An Optimized Ku-Band Conical Horn Reference Antenna for Far-Field Antenna Measurements

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Abstract. The research discusses the vital role of antennas in communication and telecommunications systems, with a focus on the design of a conical horn antenna for far-field measurements in the Ku-Band frequency range. Simulations using CST Studio 2019 were conducted to obtain the best design that meets the required standards for return loss and gain within the 10.7-14.5 GHz frequency range. The optimized design exhibits linear polarization, directional radiation patterns, and superior size efficiency compared to the Balanis design. The optimized design features smaller dimensions with a cone diameter of 8.68 cm and cone length of 9.73 cm and boasts the lowest return loss value of approximately -36.022 dB, the highest VSWR value of 1.055 as well as the lowest gain value of 18.265 dBi. In conclusion, this optimized conical horn antenna holds significant potential for practical applications in communication and telecommunications systems within the Ku-Band frequency range.

Keywords: conical horn antenna, far-field measurement, Ku-Band, reference antenna.

1 Introduction

In communication and telecommunications systems, antennas play a crucial role in transmitting and receiving wave signals. For antennas to function effectively, it is necessary to measure and understand their characteristics based on specific standards. Several fundamental antenna characteristics that need to be measured include VSWR, return loss, gain, radiation patterns, and polarization. All of these factors determine the performance capabilities of the antenna. Measurement of antenna characteristics can be conducted under two conditions: near-field and far-field [1]. The near-field method is used to measure the electromagnetic field produced by an antenna at very close distances [2]. However, for specific situations, the far-field measurement technique is preferred for identifying amplitude and phase features of the Tested Antenna Under Test (AUT) [3]. The far-field approach serves to assess antenna radiation patterns, polarization, and gain. In the traditional scenario of far-field antenna measurements, the transmitting and receiving antennas are usually positioned at a sufficient distance to simulate the desired operational environment. Ideally, far-field measurements are conducted within an anechoic chamber, a space designed to minimize wave reflections [1].

ABEC 2023, September 21, Bengkalis, Indonesia

DOI 10.4108/eai.21-9-2023.2342896

Apart from anechoic chambers, a critical component in measurement systems is the reference antenna. Specific requirements must be met for an antenna to function as a reference antenna in antenna measurements. These requirements encompass various criteria, including radiation pattern stability, measurable characteristics, the ability to generate focused radiation patterns, and the capacity to produce symmetrical radiation patterns. Radiation pattern stability indicates that the reference antenna must consistently produce consistent and symmetrical radiation patterns. This enables the reference antenna to be used as a benchmark for comparison with more complex antennas [4]. Measurable characteristics encompass aspects such as impedance, return loss, VSWR, bandwidth, gain, and radiation patterns, all of which must be accurately measurable on the reference antenna [5]. Proficiency in producing focused radiation patterns signifies that the reference antenna used in antenna measurements should be capable of generating focused and stable radiation patterns. This can be achieved using antenna types like horn antennas or parabolic reflector antennas [6],[7]. This research employs a horn antenna with a focus on the utilization of the Ku-band frequency. The first study [8] utilized brass material for antenna realization, yielding promising outcomes, with a VSWR value recorded at 1.216. The radiation pattern was unidirectional, polarization was linear, and the gain value reached 13.52 dB. However, the resulting antenna dimensions were quite large, with a cone diameter of approximately 116.66 mm and a cone length of 200 mm. The second study developed a Ku-band horn designed by using brass, with a VSWR value of 2 at 5-18 GHz and a gain value of 11.551 dBi. The antenna dimensions were also large, with a cone diameter of 220 mm and a cone length of 270 mm [9].

