Design, Fabrication and Simulation of Pyramidal Horn Antenna at 950MHz frequency

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Abstract— **In Modern times need for wideband applications has increased. In recent years there have been many research works are going on in the design of antenna system as it is the main source for any communication system. The horn antenna is widely used in the transmission and reception of RF(Radio Frequency)microwave signals in areas of wireless communications, also used in electromagnetic sensing, nondestructive testing and evaluation, radio frequency heating and biomedicine. Horn antennas have many advantages such as they are simple to build, provide very good directional performance and show excellent peak power handling capability. Since horn antennas do not have any resonant elements they operate at wide range of frequencies and have a wide bandwidth. Moreover, they serve as a universal standard for calibration and gain measurements of other antennas. This paper highlights the design and fabrication of a pyramidal horn antenna and simulate of its parameters using MATLAB. The materials used for fabrication of proposed horn antenna is steel. The designed antenna has a gain of 10dB operating at 950MHz. Simulation and comparison of developed antenna with the available antenna were done by using MATLAB software.**

Index Terms— **Aperture, Gain, Pyramidal horn, S-Parameters, VSWR.**

I. INTRODUCTION

Horn antenna is most widely used simplest form of microwave antenna which comes from the aperture antenna family. A horn antenna is an antenna which is used to transmit electromagnetic waves from a waveguide into space or receive electromagnetic waves through waveguide. It may also be considered as the impedance matching device between the waveguide feeder and free space. These type of antenna consists of a waveguide at one end and a conical or pyramidal horn at another end [1].There are various types of Horn Antenna e.g. pyramidal Horn Antenna, Conical Horn Antenna and Sectoral Horn Antenna. Among these, the designers prefer to Pyramidal Horn Antenna because of its light weight, simplicity in its design, high directivity, large bandwidth and less return loss, low VSWR(Voltage Standing Wave Ratio) and for its good results[2].These antenna can be designed in variety of shapes and sizes to fulfill many practical applications and can be used as feed element for other antennas such as reflectors, compound and lens antennas[3].
These Antennas are used at ultrahigh frequencies above 300MHz and as high as 140GHz [1].Depending on the application, e.g. satellite communication, radar, radio astronomy, feed element of Parabolic and Dish antenna etc, these antennas are designed so that the desired result is obtained. Here the operating frequency and gain are important factor for designing. In order to achieve high gain, the horn antenna should have large aperture[3]. On the other hand, aperture size depends on operating frequency and directivity depends on gain. The directivity is one of the parameters that is often used as a figure of merit to describe the performance of an antenna. To find directivity, the maximum radiation is formed. The first horn antenna was constructed by an Indian radio researcher and one of the father of radio science Jagadish Chandra Bose (1858-1937), in the year 1897(Biswa,2017).
Many researches are going on in the design of antenna system as it is the main source for any communication system, especially on horn antenna because of its extensive application. The horn is nothing more than a hollow pipe of different cross sections, which has been tapered (flared) to a large opening[3] It is fabricated by flaring a hollow pipe of rectangular or square cross section to a larger Opening in which the walls of the rectangular wave guide are flared out in both e-plane and h-plane directions. Here, we designed a pyramidal horn antenna considering both H-plane and E-plane with frequency 950MHz assuming the gain as 10dB.

II. MATERIALS AND METHODS

The design of pyramidal horn includes design of waveguide,aperture, radiating elements and flared angle. After determining all parameters and designing all components the antenna was fabricated and then test in the laboratory.Finally, simulation was carried out by using MATLAB.

III. PROPOSED ANTENNA DESIGN

Hollow conducting tube used to transfer electromagnetic power efficiently from one point in space to another is known as waveguide[4]. There are different types of guiding structures e.g. typical coaxial cable, the two-wire and microstrip transmission lines, hollow conducting waveguides (rectangular & cylindrical), and optical fiber. The choice of structure depends on desired operating frequency band, amount of power to be transferred, andthe amount of transmission losses that can be tolerated. Among waveguide types, rectangular waveguides are used to transfer large amounts of microwave power at ultra-high frequencies.

