QUALITY ASSURANCE IN THE MANUFACTURING OF 92GHz DIRECTIONAL COUPLER

Lappeenranta–Lahti University of Technology LUT

Bachelor's Degree programme in Mechanical Engineering, Bachelor's thesis

2025

Samuel Chinonso Ozumba

Examiners: Adjunct Professor, Ph.D. (Mil.), Tapio Saarelainen

ABSTRACT

Lappeenranta–Lahti University of Technology LUT

LUT School of Energy Systems

Mechanical Engineering

Samuel Chinonso Ozumba

Quality assurance in the manufacturing of 92GHz directional coupler

Bachelor's thesis

2025

54 pages, 18 figures, 4 tables and 3 appendices

Examiner: Adjunct Professor, Ph.D. (Mil.), Tapio Saarelainen

Keywords: Quality Assurance, Microwaves, W-bands, geometric tolerance, measuring devices.

This study investigates the application of Quality Assurance (QA) practices in the manufacturing of a 92 GHz Directional Coupler, focusing on the methods from the design stage to the manufacturing stage. The study emphasises the importance of geometric and dimensional tolerances, material selection, and surface finishing, which affect the device's performance. Through the use of the triangulation method, by combining the results from the literature review, Expert interview, and CAD-Analysis, the study shows important manufacturing considerations, like the material selection, which is important for the conductivity performance. The study also shows the importance of gold coating and the challenges associated with it, and the soldering techniques to be used. Recommendations were also made for future research in regards to changes in the shape of the device, a possible change in the material, and the manufacturing of the device.

ACKNOWLEDGEMENTS

First and foremost, I would like to express my sincere gratitude to my supervisors, Tapio Saarelainen and Harri Eskelinen, for their invaluable guidance, support, and encouragement throughout the course of this thesis. Their insightful feedback and constant motivation have been instrumental in shaping this work.

I am also deeply thankful to the faculty and staff of the Double Degree Mechanical Engineering Department at LUT University, whose knowledge and assistance have greatly contributed to my academic development.

I am grateful to my family and friends for their unwavering support, patience, and belief in me during this journey. Their encouragement has been a constant source of strength.

Finally, I would like to acknowledge all the participants and contributors who provided the necessary data and insights for this study. Without their cooperation, this thesis would not have been possible.

Thank you all.

ABBREVIATIONS

2D	Two-Dimensional
3D	Three-Dimensional
CAD	Computer Aided Design
GaN	Gallium Nitride
GHz	Gigahertz
mm	Millimetre
MW	Microwave
ISO	International Organisation for Standardisation
QA	Quality Assurance

Table of contents

Abstract

Acknowledgements

Abbreviations

1 Introduction 7
1.1 Goal of Research 8
1.2 Manufacturing of Directional Couplers 8
1.3 Background and Motivation 10
1.4 Research problem and Research questions 11
1.5 Research Methods for Quality Assurance 13
1.6 Expected contribution 13
2 Methods 14
2.1 Expert Interview 15
2.2 Literature Review 16
2.3 CAD Analysis 18
2.4 Utilisation of Triangulation 18
2.5 How will reliability analysis be achieved? 19
2.5.1 Literature review analysis 19
2.5.2 Utilisation of a stepwise Quality Assurance procedure and SolidWorks illustration 20
3 Results of Quality Assurance 22
3.1 Literature review results 22
3.1.1 Manufacturing W-band Components 22
3.1.2 Optimal materials for microwave devices 22
3.1.3 3D printing high frequency devices 23
3.1.4 Challenges with Gold coating 24
3.1.5 Importance of geometric tolerance 24
3.1.6 Improved soldering techniques 25
3.1.7 Challenges with metal bending 26
3.1.8 Application of W-bands 26

3.1.9 ISO standard for Engineering Manufacturing and Design 27
3.2 Expert Interview results 28
3.2.1 Gold Embrittlement 29
3.2.2 Material composition and bending effects on high-frequency devices 29
3.2.3 Manufacturing challenges and Quality Assurance 29
3.2.4 Importance of Hole formation and position 29
3.2.5 General Observation 29
3.3 CAD-based analysis 30
3.3.1 Measurement of microwave devices 30
3.3.2 Importance of geometric and dimensional tolerance 33
3.4 Triangulation based observations 37
4 Discussion 39
4.1 Key findings 39
4.1.1 Accurate measurement with precision tools 39
4.1.2 Design and manufacturing stage 40
4.1.3 Material selection 40
4.1.4 Coating and Soldering 41
4.1.5 3D printing of high-frequency devices 41
4.2 Comparison and connection with previous research 42
4.3 Reliability assessment of the results 42
4.4 Conclusion 45
4.4.1 Effects of over-quality in production 45
4.4.2 Application of this thesis research in future Quality Assurance research works 46
4.5 Topics for future research 46
5 Summary 49
References 50

Appendices

Appendix 1: Literature Reliability Analysis

Appendix 2: Technical Drawings

Appendix 3: Geometric Tolerance in 3D

1 Introduction

Recent advancements in W-band communication systems have garnered significant attention. These communication systems possess the attributes of a broad bandwidth, high transmission quality, and strong detection ability. A crucial component of the communication system is the filter, and it is evolving towards achieving minimal loss and optimal performance (Huang et al., 2021).

The millimetre-wave (mm-wave) frequency band is quite interesting for its financial value and high potential for utilization. The functionalities of this system are currently in high demand across various sectors, including imaging, sensing, life sciences, and wireless communications. In wireless communications, the current era of ultra-fast and easy cyberspace accessibility has raised concerns about the potential of the underutilised part of the spectrum, which corresponds to mm-wave bands, for short-range communications. The W-band bandwidth can satisfy the demand for substantial data throughput in prospective 5G systems. Building on the technology involved in cellular networks, the mm-wave band has played a key role in the development of current Wi-Fi communication standards. Subsequently, mm-wave communication systems are now being suggested for satellite and military use (Sanchez-Olivares et al., 2023).

Dual-polarised antenna systems are used extensively in satellite communications, radio signals, and radars for various applications, including weather forecasting and air traffic control. In these systems, different frequency bands for utilisation are widely different. The innovation of new uses for frequency bands means that the old systems cannot keep up with these new applications, as they can only function at lower frequencies. This has created room for research in developing the work output of the structures in particle accelerators, molecular spectroscopy, or plasma diagnosis, leading to the restructuring of new systems for the microwave instruments at these high-frequency bands (Montejo-Garai et al., 2019).

Subsequently, section 1.1 describes the research goal, section 1.2 discusses the manufacturing of directional couplers, and section 1.3 discusses the background and motivation for the research. Section 1.4 discusses the research problem and questions, section 1.5 also discusses the research methods of Quality Assurance, and finally, section 1.6 discusses the expected contribution from the thesis.

1.1 Goal of Research

Bending is a mechanical forming process involving a punch and a die to bend a metal sheet. During this process, the sheet stretches in the bending zone, requiring certain adjustments to ensure the final part's correct measurements. However, determining the required adjustments is challenging due to variations in metal types, sheet thicknesses, tools used, and bending angles. To combat this, regular testing is a must to ensure that the metals are up to standard before mass production, most especially when dealing with the angles, which have been proven to almost always cause difficulties (Silva et al., 2024)

Gold (Au) is a popular choice for use in electronics due to its properties, such as easy attachment to other metals during soldering and wire bonding, as well as its resistance to rust and tarnish. However, soldering with gold will always leave a possibility for embrittlement, where the bond becomes weak or breaks.

The gold (Au) embrittlement phenomenon is well-documented and has been explained in publications dating back to the 1960s. Therefore, the use of gold in soldering must always consider the possible issue of embrittlement. This phenomenon arises as a result of the presence of gold and tin intermetallic compound (IMC) particles (AuSn4) (Wheeling et al., 2022)

Taking all these into consideration, this research thesis focuses on improving the quality analysis methods employed in the production and manufacture of these devices, aiming to optimise their structural and functional properties.

1.2 Manufacturing of Directional Couplers

The 92GHz directional couplers are composed of four parts, made up of three mounting flanges, six guiding pins, a special perforated plate, and two waveguides. Both the assembly and detailed pictures of the assembly parts are shown below. There are two waveguides, which are made of gold-plated copper alloys. There is the option of aluminium alloy, but copper alloy is the best material in this study due to its easy machinability and high conductivity. The first waveguide is a straight rectangular tube, hollow on the inside and cut at midplane for the placement of the special perforated plate. The second waveguide is cut

and bent at an angle of 90 degrees and soldered to the straight waveguide, with the perforated plate in between them, and the mounting flanges are mounted perpendicularly to the waveguides. The guiding pins of steel tightly fit into the holes in the mounting flanges. The directional couplers are manually assembled, and this increases the cost of production as it requires expert assembly. Though the production of individual parts is not expensive, the high precision required in the assembly and coating of the devices, along with ensuring their smoothness for good microwave propagation, results in only a few good-quality devices being obtained from the large number of devices produced. In Figure 1.1.

Figure 1.1 Image of 92 GHz Directional Coupler

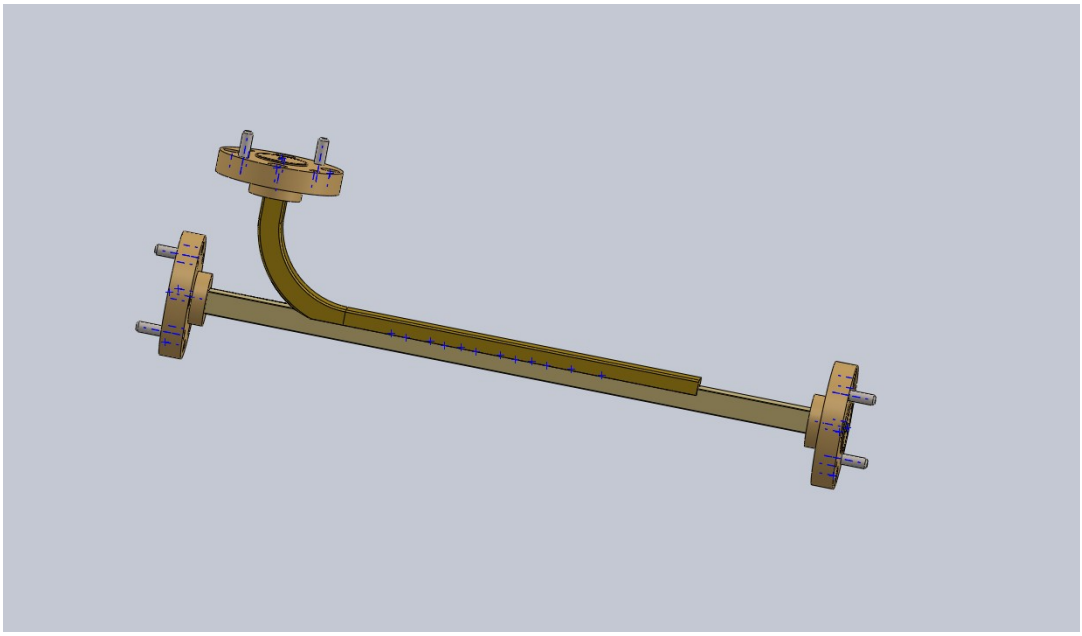


Figure 1.2 Directional coupler Assembly

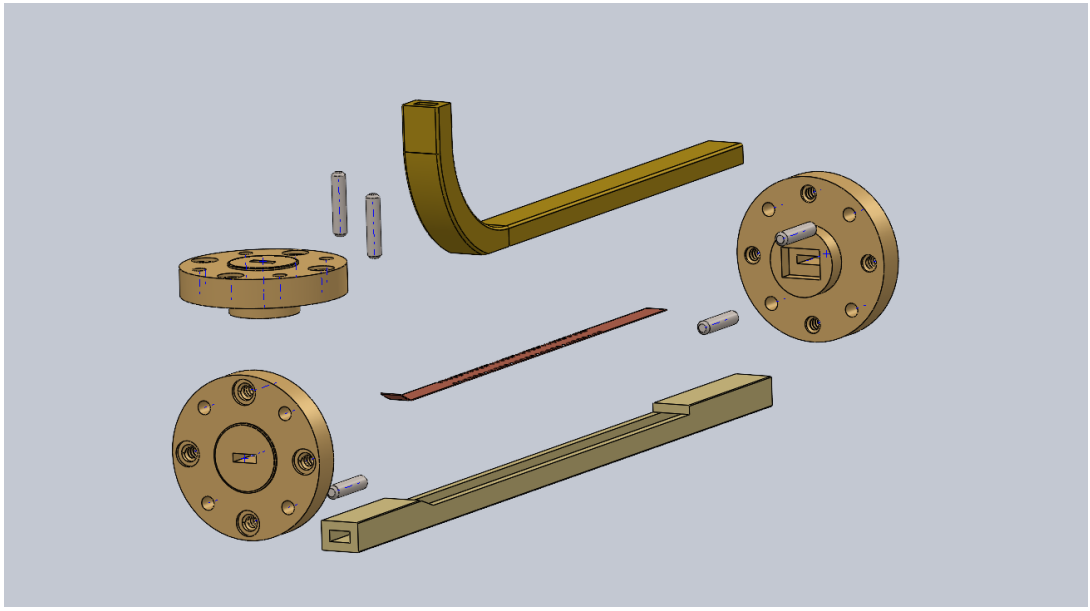


Figure 1.3 Exploded view of Directional coupler assembly

1.3 Background and Motivation

Most recently developed are high-frequency radar systems, such as those operating in the W-band (typically 75 GHz to 110 GHz), which are important in applications like frequency

multiplication for providing power to devices (Sonnenberg, Verploegh et al., 2023). The millimetre-wave part of the electromagnetic spectrum above 50 GHz, in V-bands (50–75 GHz) and W-bands (75–110 GHz), is being used for return communication links for earth and space systems, imaging, spectroscopy, radio astronomy, and automotive radar. This frequency range offers a high data processing rate from a modest fractional bandwidth, high imaging resolution resulting from short wavelengths, and lower wave attenuation in atmospheric window frequency bands, as well as when propagating through dust, smoke, and fog. The frequency allocations in V and W bands are still evolving and are applied in the state-of-the-art front-end gallium nitride (GaN) integrated circuits (Sonnenberg, Romano et al., 2023).

During the bending process of metals, after applied forces have been removed, the metal attempts to revert to its initial form. This phenomenon is known as spring-back. Spring-back is greatly influenced by the material's physical properties as well as the die structure. Factors that could cause a higher spring-back include a die gap, a larger bend radius, a lower elastic modulus, and a higher material strength. Minimising this during the bending process is one of the most troublesome problems in die design (Chou and Hung, 1999). Due to challenges such as this and gold embrittlement, an optimal quality assurance method is needed to ensure the viability of the devices.

1.4 Research problem and Research questions

For the device to deliver a high and optimal performance, strict tolerance during the manufacturing process is essential. A W-band directional coupler for 92 GHz docking radar is an example of a high-frequency device in such an instance.

Strict standards for the highest quality in the production of these devices must be followed to ensure efficient microwave propagation, as they contain numerous complex elements, such as waveguides, flanges, and perforated plates, which are necessary. Waveguide bending and soldering are particularly challenging problem areas in key manufacturing processes. When a waveguide is bent, its cross-section may twist or flatten or may be otherwise distorted such that the quality of the microwave signals sent through the waveguide is degraded. In the case of soldering, a likely problem could be poor bonding. However, this is not the only issue that could be faced. A strong and irregular bond will scatter the signals

and reflect within the system, which could then affect the quality or condition of the signal being distributed through the waveguide.

Material selection plays an essential role in determining the waveguide's structural integrity, machinability, soldering compatibility, conductivity, and thermal stability. Trade-offs must be evaluated between various materials, including the potential benefits of gold or silver plating for electrical shielding and durability. Furthermore, ensuring mechanical and thermal stability while minimising deformation is critical to maintaining the directional coupler's performance over time.

Despite technological advancements in the manufacturing industry, the issue of quality consistency during the manufacturing process is yet to be solved. Small deviations can lead to serious performance drops. Bad performance could lead to device failure. A failure, in this case, means that the component does not meet the international standards for high-frequency devices. It is very important to achieve a certain level of quality for optimal performance, even without the presence of strong quality assurance protocols. The absence of these protocols leaves us to wonder about the extent of defects the faulty devices would have and the number of reattempts it will take to produce devices that could compete internationally in achieving high-frequency performance.

Research Question:

How can quality assurance protocols be developed and implemented to ensure the optimal performance of W-band directional couplers in high-frequency radar applications?

Supporting Questions:

1. What are the leading causes of waveguide distortion during bending, and how do these causes affect the dissemination of electromagnetic signals?

2. What defects in soldering regularly occur in high-frequency components, and how do these defects affect the overall performance of the devices?

3. How does gold embrittlement during coating and soldering affect the performance of the device?

1.5 Research Methods for Quality Assurance

The method applied in this thesis is the methodological triangulation method, one of the triangulation methods that involves an intricate analysis of various methods to ensure a comprehensive quality framework. The simulation predicts distortions in waveguide bending and assesses solder joint quality by defining material properties and creating CAD models, followed by running simulations to analyse deformations and electromagnetic performance.

The literature review analyses existing research on waveguide bending, soldering, and quality assurance (QA) methods by grouping key findings and mapping them to the research questions. A combination of insights from industry professionals with practical expertise and those with theoretical insights provides an extensive understanding of the subject, as further insights are gained into the challenges faced and best practices.

1.6 Expected contribution

This research aims to suggest credible ways to achieve high-quality performance in w-band high-frequency devices through quality guidelines. This will be achieved by examining ways to effectively reduce and eventually phase out common issues and current routines in the production of low-quality devices, resulting in increased reliability and performance.

The research also provides other alternatives to the production and functions of the device, considering the challenges encountered with the device, seeking better alternatives to improve its performance is highly critical, though it is theoretical, it is still a field that can be further researched.