This research chose to use a horn antenna due to its mechanically simple nature and its relative simplicity in terms of electrical components. The advantage of mechanical simplicity facilitates ease of antenna replication. The simplicity of electrical components allows for easier design and the use of established design formulas. The horn antenna, resembling a horn in shape, is capable of operating at high frequencies. Some specific advantages include its widespread use in various fields such as electromagnetic compatibility (EMC) testing, antenna gain measurements, satellite tracking systems, and as a reflector in radar applications [10]. These advantages stem from the horn antenna's special characteristics, including ease of initiation, relatively simple fabrication processes, high gain and directivity performance, and high power capabilities [11]. This study aims to design a superior conical horn antenna, particularly in terms of gain when compared to previous research. The antenna's dimensions are planned to be more compact, and aluminum material, which is more cost-effective and readily available than brass, will be used.

2 Research Methods

This research employs both analytical and applicative approaches in developing a study that focuses on the Design and Construction of a Conical Horn Antenna as a Reference Antenna for Far-Field Measurement of Antennas in the Ku-Band Frequency. Several methodologies are utilized to support this research. The following are the methodologies applied in completing the conducted study, as depicted in Figure 1.

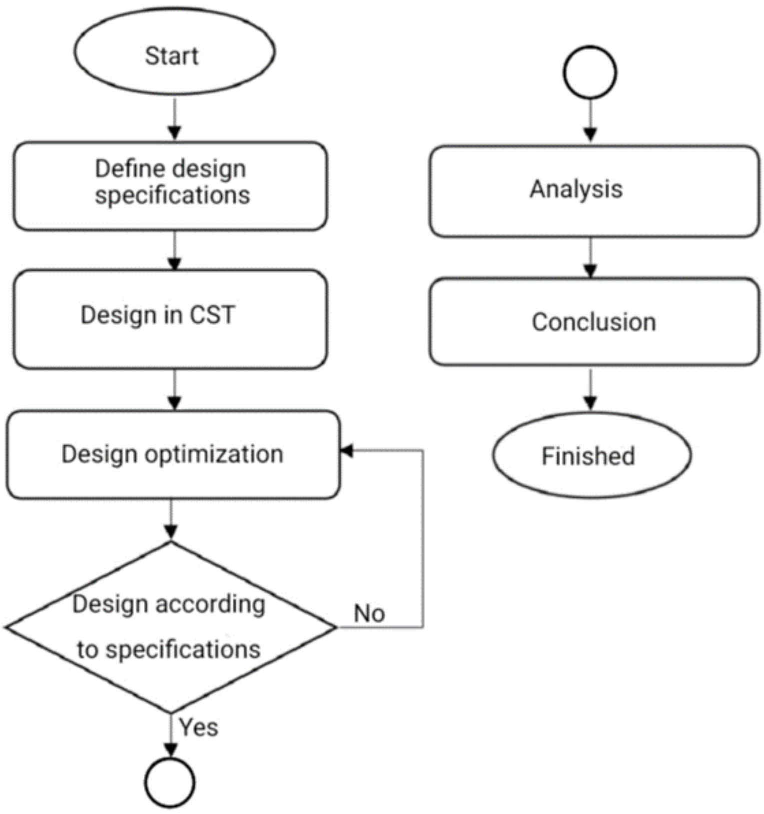

Fig 1. Flowchart of research implementation stages

2.1 Determination of Antenna Design Specifications

In the initial stage of antenna design, a crucial step is to define specifications that are suitable for the intended antenna design. The purpose of these specifications is to provide a better understanding of the design process and to meet the desired antenna parameters. Table 1 presents a summary of the intended specifications.

Table 1. Antenna design specifications

Antenna Type	Conical Horn
Operating Frequency	
• Receiver	10.7-12.75 GHz
• Transmitter	13.75-14.5 GHz
Gain	> 10 dB
VSWR	1: 1.5
Return Loss	<-10 dB
Polarization	Linear
Radiation Pattern	Unidirectional

2.2 Design of Conical Horn Antenna in CST

In the antenna design process, the dimensions of the antenna need to be determined according to the operating frequency used. Generally, the dimensions of a conical horn antenna can be observed in Figure 2. To design a horn antenna with specific gain, wavelength, and frequency within an antenna design, the following procedure can be employed [12] :

