

**DRGH ANTENNA WITH IMPROVED GAIN AND BEAMWIDTH
PERFORMANCE**

by

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Submitted in partial fulfilment of the requirements for the degree
Master of Engineering (Electronic Engineering)

in the

Department of Electrical, Electronic and Computer Engineering
Faculty of Engineering, Built Environment and Information Technology

UNIVERSITY OF PRETORIA

September 2018

SUMMARY

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Keywords: Beamwidth, characteristic mode impedance taper, Double Ridge Guide Horn antenna, elliptical profile, numerical model, ridge.

Double Ridge Gain Horn (DRGH) antennas are used widely in test facilities for gain standards and source antennas, more specifically in ElectroMagnetic Compatibility (EMC) testing. The capability of the DRGH antenna to obtain a relatively constant 3 dB and 10 dB beamwidth, within the operating frequency band of 1-18 GHz, deems it appropriate for these applications. The ridges form an essential part of the DRGH antenna and are selected to focus on during this investigation. It was hypothesised that by changing both the profile and width of the ridges across the axial length of the DRGH antenna will improve the gain and beamwidth performance. The starting point was determined by selecting a DRGH antenna that adhered to the EMC requirements. An accurate numerical model was developed of the 1-18 GHz DRGH antenna and used as the box dimensions. The ridges were then improved by implementing the elliptical profile and tapering out the width linearly. Based on the results observed of the prototype DRGH antenna developed the hypothesis was confirmed with the improved ridges implemented.

ACKNOWLEDGEMENTS

I would like to acknowledge the financial assistance of SAAB Electronic Defence Systems, in particular the direction from the Antennas group, more specifically Bennie Jacobs, for his mentoring role and by providing me with valuable learning opportunities.

I would like to thank the following people whose support and reassurance made this dissertation possible:

The Lord, Jesus Christ, who through this whole process has blessed me in abundance, opening doors for me and giving me strength and courage during the years.

My wonderful family, my father Johann Gerber, for setting an example, and from whom we could learn that nothing was too difficult to understand and opening our eyes to the wonderful world of engineering; then especially my mother Hannelie Gerber, whose inspiration, guidance and support pulled me through. My friends and my boyfriend, Hein Tempel for their help and love during the difficult times.

My supervisors, Professors J. W. Odendaal and J. Joubert for guiding me through the process with their continuous encouragement and support. I am incredibly grateful towards them for opening the world of antennas to me and for the opportunities they gave me.

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CHAPTER 1 INTRODUCTION

1.1 PROBLEM STATEMENT

Since the late 1950's the Horn antenna has been used in various applications, ranging from gain standards in EMC testing to radar systems, source antennas in Electronic Warfare (EW), measurement facilities and communication systems. Ridges were added to the conventional pyramidal horn in the 1970s to decrease the fundamental modes cut-off frequency and thereby improving the bandwidth of the horn antenna [1]. It is well known that Double Ridge Gain Horn (DRGH) antennas have evolved to become the preferred source antenna in EMC/EMI testing facilities with its 18:1 operation bandwidth, developed from the traditional 1-12 GHz horn antenna by Kerr [2].

The DRGH antenna has superior performance in comparison to the conventional pyramidal horn antenna with a broader operation bandwidth [3-5]. The capability of the DRGH antenna to have as much gain as possible, and a relatively constant beamwidth, over the 1-18 GHz bandwidth is an important requirement for antenna gain standards. The improvements to these antenna parameters will enhance the capabilities of the EMC testing facilities.

The standard used to specify the dimensions of a 1-18 GHz DRGH antenna for testing purposes is MIL-STD-461F [6]. Fixed dimensions for the aperture of a DRGH antenna are specified in this standard. This imposes a limitation on the variables that can be optimised for the goal of improving the performance of the DRGH antenna. The focus point of this study became the ridges that are implemented into the DRGH antenna and also the improvement of the performance for EMC/EMI testing capabilities, as they could be manipulated and improved whilst still complying with the necessary standards.

1.1.1 Context of the problem

A number of studies have been conducted on the overall improvement of the DRGH antenna, with few focusing on EMC/EMI testing requirements. Even fewer studies have been extensively conducted on the ridges of the DRGH antenna; most of which implement the basic exponential curve. In [7], a sinusoidal ridge profile was applied to the ridges of the DRGH antenna which showed good performance with the 3 dB beamwidth in the elevation and azimuth ranging from 36° to 13° and from 26° to 12° respectively. A minimum gain of 13 dB and maximum gain of 27 dB was achieved. This paper is one of the few obtained that implemented a ridge profile other than the conventional exponential profile and that also investigated the beamwidth performance.

An improved design of a DRGH antenna has been published in [4] that presented with a VSWR below 2 over the frequency bandwidth of 1-18 GHz, displaying no radiation pattern break-up [4]. This antenna complies with the EMC/EMI standards [6]. The redesign of the transition section helped in suppressing the higher order mode excitations displayed in previously published antennas. In [4], the Bezier profile was implemented into the DRGH antenna.

1.1.2 Research gap

In the literature review, it was found that an essential requirement for antennas, in wideband applications, is to operate with a relatively constant beamwidth, high gain and have well behaved patterns over the broad frequency range. Emissions and immunity testing within the 1-18 GHz range requires a specified antenna defined in MIL-STD-461F [6]. This limits the DRGH antennas performance due to the fixed dimensions, especially the aperture size. Few investigations have been done on DRGH antennas that specifically focused on the ridges within the confined EMC/EMI fixed dimensions.

This realisation prompted an investigation into ridge improvements made in other antennas, specifically the Quad Ridged Gain Horn (QRGH) antenna and Transverse Electromagnetic

(TEM) horn antenna. It was found that the elliptical profile showed promising results in TEM horn antennas, causing the beamwidth performance to be relatively constant [8, 9]. Another method not yet applied on DRGH antenna ridges is the tapering of the ridge width across the axial length of the antenna, this was seen in [10].

1.2 RESEARCH OBJECTIVES AND GOALS

The goal of this study is to improve the gain of the DRGH antenna and to obtain a relatively constant beamwidth response. The ridges of the DRGH antenna have a significant influence on the performance of the antenna and can be observed in a number of DRGH antenna designs. The extent to which the ridges could improve the gain and beamwidth needs to be investigated. As was noted in the literature study, this area of the DRGH antenna has not been studied extensively within the confined dimensions of a specified DRGH antenna for EMC/EMI testing; therefore, the following research objectives are defined below:

Development of a DRGH antenna numerical model: In order to further investigate the methods mentioned in the previous section on the DRGH antenna a numerical model needs to be developed for simulation in FEKO [11] of an existing DRGH antenna and thereafter the changes to the ridges can be applied. A DRGH antenna that complies with the EMC/EMI specified dimensions needs to be selected as the starting point of this dissertation. To ensure that the numerical model is a valid representation of the DRGH antenna simulation results need to be compared with the measured results.

Improvement of DRGH antenna ridges: Due to the requirement of the aperture dimensions remaining fixed for EMC/EMI applications, the ridges are the main focus of the investigation for model improvements. The ridge profile will be studied first and thereafter the characteristic wave mode impedance taper of the axial length will be evaluated by looking at the effect on the DRGH antennas performance, specifically the gain and beamwidth performance. These two approaches are based on improvements identified in other antennas. It is hypothesised that an increase in the ridge area will cause a noticeable increase in the antenna gain.

New improved DRGH antenna: The goal of this study is to adhere to the fixed dimensions of the specified DRGH antenna for EMC/EMI testing and improve the performance by only changing the ridges. Using the methods identified and conducting a study on the effects of different profiles on the ridges and tapering the ridges across the axial length the 1-18 GHz DRGH antenna will be improved.

1.3 RESEARCH CONTRIBUTIONS

The contributions to this study are:

New improved DRGH antenna: The knowledge gained from the study on the effect that the ridges have on the gain and beamwidth result of the DRGH antenna, was used to obtain an improved DRGH antenna, with improved gain performance and a relatively constant beamwidth over the desired frequency range.

Knowledge of ridge effect: The investigation focused on the effect that ridges had on the overall performance of the DRGH antenna was investigated. The remaining dimensions of the DRGH antenna were kept constant and obtained from the selected box dimensions of the DRGH antenna from [4]. Three ridge profiles were simulated in the numerical model of the DRGH antenna after which the performance of each profile was compared. The elliptical profile from [8, 9], proved to be the preferred option, with improved gain at the lower frequency ranges. The impedance transformation of the axial length, as presented in [10] was also investigated on the ridges of the DRGH antenna. Three impedance transition profiles were investigated to improve the gradual characteristic wave mode impedance the flared section. By adding a width taper to the ridges, the characteristic wave mode impedance could be realised to follow a specific impedance transition, this was done by changing the ridge width. This resulted in the width profile of the ridges to contain irregularities, causing discontinuities in the gain of the antennas. The width profile was then changed to be linear, and a parameter study was conducted to determine the taper profile of the ridge width that delivers the most improved result.

1.4 RESEARCH OUTPUTS

A conference paper focusing on the three different ridge profiles, which were analysed in this study, has been accepted by the IEEE Radio and Antenna Days of the Indian Ocean (RADIO) International Conference. The conference will take place from the 15th to the 18th of October 2018 in Mauritius. Furthermore, a journal article will be written regarding the improvement of the ridges, focusing on the width taper profile and how an increase in the ridge area improved the gain of the antenna and also created a relatively constant beamwidth performance.

1.5 DISSERTATION OVERVIEW

In this chapter, the research problem examined during this dissertation is discussed. The context of the problem, the research gap identified and the objectives of the study are reviewed. The contributions made by this study are also listed. The structure of the remaining chapters of this dissertation are as follows:

Chapter 2 contains a literature study. The primary focus is published DRGH antennas and their performance, with specific attention to research done on the ridge effect and possible improvement thereof. Previously published variations of DRGH antennas with different designs and performance characteristics are discussed. Different methods of improving the ridges are identified.

Chapter 3 focuses on the numerical model of the DRGH antenna for the start of the investigation. The antenna from [4] was selected and modelled in FEKO. The simulation results were compared against the measured DRGH antenna in order to validate the numerical model as an accurate representation of the manufactured DRGH antenna.

Chapter 4 provides detail information about the improvement of the ridges of the DRGH antenna. Three different ridge profiles are investigated in simulation to determine the profile

which provides the most improved performance. The gain and beamwidth are analysed as used as deciding factors. Elliptically shaped ridges provide the most improved gain at the lower frequencies. Specific impedance tapers are defined across the axial length of the DRGH antenna by changing the ridge width. The linearly implemented ridge width taper enhanced the performance of the DRGH antenna to obtain a relatively constant beamwidth over a wide frequency range and also a higher gain over the centre frequencies. To further understand the effect of the increased ridge width, a near field simulated analysis was done on the two models and a comparison of the results is presented. The obtained simulation results are compared to the numerical model result from Chapter 3 to quantify the improved performance.

The operation performance evaluation of the prototype antenna is presented in Chapter 5. The mechanical implementation of the improved DRGH antenna concerning the ridge improvement is demonstrated. The simulated and measured data is compared and the differences and similarities are used to validate the numerical model. The compared performance composes of VSWR, boresight gain, radiation patterns and beamwidths.

Chapter 6 concludes the investigation conducted in this dissertation. The content is summarised in this chapter and conclusions on discoveries made are provided. Recommendations for possible future improvements on the proposed for the DRGH antenna.

The next chapter focusses on the literature study and background.

CHAPTER 2 LITERATURE STUDY AND BACKGROUND

2.1 INTRODUCTION

A literature study is presented in this chapter on the DRGH antenna, focusing on the most recent improvements, more specifically pertaining to an investigation regarding the ridges of the DRGH antenna. Section 2.2 presents a brief background of the DRGH antenna. Published DRGH antennas are set out in Section 2.3, which focusses on the most significant improvements over the years. Additional antennas are listed in Section 2.4, regarding their methods to improve the ridges.

Published designs are compared with one another by looking at the performance of the antenna, primarily the VSWR, operational bandwidth, size, gain, and beamwidth. A summary of this chapter regarding the content is provided in Section 2.5, with regards to the DRGH antenna literature study, relevant findings and focal points of this dissertation.

2.2 BACKGROUND OF THE DRGH ANTENNA

Widespread applications of horn antennas have been investigated since the late 1950s and have proven to present many beneficial characteristics such as low side lobes, high directive gain, good excitation and efficient power handling capabilities [12]. Ridges, which extend from the feed of the horn antenna into the flared section, were inserted into the waveguide and formed the DRGH antenna. DRGH antennas were first published in 1964 [1]. In 1973 it

was proven that good antenna performance is obtained for a usable 18:1 bandwidth when the axial length is shortened [2]. Two of the primary applications for DRGH antennas are in Electromagnetic Compatibility (EMC) and Electromagnetic Interference (EMI) measurement facilities [6].

DRGH antennas are also commonly used as source antennas and for gain standards in antenna measurement facilities, where the antenna is used to determine the gain of different antennas by operating as a reference. They are therefore in high demand for certificated EMC test laboratories. The broad impedance matching band and stable radiating features are appropriate for radiated susceptibility tests. A uniform electromagnetic wave can be generated throughout the area of interest for the DRGH antenna over the whole test spectrum. The application that this property can result in promising applications is field-uniformity characterisation and test site calibration. This is a reason why the beamwidth response is a desirable aspect of the DRGH antenna to improve by providing a relatively constant response.

The traditional designs are founded on the published 1-12 GHz DRGH antenna presented by Kerr [2] which consists of two sections, namely the coax to waveguide launcher and the flared section. Throughout the years researchers and organisations have implemented many different design improvements which have led to the conventional 1- 18 GHz DRGH antenna. EMC/EMI application antennas have specified fixed aperture dimensions and therefore, the ridges are a changeable variable which could be modified for improvement. The need for a more constant operating beamwidth in EMC/EMI testing antennas has become a significant role player in electromagnetic devices as the complexity of navigation, radar and telecommunication systems continuously increases. Ideally, an antenna must operate under matched conditions and present relatively constant patterns over the desired frequency band [9].

2.3 PUBLISHED DRGH ANTENNAS

Barrow described one of the first horn antennas in [12]. This design is widely used today for the conventional pyramidal horn antenna. Ridges are inserted across the axial length of

the flared section of the DRGH antenna for the purpose of maximising the functional bandwidth. Ridges were first presented in waveguide investigations for the goal of expanding the range of the single mode and also to lower the fundamental modes cut-off frequency. In [12-15] this effect is exploited. Many different published improvements are based on the traditional 1-18 GHz DRGH antenna, modified from designs published by Kerr [2]. The primary emphasis of these studies have been to ensure the propagation of only the dominant mode in the largest bandwidth achievable.

Botello, Aguilar, and Ruiz reported a detailed investigation in [16], for a 1-14 GHz compatible DRGH antenna designed as a broadband electromagnetic device. A standard pyramidal horn, coaxial feed, cavity, and flared section are present in the antenna. The ridges which were implemented used an exponential curve, designed to operate from 1-18 GHz but presented splitting in the main beam at frequencies above 12 GHz. All similar broadband DRGH antenna studies displayed similar boresight gain degradation in the higher frequency ranges. This is due to the unsuccessful goal of suppressing the propagation of higher order modes effectively. Deterioration in the antenna occurs typically occurring after 12 GHz when the four off-axis lobes are seen due to the main beams axis starting to split.

Another thorough investigation is presented in [17] regarding a further optimisation of the 1-18 GHz broadband DRGH antenna based on the basic design presented by Walton in [5]. A drop up to 6 dB is observed above 12 GHz where the radiation patterns main lobe begins to split in the off-axis direction into four side lobes. Mechanical imperfections that were introduced into the simulation model significantly enhanced the correlation between the simulated and measured results. Another study that showed deterioration at higher frequencies in the radiation patterns can be observed in [18].

Implementation of a sinusoidal ridge profile is presented in [7], over a frequency band of 6-18 GHz. This is one of the few investigations where the profile of the ridges was changed from the conventional exponential curve. During this study, an adequate configuration was selected to implement for feeding the ridges. The DRGH antenna showed acceptable

matching performance with the reflection coefficient value below - 10 dB in the operation bandwidth of 6 - 18 GHz. The DRGH antenna presented with a 3dB beamwidth in the elevation plane from 36° to 13° and in the azimuth plane from 26° to 12°. The minimum gain is observed at 6 GHz to be 13 dB and the maximum gain at 18 GHz to be 27 dB for the measured results.

An investigation was done by Jacobs in [19] to fully understand the sensitivity of the tolerances in assembly and manufacturing of DRGH antenna by conducting an intensive parameter study. In [4] an alternative improved DRGH antenna is proposed with the redesign and optimisation of the coaxial to ridged waveguide launcher was done to obtain a VSWR less than 2 from 1 to 18 GHz. Metallic grid sidewalls were added that resulted in a gain ranging from 8 dBi to 16 dBi in the desired frequency band. The new designs performance in the 1-18 GHz bandwidth did not display any pattern breakup. A fundamental implementation of this study was the utilisation of the ridged cubic Bezier control points to create the profile for the ridges. The simulated and measured results correlated well and showed the advantage of adding a different profile in the ridges of the DRGH antenna and changing the implemented sidewalls.

One of the most recent studies published on a 1-18 GHz DRGH antenna can be found in [20]. In this paper, the flared sections taper profile is improved as well as the coupling structure of the coaxial feed. The purpose of this new design is mainly for field uniformity tests. The result showed a constant response at the 3m measurement distance over the entire frequency range. Thus is a desirable characteristic for practical EMC applications.

A 2-18 GHz DRGH antenna was designed in [21], where the exponential ridge profile was modified by adding a curved section to the end of the ridge. This improvement led to the reduction of the deterioration at high frequencies, which affected the radiation patterns. The results presented with better matching properties between the waveguides impedance and impedance of free space. The known deficiencies of a conventional DRGH antenna were not observed in the presented design that has a smaller physical dimension. The feeding section of the antenna has been optimised for the purpose of achieving a better

VSWR. These alterations resulted in the lower frequency VSWR remaining below 2.7 and at the higher frequencies displaying a VSWR result less than 1.8. The main advantages of the design changes of the DRGH antenna, which presented with a gain ranging from 4 dB to 15 dB, was the weight reduction and also the construction ease when manufacturing. The modified antenna also removed the H-plane flares and altered the E-plane flares with circular arches.

2.4 QRGH AND TEM ANTENNA IMPROVEMENT TECHNIQUES

In [22], Beukman proposed a technique to synthesise the taper of the antenna by considering the modal propagation characteristics of the QRGH antenna. This technique showed promising results for improving the radiation properties of the antenna by means of profiling the ridge taper. The design method is one of the earliest published that focused on the cut-off frequencies of the different propagating modes, rather than optimising a design with brute-force. Another difference observed in [22] is the ridge tapering that does not implement a commonly used profile, but rather a new optimised profile was determined by focusing on the modes and the different cut-off frequencies.

A different technique is introduced in [23] for the tapering across the axial length of the flared section of the QRGH antenna. This technique presented a different coaxial line to quadruple-ridge waveguide (QRG) transition than implemented before. The return loss and impedance matching has been improved by the new design. The four identical ridges are shaped with the exponential curve for the purpose of following a gradual taper from the waveguide impedance ($50\ \Omega$ or less) until the impedance free space ($377\ \Omega$). The axial length of the QRGH antenna is divided into different sections that then become small quad-ridged waveguides on their own. Each of these sections have their own impedance and with this method a gradual impedance taper is achieved.

The elliptical profile has been observed to be implemented instead of the conventional exponential profile in QRGH antennas published in [24] and [25]. The sidewalls and ridge

flared profile was improved to keep the beamwidth constant over a wider bandwidth of the QRGH antenna for the purpose of obtaining greater rotational pattern symmetry [26].

Malherbe presented promising results regarding the constant response of the beamwidth of a TEM horn antenna [8]. An elliptical flared waveguide was implemented in [8], and in [9] an elliptical profile was used for the cross-section to create an optimal impedance transformer. The TEM horn antenna behaves very differently to the standard DRGH antenna, due to the type of modes which propagate through the antenna. It is unknown how a profile implemented into a TEM horn antenna will behave in a DRGH antenna.

Another paper published implemented for a 2-18 GHz TEM DRGH antenna can be found in [27] where the two identical ridges are tapered out. The ridge height and ridge width are the factors which ensure that the impedance taper of the structure is a gradual transition from the characteristic wave mode impedance ($50\ \Omega$) at the start of the ridges to the impedance of free space ($377\ \Omega$). To increase the smooth transition between the impedance of double-ridged waveguide (DRG) and the impedance free space, the tapering is applied in the lateral and longitudinal axis of the ridges. In the flared section the height and width of the ridges differ across the axial length of the TEM DRGH antenna. This tapering of the TEM DRGH ridges is based on an exponential function in the longitudinal plane (y-axis) and is tapered linearly in the lateral plane (x-axis).

2.5 SUMMARY

A literature review has been conducted in this chapter on DRGH antennas, focusing on the improved designs over the years. The improvement of the ridges for the purpose to obtain a relatively constant response of the beamwidth, over a wide bandwidth for EMC/EMI testing is the focus of this study.

In Section 2.2 the background information is briefly discussed. Various DRGH antennas are mentioned, and their performance discussed, specifically with regard to the optimisation of the traditional DRGH antenna in Section 2.3. Different methods are identified in other

antennas, namely the QRGH antenna and TEM horn antenna in Section 2.3. These papers are discussed due to the improvements noted on the ridges of the proposed antennas and the possibility of applying the different techniques on the DRGH antenna ridges. The method of tapering the ridges over the axial length of the flared section, used on these QRGH antennas, is investigated for the possibility of implementing it in the DRGH antenna. The elliptical profile will also be viewed as a possible substitute to the conventional exponential profile in the DRGH antenna, due to promising results seen in the TEM horn antenna. Finally, the aspect of not only tapering the ridge in one direction, but laterally as well as longitudinally, will also be investigated and applied into the DRGH antenna.

The next chapter focusses on the chosen DRGH antenna of this study for the starting point in the form of a numerical model.

CHAPTER 3 NUMERICAL MODEL OF THE DRGH ANTENNA

3.1 INTRODUCTION

One of the principal applications of the 1-18 GHz DRGH antenna is for EMC/EMI measurements. Standards for an EMC/EMI testing of DRGH antennas are listed in [6]. Published articles that comply with these standard specifications for a 1-18 GHz DRGH antenna can be found in [4], [18], [27-29] and [30].

The DRGH antenna presented by Jacobs in [4], is selected to be the starting design of this dissertation. Different papers published concerning EMC/EMI DRGH antennas were considered as benchmark designs. The DRGH antenna from [4] showed the most promise, with no pattern breakup in the 1-18 GHz desired frequency band. An optimisation of the coaxial to ridge waveguide transition section can be seen in [4] and also the ridge profile was investigated and changed from the conventional exponential curve, to the cubic Bezier curve. Jacobs also investigated manufacturing tolerances in [19], thereby removing any uncertainties in the reliability of the simulated model and design procedure. The new design presented better gain and VSWR performance within the confined EMC/EMI specified standard dimensions. Another desirable aspect of the proposed DRGH antenna from [4], was the manufactured antenna consisting of fewer parts compared to other studies, which reduced performance deterioration caused by manufacturing tolerances and imperfections introduced during assembly.

In Section 3.2, the analysis of the selected DRGH antenna is presented; with regards to the coaxial line feed transition to the ridged waveguide section, the cavity section and the flared horn section. This design analysis with values was obtained from [4], and used to create the numerical model in FEKO of the DRGH antenna. The simulation results generated of the numerical model are compared to the DRGH antenna from [4] in Section 3.3 that was obtained and measured for comparison. This is completed in order to confirm the validity of the numerical model used as the starting point of this investigation. The DRGH antenna parameters compared are the VSWR, boresight gain and radiation patterns at specific frequencies. A summary of this chapter is provided in Section 3.5.

3.2 NUMERICAL MODEL DEVELOPMENT IN FEKO

The DRGH antenna contains two main implemented parts; the coaxial line feed transition to the ridged waveguide section, and the flared horn section with ridges. These two antenna sections are briefly discussed and modelled in FEKO from dimensions obtained from [4].

3.2.1 The co-axial to ridged waveguide transition section

The feed section of the DRGH antenna uses a standard $50\ \Omega$ N-type connector. This impedance is then transformed through the waveguide launcher to the ridged waveguide impedance. This transformation must be optimal to ensure that the maximum power is transferred. The waveguide launcher plays a critical role in the overall performance of the DRGH antenna [19].

Jacobs optimised and redesigned the waveguide launcher in [4] that acted as a hybrid between the pyramidal cavity structure and the traditional 1-18 GHz transition structure. This improvement reduced manufacturing cost by 50 % and removed the unwanted higher order modes excitation. Table 3.1 tabulates the cavity height and flare angles [4], while Figure 3.1 presents the waveguide launcher designed in FEKO.

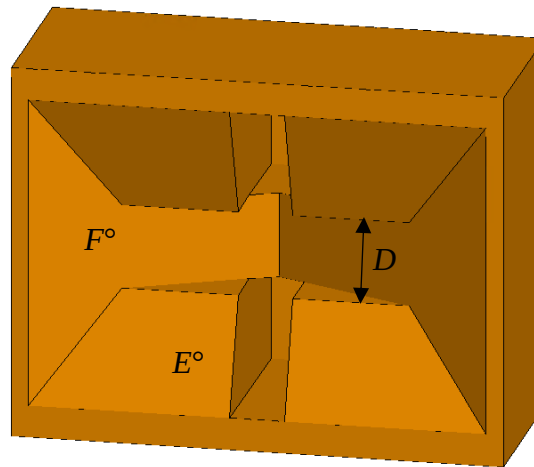


Figure 3.1. Waveguide launcher dimensions.

Table 3.1. Initial parameter values for the waveguide launcher [4].

Variable (Figure 3.1)	Description	Dimension
D	Launcher Cavity Height	15 mm
E	Vertical Flares Angle	19.29°
F	Horizontal Flares Angle	25.29°

The ridges were added into the waveguide to lower the frequency range whilst simultaneously reducing the cut-off point of the main propagating mode, namely TE_{10} [31]. Figure 3.2 presents a cross-sectional view where the variables are given below as described in [3]:

- a - the waveguide width
- b - the waveguide height
- d - the ridge gap
- s - the ridge width in mm

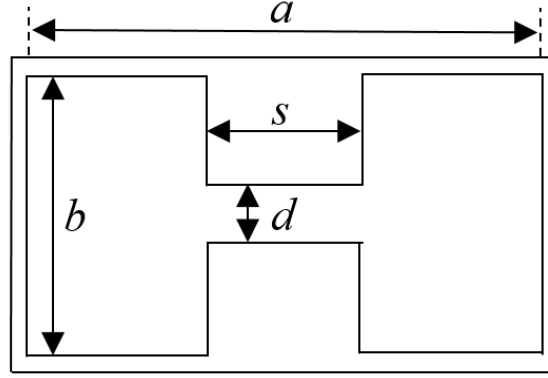


Figure 3.2. Cross-sectional view of ridged waveguide.

The earliest recorded method presented in literature to determine the cut-off frequency and characteristic wave mode impedance of a waveguide was published by Cohn [3], where the results corresponded well with the theoretically obtained values. Hopfer [5], later published similar design equations with improved approximations. After that, Walton and Sundberg approximated the equations to design the coaxial to ridged waveguide launcher [1]. The TE_{10} mode represents the rectangular waveguides dominant mode and the DRGH antenna can effectively be improved by lowering the cut-off frequency of this mode. This can be accomplished by adding the ridges in the waveguide [3]. The transverse resonance method is used to approximate the double ridge in rectangular waveguides by a captive susceptance introduced into the middle of the waveguide [3, 4]. The cut-off conditions are determined by using the following equations for the corresponding modes in the rectangular waveguide of the TE_{n0} mode.

$$\cot(k_x L) - \frac{b}{d} \tan\left(k_x \frac{s}{2}\right) - \frac{B}{Y_{01}} = 0 \quad (3.1)$$

$$\cot(k_x L) + \frac{b}{d} \cot\left(k_x \frac{s}{2}\right) - \frac{B}{Y_{01}} = 0 \quad (3.2)$$

The odd and even TE_{n0} corresponding modes are provided in (3.1) and (3.2) respectively with $L = (a - s)/2$ and B/Y_{01} representing the DRGs discontinuity effect. $k_x = 2\pi/\lambda_c$

gives the propagation constant in the x direction with $\alpha = \frac{b}{d}$. The admittances are given by the following equations [3]:

$$Y_{01} = \frac{k_x}{\omega\mu} \frac{1}{b} \quad (3.3)$$

$$Y_{02} = \frac{k_x}{\omega\mu} \frac{1}{d} \quad (3.4)$$

The normalised susceptance for the lowest mode is given by [10],

$$\frac{B}{Y_{01}} = \frac{2b}{\lambda_c} \left[\left(\frac{\alpha^2 + 1}{\alpha} \right) \cosh^{-1} \left(\frac{1 + \alpha^2}{1 - \alpha^2} \right) - 2 \ln \left(\frac{4\alpha}{1 - \alpha^2} \right) \right] \quad (3.5)$$

with

- $c = 3 \times 10^8 \text{ m/s}$
- $\mu_0 = 4\pi \times 10^{-7} \text{ H/m}$
- $\epsilon_0 = 8.8541 \times 10^{-12} \text{ F/m}$

Using the above equations, the cut-off frequency is determined by inserting all the different variables into the even or odd mode characteristic equation and finding which value relates to a zero cut-off equation. The following equation relates the characteristic TE₁₀ mode characteristic wave impedance ($Z_{0\infty}$) to the cut-off frequency f_c' as follows [3]:

$$f_c' = \frac{c}{\lambda_c} \quad (3.6)$$

$$Z_{0\infty} = \frac{1}{Y_{0\infty}} \quad (3.7)$$

$$Y_{0\infty} = 2 \sqrt{\frac{\epsilon_0}{\mu_0}} \frac{\lambda_c}{2\pi d} \left\{ \frac{2d}{\lambda_c} \cos\left(\frac{\pi s}{\lambda_c}\right)^2 \ln \csc\left(\frac{\pi d}{2b}\right) + \frac{\pi s}{2\lambda_c} \right. \\ \left. + \frac{1}{4} \frac{\cos\left(\frac{\pi s}{\lambda_c}\right)^2}{\sin\left(\frac{\pi}{\lambda_c}(a-s)\right)^2} \left[\frac{\pi(a-s)}{2\lambda_c} - \frac{1}{4} \sin\left(\frac{2\pi(a-s)}{\lambda_c}\right) \right] \right\} \quad (3.8)$$

$$Z_{TE} = \frac{Z_{0\infty}}{\sqrt{1 - \left[\frac{f_c'}{f}\right]^2}} \quad (3.9)$$

The ridged waveguide dimensions were obtained from [4] and are tabulated in the Table 3.2.