2 Methods

Since the early days of social sciences, mixing different research methods and data types in the experimental study of certain developments has been common. Combining research techniques gives a deeper understanding since multiple alternatives are available. Quantitative researchers are generally known for their practice of mixed methods. An example of such researchers is Paul Lazarsfeld. However, after Campbell's publication on triangulation as a way of merging validations and then the discovery of grounded theory, which involved continuous comparisons of methods that included various data sources, triangulation became well recognized in the field of qualitative research.,

Ivankova and Kawamura conducted a detailed bibliometric analysis of modern method practice mixing. The research involved a deep dive into five databases, which include PubMed, ERIC, PsychInfo, Academic OneFile, and Academic Search Premier, as well as two journals, namely, the Journal of Mixed Methods Research and the International Journal of Multiple Research Approaches. The researchers noted a steady increase in the number of users of mixed research methods, which rose from 10 in 2000 to approximately 243 in 2008. (Fielding, 2012). As such, the principle would be applied here by combining different methods.

Applied triangulation

Figure 2.1, which shows the triangulation method, provides a breakdown of the different methods and steps involved in ensuring a quality and comprehensive framework.

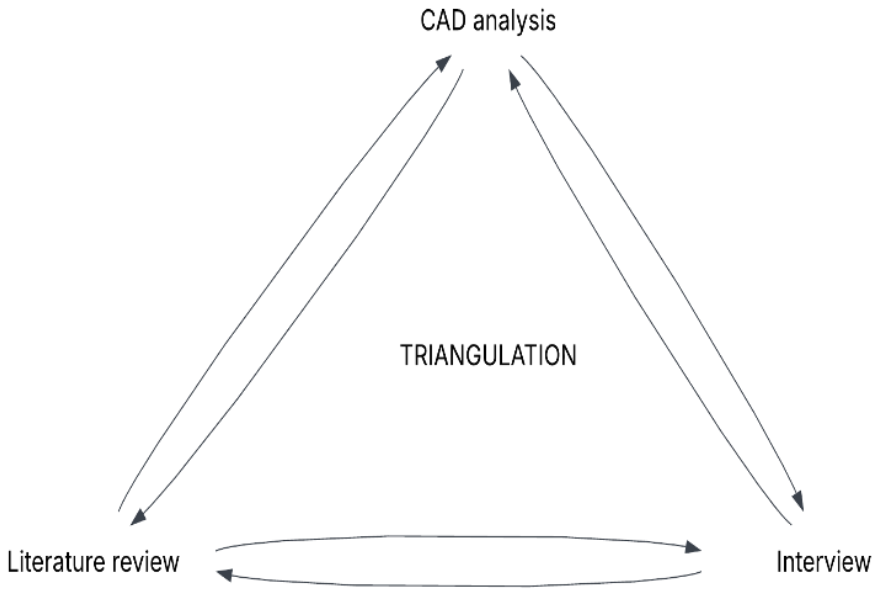


Figure 2.1 Triangulation method

Sections 2.1 to 2.3 offer a breakdown of each triangulation method, while sections 2.4 to 2.5 discuss how to utilise the method and also how the reliability analysis of the methods is conducted.

2.1 Expert Interview

The interview aims to draw practical insights from industry experts to substantiate theoretical findings. It begins by defining key objectives, focusing on practical challenges, QA strategies, and manufacturing insights. The relevant participants are identified, including engineers and academics specializing in high-frequency radar components. A structured set of open-ended questions is developed, covering bending and soldering challenges, QA techniques, and industry best practices.

The interviews could then be conducted virtually or in person, recorded, and then transcribed for later evaluation. Common themes and unique insights are then extracted, and findings are integrated with simulation and literature review results to ensure a well-rounded understanding of the subject.

Arrangements for Expert Interview

The interviewee for the research is a specialist in electrical engineering, who has worked in closely related fields and carried out lots of research on electrical components, making them appropriate for the questions that were asked to better understand the issues caused by insufficient materials and other insights that can only be provided by an expert with major experience. The major question asked was, how does gold embrittlement during coating and soldering, and the compensation of metal during bending, affect the performance of high-frequency wave bands? This question is sure to obtain an expert's insight and give other strong solutions to ensure quality assurance guidelines during the production of high-frequency devices

2.2 Literature Review

The literature review evaluates existing research on waveguide bending, the soldering process, and quality assurance. It starts by pinpointing important sources, which include academic papers, industry standards, and case studies from databases like IEEE, Xplore, Google Scholar, and ScienceDirect.

The collected literature has been grouped and organized into themes such as bending distortions, soldering quality, and QA methods. Important findings have been evaluated to note the best practices, challenges, and research gaps. These insights are aligned with the thesis research questions to ensure relevance. Figure 2.2 shows the flowchart presentation of how to go about the literature review.

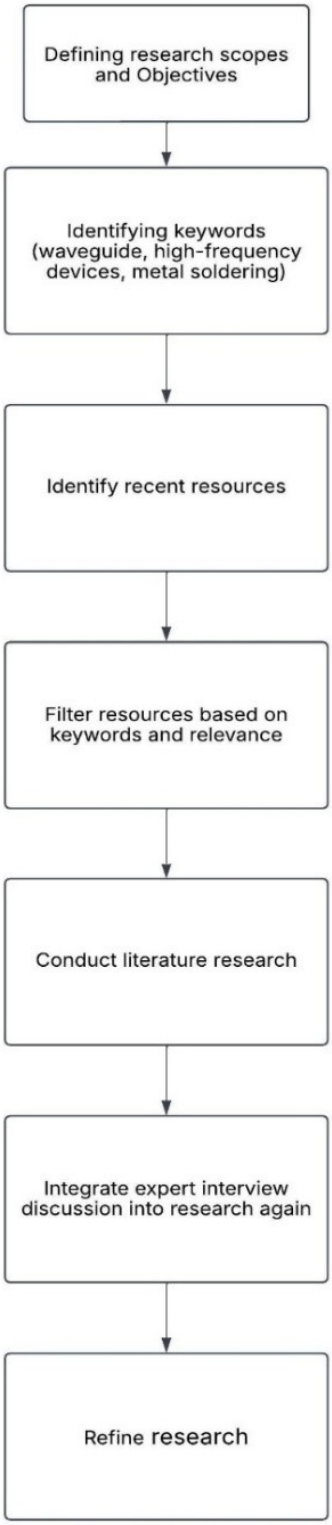


Figure 2.2 Flowchart presentation of literature search and review

2.3 CAD Analysis

CAD stands for computer-aided design. Analysis is a process that uses computational tools and digital modelling to assess, test, and improve designs. It entails creating, modifying, and analyzing 2D or 3D models of things, structures, or systems using specialized CAD software. To improve accuracy, productivity, and performance, CAD analysis is frequently used in engineering, architecture, product design, and manufacturing. Crucial elements of CAD Analysis:

1. Model Creation: Using CAD software, users can create intricate geometric models of their designs. These models may incorporate physical attributes, materials, and dimensions

2. Manufacturing Integration: Computer-aided manufacturing (CAM) procedures, such as computer numerical control (CNC) machining and 3D printing, can be performed directly using CAD models. This guarantees a smooth transition between design and manufacturing.

3. Error Detection and Design Optimization: Before physical prototyping, CAD Analysis assists in locating design defects, interferences, or inefficiencies. By testing changes in a virtual setting, development expenses and material waste can be decreased.

2.4 Utilisation of Triangulation

A combination of all three methods of the proposed triangulation would be used as they are very vital and complement each other in various ways. The expert's interview provides first hand insight into the directional coupler, filling in the gaps and answering questions that arose during the research work. The literature review is also essential, as it not only provides background knowledge on the device being worked with but also helps establish a foundation for further research. Hence, it is also used to validate the experts' interview responses, thereby creating a stronger validation, as it is no longer the opinion of just one person, seeing as various sources and experts have also verified it.

The importance of strict geometric tolerances and dimensions in a device like this cannot be overemphasised as any slight deviation leads to disruption of the performance and possibly failure and also going back to the experts' interview and literature review it is essential to

point out how both methods justify the importance of geometric tolerance during the manufacturing process stage of the device.

2.5 How will reliability analysis be achieved?

Reliability is an important aspect of every research work, as it does not show credibility only, it shows and creates understanding and awareness of the procedures involved, what the researcher was thinking, and the approach to handling challenges and issues, thereby creating a reliable result and also gives one the opportunity to reapply the same procedures in a different research topic.

For the literature review, drawings, and the expert interview, the Table 1 template attached below is used, which ensures quality and acceptable work, and verifies all information provided by the expert interview by employing different quality sources to verify various questions and answers. Subsequently too the literature review analysis and the utilisation of stepwise quality assurance in SolidWorks analysis are also presented.

Table 1: Reliability Analysis Table

CRITERIA	**SolidWorks**	**Expert Interview**	**Literature Review**	**Triangulation**
Validity				
Reliability				
Sensitivity				
Error Analysis				
Accuracy				
Saturation				

2.5.1 Literature review analysis

The following guideline in Table 2 provides a detailed overview of how the references utilized in addressing the literature review questions will be organized and presented. This

structured format is intended to enhance clarity, ensure consistency, and facilitate easy tracking of the sources consulted throughout the review process. This structured approach is designed to systematically categorize the sources, thereby enhancing the overall clarity and coherence of the literature review. By adhering to this format, the review ensures consistency in citation practices and presentation style. Furthermore, the tabular organization facilitates efficient tracking and cross-referencing of the consulted literature, making it easier for readers to follow the development of ideas and evaluate the relevance and credibility of each source. Ultimately, this method contributes to a more transparent and methodical review process, strengthening the foundation for the study's theoretical and empirical discussions.

Table 2: Literature Review Analysis Table

Questions Q1-Qn, for which the answers are searched for	Reference 1	Reference n	Summarised observations to integrate the final answers to each question
Q1			
Q2			
Summarised observations about the relevance of each reference			

2.5.2 Utilisation of a stepwise Quality Assurance procedure and SolidWorks illustration

To properly assess and guarantee the dependability of the design process, this study uses a step-by-step quality assurance procedure. SolidWorks illustrations, which offer visual representations of important components and design stages, are incorporated throughout the process to improve the analysis's efficacy and clarity. These examples aid in the interpretation of quality checkpoints and provide a thorough comprehension of the design results.

Before manufacturing begins, precise tolerances and quality requirements must be established to ensure proper waveguide performance at 92 GHz. Table 3 below shows a guideline for the application of tolerances to be used to ensure quality assurance.

Table 3: Quality Standards of waveguide parts

Feature	**QA Check**	**Hole Position**	**SolidWorks tool**
Waveguide Inner Surface	Surface Finish	Ra ≤ 0.4 µm	Surface finish symbol
Mounting Flange surface	Flatness	≤ 0.8 µm	GD&T-Flatness (□)
Guiding Pin Holes	Positional Accuracy	IT5 fit	GD&T-True position (Ø)
Perforated Plate (Ø0.6 mm Holes)	Hole Position	Critical for Signal Performance	GD&T-True position (Ø)

3 Results of Quality Assurance

The research results are presented after carefully executing the methodology to be used as described in Chapter 2. Section 3.1 talks about the literature review results, section 3.2 talks about the expert interview results, and lastly, section 3.3 talks about the CAD-based results. Finally, the triangulation observation of all results obtained is also discussed, considering how all results correlate and complement each other.

The literature reliability analysis results, the question it answers, and its importance have been added as an appendix in Appendix 1 at the end of the research work, while a better view of the CAD drawings is added as Appendix 2.

3.1 Literature review results

The literature review analysed crucial inquiries concerning waveguide manufacturing, material choices, fabrication methods, and quality assurance hurdles. The results shed light on effective strategies for achieving high performance in W-band directional couplers.

3.1.1 Manufacturing W-band Components

The research highlights several methods for producing W-band waveguides. Important factors considered during production include reducing signal loss and ensuring structural strength through accurate machining and optimised bending techniques. Cutting-edge fabrication processes, such as precision milling and controlled soldering, have been shown to enhance performance by limiting deformation and preserving conductivity (Deng et al., 2024; Manafi et al., 2019).

3.1.2 Optimal materials for microwave devices

Literature has shown that material selection is crucial in waveguide efficiency. The most commonly used materials are copper and aluminium, and they are valued for their high

conductivity and structural stability. However, for this study, a copper alloy will be used, specifically Copper C101, also known as Oxygen-Free Electronic (OFE) copper. Copper C101 has very high electrical conductivity and a purity of 99.99%, making it an ideal metal selection for the device. In addition to gold coating, it prevents contamination by dust particles. It also possesses high mechanical strength, good corrosion resistance, which is very vital, especially in aerospace applications, and good welding characteristics, which are vital for the device assembly.

3.1.3 3D printing high frequency devices

Additive Manufacturing, which is also known as 3D printing, is a common technique used in the production of complex materials directly from their 3D models, by breaking them down through a method known as slicing. The inputs in the settings determine the quality of the structure before printing, which the printer then begins to print layer by layer. The 3d printing of the wave guides is a possible path to explore, seeing as it would reduce the need for soldering, cutting and bending of the waveguide, which could affect the propagation of microwaves. Several high-frequency devices have been successfully 3D printed. For instance, in the case of frequency-selected surfaces (FSS) for millimetre and low-THz applications, the use of the Aerosol Jet 3D printing technique has been applied, demonstrating high resolution and precision (Shastri et al., 2020) The devices that has been printed with this method operates at a frequency of 125GHz and 280GHz which is way higher than the 92GHz directional coupler. Another study done by (Proyavin et al., 2021) shows the 3D printing of window barriers and has been tested up to 160GHz. A study showing fabrication of composites with broad range of electromagnetic properties and high Dielectric permittivity was done (Wu, Isakov and Grant, 2017) to show the combination of different materials to produce a desired filament for the 3D printing of the devices, such an example is the stereolithography (SL) process, with mixed fine ceramic powders suspended in a liquid photocurable resin has been used for many years for the fabrication of green parts with arbitrary final 3D shape. Also using photosensitive acrylic resin with piezoelectric micro-particles, and magnetite nanoparticles, SL has also been used for the fabrication of a green structure for piezoelectric and magnetic flow sensors, respectively. The same method was utilised to demonstrate various 3D structures with excellent capacitive properties and high dielectric constant using Ag-surface-coated nanoparticles incorporated into the

photocurable polymer solution. However, there have been challenges associated with 3D printing of materials, which is ensuring the quality of the dimensional tolerance and surface roughness of the device, as this is very crucial and important to its function, any change in its physical properties from whether small or huge, will possibly lead to malfunction or even in some cases failure of the device (Zhang et al., 2017).

3.1.4 Challenges with Gold coating

The need for a gold coating/finish arose when the tin-lead finish was banned from low-priority applications due to the leaching of lead from waste electronics into water supplies, which poses a significant environmental concern. Due to the ban, other coating options in which the demand for the use of gold and pure tin increased, but the challenge of gold has always been embrittlement, especially in soft solders. This has always been a challenge in the production of this device, gold embrittlement occurs during the soldering of the device, this is a phenomenon where the gold finish on the device comes in contact with the tin or tin-lead solder, and then the gold content becomes bigger than 3% of the total weight of the solder. The passing of the 3% weight makes the soldered joints weak and, in some or most cases, causes cracks, thereby creating a weak soldered joint and leading to the malfunction of the device (Wolverton, 2014). However, gold coating is frequently utilised to enhance conductivity and resistance to corrosion. There are, however, limitations to this, such as problems with adhesion, cost limitations, and long-term durability (Zhang et al., 2017; Shastri et al., 2020). Some studies propose alternative thin-film deposition methods or composite coatings that provide similar advantages at reduced costs (Torregrosa-Penalva et al., 2022; Proyavin et al., 2021). To ensure the reliability of waveguide components, it is important to ensure consistent coating thickness and robust adhesion (Wu et al., 2017).

3.1.5 Importance of geometric tolerance

Tolerance in manufacturing is the permissible variation from the base measurement allowed during production, to ensure high-quality performance of the device. The importance of tolerance indicated in drawing models cannot be overlooked, because these are international guidelines that make the drawings easy to read and understand by any manufacturing

company all over the globe. The geometric and dimensional tolerance for each of the parts of the microwave device has been provided in the results section, a strict adhesion to them ensures high-quality assurance in the production of the device, as the performance of these devices is very high, and any slight deviation could lead to poor performance and in some cases failure. Geometric tolerances ensure that parts fit in and function correctly, mostly in assemblies where there is an interaction between multiple parts. They ensure that functional capability, manufacturability and the quality of the final product are maintained. Proper tolerance design can reduce manufacturing costs. This can be done by ensuring that the balance between the tight and loose tolerances is optimised. The product development cycle can be shortened, and the overall product quality can be improved through effective tolerance management. When used with modern technologies, geometric tolerances help make better decisions and fewer errors. Geometric tolerances give space for statistical analysis of deviations essential for process optimisation and quality control. It also provides a standardised way to communicate design requirements across the different product development stages and ensure production consistency and reliability.

3.1.6 Improved soldering techniques

Advancements in soldering techniques focus on ensuring joint quality enhancement, process stability and operational efficiency. A new key technique/innovation is energy optimisation in reflow soldering. This process involves optimising the reflow oven's energy consumption through state-based modifications to minimise energy consumption during waiting periods. It also optimises the cooling stage of the reflow soldering process using numerical techniques to reduce thermal stress and improve solder joint quality (Fan et al., 2024). Another new technique is selective soldering, which involves adjusting preheat temperature, solder temperature, and well time to improve hole-fill and overall solderability in lead-free processes. This process gives room for flexibility and precision and reduces contamination, bridging, and rework. Laser soldering involves the use of temperature control or low-temperature laser-assisted bonding by implementing an adjustable upper limit variable-structure PID control method or the use of indium solder and laser non-conductive paste, which is another new technique. This method ensures precise temperature regulation, enhances solder joint quality and production efficiency, and allows for low-temperature bonding, which is beneficial for heat-sensitive components (Zhang et al., 2024). There are

some challenges involved with these new techniques, such as solder paste misalignment and poor thermal design, both of which can be addressed through real-time data collection, statistical approaches, board design optimisation, and component mounting (Fan et al., 2024).