A. Waveguide Design

The fields within the horn can be expressed in terms of Pyramidal TE(Traverse electric)and TM(Traverse magnetic) wave functions[2]. Radio waves can propagate in many different modes in a rectangular waveguide. For our purpose, the dominant mode of transverse electromagnetic propagation is selected. The TE10 mode has the lowest attenuation of all modes in a rectangular waveguide and its electric field is vertically polarized. In order to design the dimension of the waveguide, we must calculate the cut-off frequency for the dominant mode of propagation. For 950 MHz wave to propagate inside the waveguide, the cutoff frequency must be lower than the mode of propagation.

Only TM_{mn} and TE_{mn} mode support the single conductor wave guide (e.g. rectangular waveguide). We know that, the cutoff frequency

$$(f_c)_{mn}=\frac{1}{2\sqrt{\mu\varepsilon}}\sqrt{\left(\left(\frac{m}{a}\right)^2+\left(\frac{n}{b}\right)^2\right)}$$

The mode having the minimum value of m & n for which the cutoff frequency will be lowest is known as the dominant mode of the waveguide.

Hence, the TE_{10} mode is the dominant mode of a rectangular wave guide with a>b. Because the TE_{10} mode has the lowest attenuation ($\alpha = \frac{\sigma\eta}{2\sqrt{1-\left(\frac{f_c}{f}\right)^2}}$) of all mode in a rectangular wave guide.

Operating frequency $f = 950MHz$

Operating wavelength $\lambda = 31.6cm$

Waveguide cutoff frequency f_c =850 MHz

Waveguide cutoff wavelength, $\lambda_c = \frac{c}{f_c} = \frac{3*10^8}{850*10^6} = 35.3\ cm$

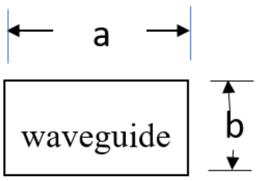
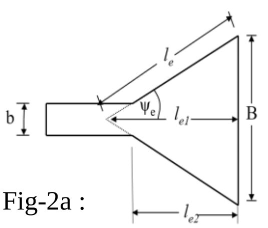


Fig-1: waveguide dimension

Width of waveguide, $a = \frac{\lambda_c}{2} = \frac{35.3}{2} \cong 18cm$

Height of waveguide, b=8 cm.

B. *Aperture Design*



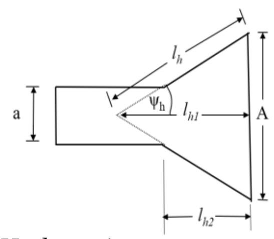


Fig-2a : E-plane view   Fig-2b: H-plane view

We know, Gain *G(dB)*=10 $\log_{10}$G =10^1 =10 (Assuming G=10)

To physically construct a pyramidal horn the dimension l_{e2} will be, $l_{e2} = (B-b)\left[\left(\frac{l_e}{B}\right)^2-\frac{1}{4}\right]^{\frac{1}{2}}$

This should be equal to the dimension l_{h2},

$$l_{h2} = (A-a)\left[\left(\frac{l_h}{A}\right)^2-\frac{1}{4}\right]^{1/2}$$

For the optimum directivity, $A = \sqrt{3\lambda l_{h1}}$ and $B = \sqrt{2\lambda l_{e1}}$

Now gain $G = \frac{4\pi}{\lambda^2}A_{em} = \epsilon_{ap}\frac{4\pi}{\lambda^2}A_p$

(where, A_{em} = maximum effective aperture,

A_p = physical area of the horn aperture and ϵ_{ap} is the aperture efficiency)

Since overall efficiency of a horn antenna is about 50%, then gain

$$G = 0.5\frac{4\pi}{\lambda^2}(AB) = \frac{2\pi}{\lambda^2}\sqrt{3\lambda l_{h1}} * \sqrt{2\lambda l_{e1}}$$ (Placing the value of A and B)