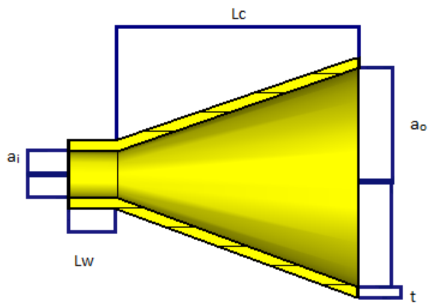

Fig 2. Conical horn antenna dimensions

$$\lambda = \frac{c}{f} \tag{1}$$

In the initial stage, it is necessary to determine the value of λ (wavelength) from the operating frequency. In this step, the value of f represents the average of the operating frequency range of this study, which is 10.7-14.5 GHz. The value of c, the speed oof lighin a vacuum, is 3×10^8 m/s. Once the value of λ is obtained, the process moves to the next step, as described by the following equation:

$$a_i = \frac{3\lambda}{2\pi} \tag{2}$$

The equation above is used to determine the dimensions of the waveguide radius that will be designed.

$$a_o = \frac{\lambda}{2\pi}\sqrt{10^{(G_{dBi}+2.91)/10}} \tag{3}$$

Then, the process continues by calculating th cone radius in the design using equation 3.$R = \frac{4a_o^2}{3\lambda}$ (4)

$$\theta = arcsin\left(\frac{a_o}{R}\right) \tag{5}$$

$$L_C = \frac{a_o - a_i}{tan\,\theta} \tag{6}$$

To determine the length of the cone to be designed, the first step is to determine the value of R using equation 4. Then, proceed to find the value of θ as described in equation 5. With this t cone elength denotedas L_C, can be calculated b ased on equation 6

. $\lambda_c = \frac{2\pi a_i}{X_{mn}}$ (7)

$$\lambda_g = \frac{\lambda}{\sqrt{1-\left(\frac{\lambda}{\lambda_C}\right)^2}} \quad (8)$$

$$L_w = \frac{3}{4}\lambda_g \quad (9)$$

The equation above represents the process of obtaining the waveguide length, where λ_c is the wavelength of TE11 mode (dominant for conical horn antenna), athenandx_{mn} value used is 1.841. This leads to the antenna dimensions as shown in Table 2.

Table 2. Balanis equation design

Frequency (GHz)	a_o (cm)	L_C (cm)	a_i (cm)	L_w (cm)	t (cm)
10.7 – 14.5	5.34	11.73	1.1464	2.28	0.5

a. Waveguide Diameter (a_i)

