Design of a Parabolic Feeder Corrugated Horn Antenna for Ku-Band VSAT Application

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Abstract. VSAT (Very Small Aperture Terminal) technology is one of the technologies that can be used to reach and connect internet networks on islands. Ku-Band VSAT is widely used for residential internet needs, rural areas, schools, small and medium enterprises, hospitals and various types of small businesses. Ku-Band VSAT has the disadvantage of weakening the signal due to weather changes, especially rain and weakening the signal emitted in areas outside the scope of the satellite's working area. Signal weakening can increase delay and packet loss, delay and packet loss are important factors that must be considered in VSAT network data communication. To be able to cover these weaknesses can be done by having a strong antenna gain. Antennas with strong gain can improve the quality and durability of the signal obtained. In general, antennas consisting of parabolic reflectors and horn transmitters are used in VSAT systems due to the high gain specifications of this type of antenna. Axial corrugated horns are among the most commonly used types of horn feeders in the industry. Therefore, we propose an axial corrugated horn antenna design to obtain a high-gain antenna design as a parabolic feeder for Ku-Band VSAT applications. We simulate and optimize the proposed design using CST Microwave Studio. The proposed corrugated horn antenna shows characteristics at a receiver working frequency of 10.7–12.75 GHz with the highest gain of 15.9 dB, VSWR of 1.5:1, and linear polarization. characteristics at a transmitter working frequency of 13.75–14.5 GHz with the highest gain of 16.9 dB, VSWR of 1.5:1, and linear polarization. This study has obtained the development of a axial corrugated horn antenna design structure as a parabolic feeder for Ku-Band VSAT application and is expected to help pave the way for the development of research on the application of horn antennas.

Keywords: Ku-Band VSAT, Parabolic Feeder, Corrugated Horn.

1 Introduction

VSAT technology is one of the technologies that can be used to reach and connect internet networks on islands. VSAT based on the spectrum band can be divided into C-Band and Ku-Band . C-Band VSAT is often used in banking, emergency services and ERP. Ku-Band VSAT has an affordable price and smaller size than C-Band VSAT with its larger internet speed capacity but smaller receiver power [1]. Ku-Band VSAT is usually used for residential internet

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needs, rural areas, schools, small and medium businesses, hospitals and various other types of small businesses.

Ku-Band VSAT has several disadvantages including being vulnerable to weather disturbances and having limited coverage area. Weather disturbances, especially rain, impact the performance of Ku-Band VSAT, where the higher the rainfall intensity, the higher the attenuation. Rainfall with high intensity ($\leq$ 80.2 mm/hour) has an attenuation of $\pm$ 80.2 mm/hour; rainfall with medium intensity ($\leq$ 51 mm/hour) has an attenuation of $\pm$ 10 dB; and rainfall with light intensity ($\leq$ 10 mm/hour) has an attenuation of $\pm$ 3 dB [2]. Indonesia is a tropical area that has a fairly high rain intensity so that this can interfere with the performance of the Ku-Band VSAT antenna. Satellites that provide services for Ku-Band VSAT have limited coverage areas. There are islands that get a strong signal quality from satellites, but there are also islands that get a less strong signal quality from satellites [3]. Weakening the signal can increase delay and packet loss, delay and packet loss are important factors that must be considered in VSAT network data communication [4]. To be able to cover these weaknesses can be done by having a strong antenna gain. Antennas with strong gain can improve the quality and durability of the signal obtained.

VSAT consists of several parts, namely the outdoor unit (ODU) and indoor unit (IDU). The outdoor unit consists of an antenna and a radio frequency (RF) unit. Antennas are electronic equipment designed to receive and send radio signals. Antennas consisting of a horn supply and a parabolic reflector have high gain specifications, which are generally used in VSAT systems. Horn plugs and parabolic reflectors have the ability to minimize energy radiated elsewhere to only illuminate the reflector and the ability of the plug to illuminate the reflector uniformly[5].