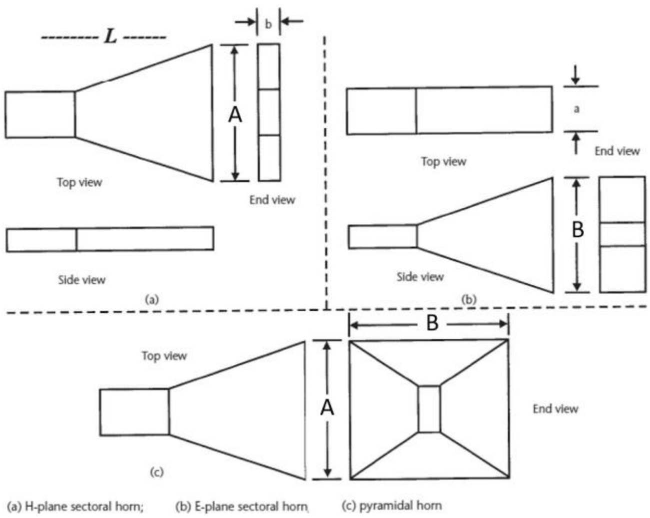


Fig-3: Different view of Horn antenna

In order to make a pyramidal horn physically realizable l_{e2} and l_{h2} must be equal.

$$\left(\sqrt{2\chi}-b/\lambda\right)^2(2\chi-1) = \left(\frac{G}{2\pi}\sqrt{\frac{3}{2\pi}}\frac{1}{\sqrt{\chi}}-\frac{a}{\lambda}\right)^2\left(\frac{G^2}{6\pi^3}\frac{1}{\chi}-1\right) \quad (1)$$

Where, $\frac{l_e}{\lambda} = \chi$ .... (2)

And $\frac{l_h}{\lambda} = \frac{G^2}{8\pi^3}\left(\frac{1}{\chi}\right)$ .... (3)

From previous, we know that a=18cm, b=8cm and G=10

By solving the eq^n (1) using the iterative technique, we get the value of χ is, χ=0.5224

Now from eq^n (2), we get, $l_e = \chi\lambda = 0.5224*31.6 = 16.5$ cm

And from eq^n (3), we get $l_h = \left[\frac{G^2}{8\pi^3}\left(\frac{1}{\chi}\right)\right] * \lambda = 24.3\ cm$

So, from the E-plane view,

We get, $l_{e1}^2 = l_e^2 - \left(\frac{B}{2}\right)^2 = 16.5^2 - \left(\sqrt{2\lambda l_{e1}}/2\right)^2$

by solving this equation, l_{e1} = 9.84 cm

Similarly, from H-plane view

$$l_{h1}^2 = l_h^2 - \left(\frac{A}{2}\right)^2 = 24.3^2 - \left(\frac{\sqrt{3\lambda l_{h1}}}{2}\right)\text{^}2$$

by solving this equation, we get l_{h1}=14.37cm

Aperture side,

$$A = \sqrt{3\lambda l_{h1}} = \sqrt{3*31.6*14.37} = 38.2cm$$

And side,

$$B = \sqrt{2\lambda l_{e1}} = \sqrt{2 * 31.6 * 9.84} = 25.64cm$$

Determination of Flared Angle

$$l_{e2} = (B - b)[(\frac{l_e}{B})^2 - 1/4]^{\frac{1}{2}} \cong 8cm$$

and $l_{h2} = (A - a)[(\frac{l_h}{A})^2 - 1/4]^{\frac{1}{2}} \cong 8cm$

Since the value of l_{e2} and l_{h2} are equal, so it can be concluded that the design parameters that are selected for antenna are correct at gain 10dB.