3.1.7 Challenges with metal bending

During the bending process of metals, after applied forces have been removed, the metal attempts to revert to its initial form. This phenomenon is known as spring-back. Spring-back is greatly influenced by the material's physical properties as well as the die structure. Factors that could cause a higher spring-back include a die gap, a larger bend radius, a lower elastic modulus, and a higher material strength. Minimising this during the bending process is one of the most troublesome problems in die design (Chou and Hung, 1999). The physical properties of the material can pose a challenge to bending. Different materials have varying resistance to bending based on their mechanical properties. Brittle materials may fracture under bending stress, while ductile materials may become permanently deformed. Materials experience tensile and compressive stresses on bending, and the distribution of these stresses can lead to failure if the materials' yield strength is exceeded (Nikhare et al., 2022). The bending behaviour of a material is also greatly influenced by its thickness and cross-sectional geometry – thinner materials are more susceptible to buckling and deformation (Chou et al., 1999). Bending challenges limit designs and can cause design failures if the wrong material is used. Repeated bending can lead to fatigue failure and, when subjected to high temperatures, some may experience creep, leading to permanent deformation under constant stress (Nikhare et al., 2022). Bending can affect the integrity of joints and connections in structures and cause stress, which can lead to premature failure. In flexible electronics, bending can lead to mechanical stress on components, potentially causing failures in solder joints or interconnects (Liu et al., 2015).

3.1.8 Application of W-bands

W-band radar systems are used in UAVs for high-definition video imaging and shadow analysis of moving objects, while W-band ISAR systems provide high resolution and

detailed scattering properties for precise imaging applications and forward-looking imaging radar systems that generate three-dimensional images with excellent range resolution to help differentiate closely positioned targets (Montejo-Garai et al., 2019; Sanchez-Olivares et al., 2022).W-band radar systems explore the incorporation of collision avoidance and safety features into automotive systems to support functions like collision prevention, adaptive cruise control, and parking aid. They are utilised for precise detection and imaging to help prevent runway incursions and manage foreign object debris (FOD) (Sanchez-Olivares et al., 2022).W-band filters are crucial for today's millimetre-wave communication systems, enabling faster data speeds and reliable wireless communication. The extensive bandwidth offered by the W-band is utilized for rapid data transmission in space-based communication systems, including those operating on low-Earth orbit (LEO) platforms (Huang et al., 2021; Sanchez-Olivares et al., 2022). W-band radars are employed for environmental monitoring, delivering high-resolution data on physical size, distances, and object classifications, while advanced imaging systems with rapid scanning capabilities are designed for sophisticated imaging applications (Monejo-Garai et al., 2019) the creation of W-band filters and antennas, including substrate-integrated waveguide (SIW) filters, improves performance and integration options, while phased-array antennas are essential for achieving high-speed data rates and dynamic beam steering in communication and radar systems. Developments in GW-based antenna systems and components are crucial for mm-wave and sub-THz applications, enhancing the control of electromagnetic wave propagation (Sanchez-Olivares et al., 2022; Huang et al., 2021).

3.1.9 ISO standard for Engineering Manufacturing and Design

The ISO standards are internationally recognised standards developed by the International Organisation for Standardisation (ISO) to ensure the safety, quality and operational efficiency of processes as well as help streamline operations and aid compliance with regulatory and customer requirements (Lima, 2008). The adoption of ISO standards by a company offers varying advantages, the most important of which are ensuring quality assurance in products and services, increased operational efficiency, quality control mechanisms, and customer satisfaction. Some ISO standards are especially relevant in engineering, manufacturing, and design – ISO 9001, ISO/IEC 17025, ISO/TC 261, ISO 2394, ISO 14000 series, especially ISO 14001, ISO 128, and ISO 56002. The ISO 9001

helps establish and maintain effective processes and procedures that will consistently deliver high-quality products that meet and exceed customer expectations (ISO, 2015). ISO 14001 provides a structured framework that enables the integration of sustainable practices into core operations while promoting a life cycle perspective in environmental management (ISO, 2015; ISO, 2024). ISO/TC 261 is focused on the standardisation of additive manufacturing processes, including materials, hardware, test procedures, quality parameters, etc. ISO 2394 deals with the reliability basis of structural design, harmonizing reliability principles and ensuring compliance with reliability-based assessment of structural performance (ISO, 2015). The fundamental principles for the presentation of technical drawings are laid down by ISO 128 to facilitate seamless international exchange of information through technical drawings by ensuring uniformity and consistency that is in line with a system that relates to various technical functions (ISO, 2022). ISO/IEC 17025 gives stringent requirements for laboratory quality management, technical competence, impartiality, and the ability to produce valid, reliable test and measurement results (ISO, 2017). This is to ensure testing processes are sound and measurement equipment are properly calibrated and traceable to international standards. A comprehensive framework for establishing, implementing, maintaining, and continually improving an innovation management system within organizations of all types and sizes is provided by the ISO 56002 (ISO, 2019). The ISO 2876 is an international benchmark for packaging that provides a standardised method for assessing the integrity of packaging when subjected to forces associated with rolling.

3.2 Expert Interview results

The expert interview (Eskelinen) provided good insight on questions regarding the device in terms of the functionality of the device, challenges, and problems associated with it. The primary question asked was: How does gold embrittlement during coating and soldering, and the compensation of metal during bending, affect the performance of high-frequency wave bands? An answer was provided with relevant comments in regard to the functionality of the device, and also Microwave devices in general.

3.2.1 Gold Embrittlement

Gold embrittlement is a significant issue that affects performance. If gold is not applied as a smooth, continuous surface, it can lead to structural and functional failures in the directional coupler. The embrittlement of gold due to improper coating or soldering can cause signal degradation and device failure. Both of which have been the biggest challenges in the device's production.

3.2.2 Material composition and bending effects on high-frequency devices

Waveguide performance is directly affected by the composition of metals used in bending. Improper material selection can cause distortion, which in turn affects the signal integrity in W-band applications (Nikhare et al, 2022; Chou et al., 1999).

3.2.3 Manufacturing challenges and Quality Assurance

A large number of samples must be produced to obtain a few successful components due to process limitations. High precision in assembly is required, and manual labour is still necessary due to the complexity of the components (Sanchez-Olivares et al., 2022; Montejo-Garai et al., 2019).

3.2.4 Importance of Hole formation and position

To maintain signal integrity, it is necessary to create precise holes in thin sheets without causing distortion. It is essential for quality assurance to avoid dimensional distortion during hole creation (Huang et al., 2021; Sanchez-Olivares et al., 2022).

3.2.5 General Observation

The general observation made was that when it comes to microwave devices, the first thing to consider is the suitable metal used in the manufacturing of the device, the purpose the device will serve, the frequency output, and the design of the device, as although there are

cases where a metal would work using Aluminium as an example, but Copper could serve way more better, and in some cases brass also, so the material selection phase is very crucial. The next thing to consider is the manufacturing stage and the technique employed, which is to ensure the quality output of the device, as any small deviation from the design could lead to malfunction and, in some cases, total failure of the device. When dealing with coating, especially gold coating, which is used to prevent corrosion of the device, increase conductivity, and improve surface roughness, ensure that the coating surface is even and there are no bumps or uneven surfaces so as the quality of the signal does not get affected. When dealing with screws and alignment pins, they serve as tightening tools, to hold the devices in place, when it has been attached to the main device, so the omission of one or few screws, could easily be negligible as it won't fully affect the function of the device.

3.3 CAD-based analysis

The importance of accurate measurement of equipment, drawing, and designing is highly crucial to the performance of the device, so to ensure quality, the appropriate equipment is expected to be used in measuring the dimensions of the device, before the design with SolidWorks or AutoCAD

3.3.1 Measurement of microwave devices

The Vernier caliper was used to measure the dimensions of the directional coupler, including the width, length, height, and diameter of both the flanges and guiding pins. In Figures 3.1 - 3.3 below, images are shown illustrating the life measurement of certain parts such as the height of the device assembly, the diameter of the mounting flange and the thickness of the device accordingly. The accuracy of a Vernier caliper is quite precise, as it can be used to measure both internal and external diameters of any device, and it can measure values to the range of 0.1mm, which provides a high level of accuracy.

Figure 3.1 Measurement setup of device height

Figure 3.2 Measurement setup of flange diameter

Figure 3.3 Measurement setup of waveguide height

Another general measuring device which is vital is the spectrum analysers and Automatic testing equipment (ATE). Spectrum analysers measure the frequency spectrum of microwave signals, The measurement is done in hertz (Hz). It uses techniques to eliminate systematic errors, essential when carrying out high-frequency measurements. while ATE is used for high-volume production testing of RF and microwave devices. Both devices are depicted in Figures 3.4 and 3.5 below.

Figure 3.4 Spectrum Analyser

Figure 3.5 Automatic testing equipment (ATE)

3.3.2 Importance of geometric and dimensional tolerance

Geometric and dimensional tolerances ensure that parts fit in and function correctly, mostly in assemblies where there is an interaction between multiple parts. They ensure that functional capability, manufacturability, and the quality of the final product are maintained. Proper tolerance design can reduce manufacturing costs. This can be achieved by ensuring that the balance between tight and loose tolerances is optimized. The product development cycle can be shortened and overall product quality improved through effective tolerance management. When used in conjunction with modern technologies, geometric tolerances enable more informed decisions and reduced errors.

Geometric and dimensional tolerances provide space for statistical analysis of deviations, which is essential for process optimization and quality control. It also provides a standardized way to communicate design requirements across different product development stages, ensuring production consistency and reliability. The required tolerances to be followed during the manufacturing of individual parts of the coupler are shown in the 2D model figures, which are Guiding pin (Figure 3.6), Straight waveguide (Figure 3.7), Directional Coupler assembly (Figure 3.8), Circular or Mounting Flange (Figure 3.9), Perforated plate (Figure 3.10), and Bent Waveguide (Figure 3.11) as well as the soldering (Figure 3.12), the surface roughness required for the device is also shown in the figures, and the more visible view is attached as appendix in appendix 2 and the geometric tolerance of the assembly is attached as appendix 3. Strict adherence to the design parameters ensures

optimal performance; any deviation can lead to poor performance and, in some cases, device failure.