Axial corrugated horn is the most common type of antenna used in industry as a satellite dish for VSAT applications. Through a simple formula, the axial corrugated conical horn design is obtained, with a gain of 10.5 to 14.5 dBi [6]. Horn antenna is a type of antenna that is shaped like a funnel and is able to work at high frequencies. This type of antenna has characteristics in the form of high gain and wide bandwidth so that its applications are quite numerous, such as transmitters for satellites and communication equipment around the world, as well as measurement reference antennas [7]. This is because Horn antennas have some special characteristics, such as high power capability, relatively simple fabrication, easy excitation, high gain, and directivity performance [8].

To improve the properties of this axial corrugated horn, many researchers have conducted research, including research on elliptically shaped taper on axial corrugated horns that increases return loss, side-lobe level, and cross-polarization of axially corrugated horn [9]. Presenting a low cross-polarization design with wide band dual polarization in Ku-Band dual-polarized corrugated horn axial corrugated horn research [10]. Using ANFIS (Adaptive Neuro-Fuzzy Inference System) for the design and optimization of axial corrugated horn antennas can be seen in research [11].

Based on the description above, to meet the needs of horn supply at Ku-Band working frequency, this research proposes a horn supply design with high gain, linear polarization, and broadband working frequency.

2 Research Methods

The study applied in this research is analytical and applicable, namely about the design of the axial corrugated horn antenna as a parabolic feeder for Ku-Band VSAT applications. In the corrugated horn antenna design process, several methodologies are used to support this final project. The methodology used in completing this research is as follows:

2.1 Studi Literatur

Conducting a literature review is necessary to understand the analysis of the Corrugated Horn Antenna Design as a parabolic amplifier for Ku-Band VSAT Applications. In this literature study method, several basic reference points are obtained which are used to compile research.

A. VSAT

VSAT stands for Very Small Aperture Terminal. VSAT is a small dish antenna that uses satellites for communication lines. VSAT is used to subscribe to satellite Internet, data, TV, LAN, voice, fax, and VoIP. VSAT-based networks provide an efficient, cost effective and reliable method for data distribution to a number of different locations without distance. VSAT types based on spectrum bands consist of C-Band VSAT and Ku-Band VSAT. C-Band VSAT service is known for its reliability against weather changes and high Service Level Agreement (SLA). Generally used for applications that require a high level of reliability and security, such as banking applications, emergency services, and ERP implementation, Ku-Band VSAT is a service that offers broadband connections with smaller antenna devices and lower prices. Ku-Band VSAT services can be used for Internet connection, be it at home, in schools, in rural areas (village offices), in small and medium enterprises (SMEs), in clinics, in hospitals, and by various types of companies across industries. VSAT devices usually consist of an outdoor unit and an indoor unit. The outdoor unit usually consists of a horn supply (feed), a parabolic antenna (reflector), Low Noise Block Downconverter (LNB), and Block Upconverter (BUC). Indoor unit, which usually consists of an Ethernet device, modem, or something else that connects to a computer or Ethernet interface.

B. Axial Corrugated Horn

Figure 1 shows the geometry of the axial corrugated conical horn antenna. At a given frequency, this axial corrugated horn design has a gain of 10.5 dBi $\leq$ GdBi $\leq$14.5 dBi. The captions in Figure 1 show (w) corrugated width, (dj) corrugated depth, (Θ) aperture angle, (ai) antenna waveguide diameter, and (t) [p-w] corrugated wall thickness.

