn antenna performance.

Aperture Fields

The analysis begins with the approximation of the tangential components of the E- and H-fields over the aperture of the horn antenna. These components are given by [5], [6]:

$$E_y'(x', y') = E_0 \cos\left(\frac{\pi x'}{\mathrm{A}}\right) e^{-j\left[\frac{k(x'^2/\mathrm{R}_2 + y'^2/\mathrm{R}_1)}{2}\right]} \tag{1}$$

$$H_x'(x', y') = -\frac{E_0}{\eta} \cos\left(\frac{\pi x'}{a_1}\right) e^{-j\left[\frac{k(x'^2/\mathrm{R}_2 + y'^2/R_1)}{2}\right]} \tag{2}$$

$x', and\ y'$ are the unit vectors (See **Figure 4**). The equivalent current densities are then defined as [5], [6]:

$$J_y(x', y') = -\frac{E_0}{\eta} \cos\left(\frac{\pi x'}{A}\right) e^{-j\left[\frac{k\left(\frac{x'^2}{\mathrm{R}_2} + \frac{y'^2}{\mathrm{R}_1}\right)}{2}\right]} \tag{3}$$

$$M_x(x', y') = E_0 \cos\left(\frac{\pi x'}{A}\right) e^{-j\left[\frac{k\left(\frac{x'^2}{R_2} + \frac{y'^2}{R_1}\right)}{2}\right]} \tag{4}$$

Radiated Fields

The far-zone E- and H-field components can be derived from the equivalent current densities, leading to the following expressions for the radiated fields [5], [6]

$$E_r = 0 \tag{5}$$

$$E_\theta = -j\frac{kE_0 e^{-jkr}}{4\pi r}\sin\phi(1+\cos\theta)\, I_1 I_2 \tag{6}$$

$$E_\phi = -j\frac{kE_0 e^{-jkr}}{4\pi r}\cos\phi(\cos\theta+1)\, I_1 I_2 \tag{7}$$

Where I_1 and I_2 are given by [5], [6]

$$I_1 = \int_{-\frac{A}{2}}^{\frac{A}{2}} \cos\left(\frac{\pi}{a}x'\right) e^{-jk\left[\frac{x'^2}{2R_1} - x'\sin(\theta)\cos(\phi)\right]}\, dx' \tag{8}$$

$$I_2 = \int_{-\frac{B}{2}}^{\frac{B}{2}} e^{-jk\left[\frac{y'^2}{2R_1} - y'\sin(\phi)\sin(\theta)\right]} dx' \tag{9}$$

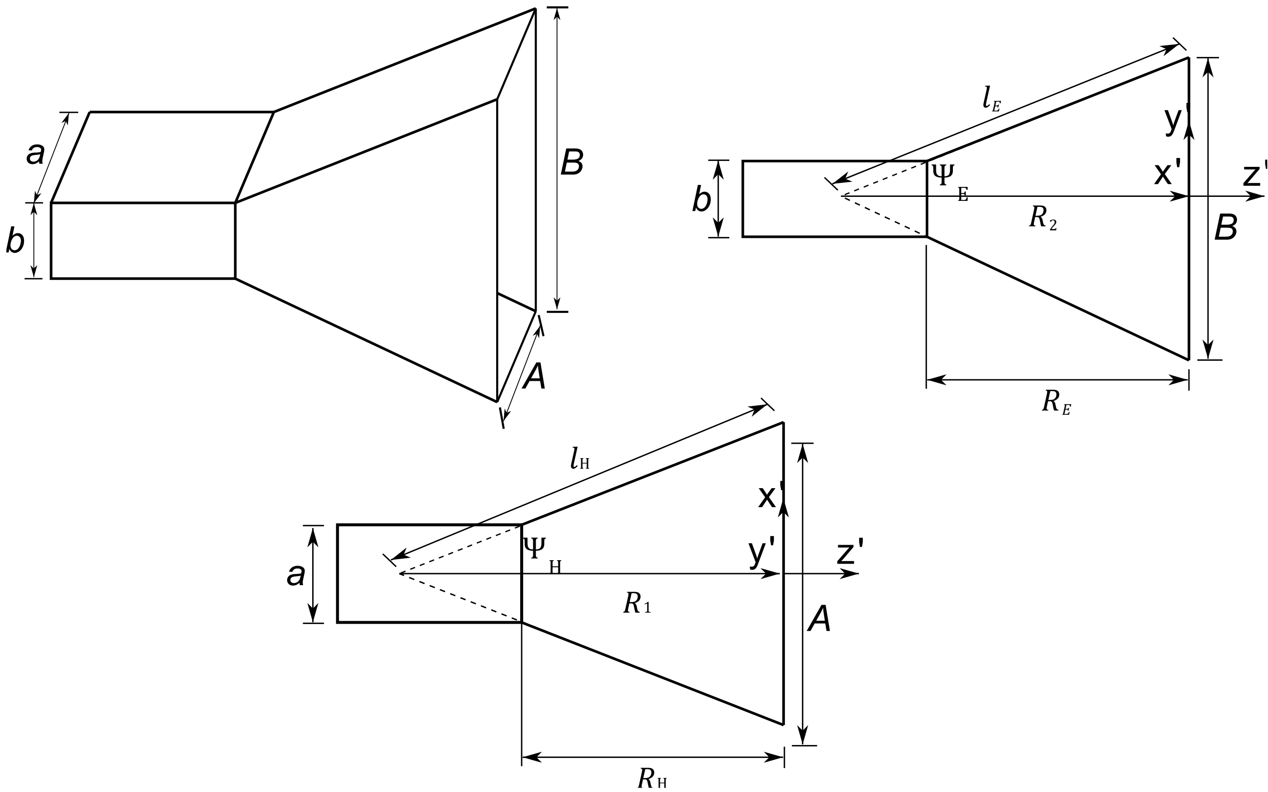


Figure 4: Annotated pyramidal horn antenna.

Traditional horn design techniques

This section covers the steps required to compute the horn antenna geometries using the traditional horn design procedure. The traditional method is covered by Balanis in [5].

Step 1

Specify the following parameters:

- sought after gain (G) as a ratio and not in dB.
- centre frequency of operation (f) in hertz.
- waveguide dimensions (a and b) in meters.

