Design, fabrication and testing of pyramidal horn antenna

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Abstract— **Horn antennas are widely used in areas of wireless communications, electromagnetic sensing, nondestructive testing and evaluation, radio frequency heating and biomedicine. They are also widely used as high gain elements in phased arrays and as feed elements for reflectors and lens antennas in satellite, microwave and millimeter wave systems. Moreover, they serve as a universal standard for calibration and gain measurements of other antennas.**

An optimum pyramidal horn with gain 20dB and center frequency 9.5GHz is designed. Using the design values two horn antennas are fabricated using aluminum sheets of different thickness namely 1mm and 2mm. The performance parameters like gain, directivity, impedance and s parameters are evaluated. The results are discussed.

Index Terms— **Optimum Horn, gain, directivity, radiation pattern, S parameters.**

I. INTRODUCTION

Horn antenna is one type of aperture antenna. The radiation fields from aperture antenna can be determined from the knowledge of the fields over the aperture. The aperture fields become the sources of the radiated fields at large distances.

Horn antennas are very popular at UHF and higher frequencies. Microwave horn antennas occur in a variety of shapes and sizes. There are different types like E plane H plane and EH or Pyramidal horn. Of these the simplest horn antenna is the pyramidal horn. It is fabricated by flaring a hollow pipe of rectangular or square cross section to a larger opening. It is robust, simple to construct, easy to excite and can provide high gain. Horn antennas have a wide impedance-bandwidth, implying that the input impedance is fairly constant over a wide frequency range. The bandwidth for practical horn antennas can be on the order of 20:1

A very long horn with small flare angle is required to obtain as uniform an aperture distribution as possible. For practical convenience horn should be as short as possible. Optimum horn antenna is a compromise between extremes that provides minimum beam width without excessive side lobe level.

For given length L as aperture and flare angle are increased Directivity increases and bandwidth decreases.

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However, if they become very large the phase shift between paths at edge and axis may become equivalent to 180 electrical degrees and field at aperture edge will be in phase opposition to field along axis. This results in reduced directivity and increased side lobe levels. Maximum directivity occurs at largest flare angles for which the phase shift does not exceed a certain value (usually 0.1 to 0.4λ). Optimum horn is preferred as it results in the shortest axial length for a specified gain.
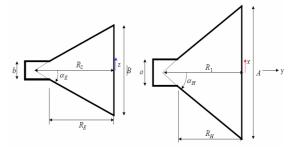

Figure1- Dimensions of horn antenna

The whole design can be actually reduced to the solution of a single fourth-order equation. For a horn to be realizable, the following must be true: $R_E = R_H = R_P$

The expression for designing optimum horn dimensions is

$$A^4 - aA^2 + \frac{3bG\lambda^2}{8\pi\varepsilon_{ap}}A - \frac{3G^2\lambda^4}{32\pi^2\varepsilon_{ap}^2} = 0 \quad \ldots\ldots (1)$$

Design Procedure:

For a given gain G and operating frequency f and with a & b dimensions of feed wave guide the design procedure is

- Calculate the first approximate value of A using

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

- Calculate $B = \frac{1}{4\pi}\frac{G\lambda^2}{0.51A}$ ......(2)

- Calculate $R_1 = \frac{A^2}{3\lambda}$ ....(3)

- Calculate $R_2 = \frac{B^2}{2\lambda}$ ....(4)

- Calculate $R_E = R_2\left(1 - \frac{a}{A}\right)$ ....(5)

- Calculate $R_H = R_1\left(1 - \frac{b}{B}\right)$ ......(6)

- Check if $R_E = R_H$.

- If not, change the approximation of A and repeat the above procedure till $R_E=R_H$ is satisfied.