Flared angle, in the E-plane view, $\Psi_e = \tan^{-1}\frac{\frac{B}{2}}{l_{el}} = \tan^{-1}\frac{12.82}{9.84} \cong 53^o$

And in the H-plane view, $\Psi_h = \tan^{-1}\frac{\frac{A}{2}}{l_{h1}} = \tan^{-1}\frac{19.1}{14.37} \cong 53^o$

The gain of this designed horn is,

$$G = \frac{2\pi}{\lambda^2}\sqrt{3\lambda l_{h1}} * \sqrt{2\lambda l_{e1}} = 9.2 \cong 10$$

So, this derived parameter agrees closely with the designed value of 10dB.

C. Design of Radiating Element

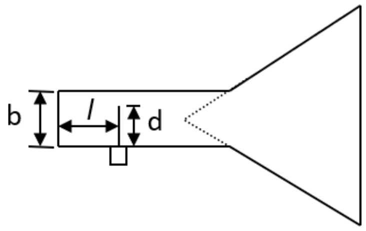


Fig-4: E-plane view with radiating element

D. Designed Antenna Dimension:

The guide wavelength, $\lambda_g = \frac{\lambda}{\sqrt{1-(\frac{f_c}{f})^2}} \cong 70cm$

Distance of the radiating element from the back side of the waveguide is, $l = \frac{\lambda_g}{4} = 17.5cm$

And the length of the radiating element is, $d = \frac{\lambda}{4} = 8cm$

The total length of the Waveguide part will be, $L=0.75\lambda_g= 0.75*70=52.5$cm.

Section	Description	Dimension(cm)
Waveguide	Width, a	18
	Height, b	8
	Length, L	52.5
Aperture	Side, A	38.2
	Side, B	25.64
	E-plane, l_e	16.5
	E-plane, l_{e1}	9.84
	E-plane, l_{e2}	8
Pyramidal Horn	*E-plane* Flared Angle, Ψ_e	53°
	H- plane, l_h	24.3
	H-plane, l_{h1}	14.37
	H-plane, l_{h2}	8
	H-plane Flared Angle, Ψ_h	53°
Radiating Element	*Length, d*	8
	Distance from back side of wave guide, l	17.5

IV. FABRICATION

This section include cutting, bending and joining of all the materials together. The materials used for developing the antenna is steel which was collected from local market. Waveguide section of the horn antenna is a simple rectangular tube and the flange or horn section has otherwise the same geometry, but it is tapered linearly. For maximizing the electrical performance of antenna, the sides of bend and waveguide were bended first and then welded with longitudinal welds. Sheet metal is shaped by cutting using CNC cutting tool. After that holes, openings and threads were machined. Sheet metal parts then bent to their geometry according to required angles and bending radius. Spring back effect and allowed minimum bending radius must be considered. After performing all this, bent sheets were joined together by welding. Either laser, TIG or even MIG welding could be used. However, due to accuracy requirements only TIG-welding were used here as they give reasonable sound.