Step 2

Solve for χ using (10) until χ satisfies (11) and (12). Obtaining χ_{trial} is an iterative process:

$$\chi_{trial} = \chi_1 = \frac{G_0}{2\pi\sqrt{2\pi}} \tag{10}$$

$$l_E = \chi\lambda \tag{11}$$

$$l_H = \frac{G_0^2}{8\pi^3}\left(\frac{1}{\chi}\right)\lambda \tag{12}$$

The verification of whether χ satisfies (11) and (12), can be done using (14).

$$G_0 \approx \frac{2\pi}{\lambda^2}\sqrt{3\lambda l_H}\sqrt{2\lambda l_E} \tag{13}$$

Step 3

This step entails back calculating the remainder of the parameters. Narrow, and broad sides of the horn flare can be calculated using χ:

$$A = \frac{G_0}{2\pi}\sqrt{\frac{3}{2\pi\chi}}\lambda \tag{14}$$

$$B = \sqrt{2\chi}\lambda \tag{15}$$

The lengths of the horn flare can be calculated using (16) and (17):

$$R_E = (B-b)\left[\left(\frac{l_E}{B}\right) - \frac{1}{4}\right]^{\frac{1}{2}} \tag{16}$$

$$R_H = (A-a)\left[\left(\frac{l_h}{A}\right) - \frac{1}{4}\right]^{\frac{1}{2}} \tag{17}$$

Optimum horn design techniques

This section covers the steps required to compute the horn antenna geometries using the optimum horn design procedure. This method is covered extensively by Pereira et al. [30].

Step 1

Specify the following parameters:

- sought after gain (G) as a ratio and not in dB.
- centre frequency of operation (f) in hertz.
- waveguide dimensions (a and b) in meters.

Step 2

Solve the roots of the following fourth-order quadratic equation:

$$A^4 - aA^3 + \frac{3bG\lambda^2}{8\pi\varepsilon_{ap}}A - \frac{3G^2\lambda^4}{32\pi^2{\varepsilon_{ap}}^2} = 0 \tag{18}$$

Where:

$$\varepsilon_{ap} = 0.51 \tag{19}$$

$$\lambda = \frac{c}{f} = \frac{2.9979 \times 10^8}{f}\ meters \tag{20}$$

Whose coefficients are in the form:

$$fx^4 + gx^3 + hx^2 + ix + j = 0 \tag{21}$$

$$\begin{gathered} f = 1 \\ g = -a \\ h = 0 \\ i = \frac{3bG\lambda^2}{8\pi\varepsilon_{ap}} \\ j = \frac{3G^2\lambda^4}{32\pi^2{\varepsilon_{ap}}^2} \end{gathered} \tag{22}$$

The roots of this equation will yield the dimension of broad side of the flare of the horn (A) in meters. Take note that negative roots, or any roots containing imaginary components can be discarded.

Step 3

This step entails back calculating the remainder of the parameters.

Obtain B, the narrow side of the flare of the horn, by back calculating using the gain equation:

$$G = 0.51 \frac{4\pi}{\lambda^2} AB$$

$$B = \frac{G}{0.51 \frac{4\pi}{\lambda^2} A} \tag{23}$$

Obtain R_1, R_H and l_H:

$$A = \sqrt{3\lambda R_1}$$

$$R_1 = \frac{A^2}{3\lambda} \tag{24}$$

$$\frac{R_1}{R_H} = \frac{A}{A - a}$$

$$R_H = \frac{A - a}{A} R_1 \tag{25}$$

$$l_H{}^2 = R_1{}^2 + \left(\frac{A}{2}\right)^2$$

$$l_H = \sqrt{R_1{}^2 + \left(\frac{A}{2}\right)^2} \tag{26}$$

Obtain R_2, R_E and l_E::

$$B = \sqrt{2\lambda R_2}$$
$$R_2 = \frac{B^2}{2\lambda} \tag{27}$$

$$\frac{R_2}{R_E} = \frac{B}{B-b}$$
$$R_E = \frac{B-b}{B} R_2 \tag{28}$$

$${l_E}^2 = {R_2}^2 + \left(\frac{B}{2}\right)^2$$
$$l_E = \sqrt{{R_2}^2 + \left(\frac{B}{2}\right)^2} \tag{29}$$

Step 4

Validate your solution by checking:

$$R_E = R_H \tag{30}$$

$$s = \frac{1}{8}\left(\frac{B}{\lambda}\right)^2 \frac{\lambda}{R_2} = 0.25 \tag{31}$$

$$t = \frac{1}{8}\left(\frac{A}{\lambda}\right)^2 \frac{\lambda}{R_1} = 0.375 \tag{32}$$

If this step checks out ($s = 0.25$ and $t = 0.375$), the calculated geometries may be considered mathematically sound.

Optimisation algorithm horn design techniques

The difference between this method and the previous two, is the fact that this method uses a feedback algorithm to numerically tweak the geometries. The algorithm then feed this into field equations mentioned above, iteratively, until a certain cost of performance is achieved. One promising technique is the genetic algorithm (GA) used by Zheng et al. [31].

The “base” geometry is calculated using one of the two previous analytical methods, the optimization algorithm then obtains the best possible geometry for the given specification.

Additive Manufacturing

Fabrication of antennas using additive manufacturing sound too good to be true. Currently, it is. The major issue with 3D printing on a consumer level is the lack of conductive material selection. This poses a problem for antennas as the operating principle is to convert electromagnetic energy into electrical energy – requiring conductivity. To overcome this limitation, a common approach is to add a conductive metal layer to the surface of the 3D-printed part. This was covered in Chapter 2 Literature Review

This section covers the theory around designing an additive manufacturing process.

3D Printing

The only important concepts regarding 3D printing in antenna manufacturing (purely for proof of concept) are surface roughness, and part tolerance. Surface roughness is less scientific, but tolerance can be calculated as follows [32], [33]:

$$\text{Tolerance}_{\text{SLA}} = \sqrt{(\frac{\text{Screen Size}}{\text{Resolution}})^2 + (\text{Layer Height})^2} \tag{33}$$

$$\text{Tolerance}_{\text{SLS}} = \sqrt{(\text{Laser Spot Size})^2 + (\text{Layer Thickness})^2 + (\frac{\text{Particle Size}}{2})^2} \tag{34}$$

$$\text{Tolerance}_{\text{FDM}} = \sqrt{(\frac{\text{Nozzle Diameter}}{2})^2 + (\text{Layer Height})^2 + (\frac{\text{Extruder Precision}}{2})^2} \tag{35}$$

Metal plating

The skin effect is a phenomenon where alternating current (AC) tends to flow near the surface of a conductor, with the current density decreasing exponentially with depth from the surface. This effect is crucial to understanding why surface conductivity is so important for antennas made using AM techniques. Skin depth can be calculated as follows:

$$\delta = \sqrt{\frac{2\rho}{\omega\mu}} \tag{36}$$

Where ρ is the resistivity of the material, ω is the angular frequency (2πf) of operation, and μ is the permeability of the material.

For a material like copper, the skin depth is about 4.86 microns at 18GHz (lowest in K-band). Anything thicker than this is sufficient and will provide a low loss exchange.

The thickness of metal can be controlled in electroplating using Faraday's law of electrolysis [23]:

$$Thickness = \frac{M \cdot I \cdot t}{n \cdot F \cdot \rho \cdot A} \tag{37}$$

Where:

M is the molar mass of plating metal, I is the current (DC), t is the time, n is the valence number of plating metal, F is Faraday's constant, ρ is the density of plating metal, A is the surface area of the part to be plated.

