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DESIGN OF AN L-BAND PYRAMIDAL HORN ANTENNA

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Abstract:Practically, well designed horn antennas have been found useful for signal transmission and reception. They are also being used as feeds especially on dish antennas. The aim of this work is to design a pyramidal horn antenna that operates on L-band frequency spectrum. Mathematical computation method was used to design the antenna. The designed antenna will operate at the frequency range 1.1357 GHz – 1.717 GHz, as low and highcutoff frequency respectively.The designed antenna will have the gain of 13 dB, with the following parameters- A = 0.744805m, B = 0.083788m, R1 = 0.924557m, R2 = 0.017551m, RH = 0.01366m, RE = 0.01366 m at which the design is realizable.
Keywords: Antenna, Gain, E-plane, Microwave, Waveguide,

1.0 Introduction

A horn antenna or Microwave horn is an antenna that consists of a flaring metal waveguide shaped like a horn to direct radio waves in a beam. Horn antenna is a form of aperture antenna.

Antennas of this type are very useful for aircraft and spacecraft applications, because they can be very conveniently flush-mounted on the skin of the aircraft or spacecraft [Constantine, 2005]. Horn antennas also known as aperture antenna are popular in the microwave band generally above 1 GHz. These antennas provide high gain, relatively wide bandwidth, low VSWR, and they are ease to construct [Arvind and Isha, 2015].Some applications of horn antenna are: It is used as feed antennas(called feed horns) for larger antenna structures such as parabolic antennas; as standard calibration antennas to measure the gain of other antennas; and as directive antennas for such devices as radar guns, automatic door openers, and microwave radiometers [Bevilaqua, 2009].

Some advantages of horn antenna are: It can operate over a range of frequencies, has low Voltage Standing Wave Ratio (VSWR), has higher gain, of between 10 – 20dB typical, and very little losses.The major types of horn antenna are h-plane sectoral antenna, E-plane sectoral antenna, pyramidal horn antenna, and conical horn antenna. However, this work is done on pyramidal horn antenna. The pyramidal horn antenna provides higher gain and directivity than the Sectoral horn antennas [Arvind and Isha, 2015].

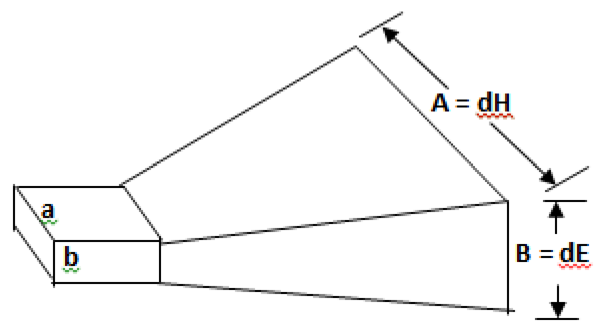

Fig.1.1: Schematic diagram of a pyramidal horn antenna

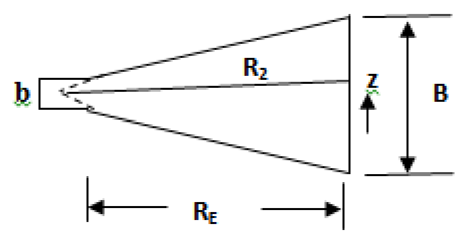

Fig.1.2: Schematic diagram of an E-plane sectoral horn antenna

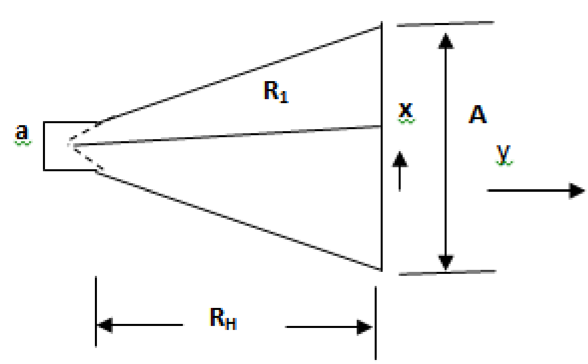

Fig.1.3: Schematic diagram of a H-plane sectoral horn antenna

2.0 Methodology

The first step in building a horn antenna is defining the necessary gain the antenna should have in the desired frequency range of operation. Antenna gain (G) is defined as the ratio of the power transmitted in the direction of peak radiation and of an isotropic source (radiates equally in all directions) [Goran and Krešimir, 2015].

