FACULTY OF ENGINEERING AND THE BUILT ENVIRONMENT

DEPARTMENT OF ELECTRICAL ENGINEERING

MICROWAVE ENGINEERING

EEE4086F

HORN ANTENNA DESIGN AND FABRICATION

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For

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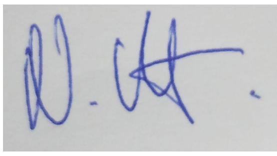

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Monday 6$^{\text{th}}$ May, 2019

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1 INTRODUCTION

1.1 Design Problem Formulation.

Antennas are used for transmitting electromagnetic waves which carry information. There are different types of antennas including Dipole, Yagi,Parabolic and Horn antennas. Specific antennas are more suited for specific requirements and this gives rise to differently designed antennas.

1.2 Purpose of this Project.

The purpose of this project is to design, simulate, fabricate and test the performance of a pyramidal horn antenna. The horn antenna should have a gain of **14 dB** between **8** and **8.5 GHz**. Horn antennas are simple to construct, deliver adequate directivity but the gain is usually limited to 20 dB for a reasonable length antennas.

1.3 Scope and Limitations of the Project.

In this project only the **14 dB** gain pyramidal horn antenna will be designed and tested for its performance. No other antenna will be designed or tested. The Horn antenna is to be fabricated with cardboard and an aluminium foil sheet.

1.4 Plan of Development

The project will follow four phases: Calculation, Simulation, Implementation and Testing, respectively. The first phase will include finding the measurements for the antenna using mathematical tools from the *EEE4086F* class. Then computer simulation will be done to come up with the final design. After the design has been finalised, the pyramidal horn antenna will be constructed using cardboard box and aluminium foil. The pyramidal horn antenna will then be tested to see if it meets the user requirements.

2 BACKGROUND TO THE PROJECT

Horn antennas are simple to construct, deliver adequate directivity, offer a bandwidth of about 10 % and can deliver a reasonably high gain. The gain should be limited to 20 dB to make sure the antenna does not become too long. In construction, microwave horn antennas can be constructed from cardboard box. Amazingly, if the cardboard box is laminated with aluminium foil, the horn antenna will provide reliable results almost similar to one constructed from metal.

Horn antennas are easy and fast to make and the Fig.1 below is an example of a horn antenna plugged to a coaxial cable via a flange.

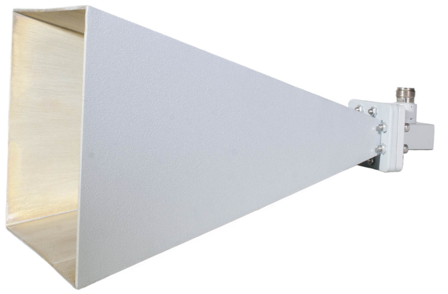

Figure 1: An example of a pyramidal horn antenna.

3 REQUIREMENTS AND ANALYSIS

3.1 User's needs and analysis.

The user requires an X-band pyramidal horn antenna to operate in the frequency band 8.0 GHz to 8.5 GHz. The horn antenna is required to have a gain of 14 dB (linear gain of 25.12) and to have the same beamwidth in the **E**-plane as the **H**-plane.

The horn antenna would be fed from an X band waveguide, and as a result, the user requires that the horn antenna should have an X-band flange that can easily connect to the X-band waveguide with screws. The phase difference between the centre and the edge of the horn antenna radiation can be allowed to go up to $\lambda/8$. The user requires that the horn antenna should be fabricated from cardboard and covered in an aluminum foil.

3.2 Horn Antenna Functional requirements.

The index table below shows the horn antenna functional requirements. The indexed functional requirements will be used for the horn antenna acceptance testing and design validation.

Table 1: The indexed list of Functional Requirements for the horn antenna.

Index	Functional Requirements
F1	The horn antenna should operate in the band 8 to 8.5 GHz.
F2	The horn antenna should have a gain of 14 dB.
F3	The horn antenna should have an X-band flange ending.

3.3 Horn Antenna performance specifications.

The horn antenna should meet the following performance specifications.

Table 2: The list of performance specifications for the horn antenna.

Index	Performance specifications
S1	Centre frequency of 8.25 GHz and band of 8 to 8.5 GHz.
S2	Isotropic Gain of 14 dB (25.12).
S3	Centre-Edge phase difference of $\lambda/8$.
S4	Equal beamwidth in **E**-plane and **H**-plane.

3.4 ACCEPTANCE TEST PROTOCOLS

The following table outlines the test protocols and metric for the acceptance or rejection of the horn antenna design and fabrication. The test are designed to test for all the function requirements described above. A fully known will be used to transmit signals and the designed horn antenna will be used in receive mode and the following pass metrics are outlined.