Chapter 4 Methods and Methodology

Research Methodology

The research methodology for this project is quantitative, focusing on the design, manufacturing, and performance analysis of a K-band PHA using AM techniques. This approach is chosen because it allows for the systematic investigation of the antenna's performance characteristics, such as gain and directivity, through controlled experiments and statistical analysis.

The primary goal is to measure and optimize the gain and directivity of the K-band SGHA, which requires precise and objective measurement techniques. Quantitative methodology provides the framework for controlled experiments, ensuring that variables affecting antenna performance can be systematically manipulated and studied. The use of statistical tools allows for the validation of hypotheses regarding the performance improvements achieved through AM techniques.

Research Methods

Plan for data collection

The data collection plan involves both computer simulations and physical experiments. Computer simulations will be used to model and optimize the antenna designs before physical prototypes are created and tested. This two-pronged approach ensures that the designs are both theoretically sound and practically feasible. All experimentation below shall be captured in tabular form, except for antenna simulation and physical measurements. OneDrive shall be used to store all data, backups will be made regularly.

Antenna performance metrics shall be captured in touchstone files for analysis. Historical data cannot necessarily be used, unless the antenna under test (AUT) is identical to antenna in the historical data. The data captured from simulations will be used to verify data from physical measurements.

Based on the success of initial physical experiments, the exact number of antennas manufactured and tested can be decided. However, at least three of each design should be tested. A sample size of 3, in this context, is enough to show statistical significance and evidence whether the investigation is successful or not.

Design of computer experiment

Python will be used for calculating the horn geometries and solving complex equations quickly and reliably. Python scripts will automate the process of adjusting design parameters to optimize performance metrics.

Ansys high-frequency structure simulator (HFSS) will be used to simulate the electromagnetic performance and the optimization thereof. HFSS allows for the simulation of radiation patterns, reflections, losses, directivity, and gain. HFSS makes use of the finite element method (FEM) as its electromagnetic field solver, which has been shown to be superior to other methods such as method of moments (MOM) [34]. The optimization tool within HFSS will help in fine-tuning the design for optimal performance. Some of the optimization algorithms within HFSS that shall be explored are: Genetic algorithm, multi-objective genetic algorithm, Adaptive single-objective, Adaptive multi-objective.

Autodesk Fusion 360 CAD software will be used to design the horn and integrate the WR-42 flange, adding the necessary wall thickness to the horn geometry. Fusion 360 will convert conceptual designs into detailed mechanical parts ready for 3D printing. This is a crucial part of the computational experimentation, as this “real-life” part can be re-integrated into HFSS for re-analysis to see if there are any negative implications.

Design of physical experiments

Some of the physical experiments will be conducted in parallel with computer simulations to validate the designs and assess the practical feasibility of the proposed antenna.

Evaluating different 3D printing methods based on criteria such as dimensional accuracy and surface roughness. This step ensures that the printed parts meet the required specifications for optimal antenna performance.

Conducting electroless and electroplating experiments to improve surface coverage and bond strength of the metal plating on plastic parts. Surface preparation techniques for both electroless and electroplating will be critical to achieving high-quality metallization, and will be covered as a part of the investigation. The experiments will ultimately determine whether an antenna can optimally be realized from a 3d printed part within the K-band.

Post-metallization, antenna measurements will be carried out according to the "IEEE Recommended Practice for Antenna Measurements" [35]. This will be the most important part of the entire experimentation process. Some important antenna parameters that will be used to determine the efficacy of the manufactured antenna are [5]:

- **Gain**: This will be represented as a ratio of transmitted power to received power as a function of frequency.
- **Directivity**: A dimensionless quantity used to describe radiation intensity as a function of the direction of the boresight of the antenna.
- **Efficiency**: This is a representation of loss of energy within the antena
- **Bandwidth**: Frequency range, in which the antenna meets all required specifications to which it is used.
- **Reflection coefficient**: The ratio of power reflected power VS transmitted power.
- **Radiation pattern**: A plot of gain vs direction (angular coordinates) of the antenna under test relative to the testing antenna. See **Figure 5**.

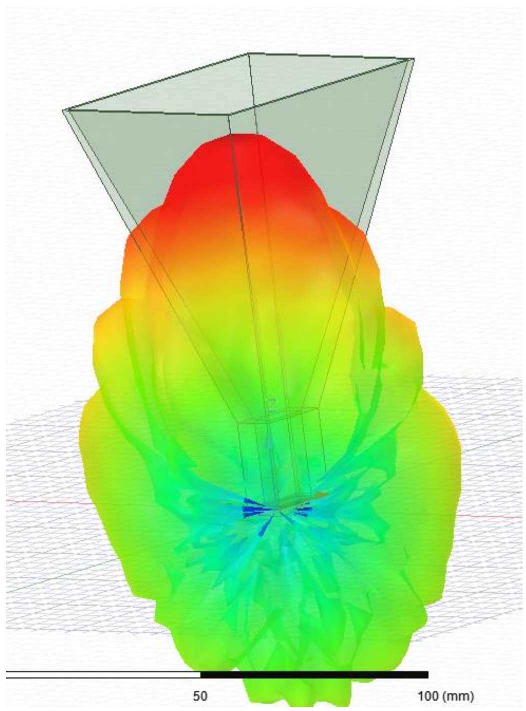


Figure 5: Example radiation pattern.

These measurements will be performed in an anechoic chamber using a Vector Network Analyzer (VNA) capable of measuring up to 26.5 GHz. The measurement equipment and facilities shall be rented from Stellenbosch University and their high-frequency lab.

The two-antenna method can be employed, where the gain of the test antenna has been characterized very well, or calculated as half of the total system gain if the two antennas are identical. **Figure 6** shows the basic S_{11} measurement setup. **Figure 7** shows the basic setup for measuring Gain, Directivity, Radiation pattern, etc. In order to obtain data for plotting radiation pattern, the AUT should be rotated by its azimuth for both E-plan and H-plane orientations of the AUT.