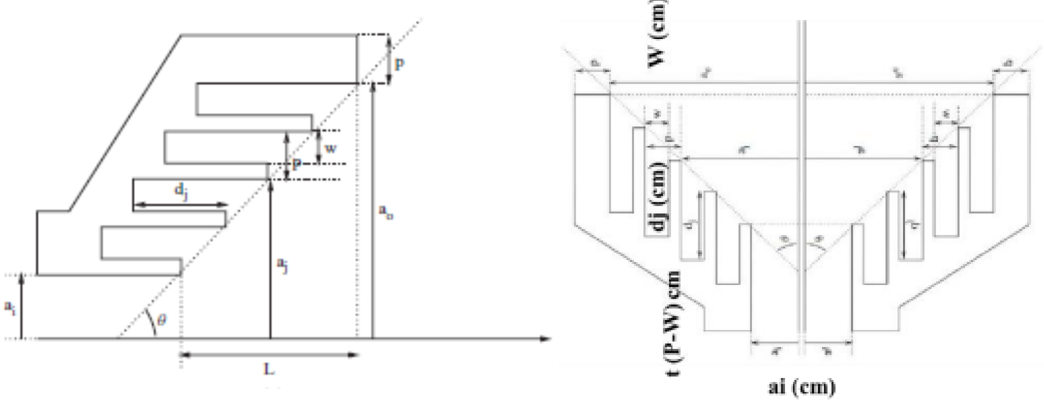


Fig.1. Geometri of axial corrugated conical horn

To get the geometry size of the axial corrugated horn as an initial design with a wavelength of λ (m), use the following formula:

$a_i = 3\lambda/2\pi$ (1)

Nslots = Nearest integer of (-343,325+84.7229 GdBi – 6,99153 G_{dBi}^{2} + 0,194452 G_{dBi}^{3}) (2)

$\Theta = 45°$ (3)

$p = \lambda/8$ (4)

$w = 0{,}8p$ (5)

$L = N_{\text{slots}P}$ (6)

$A_j = a_i + jp \quad \text{for } 1 \leq j \leq N_{\text{slots}}$ (7)

$d_j = \frac{\lambda}{4}\exp\left[\frac{1}{2{,}114(2\pi aj/\lambda)^{1{,}134}}\right] for\ 1 \leq j \leq N_{\text{slots}}$ (8)

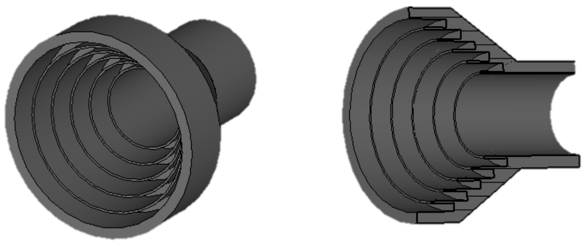


Fig.2. Axial corrugated horn, full view, and longitudinal section

C. Parameters of Antennas

The following parameters are used in this study to describe the performance of the antenna:

- VSWR

VSWR can also be interpreted as the ratio between the maximum wave and the minimum wave. VSWR is a parameter that also determines the matching between the antenna and transmitter. The most expected condition for the best VSWR value is 1, but the largest VSWR value that can be tolerated based on theory is ≤ 2. There are two components of the voltage wave on the transmission line, namely V0- (reflected voltage) and V0+ (transmitted voltage). The comparison of V0- and V0+ is referred to as the voltage reflection coefficient (Γ), which can be formulated as in the following equation [13]:

$$\Gamma = \frac{V_0^-}{V_0^+} = \frac{Z_L - Z_0}{Z_L - Z_0} \tag{9}$$

Based on the formula above, where Z0 is the line impedance and ZL is the load impedance, to find VSWR can use the following equation:

$$VSWR = \frac{|V|_{max}}{|V|_{min}} = \frac{1 + |\Gamma|}{1 - |\Gamma|} \tag{10}$$

- Return loss

Return loss is the ratio between the amplitude of the reflected wave and the amplitude of the transmitted wave. Return loss can occur due to discontinuities between the transmission line and the input impedance of the antenna load. The most expected condition for the best return loss value is less than -10 dB, so it can be said that the reflected wave value is not too large compared to the transmitted wave (the transmission line is matched). The value of this parameter is one of the references to see whether the antenna can work at the expected frequency or not [13].