Table 3.2. Ridged waveguide parameters.

Description	Value
Waveguide width (a)	80 mm
Waveguide height (b)	55 mm
Ridge separation (d)	1 mm
Ridge width (s)	9.6 mm
Cut-off Frequency (f_c')	0.4005 GHz
Characteristic Wave Mode Impedance ($Z_{0\infty}$)	32.125 Ω

3.2.2 The flared horn section with ridges

The aperture size is kept fixed to adhere to the dimension specifications in the MIL standard [6], and the axial length of the flared section was obtained from [4]. The purpose of the ridge profile is to gradually transform the characteristic wave mode impedance at the start of the axial length until free space. The ridge width is fixed in the ridged waveguide section and used throughout the axial length of the DRGH antenna. The DRGH antenna in [4] implemented conducting grid sidewalls to improve the lower frequency's matching

capability. The cubic Bezier profile was selected in [4] as the optimum transition used in the final design for the DRGH antenna. The specific control points are provided in Table 3.3 and a Matlab code was written to generate the points for the implementation of the cubic Bezier profile in FEKO. The profile generated is shown in Figure 3.3.

Table 3.3. Ridge cubic Bezier control points from [4].

Bezier point	Description	X (mm)	Y(mm)
P0	Start point	3	0.5
P1	Tangent line to start	205	0.5
P2	Tangent line to end	175.51	68.01
P3	End point	175.5	68

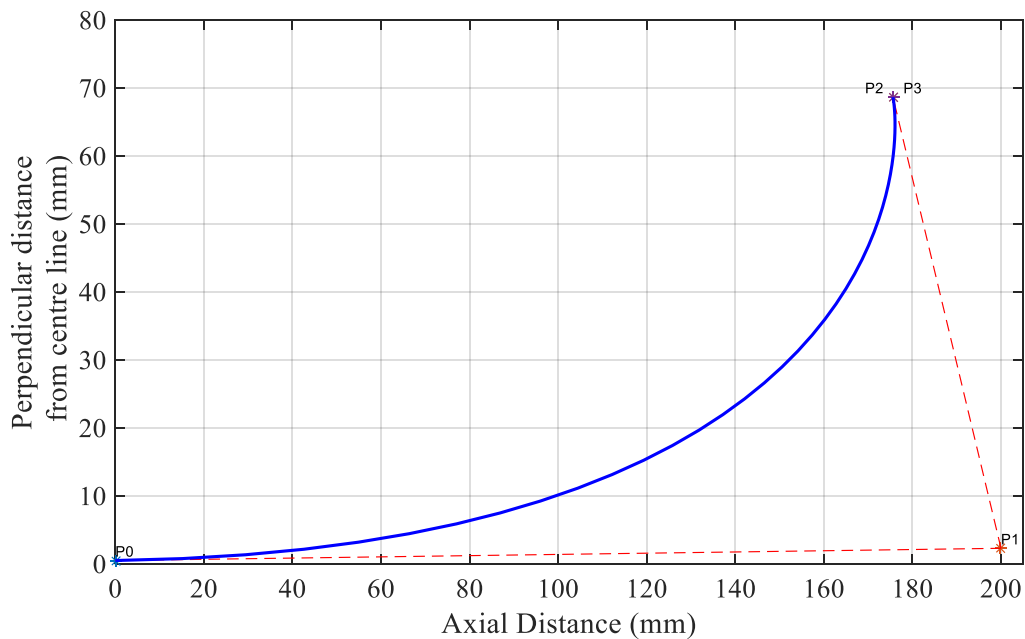


Figure 3.3. Ridge profile (blue) implemented with Bezier control points (red).

3.3 SIMULATED RESULTS OF NUMERICAL MODEL BASED ON [4]

The purpose of this section is to develop the numerical model of the DRGH antenna and compare the results to the measured DRGH antenna. This is done to validate the model as a correct representation of the manufactured prototype antenna. The model generated is also used as the starting point for further investigation. The DRGH antenna from [4] was obtained and measured at the start of the investigation and these results are used throughout this section.

The final model of the DRGH antenna is seen in Figure 3.4. The outline dimensions are presented in Table 3.4. These values, together with the previous tables, were utilised to generate the numerical model of the DRGH antenna. FEKO was used to simulate the DRGH antenna for the purpose of determining the s-parameters, gain, and far-field results at specific frequencies.

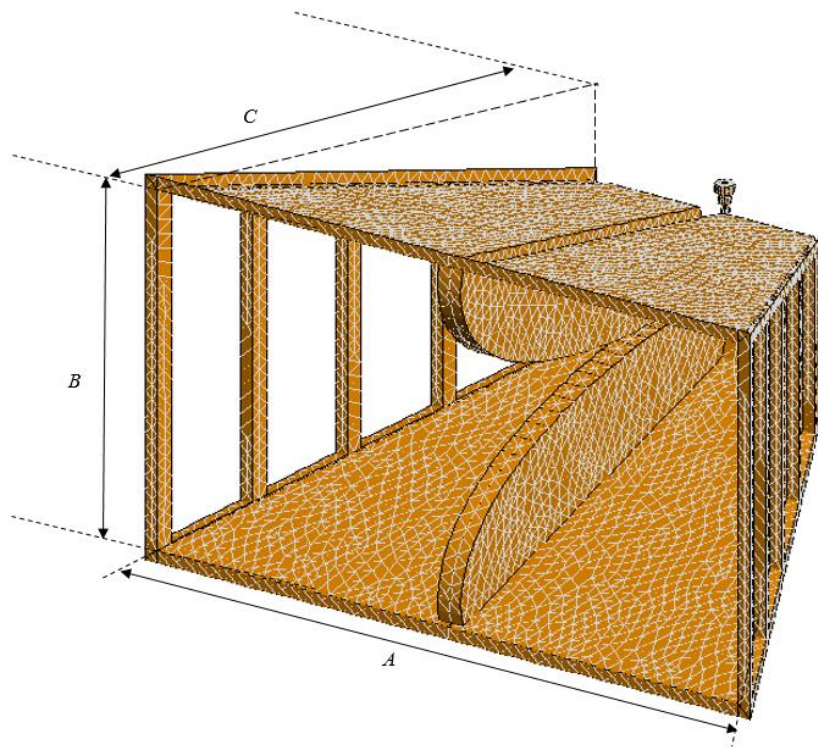
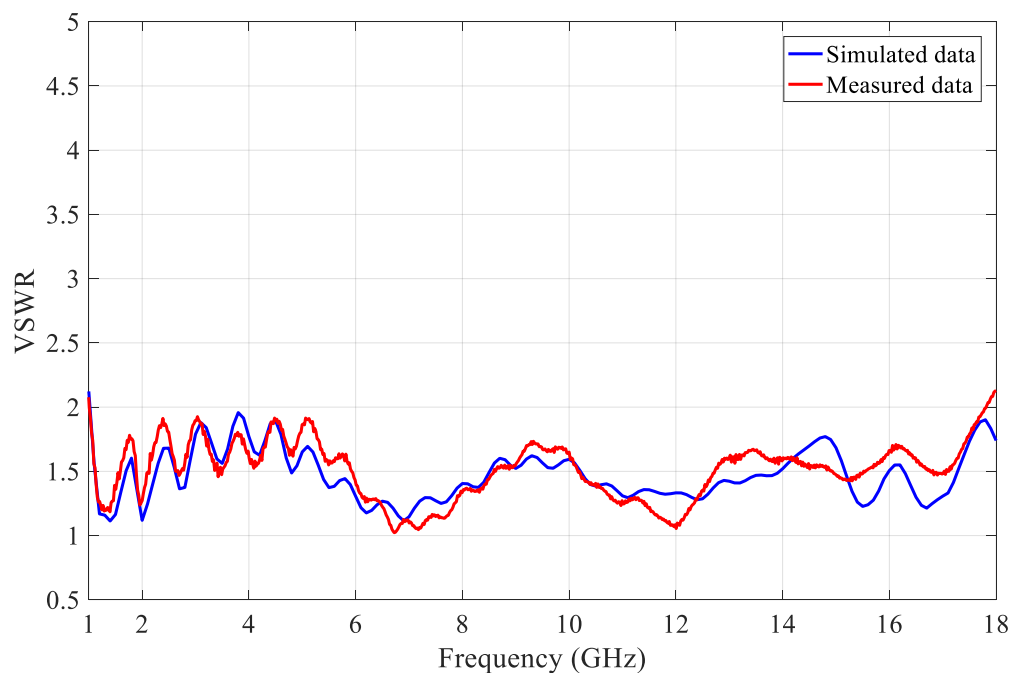


Figure 3.4. DRGH Antenna perspective view in FEKO.

Table 3.4. DRGH antenna dimensions obtained from [4].

Figure 3.5 reference	Description	Dimension (mm)
<i>A</i>	Aperture Width	242
<i>B</i>	Aperture Height	136
<i>C</i>	Flared section axial length	168.8

The simulation results presented in Figure 3.5 compare relatively well with the measured DRGH antenna results. The VSWR remains below 2 over the entire frequency range. The boresight gain performance shown in Figure 3.6 also aligns well, ranging from 7 dBi to 16 dBi. The only deviation is seen at 15 GHz and 18 GHz where the simulated data is 1 dBi higher than the measured data.

**Figure 3.5.** VSWR results of DRGH antenna.

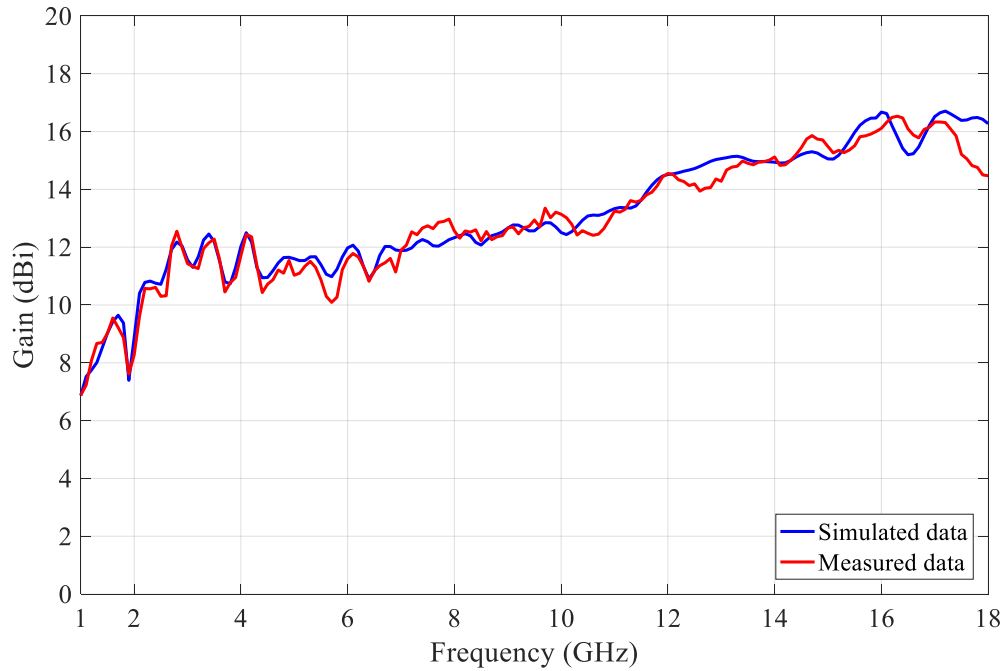


Figure 3.6. Boresight gain result of the DRGH antenna.

When comparing the simulated radiation patterns in Figures 3.7 to 3.15 for 1, 6, 12 and 18 GHz with the measured results, small differences are observed. The main outline of the H-plane and E-plane patterns follow the measured DRGH antennas performance. The measured data compares well with the simulated data, with only a small ripple added to the measured performance. The addition of the ripple can be explained by the simulation model only considers ideal conditions whereas the real world measurement has external factors effecting the performance. The sidelobe levels are below -15 dB over all the frequencies.

The results obtained match up with the measured data; therefore, the numerical model can be used with confidence for the further investigation in this dissertation.

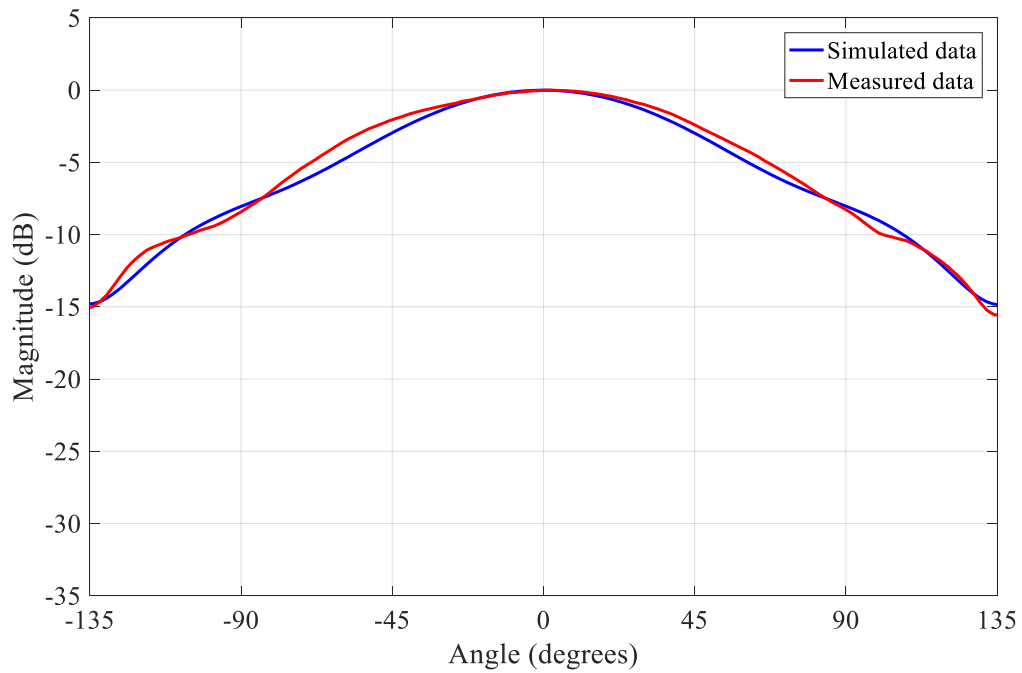


Figure 3.7. Radiation E-plane pattern results at 1 GHz of the DRGH antenna.

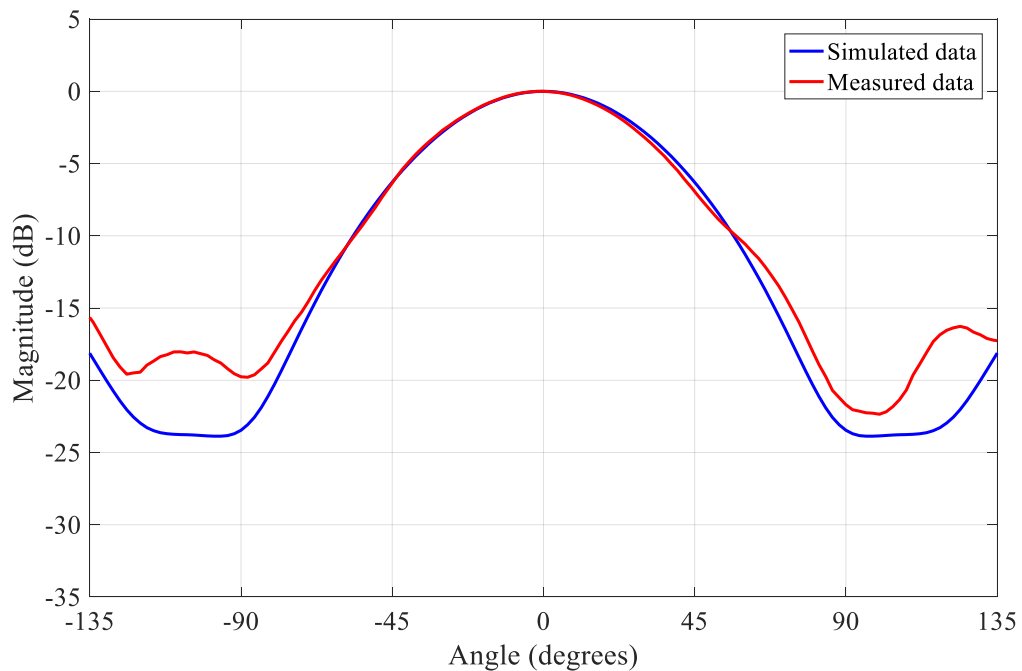


Figure 3.8. Radiation H-plane pattern results at 1 GHz of the DRGH antenna.

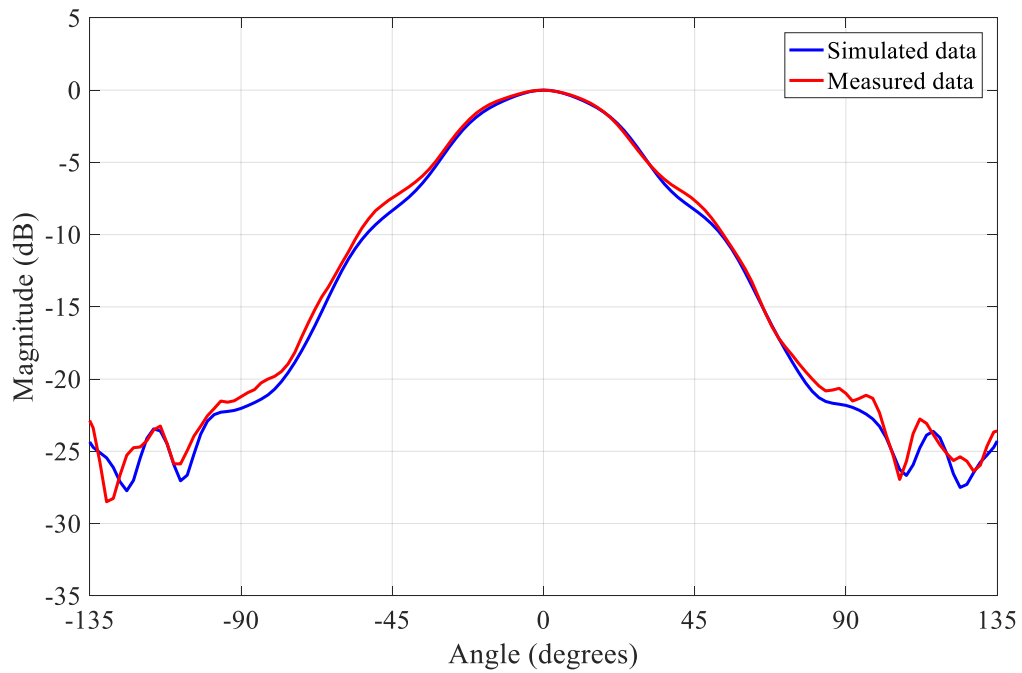


Figure 3.9. Radiation E-plane pattern results at 6 GHz of the DRGH antenna.

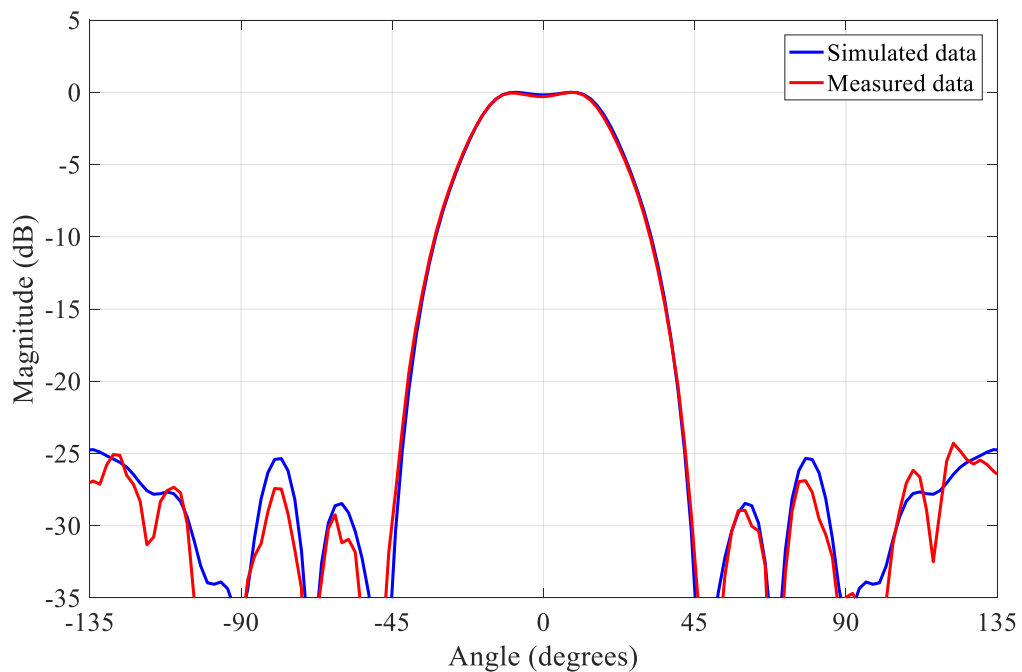


Figure 3.10. Radiation H-plane pattern results at 6 GHz of the DRGH antenna.

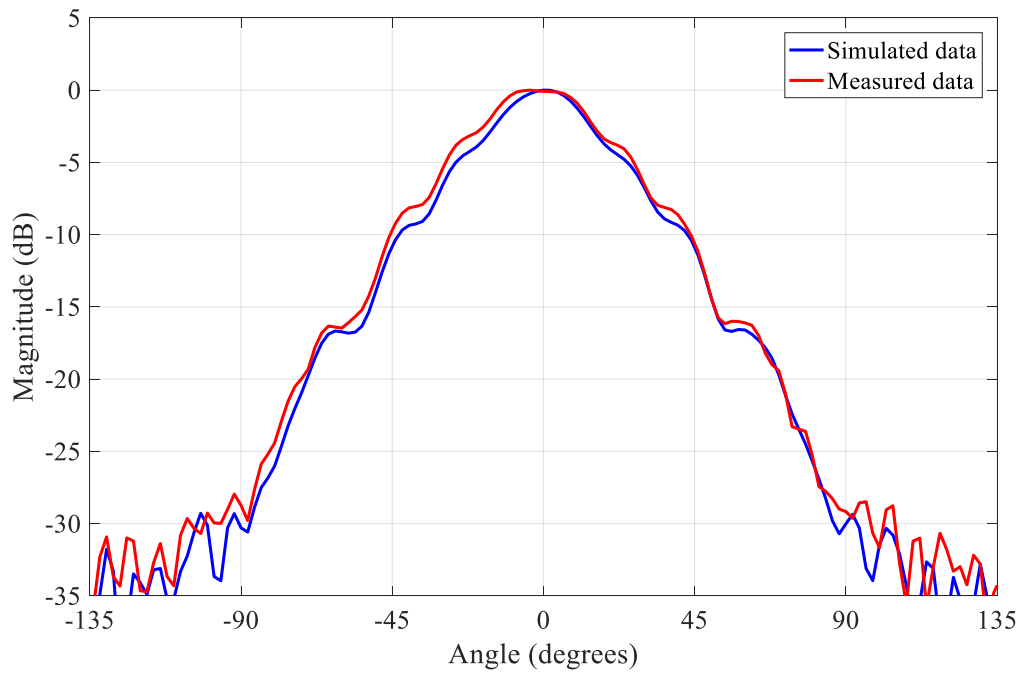


Figure 3.11. Radiation E-plane pattern result at 12 GHz of the DRGH antenna.

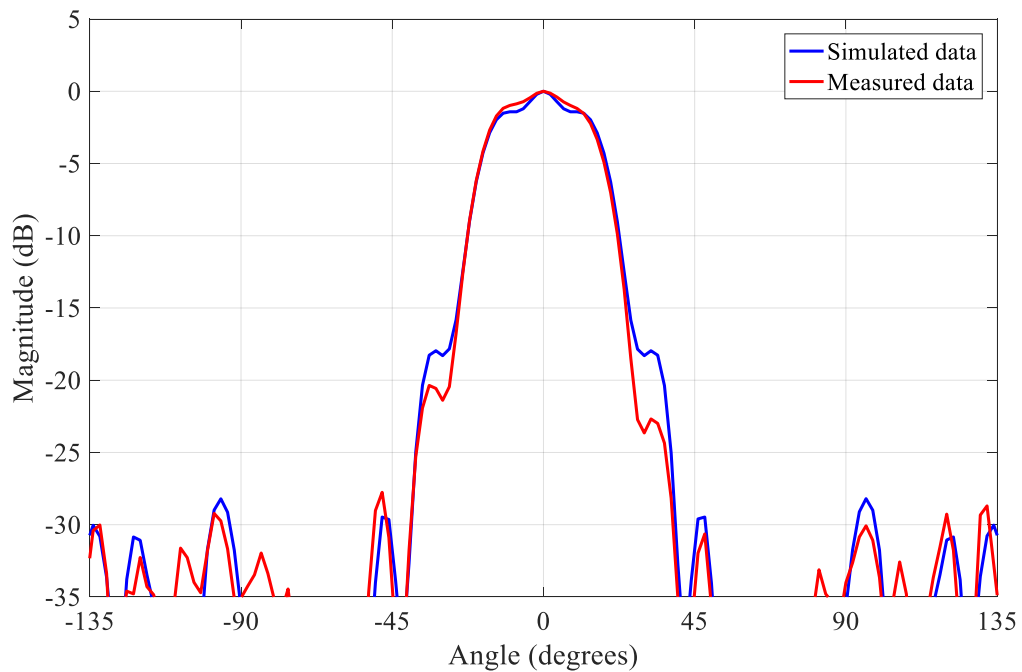


Figure 3.12. Radiation H-plane pattern results at 12 GHz of the DRGH antenna.

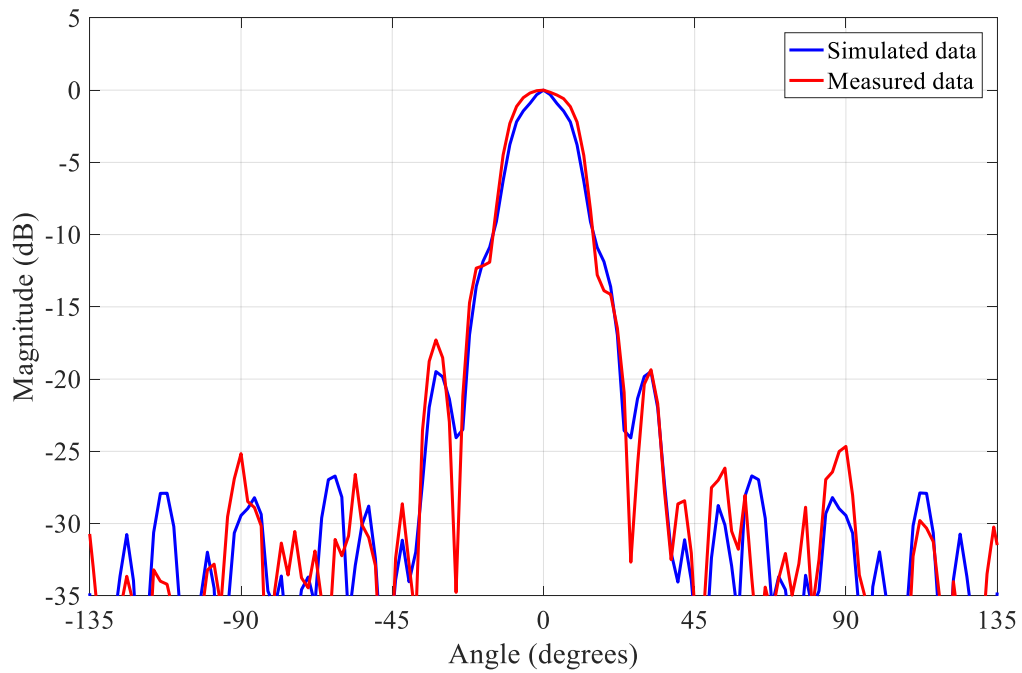


Figure 3.13. Radiation E-plane pattern result at 18 GHz of the DRGH antenna.

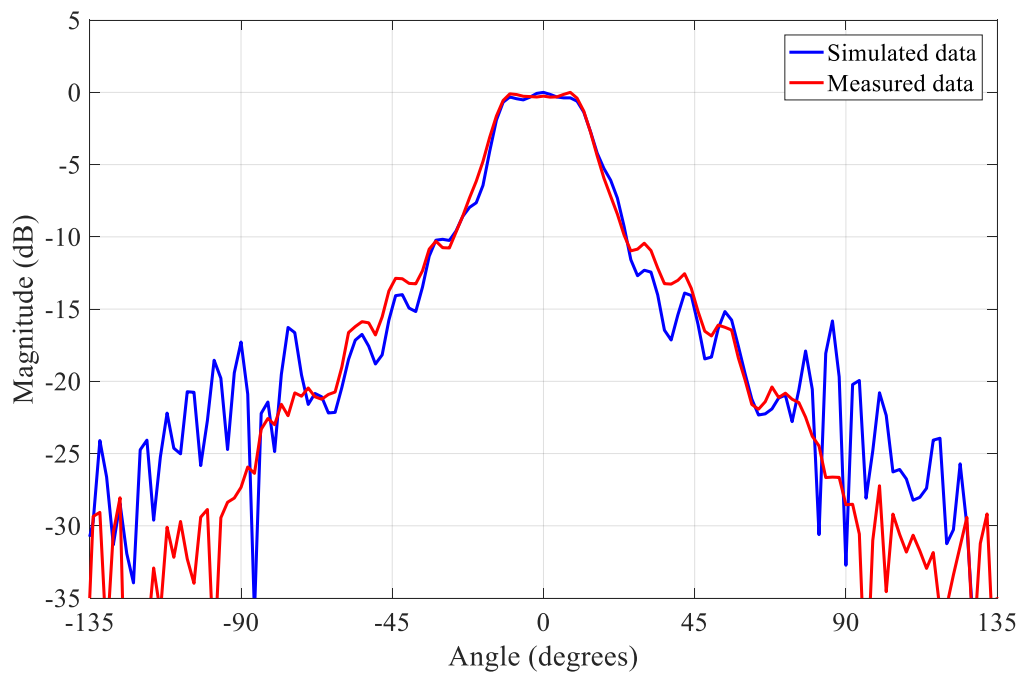


Figure 3.14. Radiation H-plane pattern result at 18 GHz of the DRGH antenna.