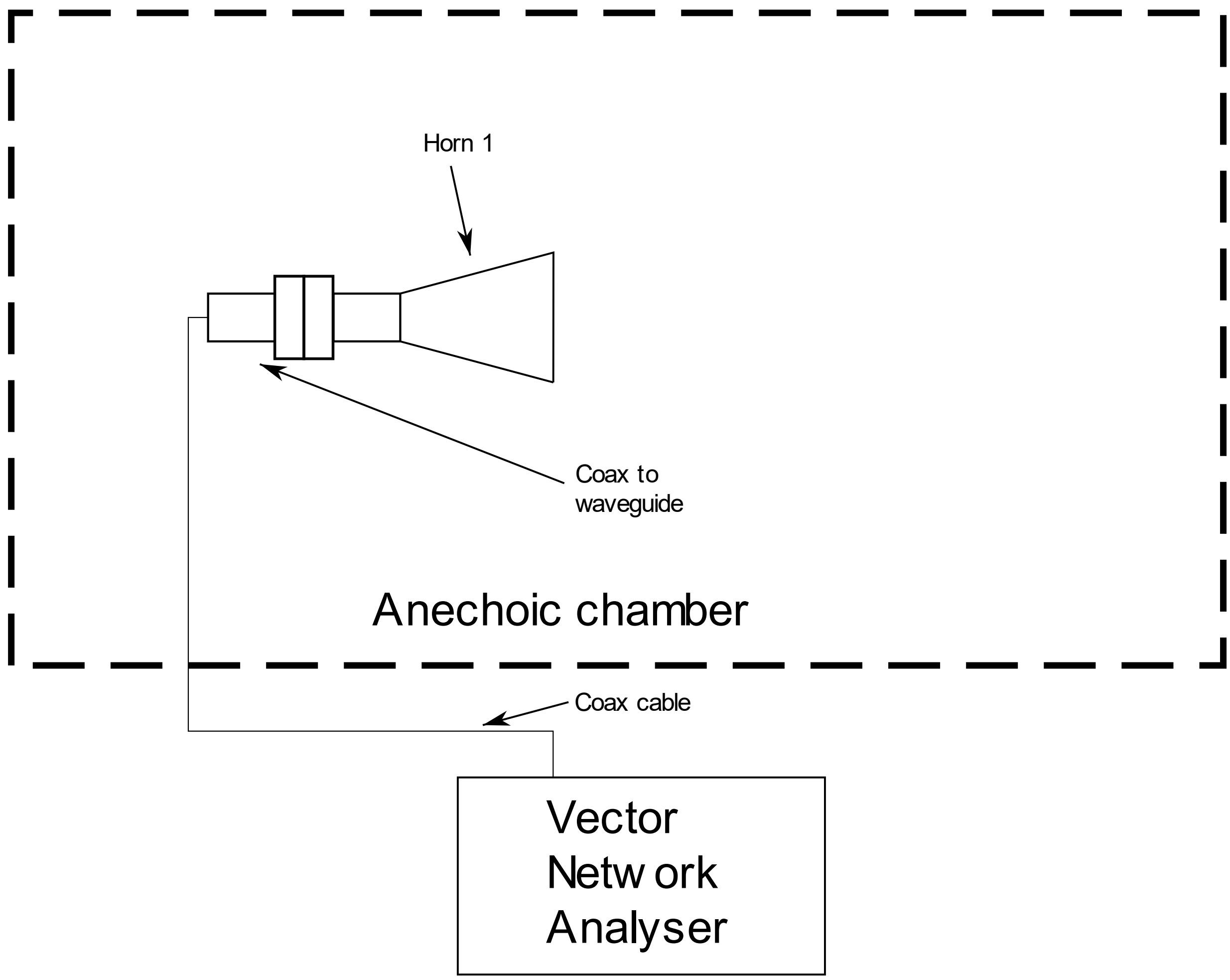


Figure 6: Reflection coefficient measurement.

The far-field distance is calculated as follows:

$$D = \frac{2L^2}{\lambda} \tag{38}$$

Where L is the longest dimension of the antenna. The AUT should be spaced ≥ 1×D from the reference antenna. The gain can subsequentially be calculated by:

$$G_T + G_R = 20\log\left(\frac{4\pi R}{\lambda}\right) + 10\log\left(\frac{P_R}{P_T}\right) \tag{39}$$

Where $20\log\left(\frac{4\pi R}{\lambda}\right)$ is the loss of free-space, and R is the distance between the two antennas.

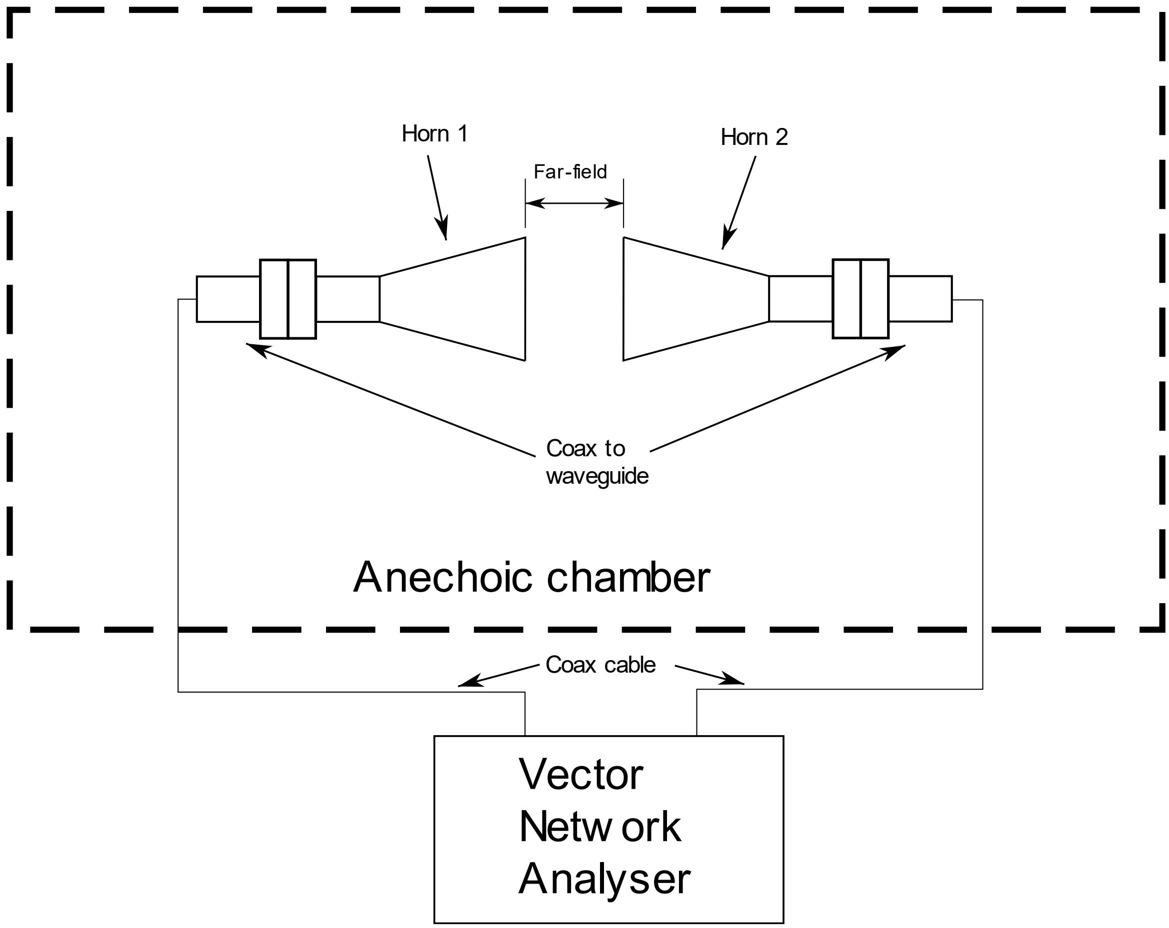


Figure 7: Gain measurement.