2.1 Design procedure for a pyramidal horn antenna

i. Selection of operating frequency, f, and expected or desired gain, G: The first step in building a horn antenna is defining the necessary gain the antenna should have in the desired frequency range of operation (Goran and Kresimir, 2015).

ii. Selection of the inner dimensions of the antenna according to the operating frequency range: These values are taken from a standard table, and they represent the horizontal and vertical dimensions of the wave guide. They are represented as 'a' and 'b', with 'b' (the vertical inner dimension) is in most cases half of 'a' (the horizontal inner dimension).

iii. Calculation of wavelength: This is called free space wavelength. It is the wavelength at which the antenna will operate. It is calculated with the formula given as:

$$\lambda = \frac{c}{f} \quad \text{------------------ } 1$$

iv. Calculation of approximate value of A, and the value of 'B': A and B, are the width of the aperture along the magnetic field and electric field in that order. A is calculated using the formula given as:

$$A = 0.45\lambda\sqrt{G}$$

Where *G*, is the expected gain (dB) and λ is wavelength (m). Also, for B, it is represented mathematically as:

$$B = \frac{1}{4\pi}\frac{G\lambda^2}{0.51A} \quad \text{-------- } 2$$

v. Calculation of R_1 and R_2: These are the slant lengths along the electric (E) field and magnetic (H) field respectively [figs.1.2 & 1.3]. They are calculated using the equations given as follows:

$$R_1 = \frac{A^2}{3\lambda} \quad \text{--------------------3a}$$

$$R_2 = \frac{B^2}{2\lambda} \quad \text{----------------- 3b}$$

vi. Calculation of R_E and R_H: They are calculated using the formulas given as:

$$R_E = R_2\left(1 - \frac{a}{A}\right) \quad \text{----------------------4a}$$

$$R_H = R_1\left(1 - \frac{b}{B}\right) \quad \text{---------------------4b}$$

vii. Adjustment of values of '*A*' by iteration process until R_E is equal to R_H ($R_E = R_H$). When $R_E = R_H$, the values or parameters gotten are the values up on which the antenna will be designed and/or constructed as the case may be.

viii. Calculation of cutoff wavelength. The cutoff wavelength is calculated based on the transmission mode. The common transmission mode used in such designs is the transmission along the electrical field (TE) mode. Cutoff wavelength is calculated using the formula given as:

$$(\lambda_c)_{mn} = \frac{2}{\sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2}} \quad \text{----------------------- 5a}$$

n and *m* are numbers which vary but the common ones used are m = 1, and n = 0, as in $TE_{mn} = TE_{10}$. Thus, when 1 and 0 are substituted for *m* and *n* respectively in equation 5a, we have;

$$\therefore (\lambda_c)_{10} = \lambda_c = 2a \quad \text{--------------------------- 5b}$$

Where '*a'*, is the longer inner dimension.

ix. Calculation of cutoff frequency. Cutoff frequency is calculated from the ratio of wave speed to cutoff wavelength. It is calculated using the formula given as:

$$f_c = \frac{c}{2a} \quad \text{------------------------------ 6}$$

x. Calculation of low and high cutoff frequencies. The low cutoff frequency is the minimum frequency at the antenna will operate, while high cutoff frequency is the maximum frequency at the antenna will operate. They are calculated using the equations given as:

$$f_{Hc} = 1.89 f_c \quad \text{------------------------7 a}$$

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$f_{Lc} = 1.25 f_c$ ----------------------- 7b

xi. Calculation of low and high cutoff wavelengths. The low and high wavelengths are the lower and upper limit wavelength at which the designed antenna will transmit or receive signal.

Low cutoff wavelength is given as:

$$\lambda_{Lc} = \frac{c}{f_{Hc}}$$ ------------------------------ 8a

High cutoff wavelength is given as:

$$\lambda_{Hc} = \frac{c}{f_{Lc}}$$ ------------------------------- 8b

xii. Calculation of wavelength inside the waveguide: The speed of wave inside the waveguide is less than the speed of light [Daniyan, *et al.*, 2014]. Thus, there is need to calculate the wavelength of the wave when travelling in the waveguide. It is calculated using the formula given as:

$$\lambda_g = \frac{1}{\sqrt{\frac{1}{(\lambda)^2} - \frac{1}{(\lambda_c)^2}}}$$ ---------------------- 9

where λ is the free space or operating wavelength of the antenna and λ_c is cutoff wavelength.

xiii. Calculation of waveguide length: The waveguide length is the calculated from the ratio of wavelength in waveguide to a number 2. In other words, it is half of the waveguide wavelength. By formula, it is given as:

$$W_{GL} = \frac{\lambda_g}{2}$$ ----------------------- 10

xiv. Calculation of feed antenna distance or probe distance: This is the distance from the closed end of the waveguide to the position in which the feed cable or element is attached.

$$\Pr obe_{Distance} = \frac{\lambda_g}{4}$$ --------------------- 11

xv. Calculation of feed antenna (element) height or probe depth: The horn antenna has another element in the waveguide which is always very short. In many designs, it was taken as $\lambda/2$ or $\lambda/4$, but in this design, it is taken as $\lambda/4$.

$$\Pr obe_{Depth} = \frac{\lambda}{4}$$ ---------------------- 12

xvi. Calculation of gain: Gain is a parameter which measures the degree of directivity of the antenna's radiation pattern. The gain in decibel (dB) is calculated using the formula given as:

$Gain = 10\log\left(\frac{4\pi AB}{\lambda^2}\right)$dB, where *A*, is the width of the aperture along the H-plane and *B*,is width of the aperture along the E-plane.

xvii. Calculation of directivity: It is defined as the degree to which the radiation of the antenna is emitted is concentrated in a single direction.