3.4 SUMMARY

The DRGH antenna in [4] was identified as the starting point for this study and modelled numerically using the software package FEKO. Section 3.2 detailed the development of the numerical model by dividing the DRGH antenna into different sections and briefly discussing each of them with the focus on the design from [4]. In Section 3.3 the numerical model was simulated and compared to the measured DRGH antenna.

After comparing the results obtained, it is possible to conclude that the numerical model of the DRGH antenna will act as an adequate starting point for further investigation and improvement in this dissertation. The numerical model corresponded well with the measured DRGH antennas results with slight deviations; less than 1 dBi.

The following chapter focusses on the ridge improvement.

CHAPTER 4 RIDGE IMPROVEMENT

4.1 INTRODUCTION

The flared section of the conventional pyramidal horn is made up of E and H plane flared sidewalls. The DRGH antenna is an improvement of the conventional horn with the ridges inside the ridged waveguide continuing gradually across the flares out until the aperture. Most published papers sketch the flared section of the DRGH antenna as an impedance transformer which is normally designed to gradually change the characteristic wave mode impedance of the ridged waveguide to the impedance of free space.

In Section 4.2, the thick sidewalls manufactured and implemented into the numerical model in Chapter 3 are investigated. Thinner sidewalls are simulated and the boresight gain of the two different sidewalls are compared.

As mentioned in the previous chapters the aperture dimensions of a 1-18 GHz DRGH antenna are fixed for EMC/EMI testing facilities. The ridges were identified as the structural part to improve for this investigation. Different methods identified in the literature study in Chapter 2 are applied in this section, mainly focusing on the antennas gain and beamwidth performance. The first method focuses on the ridge profile and the second on the gradual taper of the characteristic wave mode impedance by changing the ridge width.

The standard exponential curve has been implemented into most DRGH antennas to date with little research done into improvement of the ridges profile. The DRGH antenna selected from [4] as the starting point for this investigation has been simulated and a numerical model has been created in Chapter 3. A Bezier curve was used as the ridge profile DRGH antenna

from [4] that showed improved results compared to the conventional exponential profile. The gain of the DRGH antenna is a crucial parameter that is affected by the profile of ridges. It also effects smooth transfer of the characteristic wave mode impedance. The VSWR and boresight gain are investigated and used to determine the ridge profile that delivers the most improved performance by implementing three different profiles into the DRGH antenna. This is the first method investigated and shown in Section 4.3.

Section 4.4 investigates the characteristic wave mode impedance of the flared section across the DRGH antennas axial length, this is the second method investigated. The ridged waveguides characteristic wave mode impedance depends on the dimensions of the width, height and the gap between the ridges. The axial length, aperture dimensions and coaxial to waveguide transitions sections are kept fixed during this chapter which leaves the ridge width as the only variable that can change the impedance transition profile. This finding is exploited by realising three different impedance tapers into the flared section.

The numerical model in Chapter 3 of the DRGH antenna presents a very high beamwidth at the lower frequencies with a downward slope until levelling out at the upper frequencies. The typical gain form of a DRGH antenna is that starts low at the bottom frequency and progresses higher to the upper frequencies. The relationship between the gain of an antenna and the beamwidth is a crucial property to understand for this investigation. The more constant the gain of an antenna is the more likely the beamwidth will also become relatively more constant. The theory to obtain a relatively more constant beamwidth performance is by increasing the gain at the lower frequency ranges.

A hypothesis from basic antenna theory [33], is that by enlarging the radiating area of an antenna causes the gain to increase, that will inherently lower the beamwidth at the specific frequencies. This hypothesis is investigated in Section 4.5 by comparing the near field results at different frequencies. The conventional ridges containing a constant width across the flared section and the improved ridges, with linear tapered ridges are compared. Section 4.6 consists of a summary of the findings made during the chapter.

4.2 SIDEWALL IMPROVEMENT

The thick sidewalls presented in the prototype antenna from [4] were removed and replaced with thin PCB (printed circuit board) sidewalls in FEKO. This effected the gain significantly, providing a more stable slope in the gain and also higher result in the lower frequency range. This result is presented in Figure 4.1. The thinner sidewalls show a smoother result with a slightly higher gain at the lower frequencies and less dips in the gain at the higher frequencies. The thin sidewalls are implemented into the numerical model and applied from this point on for the further investigation.

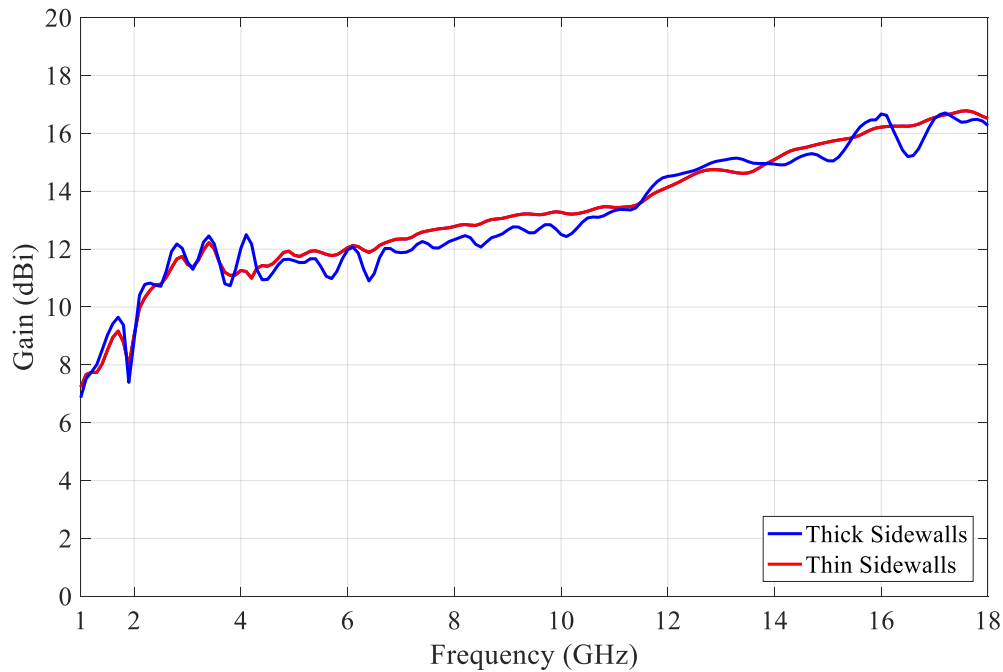


Figure 4.1. Boresight gain of the DRGH antenna.

4.3 RIDGE PROFILE INVESTIGATION

The purpose of changing the ridge profile is to improve the gain of the DRGH antenna, especially in the lower frequency band, which will inherently cause the gain to become more constant and thereby also change the beamwidth to follow a relatively more constant response. Three different profiles have been selected to investigate as possible solutions to

improve the numerical model in Chapter 3. According to the MIL standards [6] the aperture size of the DRGH antenna is kept fixed as 242×136 mm respectively. The length of the flared section is 175.5 mm [4].

The three profiles selected for this study consisted of the cubic Bézier profile, based on the design from [4], the standard exponential profile found in [10] and the elliptical profile that showed promising results in TEM horns [8]. The exponential curve is utilised on the DRGH antenna over the years as being the standard mathematical profile for the ridge profile. Malherbe published papers concerning the constant response of the beamwidth of a TEM horn antenna wherein [8] an elliptical flared profile was introduced, and in [9] an elliptical profile was implemented for the cross-section to create an optimal characteristic wave mode impedance transformer. A limited number of studies were found to use the cubic Bezier profile in DRGH antennas.

In Section 4.3.1 the cubic Bezier profile is discussed with the mathematical equations presented. This is done for the exponential profile in Section 4.3.2 and the elliptical profile in Section 4.3.3. The values used to determine each profile are given in Table 3.1 and 3.4 within Chapter 3. Section 4.3.4 compares all three ridge profiles.

4.3.1 The cubic Bézier profile

The exact approximation points from [4] are used to create the cubic Bézier profile. The equations shown below are used to obtain the x and y coordinates, along with the control points. Figure 4.2, displays the profile implemented in the flared section across the axial length of the DRGH antenna.

$$x = x_{P_0}(1-t)^3 + 3x_{P_1}(1-t)^2 + 3x_{P_2}(1-t)t^2 + x_{P_3}t^3, \quad t \in [0,1] \quad (4.1)$$

$$y = y_{P_0}(1-t)^3 + 3y_{P_1}(1-t)^2 + 3y_{P_2}(1-t)t^2 + y_{P_3}t^3, \quad t \in [0,1] \quad (4.2)$$

The control points are represented by,

$$x_{P_0} \text{ to } x_{P_3} \text{ and } z_{P_0} \text{ to } z_{P_3}.$$

They are used to generate the fixed profile across the axial length of the fared section. The control point values are:

$$(x_{P_0}, y_{P_0}) = (3, 0.5)$$

$$(x_{P_1}, y_{P_1}) = (205, 0.5)$$

$$(x_{P_2}, y_{P_2}) = (175.51, 68.01)$$

$$(x_{P_3}, y_{P_3}) = (175.5, 68)$$

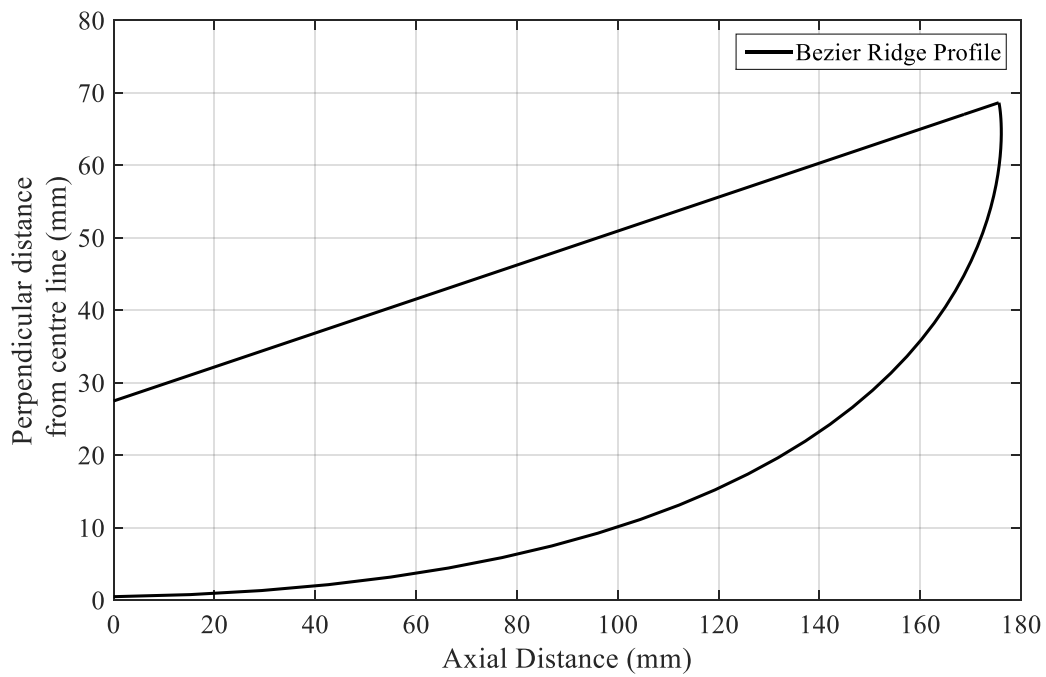


Figure 4.2. Bezier ridge profile.

4.3.2 The Exponential profile

The mathematical equation of the exponential profile is obtained from [16], and calculated for the axial length of the flared section of the DRGH antenna. The calculated exponential profile is presented in Figure 4.3.

$$y(x) = e^{mx+c} \quad (4.3)$$

Equations (4.4) and (4.5) represent m and c respectively, where half the DRGH antennas aperture height is equal to y and the axial length is equal to x .

$$m = \frac{\log(y_{end}) - \log(y_{start})}{x_{end} - x_{start}} \quad (4.4)$$

With

$$c = (\log(y_{start}) - x_{start} \times m) \quad (4.5)$$

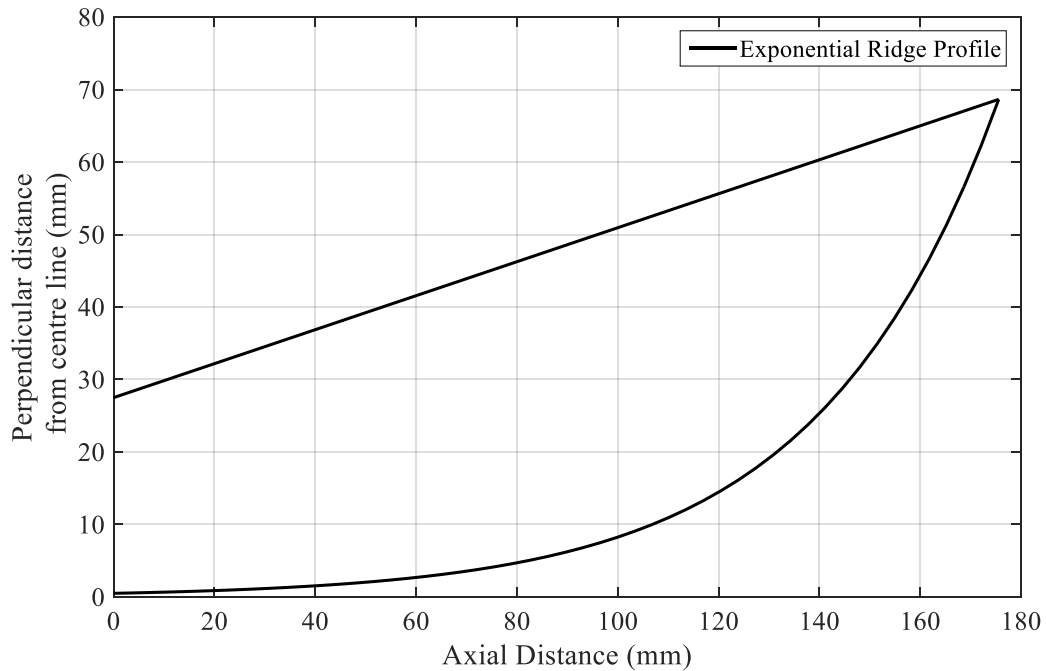


Figure 4.3. Exponential ridge profile.

4.3.3 The elliptical profile

A quarter section of an ellipse is applied into the ridges to implement an elliptical profile. The mathematical equation is as follows [8]:

$$\frac{x^2}{x_{end}^2} + \frac{y^2}{y_{end}^2} = 1 \quad (4.6)$$

The variables are represented by the same values as stated in the exponential profile. A cut section of the flared part of the DRGH antenna displayed in Figure 4.4, with the inserted elliptical profile that has been sliced into the specific section desired for the curve.

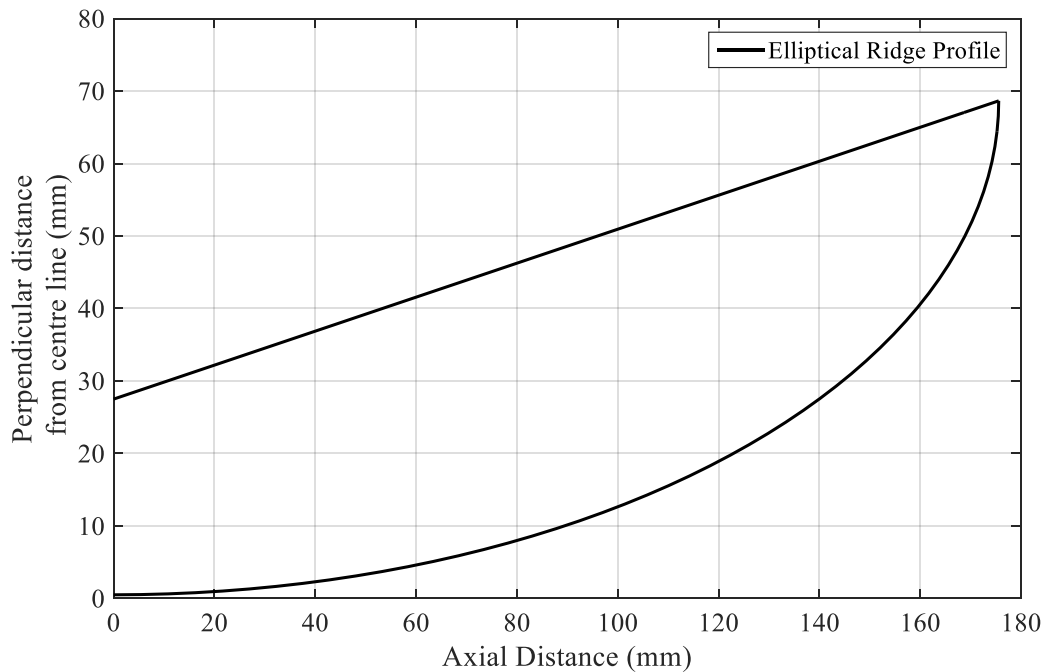


Figure 4.4. Elliptical ridge profile.

4.3.4 Profile comparison

The three profiles are presented in Figure 4.5 within the confined fixed DRGH antenna dimensions from the numerical model in Chapter 3.

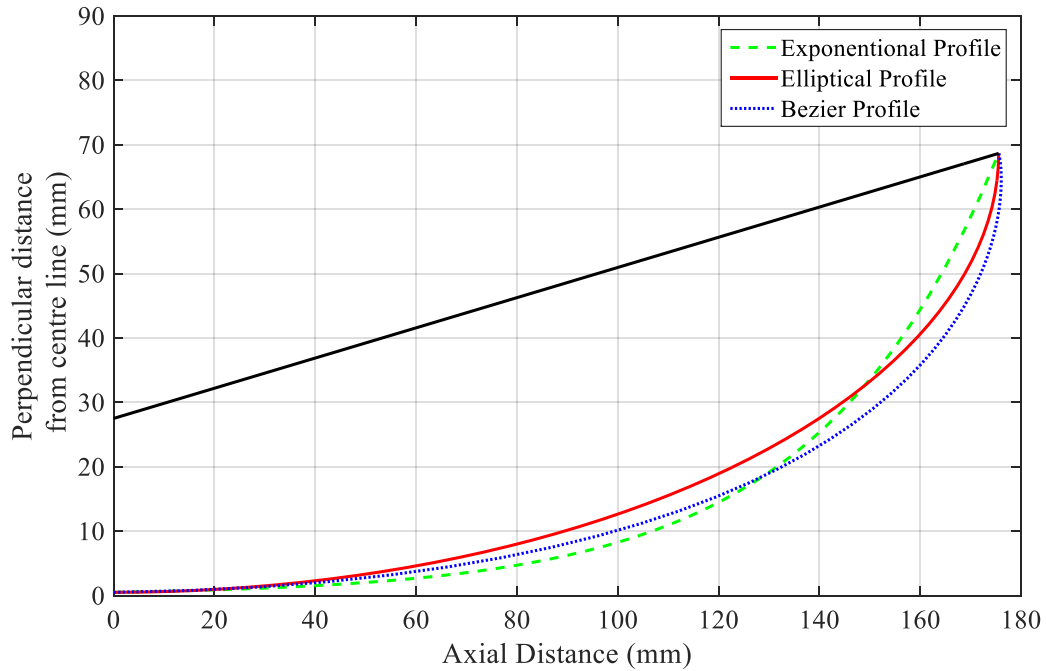


Figure 4.5. Different ridge profile configurations.

4.3.5 Simulation results

The numerical model in Chapter 3 is used. The DRGH antenna is simulated in FEKO with the different implemented ridge profiles. Figure 4.6 compares the VSWR performance of the specified profiles. All three of the profiles display VSWR values below 2 over the frequency band of 1.5 to 18 GHz.

The VSWR only changes slightly alongside the change of the ridge profile as expected. The ridge profile affects the antennas gain which is why the gain is utilised as the indicator to determine the ridge profile that delivers the most improve performance. The boresight gain, 3 dB and 10 dB beamwidths of the three different ridge profiles can be seen in the Figures 4.7 to 4.9.

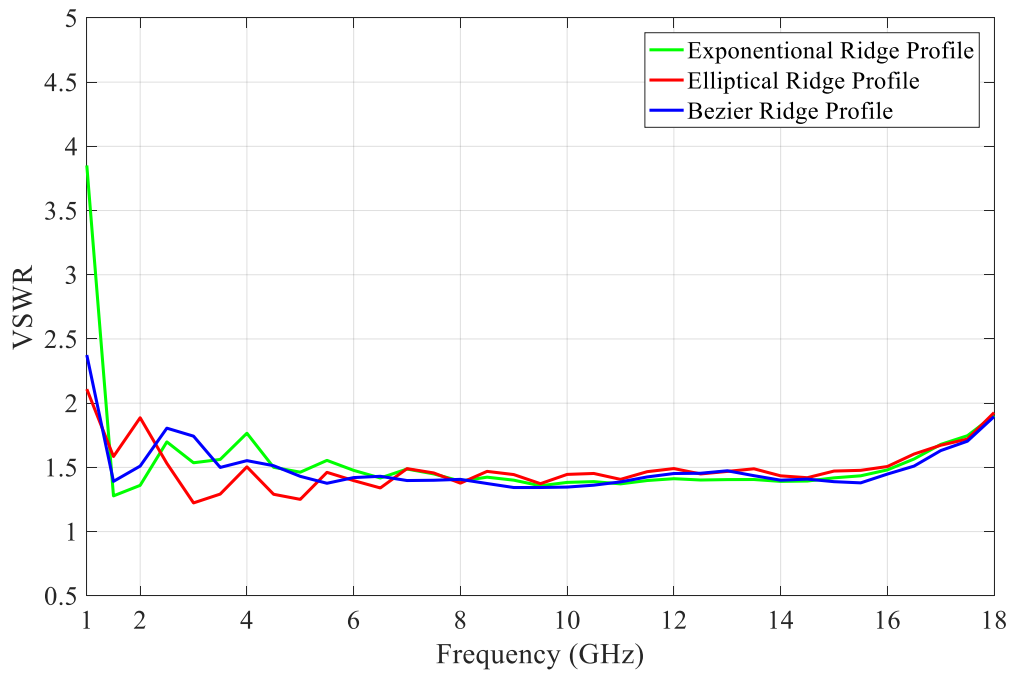


Figure 4.6. VSWR of the DRGH antenna with the three different ridge profiles.

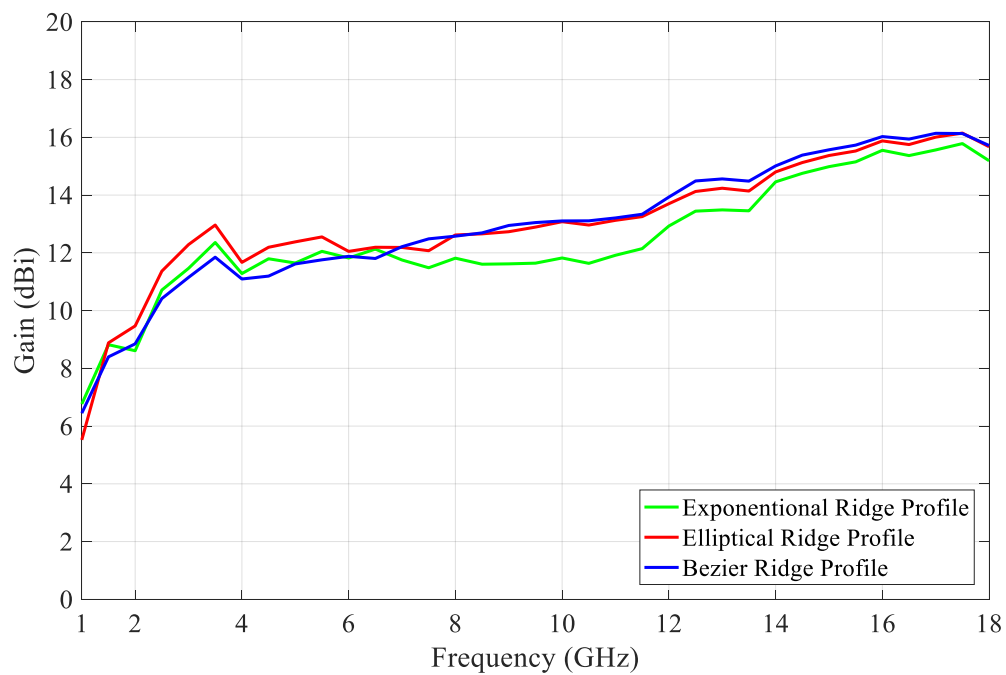


Figure 4.7. Boresight gain of the DRGH antenna with the three different ridge profiles.

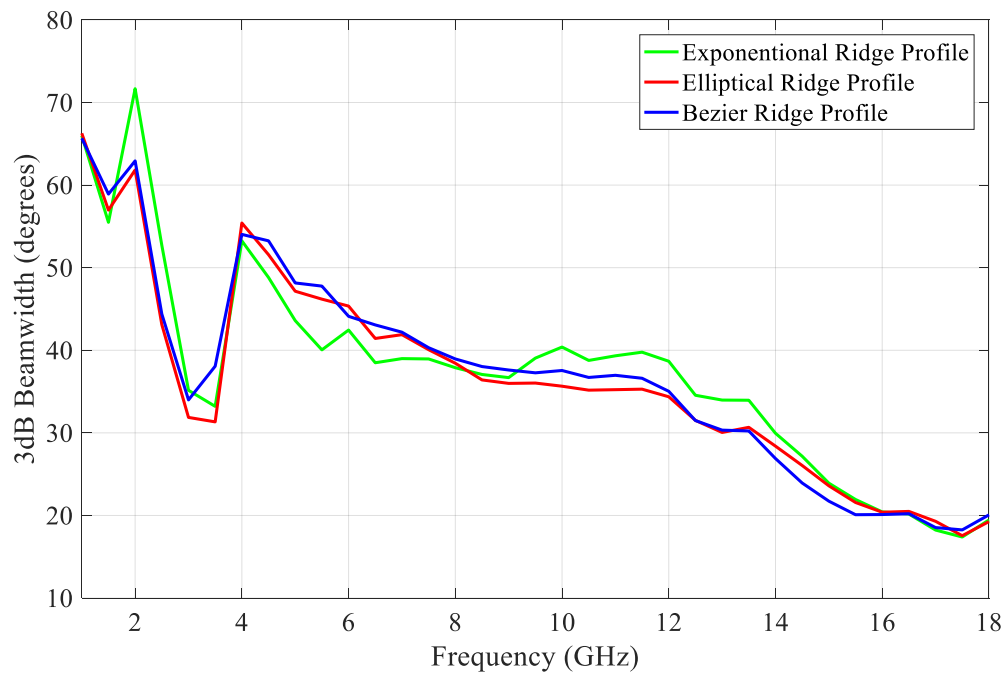


Figure 4.8. 3 dB Beamwidth of DRGH antenna with the three different ridge profiles.

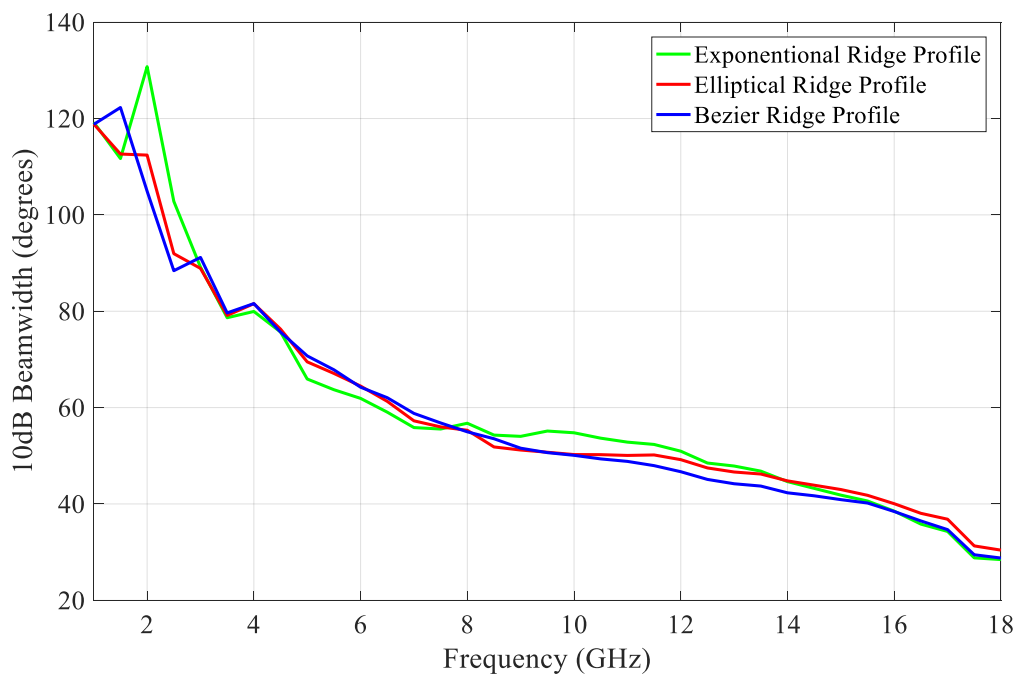


Figure 4.9. 10 dB Beamwidth of the DRGH antenna with the three different ridge profiles.

The elliptical profile displays the most improved performance according to the results investigated above, focusing on the boresight gain. The lower frequency gain increases and the higher frequencies gain remain relatively the same. This result did not reflect to the beamwidth result. Further investigation is done by change the profile of the ridges to an elliptical profile.

4.4 RIDGE WIDTH TAPER INVESTIGATION

To ensure that the signals transmit effectively from the DRG into free space the gradual impedance transition of the DRGH antenna must be improved by investigating the flared section. In this case the characteristic wave mode impedance of the aperture is used as the matching impedance desired at the end of the axial length. Therefore the transformation will be applied across the flared section in terms of the characteristic wave mode impedance of the start and end of the axial length. The conventional DRG is given in Figure 3.2, with the mathematical equations given in Chapter 3 to calculate the TE_{n0} modes cut-off wavelength. The box dimensions in Chapter 3 fixes some of the DRG variables. The cut-off wavelength (λ_c) calculated in Chapter 3 based on the findings in [10] is used to determine the TE_{10} modes DRG characteristic wave mode impedance. An approximation at the infinite frequency from [3] is used with the following equations,

$$Z_{0\infty} = 1 / \left(\sqrt{\frac{\epsilon}{u}} \frac{\lambda_c}{\pi d} [L_1 + L_2] \right) \quad (4.7)$$

with

$$L_1 = \frac{2d}{\lambda_c} \cos^2\left(\frac{\pi a}{\lambda_c}\right) \ln \csc\left(\frac{\pi d}{2b}\right) + \frac{\pi s}{2\lambda_c} + \frac{1}{4} \sin\left(\frac{2\pi s}{\lambda_c}\right) \quad (4.8)$$

and

$$L_2 = \frac{d}{b} \frac{\cos^2\left(\frac{\pi s}{\lambda_c}\right)}{\sin\left(\frac{\pi(a-s)}{\lambda_c}\right)} \left[\frac{\pi(a-s)}{2\lambda_c} - \frac{1}{4} \sin\left(\frac{\pi(a-s)}{\lambda_c}\right) \right] \quad (4.9)$$

The dominant TE₁₀ characteristic wave mode impedance is given as,

$$Z_{TE} = \frac{Z_{0\infty}}{\sqrt{1 - \left(\frac{f'_c}{f}\right)^2}} \quad (4.10)$$

Equations (4.7) to (4.14) were implemented in a Matlab program to determine the start, and end characteristic wave mode impedance of the DRGH antennas flared section. The results are given in Table 4.1. To calculate the impedance taper across the flared section the axial length of the DRGH antenna is divided into different section cuts. Thereafter the characteristic wave mode impedance of each section is calculated at infinite frequency. The start and end impedances of the flared section are fixed thought out the investigation and only the sections in between were effected.