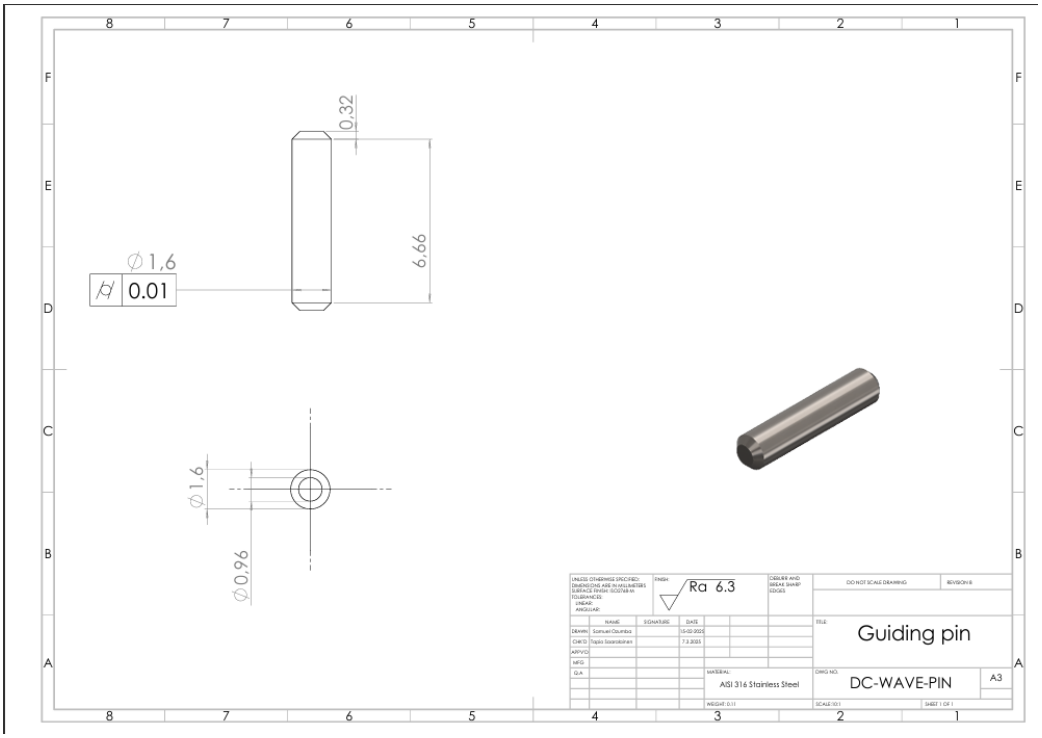


Figure 3.6 GD&T of Guiding pin

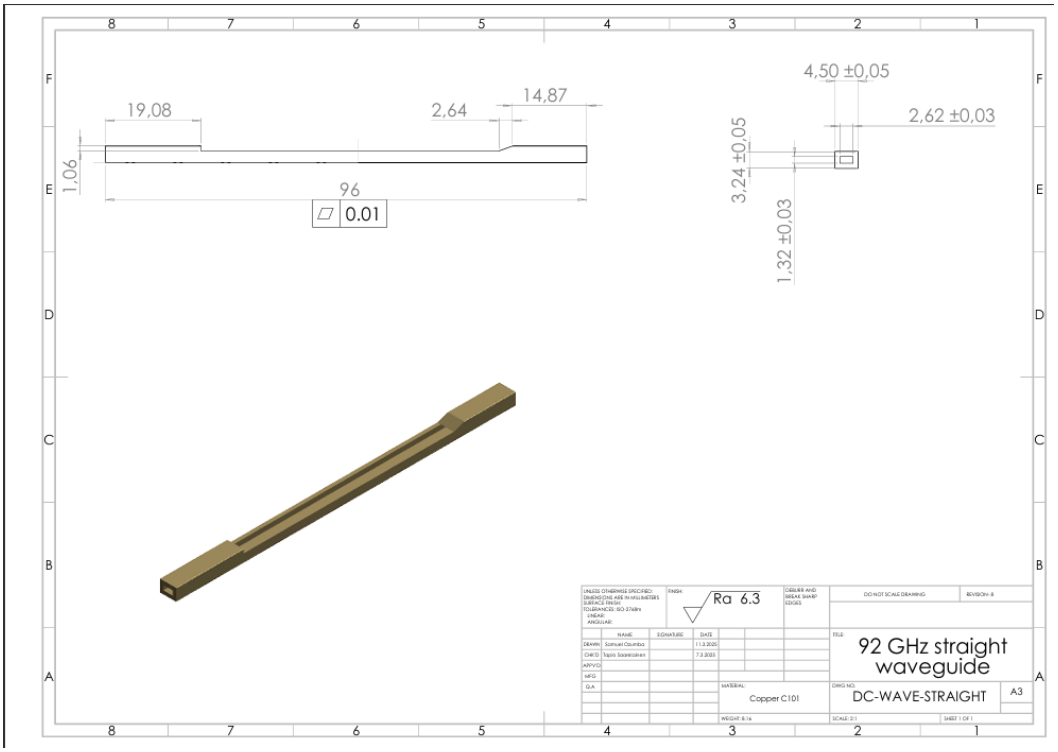


Figure 3.7 GD&T of Straight waveguide

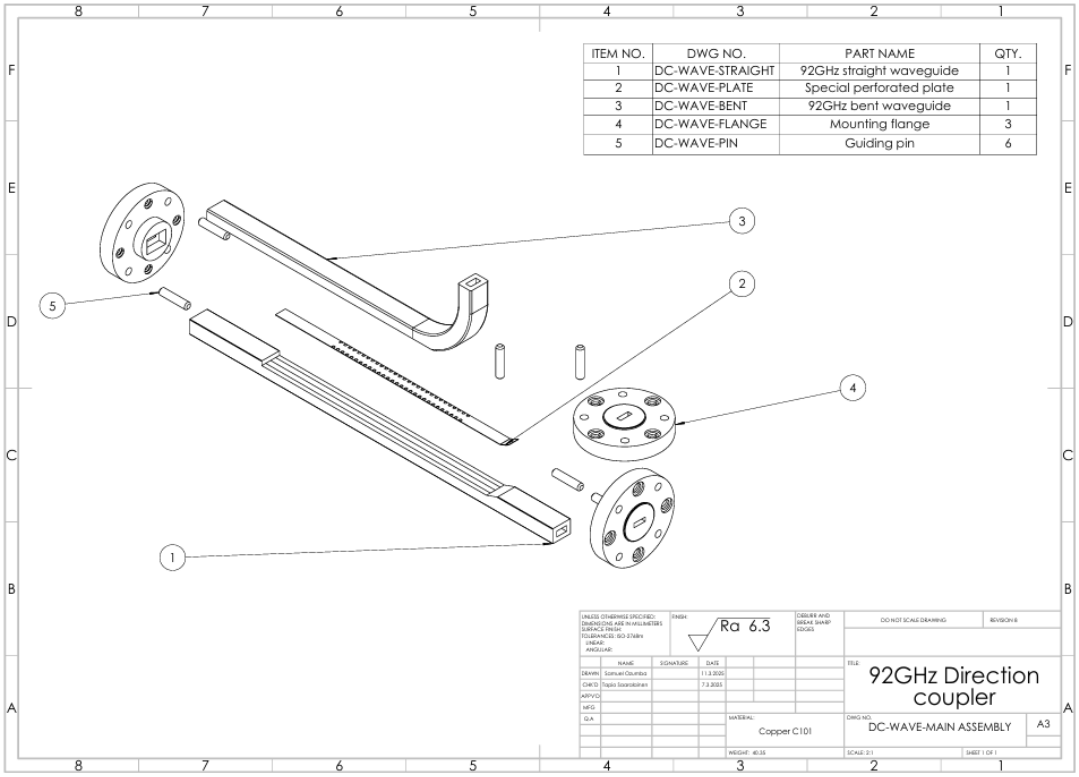


Figure 3.8 Exploded view assembly drawing

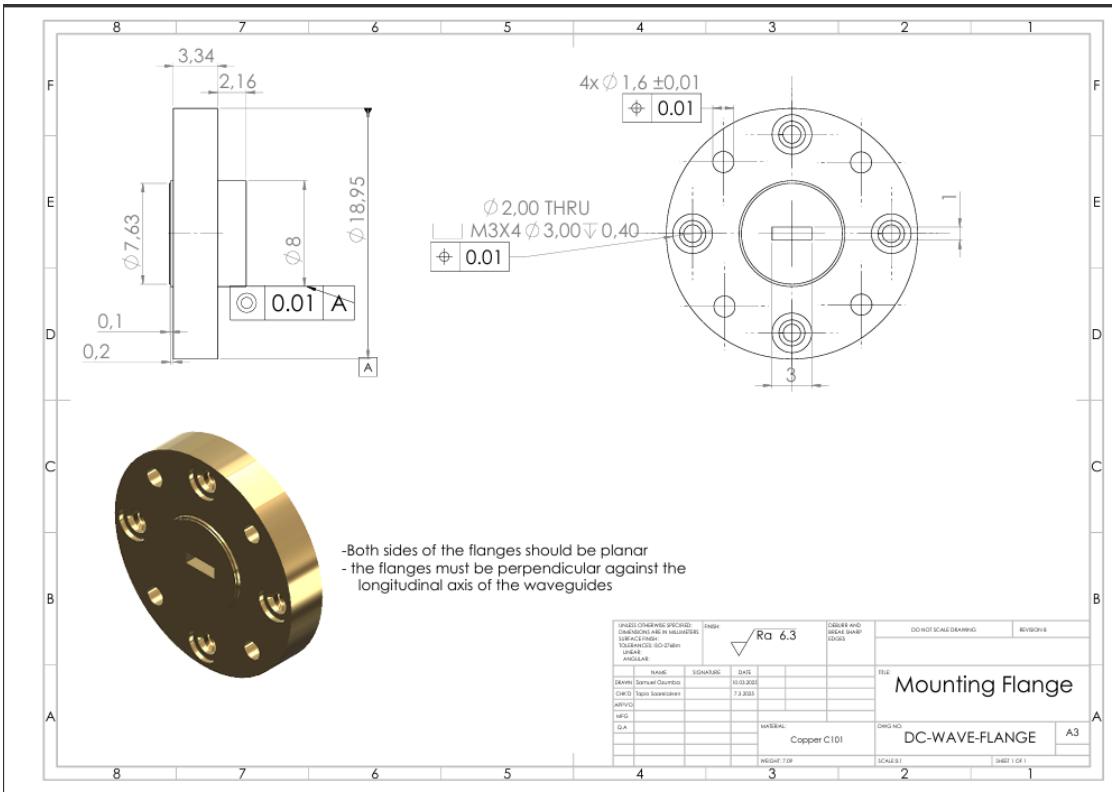


Figure 3.9 GD&T of Mounting Flange

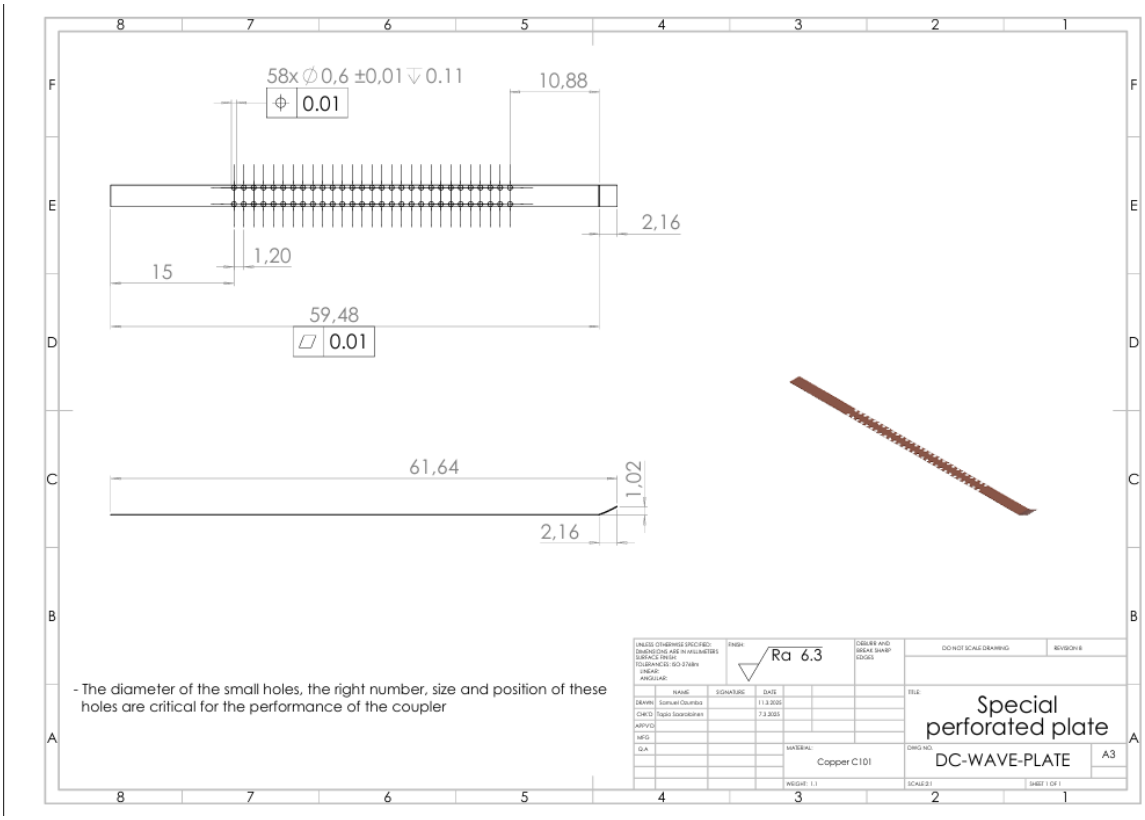


Figure 3.10 GD&T of Special perforated plate

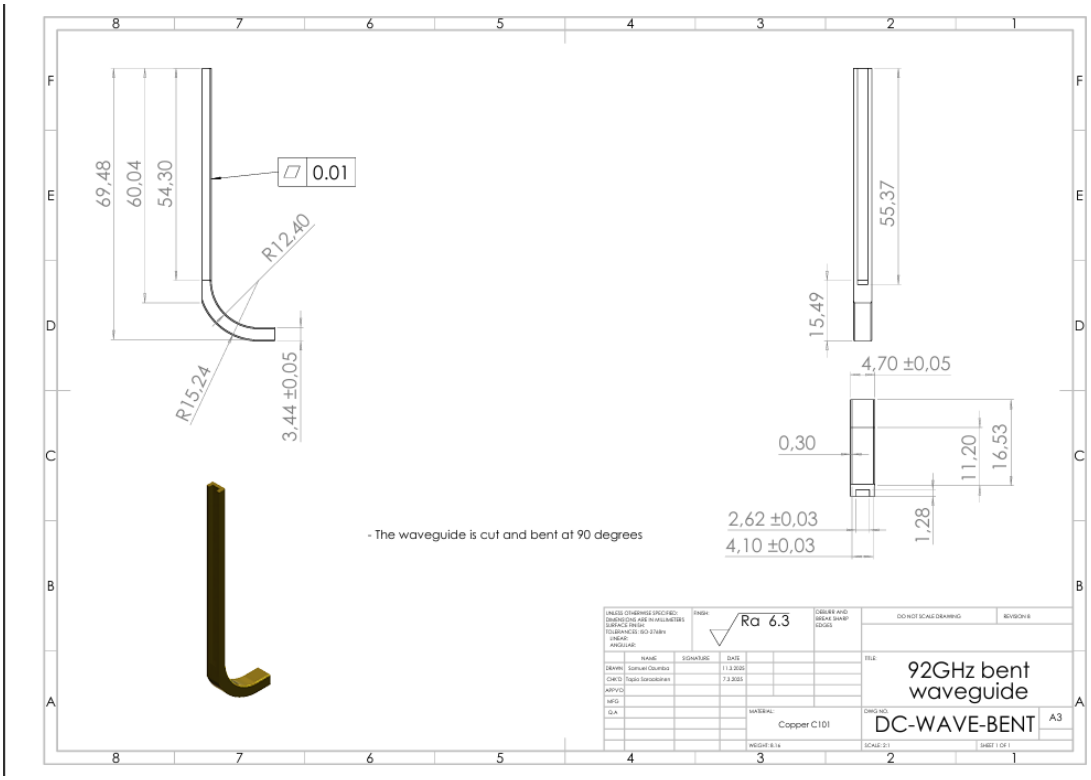


Figure 3.11 GD&T of bent waveguide

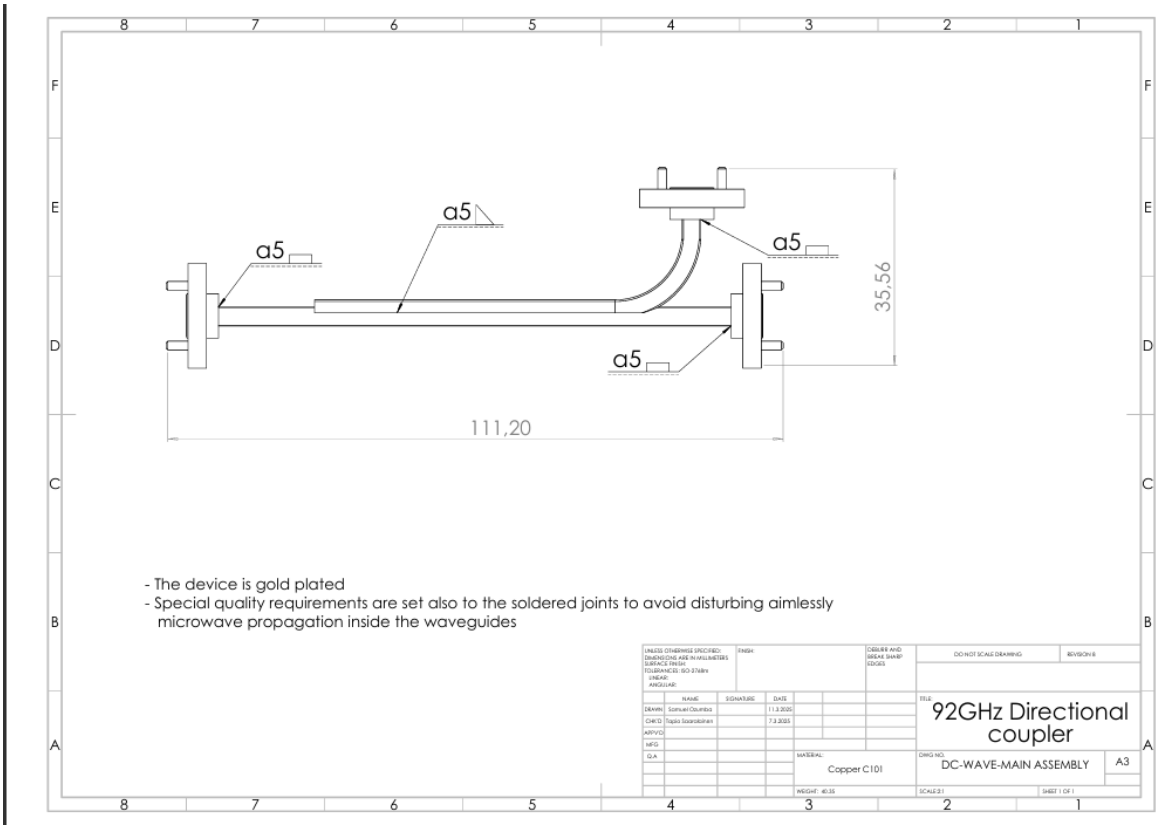


Figure 3.12 GD&T of waveguide assembly

3.4 Triangulation based observations

Starting with the manufacturing stage, all methods agree on the importance of Geometric and Dimensional tolerance, these tolerances are fundamental to ensuring the optimal performance of microwave devices, as even slight deviations can lead to signal losses, mismatched interfaces, or mechanical instability during operation.

For the metal used in the production, the Expert during the interview ruled out the use of Aluminium alloy and instead suggested copper alloy as the metal more appropriate, This recommendation was also strongly supported by the literature review, which highlighted copper's high electrical and thermal conductivity, as well as its excellent machinability. These characteristics make copper alloys particularly favourable for precision milling and machining processes required in the production of microwave components.

The issue of gold embrittlement, which has posed a significant challenge in the coating and soldering industry, was verified by both the Expert and during the Literature review, both stressed how challenging it has been over the years to overcome the challenge presented by gold embrittlement. Despite ongoing advancements, it remains a complex and persistent issue that requires careful consideration during both the coating and assembly phases of device manufacturing.

4 Discussion

This chapter discusses the main findings of the study about the research questions and objectives outlined earlier. The results are interpreted and compared with previous research to highlight their significance and contribution to the field. Additionally, the strengths and limitations of the study are examined to assess the reliability and applicability of the findings. Finally, recommendations for future research are proposed based on the insights gained.

Section 4.1 talks about the key findings of the result, 4.2 the comparison and connection with previous research, 4.3 the reliability analysis of the whole thesis research, 4.4 the conclusion of the research, and lastly 4.5 the topics for future research.

4.1 Key findings

When it comes to quality assurance in the manufacturing of any device, strict and proper adherence to process integrity is required at every stage, from measurement and design to production. This is not just about professionalism, but also about ensuring the optimal performance of the device.

Asides the integrity and concerns dealing with the structure, another significant aspect is the geometric and dimensional tolerance, this gives free room for margin of error, and still ensures the functionality of the device, it must not be overlooked, and also ensures that the device can easily be replaced or used in another situation and still perform optimally, because it follows the ISO standard during production.

4.1.1 Accurate measurement with precision tools

The key fundamental part of quality assurance is precise measurements. By using high-precision tools, accurate dimensions are ensured, leading to higher performance and consistency during production. Additionally, using good measuring tools and techniques significantly reduces the chance of error and the cost of redoing the work. In this study, the

use of callipers, laser scanners, micrometres, and coordinate measuring machines (CMM) is essential to achieving quality measurements.

4.1.2 Design and manufacturing stage

The next crucial stage, which is very vital and can't be overlooked, is the design stage, as it lays the foundation of the device's functionality; therefore, several factors must be considered during the design of the device:

Flange Mounting: Ensure that the flanges are mounted perpendicularly against the longitudinal axis of the waveguides, which is important to ensure the performance of the device. The surfaces of the flanges should also be planar.

Waveguides: Both waveguides are split through their middle planes, then one of the waveguides is cut and bent 90 degrees to ensure the efficiency of microwaves.

Alignment Pin: The position of the alignment pin is very crucial to the alignment and attachment of the device.

4.1.3 Material selection

The next important factor is material selection, which is another cornerstone in the performance of this device, as the material chosen determines the longevity, durability, and most importantly, the level of performance of the coupler. There are mainly two fields to be considered, aluminium alloys and copper alloys. Still, the copper alloy, Copper C101, also known as Oxygen-free electron (OFE), has been chosen as the best metal to use because of its properties:

Purity: It has a 99.99% purity percentage, ensuring minimal impurities and contamination, thereby reducing the risks of defects.

High Electrical and Thermal Conductivity: Due to its high conductivity, it makes it an ideal metal for use in the manufacturing of this device, especially when dealing with high frequencies at 92 GHz.

Excellent Malleability: Its good malleability properties make it easier for shaping and bending, which is crucial, especially in the production of the bent waveguide.

Corrosion Resistance: This ensures the coupler's longevity and reliability in applications such as space exploration, where its high corrosion resistance is particularly beneficial due to the absence of oxygen.

4.1.4 Coating and Soldering

Coating and soldering have always been a big challenge with this device, gold embrittlement, which is the phenomenon where the gold finish on the device comes in contact with the tin or tin-lead solder, and then the gold content becomes greater than 3% of the total weight of the solder. This increases the cost of production and material wastage, as too many devices have to be produced, and in the end, just a few have been assembled efficiently without any defect in terms of embrittlement caused by gold during soldering.

4.1.5 3D printing of high-frequency devices

3D printing is an additive manufacturing technique used in the production of complex materials, which are printed layer by layer until completion. Several high-frequency devices have been successfully 3D printed. For instance, in the case of frequency-selected surfaces (FSS) for millimetre and low-THz applications, the use of the Aerosol Jet 3D printing technique has been applied, demonstrating high resolution and precision (Shastri et al., 2020) The devices that have been printed with this method operate at a frequency of 125GHz and 280GHz which is way higher than the 92GHz directional coupler. Another study, conducted by (Proyavin et al., 2021), demonstrates that the 3D printing of window barriers has been tested up to 160 GHz. Though there have been challenges associated with 3D printing of materials, which is ensuring the quality of the dimensional tolerance and surface roughness of the device, as this is crucial to its function, any change in its physical properties from whether small or huge, will possibly lead to malfunction or even in some cases failure of the device (Zhang et al., 2017).

4.2 Comparison and connection with previous research

This study's findings align with and build upon existing literature in several key ways. The results support prior research on various issues, such as, the challenges with gold embrittlement, which has been proven by (Wheeling et al., 2022) and the expert Interviewer also, the study also provided the issues with spring-back, which occurs frequently and causes distortion of signals, was also supported by the research performed by (Chou and Hung, 1999).

The use of 3D printing is proven to be possible in the production of high-frequency devices, as it has been used to produce devices of 125GHz and 280GHz, respectively. This research was conducted by (Shastri et al., 2020).

4.3 Reliability assessment of the results

The reliability assessment of the results makes use of the following factors and table 4 showing how each of the criteria are combined is shown below:

Validity: The SolidWorks models were drawn according to the ISO Standards, which ensures that they meet international requirements for design quality and manufacturing process. The use of ISO Standards contributes significantly to the validity of the work. The Expert interview also provided good insight into the importance of quality drawings drawn according to standards, as they make manufacturers understand what is expected of them and how the device would function properly. Lastly, a thorough literature review was conducted to support the validity of quality drawings by utilizing articles and journals that verified the application of ISO standards and quality control principles. By integrating these three approaches, drawing analysis, expert validation, and academic support, the triangulation method provided strong evidence that the results are valid and consistent across different forms of evaluation.

Reliability: To achieve reliability, the SolidWorks drawings were crosschecked repeatedly and also by supervisors, focusing mainly on the Geometric tolerances and dimensions, to confirm accuracy and quality of the drawings. The expert interview aligned with these findings, as professionals consistently emphasize the importance of tolerance and dimension

to achieve a quality product. The literature also supported this, stating the importance of tight tolerances and repeatability in engineering practices. Since all three methods produced consistent information, the triangulated data confirms a high level of reliability in the overall analysis.

