Design and analysis of quad ridged horn antenna for high gain application

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Abstract- This paper discusses the design consideration of a Quad Ridged horn Antenna (QRHA). The different ridge profiles that are inserted in the horn have different significant effect on the horn performance that are discussed in the paper. The paper is based on the QRHA that can be used as a Standard Gain Horn Antenna. The QRHA is simulated using HFSS software and the results obtained are mentioned.

Index Terms- Horn Antenna, Ridged Waveguide, Quad Ridged Horn.

1. Introduction

From many years we have been using horn antenna for transmission and reception of microwave signals. Horn Antennas can be used all by themselves or as an element for some other antenna. Horn antennas are commonly used as the active element in a dish antenna for feeding the dish. They are used in short range radar systems to measure the speeds of approaching or retreating vehicles.

As we know the theoretical analysis of the horn antenna and most of the antennas are done from Maxwell’s Equations. A hollow pipe possesses many desirable features as a conductor for electromagnetic energy at extremely high frequencies. Some of these features are substantially perfect shielding, the low dielectric and conductive losses, and the simple and rugged construction, suggested that an open-ended hollow pipe might serve as an effective radiator or absorber for radio waves, in place of the more conventional types of antennas and reflectors.[2]

These hollow structures are commonly known as waveguide. The waveguides can be classified into different types based on their shape – Rectangular Waveguide, Circular Waveguide, Elliptical Waveguide, Single ridged Waveguide, Double ridged Waveguide. The electromagnetic wave travels through these waveguides and then through the horn antenna.

Horn antenna can be thought of as a flaring metal waveguide used to direct the electromagnetic waves in a beam. These horn antennas are very popular at Ultra-High Frequency i.e. 300MHz – 3 GHz.

This paper covers the details about horn antenna, types of horn antenna, important parameters of horn antenna, details about ridged horn antenna – dual and quad ridged horn antenna, parameters to be considers to design a horn antenna using HFSS.
2. Horn Antenna

Horn Antenna at the transmitter side transmit radio waves from a waveguide out into space and at the receiver side it collects radio waves into a waveguide. The horn antenna seems to be a waveguide that has been widened out in the form of a horn as shown below in Fig 1. As a result, it finds many applications in areas where waveguides are used. To improve the radiation efficiency and directivity of the beam, the wave guide is provided with an extended aperture to make the abrupt discontinuity of the wave into a gradual transformation. So that all the energy in the forward direction gets radiated. This can be termed as Flaring. This is done using a horn antenna.[2][3] When the waveguide is terminated by a horn, impedance matching is obtained due to smooth transformation.

The energy of the beam when slowly transform into radiation, the losses are reduced and the focusing of the beam improves. A Horn antenna may be considered as a flared-out wave guide, by which the directivity is improved and the diffraction is reduced.

Source: 10.1109/TAP.1970.1139799

Figure 1. Rectangular Horn Antenna in 3D[5]

When radio waves travelling through the waveguide hit the opening only a small portion of the energy will be reflected. This happens because of mismatch at the end of the waveguide with space. Some of the important observations about horn antenna are mention in the following points:

- Horn antenna has high degree of directivity and the radiated power is as a spherical wave front shape
- For any horn antenna, the directivity is almost equal to its gain.
- As the frequency increases the gain of the horn antenna also increases.[6]

Horn antennas are constructed in a variety of shapes for the purpose of controlling one or more of the fundamental properties: gain, radiation pattern and impedance.[12] broadly the horn antenna can be classified into Rectangular, Circular and Diagonal horn antennas. Depending on the flaring rectangular horn antenna can be further classified into Pyramidal and Sectoral horn antenna.

a) Pyramidal Horn Antenna
The cross section and end of the pyramidal horn is rectangular in shape. Pyramidal Horn is normally used with the rectangular horn antenna.
It has flaring on both the sides; we can see that in Fig 2. i.e. on both E and H walls.
b) Sectoral Horn Antenna

The sectoral horn produces a fan-shaped beam. Independent control of the beam width in the two principal planes is possible by varying the rectangular aperture dimensions.[12] The sectoral horn antenna can be considered as special cases of the pyramidal horn antenna having flaring in either of the direction thus the sectoral horn antennas can be classified into two types that are E-Plane and H-Plane Sectoral horn antenna.[8]

We can conclude from the shape of the sectoral horn that the radiated beam will be narrow in the plane of flared sides and wide in the plane of narrow sides.

- E-Plane Sectoral horn antenna: Flaring is in the direction of E-field in the waveguide.
- H-Plane Sectoral horn antenna: Flaring is in the direction of the H-field in the waveguide.

c) Diagonal Horn Antenna

Diagonal Horn Antenna has square aperture and is used at the end of a rectangular waveguide. This makes it another special case of the pyramidal horn antenna. As explained in [12] this horn radiates a pattern with a high degree of rotational symmetry but it does suffer from a relatively high level of cross polarization in the inter-cardinal planes.

d) Conical Horn Antenna

Conical horn antennas have shape of cone having circular cross section. Circular horn antennas are normally used with the circular waveguides. Implementation of the circular horn antenna is easy and mounting it with reflector is less time consuming.