Using the above procedure an optimum horn is designed for the specifications (i) f= 9.5 GHz that is λ=3.15 cm (ii) Gain, G = 20dB or Gain numerical value is 100 (iii) a=2.286 cm (iv) b=1.016 dimensions of waveguide. The iterations are shown in table 1. The final dimensions obtained from the design iterations are A = 14.09cm; B=11.04cm; R_1=20.95 cm; R_2=19.33cm; $R_E=R_H$= 17.55 cm.

Table-1 calculation of dimensions of the optimum horn

S. No	A cm	B cm	R1 cm	R2 cm	Rh cm	Re cm	Rh~Re Cm
1	14.21	0.95	21.31	19.0	17.88	17.24	0.64
2	14.15	1.00	21.13	19.16	17.72	17.39	0.32
3	14.1	1.04	20.98	19.30	17.58	17.52	0.05
4	14.09	1.04	20.95	19.32	17.55	17.55	0

Fabrication:
The horn antenna is fabricated using aluminum sheet of thickness 1mm and the fabricated antenna is shown in figure2.

Figure-2 Fabricated horn antenna

Testing:
Using X band reflex klystron powered microwave bench the impedance of horn antenna is found at 9.5 GHz. With the help of rotating mechanism the radiation intensity of horn as a function of Φ the azimuth angle and θ the elevation angle is observed and the half power beam widths Φ_{HP} and θ_{HP} in azimuth and elevation are noted. The Directivity of the antenna is calculated using the relation D= $\frac{4\pi}{\Phi_{HP}\theta_{HP}}$.

With the same set up and orienting the antennas for maximum reception gain of the antenna is evaluated using 3 antenna method. For this the fabricated antenna A_1 and two other horn antennas A_2 and A_3 are used. Three sets of power transmitted and power received are measured using antennas1, 2; 1, 3; and 2, 3 respectively.

For free space communication link the Friis transmission formula is

$$P_r = P_t\left(\frac{\lambda}{4\pi R}\right)^2 G_r G_t$$

where P_r = power received. G_t=gain of transmitting antenna, G_r = gain of receiving antenna, R= distance between transmitter and receiver and λ= wavelength of signal
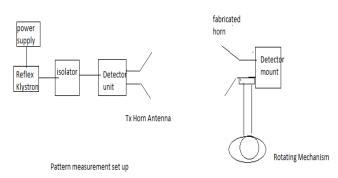

Figure-3 Radiation pattern setup

If G_1, G_2 & G_3 are the gains of the three antennas A_1,A_2, A_3 used, then using Friss formula the following three simultaneous equations can be formed.
A=G_1+G_2= 20 log $(4\pi R/\lambda)$ + 10 log (P_r/P_t) {A_2 tx, A_1 rx}
B= G_2 +G_3 = 20 log $(4\pi R/\lambda)$ + 10 log (P_r/P_t): {A_2 tx, A_3 rx}
C= G_3+G_1 =20 log $(4\pi R/\lambda)$ + 10 log (P_r/P_t): {A_3 tx, A_1 rx}
Substituting the corresponding values and solving the three simultaneous equations the gain of the fabricated antenna can be found from G_1= (A+C-B)/2:……………........ (7)
Thus in this method there is no need to have prior knowledge of gain of any antenna used.
The efficiency η of antenna can be found using the relation Gain G=η x Directivity D ……………………… (8)

In these measurements the crystal input current is kept below 20μA so that it acts like a square law device and voltage or current measurements made at crystal output are proportional to input power.
These parameters also can be estimated theoretically
(a) The Half Power Beam Widths of horn antenna are:
    Optimum E-plane rectangular horn = $56/a_{E\lambda}$
    Optimum H-plane rectangular horn= $67/a_H\lambda$
(b)The directivity of horn antenna can be estimated from

$$D = \frac{4\lambda}{\pi^2}\varepsilon_t \varepsilon_{ph}^E \varepsilon_{ph}^H AB \quad …….. (9)$$

where the phase efficiency factors can be found as follows

$$\varepsilon_t = \frac{8}{\pi^2} = 0.81 \quad ; \quad t = \frac{1}{8}\left(\frac{A}{\lambda}\right)^2\frac{\lambda}{R_1} = 0.376$$

$$p_1 = 2\sqrt{t}[1+\frac{1}{8t}] \;; \; p_2 = 2\sqrt{t}[-1+\frac{1}{8t}]; \quad q = \frac{B}{\sqrt{2\lambda R_2}} \;;$$