Table 4.1. Flared section fixed calculated characteristic wave mode impedance.

Characteristic Wave Mode Impedance ($Z_{0\infty}$) at the beginning	32.125 Ω
Characteristic Wave Mode Impedance ($Z_{0\infty}$) at the end	434.481 Ω

The characteristic wave mode impedance is calculated for the n=52 number of DRG sections across the axial length of the flared section. Figure 4.11 shows the characteristic wave mode impedance result for the three different ridge profiles from Section 4.3. The elliptical profile presents an impedance transition profile slightly different to the other two profiles. The result is inconclusive and the elliptical profile remains the chosen ridge between the three due to its effect on the gain at the lower frequencies and is kept constant in the study going forward.

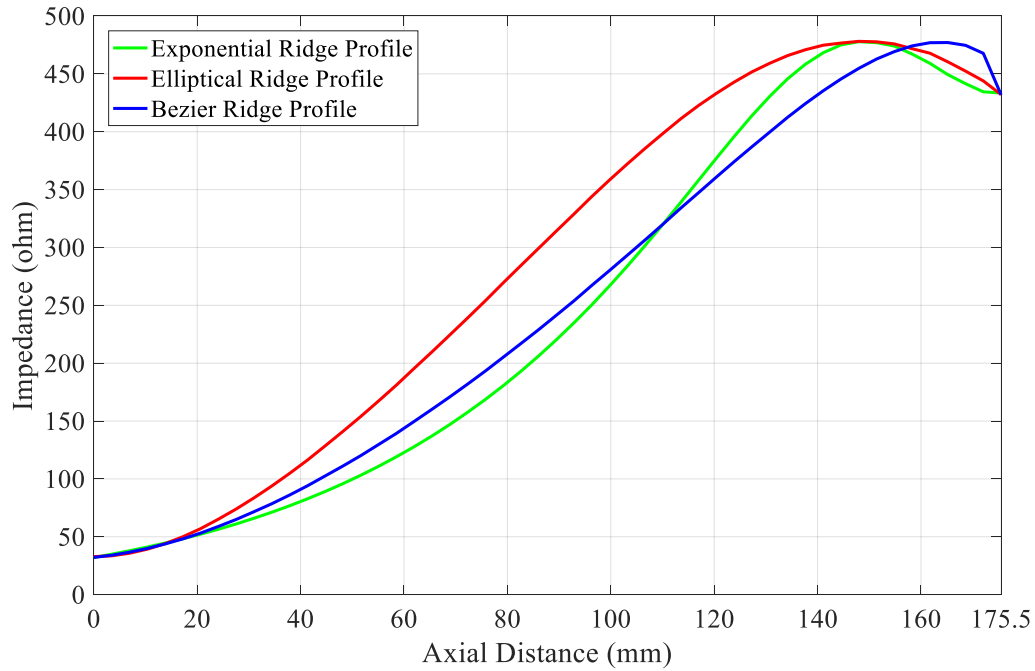


Figure 4.11. Impedance transition of the three different ridge profiles.

It was decided to investigate the characteristic wave mode impedance transfer by realising a specific impedance transition into the axial length of the DRGH antenna. Looking at the different variables used to derive the characteristic wave mode impedance of the different ridged waveguide sections there are four variables, namely the aperture height (a) and width (b), the ridge separation (d) and the ridge thickness (s). The aperture height and width are fixed values obtained from the Chapter 3, whereas the ridge separation is determined by the ridge profile, determined in Section 4.3 as the elliptical profile. This leaves the ridge width as the only unfixed variable. A Matlab code was written to calculate the ridge width along the axial length. This was done for each n section in order to realise a specific impedance transition across the axial length.

Three different transition profiles were selected and displayed in Figure 4.12 where they were calculated for the fixed starting and ending impedance values. The calculations for each transition are shown in the sections below, based on how they fit in between the fixed starting and ending impedance values.

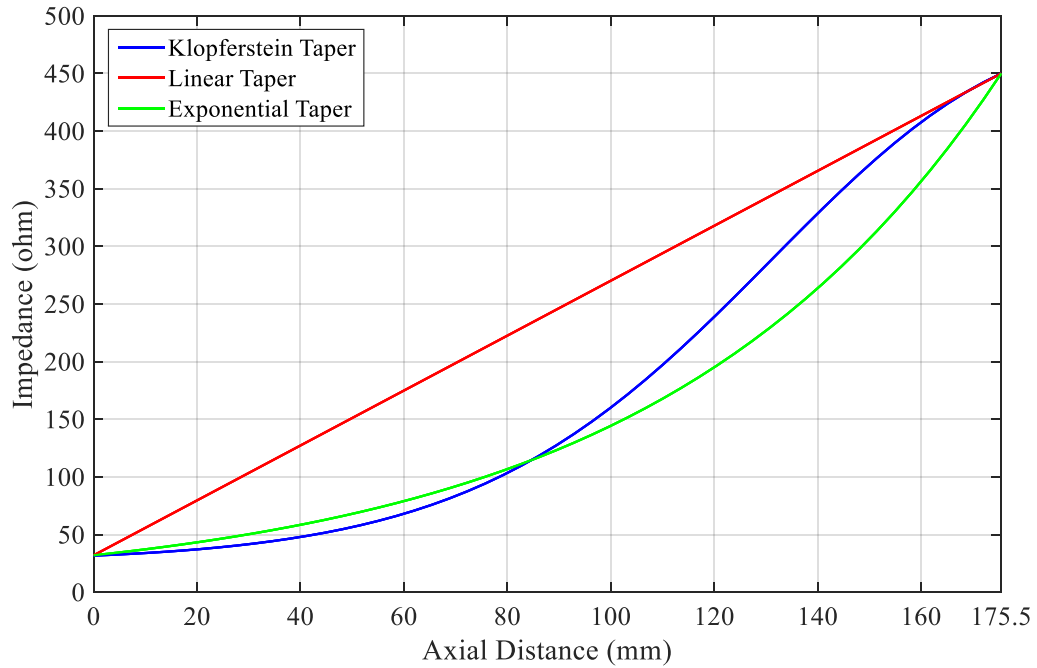


Figure 4.12. Comparison of different impedance taper profiles.

4.4.1 The Linear Taper

The linear impedance taper is calculated using the traditional formula.

$$y = mx + c \quad (4.11)$$

Calculating the slope of the line is as follows:

$$m = \frac{\Delta y}{\Delta x} \quad (4.12)$$

4.4.2 The Exponential Taper

The exponential taper is calculated exploiting using the same mathematical formulas seen in Section 4.3.2, with the starting and ending tapers changing and the aperture offset.

$$y(x) = e^{mx+c} \quad (4.13)$$

The following equations represent m , where the end aperture impedance is equal to y_{end} and the flare length equal to x_{end} .

$$m = \frac{\log(y_{end}) - \log(y_{start})}{x_{end} - x_{start}} \quad (4.14)$$

With

$$c = (\log(y_{start}) - x_{start} \times m) \quad (4.15)$$

4.4.3 The Klopfenstein Taper

The Klopfenstein taper is known as one of the impedance tapers that can be utilised to achieve a minimum reflection coefficient in the passband. In this application of the characteristic wave mode impedance transition of the axial length, the Klopfenstein taper is calculated of a unit length and then divided into a specific amount of sections, for a certain ripple. Firstly the reflection coefficient is calculate of the load, where the load is equivalent to the end characteristic wave mode impedance of the axial length. The in-between characteristic wave mode impedance values are calculated which then taper the start and end values. The equations to calculate the Klopfenstein impedance taper are given below, firstly the logarithm of the characteristic impedance variation [33]:

$$\ln Z(z) = \frac{1}{2} \ln Z_0 Z_L + \frac{\Gamma_0}{\cosh A} A^2 \phi\left(\frac{2z}{L} - 1, A\right), \quad \text{for } 0 \leq z \leq L, \quad (4.16)$$

with,

$$\phi(-x, A) = -\phi(x, A) = \int_0^x \frac{I_1(A\sqrt{1-y^2})}{A\sqrt{1-y^2}} dy, \quad \text{for } |x| \leq 1 \quad (4.17)$$

The modified Bessel function is defined as $I_1(x)$, with specific conditions defined below:

$$\begin{aligned} \phi(0, A) &= 0 \\ \phi(x, 0) &= \frac{x}{2} \end{aligned} \quad (4.18)$$

$$\phi(1, A) = \frac{\cosh A - 1}{A^2}$$

The reflection coefficient is determined by:

$$\Gamma(\theta) = \Gamma_0 e^{-j\beta L \frac{\cos\sqrt{(BL)^2 - A^2}}{\cosh A}}, \quad \text{for } \beta L > A \quad (4.19)$$

For the following conditions, $\beta L < A$, the $\cos\sqrt{(BL)^2 - A^2}$ term becomes $\cosh\sqrt{(BL)^2 - A^2}$ and then the reflection coefficient:

$$\Gamma_0 = \frac{Z_L - Z_0}{Z_L + Z_0} \cong \frac{1}{2} \ln\left(\frac{Z_L}{Z_0}\right) \quad (4.20)$$

These values are then used in a numerical integration in Matlab to calculate the characteristic wave mode impedance as a function of the distance along the flared section, which is only valid when $Z_{load} > Z_0$. The ridge width is calculated for each section over the axial length and shown in Figure 4.13 for the three different impedance tapers. Figure 4.14 displays the ridges constructed in FEKO with the calculated ridge widths for each taper. It is evident that by defining the impedance taper causes discontinuities in the ridge width profile. These discontinuities are not ideal and can have a negative impact on the overall performance of the DRGH antenna.

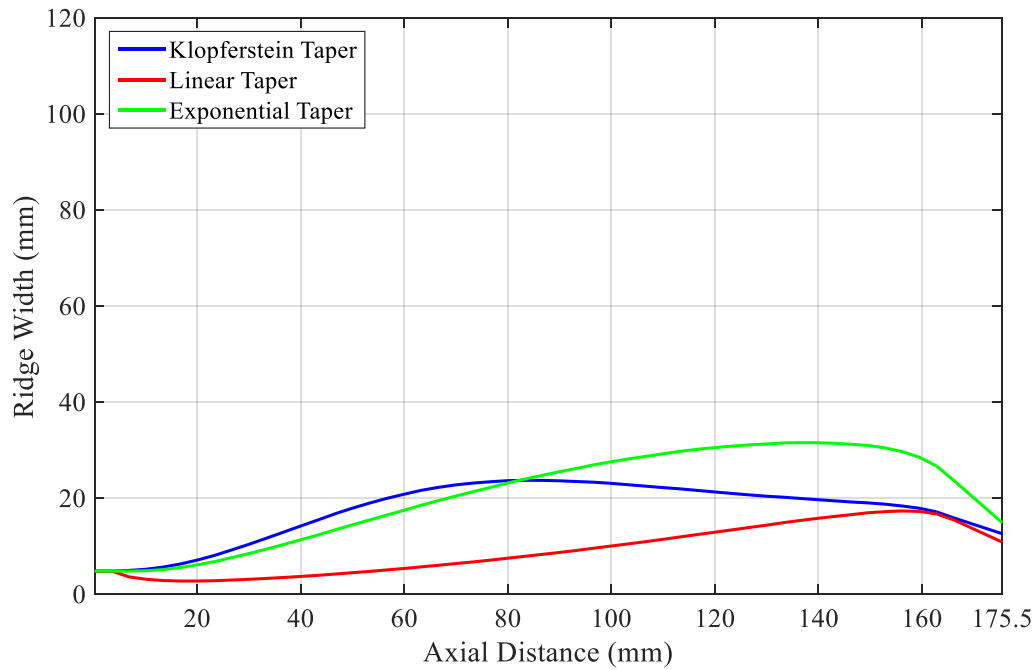


Figure 4.13. Different ridge width profiles for the different tapers.

The boresight gain result obtained for the three different tapers chosen are shown in Figure 4.15. The discontinuities in the ridge widths calculated across the axial length clearly effect the performance of the DRGH antenna and creates sharp spikes in the boresight gain. This is not ideal and will influence the beamwidth performance of the DRGH antenna very badly.

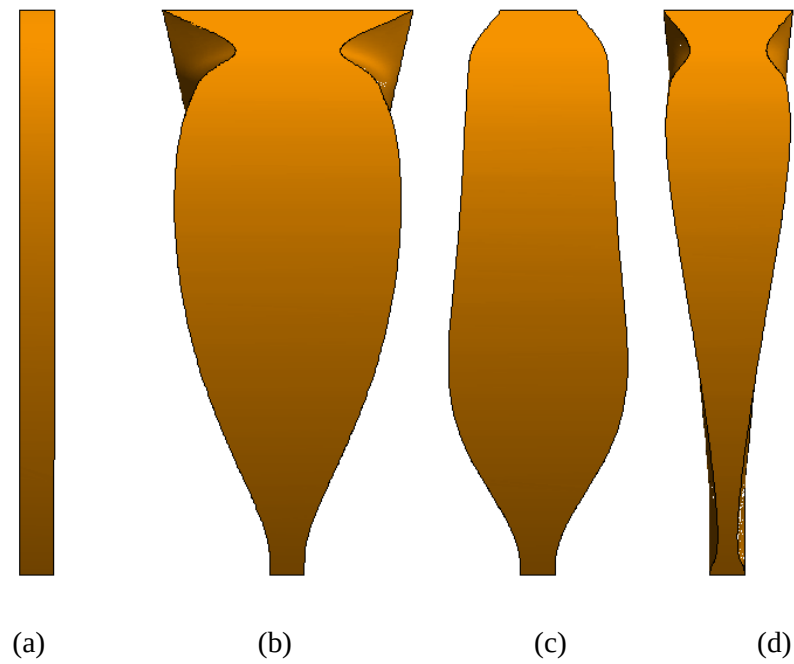


Figure 4.14. Ridge width profiles implemented in FEKO.

(a) Constant width. (b) Exponential taper. (c) Klopfenstein taper. (d) Linear taper.

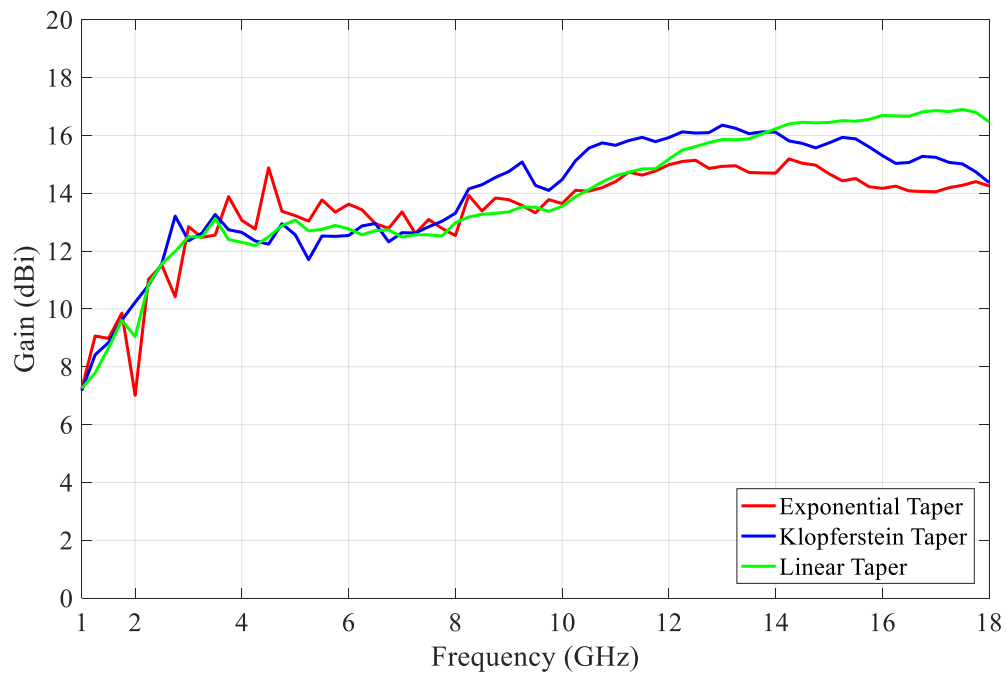


Figure 4.15. Boresight gain result of different tapers.

Due to the discontinuities obtained from the chosen taper profiles it was decided to focus on the ridge width of the different flared sections as a changeable variable on its own. To start off, three different end ridge widths were chosen to investigate. Firstly the starting width of the ridge remained fixed from the ridge waveguide with a value of 9.6 mm. The three end width values for the parameter study were selected by looking at the aperture width of the DRGH antenna as the widest width the ridge can end with. Thereafter selecting the other end width as half the aperture width. Figure 4.16 displays the three different end widths of the ridge chosen to simulate.

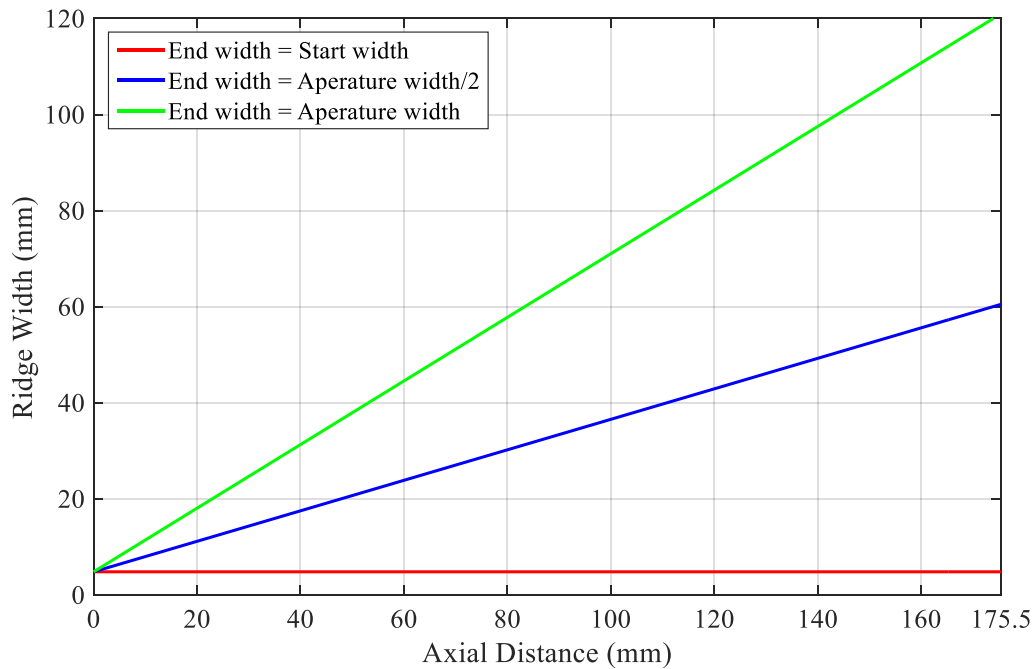


Figure 4.16. Ridge width profiles for various end widths.

The three linear ridge width profiles are shown in Figure 4.17, as implemented in the numerical FEKO model, ranging from the original constant ridge width to the largest end ridge width possible. The calculated characteristic wave mode impedance transfer profiles for the three different end ridge widths are shown in Figure 4.18. Each linear end width affects the impedance transition differently. The wider the ridges width is the more the transition become an exponential result. These width ridge profiles are inserted into FEKO to simulate and analyse the effect on the antenna performance.

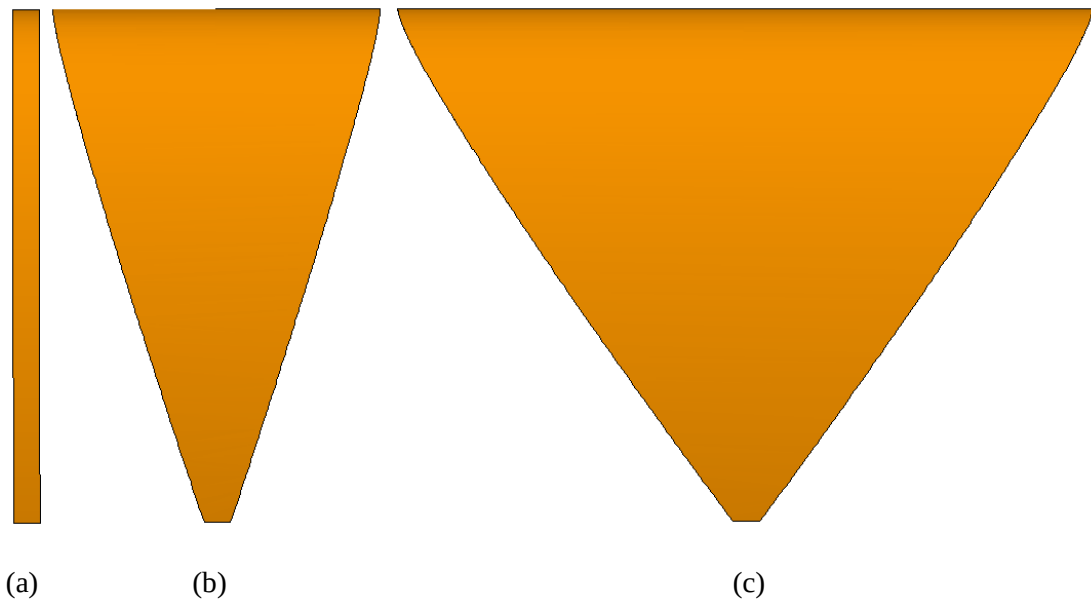


Figure 4.17. Ridge width implemented in FEKO.

(a) Constant width. (b) Aperture width/2. (c) Aperture width.

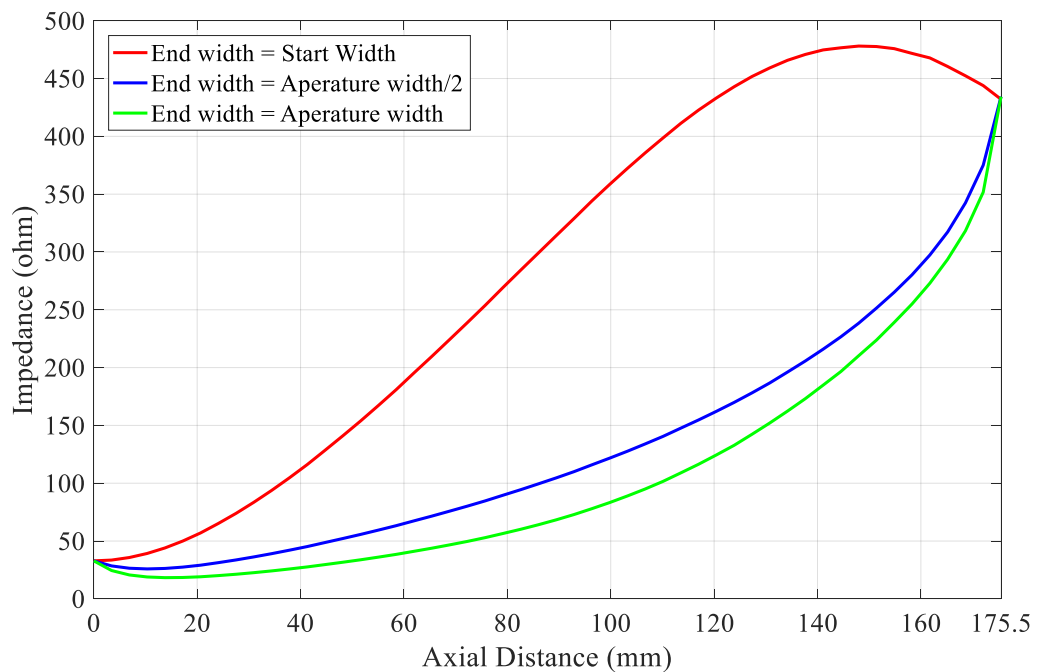


Figure 4.18. Impedance taper profiles for different end widths.

Evaluating the boresight gain result of the linear ridge widths in Figure 4.19, shows a significant change to the performance of the DRGH antenna, with fewer spikes compared to the ridge width that displayed discontinuities. The end width equal to the aperture width performs the least successful and breaks down the gain just after 3 GHz, this can be explained by higher order modes propagating. The end ridge width equal to the apertures width/2 improves the result compared to the end ridge width equal to the constant width profile. The gain is increased from 2 GHz all the up until 7 GHz. To obtain the final end ridge width a parametric study is conducted to obtain the end ridge width the presented the most improved gain and beamwidth performance.

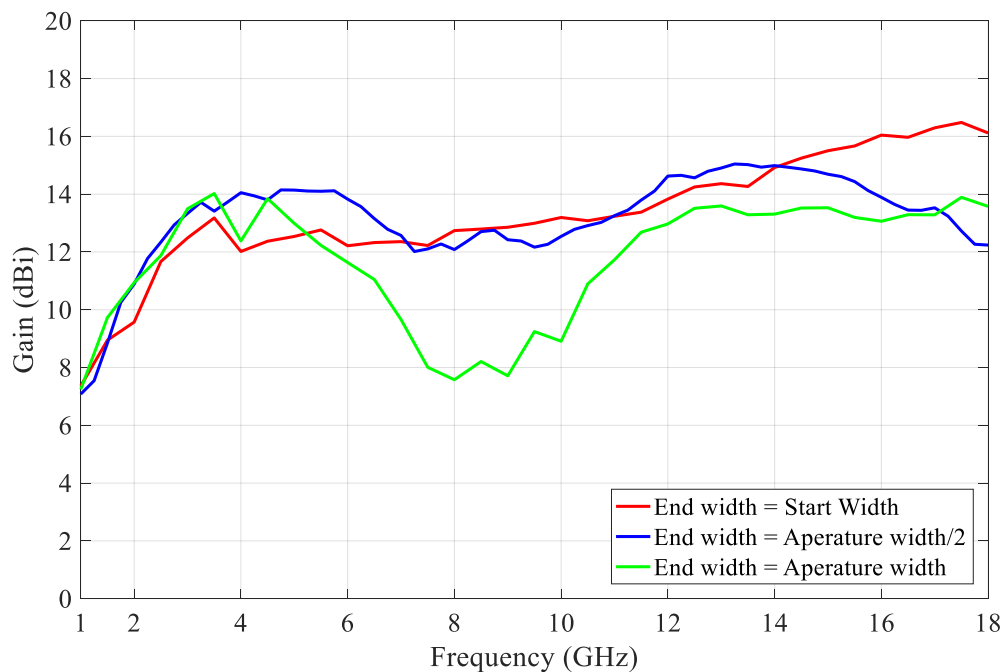


Figure 4.19. Boresight gain result of different linear ridge width profiles.

Figure 4.20 shows the next three chosen ridge end widths and subsequently in Figure 4.21 the characteristic wave mode impedance tapers are presented of these end ridge widths calculated in MATLAB. The response generated is becoming more linear and is further investigated by simulating the different linear ridge width profiles in FEKO.

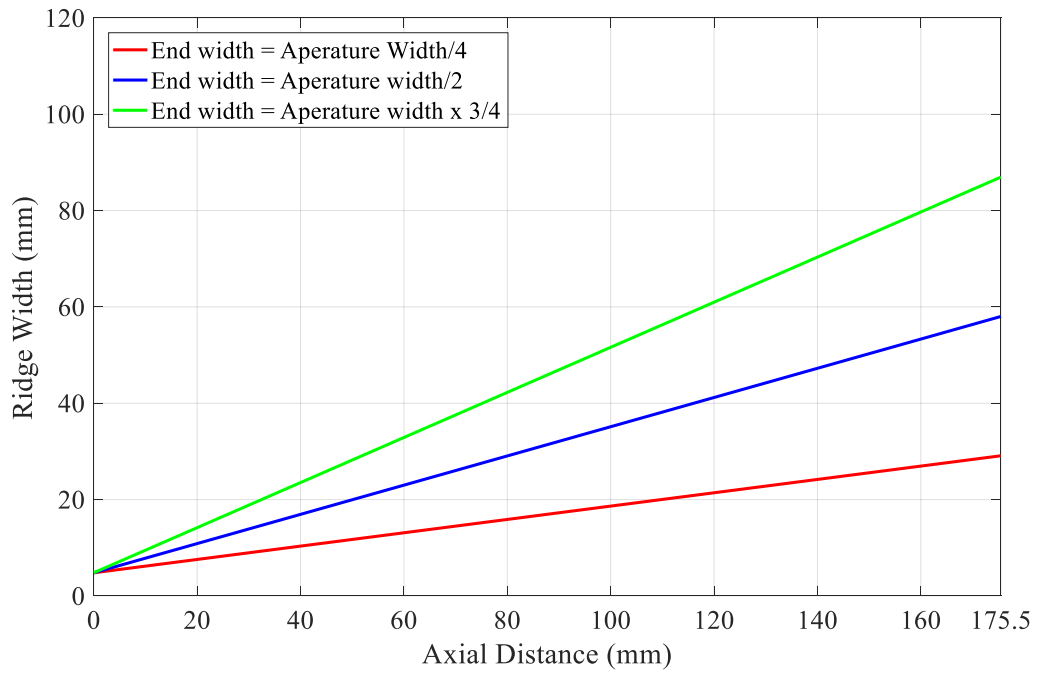


Figure 4.20. Ridge width profiles for various end widths.