$Directivity = 10\log\left(\frac{4\pi AB\varepsilon_A}{\lambda^2}\right)$dB, where ε_A is the efficiency which is usually between 0.5 and 0.6.

xviii. Calculation of Beamwidth: The beam width of a pattern is defined as the angular separation between two identical points on opposite side of the pattern maximum [Constantine, 2005].

Beamwidth along H-plane

$$\theta_H = \frac{70\lambda}{A}$$ -----------------13a

Beamwidth along E-plane

$$\theta_E = \frac{56\lambda}{B}$$ ------------------- 13b

2.2 Design computation analysis

i. Selection of operating frequency, *f*, and expected or desired gain, *G*.

The frequency and gain used for this design are 1.5GHz and 10dB respectively.

ii. Selection of the inner dimensions of the antenna according to the operating frequency range.

The longer inner dimension, *a* = 0.1651m, and the shorter inner dimension, *b* =0.08255m

iii. Calculation of wavelength: It is the wavelength at which the antenna will operate.

$\lambda = \frac{c}{f}$, c = 3 x 10^8 m/s and *f* = 1.5 x 10^9Hz.

When the values are substituted, λ will be 0.2m.

iv. Calculation of approximate value of A, and the value of 'B'. 'A' is calculated using the formula given as:

$A = 0.45\lambda\sqrt{G}$, G = 10dB and λ = 0.2m.

Then, A = 0.284605m when the values for the parameters are substituted in the formula.

Also, for B,

$B = \frac{1}{4\pi}\frac{G\lambda^2}{0.51A}$, G 10dB, λ = 0.2m and A = 0.284605m.

Hence, B = 0.219271m

v. Calculation of R_1 and R_2: These can be calculated as follows.

$R_1 = \frac{A^2}{3\lambda}$, λ = 0.2m and A = 0.284605m.

R_1 = 0.135m

$R_2 = \frac{B^2}{2\lambda}$, λ = 0.2m and B = 0.219271m.

R_2 = 0.120199m

vi. Calculation of R_E and R_H.

For R_E,

$R_E = R_2\left(1 - \frac{a}{A}\right)$, R_2 = 0.120199m, A = 0.284605m and a = 0.1651m.

Thus, when substituted accordingly,

R_E = 0.050471m.

For R_H,

$R_H = R_1\left(1 - \frac{b}{B}\right)$, R_1 = 0.135m, B = 0.219271m and b = 0.08255m.

Thus, when substituted accordingly,

R_H = 0.084176m

vii. Adjustment of value of 'A'by iteration process until R_E is equal to R_H ($R_E = R_H$).

Several iterations were done by varying the values of *'A'*, until $R_E = R_H$ = 0.01366m.

At this point, the parameters for the antenna are:

A = 0.744805m, B = 0.083788m, R_1= 0.924557m, R_2= 0.017551m, R_H= 0.01366m, R_E= 0.01366m.

viii. Calculation of low cutoff wavelength. it is calculated using the formula given as:

:. $(\lambda_c)_{10} = \lambda_c = 2a$, $where\, a = 0.1651m$

Thus, λ_c = 0.3302m

ix. Calculation of cutoff frequency. It is calculated using the formula given as:

$f_c = \frac{c}{2a}$, $where\, a = 0.1651m\ and\ c = 3x10^8\, m/s$

f_c = 0.9085m

x. Calculation of low and high cutoff frequencies.

For $f_{Hc} = 1.89 f_c$, $where\ f_c$ = 0.9085m,

f_{Hc} = 1.717GHz

For $f_{Lc} = 1.25 f_c$, $where\ f_c$ = 0.9085m,

f_{Lc} = 1.1357GHz

xi. Calculation of low and high cutoff wavelengths

Low cutoff wavelength is given as:

$\lambda_{Lc} = \frac{c}{f_{Hc}}$, $where\ f_{Hc}$ = 1.717GHz, and c = 3 x 10^8m/s,

Therefore, λ_{Lc} = 0.17m.