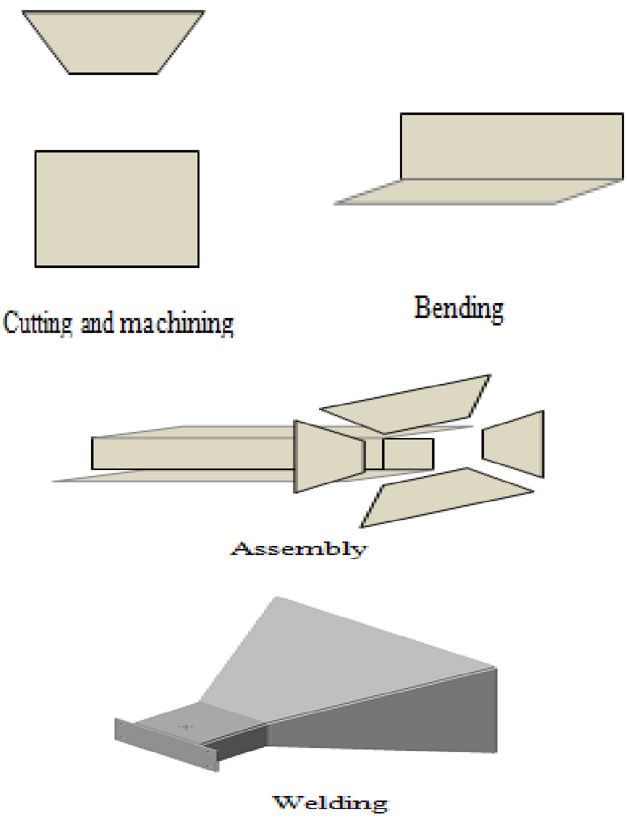


Fig-5: Stages of sheet metal processing of horn antenna

V. RESULTS AND DISCUSSION

Here, a pyramidal horn antenna was designed first by computer aided design and the radiation pattern was analyzed both in practically in lab at the department of EEE, Chittagong University of Engineering and Technologywhereas simulation was conducted by using MATLAB. The designed antenna was also compared with available lab antenna.

A. *Radiation Pattern:*

B.

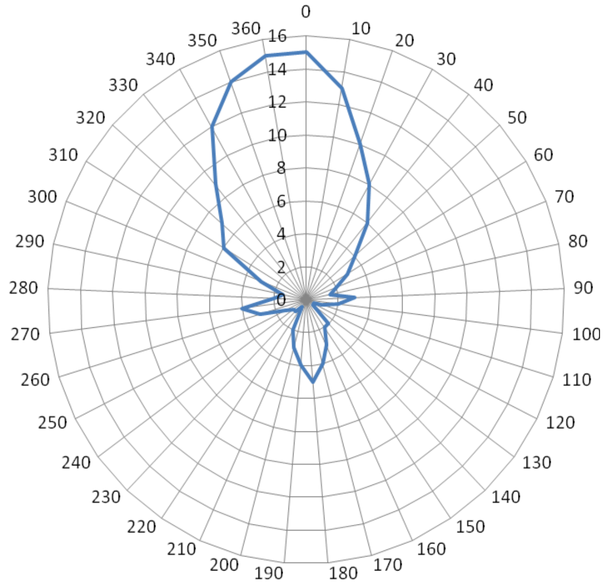


Figure 6: Radiation pattern of designed Horn Antena

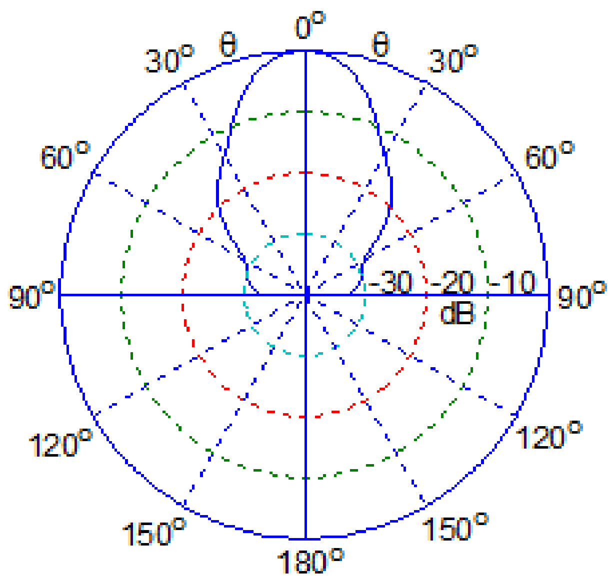


Fig 7: MATLAB Simulation result of designed Horn Antenna

Fig. 6 shows the radiation pattern of design antenna whereas Fig 7 indicates the simulated result of radiation which was done by MATLAB. From the above two figures we can see that, the radiation pattern found from our designed antenna by labdata and simulation by MATLAB is quite similar except side lobe and back lobe.