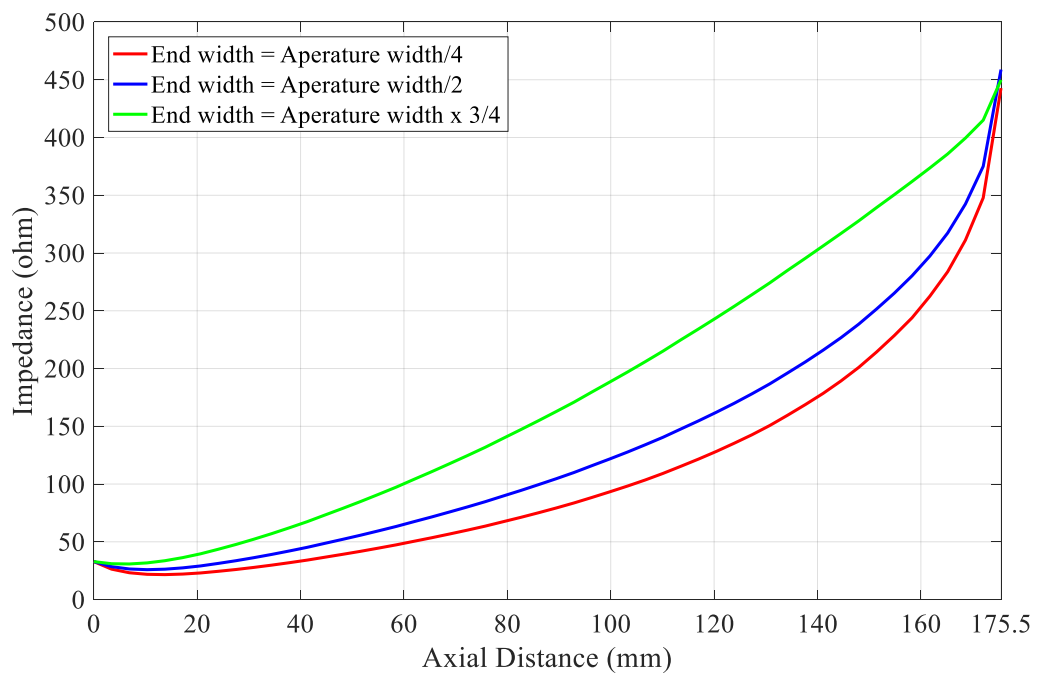


Figure 4.21. Impedance profiles for different end widths.

The boresight gain performance simulated for the next three profiles is shown in Figure 4.22, indicating that a ridge end width equal to the aperture width $\times 3/4$ is still too wide and causes the gain to start dipping after 6 GHz.

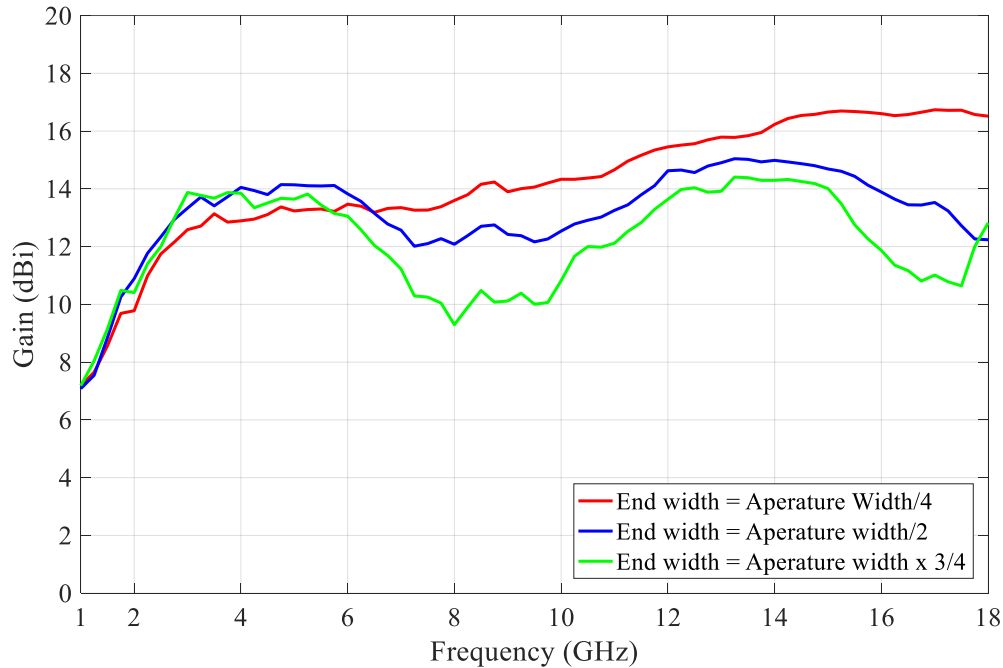


Figure 4.22. Boresight gain result of different linear ridge width profiles.

The next step was to narrow the result even more by using the ridge end width equal to the aperture width/4 and adding and subtracting 10 mm. The ridge width profiles are displayed in Figure 4.23, followed by the impedance tapers calculated for the different end widths in Figure 4.24. The results obtained are relatively close to each other and is analysed further in FEKO.

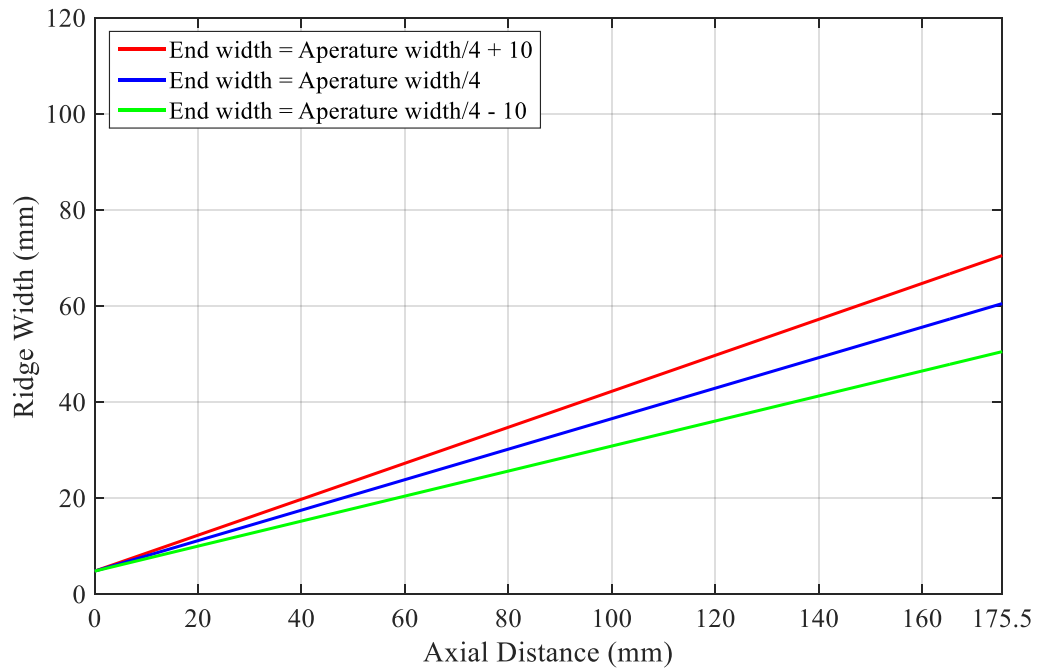


Figure 4.23 Ridge width profiles for various end widths.

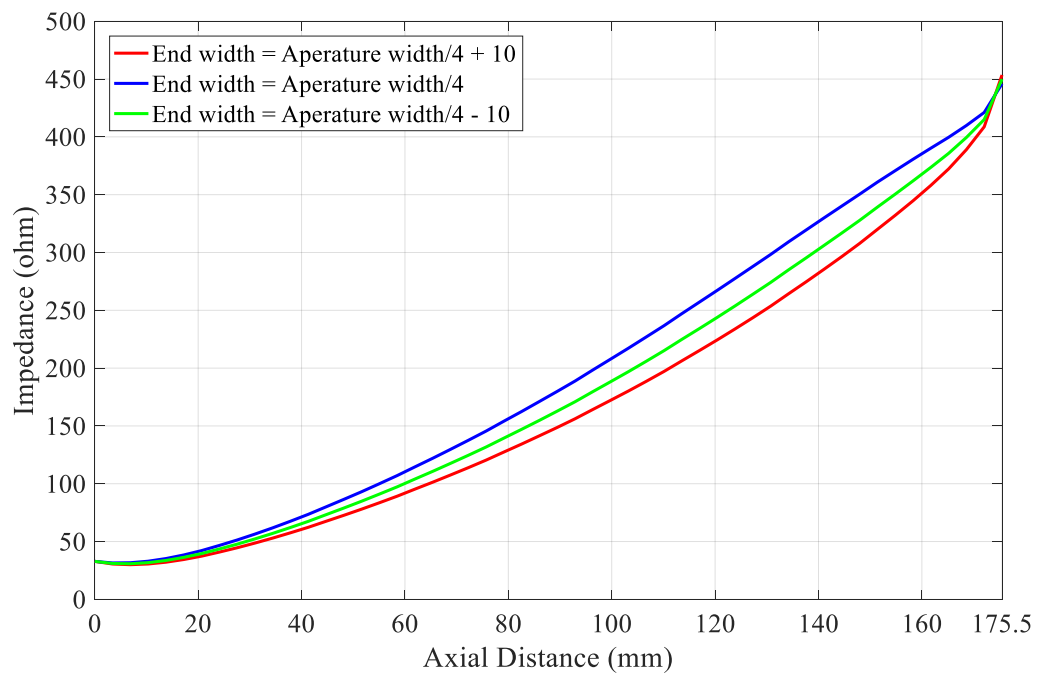


Figure 4.24. Impedance tapers for different end widths.

The boresight gain result for the three different end widths are shown in Figure 4.25 and only differs slightly, indicating that end width does not have a large effect any more in this region of values. The conclusion is that the end ridge equal to the aperture width/4 + 10 mm displays the best result and improves the desired antenna parameters the most. This end width is chosen as the final result of this study.

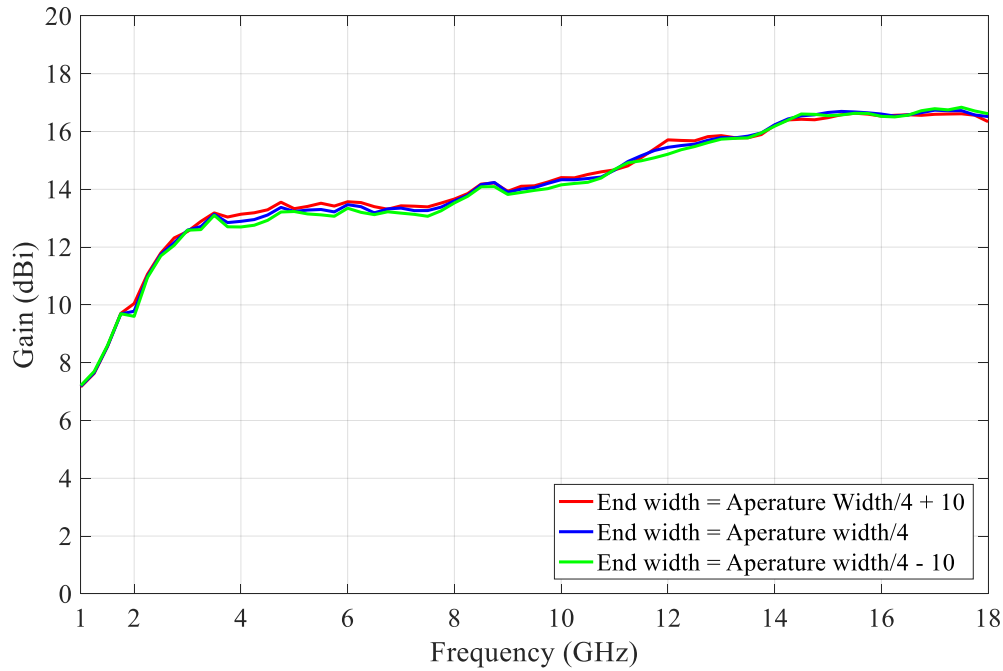


Figure 4.25 Boresight gain result of different linear ridge width profiles.

4.5 NEAR FIELD INVESTIGATION

The purpose of this section is to further investigate the results obtained of the improved ridges of the DRGH antenna from the previous sections. To effectively investigate the effect that the increased ridge area has on the radiating fields of the DRGH antenna, a near field study is done at different axial length positions of the DRGH antenna and compared to the results of the numerical DRGH antenna model from Chapter 3. The field strength is obtained from the simulation of each section at different frequencies. The hypothesis of increasing the radiating area of the ridges results in the gain to increase in investigated [32, 33].

Figure 4.26 shows the numerical DRGH antenna model from Chapter 3 (a) and the improved ridges inside the DRGH antenna (b).

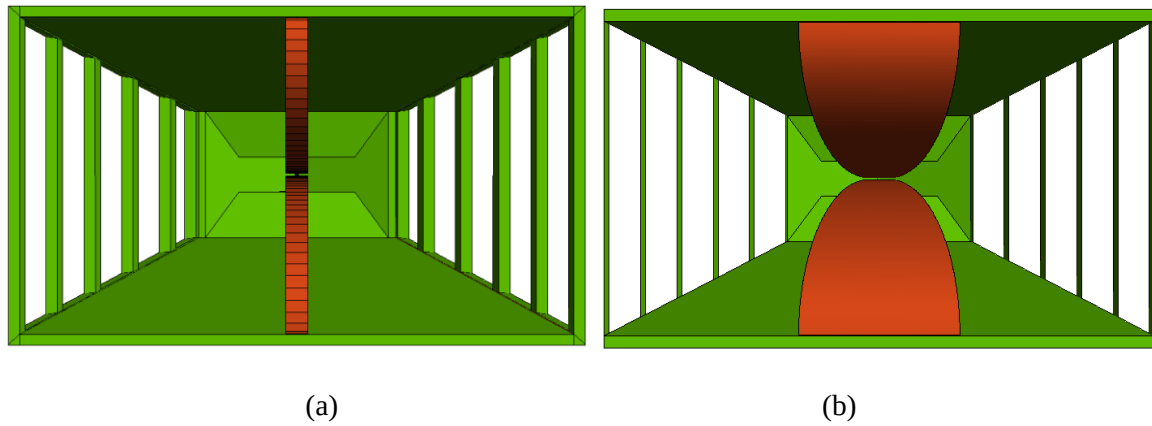


Figure 4.26. 2D Top view of ridges.

(a) Original ridges (b) Improved ridges.

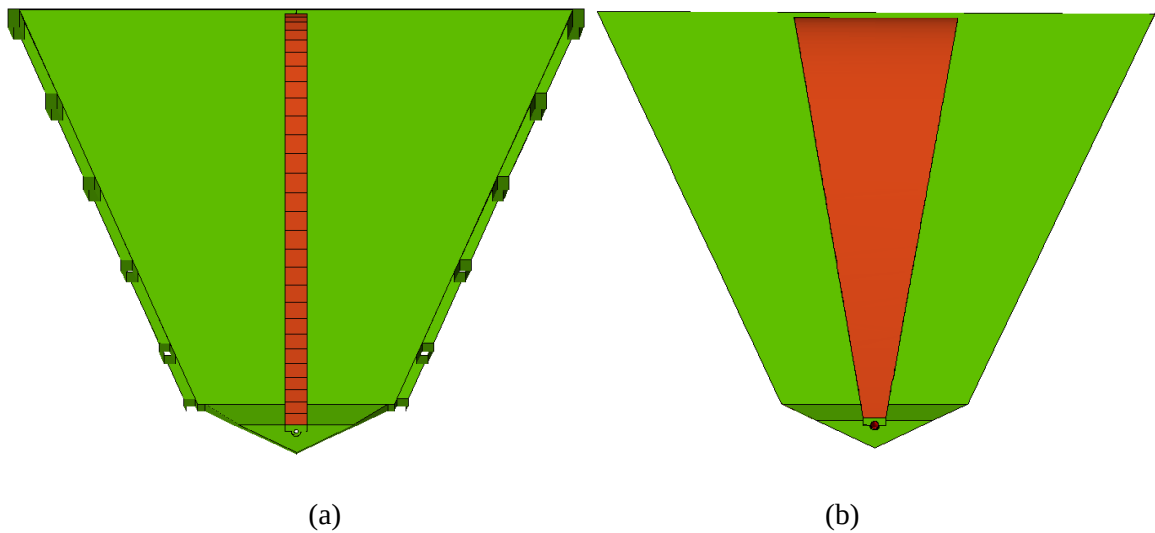


Figure 4.27. 2D Side views of ridges.

(a) Original ridges (b) Improved ridges.

The models are displayed from an aperture point of view, clearly showing the ridges and how the area is increasing across the axial length. Furthermore, a cut-plane view is shown in

Figure 4.27, indicating that the ridges are increased by a linear taper until the aperture, remaining the same at the start. The linear ridge width profile is clearly visible in the cut view of the improved DRGH antenna.

Three near field monitors are placed at different axial positions shown in Figure 4.28. The low frequencies are analysed at near field 1 and the higher frequencies and near field 3. The simulation was done in FEKO, using the near field monitors on both the DRGH antenna from Chapter 3 and the improved DRGH antenna with the wider ridges. Figures 4.29 to 4.37 compare the results obtained from the two DRGH antennas plotted on Cartesian graphs. The field strength of the results are shown on the right-hand side of the plots.

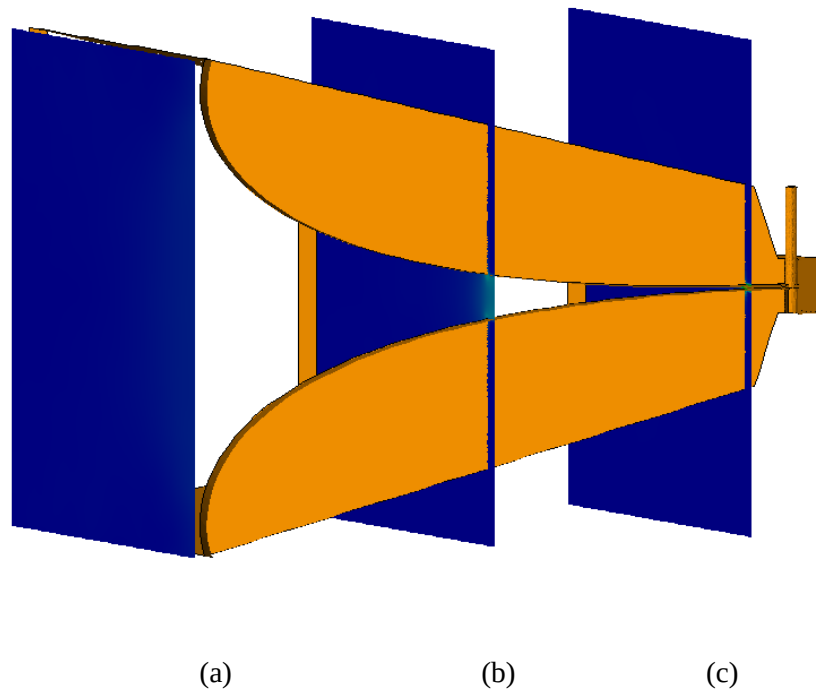


Figure 4.28. Axial positions shown in the cut plane.

(a) Near Field monitor 1. (b) Near Field monitor 2. (c) Near Field monitor 3.

Figure 4.29 shows the results of near field monitor 1 at 1 GHz, indicating that the radiating fields are mainly on the ridges as expected. Figure 4.29 (A) shows the original thin ridges where the main fields are radiating in the centre, whereas in Figure 4.29 B the radiating area

is increased to more than double due to the wider ridges at the aperture of the DRGH antenna. It proves the concept that the radiating area has an impact on the radiated field strength. Near field 1 monitor is investigated at 1 GHz, 3 GHz and 5 GHz in Figures 4.29 to 4.31 where the concept is validated again with the radiating area increasing due to the improved ridges implemented into the DRGH antenna.

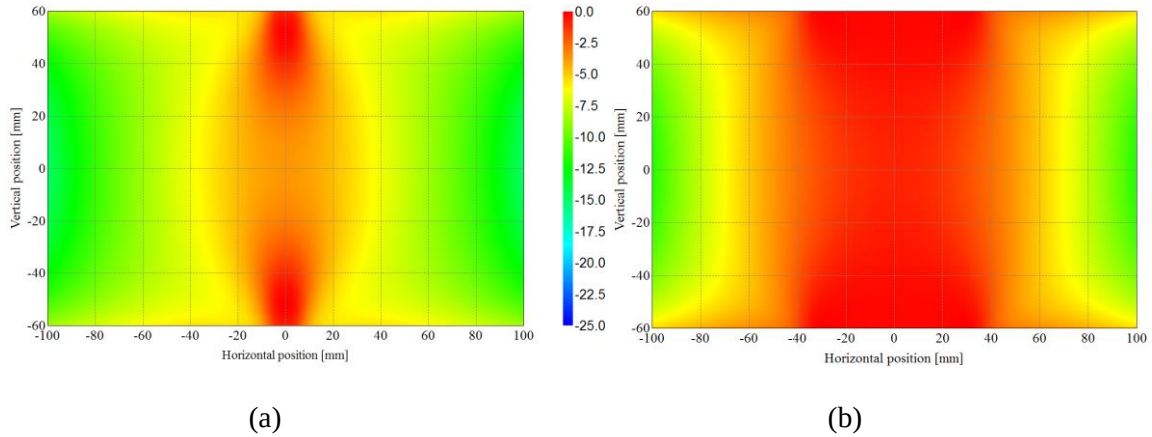


Figure 4.29. Comparison of Near Field 1 result for 1 GHz.

(a) Original ridges (b) Improved ridges.

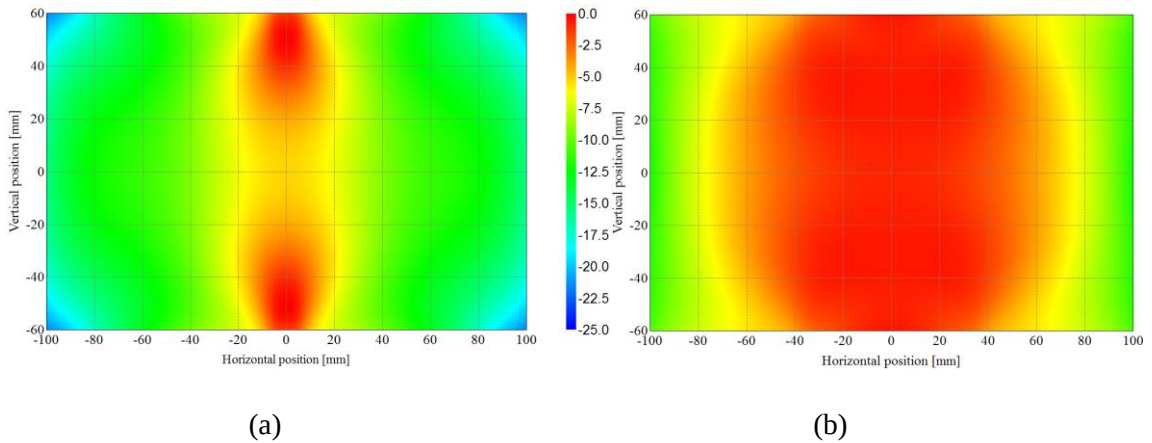


Figure 4.30. Comparison of Near Field 1 result for 3 GHz.

(a) Original ridges (b) Improved ridges.

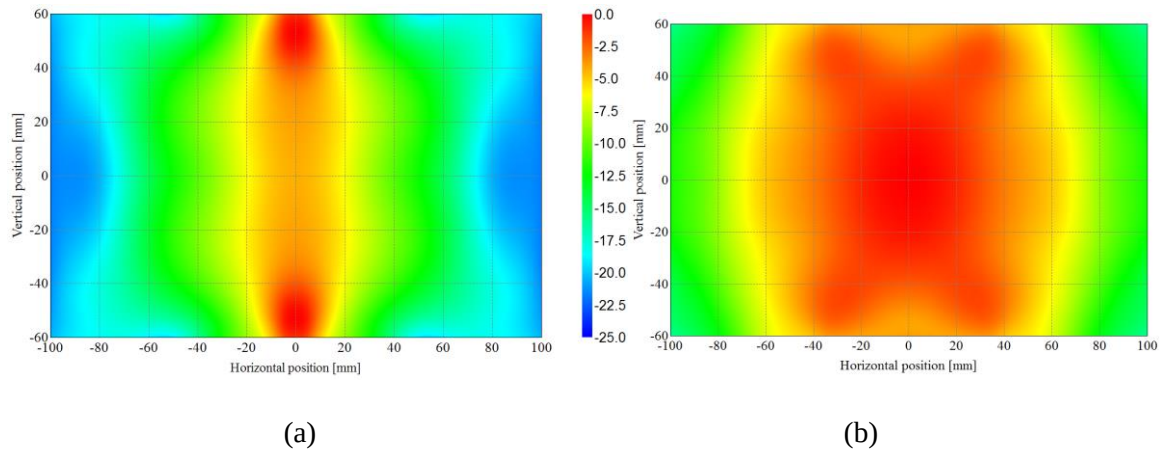


Figure 4.31. Comparison of Near Field 1 result for 5 GHz.

(a) Original ridges (b) Improved ridges.

Near field monitor 2, is investigated at 7 GHz, 9 GHz and 11 GHz, which are the centre frequencies, shown in Figures 4.32 to 4.34. The ridges are seen more prominently with the radiating fields situated between them. The ridge width is very dominant in this plane of view, with a lower field strength inside the ridges. The area that is radiating is larger than the DRGH antenna from Chapter 3 and is clear that there is a larger radiating area being evident at the other two frequencies as well.

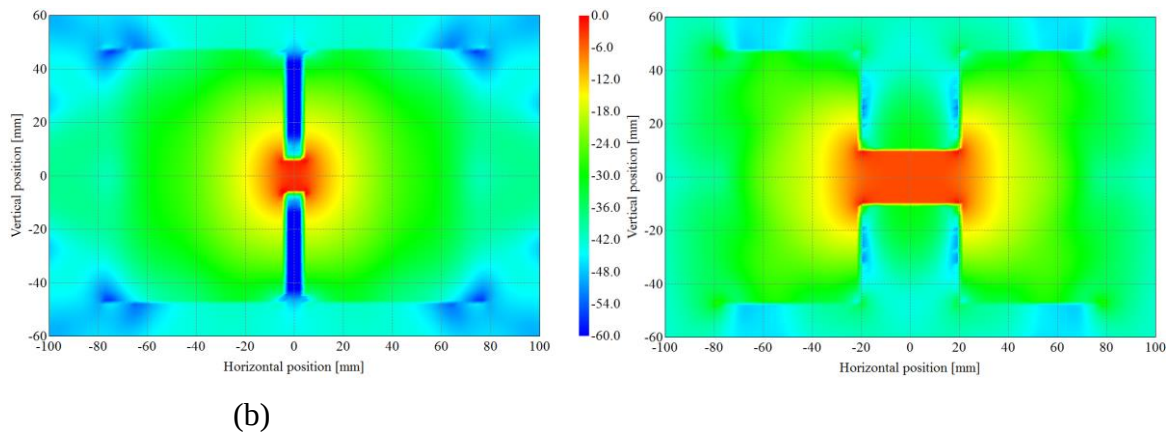


Figure 4.32. Comparison of Near Field 2 result for 7 GHz.

(a) Original ridges (b) Improved ridges.

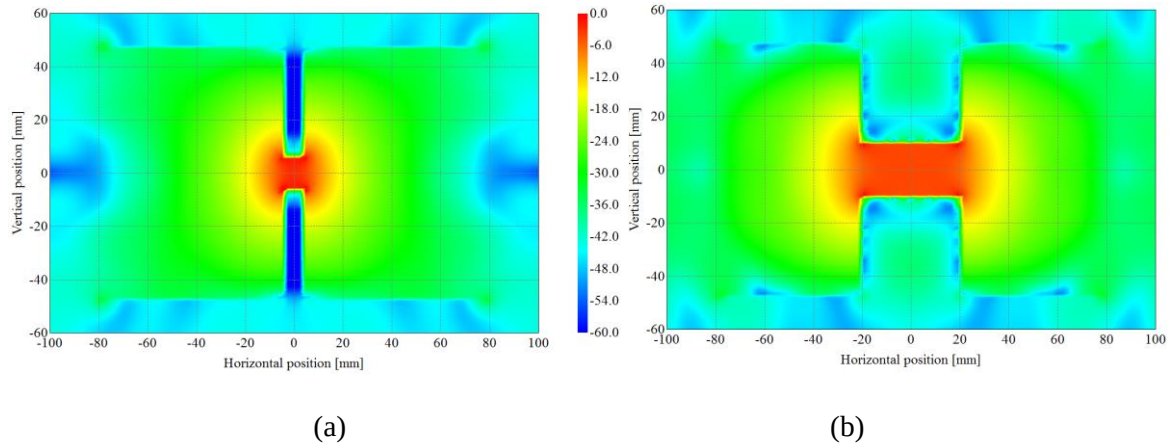


Figure 4.33. Comparison of Near Field 2 result for 9 GHz.

(a) Original ridges (b) Improved ridges.

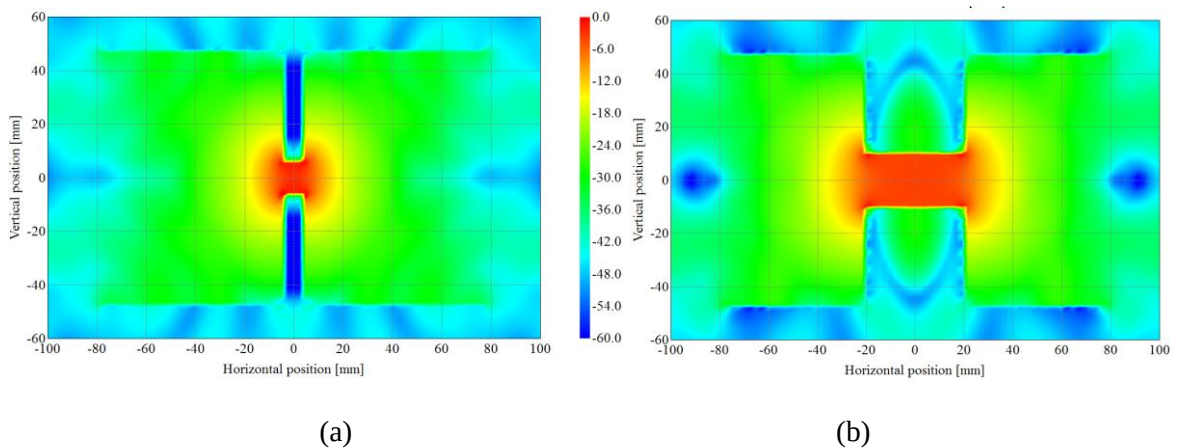


Figure 4.34. Near Comparison of Field 3 result for 11 GHz.

(a) Original ridges (b) Improved ridges.