Sensitivity: The manufacturing process and material quality had an impact on the result's sensitivity. By examining how material selection affected the design specifications in SolidWorks, the sensitivity of the findings was examined. The simulation environment made it possible to modify and compare various materials, demonstrating how material characteristics affect tolerance performance and structural behaviour. Experts supported this strategy by highlighting how important material selection is to preserve the viability and quality of the final product. Findings from the literature also supported this, pointing out the significant differences in design and production that can result from material selections. Triangulation made it evident that sensitivity to material selection is an essential part of quality control, and that all

Error Analysis: SolidWorks made it possible to visualize and analyse possible design flaws, especially through cross-checking of the Geometric and Dimensional tolerances, as these determine whether the device can be manufactured efficiently or not. Expert interviews supplemented this technical understanding by identifying common manufacturing and design flaws and suggesting fixes based on industry knowledge. By describing error types and related mitigation techniques discovered in earlier research, the literature further supported these ideas. These three sources worked together to identify and reduce design flaws. Triangulation, therefore, worked well to lower the common errors associated with the product.

Accuracy: To ensure the accuracy of the SolidWorks model, strong adherence to ISO standards during the SolidWorks modelling process was the foundation for the results' accuracy. As it is a widely accepted guideline on drawings and dimensions, acceptable worldwide. This was validated by both the experts and the literature review as regards the importance of the ISO standards. All these methods combined further strengthen the accuracy.

Saturation: This was achieved by making sure that all important aspects of quality control were ensured by all methods repeatedly. The SolidWorks model had comprehensive information on the dimensions, materials, and tolerances, covering all the important parts of

quality control. The expert provided significant insights into factors covering the QA of the device, ensuring all vital details were covered. By using sources that provide details, the literature review provided more depth to the quality of the work. The triangulation method ensured thorough and complete utilization of all three methods.

Table 4: Reliability Assessment Table

CRITERIA	**SolidWorks**	**Expert Interview**	**Literature Review**	**Triangulation**
Validity	Drawings according to ISO Standards	Expert validates quality control	Journals and Articles used for verification	All methods agree and show correlation
Reliability	Repeated verification of drawing tolerances	Experts provided good insight	Articles confirmed the importance of tolerance	All methods are crucial in drawing
Sensitivity	The effect of the material used is analysed	The choice of material is very important	Literature covers the variation of material used	All methods are vital in material selection
Error Analysis	Availability of error margins	Common errors pointed out	Materials confirm it	Error minimised after combining all methods
Accuracy	Adherence to ISO standards	Expert confirms the importance of ISO standards	Literature establishes standards	Common conclusion from all methods
Saturation	Drawings cover all necessary quality control aspects	Expert addresses all QA factors	References on QA are included	Conclusion drawn from all methods

4.4 Conclusion

When discussing Quality Assurance, the precise tool used and accurate measurement of the device are crucial; the choice of material used is also vital to the device's performance. During the design stage, ensuring strict adherence to the geometric and dimensional tolerances is essential. Additionally, during the manufacturing stage, it is crucial that the manufacturer adheres to the design and does not deviate from it. Gold embrittlement has always been a challenge, so during coating and soldering, the technique employed must ensure that it avoids gold embrittlement, thereby preserving the device's quality. Alternate production options can also be explored for the device's performance, particularly through 3D printing, which provides an edge in reducing various defects commonly associated with the device, such as spring-back due to bending and gold embrittlement caused by soldering.

There are also other factors to consider, while providing the conclusion of this research, we have to think about the effects of over-quality in production, and the application of this thesis in future research works related to quality assurance.

4.4.1 Effects of over-quality in production

Although quality is a key component of production processes, too much quality, or "over-quality," can lead to inefficiencies and unforeseen negative effects. Over-quality happens when a product or service goes above and beyond what the customer needs or expects, resulting in the wasteful use of resources without commensurate value growth. Higher production costs are one of the main effects of over-quality. To improve features or tolerances beyond what is functionally required, resources like time, labor, materials, and machinery are used. Customers might not appreciate or pay for these extra efforts, which would reduce profitability and cost-effectiveness.

Furthermore, excessive quality can lead to increased and disrupted workflow efficiency to be disrupted. The production timeline extends when operators place a higher priority on flawlessness or unnecessary inspections, which impacts delivery schedules and client contentment. This can lead to bottlenecks and lower overall throughput in high-volume production settings.

Over-quality can also result in waste production, especially when excessive precision or tight tolerances force more parts that would otherwise be acceptable to be reworked or rejected. This runs counter to the objective of reducing waste and preserving only value-adding operations in lean manufacturing systems.

Furthermore, scalability and standardization may be hampered by excessive quality. Replicating the same quality level consistently across batches or increasing production may become unfeasible or unsustainable when products are manufactured with specifications above the minimum requirements.

In conclusion, while aiming for quality is important, excessive quality should be recognized and avoided. To make sure that the value produced justifies the quality goals, they should be in line with customer needs, economic viability, and production capabilities to avoid the high cost of production.

4.4.2 Application of this thesis research in future Quality Assurance research works

The methods used and results presented in this thesis offer a practical framework for strengthening quality assurance in research projects beyond this study. By demonstrating the use of triangulation with visual drawings rather than simulations, this work provides an alternative approach to validating research outcomes, particularly where traditional methods may be limited or infeasible. Future studies can adopt and adapt this method to enhance the reliability and transparency of their results. Moreover, the structured approach to assessing and documenting quality assurance measures outlined in this thesis can serve as a reference model for researchers aiming to systematically incorporate QA practices into their work, promoting greater consistency, accountability, and trust in research outputs.

4.5 Topics for future research

There are various aspects of the device's shortcomings that require further research to explore better alternatives for both the production and improvement of the device, though it is important to note that some of them are theoretical analysis and for some they are in need of further work as research on them has been made with little progress. So, taking that into

account, the following topics are 3D printing, Gold embrittlement, and L-shaped Coupler are topics that should be considered for further research:

3D Printing: This is a huge field that has grown tremendously over the past decade and the relevance cannot be overlooked, as it simplifies production, especially when dealing with complex structures, by exploring this field properly, we can eliminate the challenges of gold embrittlement, as there would be no need for soldering, the issue of spring-back that occurs during bending would be eliminated, so it provides great rewards for the future of the device. The research should focus on how to ensure surface roughness, Geometric, and dimensional tolerances, as these are essential to the device's performance.

Gold embrittlement: This has long been a challenge in the coating industry; further research is needed to eliminate the occurrence of embrittlement during soldering. Another angle that can be considered is the act of first soldering the devices, smoothening the soldered area, and then gold coating it. This eliminates the formation of embrittlement on the device but then presents the challenge of a smooth and even surface inside the device.

L-Shaped Coupler: Springback is a challenge common in the production of this device due to the type of metal used, the bending method employed, purity and malleability of the metal, considering all this factor, a change in shape of the bent waveguide is a possibility that needs to be considered and extensive research should be performed on, which would eliminate the springback effects and by extension not affect the propagation of frequency. Instead of having a bent waveguide, the option of an L-shaped waveguide, as shown below, can be explored as it eliminates the challenge with spring-back, by making it L-shaped and ensuring it is Perpendicular and at an angle of 90 degrees, there will be no need for spring-back effect and also the distortion of waves due to bending defects can be avoided. Though this is just a theoretical approach, research should be performed to see the possibility. The proposed image of the full assembly of the L-shaped Directional coupler is attached below in Figure 4.1.

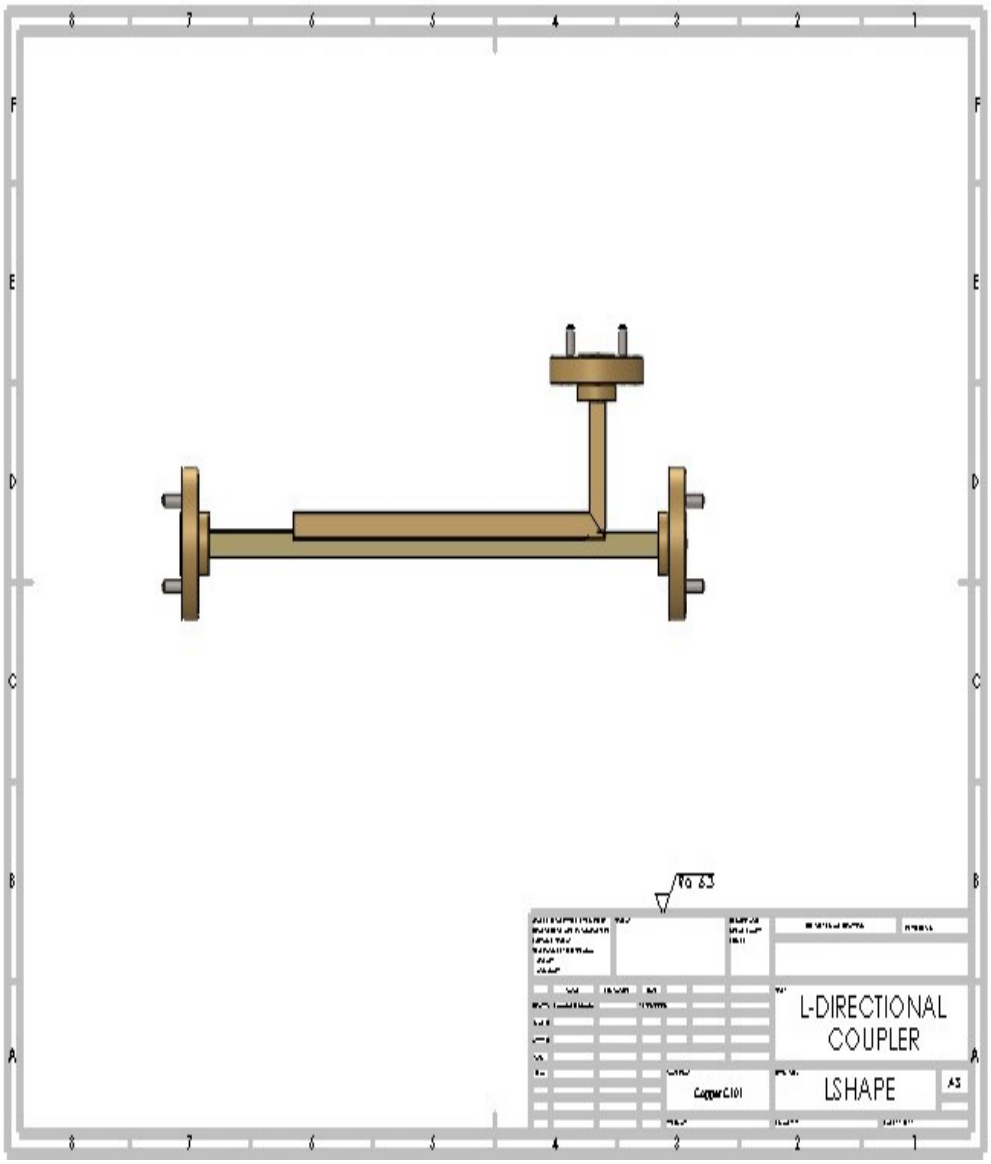


Figure 4.1 L-Shaped Coupler

5 Summary

The application of Quality Assurance (QA) protocols in the design and production of a 92 GHz W-band directional coupler is examined in this thesis. The goal is to use efficient QA procedures to improve the performance and dependability of high-frequency microwave devices.

The study assesses the effects of material selection, dimensional and geometric tolerances, and coating techniques (especially gold plating) on device quality using a triangulation methodology that combines literature review, expert interviews, and CAD-based analysis. The thesis addresses the difficulties caused by gold embrittlement during soldering and emphasizes the vital role of Copper C101 (Oxygen-Free Electronic copper) because of its high conductivity and machinability. The technical analysis is supported by detailed drawings that include GD&T standards, tolerance tables, and QA checklists. Several criteria (validity, sensitivity, accuracy, etc.) are used to evaluate reliability, and all three data sources are used to validate the results. According to key findings, the production of high-performance couplers requires strict adherence to standards, optimized manufacturing processes, and precise measurement. Future research is suggested on 3D printing alternatives, material modifications, and design changes, like an L-shaped coupler, to overcome problems like spring back. In line with industry demands and international standards, the thesis offers helpful suggestions for improving quality assurance in the production of high-frequency devices.

References

Chou, I. and Hung, C. (1999) 'Finite element analysis and optimization on springback reduction', *International Journal of Machine Tools and Manufacture*, 39(3), pp. 517–536. doi:10.1016/S0890-6955(98)00031-5.

Deng, T., Chan, K.Y., Fu, Y. and Ramer, R. (2024) 'An analytical design method for a wideband differential waveguide directional coupler with de-embedding analysis', *IEEE Transactions on Instrumentation and Measurement*, 73, pp. 1–11. doi:10.1109/TIM.2024.3398132.

Eskelinen P, (2003) Microwave Component Mechanics. Boston, MA: Artech House

Fan, Z. and Chen, C. (2024) 'Microstructure, joining mechanism, mechanical properties and optimization of inactive solder (Sn9Zn) in low temperature ultrasonic soldering of AlN ceramics and 2024Al', *Ceramics International*, 50, pp. 43054–43069. doi:10.1016/j.ceramint.2024.08.157.

Fielding, N. G. (2012) 'Triangulation and Mixed Methods Designs: Data Integration With New Research Technologies', *Journal of Mixed Methods Research,* 6(2), pp. 124–136.

Huang, Z., Jiang, Y., Wu, W., Liu, B., Hu, W. and Yuan, N. (2021) 'W-band bandpass filter using rectangular microcoaxial structure', *IEEE Microwave and Wireless Components Letters*, 31(8), pp. 957–960. doi:10.1109/LMWC.2021.3092144.

International Organization for Standardization (2025) 'About ISO'. Available at: https://www.iso.org/about (Accessed: 5 April 2025).

International Organization for Standardization (2019) *ISO 14002-1:2019 - Environmental management systems — Guidelines for using ISO 14001 to address environmental aspects and conditions within an environmental topic area*. Available at: https://www.iso.org/standard/70138.html (Accessed: 5 April 2025).

International Organization for Standardization (2024) *ISO 14001:2015/Amd 1:2024 - Environmental management systems — Requirements with guidance for use — Amendment*

1: Climate action changes. Available at: https://www.iso.org/standard/88209.html (Accessed: 5 April 2025).

International Organization for Standardization (2015) *ISO 14001:2015 - Environmental management systems — Requirements with guidance for use*. Available at: https://www.iso.org/standard/60857.html (Accessed: 5 April 2025).

International Organization for Standardization (2022) *ISO 128-2:2022 - Technical product documentation (TPD) — Presentation of lines on mechanical engineering drawings*. Available at: https://www.iso.org/standard/83355.html (Accessed: 5 April 2025).

International Organization for Standardization (2022) *ISO 128-3:2022 - Technical product documentation (TPD) — Views, sections and cuts*. Available at: https://www.iso.org/standard/83356.html (Accessed: 5 April 2025).

International Organization for Standardization (2020) *ISO 128-1:2020 - Technical product documentation (TPD) — General principles of representation*. Available at: https://www.iso.org/standard/65296.html (Accessed: 5 April 2025).

International Organization for Standardization (2017) *ISO/IEC 17025:2017 - General requirements for the competence of testing and calibration laboratories*. Available at: https://www.iso.org/standard/66912.html (Accessed: 5 April 2025).

International Organization for Standardization (2015) *ISO 2394:2015 - General principles on reliability for structures*. Available at: https://www.iso.org/standard/58036.html (Accessed: 5 April 2025).

International Organization for Standardization (2019) *ISO 56002:2019 - Innovation management system — Guidance*. Available at: https://www.iso.org/standard/68221.html (Accessed: 5 April 2025).

International Organization for Standardization (2015) *ISO 9001:2015 - Quality management systems — Requirements*. Available at: https://www.iso.org/standard/62085.html (Accessed: 5 April 2025).

Lima, M. (2008) 'Standards review, standards bearers', *Resource : engineering & technology for a sustainable world,* 15 (6), pp. 7–9.

Liu, S., Hu, J., Zhang, Y., Liu, Y., Ren, T., Xu, R. and Xue, Q. (2015) 'Sub-millimeter-wave 10 dB directional coupler based on micromachining technique', *International Journal of Antennas and Propagation*, 2015, Article ID 940212. doi:10.1155/2015/940212.

Manafi, S., Boskovic, L.B. and Filipovic, D.S. (2019) 'H-plane narrow-wall double-ridge waveguide coupler in V- and W-bands', *IEEE Microwave and Wireless Components Letters*, 29(3), pp. 204–206. doi:10.1109/LMWC.2019.2893385.

Montejo-Garai, J.R., Leal-Sevillano, C.A., Ruiz-Cruz, J.A. and Rebollar, J.M. (2019) 'Development of a high-performance W-band duplexer for plasma diagnosis using a single band with dual circular polarization', *Nuclear Instruments and Methods in Physics Research Section A*, 947, p. 162712. doi:10.1016/j.nima.2019.162712.

Nikhare, C.P., Kotkunde, N. and Singh, S.K. (2022) 'Effect of material discontinuity on springback in sheet metal bending', *Advances in Materials and Processing Technologies*, 8(Sup3), pp. 1800–1819. doi:10.1080/2374068X.2021.1953925.

Proyavin, M.D., Sobolev, D.I., Parshin, V.V., Belousov, V.I., Mishakin, S.V. and Glyavin, M.Y. (2021) 'Study of 3D-printed dielectric barrier windows for microwave applications', *Electronics*, 10(18), p. 2225. doi:10.3390/electronics10182225.

Sanchez-Olivares, P., Ferreras, M., Garcia-Marin, E., Polo-López, L., Tamayo-Domínguez, A., Córcoles, J., Fernández-González, J.M., Masa-Campos, J.L., Montejo-Garai, J.R., Rebollar-Machain, J.M., Ruiz-Cruz, J.A., Sierra-Castañer, M., Sierra-Pérez, M., Barba, M. and Besada, J.L. (2022) 'Manufacturing guidelines for W-band full-metal waveguide devices: Selecting the most appropriate technology', *IEEE Antennas and Propagation Magazine*, 65(2), pp. 48–62. doi:10.1109/MAP.2022.3143435.

Shastri, A., Sanz-Izquierdo, B., Parker, E.A., Gao, S., Reynaert, P., Chen, Z. and Winchester, L. (2020) '3D printing of millimetre wave and low-terahertz frequency selective surfaces using aerosol jet technology', *IEEE Access*, 8, pp. 177341–177350. doi:10.1109/ACCESS.2020.3024584.