After the comparison made in, they conclude that the rectangular horn antenna gives better results than circular horn antenna when used as a feeder.[6]

The paper includes comparison of parameters like Reflection Coefficient, VSWR, and gain for rectangular and circular horn as a feed for 2.4GHz and concludes that Rectangular horn antenna gives better results than the circular horn.[6]

The beam widths in the principal planes are generally unequal even though the antenna follows axial symmetry.[12] This is because of the requirement of dual polarization that the aperture of horn must be circle (or square for rectangular horn). This horn is well suited for circular polarization because of its circular aperture that follows the axial symmetry (but with unequal radiation patterns in two principal planes).[11]
Other types of Antenna are

e) Exponential Horn Antenna
f) Septum Horn Antenna
g) Corrugated Horn Antenna
h) Ridged Horn Antenna

3. Ridged Horn Antenna

Many times, Ridged horn antennas can be used for radio emission testing [9]. In ridged horn antenna fins are attached (shown in Fig 3) to the inside of the horn, these fins help in lowering the cut off frequency and so the bandwidth of the horn increases. The ridged horn may have two or four ridges and based on the number of ridges they are called as Dual Ridged and Quad Ridged horn antenna.

When broadband or ultra-wideband (UWB) horn antennas are required, it is well known that ridges in the waveguide transition portion and the flare region are required.[15] In [13] [14] an E-sectoral horn antenna for broadband application using a double-ridged is provided. Paper [15] describes a novel design of a dual-polarized Ultra-wideband horn antenna most suitable figure for radar systems.

The ridges introduced in the waveguides are tapered and extended to the flaring of the till the aperture of the horn. If we insert the ridges in any one plane of the waveguide it makes a Dual Ridged horn antenna. The cut off frequency of this waveguide is less than the cut off frequency of the waveguide with same width but without ridges. The ridges also rise the cut off frequency of the higher modes thus the bandwidth of the waveguide can be increased till 10:1 or more. Near the aperture the horn supports higher modes as the frequency increases. The author has mentioned the details about ridged waveguide and the mode of propagation in [16]

![Dual Ridged Horn Antenna](source)

Figure 3. Dual Ridged Horn Antenna

The reason for the lowering in the cut off frequency is the capacitance that develops in between the ridged of the ridged waveguide. The ridge width and the height thus play a vital role in change of cut off frequency of waveguide. If the gap between the ridges is decreased the capacitance developed between the ridges increases as a result the frequency decreases.

Dual Ridged Horn supports single linear polarization. Over the years the ridges were increased from two to four so that the horn antenna supports dual linear or circular polarization. The horn antenna with four ridges is known as Quad Ridged horn antenna.

This paper includes our quad ridged horn antenna design that supports linear polarity in two directions.
4. Design Considerations of the Quad Ridged Horn Antenna

The design of quad-ridged horn antenna mainly includes quad-ridged waveguide, horn and converter of the coaxial-line and the ridged waveguide.

The designing of the waveguide section is quite complicated. The waveguide section of the quad ridged horn antenna consists of two pairs of ridges. These ridges help to support the dual linear polarization and as mentioned before they help in decreasing the cut off frequency of the waveguide. Our Quad Ridge horn antenna supports the linear polarization in the direction H-plane and E-plane and works in the frequency range from 700MHz to 2GHz.

The height and width of the ridges has a very significant effect on the propagation modes supported by the waveguide.

The cut off frequency of the rectangular waveguide can be easily calculated from the following equation:

\[ f = \frac{c}{2} \left( \frac{m^2}{a^2} + \frac{n^2}{b^2} \right)^{1/2} \]  \( \ldots (1) \)

Here, 
\( c = \) velocity of light 
\( m, n = \) Mode of propagation 
\( a = \) broader dimension of the waveguide 
\( b = \) smaller dimension of the waveguide

TE10 mode is the dominating mode in the rectangular waveguide thus substituting the values of \( m \) and \( n \) in the equation (1) we can find out the cut off frequency of the waveguide by the following formula:

\[ f = \frac{c}{2a} \]  \( \ldots (2) \)

You can find the required broader dimension for your antenna according to your cut off frequency using equation (2). As our antenna support linear polarization in the two directions the waveguide, we considered is square.

Depending on the requirement of the gain and the frequency range you can find the height and the width of the ridges that are to be inserted in your waveguide.

The width and height of the ridge are obtained from various iterations of the relation between the broader dimension of the waveguide and the ridge width and the relationship between the broader dimension of the waveguide and the ridged height.

Once you have a perfect design for your waveguide you can insert the coaxial feed at the end of the waveguide. This is the next section of the quad ridge horn antenna design.

Fig 4 & 5 are the results of the reflection coefficient (\( S_{11} \)) and \( S_{21} \) plot for our quad ridged waveguide on HFSS.