Table 3: The Horn Antenna acceptance test protocols.

Index	Target(s)	Test	Acceptance Metrics
A1	F3	Visual measurements check.	The flange should be 22.86 mm by 10.16 mm.
A2	F1, F2, S1, S2	Sweep the signal frequency form 7 to 10 GHz and measure the received signal power/gain.	The gain should be around 14 dB for 8 to 8.5 GHz and maximum at 8.25 GHz.
A3	S3	Measure the phase difference between the center and the edge antenna received signals.	The phase difference should be less than $\lambda/8$.
A4	S4	Measure the **E**-plane and **H**-plane beamwidth.	The **E**-plane beamwdith should equal the **H**-plane beamwidth.

4 THEORETICAL DIMENSIONS DESIGN CALCULATIONS

4.1 The Horn Antenna dimensions.

The centre frequency, $f_c = 8.25\ GHz$ and therefore the wavelength:
$\lambda = \frac{c}{f_c} = \frac{3.10^8\ m/s}{8.25\ GHz} = 0.03636\ m = 3.636\ cm$

The gain of the antenna is required to be $G = 14\ dB = 25.1189$ and the antenna efficiency, η, is taken to be 60 %.

The effective area and physical area of the Horn antenna can be calculated as:

$$A_{eff} = \frac{G\lambda^2}{4\pi}$$

$$A_{eff} = \frac{(25.1189)(0.03636)^2}{4\pi}$$

$$\therefore A_{eff} = 2.6426 \times 10^{-3}\ m^2$$

The actual physical area can be determined as:

$$\begin{aligned}
A_{eff} &= 0.6A_{actual} \\
A_{actual} &= \frac{A_{eff}}{0.6} \\
A_{actual} &= \frac{2.6426 \times 10^{-3}\ m^2}{0.6} \\
\therefore A_{actual} &= 4.4043 \times 10^{-3}\ m^2
\end{aligned}$$

It is required that the antenna should have the same beamwidth in the **H**-plane as the **E**-plane, therefore, the **H**-plane dimension, A, should be 4/3 times bigger than the **E**-plane dimension, B.

With the condition that $A = \frac{4}{3}B$:

$$\begin{aligned}
A_{actual} &= A \times B \\
A_{actual} &= \frac{4}{3}B \times B \\
\therefore B &= \sqrt{\frac{3}{4}A_{actual}} \\
\therefore B &= \sqrt{\frac{3}{4} \times 4.4043 \times 10^{-3}\ m^2} \\
\therefore B &= 0.0575\ m \\
\therefore B &= 5.75\ cm
\end{aligned}$$

The **H**-plane dimension, A is:

$$\begin{aligned}
A &= \frac{4}{3}B \\
A &= \frac{4}{3} \times 5.75\ cm \\
\therefore A &= 7.66\ cm
\end{aligned}$$

To have a maximum phase difference of $\lambda/8$ between the centre and edge radiations, the length of the Horn antenna, l can be determined as:

$$\begin{aligned}
l &= \frac{B^2}{\lambda} \\
l &= \frac{(5.75\ cm)^2}{3.636\ cm} \\
\therefore l &= 9.10\ cm
\end{aligned}$$

4.2 Discussions of the calculation results.

The dimension of the Horn antenna are fully defined from the user requirements and antenna specifications. The **H**-plane dimension, $A = 7.66\ cm$, the **E**-plane dimension, $B = 5.75\ cm$ and the length of the Horn antenna is $l = 9.10\ cm$.

The mathematically determined dimensions and the length of the Horn antenna are within reasonable range for a gain of 14 dB. The Horn antenna is therefore practical to fabricate and short enough to operate without difficulties.

4.3 The theoretical half-power beamwidth of the horn antenna

The horizontal half-power beamwidth, θ_H:

$$\theta_H = \frac{80\lambda}{A}$$
$$\theta_H = \frac{80 * 3.636}{7.66}$$
$$\therefore \theta_H = 37.97°$$

The vertical half-power beamwidth, θ_V:

$$\theta_V = \frac{60\lambda}{A}$$
$$\theta_V = \frac{60 * 3.636}{5.75}$$
$$\therefore \theta_V = 37.94°$$

5 SOFTWARE SIMULATION OF THE ANTENNA DESIGN

The horn antenna was simulated in CST software. The figures below shows the results of the antenna radiation with the above calculated dimensions. Fig.2 shows the 3-D radiation of the antenna. The Fig.3 and Fig.4 show the polar radiation and gain of the antenna.