Silva, B., Rocha, A., Miranda, D. and Chaves, F.J.P. (2024) 'Bending processes precision and efficiency in the design and production of metal plates', *International Journal of*

Materials Engineering Innovation, 15(4), pp. 339–364. doi:10.1504/IJMATEI.2024.10061780.

Sonnenberg, T., Romano, A., Verploegh, S., Pinto, M. and Popović, Z. (2023) 'V- and W-band millimeter-wave GaN MMICs', IEEE Journal of Microwaves, 3(1), pp. 453–464. doi:10.1109/JMW.2022.3221281.

Sonnenberg T., Verploegh S., Pinto M. and Popovic Z. (2023) 'W -Band GaN HEMT Frequency Multipliers', *IEEE Transactions on Microwave Theory and Techniques,* 71(10), pp. 1–10.

Sunderraj, A.J.D., Ananthapadmanaban, D. and Kathiresan, A.V.G. (2023) 'Mechanical testing and characterization of tin–zinc–antimony–lanthanum lead-free solders produced using mechanical alloying and furnace melting techniques', *Soldering & Surface Mount Technology*, 35(2), pp. 115–122. doi:10.1108/SSMT-03-2022-0018.

Torregrosa-Penalva, G., García-Martínez, H., Ortega-Argüello, Á.E., Rodríguez-Martínez, A., Busqué-Nadal, A. and Ávila-Navarro, E. (2022) 'Implementation of microwave circuits using stereolithography', *Polymers*, 14(8), p. 1612. doi:10.3390/polym14081612.

Wheeling R, Vianco P, Williams S, Jauregui L and Gallis DFS (2022) Impact of Gold Thickness on Interfacial Evolution and Subsequent Embrittlement of Tin–Lead Solder Joints. *Journal of Electronic Materials* 51(12): 7337–7352.

Wolverton, M. (2014) *The art of soldering for jewelry makers*. Cincinnati: Interweave Press.

Wolverton M (2014) *Solder Joint Embrittlement Mechanisms, Solutions and Standards.* IPC APEX EXPO Conference Proceedings.

Wu, Y., Isakov, D. and Grant, P.S. (2017) 'Fabrication of composite filaments with high dielectric permittivity for fused deposition 3D printing', *Materials*, 10(10), p. 1218. doi:10.3390/ma10101218.

Zeng, L., Lu, W.C., Grimes, P.K., Chen, T.J., Chang, Y.P., Tong, C.Y. and Wang, M.J. (2020) 'A silicon chip-based waveguide directional coupler for terahertz applications', *IEEE Transactions on Terahertz Science and Technology*, 10(6), pp. 698–703. doi:10.1109/TTHZ.2020.3022018.

Zhang, B., Chen, W., Wu, Y., Ding, K. and Li, R. (2017) 'Review of 3D printed millimeter-wave and terahertz passive devices', *International Journal of Antennas and Propagation*, 2017, Article ID 1297931. doi:10.1155/2017/1297931.

Zhang, X., Fu, W., Song, X., Chen, L., Li, Z. and Hu, S. (2024) 'Ultrasonic-assisted soldering W90 tungsten heavy alloy to AZ31B Mg alloy using Sn–xAl alloy', *Journal of Materials Science & Technology*, 175, pp. 132–140. doi:10.1016/j.jmst.2023.07.048https://doi.org/10.1088/1748-9326/3/4/044006.

Appendix 1: Literature review reliability analysis

Table 1: Literature review analysis table

Question	Reference #1	Reference #2	Reference #3	Reference #4	Reference #5	Reference #6	Summarised Observations
Q1: Manufacturing of W-bands	Manafi et al. (2019)	Deng et al. (2024)		–	–		Precision machining and controlled bending reduce signal loss and improve structural integrity.
Q2: 3D printing and laser cutting	Shastri et al. (2020)	Zhang et al. (2017)	Proyavin et al. (2021)	Wu et al. (2017)			Additive manufacturing cuts soldering needs but requires surface and dimensional accuracy for high-frequency performance.

Q3: Issues with gold coating	Zhang et al. (2017)	Wolverton M (2014)	Shastri et al. (2020)	Torregrosa-Penalva et al. (2022)	Proyavin et al. (2021)	Wu et al. (2017)	Gold improves conductivity and resistance to corrosion but risks embrittlement if over ~3% in solder.
Q4: Challenges with bending	Chou et al. (1999)	Nikhare et al. (2022)	Liu et al. (2015)	–	–		Material properties influence bend quality; excess stress can cause fractures or deformations.
Q5: Applications of W-band	Sanchez-Olivares et al. (2022)	Montejo-Garai et al. (2019)	Huang et al. (2021)	–	–		Used in radar, imaging, UAVs, autos, satellites. Advanced soldering boosts

							efficiency and reduces defects.
Q6: Improved soldering techniques	Zhang et al. (2024)	Fan et al. (2024)	-	–	–		Reflow, selective, and laser soldering improve quality, energy use, and reduce defects.

Summarized observations about the relevance of each reference

Manafi et al. (2019) demonstrate a W-band (75–110 GHz) double-ridge waveguide coupler design that is fabricated in three parts using standard CNC milling, achieving wideband coupling (covering V- and W-band) with excellent agreement between simulation and measurement. This work proves that complex W-band components can be realised with conventional machining techniques (including effective assembly methods), confirming the feasibility of traditional manufacturing for high-frequency waveguide devices.

Deng et al. (2024) introduce an analytical design methodology for a wideband differential waveguide directional coupler, alongside a novel de-embedding measurement technique, to ensure accurate characterisation of the prototype. The authors fabricate the coupler using low-cost additive manufacturing (stereolithography 3D printing followed by copper plating) and demonstrate that the device achieves the expected coupling performance, highlighting a rapid fabrication approach and careful calibration process for W-band coupler development.

Hrobak et al. (2012) present the design of an ultra-wideband backward-wave directional coupler (2–50 GHz) using coupled planar lines and include an analysis of how typical manufacturing and assembly tolerances affect device performance. By accounting for dispersive effects with a non-uniform (wiggly-line) design and evaluating fabrication

inaccuracies, this study underlines critical considerations in the practical construction of broadband couplers, which is directly relevant to ensuring successful manufacturing of W-band components.

Shastri et al. (2020) demonstrate the use of aerosol jet 3D printing to create millimetre-wave frequency selective surfaces (FSS) operating in the low-THz range, showing that fine conductive patterns can be additively manufactured with sufficient precision for high-frequency applications. The work validates that aerosol jet printing can produce functional electromagnetic surfaces at W-band and beyond, highlighting additive manufacturing as a viable method for complex microwave structures that would be difficult to fabricate by traditional means.

Torregrosa-Penalva et al. (2022) utilise stereolithography (SLA) 3D printing to fabricate dielectric substrates for microwave circuits, followed by metallisation, and thoroughly characterise the resin's dielectric properties ($\varepsilon_r \approx 3.25$, $\tan\delta \approx 0.03$). As a proof of concept, a multi-height substrate is printed to realise a compact stepped-impedance filter, achieving size reduction without performance loss, which exemplifies how commercial polymer printers can enable innovative microwave component designs with geometric and material flexibility not attainable via conventional machining.

Proyavin et al. (2021) explore the fabrication of wideband low-reflection dielectric barrier windows using 3D printing, evaluating several printing methods and materials up to 190 GHz. The authors identify suitable polymers (e.g. SBS and nylon) and demonstrate that a 3D-printed window with optimised double-sided surface gratings can achieve reflection below –18 dB across a broad millimetre-wave band (up to 160 GHz), illustrating the potential of additive manufacturing to produce high-frequency components with complex surface profiles that enhance performance.

Ding et al. (2017) provide a comprehensive review of 3D printing techniques for millimetre-wave and terahertz passive devices, discussing the advantages of additive manufacturing (such as design freedom, reduced cost, and shorter production cycles) compared to traditional machining. The review highlights key challenges like surface roughness and dimensional accuracy that impact device performance and surveys various printed components (e.g. waveguides, antennas), thereby positioning 3D printing as an emerging

fabrication approach for high-frequency devices while noting the technical improvements needed for optimal results.

Wu et al. (2017) describe the development of a bespoke composite filament (ABS loaded with 32% barium titanate) for fused deposition modelling, achieving a high permittivity material suitable for printing microwave components. The study details the fabrication of filaments and their successful use in 3D printing, demonstrating that enhancing FDM feedstock with ceramic fillers can yield printed parts with an elevated dielectric constant, which is crucial for creating compact, high-performance RF structures via additive manufacturing.

Wheeling et al. (2022) investigate the effect of gold plating thickness on the integrity of tin–lead solder joints, showing that excessive gold causes significant intermetallic growth and leads to embrittled joints. This study highlights a critical trade-off in gold-coating practices: while gold is needed for conductivity and corrosion resistance in microwave components, its thickness must be carefully controlled to prevent solder joint degradation during assembly.

Silva et al. (2024) focus on improving precision and efficiency in sheet metal bending processes for metal plates, proposing methods to enhance bend accuracy and throughput in manufacturing. The paper emphasises advanced measurement and adjustment techniques to minimise errors (such as springback-induced deviations), thereby addressing common bending challenges and improving the reliability of bent components in device fabrication.

Chou & Hung (1999) use finite element analysis and optimisation techniques to reduce springback in sheet metal bending, identifying how process parameters and tooling modifications can mitigate the elastic recovery after bending. By quantifying and minimising springback, this work provides insight into achieving more accurate bend angles and shapes, directly tackling a key challenge in producing precise bent parts for high-frequency waveguide assemblies.

Nikhare et al. (2022) examine how material discontinuities (such as gaps or joints in the sheet metal) influence springback behaviour during bending. The authors find that non-uniform material conditions can exacerbate bending springback or variability, underscoring the importance of considering material heterogeneity in design and tooling to ensure consistent bending outcomes for critical components.

Sanchez-Olivares et al. (2023) outline various fabrication technologies for W-band all-metal waveguide devices and provides guidelines for selecting the most appropriate manufacturing method based on the application and device requirements. The article surveys techniques such as CNC milling, electric discharge machining, micromachining, and additive manufacturing, comparing their capabilities and limitations, which helps designers choose an optimal production process for W-band components in practical applications ranging from communications to sensing.

Montejo-Garai et al. (2019) describe the development of a high-performance W-band duplexer used for plasma diagnostics, featuring a single waveguide band handling dual circular polarisations. The paper demonstrates a complex W-band component designed for a specific scientific application (fusion plasma measurement), validating that precision-engineered waveguide structures can meet stringent performance criteria (low loss, high isolation) in an advanced real-world system.

Huang et al. (2021) introduce a W-band bandpass filter implemented in a rectangular microcoaxial structure, achieving low insertion loss and compact size at 95–100 GHz. This work showcases an innovative filtering approach where a coaxial-like waveguide format is used to realise a W-band component, indicating how novel structures can fulfil millimetre-wave filtering needs (for example, in next-generation radar or wireless links) while maintaining excellent performance.

Zhang et al. (2024) give an ultrasonic-assisted soldering process for joining dissimilar metals, successfully bonding a tungsten-heavy alloy (W90) to a magnesium alloy (AZ31B) using a Sn–Al solder. The application of ultrasonic vibration during soldering breaks oxide films and improves wetting, resulting in a strong metallurgical bond; this exemplifies how advanced soldering techniques can overcome material incompatibility and produce reliable joints for challenging material combinations.

Fan & Chen (2024) investigate the microstructure and bonding mechanism of a low-temperature ultrasonic soldering method using Sn–9Zn solder to join aluminium nitride (ceramic) to 2024 aluminium. By analysing joint interfaces and optimising processing parameters, the study shows that ultrasonic energy activates the otherwise “inactive” zinc solder, achieving sound joints with improved mechanical properties, thus highlighting a way to solder difficult materials (metals to ceramics) effectively in electronic assemblies.

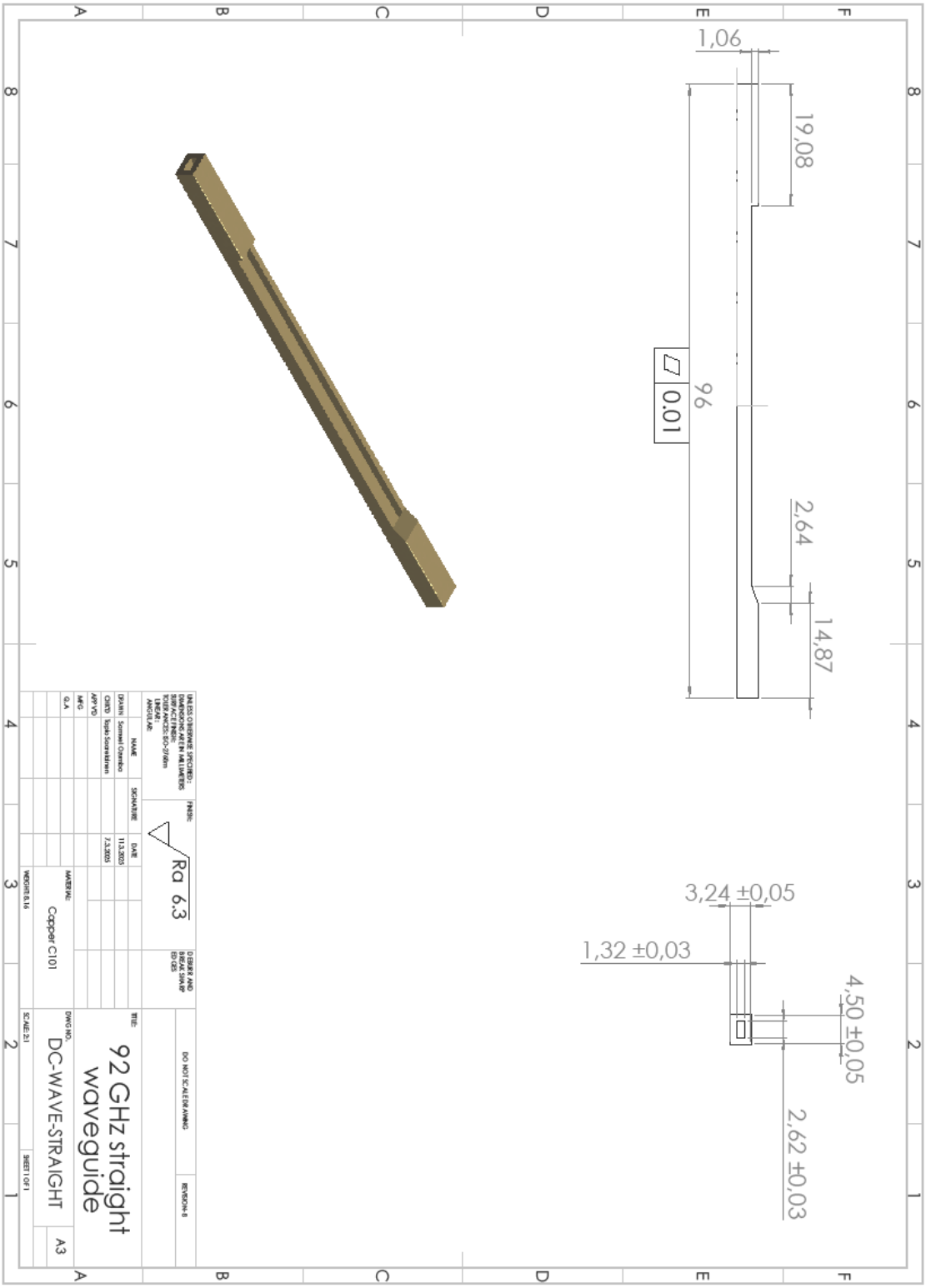
D. et al. (2023) evaluate a novel Sn–Zn–Sb–La lead-free solder alloy by comparing two production methods: mechanical alloying versus conventional melting. Through mechanical testing and microstructural characterisation of solder joints, the authors demonstrate that the alloy's properties can be enhanced and made more consistent with the mechanical alloying approach, providing insights into improving solder material formulation and processing for stronger, more reliable interconnects in microwave device fabrication.

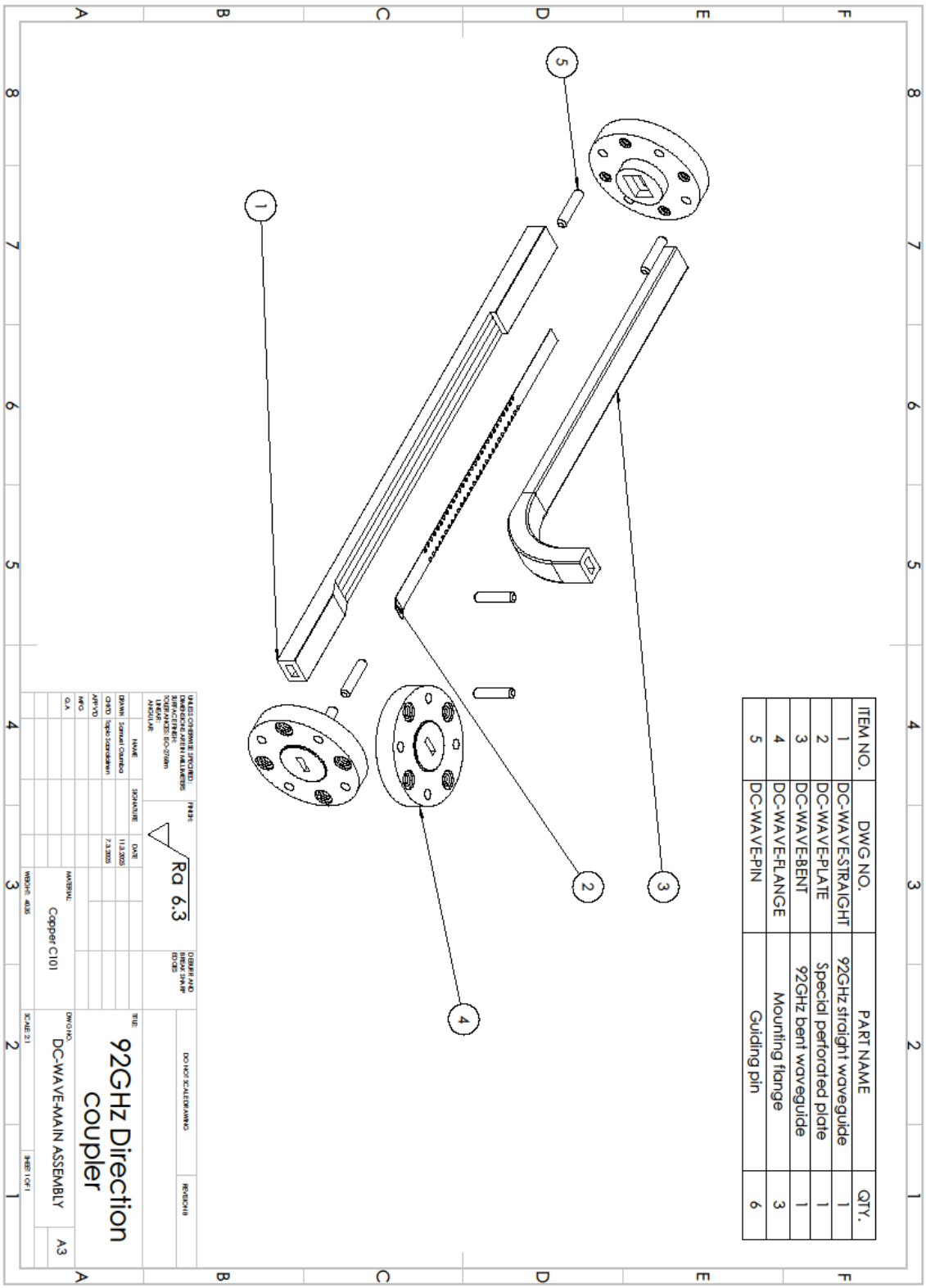
Zeng et al. (2020) discussed a terahertz waveguide directional coupler implemented on a silicon chip, illustrating how on-chip waveguide sections and coupling slots can be used to split and direct THz signals. This silicon-based coupler achieves the desired coupling level and directivity at sub-millimetre-wave frequencies, exemplifying the function of a directional coupler component and how its constituent parts (waveguide cores, coupling apertures, etc.) operate in an integrated THz system.