Near field monitor 3 is investigated at 13 GHz, 15 GHz and 18 GHz in Figures 4.35 to 4.37. Here the ridge width of the improved ridges is smaller but still different to the ridges from Chapter 3. A similar radiating surface is obtained with minor changes due to the improved ridges starting to taper outwards. Examining the near field monitor results, especially in the apertures cross section at the lower frequencies clarifies the effect of the increased area.

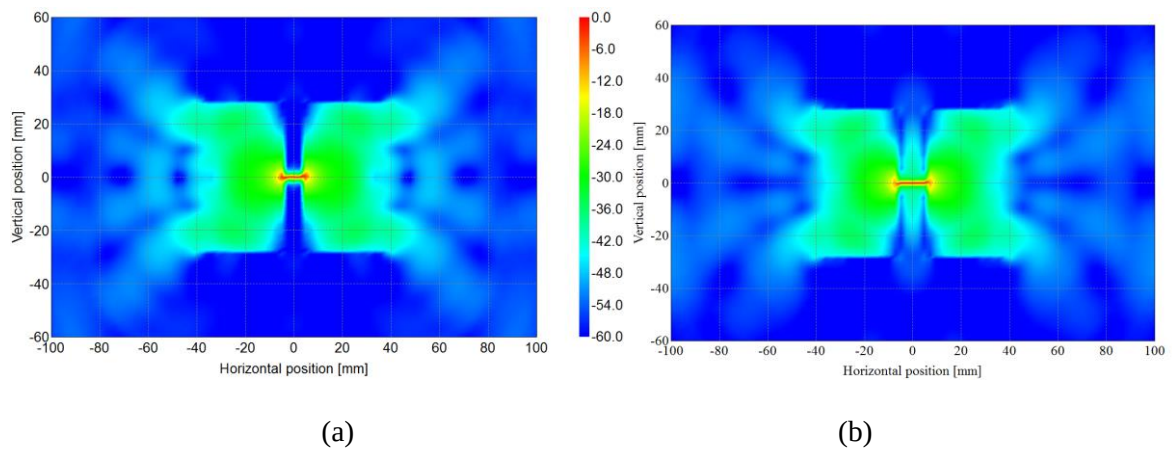


Figure 4.35. Comparison of Near Field 3 result for 13 GHz.

(a) Original ridges (b) Improved ridges.

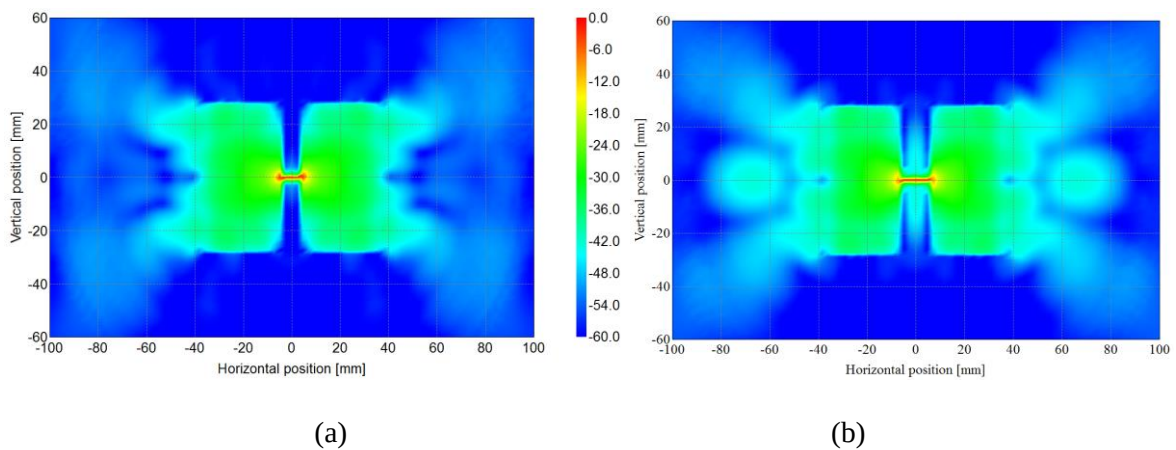


Figure 4.36. Comparison of Near Field 3 result for 15 GHz.

(a) Original ridges (b) Improved ridges.

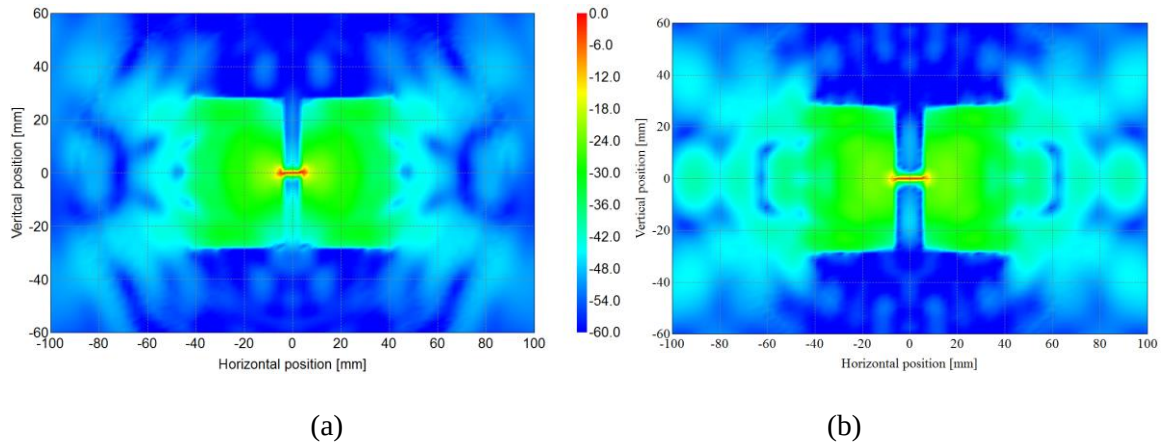


Figure 4.37. Comparison of Near Field 3 result for 18 GHz.

(a) Original ridges (b) Improved ridges.

4.6 SIMULATION RESULT COMPARISON

In this section the overall antenna performance of the improved DRGH antenna is compared to the DRGH antenna from Chapter 3. This is done to fully understand the effect that the improved ridges have on the antennas performance. Figure 4.38, presents the numerical FEKO model of the improved DRGH antenna with elliptical the ridge profile and linear ridge width taper.

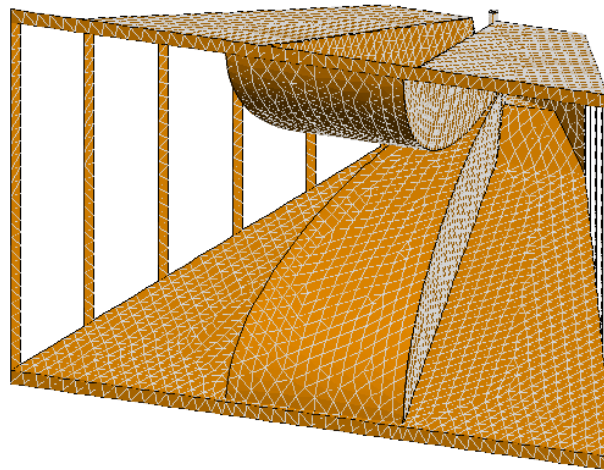


Figure 4.38. 3D layout of improved DRGH Antenna in FEKO.

The fundamental antenna properties are simulated in FEKO and compared to the results obtained in Chapter 3. This is done in order to ensure that the improved ridges implemented into the DRGH antenna did not affect its overall operational capabilities. The VSWR shown in Figure 4.39 presents a fair comparison between the results, the difference detected at the low frequencies is mainly where the ridges changed the most.

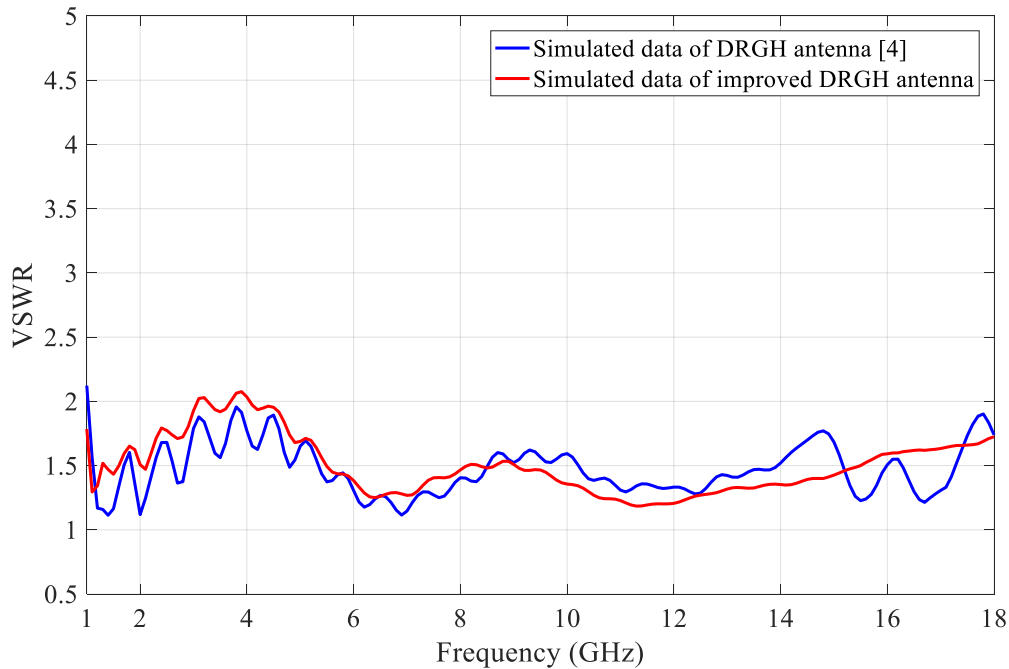


Figure 4.39. Comparison of VSWR results.

Figure 4.40 compares the boresight gain. Here the results are not expected to remain the same, but the improved ridges increase the boresight gain, especially at the lower frequencies. This is due to the largest change occurring at the aperture of the DRGH antenna, where the low frequencies start radiating. It is evident that the boresight gain has increased the frequency band between 3 GHz and 17 GHz and not only at the lower frequencies. At round about 4 GHz, up until 15 GHz, the boresight gain has been increased between 0.5 dB up until 1 dB. Due to the starting ridge profile at the start of the axial length not changing extensively, it is expecting that the higher frequencies boresight gain level remains similar from 17 GHz, which is observed.

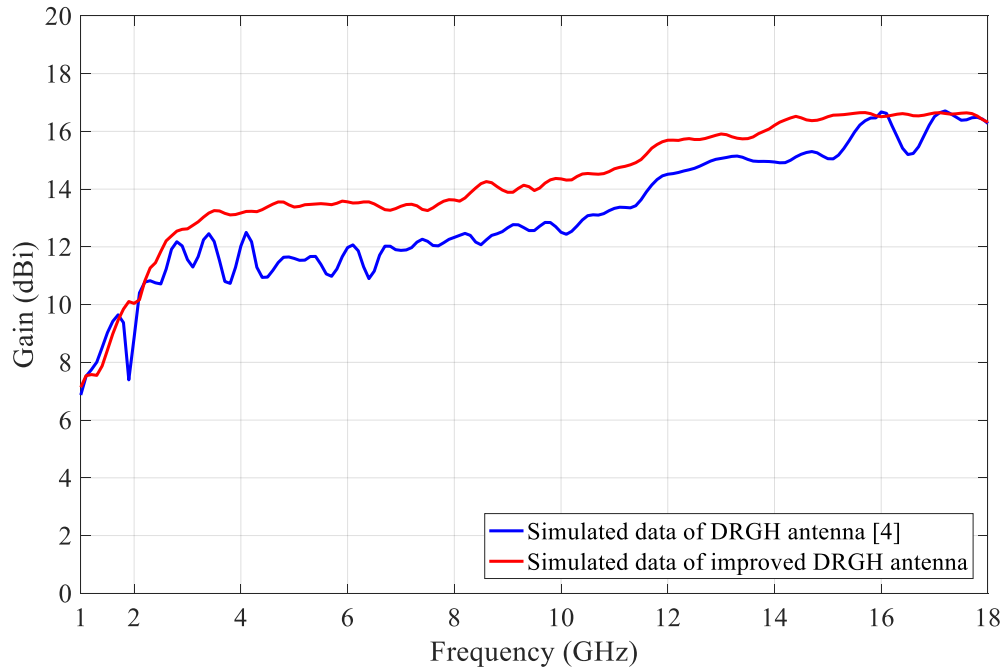


Figure 4.40. Comparison of boresight gain results.

The radiating patterns at specific frequencies are compared in Figures 4.41 to 4.48. The increase in the boresight gain, due to the improved ridges is evident. The axial length and aperture variables that remained fixed from the numerical DRGH antenna model in Chapter 3 are usually the parameters that are increased to ensure achieving a higher gain performance, this is not the case for the improved ridges in this dissertation.

The Cartesian plots of the 1 GHz results remain the same as expected when looking at the boresight gain in Figure 4.40 and only changing after 2 GHz. At the 6 GHz and higher patterns, the result shows the beamwidth narrowing of the improved DRGH antenna, which explains the increased gain. Overall the improved ridges cause the DRGH antenna gain from Chapter 3 to increase from 2 GHz up to 17 GHz, with a value of 0.5 dB up until 1 dB.

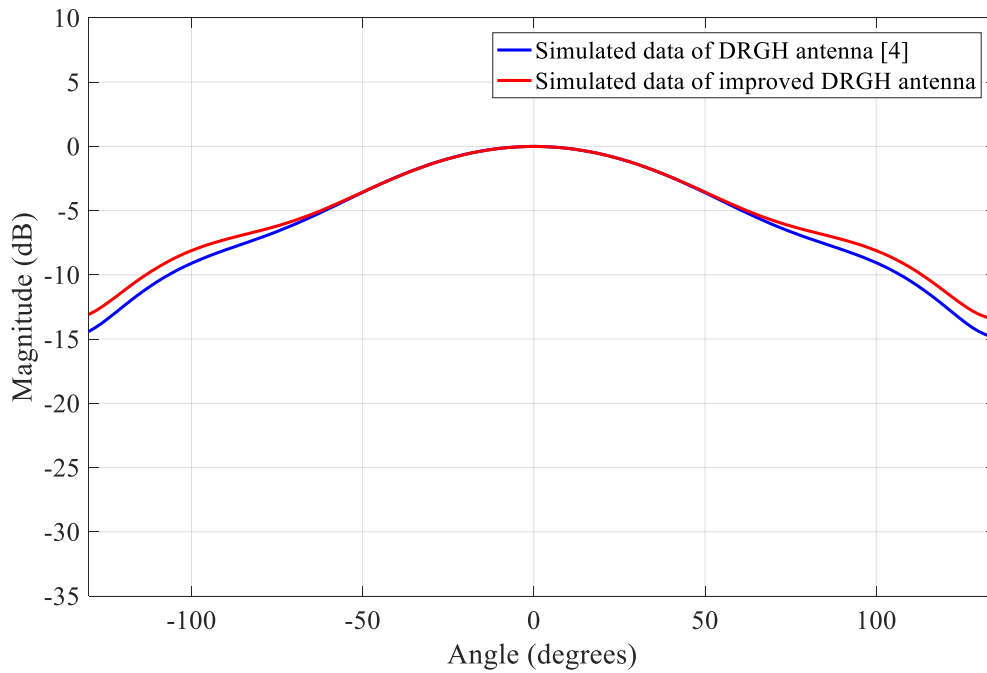


Figure 4.41. Comparison of radiation E-plane pattern results at 1 GHz.

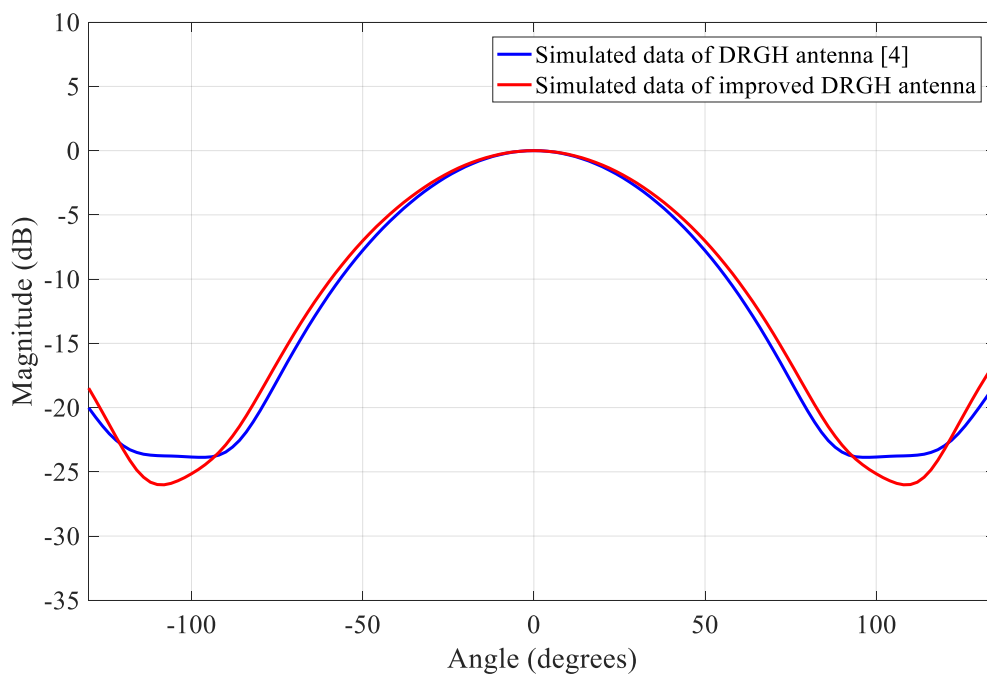


Figure 4.42. Comparison of radiation H-plane pattern results at 1 GHz.

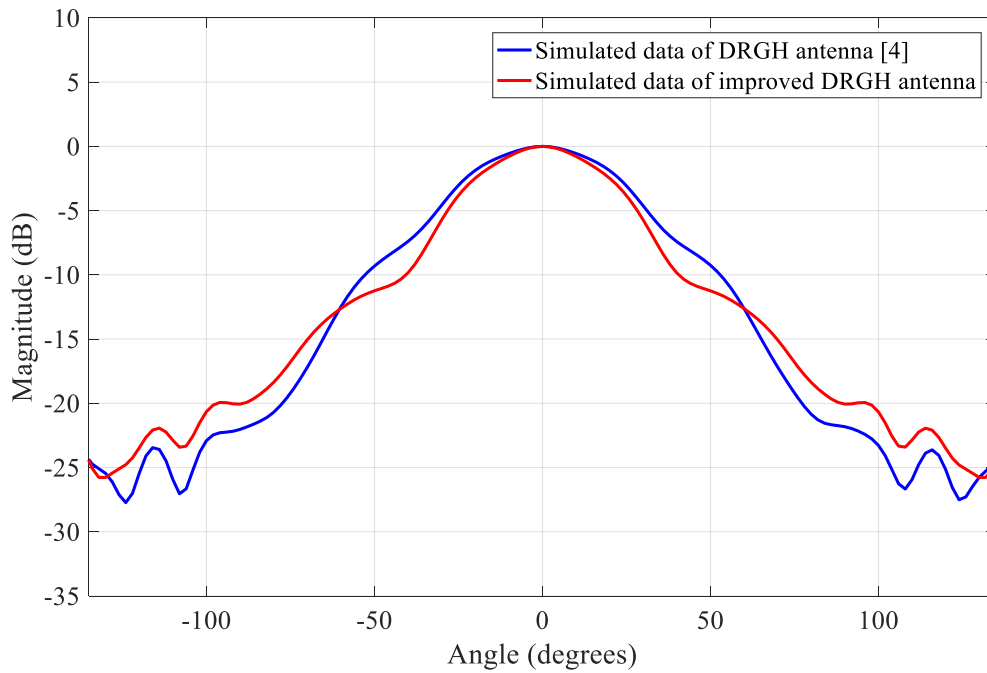


Figure 4.43. Comparison of radiation E-plane pattern results at 6 GHz.

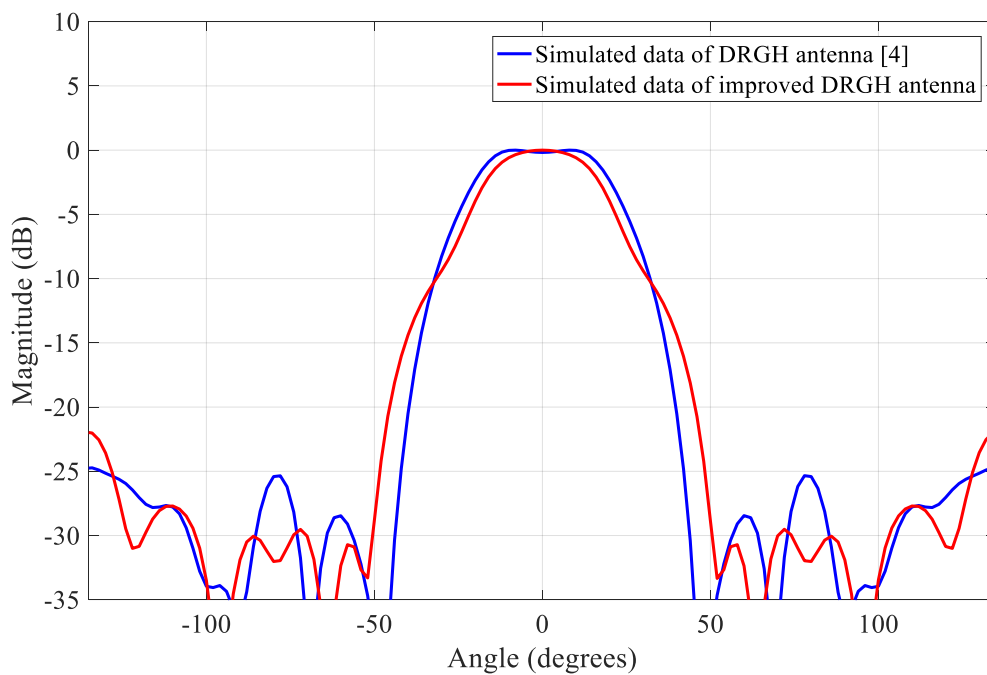


Figure 4.44. Comparison of radiation H-plane pattern results at 6 GHz.

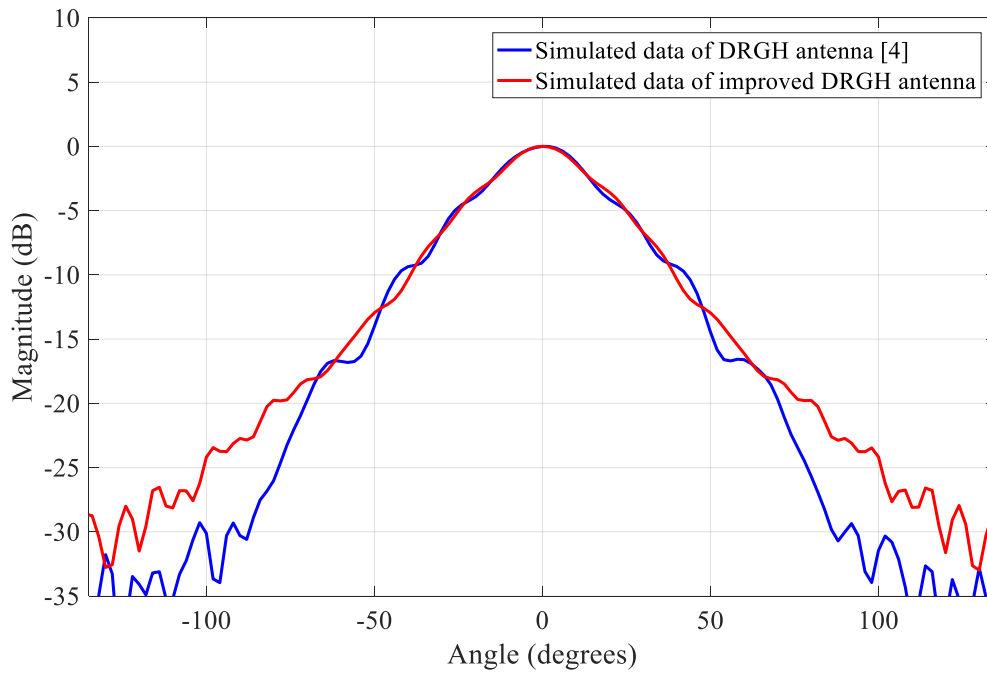


Figure 4.45. Comparison of radiation E-plane pattern results at 12 GHz.

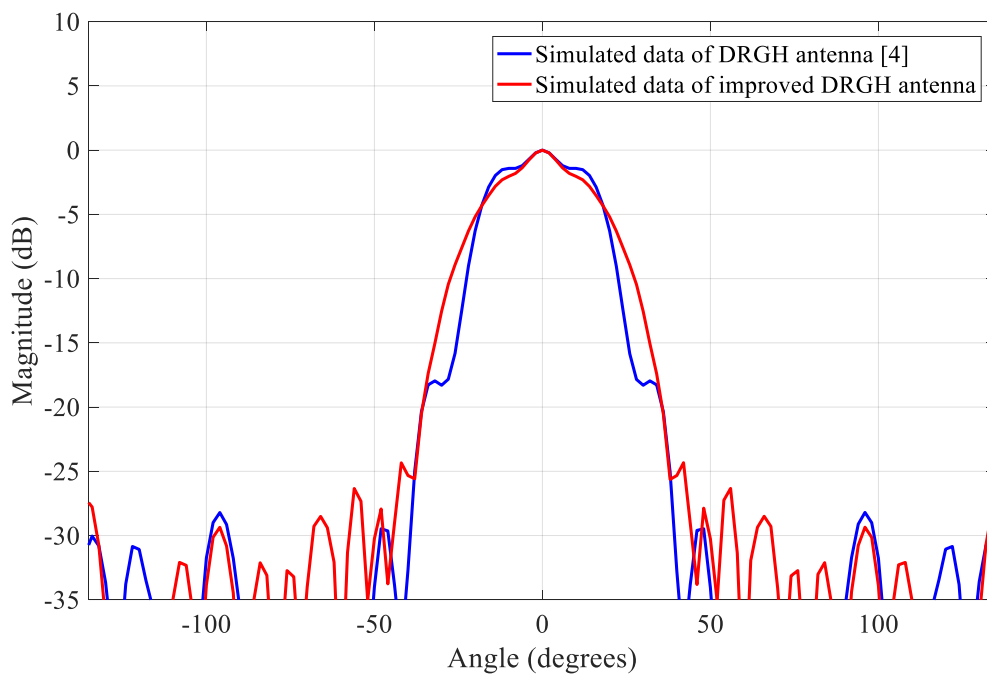


Figure 4.46. Comparison of radiation H-plane pattern results 12 GHz.

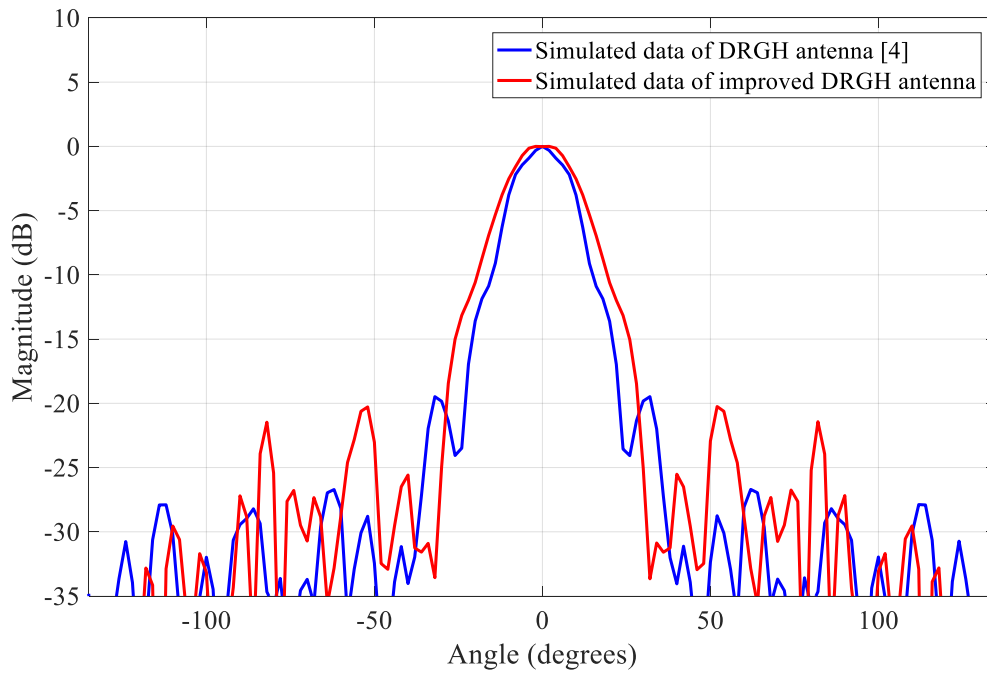


Figure 4.47. Comparison of radiation E-plane pattern results at 18 GHz.

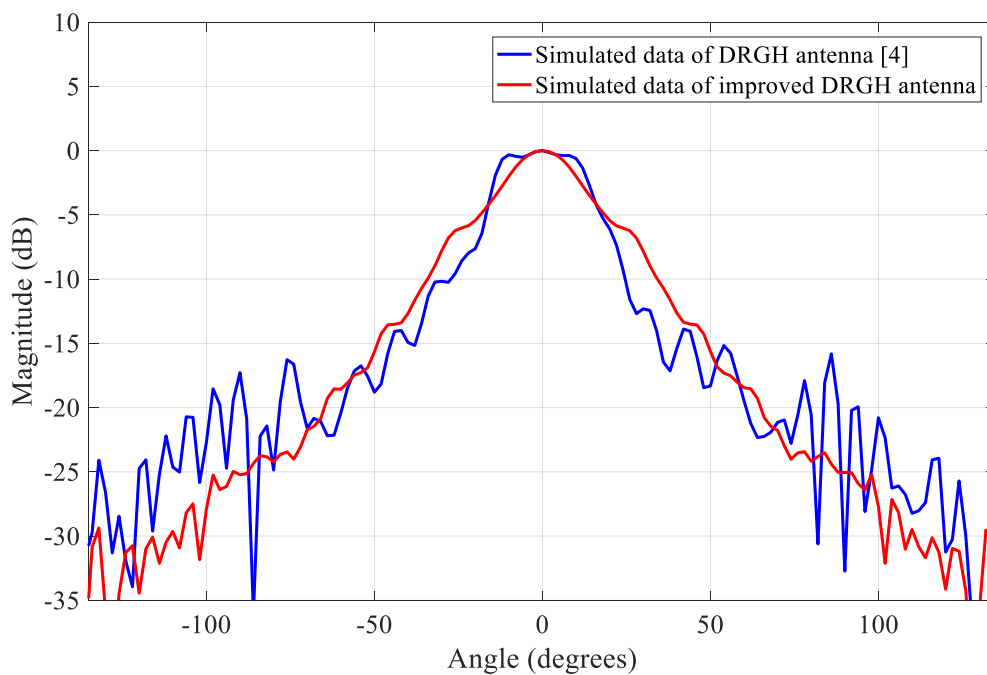


Figure 4.48. Comparison of radiation H-plane pattern results at 18 GHz.