If both of the antennas in **Figure 7** are the exact same, the gain is assumed to be exactly the same, hence

$$G_T = \frac{G_{Total}}{2} = G_R \tag{40}$$

Data Analysis and Management

The simulated data of the antenna performance in touchstone files can be compared directly with the measured touchstone files using Python code and the matplotlib library. The generated plots from this data will directly dictate the performance of the manufactured antenna with the simulated antenna.

The data collected from both simulations and physical experiments will be systematically analyzed using statistical tools. This analysis will involve:

- **Statistical Validation**: Hypotheses regarding the performance improvements achieved through AM techniques will be tested and validated.
- **Comparison of Results**: Simulation results will be compared with physical measurements to identify any discrepancies and refine the models accordingly.
- **Optimization**: Data from the experiments will be used to further optimize the antenna design, ensuring the best possible performance in terms of gain and directivity.

All results shall be presented in the final report, as well as potential conferences or journal papers.

Ethics and environmental impact

For this study, the only major concern is the use of harsh chemicals. Most of the chemicals involved in the 3D printing and plating processes are incredibly toxic to the environment and will not be stored or disposed of in an irresponsible manner. A chemical disposal service shall be used for all byproducts in this study, additionally, PPE shall be used through all stages of involving harsh chemicals. These activities shall take place in a well-ventilated, secluded environment.

Chapter 5 Budget

Cost estimates

The costing information for this project is broken down in this section. See **Table 5** for total cost of this project. For context, the same horn proposed in this report would cost R20 000 using a CNC, excluding man hours.

Table 5: Total costing breakdown.

Number	Cost type	Price
1	Materials	R10 000
2	Equipment	R12 000
3	Software	R0
4	Hours	R94 000
Total		R116 000

Costing information

Table 6 breaks down the cost of the equipment required, if one does not already have access to this equipment.

Table 6: Bill of equipment.

Item number	Part name	Part number	Item cost
1	3D printer	TBD	R8 000
2	Power supply	TBD	R2 000
3	Hot plate magnetic stirrer	TBD	R2 000
4	Personal computer (PC)	N/A	N/A
Subtotal			R12 000

The bill of materials (BOM) in **Table 7** gives a breakdown on the materials required to build the project. This includes chemicals, consumables, and hardware. This costing is based on the literature referenced in this proposal, and what materials were used successfully by other sources. Prices were obtained online and tallied.

Table 7: Bill of materials.

Item number	Description	Item cost
1	3D printer consumables	R4 000
2	Metal plating chemicals and consumables	R5 000
3	Personal protective equipment (gloves, etc)	R500
4	Cleaning supplies (Isopropanol, etc)	R500
Subtotal		R10 000

Table 8 breaks down the cost of the software required to design and simulate everything within this project.

Table 8: Bill of software.

Item number	Software name	Item cost
1	Ansys HFSS 2022 student version	R0
2	Python (programming language)	R0
3	Autodesk Fusion 360 student version	R0
Subtotal		R0

If the project runs for 40 weeks, assuming an average of 4 hours per week dedicated to this project. A metrologist and test facilities would also be required as part of the experimentation. **Table 9** breaks down the cost of the hours required to complete this project.

Table 9: Bill of hours.

Designation	Hours required	Cost per hour	Total cost
Technologist	160	R400	R64 000
Metrologist and facilities	10	R2000	R20 000
Mentor/supervisor	10	R1000	R10 000
Sub total			R94 000

Chapter 6 Project Plan

The project timeline can be seen in the Gantt chart in **Figure 8**.

Gantt chart

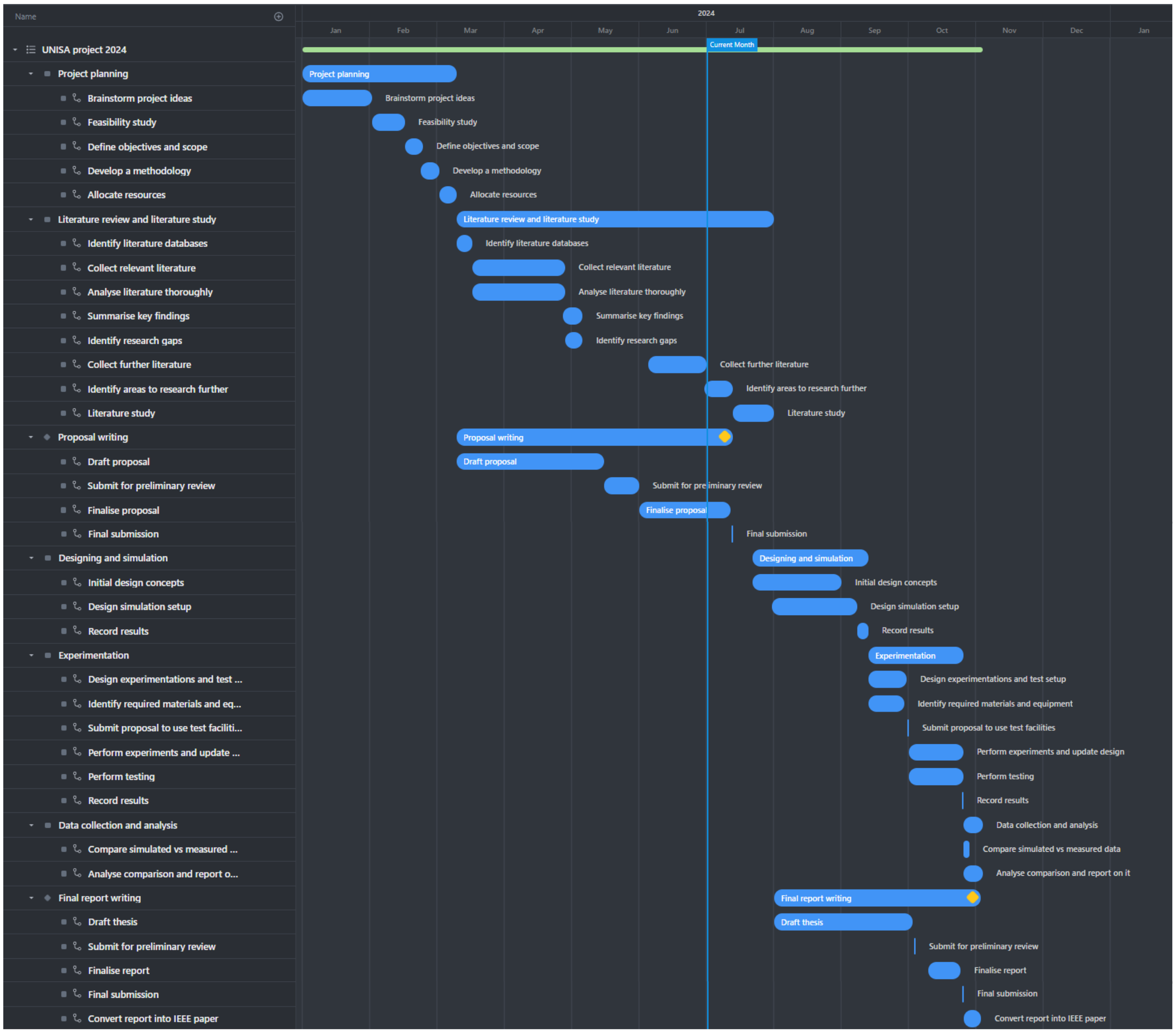
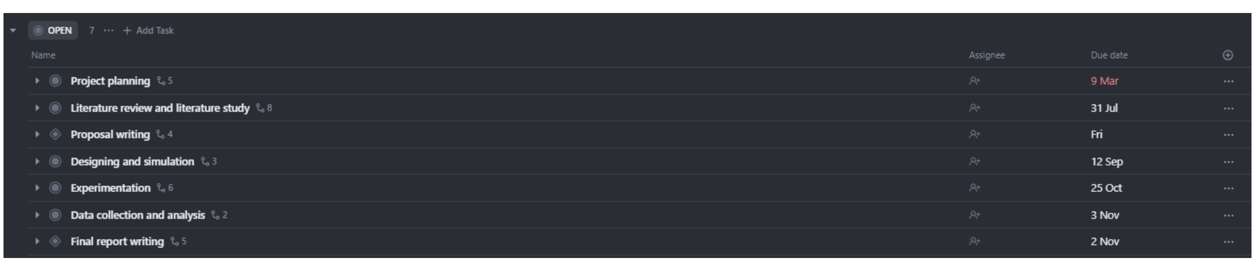