Xue et al. (2015) developed a 10 dB directional coupler for sub-millimetre-wave frequencies using precision micromachining techniques, realising the coupler in a waveguide format with internal coupling structure. The design and experimental results (near 300 GHz) show how each part of the device – from the coupling holes to the waveguide ports – contributes to achieving the targeted coupling and isolation, thereby shedding light on the functional role of each section in a high-frequency coupler.

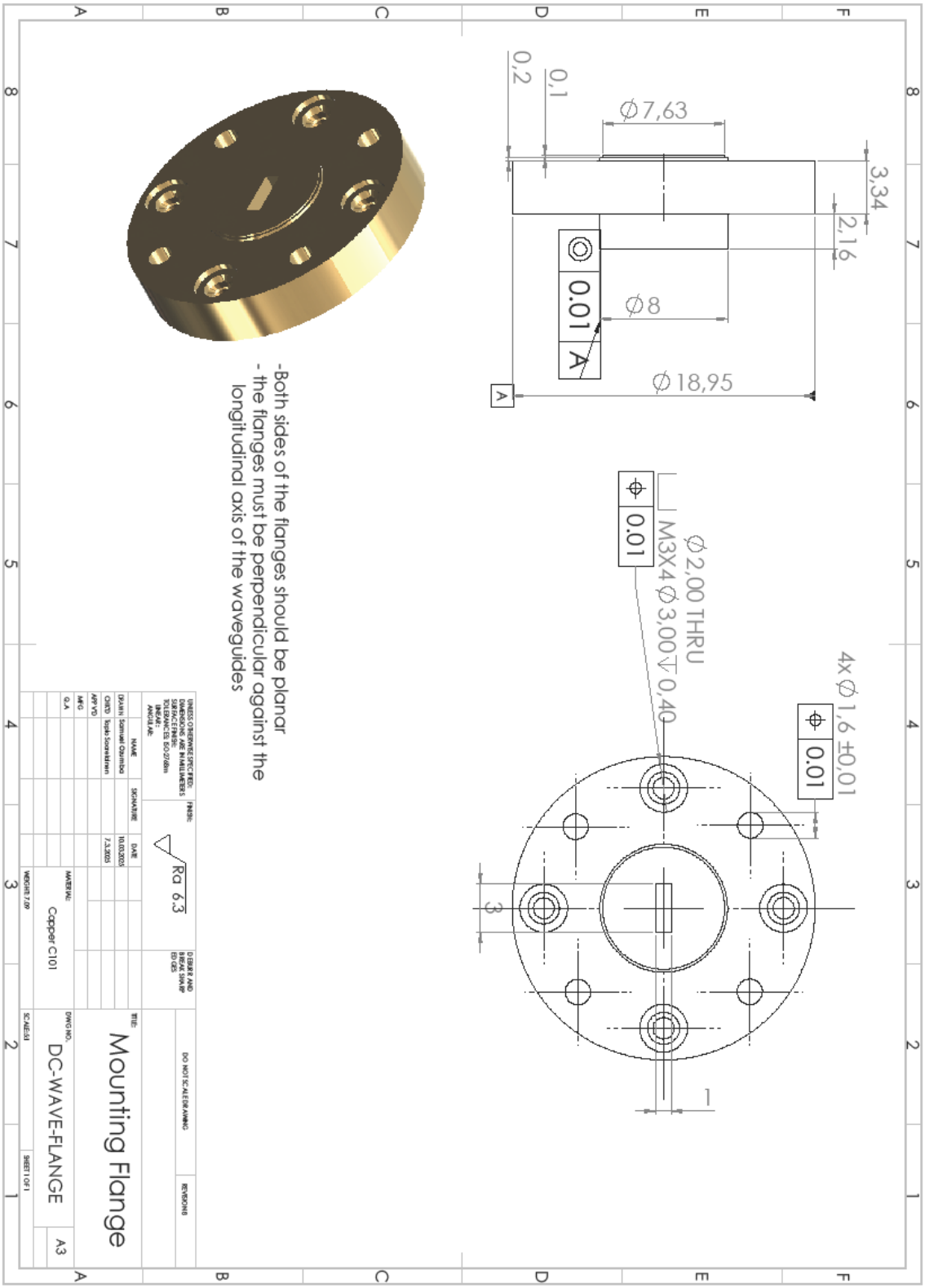
Abbosh & Bialkowski (2007) present an ultra-wideband 3 dB quadrature coupler that combines microstrip and slotline transmission paths. They use their orthogonal fields to achieve broad bandwidth and a 90° phase difference between outputs.