High cutoff wavelength is given as:

$\lambda_{Hc} = \frac{c}{f_{Lc}}$, $where\ f_{Lc}$ = 1.1357GHz, and c = 3 x 10^8m/s,

Therefore, λ_{Hc} = 0.26m

xii. Calculation of wavelength inside the waveguide

$$\lambda_g = \frac{1}{\sqrt{\frac{1}{(\lambda)^2} - \frac{1}{(\lambda_c)^2}}},$$

$where\, \lambda_c = 0.3302m\ and\ \lambda = 0.02m$,

Therefore, λ_g = 0.2514m

xiii. Calculation of wave guide length.

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$$W_{GL} = \frac{\lambda_g}{2}, \quad where \ \lambda_g = 0.2514\text{m},$$

Therefore, $W_{GL} = 0.01257$m.

xiv. Calculation of feed antenna distance or probe distance: This is the distance from the closed end of the waveguide to the position in which the feed cable or element is attached.

$$\mathrm{Pr}obe_{Distance} = \frac{\lambda_g}{4}, \quad where \ \lambda_g = 0.2514\text{m},$$

Therefore, $\mathrm{Pr}obe_{Distance} = 0.6628$m.

xv. Calculation of feed antenna (element) height or probe depth:

$$\mathrm{Pr}obe_{Depth} = \frac{\lambda}{4}, \quad where \ \lambda = 0.2\text{m},$$

Therefore, $\mathrm{Probe}_{\mathrm{Depth}} = 0.05$m.

xvi. Calculation of gain:

$$Gain = 10\log\left(\frac{4\pi AB}{\lambda^2}\right)\text{dB},$$ where $\lambda =$ 0.2m, A = 0.744805m, B = 0.083788m and π = 3.142,

Therefore, Gain = 12.70dB.

xvii. Calculation of Directivity:

$$Directivity = 10\log\left(\frac{4\pi AB\varepsilon_A}{\lambda^2}\right)\text{dB},$$ where ε_A = 0.51 in this design and $\lambda =$ 0.2m, A = 0.744805m, B = 0.083788m and π = 3.142,

Thus, *Directivity* = 10dB.

xviii. Calculation of beamwidth

Beamwidth along H-plane

$$\theta_H = \frac{70\lambda}{A}, \quad \lambda = 0.2\text{m and } A = 0.744805\text{m},$$

Therefore, $\theta_H = 19^0$.

Beamwidth along E-plane

$$\theta_E = \frac{56\lambda}{B}, \quad \lambda = 0.2\text{m } \textit{and } B = 0.083788\text{m},$$

Therefore, $\theta_E = 134^0$.

3.0 RESULTS AND DISCUSSIONS

3.1 Summaries of Results

S/N	Parameters	Value
1	Frequency	1. 5GHz
2	*Gain (Selected)*	10dB
3	***a***	0.1651m
4	***b***	0.08255m
5	λ	0.2m
6	***A***	0.7448
7	***B***	0.0838M
8	R_1	0.9246m
9	R_2	0.0176m
10	R_H	0.0137m
11	R_E	0.0137m
12	λ_{Lc}	0.17m
13	λ_{Hc}	0.26m
14	λ_g	0.2514m
15	W_{GL}	0.1257m
16	P_d	0.6628m
17	*Feed height*	0.05m
18	*Gain (calculated)*	13dB
19	*Directivity*	10dB
20	Θ_H	19^0
21	Θ_E	134^0

3.2 Discussions

The design of a pyramidal horn antenna which would operate at the frequency of 1.5 GHz has been done using mathematical method. From the result, it was observed that the antenna will operate within the frequency range of 1.1357 GHz and 1.717 GHz. The parameters at which the design of the antenna is realizable are: A = 0.744805m, B = 0.083788m, R_1 = 0.924557m, R_2 = 0.017551m, R_H = 0.01366m, R_E = 0.01366m. It was also observed that the width along the H-plane was longer than that along the E-plane thereby making the beamwidth along the H-plane to be smaller than that along the E-plane. This will result in the “spreading out” of more signal in E-plane than in the H-palne. In addition, the selected or expected gain of the antenna was 10dB, but it was observed that the gain of the designed antenna based on the parameters with which the design of the antenna will be realizable has increased to 13dB.

4. Conclusion

The design of a pyramidal horn antenna to operate at the frequency of 1.5 GHz has been carried out using mathematical

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method. From the result, it was observed that the antenna will be designed with the parameters given as A = 0.744805m, B = 0.083788m, R_1 = 0.924557m, R_2 = 0.017551m, R_H = 0.01366m, R_E = 0.01366m. With these parameters, the designed antenna will have the gain and directivity of 13 dB and 10dB respectively. This antenna, when constructed, can be used in the design of GPS/GNSS technologies, radios receivers and aircrafts.

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