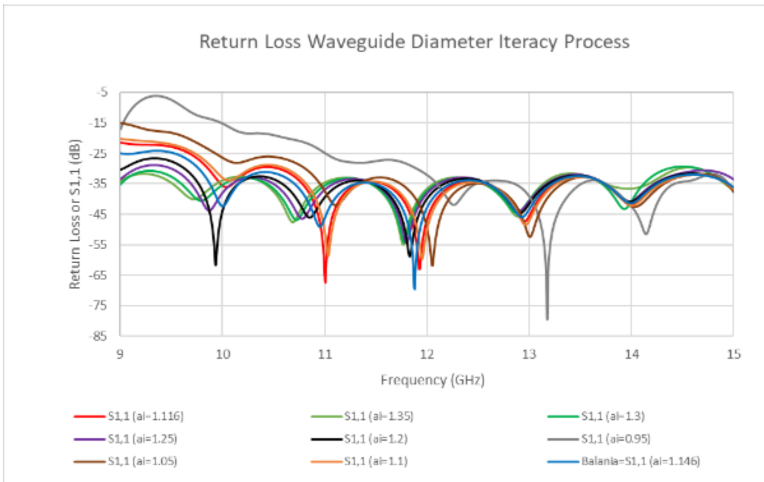

Fig 3. Iteration Graph of Return Loss for Variable a_i

Figure 3 displays a comparison of simulated return loss results during the iteration of the a_i size variable in the frequency range of 10.7-14.5 GHz. The return loss results at 10.7 GHz have the highest value of -20.505 dB with an a_i variable size of 0.95 cm and the lowest value of -47.283 dB with a size of 1.35 cm a_i. At 14.5 GHz, the highest value is -29.242 dB with an a_i size of 1.3 cm, and the lowest value is -34.292 dB with an a_i size of 0.95 cm. Overall, the return loss graph indicates the highest average value with an a_i variable size of 0.95 cm and the lowest average value with an a_i size of 1.116 cm. The simulation results for the return loss parameter obtained eexceedtheAlanisequation return loss value. As a result, for the best iteration, the $a_i$variable size is 1.116 cm.

b. Waveguide Length (L_w)

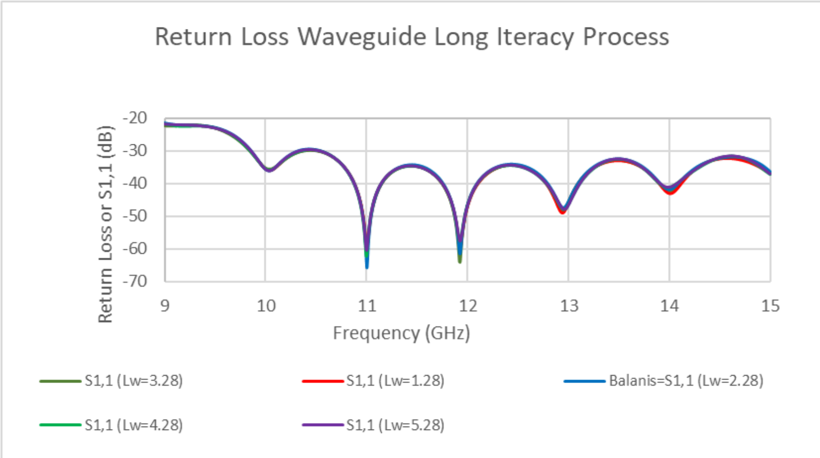

Fig 4. Iteration graph of return loss for variable L_w

Figure 4 depicts the return loss parameter results from the iteration of the variable L_w size, with two sizes (L_w 3.28 cm and 1.28 cm) having average return loss values lower than the Balanis' equation L_w size. The simulation results for the return loss at the L_w variable size of 1.28 cm closely approach the parameter values of the Balanis' equation L_w variable size. However, in antenna fabrication, the L_w size of 1.28 cm is challenging for adapter installation. Therefore, it is recommended to use the L_w size of 3.28 cm.

c. Cone Diameter (a_o)