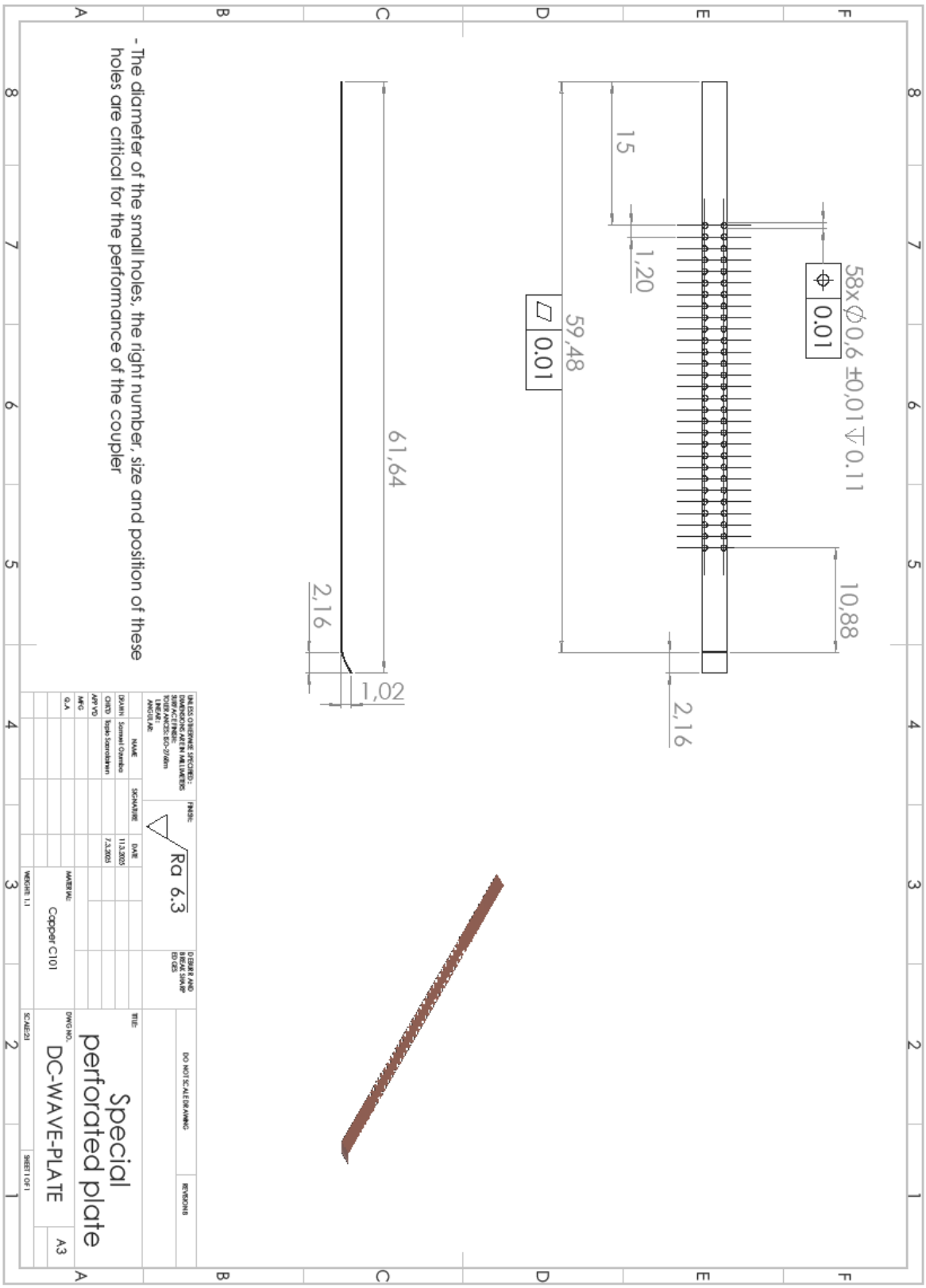
Appendix 2: Technical Drawings

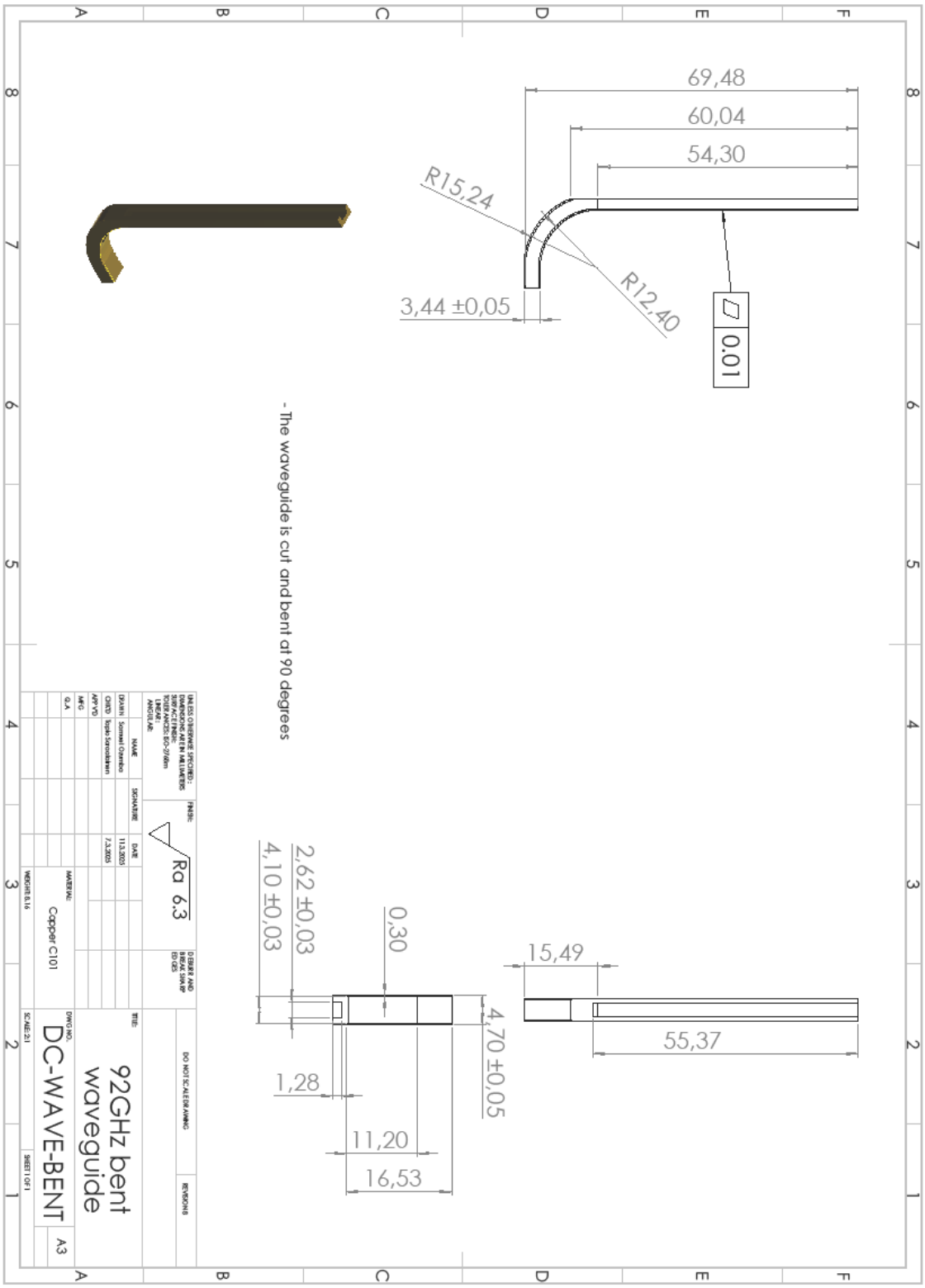


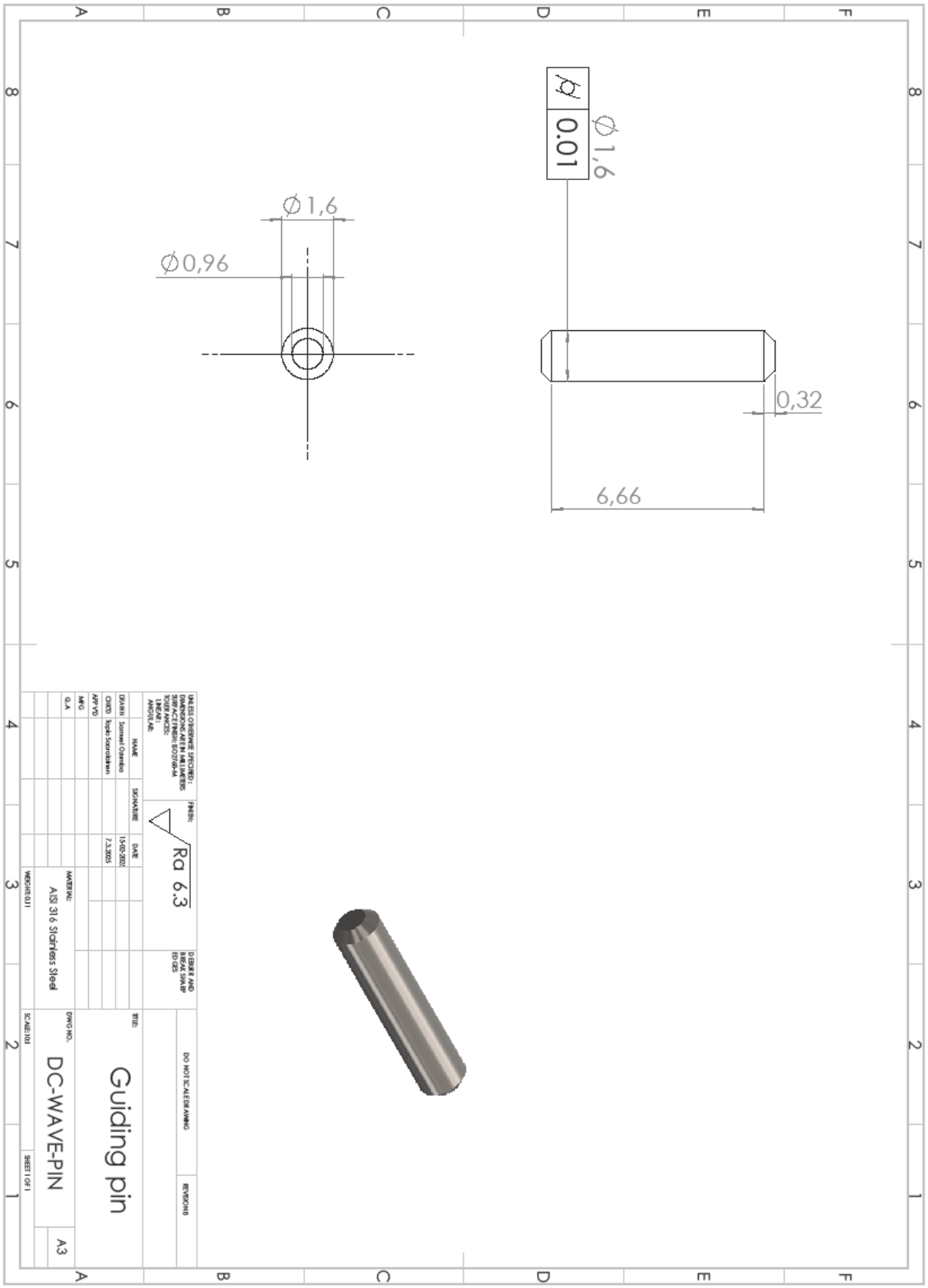


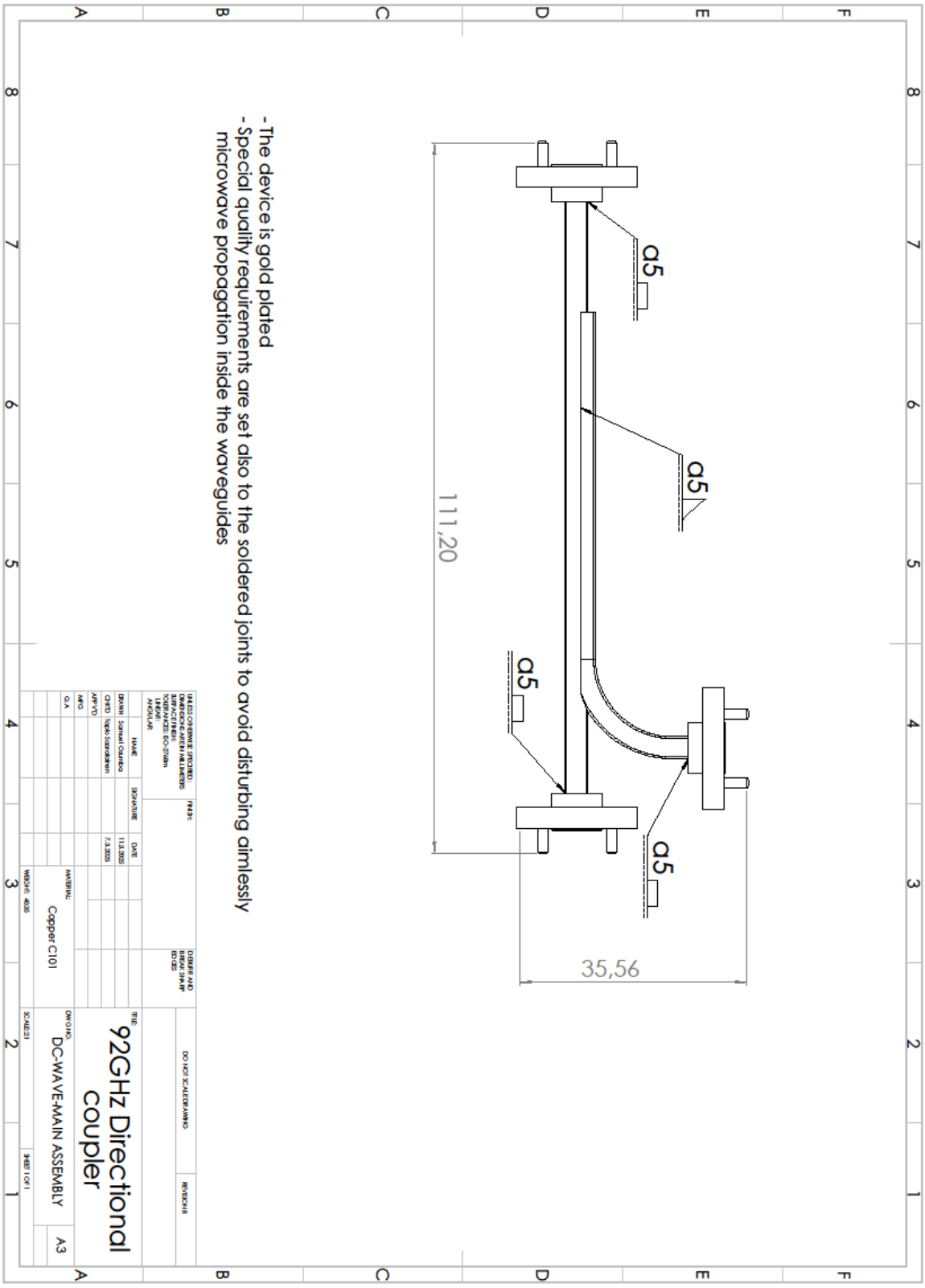
ITEM NO.	DWG NO.	PART NAME	QTY.
1	DC-WAVE-STRAIGHT	92GHz straight waveguide	1
2	DC-WAVE-PLATE	Special perforated plate	1
3	DC-WAVE-BENT	92GHz bent waveguide	1
4	DC-WAVE-FLANGE	Mounting flange	3
5	DC-WAVE-PIN	Guiding pin	6


3,34
2,16
0,1
0,2
Ø7,63
0.01 A
Ø8
Ø18,95
A
4x Ø 1,6 ±0,01
0.01
Ø 2,00 THRU
M3X4 Ø 3,00 ↧ 0,40
0.01
3
1
-Both sides of the flanges should be planar
- the flanges must be perpendicular against the longitudinal axis of the waveguides
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCE: ISO 2768m
BREAK ALL SHARP EDGES
FINISH:
Ra 6.3
DRAWN
Samuel Olumba
10.03.2025
CHK'D
Isaak Szarafinen
7.3.2025
APP'D
MFG
Q.A
MATERIAL
Copper C101
WEIGHT: 7.09
DO NOT SCALE DRAWING
REVISION
TITLE:
Mounting Flange
DWG NO.
DC-WAVE-FLANGE
A3
SCALE: 5/1
SHEET 1 OF 1


58x Ø0,6 ±0,01 ⌀ 0.11
0.01
0.01
15
1,20
59,48
10,88
2,16
61,64
2,16
1,02
Ra 6.3
Copper C101
Special perforated plate
DC-WAVE-PLATE
A3
- The diameter of the small holes, the right number, size and position of these holes are critical for the performance of the coupler


69,48
60,04
54,30
R15,24
R12,40
3,44 ±0,05
0.01
- The waveguide is cut and bent at 90 degrees
2,62 ±0,03
4,10 ±0,03
0,30
15,49
4,70 ±0,05
55,37
1,28
11,20
16,53
Ra 6.3
Copper C101
92GHz bent waveguide
DC-WAVE-BENT
A3


⌀ 0.01
⌀1,6
⌀1,6
⌀0,96
0,32
6,66
Ra 6.3
UNLESS OTHERWISE SPECIFIED:
NAME
SIGNATURE
DATE
DRAWN
CHKD
APP'VD
MFG
Q.A
MATERIAL:
AISI 316 Stainless Steel
WEIGHT: 0.11
FINISH:
DO NOT SCALE DRAWING
REVISION
TITLE:
Guiding pin
DWG NO.
DC-WAVE-PIN
A3
SCALE:1:01
SHEET 1 OF 1



- The device is gold plated
- Special quality requirements are set also to the soldered joints to avoid disturbing aimlessly microwave propagation inside the waveguides

	NAME	SIGNATURE	DATE
DRAWN	Samuel Cuerbo		11.3.2025
CHKD	Topi Sorsdahen		7.3.2025
APP'D			
MFG			
Q.A			

MATERIAL: Copper C101

FINISH:

DO NOT SCALE DRAWING

REVISION

TITLE: 92GHz Directional coupler

DWG NO. DC-WAVE-MAIN ASSEMBLY

A3

SCALE: 2:1

WEIGHT: 40.35

SHEET 1 OF 1

Appendix 3. 3D geometric tolerance of assembly

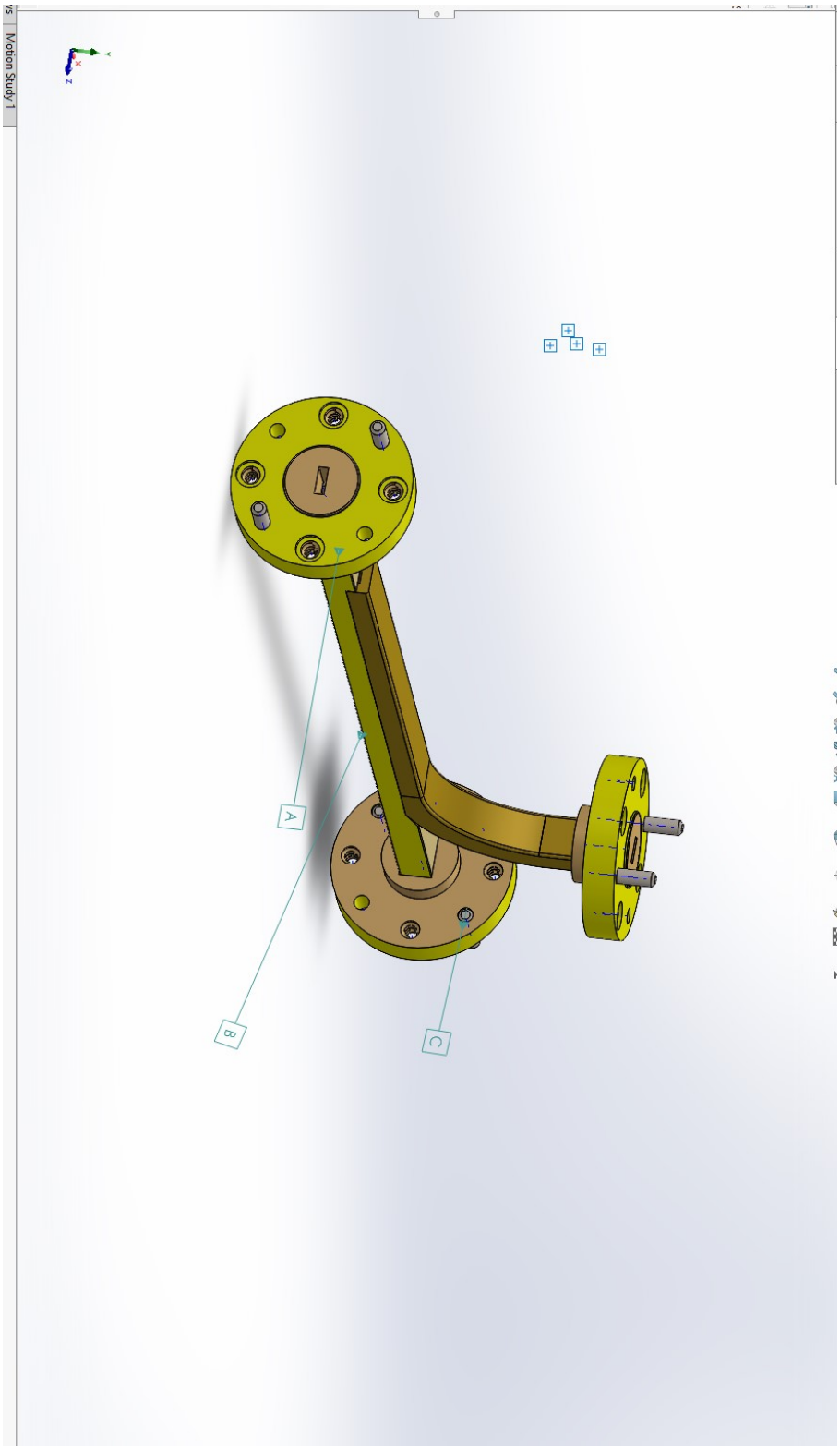


Figure 1: Datum Positions

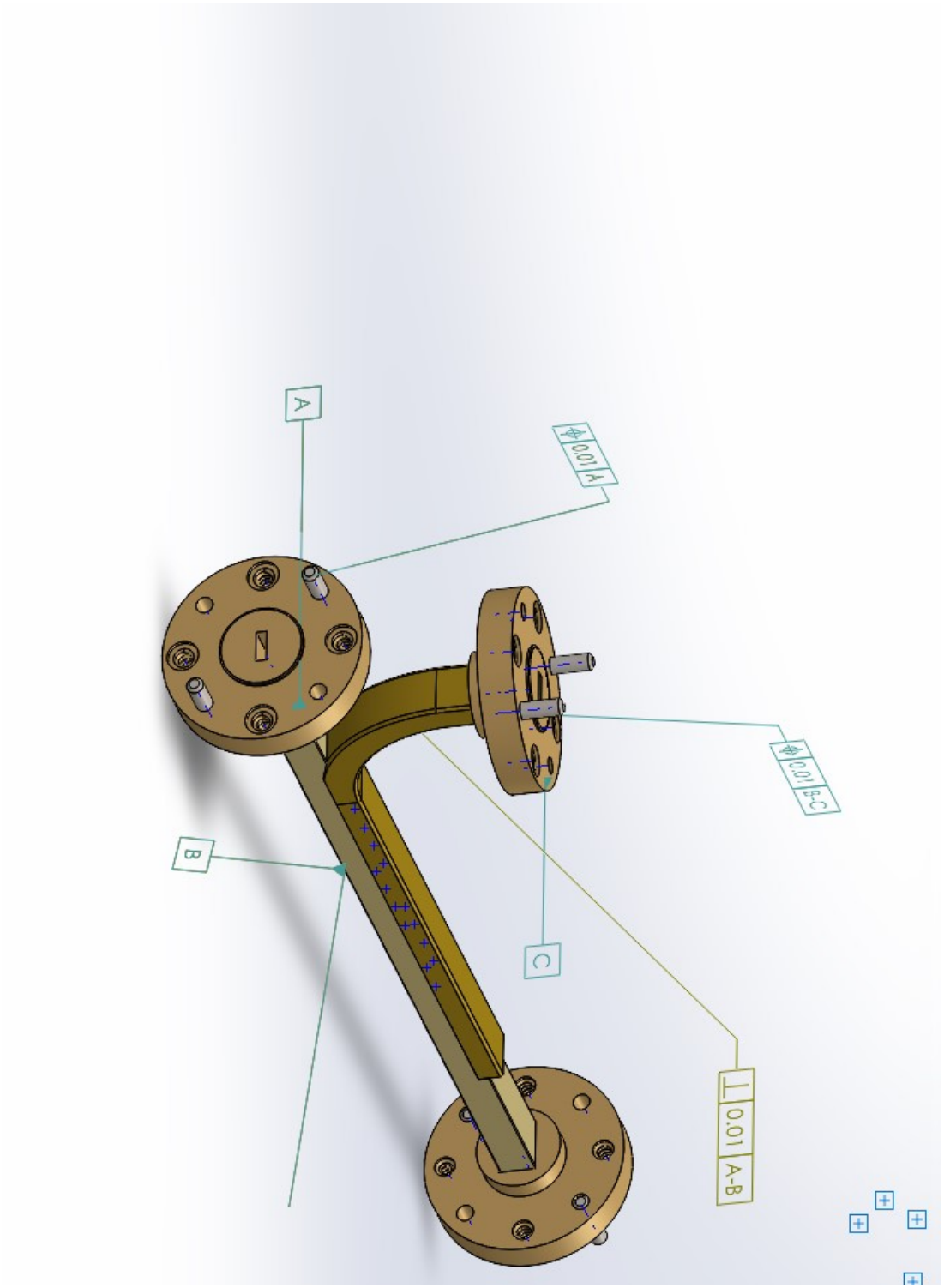


Figure 2: Geometric position of Guiding pins and bent waveguide

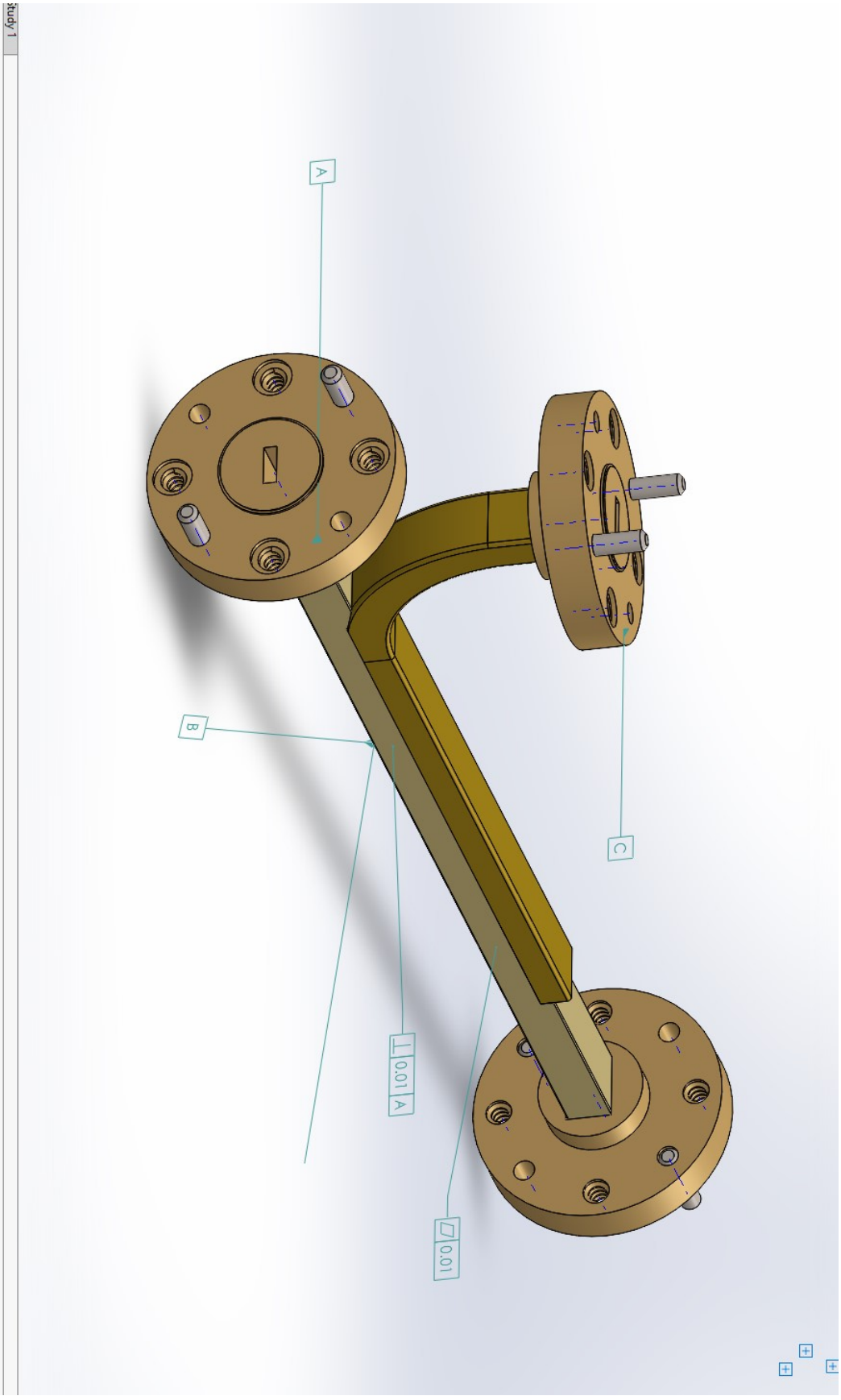


Figure 3: Geometric tolerance of straight waveguide