- Gain

Gain (directive gain) is an antenna characteristic related to the antenna's ability to direct its signal radiation or receive signals from a particular direction. The radiation pattern of an antenna with low gain is wide, so the energy emitted is widely distributed sectorally (angularly). While an antenna with a large gain has a narrow transmit pattern, the energy emitted is not wide, but in the main beam direction, this energy can reach farther places. The ratio between the intensity in a particular direction and the radiation intensity obtained if the power received by the antenna is radiated isotropically is defined as the absolute gain of the antenna. The absolute gain can be calculated using the following equation:

$$G(\text{Gain}) = 4\pi \frac{radiation\ intensity}{total\ input(accepted)power} = 4\pi \frac{U(\Theta, \emptyset)}{P_{in}} \tag{11}$$

- Polarization

Antenna polarization is the orientation of the propagation of electromagnetic wave radiation emitted by an antenna. If the direction is not specified, then polarization is considered to be polarization in the direction of maximum gain [13]. There are several types of polarization, namely linear polarization, circular polarization, and elliptical polarization. The polarization of electromagnetic waves can be categorized based on the axial ratio (AR) parameter. The axial ratio is the ratio of the major and minor axes of elliptical wave polarization, which is generally expressed in dB. Elliptical polarization has an axial ratio value of 3–<40 dB, while linear polarization has an axial ratio value of >40 dB [14].

2.2 Antenna Specification Determination

To get the desired antenna design, at the initial stage, the specifications of the antenna to be designed are determined. The determination of antenna specifications aims to serve as a reference for antenna parameters and to assist in the desired antenna design process. The designed antenna specifications can be seen in Table 1. The characteristics of the antenna are determined: axial corrugated horn antenna type with receiver working frequency 10.70 GHz–12.75 GHz, transmitter working frequency 13.75 GHz–14.5 GHz, linear polarization, a gain of 10–14.5 dBi, and VSWR of 1.5.

Table 1. Antenna design specifications

Antenna Type	Axial Corrugated Horn
Receiver working frequency	10,70 GHz – 12,75 GHz
Transmitter Receiver working frequency	13,75 GHz – 14,5 GHz
Polarization	Linear
Gain	10 – 14.5 dBi
VSWR	1,5 : 1

2.3 Antenna Design Using CST STUDIO SUITE 2019

In this study, two design processes were carried out consisting of initial design and proposed design. The general description for initial design and proposed design is as follows:

Initial design: The design is based on the literature [6]. From the reference, a description of the design shape and calculation formula is obtained to obtain the size of the axial corrugated conical horn. After getting an overview of the design and size, the next process is the design and simulation carried out using CST Microwave Studio software. The process of iterating on several variables was carried out to obtain the antenna design with the best performance based on the parameters reviewed.

Proposed design: After obtaining the best design from initial design, it is then compared with the antenna specifications to be achieved. Proposed design is the development of initial design with the addition of techniques on the axial corrugated conical horn to improve antenna performance [10, 12].

To get the desired design in accordance with the antenna specifications that have been determined in this study, there are several stages. Figure 2 is a flowchart of antenna design using CST. After the antenna specifications are known, the initial stage is to determine the shape and size of the antenna. Based on the shape and size of this antenna, the design is carried out and simulated in CST. After simulation, it will be known whether the design made has obtained the best results according to the design parameters or not. If getting the optimum results according to the design parameters, then the simulation is complete; if not get the optimum results according to the design parameters, then the antenna size iteration process is carried out. The antenna size iteration process is carried out by changing the size variables on the antenna until the best simulation results are obtained and according to the design parameters. The size variable on the antenna that is changed in the iteration process consists of the variables ai, dj, w, and t. After obtaining the best results according to the design parameters, the simulation process is complete.