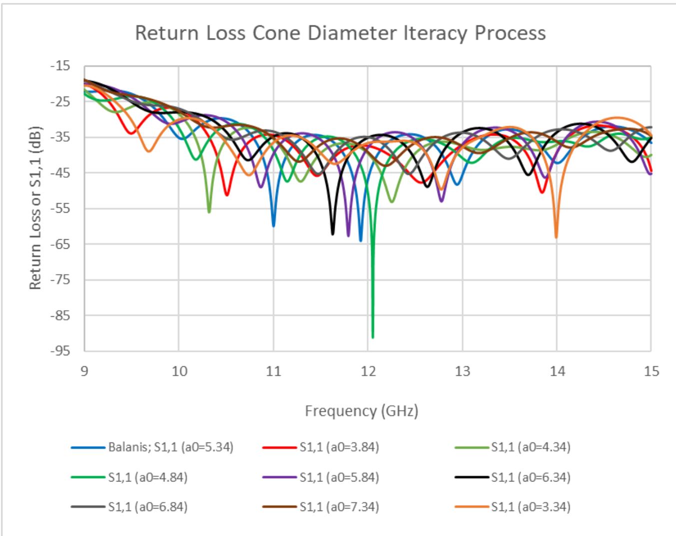

Fig 5. Iteration Graph of return loss for variable a_o

Figure 5 presents a comparison of the simulated return loss results as they change during the iteration of the a_o variable size. All variables meet the return loss parameter specification of -10 dBi within the operating frequency range of 10.7-14.5 GHz. At 10.7 GHz, the highest return loss value is -31.457 dBi with an a_o size of 4.84 cm, and the lowest is -44.733 dB with an a_o size of 3.34 cm. At 14.5 GHz, the highest return loss value is -30.165 dB with an a_o size of 3.34 cm, and the lowest is -38.038 dB with an a_o size of 6.84 cm. The average return loss is lower for an a_o size of 4.34 cm, while the highest value is held by an a_o size of 7.34 cm. The best iteration for the a_o variable is with a size of 4.34 cm, which exhibits a lower average return loss.

d. Cone Length (L_C)

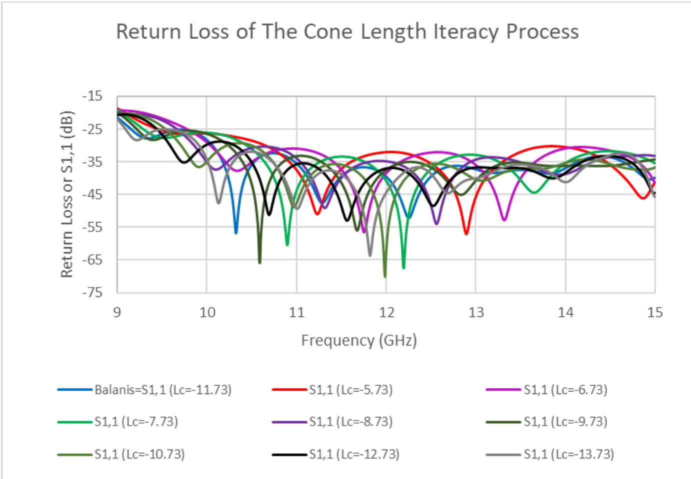

Fig 6. Iteration graph of return loss for variable L_C

Figure 6 displays the simulation results of return loss that meets the specifications within the frequency range of 10.7-14.5 GHz. At 10.7 GHz, the highest return loss is -30.55 dBi with a L_C size of 8.73 cm, and the lowest is -51.049 dBi with aacapaL_C size of 12.73 cm. At 14.5 GHz, the highest return loss is -31.664 dBi with aaL_C size of 6.73 cm, and the lowest is -36.191 dBi with aanaL_C size of 9.73 cm. The average return loss is lower for aaL_C size of 13.73 cm, while the highest value is associated with aaL_C size of 6.73 cm. The best iteration for the L_C variable is with a size of 9.73 cm, which has a smaller cone length and sufficiently low average return loss.

e. Antenna Thickness (t)

Figure 7 displays the simulation results of return loss that meet the specifications within the frequency range of 10.7-14.5 GHz. At 10.7 GHz, the highest return loss is -37.552 dBi with a t size of 0.3 cm, and the lowest is -43.758 dBi with a t size of 0.7 cm. At 14.5 GHz, the highest return loss is -34.644 dBi with a t size of 0.3 cm, and the lowest is -36.91 dBi with a t size of 0.6 cm. The average return loss is lower for a t size of 0.4 cm, while the highest value is associated with a t size of 0.7 cm. In terms of the return loss parameter, the best value is the smallest value. Therefore, for the iteration, the antenna thickness (t) of 0.4 cm is chosen.