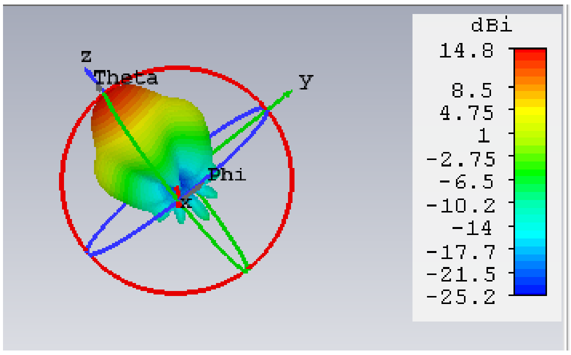

Figure 2: The 3-D radiation of the antenna.

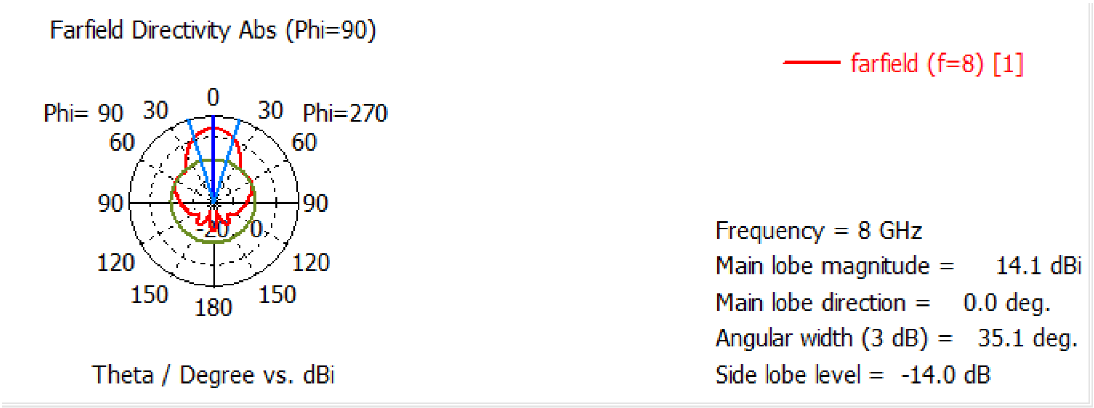

Figure 3: The polar radiation diagram at 8 GHz.

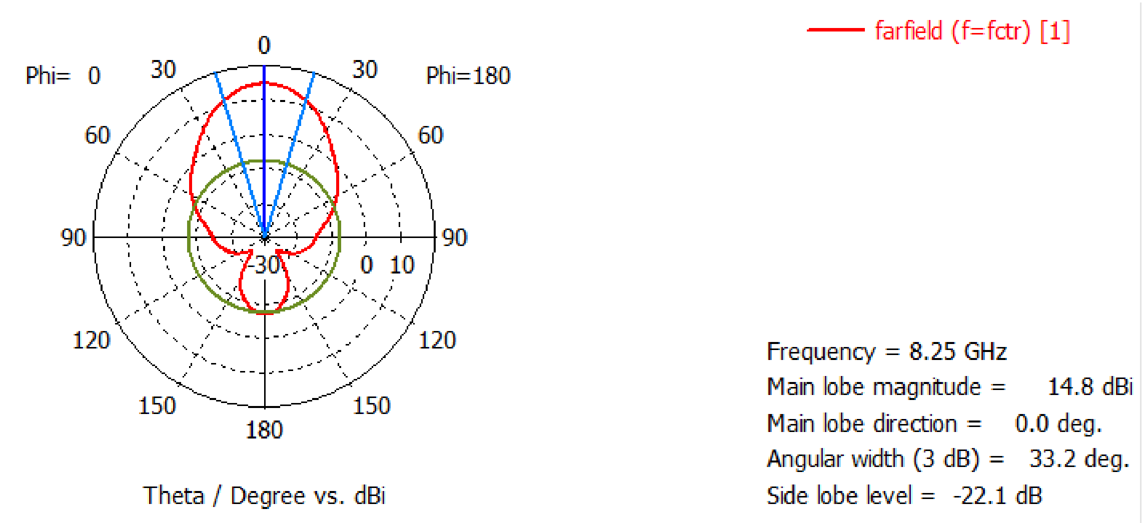

Figure 4: The polar radiation diagram at 825 GHz.

The simulation gain of the horn antenna was about 14.8 dB which is more than the designed gain of 14 dB. This is an error of about 0.8 dB which is equivalent to a linear error factor of about +1.2. This error is relatively smaller and it is therefore acceptance.

6 IMPLEMENTATION AND FABRICATION OF THE HORN ANTENNA

The theoretical and simulation dimensions and design of the horn antenna where put to practice. The horn antenna was fabricated from cardboard and aluminum foil. The four figures below shows the fabrication steps and the final images of the horn antenna.

Figure 5: The cardboard cut lines.