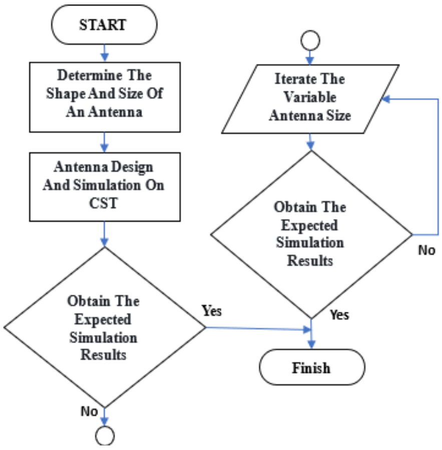
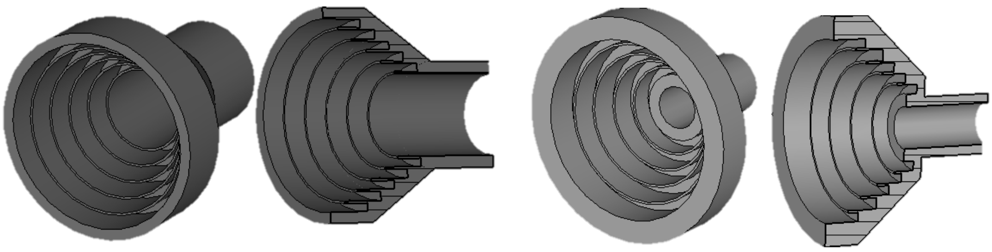


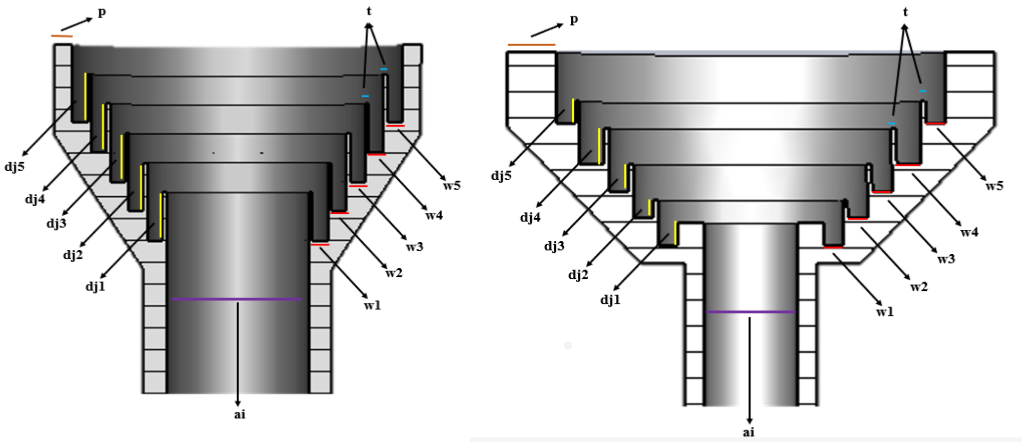
Fig.2. Flowchart of antenna design using CST

3. Result and Discussion

After antenna design and simulation using CST, the best design results were obtained that met the antenna design parameters. Figure 3 is a comparison of initial design and proposed design. Initial design is the initial design and Proposed design is the best design that meets the design parameters. From this figure, it can be seen the difference between initial design and proposed design. The difference is in the difference in the size value of the antenna variable and the difference in the repetition of the size value in the w and dj variables. Where in initial design the w variable consisting of w1-w5 has the same value and dj consisting of dj1-dj5 has the same value. Whereas in proposed design the variable w consisting of w1-w5 has a different value and dj consisting of dj1-dj5 has a different value. Due to the difference in value in the dj variable, proposed design does not have an aperture opening angle while initial design has an aperture opening angle.