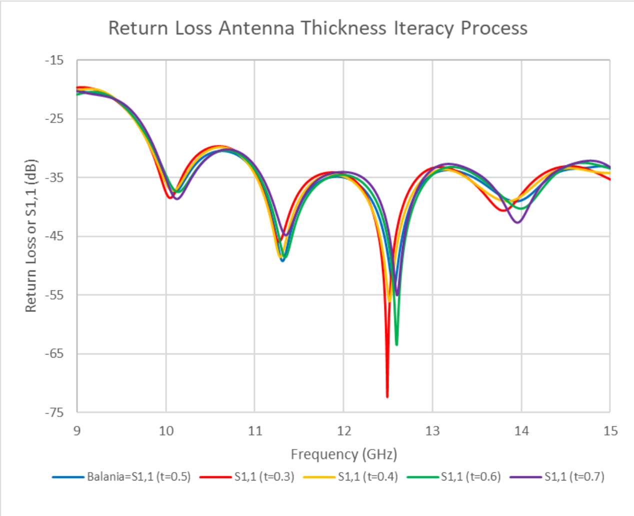

Fig 7. Iteration graph of return loss for variable t

3 Result and Discussion

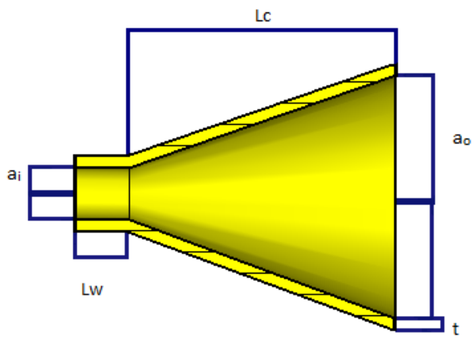

Fig 8. Conical Horn Antenna

Table 3. Balanis design sizes and optimization design sizes

Antenna Design	Frequency (GHz)	a_o (cm)	L_C (cm)	a_i (cm)	L_w (cm)	t (cm)
Balanis	10.7 – 14.5	5.34	11.73	1.1464	2.28	0.5
Optimization	10.7-14.5	4.34	9.73	1.116	3.28	0.4

Figure 8 depicts the representation of the antenna design with Balanis sizes and the optimization design of the conical horn antenna, while Table 4 contains sizes derived from the Balanis equations and the best iteration sizes. Altering the sizes has an impact on the obtained return loss and gain.