The focus of the dissertation was to improve the beamwidth of the DRGH antenna by obtaining a relatively constant radiating performance. It is evident from the results compared in Figure 4.49 and 4.50 that this goal is reached by keeping the axial length and aperture dimensions constant and only changing the ridges. The gain is largely improved from 2 GHz upward as seen from the boresight gain in Figure 4.40.

The improved DRGH antennas 3 dB beamwidth ranges from 18.3° to 66° in the main operating frequency range of 1 to 18 GHz, compared to the DRGH antenna from Chapter 3 that ranges from 17.5° to 78.5° . This results in a range of 61° for the thin ridges compared to a range 47.7° for the new ridges. This is mainly due to the spikes present in the beamwidth result of the old ridges. The standard deviation of the two data sets is 12 and 10 for the old ridges and the new ridges respectively. The main improvement occurs after 2.5 GHz where the 3 dB beamwidth of improved DRGH antenna ranges from 18.3° up to 39.4° compared to the old ridges with a range from 17.5° up to 56.8° , resulting in a 18° smaller spread.

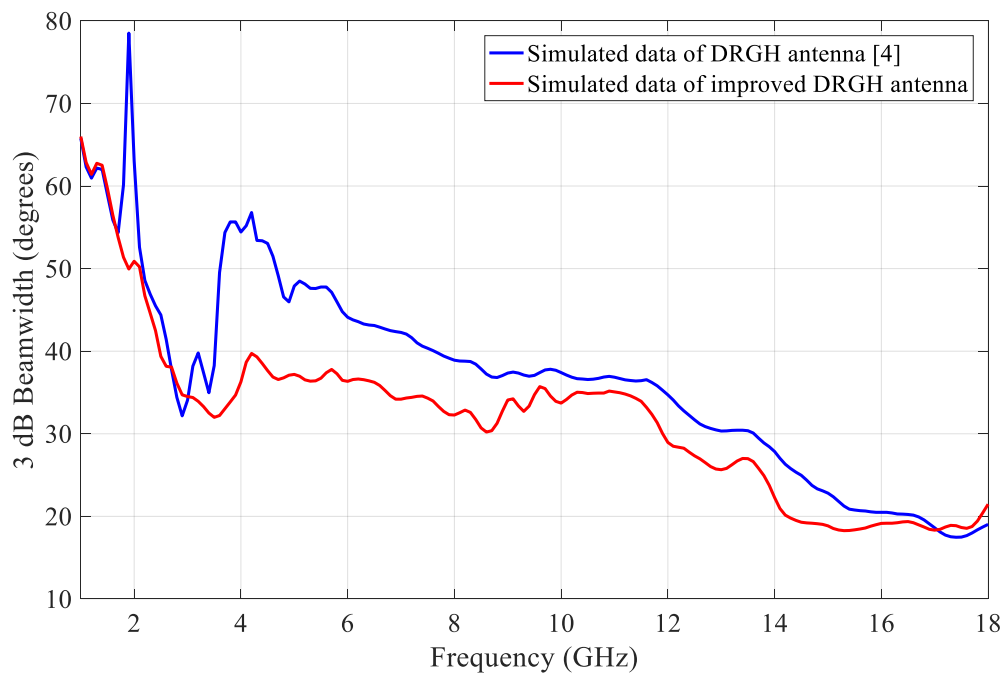


Figure 4.49. Comparison of the 3 dB beamwidth results.

Table 4.2 presents the percentage of the data of the 3 dB beamwidth result within a certain degree range. This is done to further understand the effect of the improved ridges on the beamwidths performance regarding its constant response. Three different sectors are selected to analyse. The percentage of data within a certain degree sector from the men is calculated and displayed. It is clear from the result that for the thin and improved ridges, 95 % of the data is within a $\pm 20^\circ$ range. Comparing the $\pm 5^\circ$ range a percentage difference of 15.3 % is observed which leads to a 41.5 % improvement in the 3 dB beamwidths relative constant response. This result in a more constant response that is desirable for DRGH antennas used for EMC/EMI testing.

Table 4.2. 3 dB Beamwidth result analysis.

Description	Range of data presented in degree deviation from mean	Percentage of 3 dB beamwidth within degree range from mean
Simulated data of DRGH antenna [4]	$\pm 5^\circ$	36.9 %
	$\pm 10^\circ$	57.3 %
	$\pm 20^\circ$	94.7 %
Simulated data of improved DRGH antenna	$\pm 5^\circ$	52.1 %
	$\pm 10^\circ$	67.8 %
	$\pm 20^\circ$	95.3 %

The 10 dB beamwidth also enhanced result regarding uniformity. The improved ridges obtained a 10 dB beamwidth ranging from 38.6° to 134.21° compared to the DRGH antenna from Chapter 3 ranging from 28.5° to 136.1° . This resulted in a standard deviation result of 17 compared to 23 with a 12° smaller range. Overall the improved ridges effected the beamwidth performance to become relatively more constant as desired.

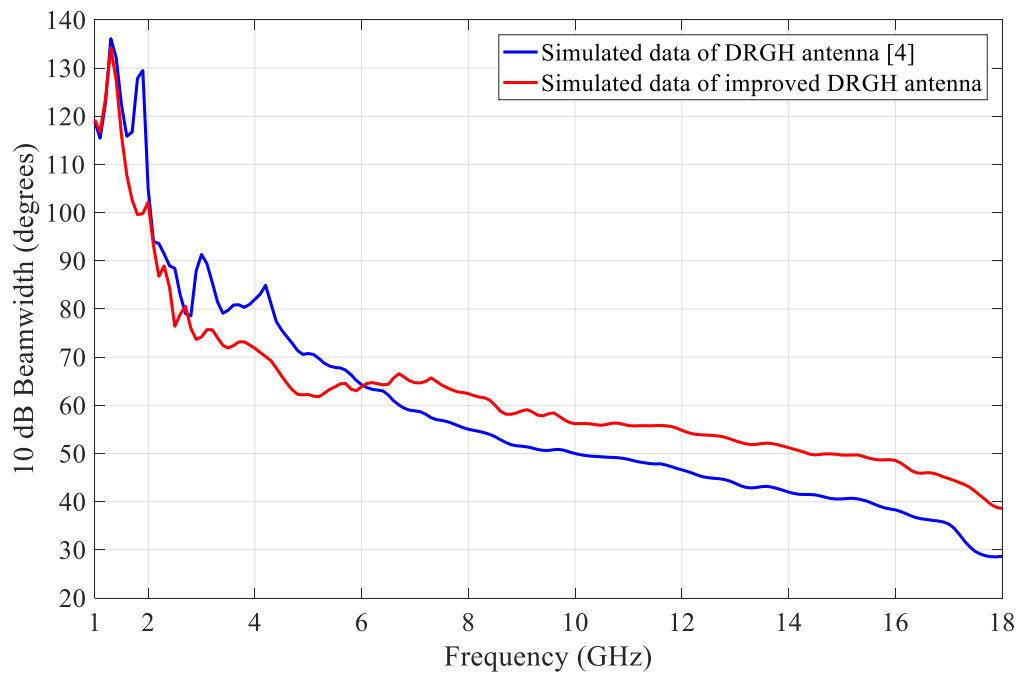


Figure 4.50. Comparison of the 10 dB beamwidth results.

Table 4.3. 10 dB Beamwidth result analysis.

Description	Range of data presented in degree deviation from mean	Percentage of 10 dB beamwidth within degree range from mean
Simulated data of DRGH antenna [4]	$\pm 10^\circ$	33.3 %
	$\pm 20^\circ$	67.8 %
	$\pm 40^\circ$	93.6 %
Simulated data of improved DRGH antenna	$\pm 10^\circ$	56.6 %
	$\pm 20^\circ$	88.3 %
	$\pm 40^\circ$	94.7 %

Table 4.3 presents the percentage of the data of the 10 dB beamwidth result within a certain degree range. The improved ridges display 94.7 % of the data is within a $\pm 40^\circ$ range, whereas the thin ridges only display 93.6 % of the data. Comparing the $\pm 10^\circ$ range a percentage difference of 23.3 % is calculated which leads to a 70 % improvement in the 10 dB beamwidths relative constant response. This result proves the goal of changing the ridge profile and width for the goal of obtaining a relatively more constant beamwidth performance.

4.7 SUMMARY

In this chapter, the DRGH antenna [4] simulated in Chapter 3 is improved by focusing on the ridges. In Section 4.2, the sidewalls of the DRGH antenna were investigated and the boresight gain was improved by implementing thinner sidewalls compared to the previously implemented sidewalls from Chapter 3. This phenomenon can be further investigated in future research due to the focus of this dissertation only mainly being on the improvement of the ridges. In Section 4.3, by implementing three different specially chosen profiles on to the ridge profile and analysing the results. The boresight gains improvement of the DRGH antenna at the lower frequencies displays the most promising results when the elliptical profile is used, therefore it was chosen as the ridge profile for the further improvement.

The investigation of the characteristic wave mode impedance taper profile of the flared section was the second part investigated in Section 4.4 as a possible solution to obtain the desired goals. The impedance taper could be specified by tapering out the ridge width from the axial length start up until the end, which remained fixed impedance values. This was due to the box dimensions of the DRGH antenna from Chapter 3 kept constant. Again, three different impedance profiles were selected to implement and investigate the effects on the antennas performance.

The specific impedance taper resulted in the ridge widths to present with discontinuities, and thereby also spikes in the boresight gain. After that, the ridge width profile was kept linear with no discontinuities and investigated with a parameter study. This was done by changing

the end width of the ridge from the widest it can be, namely the aperture width and performing a further study by changing this value. The optimum value of the ridge profiles end width was determined to be the aperture width/4 + 10 mm.

To analyse the improved ridges a nearfield investigation is done in Section 4.4 to understand in what way the performance was effected of the numerical model in Chapter 3 of DRGH antenna from [4]. The result clearly showed how by increasing the radiation area of the ridges at the lower frequency radiating area, caused the boresight gain to increase and overall improve the antennas performance. The results of the improved ridges were analysed in this chapter and compared to the numerical DRGH antenna from Chapter 3 in Section 4.6. The overall antenna performance was clearly improved by just changing the ridges.

The next chapter focusses on the simulated and measured results of the prototype DRGH antenna.

CHAPTER 5 PROTOTYPE DRGH ANTENNA AND MEASURED RESULTS

5.1 INTRODUCTION

The improved ridges of the DRGH antenna in Chapter 4 are manufactured and incorporated into the DRGH antenna obtained from [4]. The final prototype antenna is tested and the results are compared to the FEKO simulation result. This is done to verify the improved DRGH antenna and also to confirm the accuracy of the numerical model. The mechanical implementation of the ridges are discussed in Section 5.2, and subsequently, a comparison of the measured and simulated data is presented in Section 5.3. Lastly, this chapter is summarised in Section 5.4 where the core findings are discussed.

5.2 MECHANICAL IMPLEMENTATION OF IMPROVED RIDGES

SolidWorks was utilised to create isometric drawings of the final improved ridges which is required for manufacturing. The drawings are based on the numerical model in FEKO. The complete DRGH antenna is divided into sections for assembly. The antenna consists of the waveguide transition and cavity section, the two ridges, the feed pin and the sidewalls. Section 5.2.1 describes the manufacturing of the new improved ridges whereas the complete DRGH antenna is shown in Section 5.2.2. The DRGH antenna obtained from [4] was modified by removing the old ridges and replacing them with the new improved manufactured ridges.

5.2.1 The ridges

The profile of the new improved ridges is drawn in SolidWorks and used to manufacture the ridges. A CNC 3-axis mill is used and programmed to track the Parasolid profile produced. The two ridges are manufactured using standard aluminium blocks that are commercially available. Figure 5.1 shows the improved isometric ridge outline drawing.

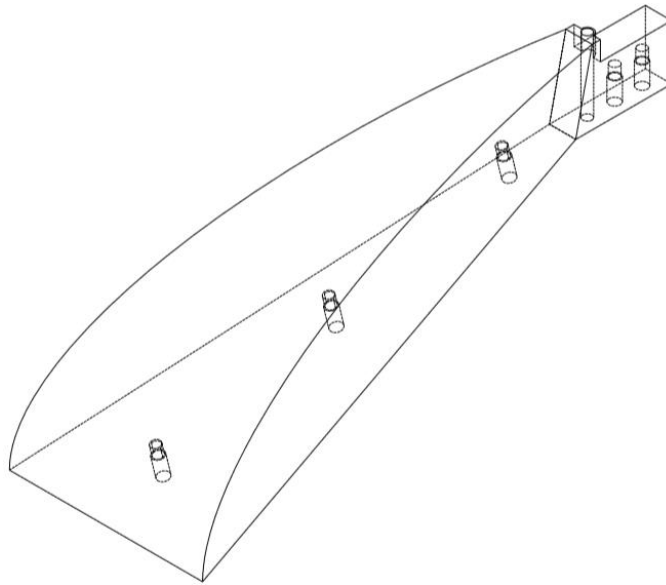


Figure 5.1. Isometric view of the improved ridge.

Specific holes are cut into the back of ridges to ensure they match up with the sidewalls of the DRGH antenna. Bushes are incorporated into the coaxial feeding section of the ridges for the purpose of forming the outer conductor that then terminates the inner conductor into the top and bottom ridges. This causes the top and bottom ridges not to be identical anymore and two different parts needed to be manufactured. A detailed side cut-view of the top ridge is shown in Figure 5.2. The top ridge removed from the DRGH antenna from [4] is compared to the new improved top ridge in Figure 5.3, where the width taper of the ridge is clearly visible.

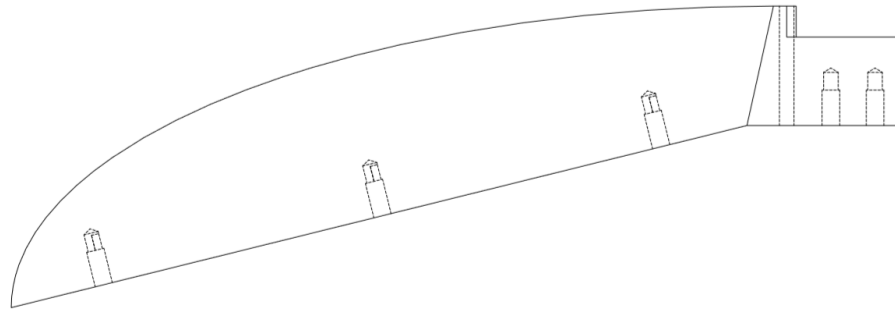


Figure 5.2. Detail cut-view drawing of the improved ridge.



Figure 5.3. Improved ridge compared to ridge from [4].

5.2.2 The complete DRGH antenna

The 3D isometric drawings of the complete DRGH antenna from Solid Works are shown in Figure 5.4 and 5.5 with the improved ridges inserted into the flared section. The thin sidewalls were implemented with etched PCB boards to replicate the thin sidewalls.

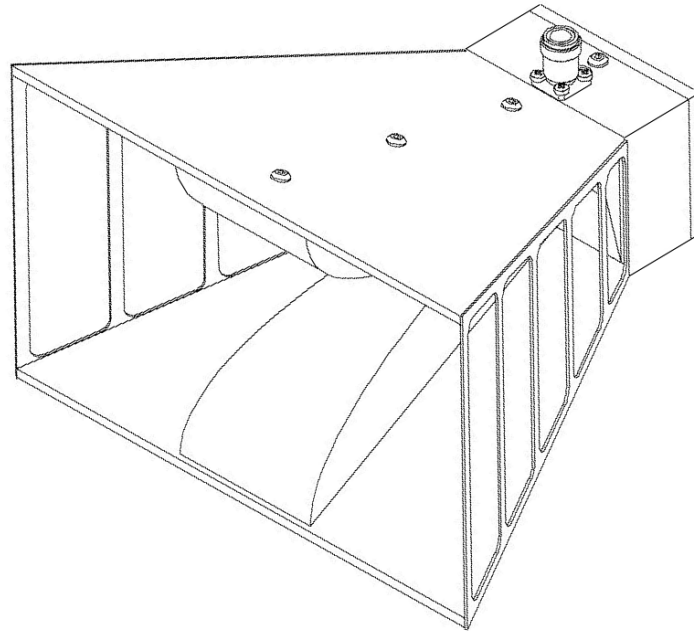


Figure 5.4. Isometric view of improved 1-18 GHz DRGH antenna.

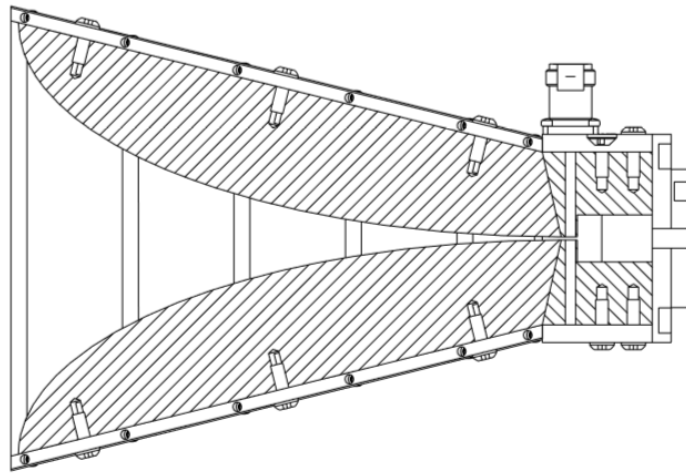


Figure 5.5. Isometric cut plane of improved 1-18 DRGH antenna.

5.3 A COMPARISON OF THE SIMULATED AND MEASURED PERFORMANCE FOR THE IMPROVED DRGH ANTENNA

In this section, a comparison is made between the measured results and simulated results. The improved ridges implemented into the DRGH antenna can be seen in Figure 5.6, as well

as the measured setup at the Compact Antenna Test Range of University of Pretoria in Figure 5.7. The following sections compare the performance results of the DRGH antenna looking at the VSWR, boresight gain, beamwidth and radiation patterns at specific frequencies.

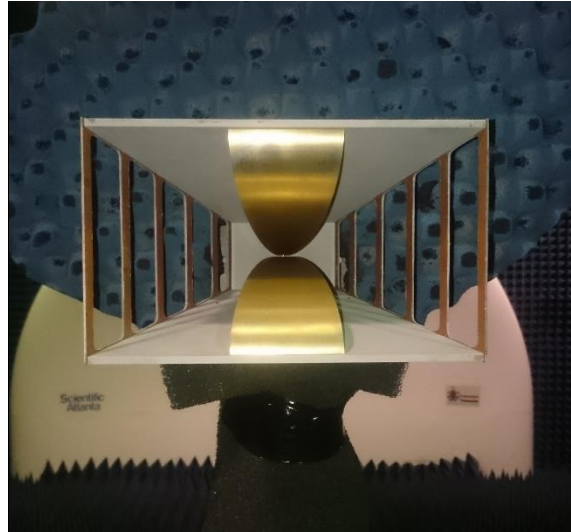


Figure 5.6. The manufactured antenna.

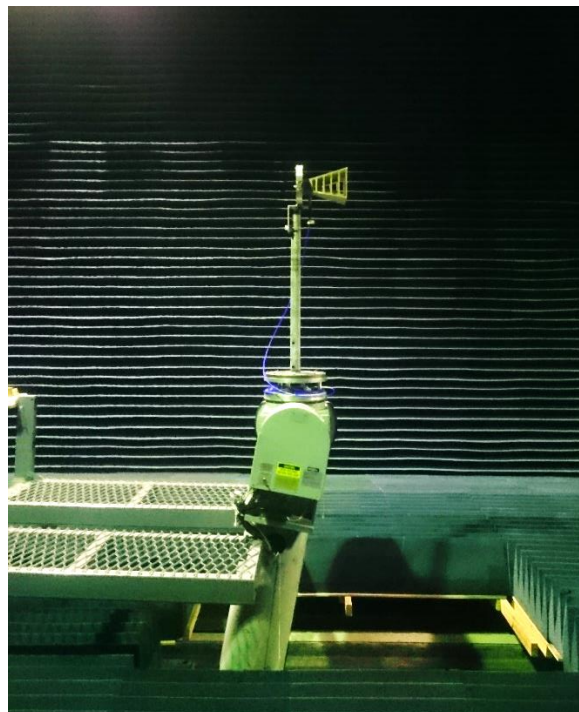


Figure 5.7. The antenna undergoing tests in the Compact Antenna Test Range.

5.3.1 VSWR

In Figure 5.8, the simulated and measured VSWR results of the improved DRGH antenna are displayed. The measured data compared well with the simulated results. The values track each other well with good agreement. A slight ripple is present in the measured results as expected due to the setup with non-ideal conditions. The VSWR remains below 2.1 for the entire frequency range from 1-18 GHz, presenting a maximum value of 2.1 at 4 GHz for the simulation data and at 2.2 GHz for the measured data.

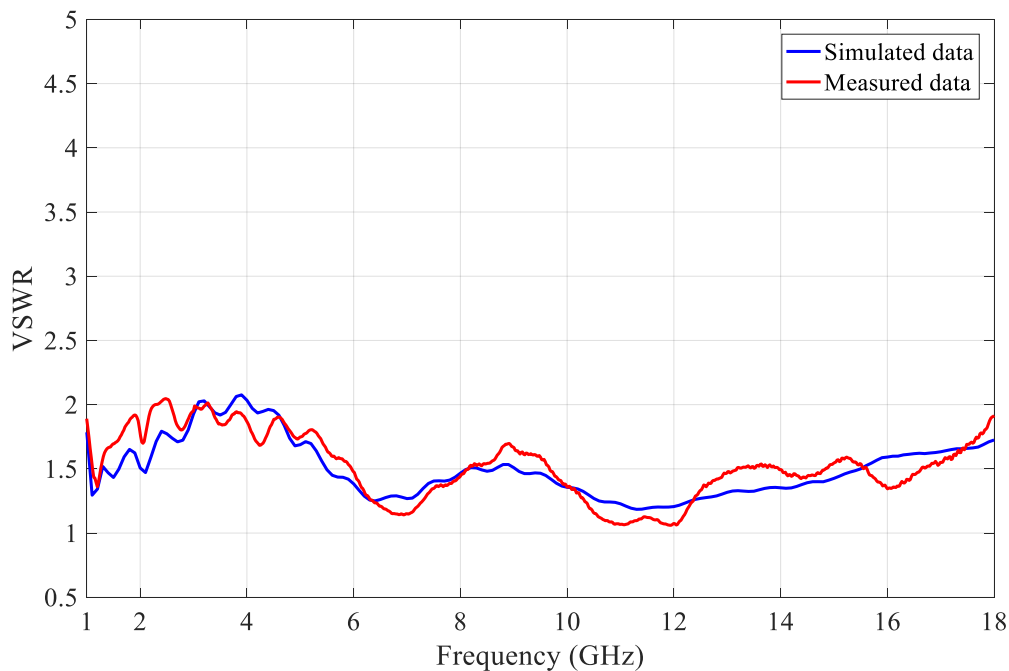


Figure 5.8. Comparison of the VSWR results.

5.3.2 Boresight gain

Figure 5.9 shows the simulated and measured boresight gain results of the improved DRGH antenna. The results compare well with each other, again displaying a slightly larger ripple in the measured data compared to the simulation data. The profile and slope of the two results remain the same with the only differences appearing 3 – 5 GHz and 13.5 GHz where the measured data differs roughly between 0.5 dB GHz to a maximum of 1 GHz. The gain increases approximately linearly over the frequency band as expected for a DRGH antenna.

The compared performance gives confidence in the numerical model as a simulation and analysis tool for the investigation and improvement of DRGH antennas.

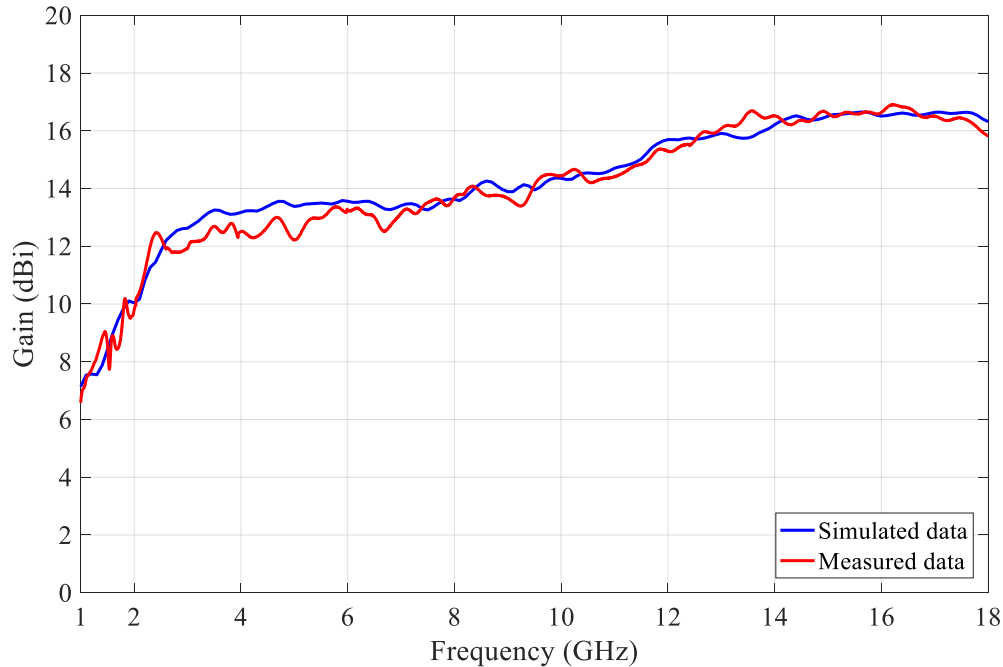


Figure 5.9. Comparison of the boresight gain results.

5.3.3 Radiation Patterns

The azimuth and elevation radiation patterns for the measured and simulated antennas are compared in Figures 5.10 and 5.11 for 1 GHz. There is a decent correlation between -90° and 90° degrees of the measured and simulated result. The off boresight outer angle differences are attributed to the space difference in the surroundings of the DRGH antenna in the measurement and simulation setup, this is mentioned in [1]. In simulation a numeric infinite space is compared to the finite anechoic chamber volume with weak scatters for measured results [1]. This phenomenon is observed in these results and as the frequencies increase the effect lessens. The results obtained at 6 GHz are shown in Figures 5.12 and 5.13 for the simulated and measured radiation patterns. The comparison between the results obtained provide an overall good agreement and is confirmed in the azimuth and elevation patterns for 12 GHz and 18 GHz shown in Figures 5.14 to 5.17.

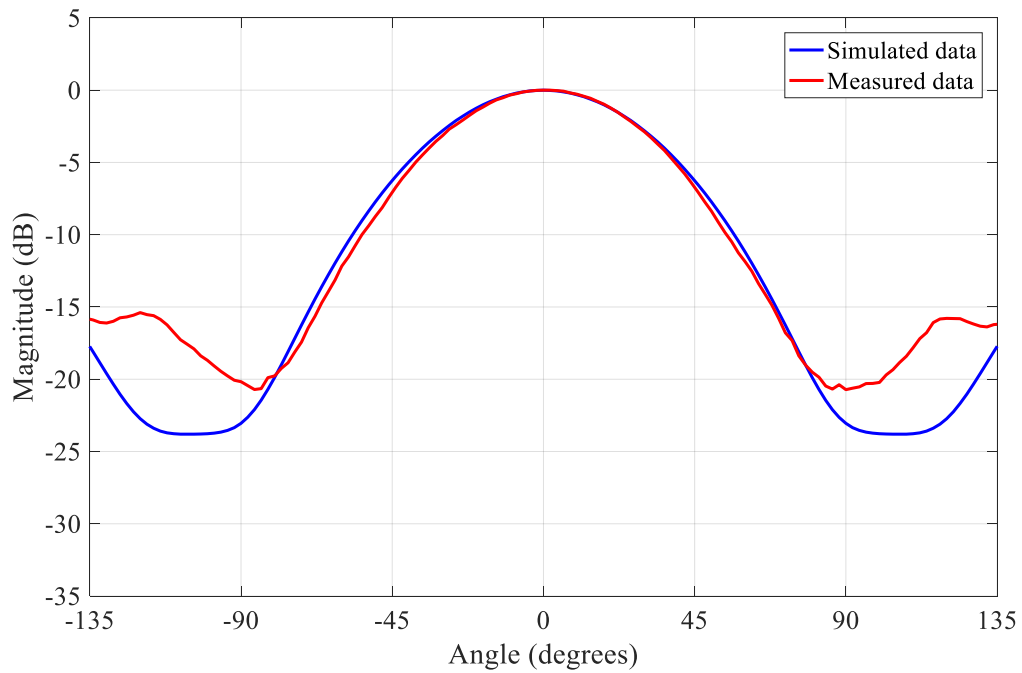


Figure 5.10. Comparison between the azimuth patterns (1 GHz).