(a) (b)



(a) (b)

Fig.3. Comparison of Initial design and Proposed design (a) Initial design, (b) Proposed design

Table 2 is a comparison of the variable sizes of the antenna initial design and the proposed design. There are several similarities and differences in the variable sizes of the antenna initial design and the proposed design. The size equation is found in the variable ai, with a size value of 2.232 cm. Size differences are found in several antenna size variables, including variable t with a value of 0.0584 cm for the initial design and 0.1 cm for the proposed design. variable w with a value of 0.234 cm for w1-w5 in the initial design and 0.4 for w1, w2, w3, w5, and 0.5 for w4 in the proposed design. variable p with a value of 0.292 cm for the initial design and 1 cm for the proposed design. variable dj with a value of 0.824 cm for dj1-dj5 in the initial design and 0.5 for dj1, dj5, 0.4 for dj2, 0.6 for dj3, and 0.8 for dj4 in the proposed design.

Table 2. Size comparison of Variable antenna Initial design and proposed design

Variable	Diameter ai	Θ	t (P-w)	w					p	dj				
				w1	w2	w3	w4	w5		dj1	dj2	dj3	dj4	dj5
Initial Design (cm)	2,232	45°	0.0584	0.234	0.234	0.23	0.234	0.234	0.292	0.824	0.824	0.824	0.824	0.824
Proposed Design (cm)	2,232		0.1	0.4	0.4	0.4	0.5	0.4	1	0.5	0.4	0.6	0.8	0.5

Figure 4 and Figure 5 show the comparison of S11 and VSWR simulation results. From the figure, the VSWR simulation results of the initial design and the proposed design can be seen. The initial design and proposed design have met the design requirements for return loss values below -10 dB and VSWR 1.5 at the working frequency range in accordance with the design specifications. Initial design at receiver working frequency (10.7–12.75 GHz): the lowest return loss value is at frequency 12.75 GHz with a value of -35.5 dB, and the lowest VSWR value is at frequency 12.75 GHz with a value of 1.03. At the transmitter working frequency (13.75–14.5 GHz), the lowest return loss value is at frequency 13.75 GHz with a value of -31.85 dB, and the lowest VSWR value is at frequency 13.75 GHz with a value of 1.052. While in the proposed design at receiver working frequency (10.7–12.75 GHz), the lowest return loss value is found at frequency 12.45 GHz with a value of -35.63 dB, and the lowest VSWR value is found at frequency 12.45 GHz with a value of 1.033. At the transmitter working frequency (13.75–14.5 GHz), the lowest return loss value is found at frequency 14.285 GHz with a value of -32.87 dB, and the lowest VSWR value is found at frequency 14.285 GHz with a value of 1.046.