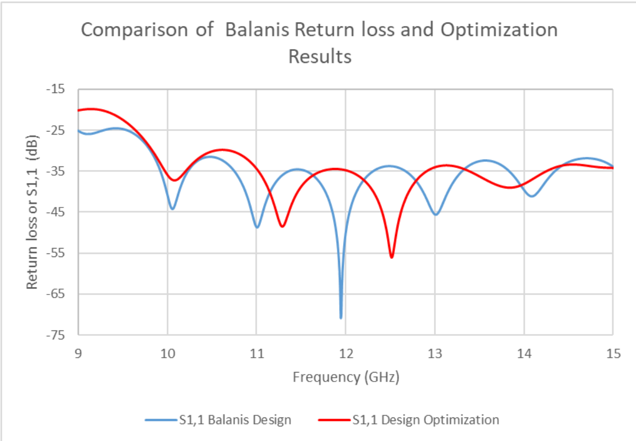

Fig 9. Iteration Graph of Return Loss

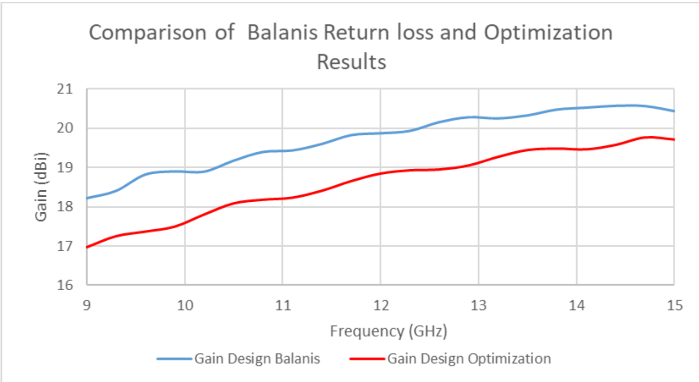

Fig 10. Iteration Graph of Gain

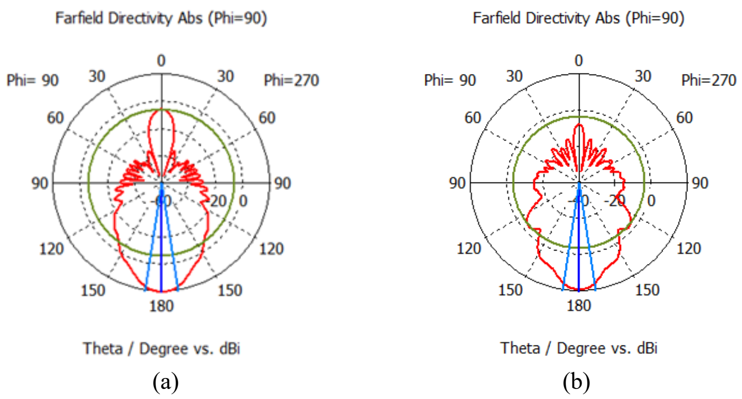

Fig 11. Radiation Pattern of Conical Horn Antenna at 12 GHz:
(a) Balanis Design; (b) Optimization Design

Figure 9 displays the simulation results of return loss meeting the specifications within the 10.7-14.5 GHz frequency range. At 14.5 GHz, the Balanis-sized design has the highest return loss (-32.791 dB), and the lowest is at 12.75 GHz (-36.443 dB). The optimization design has the highest return loss at 14.5 GHz (-36.022 dB) or VSWR value of 1.055 and the lowest at 12.75 GHz (-45.001 dB). The Balanis equation-based design exhibits a lower average return loss, whereas the optimization design has the highest return loss. Figure 10 illustrates the simulation results of gain fulfilling the 10-17 dBi specification within the 10.7-14.5 GHz frequency range. At 14.5 GHz, the Balanis-sized design achieves the highest gain (20.558 dBi), and the lowest is at 10.7 GHz (19.322 dBi). The optimization design attains the highest gain at 14.5 GHz (20.136 dBi) and the lowest at 10.7 GHz (18.265 dBi). Even though the optimization results do not surpass the gain and return loss of the Balanis-based design, they meet the expected specifications with a smaller antenna size than the Balanis design, enabling the use of the best iteration design for fabrication.

Comparing the performance of the conical antenna from the equation and previous research [8] provides insight into the extent of the optimization conducted in the design. Table 4 reveals the dimensions of the largest conical horn antenna from the literature, with a cone diameter of 11.6665 cm and cone length of 20 cm. The optimized design features smaller dimensions with a cone diameter of 8.68 cm and a cone length of 9.73 cm. These dimensions are smaller compared to those obtained from the Balanis equation, with a cone diameter of 10.685 cm and cone length of 11.7263 cm. Table 5 presents a comparison of the conical horn antenna parameters using the Ku-band frequency. The gain of the Balanis equation-based design is greater than that of other designs, exceeding 19 dBi, while the lowest gain is 13.52 dBi in the literature-based design. The optimized design boasts the lowest return loss value of approximately -36 dB, with the highest return loss in the Balanis-based design reaching -32 dB. The best VSWR value is found in the optimized design at 1.055. The polarization of all three designs is linear, and their radiation pattern is unidirectional as shown in Figure 11 for Balanis and optimization designs, in line with the specified antenna requirements.

Table 4. Antenna size comparison

Antenna Design	a_o (cm)	L_C (cm)	a_i (cm)	L_w (cm)	t (cm)
Balanis	5.34	11.73	1.1464	2.28	0.5
Literature 1 [8]	5.83325	20	1.05	2.38	unknown
Literature 2 [9]	11	27	5.44	1.35	0.1
Optimization	4.34	9.73	1.116	3.28	0.4