Considering the Fresnel cosine integral C(p), C(q) and Fresnel sine integral S(p), S(q)

$$\varepsilon_{ph}^H = \frac{\pi^2}{64t}\left((C(p_1)-C(p_2))^2 + (S(p_1)-S(p_2))^2\right)$$

$$\varepsilon_{ph}^E = \frac{C^2(q)+S^2(q)}{q^2}$$

(b) Gain $G = 8.1 + 10\log(\frac{AB}{\lambda^2})$…… (10)

The results of the parameters calculated from experimental observations and estimated from theoretical expressions are presented in the next section and discussed.

II. RESULTS AND DISCUSSION
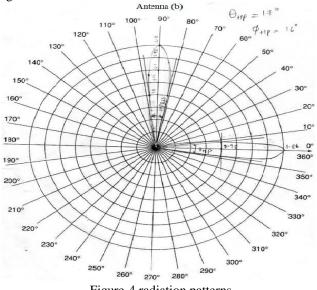
The radiation patterns in azimuth and elevation are given in figure 5

Figure-4 radiation patterns

(i) Half Power Beam Width of the antenna from Pattern is $\Phi_{HP}= 16^o=0.279$ radians; $\Theta_{HP}=17^o=0.2967$ (ii) Directivity D $= [4\pi/(\Phi_{HP}\,\theta_{HP})]$ where the half power beamwidths are taken in radians. Using the values found from pattern

Directivity D= 151.8= 21.8dB

(iii) For measurement of gain of fabricated antenna by three antenna method the readings obtained resulted in the following simultaneous equations:

A = 34.92 ; B=35.94; C=32.08

Gain of antenna G= (A-C+B)/2 = 19.49dB

From theoretical relations the estimated values are

(a) $HP_E = 56^o\dfrac{\lambda}{A} = 15.89^o$; $HP_H = 67^o\dfrac{\lambda}{B} = 17.80^o$

(b) $D = \dfrac{4\lambda}{\pi^2}\varepsilon_t\varepsilon_{ph}^E\varepsilon_{ph}^H AB$

The phase efficiency factors are found as follows

$\varepsilon_t = \dfrac{8}{\pi^2}$; $t = \dfrac{1}{8}\left(\dfrac{A}{\lambda}\right)^2\dfrac{\lambda}{R_1}$;

$p_1 = 2\sqrt{t}[1+\dfrac{1}{8t}]$; $p_2 = 2\sqrt{t}[-1+\dfrac{1}{8t}]$; $q = \dfrac{B}{\sqrt{2\lambda R_2}}$

Considering the Fresnel cosine integral C(p), C(q) and Fresnel sine integral S(p), S(q)

$\varepsilon_{ph}^H = \dfrac{\pi^2}{64t}\left((C(p_1) - C(p_2))^2 + (S(p_1) - S(p_2))^2\right)$

$\varepsilon_{ph}^E = \dfrac{C^2(q)+S^2(q)}{q^2}$

So $D = \dfrac{4\lambda}{\pi^2}\varepsilon_t\varepsilon_{ph}^E\varepsilon_{ph}^H AB$ = 20.5dB

(c) Gain from relation G (dB) = 8.1+10 log (AB/ λ^2)

G =20.05dB

The practical value of gain is 19.49 dB which is very close to the specification of 20dB. Further there is very good agreement between the theoretically estimated and practically calculated values of half power beam width and gain. However it is observed that the antenna is susceptible for shape change due to small thickness of sheet used

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