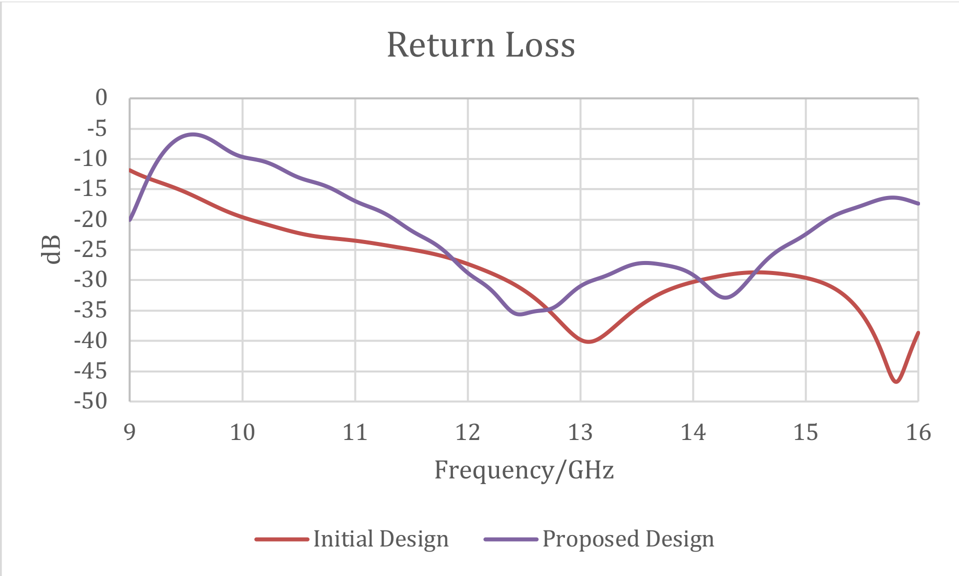


Fig.4. Comparison of return loss of initial design and proposed design

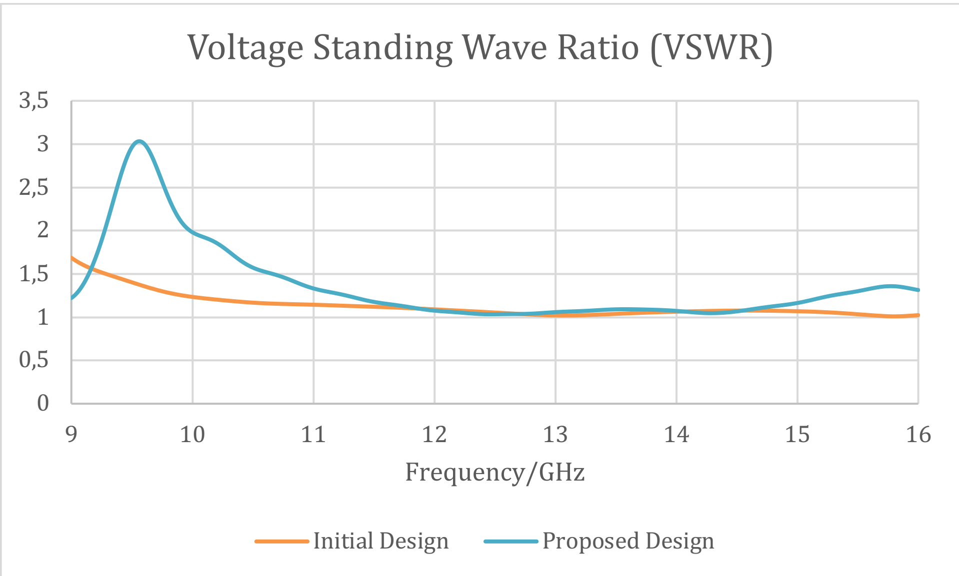


Fig.5. Comparison of VSWR of initial design and proposed design

Figure 6. shows the gain comparison of the simulation results of initial design and proposed design. Proposed design has the highest gain compared to initial design. Proposed design has the highest gain for the receiver working frequency (10.7-12.75 GHz) at a frequency of 11.45 GHz with a gain of 15.9 dB and the highest gain for the Transmitter working frequency (13.75-14.5 GHz) at a frequency of 13.9 with a gain of 16.9 dB. Initial design has the highest gain for

the receiver working frequency (10.7-12.75 GHz) at a frequency of 12.5 GHz with a gain of 15 dB and the highest gain for the Transmitter working frequency (13.75-14.5 GHz) at a frequency of 14 GHz with a gain of 15 dB. In general, proposed design has a higher gain than initial design. At the receiver frequency, proposed design has a higher gain of 1.25 dB than initial design and at the Transmitter frequency, proposed design has a higher gain of 1.22 dB than initial design.