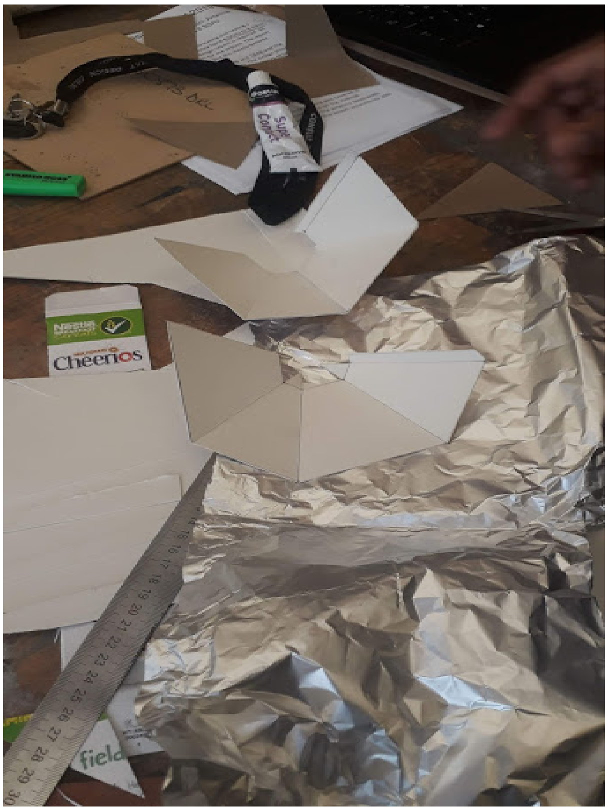

Figure 6: The foil covering of the cardboard.

Figure 7: The finished antenna.

Figure 8: The angle view of the antenna.

7 EXPERIMENTAL HORN ANTENNA TESTING

7.1 Testing and actual beamwidth

The horn antenna was tested in receive mode. A transmit antenna was set up 2 m away. The transmitter was transmitting at a frequency of 8.25 GHz and power level of 7 dBm. The transmit antenna was set to transmit vertically polarized electromagnetic waves. The designed horn antenna was set to receive vertically polarized waves and also and a maximum receiver power levels of about -24 dBm was established. The half power beamwidth was measured in the horizontal plane. Both the transmit and receiver antennas were rotate by 90 °to measure the vertical beamwidth with the limited azimuth angle-meter.

The Fig.9, Fig.10 and Fig.11 show the set up of the testing environment.

Figure 9: The testing set up environment.

Figure 10: The transmitter and transmit antenna.

Figure 11: The receive antenna and power meter.

The table below shows the beamwidth testing results for both the **H**-plane and the **E**-plane.

Table 4: The beamwidth results of the practical experiment antenna measurements

Plane	Initial Angle	Clockwise Half power	Anti-clockwise Half power	Beamwidth
H-plane	0 °	-12 °	18 °	30 °
E-plane	0 °	-17 °	12 °	29 °

From the practical experiment results, we can see that $\theta_H = 30°$ and $\theta_V = 29°$. The vertical and the horizontal beamwidth are very close to each other with an error of about 1°.

7.2 Estimating the antenna gain from practical measurements

From experimental values, the half-power beamwidth in the horizontal plane is given by 30°.

$$a = \frac{80\lambda}{\theta_H}$$
$$a = \frac{80 * 3.636}{30}$$
$$\therefore a = 9.68\ cm$$

From experimental values, the half-power beamwidth in the vertical plane is given by 29°.

$$b = \frac{80\lambda}{\theta_V}$$
$$b = \frac{80 * 3.636}{29}$$
$$\therefore\ b = 10.01\ cm$$

The gain of the antenna calculated as follows:

$$G = 10 * \log \frac{4\pi * A_{eff}}{\lambda^2}$$
$$G = 10 * \log \frac{4\pi * 0.6 * 10.01 * 9.68}{3.636^2}$$
$$\therefore G = 17.4\ dB$$

The measured/actual gain is 17.4 dB.

8 DISCUSSIONS AND CONCLUSIONS

The antenna was designed for a gain of 14 dB and the measured gain is 17.4 dB which amounts to a +3 dB error. The error is partly due to inaccurate values of a and b on the measured antenna since the designed value of a was 7.66 cm and that of b value of 9.10 cm. The measured value of a was 9.68 cm and b was 10.01 cm which introduced an error in the effective area leading to a 3 dB overshoot in the antenna gain.

From table 4, the measure vertical half-power beamwidth is 29° and the horizontal half-power beamwidth is 30°. The antenna was designed for a vertical and horizontal half-power beamwidth of 37.94° and 37.97°. Therefore the measured half-power beamwidths are off by 20%. This might be a result of errors in the measuring instrument and errors in implementing the designed antenna.

The overall performance of the antenna was satisfactory. A signal was received when the antenna was vertically polarized and no signal was received when the antenna was horizontally polarized.