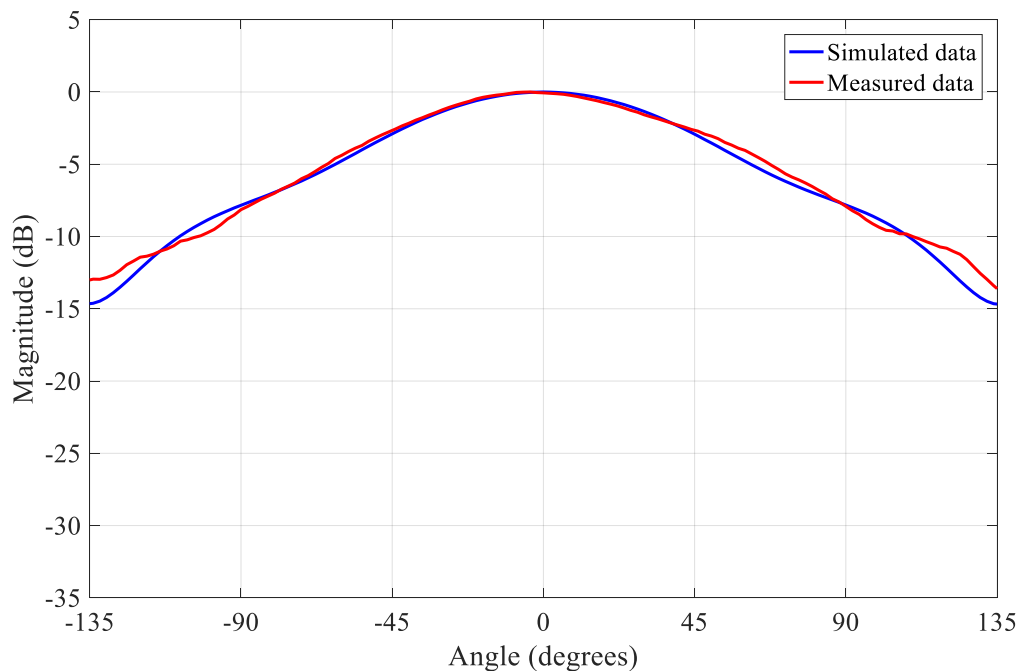


Figure 5.11. Comparison between the elevation patterns (1 GHz).

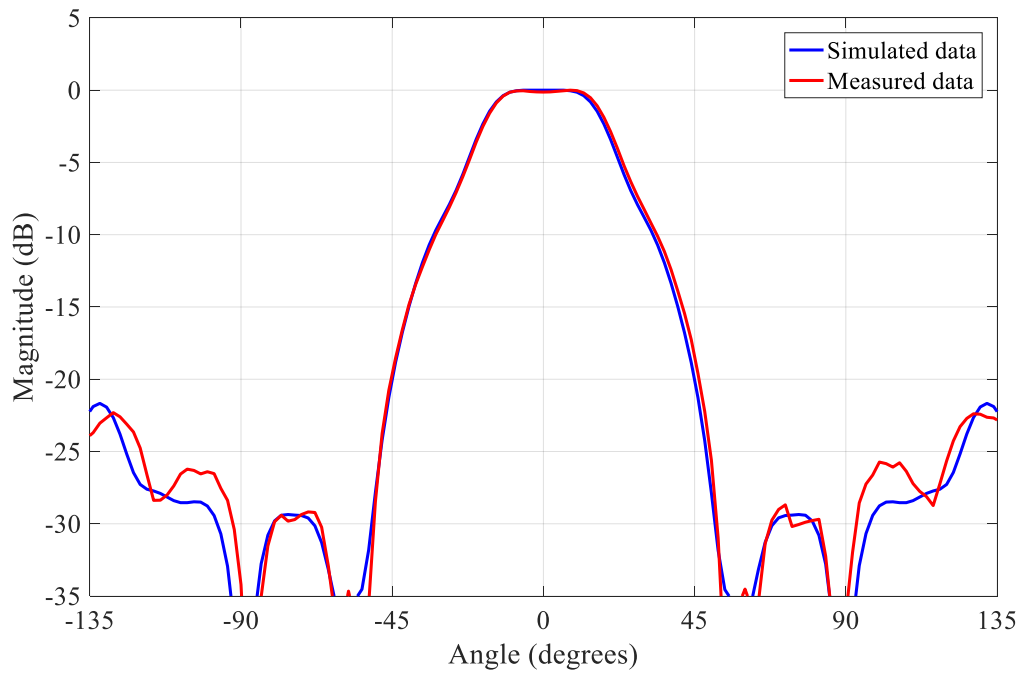


Figure 5.12. Comparison between the azimuth patterns (6 GHz).

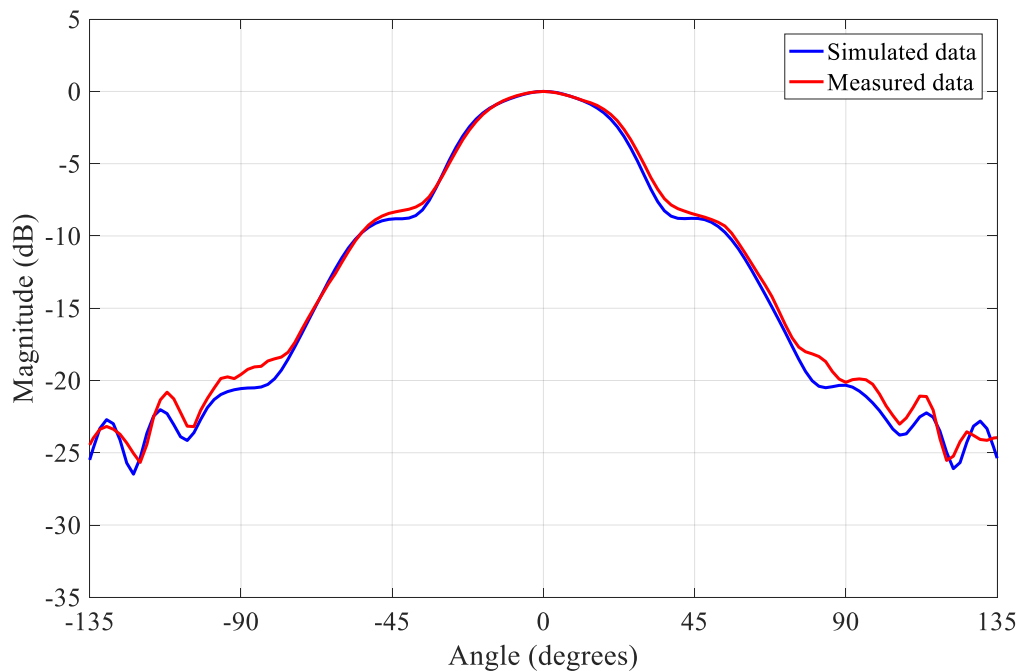


Figure 5.13. Comparison between the elevation patterns (6 GHz).

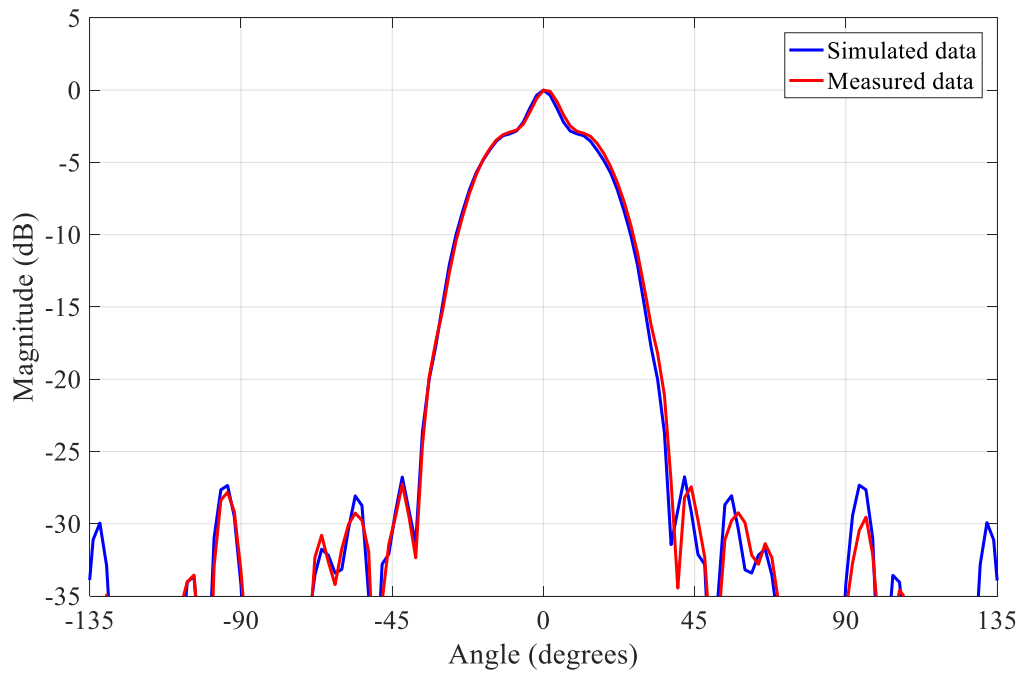


Figure 5.14. Comparison between the azimuth patterns (12 GHz).

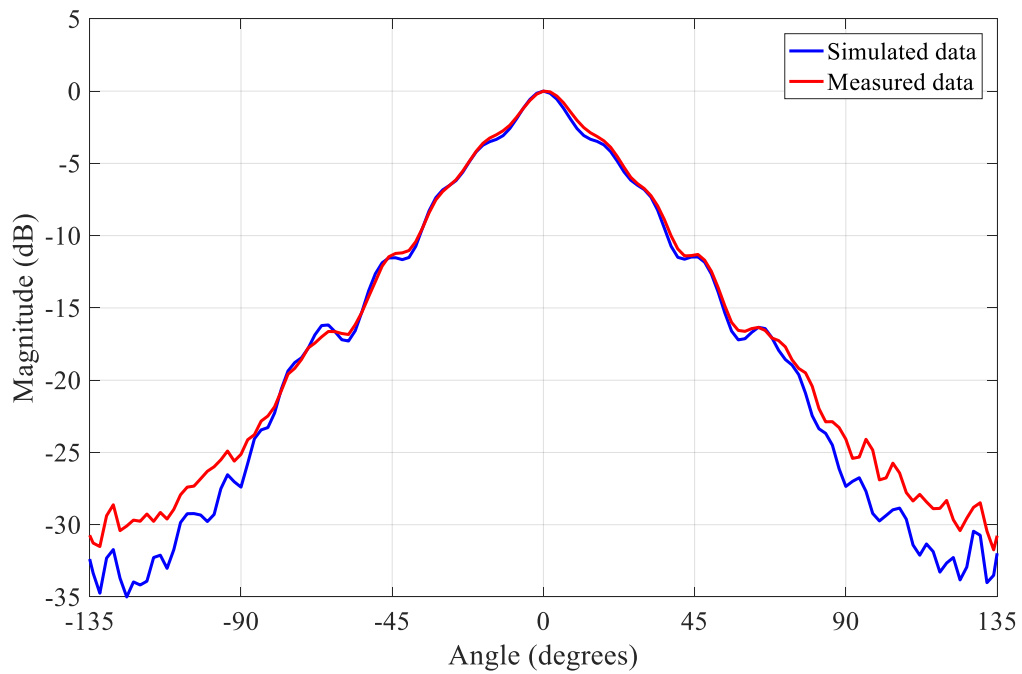


Figure 5.15. Comparison between the elevation patterns (12 GHz).

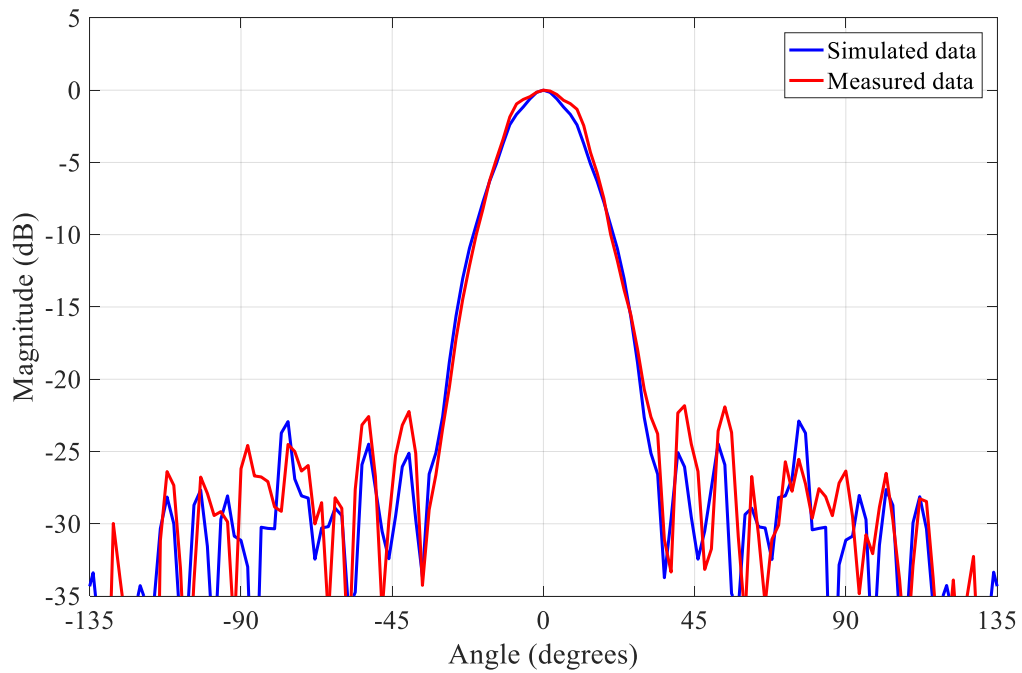


Figure 5.16. Comparison between the azimuth patterns (18 GHz).

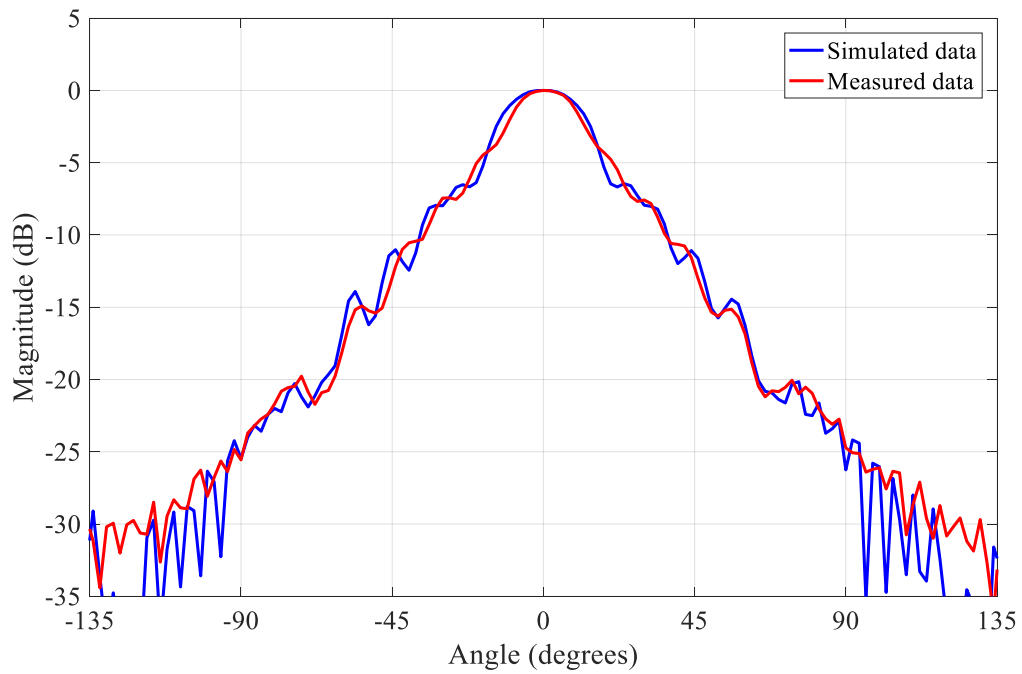


Figure 5.17. Comparison between the elevation patterns (18 GHz).

The 3D radiation pattern of the simulated numerical model at 18 GHz is shown in Figure 5.18. This is presented to confirm that no pattern breakup is obtained from the improved ridges implemented into the DRGH antenna. Small sidelobes start to form in the four off-axis positions but the main beam remains directional and well defined.

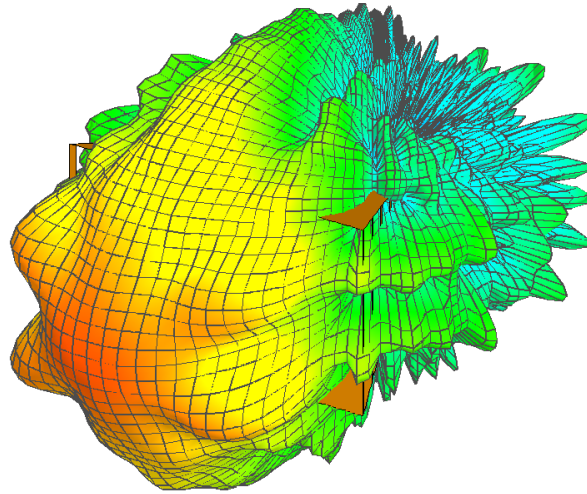


Figure 5.18. The simulated three-dimensional radiation pattern at 18 GHz.

Figure 5.19 displays the co-polarised result of the 45° plane for the simulated and measured models at 18 GHz. There is no pattern breakup present, with small sidelobes starting to form not changing the main beam directed at boresight. This is an important antenna parameter improved in [4], and it is clear from these results that the ridge improvement does not affect the improved pattern breakup.

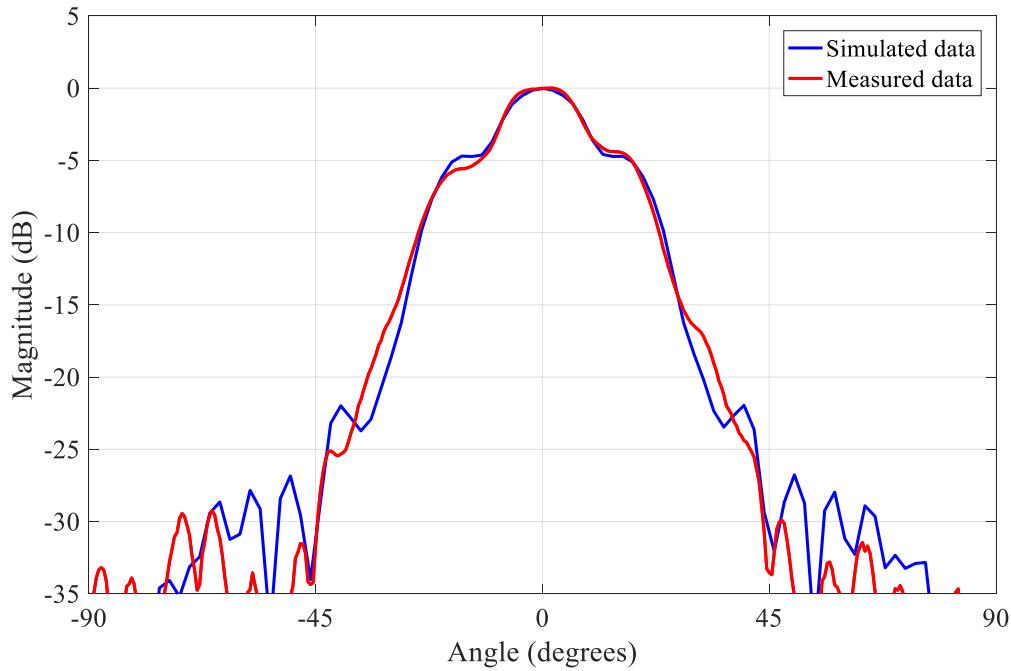


Figure 5.19. Comparison of the co-polarised pattern in 45° plane (18 GHz).

5.3.4 Beamwidth

The measured and simulated beamwidth parameters are displayed in Figures 5.20 and 5.21. The results show an overall excellent correlation, confirming the improved beamwidth result and relative constant response. The beamwidth result from 1 to 2 GHz is still very high whereas the results from 2 GHz upward presents an improved relatively constant response. This result is crucial for the purpose of this study and the comparison between the measured and simulated data confirms the goal of this dissertation. The 3 dB beamwidth ranges from 50° to 17° , indicating a centre deviation of 22.5° from 2 – 18 GHz. The 10 dB beamwidth ranges from 100° to 39° in the 2 – 18 GHz frequency range with a 30.5° deviation.

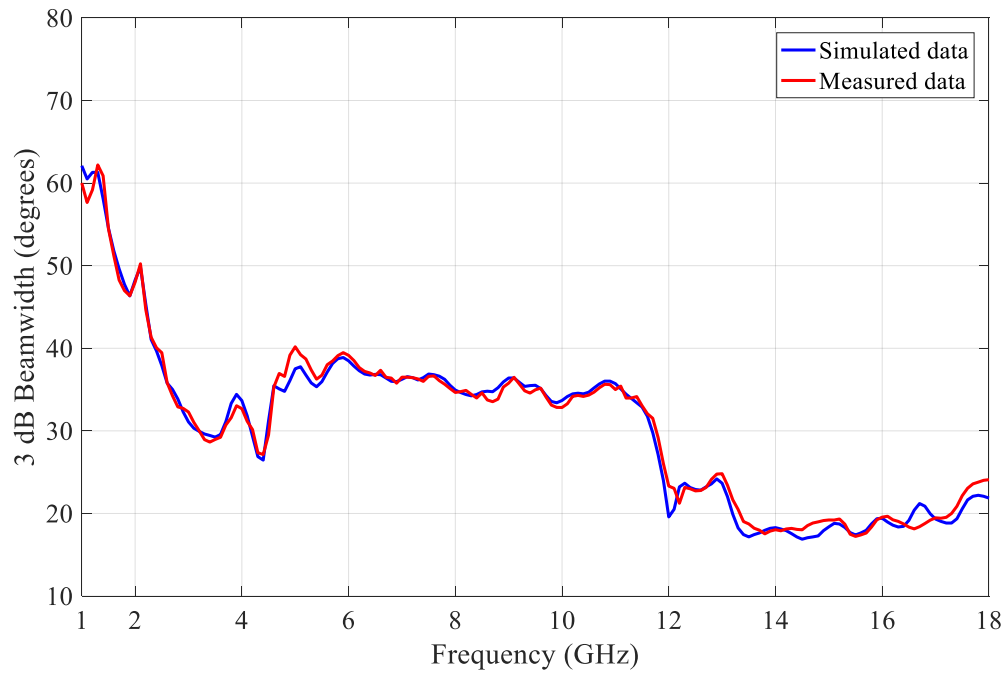


Figure 5.20. Comparison between the 3 dB beamwidth results.

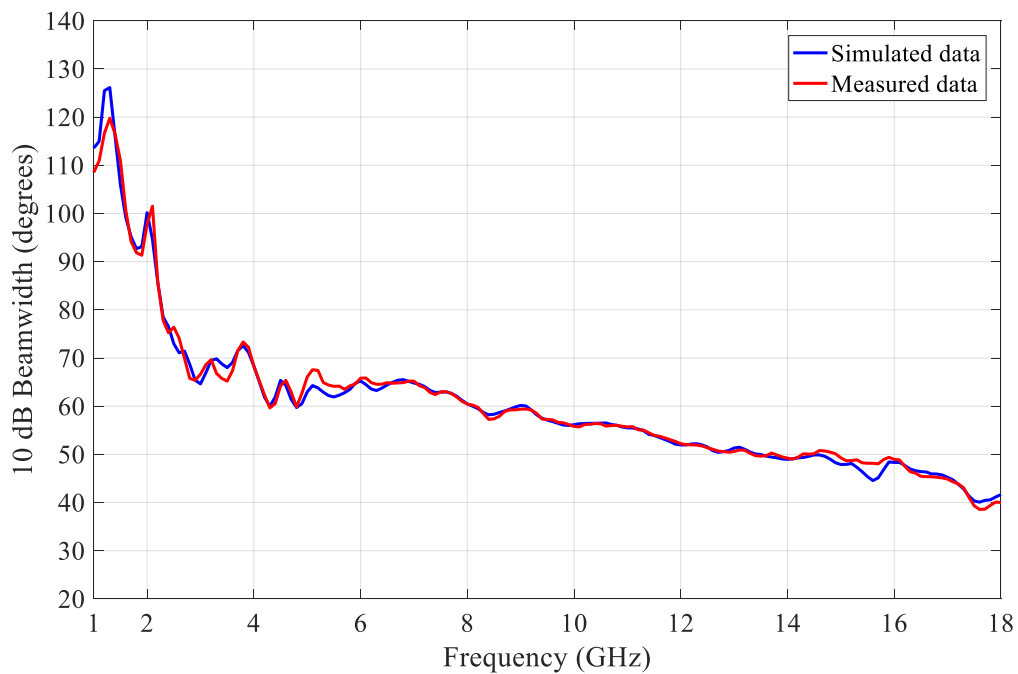


Figure 5.21. Comparison between the 10 dB beamwidth results.

5.4 SUMMARY

In this chapter the improved ridges were manufactured and incorporated into the DRGH antenna obtained from [4]. The complete improved DRGH antenna was measured and the results compared with the simulated results. The VSWR remained below 2.1 over the entire operating frequency range of 1-18 GHz. The boresight gain of the simulated and measured data matched up well ranging from 7.7 dBi to a peak value of 17 dBi. The radiation patterns also showed good agreement by following the same primary beam traces. The 3 dB and 10 dB beamwidth correlated well and confirmed the goal achieved of improving the constant response of the DRGH antenna. The overall antenna performance has been improved compared to the existing state of the art designs.

The last chapter provides a summary, conclusions and recommendations.

CHAPTER 6 CONCLUSION

6.1 GENERAL CONCLUSIONS

The main objective of this dissertation was to investigate and improve the performance of the DRGH antenna from 1-18 GHz, specifically for EMC/EMI applications. This study focused on improving the gain and beamwidth performance within the confined MIL [6] standard requirements. This was done by changing the ridges implemented in the flared section of the DRGH antenna whilst keeping the other elements constant. The literature study, presented in Chapter 2, uncovered that many improvements have been conducted on the traditional DRGH antenna with only very few focused on the effect of the ridges and even less on the effect of the width of the ridges or the profile of the ridges. The antenna published in [4] was chosen to define the box dimensions for the DRGH antenna that was simulated and verified as the starting point of this study.

Chapter 3, concentrated on creating a numerical model of the 1-18 GHz DRGH antenna that was developed in FEKO. The DRGH antenna was measured and the results compared with the simulation results. The boresight gain, VSWR and radiation patterns at specific frequencies, established confidence in the numerical model as the starting point for the further investigation and improvement. The results exhibited good agreement between the simulated numerical model and the measured results.

The ridge improvement process is presented in Chapter 4, where the effect of the ridges on the performance of the DRGH antenna was investigated. The box dimensions obtained in [4] remained constant as the starting point of the investigation. All the dimensions remained

constant except for the geometry of the two ridges. One specific parameter which was focused on was the improvement of the beamwidth response. This was achieved by increasing the boresight gain of the DRGH antenna at the lower frequencies. By doing this the beamwidth performance presented a relatively more constant response. The ridge profile was investigated and three different profiles were applied to the ridges and analysed. The selection of the elliptical profile as the new ridge profile was due to the comparison of the gain results presenting the most improved performance, especially at the lower frequencies. The second part of the ridge improvement consisted of analysing the characteristic wave mode impedance transition of the flared section across the axial length and the effect of the ridge width on the gain and beamwidth performance of the DRGH antenna.

Based on the results of this study, it was demonstrated that by tapering the width of the ridges from the start of the axial length up until the aperture of the DRGH antenna resulted in the boresight gain to increase. The characteristic wave mode impedance transition of the axial length affected the performance significantly and was improved by the type of profile that the ridge width followed. The most improved performance was observed when the ridge width taper was linear without any discontinuities implemented.

To investigate the phenomena and the effect that the ridge width had on the performance of the DRGH antenna, a near field study was conducted on the improved DRGH antenna and compared to the performance of the DRGH antenna from Chapter 3. The results indicated that by increasing the radiating area of the antenna caused the boresight gain to increase, specifically at the aperture of the DRGH antenna where the ridges are at their widest. The radiation patterns additionally explained the ridge width effect, seen in Chapter 4; the sidelobes were lowered thereby transferring this power level into the main beam. This change in the ridge width profile improved the boresight gain up 1 dB in the frequency range from 3 – 16 GHz and subsequently increasing the range of the 3 dB beamwidth constant response by 12.5° over the entire frequency range and 18° from 2.5 GHz upwards. The 10 dB beamwidth resulted in a 12° smaller range over the 1 – 18 GHz bandwidth. The improved ridged effected the 3 dB beamwidth in the 10 ° range from the mean value by 23.3 % .This

result followed through to the 10 dB beamwidth that was improved by 70 % in the $\pm 10^\circ$ range from the mean value.

Chapter 5, presented the mechanical manufacturing of the improved ridges for the DRGH antenna from Chapter 3. The prototype DRGH antenna from [4] was used by removing the old ridges and inserting the improved ridges. The DRGH antenna was measured and results were compared to the simulation results. A maximum VSWR of 2.1 was measured across the 1 to 18 GHz bandwidth, with a value of less than 2 for 98 % of the bandwidth. The boresight gain of the manufactured DRGH antenna ranges from 7.7 dBi to 15 dBi, following a relatively linear slope. The conclusion was that the measured and simulated results presented an excellent correlation and confirmed the validity of the improved DRGH antenna. The slight differences observed between the simulated and measured performances of the improved DRGH antenna can be due to manufacturing tolerance and non-ideal conditions when measuring.

In conclusion, the primary objective of the dissertation was achieved, by improving the performance of the DRGH antenna, specifically generating a relatively more constant beamwidth performance for EMC/EMI purposes. The above discussion revealed that the improved DRGH antenna improved the performance of the published DRGH antenna from [4].

6.2 CONTRIBUTION TO THE IMPROVEMENT OF THE DRGH ANTENNA

This dissertation's contributions are listed in the summary below:

- Development of a numerical DRGH antenna model.
- The effect which the ridge profile has on the boresight gain was investigated and a new ridge profile was obtained.
- A comprehensive examination into the characteristic wave mode impedance taper of the flared section of the DRGH antenna, including the effect that the taper profile

has on the performance of the DRGH antenna.

- The ridge width effect was studied by completing a parameter study and investigating how the end width value effected boresight gain of the DRGH antenna.
- Manufacture of an improved DRGH antenna with new ridges resulted in improved gain and beamwidth performance.

6.3 FUTURE RESEARCH

During the process of this dissertation, the following possible future research areas were discovered concerning the DRGH antenna.

A detailed investigation to determine the optimum sidewalls implemented into the DRGH antenna and whether the utilisation of gridded sidewalls or no sidewalls implemented into the flared section of the DRGH antenna could help to enhance the overall radiation performance of DRGH antenna.

The need for an even wider operating frequency band is required for more applications today with a nearly constant beamwidth (frequency independent). This examination of the requirement possibly achievable through developing an improved DRGH antenna for applications such as Direction Finding (DF) systems and various other applications.

Modern-day Electronic Warfare (EW) systems require increased wideband coverage. Previously, EW operating bands were from 2-18 GHz. Today, they range from 0.5 to 18 GHz and it is preferred that the entire band should be covered by a single antenna. A source antenna needed for the calibration of these antennas will also reduce measurement time and development costs. Future research will be the development of a DRGH antenna that can at least operate from 0.75- 18 GHz, this will no longer be for EMC/EMI applications.

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