Figure 8: Project timeline.



OPEN 7 ··· + Add Task

Name	Assignee	Due date
Project planning 5		9 Mar
Literature review and literature study 8		31 Jul
Proposal writing 4		Fri
Designing and simulation 3		12 Sep
Experimentation 6		25 Oct
Data collection and analysis 2		3 Nov
Final report writing 5		2 Nov

Figure 9: Major task due dates.

Chapter 7 Summary

There is strong evidence to support the successful manufacturing of antennas using AM techniques. Antennas can be optimized through this rapid and cost-effective technique with little to no trade-offs, in some cases, antenna geometries that were not possible before, are now possible.

The proposed thesis investigates the design, manufacturing, and optimization of a K-band pyramidal horn antenna using additive manufacturing techniques combined with metal plating methods. Traditional manufacturing methods often struggle with complex geometries, particularly at high frequencies.

The methodology involves both computational and physical experiments. Computational tools like Python and Ansys HFSS are used for design calculations and simulations, while Fusion 360 aids in the CAD design process. The physical experiments evaluate various 3D printing techniques and metal plating methods to ensure dimensional accuracy and surface conductivity.

The expected outcome is a high-performance K-band pyramidal horn antenna with improved gain and directivity, demonstrating the advantages of additive manufacturing in antenna design for a fraction of the cost. This research aims to contribute significantly to the field of high-frequency antenna technology, offering insights into more efficient and flexible manufacturing processes.

All the equipment and materials proposed can be procured for the price of one machined horn antenna.

References

[1] Barrow Wilmer Lanier, ‘Electromagnetic Horn patent US2467578A’, US2467578A, 1938 Accessed: Jul. 09, 2024. [Online]. Available: https://patentimages.storage.googleapis.com/4b/74/8e/33f31fdee97022/US2467578.pdf

[2] Y. Wang *et al.*, ‘3D Printed Antennas for 5G Communication: Current Progress and Future Challenges’, *Chinese Journal of Mechanical Engineering: Additive Manufacturing Frontiers*, vol. 2, no. 1, p. 100065, Mar. 2023, doi: 10.1016/j.cjmeam.2023.100065.

[3] K. Lomakin, J. Schür, and G. Gold, ‘Design Optimization of Pyramidal Horn Antennas for 3D Printing in the mm-Wave Range’.

[4] A. Alam, S. Urooj, and A. Q. Ansari, ‘Design and Simulation of 24 GHz high gain pyramidal Horn Antenna for Bio-Radar Sensing Application’, in *2023 International Conference on Recent Advances in Electrical, Electronics and Digital Healthcare Technologies, REEDCON 2023*, Institute of Electrical and Electronics Engineers Inc., 2023, pp. 596–599. doi: 10.1109/REEDCON57544.2023.10151440.

[5] C. A. Balanis, *ANTENNA THEORY ANALYSIS AND DESIGN*, 4th ed. Wiley, 2016.

[6] D. M. Pozar, *Microwave engineering*, 4th ed. Wiley, 2012.

[7] Ziyan Zhang, ‘Manufacturing plan and DFMA-analysis of a 10 GHz conical horn antenna’, Lappeenranta–Lahti University of Technology, 2024. Accessed: Jun. 06, 2024. [Online]. Available: https://lutpub.lut.fi/bitstream/handle/10024/167471/Manufacturing%20plan%20and%20DFMA-analysis%20of%20a%2010%20GHz%20conical%20horn%20antenna.pdf;jsessionid=7ACF6C39F3CF9B0B121B9327633C30F1?sequence=1

[8] Erwin Karincic, Erdem Topsaka, and Lauren Linkous, ‘Patch Antenna Calculations and Fabrication Made Simple for Cyber Security Research’, 2023.

[9] O. Ponfoort and F. Nullmeier, ‘Benefits of Additive Manufacturing for the Oil, Gas and Maritime industries |’. [Online]. Available: www.berenschot.com

[10] Haohan Yao, Shilpi Sharma, Rashaunda Henderson, Solyman Ashrafi, and Duncan MacFarlane, ‘Ka Band 3D Printed Horn Antennas’, *Texas Symposium on Wireless and Microwave Circuits and Systems (WMCS)*, 2017.

[11] D. Sablić-Nemec and M. Joler, ‘An Automated Approach to Horn Antenna Impedance Matching and Manufacturing Using 3D Printing’, *Journal of Communications Software and Systems*, vol. 19, no. 3, pp. 188–198, Sep. 2023, doi: 10.24138/jcomss-2023-0100.

[12] I. Agnihotri and S. K. Sharma, ‘Design of a 3D Metal Printed Axial Corrugated Horn Antenna Covering Full Ka-Band’, *IEEE Antennas Wirel Propag Lett*, vol. 19, no. 4, pp. 522–526, Apr. 2020, doi: 10.1109/LAWP.2020.2967996.

[13] Y. Xue Gan and C. Q. Chen, ‘Electroplating Graphite Powder with Metals and Its Use in Microwave Absorbing Composite Material’, 1994.

[14] S. Helhel, A. Genc, I. B. Basyigit, and T. Goksu, ‘Investigation of the Performances of X-Ku Band 3D Printing Pyramidal Horn Antennas Coated with the Different Metals’, 2017. [Online]. Available: https://www.researchgate.net/publication/321482076

[15] C. R. Garcia, R. C. Rumpf, H. H. Tsang, and J. H. Barton, ‘Effects of extreme surface roughness on 3D printed horn antenna’, *Electron Lett*, vol. 49, no. 12, pp. 734–736, Jun. 2013, doi: 10.1049/el.2013.1528.