Table 5. Antenna parameter comparison

Antenna Design	Gain (dB)	Return Loss (dB)	VSWR	Radiation Pattern	Polarization
Balanis	19.322	-32.791	1.06	Unidirectional	Linear
Literature 1 [8]	13.52	unknown	1.25	Unidirectional	Linear
Literature 2 [9]	11.55	-10.501	1.851	Unidirectional	Linear

Optimization	18.265	-36.022	1.055	Unidirectional	Linear

4 Conclusion

The results of this research conclude that the successful development of a conical horn antenna design has been achieved with characteristics including linear polarization, unidirectional radiation pattern, return loss less than -36.022 dB, VSWR less than 1.055 and a gain more than 18.265 dBi. The optimized design features smaller dimensions than Balanis and literature designs with a cone diameter of 8.68 cm and cone length of 9.73 cm. The simulation results demonstrate that this antenna design aligns with the desired specifications for the Ku-band frequency range.

Acknowledgments

The authors would like to express gratitude toward Politeknik Negeri Padang for funding this research with contract number 153/PL9.15/PG/2023.

References

[1] Maulana,C., D. A. Nurmantris., and Wahyu,Y.: Perancangan dan Realisasi Antena Double-Ridged Horn Untuk Standar Pengukuran Antena. e-Proceeding of Applied Science. Vol. 4, No.3 (2018)

[2] Apriono, C.: Pengukuran Antena dengan Metode Medan Dekat pada Permukaan Pengukuran Planar. Skripsi, FT UI (2009)

[3] MSA2021: The Near-Field vs. Far-Field Regions of an Antenna. Cadence System Analysis Blog. [Online]. Available: https://resources.system-analysis.cadence.com/blog/msa2021-the-near-field-vs-far-field-regions-of-an-antenna. [Accessed: Aug. 11, 2023]

[4] Sandi, E., Diamah, A., and Santoso, A. I.: Desain Antena Reflektor Parabola untuk Aplikasi Radar Maritim dengan Rekayasa Feed Horn. Vol. 11, No. 2, pp 451-465 (2023)

[5] Afkarulislam, M., Wijanto, H., and Edwar.: Perancangan dan Realisasi Antena Reflektor Parabola dengan Feed Point Mikrostrip untuk Stasiun Bumi SatelitA Geo-Kompsat-2A. Open Library of Telkom University. Vol. 3, No. 2, pp 5368- 5375 (2021)

[6] Hidayatullah, A.: Perancangan dan Realisasi Antena Reflektor Parabola dengan Feed Point Heliks untuk Stasiun Bumi Satelit Nano IINUSAT-1. Telkom University (2013)

[7] Hudzaifah, M.: Analisis Perbandingan Pengaruh Lilitan dan Bahan Antena Helical S-Band sebagai Penerima Data Satelit Lapan-A2/Lapan-Orari. Karya Ilmiah Dosen (2017)

[8] Chotimah, H. H., Wijanto, H., and Wahyu, Y.: Rancangan Dan Realisasi Antena Horn Conical Pada Frekuensi Ku-band 12-18 GHz Untuk Electronic Support Measure. eProceedings of Engineering. Vol. 2, No. 2, pp. 1-5 (2015)

[9] Wardhana, A.S., Riza, T.A., Wahyu, Y. : Perencanaan Dan Realisasi Antena Horn Conical Pada Frekuensi 4-18 GHz Elektronic Support Measures. eProceedings of Engineering, Vol. 2, No. 3, (2015)

[10] Mallahzadeh, A., and Imani, A.: Modified double-ridged antenna for 2-18 GHz. The Applied Computational Electromagnetics Society. Vol. 25, No. 2, pp. 137-143 (2010)

[11] Perez, M. B., Aguilar, H. J., and Ruiz, I. G.: Design and simulation of 1-14 GHz Broadband Electromagnetic Compatibility DRGH Antenna. ICEEE-ICE 2nd International Conference on Electrical and Electronics Engineering. pp. 118-121 (2005)
[12] Balanis, C.A.: Modern Antenna Handbook. pp 121.John Willey & Sons, Inc., Canada (2008)