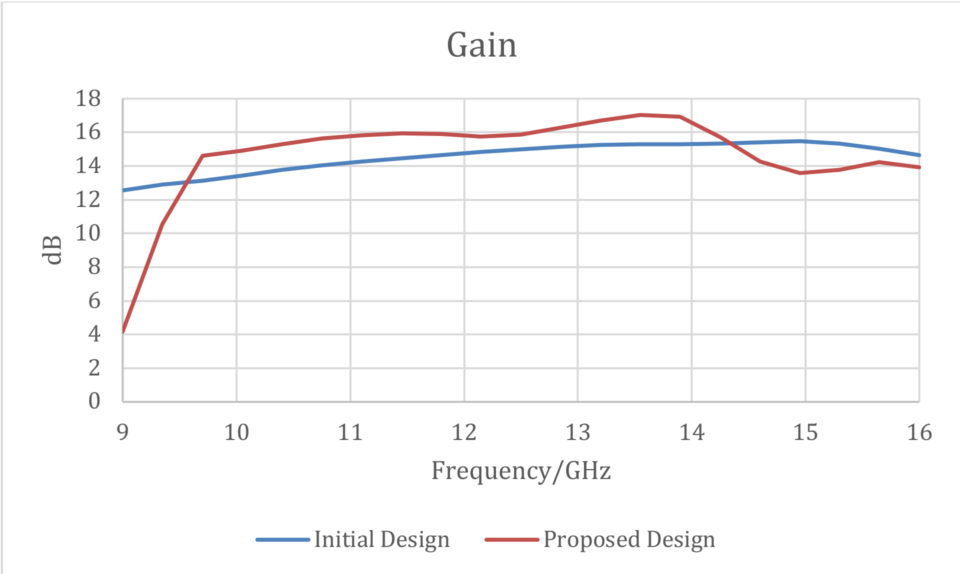


Fig.6. Comparison of Gain of initial design and proposed design

Figure 7. is a simulated axial ratio that shows initial design and proposed design have linear polarization with an axial ratio of 40 dB. This linear polarization is in accordance with the required antenna parameters, which are antennas with linear polarization.

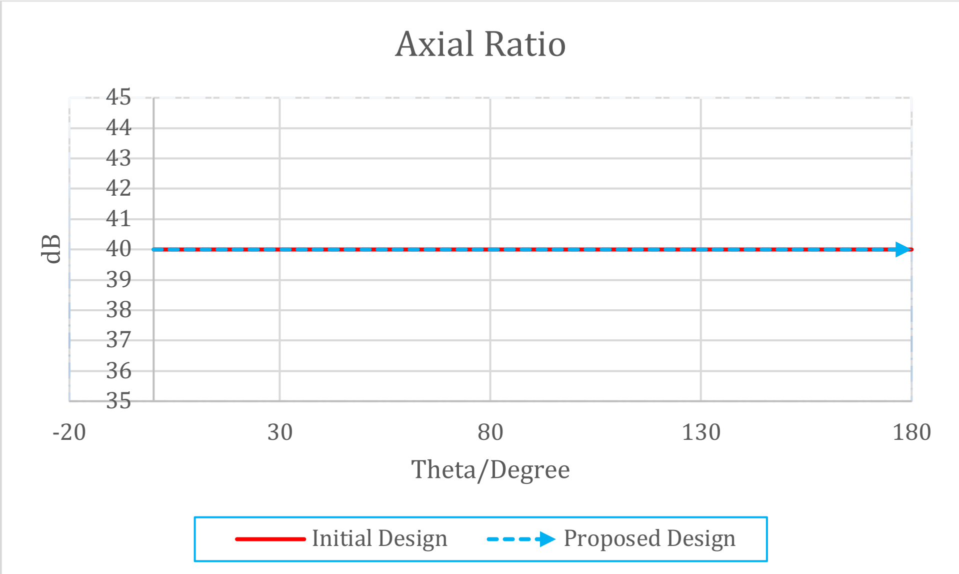


Fig.7. Comparison of Gain of initial design and proposed design

4. Conclusion

This study has obtained an antenna design that meets the specifications for a parabolic feeder for Ku-Band VSAT applications. The proposed design antenna shows characteristics of linear polarization, VSWR 1.5:1, with the highest gain of 15.9 dB at the receiver working frequency of 10.7–12.75 GHz and the highest gain of 16.9 dB at the working frequency of 13.75–14.5 GHz. In this research, the development of an axial corrugated horn antenna design structure has been obtained. This proposed design can be used as a satellite dish for Ku-Band VSAT applications and is expected to pave the way for the development of horn antenna application research. Research on the application of horn antennas allows it to be used in various fields such as antenna gain measurement, electromagnetic compatibility (EMC) testing, reflector feeders on radar, and satellite tracking systems.

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