[16] Markforged, ‘What is Selective Laser Sintering (SLS)?’, https://markforged.com/resources/learn/3d-printing-basics/3d-printing-processes/what-is-selective-laser-sintering-sls#:~:text=Selective%20laser%20sintering%20(SLS)%20is,together%20into%20a%20solid%20structure.

[17] Xometry, ‘Selective Laser Sintering (SLS) 3D Printing Technology Overview’, https://xometry.pro/en-eu/articles/3d-printing-sls-overview/.

[18] Solid Print, ‘Intro to Stereolithography 3D Printing’, https://www.solidprint3d.co.uk/wp-content/uploads/2022/01/Solid-Print-SLA-white-paper.pdf.

[19] Protlabs Network, ‘How to design parts for SLA 3D printing’, https://www.hubs.com/knowledge-base/how-design-parts-sla-3d-printing/.

[20] K. Haghsefat, ‘FDM 3D Printing Technology and Its Fundemental Properties’, May 2020.

[21] T. J. Gordelier, P. R. Thies, L. Turner, and L. Johanning, ‘Optimising the FDM additive manufacturing process to achieve maximum tensile strength: a state-of-the-art review’, *Rapid Prototyp J*, vol. 25, no. 6, pp. 953–971, Jul. 2019, doi: 10.1108/RPJ-07-2018-0183.

[22] Formlabs, ‘3D Printing Technology Comparison: FDM vs. SLA vs. SLS’, https://formlabs.com/blog/fdm-vs-sla-vs-sls-how-to-choose-the-right-3d-printing-technology/.

[23] SCHLESINGER MORDECHAY and PAUNOVIC MILAN, *MODERN ELECTROPLATING*. A JOHN WILEY & SONS, INC., PUBLICATION, 2010.

[24] G. O. Mallory and J. B. Hajdu, *Electroless Plating: Fundamentals And Applications*. American Electroplaters and Surface Finishers Society, 1990.

[25] S. Swee Song, ‘DEVELOPMENT OF A NOVEL METHOD IN ELECTROLESS COPPER PLATING DEVELOPMENT OF A NOVEL METHOD IN ELECTROLESS COPPER PLATING SENG SWEE SONG’, 2004.

[26] Z. Jing, 'DEVELOPMENT OF ELECTROLESS PLATING PROCESSES FOR LOW COST PLASTIC-METALLIZATION AND AREA-SELECTIVE METAL COATING OF THREE-DIMENSIONAL STRUCTURES', 2020.

[27] R. Bernasconi, C. Credi, M. Tironi, M. Levi, and L. Magagnin, 'Electroless Metallization of Stereolithographic Photocurable Resins for 3D Printing of Functional Microdevices', *J Electrochem Soc*, vol. 164, no. 5, pp. B3059–B3066, 2017, doi: 10.1149/2.0081705jes.

[28] Savale P. A., 'Physical Vapor Deposition (PVD) Methods for Synthesis of Thin Films: A Comparative Study', 2016.

[29] Mattox Donald M., *Handbook of Physical Vapor Deposition (PVD) Processing*. Elsevier, 2010. doi: 10.1016/C2009-0-18800-1.

[30] Leandro de Paula Santos Pereira and Marco Antonio Brasil Terada, 'New method for optimum design of pyramidal horn antennas', *Journal of Microwaves, Optoelectronics and Electromagnetic Applications*, vol. 10, no. 1, pp. 266–277, 2011.

[31] Zheng Ziyang, Fang Yulin, and Mao Junfa, 'Optimization of Pyramid Horn Antenna using Genetic Algorithm and Evolution strategy', *IEEE International Symposium on Antennas and Propagation and North American Radio Science Meeting*, 2020.

[32] C. K. Chua and K. F. Leong, *3D Printing and Additive Manufacturing*. WORLD SCIENTIFIC, 2017. doi: 10.1142/10200.

[33] Ian Gibson, David Rosen, and Brent Stucker, *Additive Manufacturing Technologies: 3D Printing, Rapid Prototyping, and Direct Digital Manufacturing*, 2nd ed. Springer, 2015.

[34] B. M. Kolundzija and V. V. Petrovic, 'Power conservation in method of moments and finite-element method for radiation problems', *IEEE Trans Antennas Propag*, vol. 53, no. 8 II, pp. 2728–2737, 2005, doi: 10.1109/TAP.2005.851857.

[35] Antennas and Propagation Standards Committee, *149-2021 - IEEE Recommended Practice for Antenna Measurements*. 2021.

Appendix 1: Research Ethics Pledge and Declaration

UNISA college of science, engineering and technology

College of Science, Engineering and Technology
Student Research Ethics Pledge

1. I have read the UNISA Policy on Research Ethics.
2. I have acquainted myself with UNISA's code of conduct on research ethics expressed in the UNISA Policy on Research Ethics and the Standard Operating Procedure on Research Ethics Risk Assessment. I shall fully comply with it.
3. I have not commenced with fieldwork relating to any data collection that involves human participants, data, animals, or other living or genetically modified organisms concerning the proposed research.
4. I understand that I cannot commence with fieldwork or data collection that involves human participants, data, animals, or other living or genetically modified organisms until I receive an approved research ethics certificate.
5. I understand that if I am required to do research work during the proposal phase related to any data collection or experiments in the laboratories and/or secondary data use, I must first apply for research ethics approval.
6. I understand that it is my responsibility to apply for research ethics approval at the earliest possible time (preferably within six months of registering for my dissertation/thesis), but under all circumstances before commencing with fieldwork.
7. I understand that I cannot submit postgraduate research for examination without a research ethics approval certificate. In the absence of a research ethics approval certificate, I will be required to redo fieldwork after obtaining research ethics approval.
8. I will use the CSET research ethics application forms and submission process as outlined on the CSET website to apply for research ethics approval: https://www.unisa.ac.za/sites/corporate/default/Colleges/Science,-Engineering-&-Technology/Research/Research-Ethics

Student name: Alec Robin Gould	Supervisor name:
Student Signature:	Supervisor Signature:
Date: 10/07/2024	Date:

College of Science, Engineering and Technology
University of South Africa
Florida, Science Campus
www.unisa.ac.za

HPELE81

TOPIC: The Design, manufacturing, and implementation of a K-band pyramidal horn antenna, using additive manufacturing techniques, for optimised gain and directivity

Acknowledgement of Unisa Research Ethics policies and confirmation of adherence to Unisa Research Ethics requirements

By signing below, I undertake to:

	Agree Please check each of the following to indicate your agreement
Execute the research in a scientific and ethically responsible way	X
Not to use the research and information in a manner that is detrimental to the University of South Africa or to persons or institutions outside the university unless it can be scientifically-academically justified	X

I confirm that:

I am familiar with the University of South Africa's Research Ethics policy and agree to adhere to it	X
I am familiar with the University of South Africa's Academic Integrity Policy	X
I will cite all sources consulted in accordance to the reference guide provided	X
I have no conflict of interests that may jeopardise my ability to undertake the research in a scientific and ethical manner.	X
Student **CONSENT IN TERMS OF THE PROTECTION OF PERSONAL INFORMATION ACT NO 4. OF 2013** 1. I declare that all the information furnished by me on this form is true and correct and undertake to inform Unisa of any changes in my personal information. 2. I undertake to comply with all the rules, regulations and decisions of the university and any amendments to it and I have taken note of advice which may be applicable to Unisa researchers, non-Unisa researchers and postgraduate supervisors. 3. I, as a postgraduate researcher, hereby consent that Unisa may collect, use, distribute, process and communicate my personal information for all required research ethics processes about my participation in Unisa research ethics activities, which may include, but is not limited to: 3.1 assessment of research ethics application; 3.2 internal administrative processing;	X

3.3 assessment of complaints and investigations of alleged violations of norms and standards for the ethical conduct of research; and

3.4 institutional and scholarly research.

4. I also consent that Unisa may share my personal information with other Universities of South Africa, third parties rendering database management facility on behalf of the university, the Department of Higher Education and Training, the National Health Research Ethics Council, Internal and External Auditors, and for the purpose of legislative requirements.
5. I understand that in terms of the Protection of Personal Information Act (POPIA) and other laws of the country, there are instances where my express consent is not necessary to permit the processing of personal information, which may be related to investigations, litigation or when personal information is publicly available.
6. I will not hold the university responsible for any improper or unauthorised use of personal information that is beyond its reasonable control.
7. I confirm that I have read the notice and understand the contents thereof.

Note: The nature of personal information collected can be viewed in the Personal Information Inventory Lists published on the Unisa webpage at www.unisa.ac.za

Student number	16412117
Student name	Alec Robin Gould
Signature	
Date	10/07/2024

STUDY SUPERVISOR:

To my knowledge the student has addressed all aspects in his/her application for research ethics approval set forth in the University of South Africa's Policy for Research Ethics. I confirm that the form is complete. I will ensure that the student notifies the committee in writing if any changes to the research are proposed that may affect any of the study-related risks for the research participants such as methodology, sampling, questionnaire, interview schedule, etc. Subsequently, I approve the submission and recommend that approval is granted for the research~~.~~

(The student declaration must be completed and securely stored by the supervisor for possible audit purposes.)

Name in capital letters:	
Signature:	
Date:	

Zertifikat

Certificat

Certificado

Certificate

Promouvoir les plus hauts standards éthiques dans la protection des participants à la recherche biomédicale
Promoting the highest ethical standards in the protection of biomedical research participants

Clinical Trials Centre
The University of Hong Kong

Certificat de formation - Training Certificate

Ce document atteste que - this document certifies that

Alec Gould

a complété avec succès - has successfully completed

Module 1 (2023) - Introduction to Research Ethics

du programme de formation TRREE en évaluation éthique de la recherche
of the TRREE training programme in research ethics evaluation

Release Date: 2024/04/06
CID : kMRfCdoqj9

Professeur Dominique Sprumont
Coordinateur TRREE Coordinator

APPROVED BY SIWF ISFM
Programmes de formation continue (2 crédits)
Continuing Education Programs (2 credits)

Foederatio Pharmaceutica Helvetiae FPH
Programmes de formation continue
Continuing Education Programs
Programmes de formation postgraduée et continue

Ce programme est soutenu par - This program is supported by :
European and Developing Countries Clinical Trials Partnership (EDCTP) (www.edctp.org) - Swiss National Science Foundation (www.snf.ch) - Canadian Institutes of Health Research (http://www.cihr-irsc.gc.ca/e/2891.html) - Swiss Academy of Medical Science (SAMS/ASSM/SAMW) (www.samw.ch) - Commission for Research Partnerships with Developing Countries (www.kfpe.ch)

[REV : 20220217]

Zertifikat

Certificado

Certificat

Certificate

TRREE

Promouvoir les plus hauts standards éthiques dans la protection des participants à la recherche biomédicale
Promoting the highest ethical standards in the protection of biomedical research participants

Clinical Trials Centre
The University of Hong Kong

Certificat de formation - Training Certificate

Ce document atteste que - this document certifies that

Alec Gould

a complété avec succès - has successfully completed

Module 2 (2023) - Research Ethics Evaluation

du programme de formation TRREE en évaluation éthique de la recherche
of the TRREE training programme in research ethics evaluation

Release Date: 2024/04/06
CID : [illegible]

Professeur Dominique Sprumont
Coordinateur TRREE Coordinator

APPROVED BY
SIWF ISFM
Programmes de formation continue (2 crédits)
Continuing Education Programs (2 credits)

Foederatio Pharmaceutica Helvetiae
FPH
Programmes de formation continue
Continuing Education Programs
Programmes de formation postgraduée et continue

Ce programme est soutenu par - This program is supported by :
European and Developing Countries Clinical Trials Partnership (EDCTP) (www.edctp.org) - Swiss National Science Foundation (www.snf.ch) - Canadian Institutes of Health Research (http://www.cihr-irsc.gc.ca/e/2891.html) - Swiss Academy of Medical Science (SAMS/ASSM/SAMW) (www.samw.ch) - Commission for Research Partnerships with Developing Countries (www.kfpe.ch)

[REV : 20220217]

TRREE

Zertifikat

Certificat

Certificado

Certificate

Promouvoir les plus hauts standards éthiques dans la protection des participants à la recherche biomédicale
Promoting the highest ethical standards in the protection of biomedical research participants

Clinical Trials Centre
The University of Hong Kong

Certificat de formation - Training Certificate

Ce document atteste que - this document certifies that

Alec Gould

a complété avec succès - has successfully completed

Module 3 (2023) - Informed Consent

du programme de formation TRREE en évaluation éthique de la recherche
of the TRREE training programme in research ethics evaluation

Release Date: 2024/04/06
CID : AaWFDNOlrL

Professeur Dominique Sprumont
Coordinateur TRREE Coordinator

APPROVED BY
SIWF ISFM
Programmes de formation continue (2 crédits)
Continuing Education Programs (2 credits)

Foederatio Pharmaceutica Helvetiae
FPH
Programmes de formation continue
Continuing Education Programme
Programmes de formation postgraduée et continue

Ce programme est soutenu par - This program is supported by :
European and Developing Countries Clinical Trials Partnership (EDCTP) (www.edctp.org) - Swiss National Science Foundation (www.snf.ch) - Canadian Institutes of Health Research (http://www.cihr-irsc.gc.ca/e/2891.html) - Swiss Academy of Medical Science (SAMS/ASSM/SAMW) (www.samw.ch) - Commission for Research Partnerships with Developing Countries (www.kfpe.ch)

[REV : 20220217]