Figure 4. S11 of Quad Ridged Waveguide
The details of inserting a coax at the end of waveguide are discussed in [17]. When inserting a co-axial feed to the waveguide the outer conductor is connected to one of the ridges while the inner conductor is extended till the other ridge, crossing the gap between the ridges. The author has done detailed analysis on the variation in capacitance due to these coax cables for both, dual and quad ridged waveguide [16]. We need to design the waveguide such that it has suitable low cut off frequency and the impedance matching between the waveguide and the coax cable is achieved.

The author in [16] has explained this arrangement of the coaxial cable as the feed of waveguide. Here we have an image (Fig 6) for dual and quad ridge waveguide which shows the capacitance between the ridges for one polarization is a series capacitance of two capacitors for other polarization.

After obtaining appropriate results for this waveguide you can start designing your horn section.

The equations for designing the flare section of the horn antenna are mentioned in [19]. It is advisable to keep the flare aperture such that the sides of the aperture make small angle with the axis of horn. This will help in decreasing the phase error of the horn. Theoretically this angle can be obtained in a range that may not yield good results when the antenna is simulated practically. The ridged and their shape have specific effect on the results of horn antenna. The ridge profile (Fig 7) inserted in the horn section is of following four types.

I. Linear Ridge profile
II. Quadratic Ridge profile
III. Exponential Ridge profile
IV. Gaussian Ridge profile

From these ridge profiles the Quadratic Ridge profiles produces widest bandwidth whereas the Gaussian Ridge profile produces the narrowest bandwidth.
The linear ridge profile provides highest gain amongst the ridge profiles whereas the Gaussian Ridge profile provides lowest gain of all the ridge profiles. These conclusions are true for both, Dual and Quad Ridged horn antenna.

Based on the parametric study a detailed comparison between the dual and quad ridged horn gain, radiation pattern and reflection coefficient for the four ridge is done in [18]. The different equations that can be used to obtain different ridges profiles is also discussed in Figure 7. Different Ridge Profiles [18]

The equation used by us for having a quadratic ridge profile is derived from the following equation

\[ Y(z) = e^{Rz} + c \quad \ldots (3) \]

Here \( R \) is a constant

\( a = \) broader dimension of the waveguide

Taking (3) as reference we derived following equation which seemed to give better results for our quad ridged horn antenna in 700MHz to 2GHz frequency range.

\[ Y(z) = e^{Rz} - 1 \quad \ldots (4) \]

Here \( R = 1.87 \)

\( a = 25.276 \text{cm} \)

Below is the table (Table 1) with dimensions of quad ridged waveguide for designing purpose. Dimensions are calculated with equations of waveguide.

| Table 1 lists the specifications of our quad ridged horn antenna |
|---------------------------------------------------------------|
| Frequency Range | 0.7 GHz to 2 GHz |
| Waveguide dimension \( a \times b \) | 25.276 cm x 25.276 cm |
| Ridge height | 8.404 cm |
| Ridge width | 0.292 cm |
| Flare A (E-field) | 40.551 cm |
| Flare B (H field) | 40.551 cm |
| Horn Length | 26.28 cm |
Figure 8. Quad Ridged Horn antenna designed using HFSS

Figure 9. Plot of Reflection Loss

Figure 10. Gain Plot of QRHA at 0.7GHz

Figure 11. Gain Plot of QRHA at 1GHz

Figure 12. Gain Plot of QRHA at 1.5GHz

Figure 13. Gain Plot of QRHA at 2GHz

Figure 14. VSWR of QRHA
Table 2 lists the gain of QRHA at various frequencies

| Frequency | Gain         |
|-----------|--------------|
| 0.7GHz    | 9.0124 dB    |
| 0.9 GHz   | 9.5 dB       |
| 1 GHz     | 10 dB        |
| 1.5 GHz   | 12.3 dB      |
| 2 GHz     | 14.1875 dB   |

5. Applications

Horn antennas are commonly used as feed for the reflector antenna, in radars all by themselves, as Standard Gain horn Antenna for testing another antenna. They are installed in the anechoic chamber for testing the performance of other antenna. The basic considerations for designing the horn antenna as a feed for parabolic reflector is given in [20]. They have considered the effect of inserting the dielectric material in the horn antenna.

A method of determining the optimum dimensions of a Horn feed for a parabolic reflector using the power transferred to the feed as a criterion is described in [3]. A technique to determine the horn dimensions that produced maximum power transmission to the feed or to maximize the aperture efficiency is discussed in [3]. This technique is based on the theory and equations given by Rudge and Withers [21].
6. Conclusion

This paper is focused on the points to be considered while designing a Quad Ridged horn antenna and the effects of ridge profile, ridge height and ridge width on the results of the antenna. The equation for Ridge profile for antenna of different frequency range may differ, the one used by us is mentioned in the paper. The Quad Ridged Horn Antenna designed by us can be used as a Standard Gain Horn Antenna for testing of antenna working in 0.7 GHz to 2GHz.

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