VI. COMPARISON OF RADIATION PATTERN BETWEEN DESIGNED HORN ANTENNA AND DIFFERENT TYPES OF LAB ANTENNA

Loop Antenna:

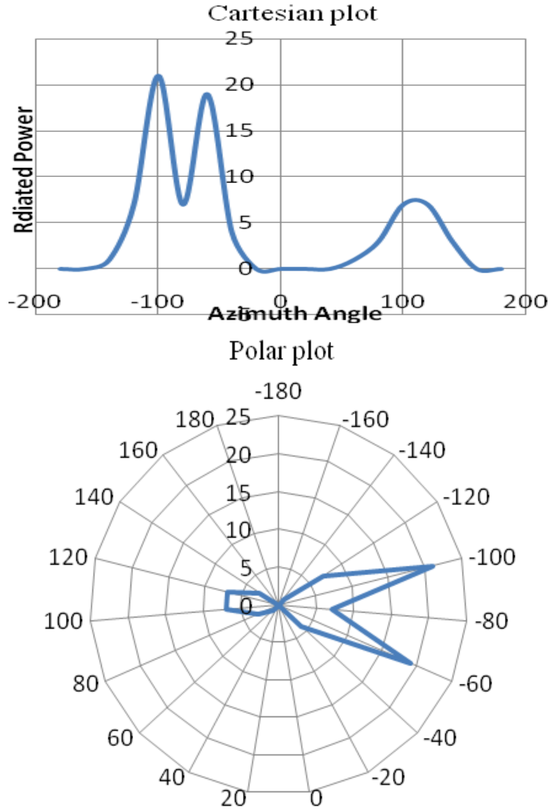


Fig-8:Radiation Pattern of Loop Antenna

Straight dipole antenna:

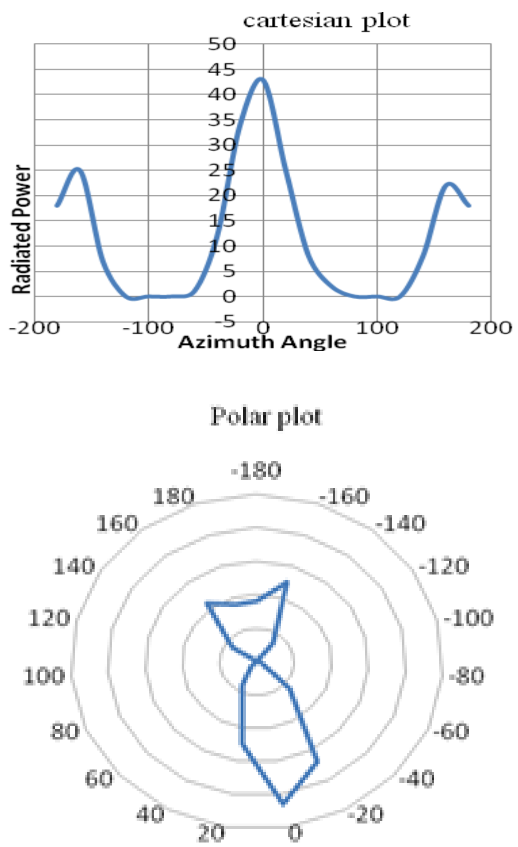
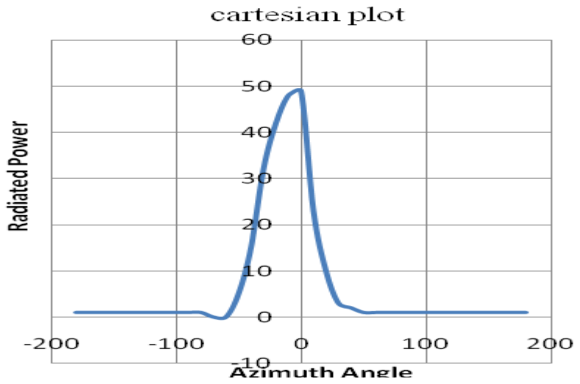


Figure 9:Radiation pattern of straight dipole antenna

Yagi-Yuda Antenna:



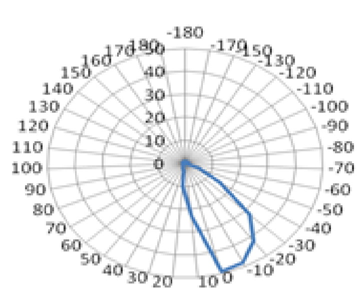
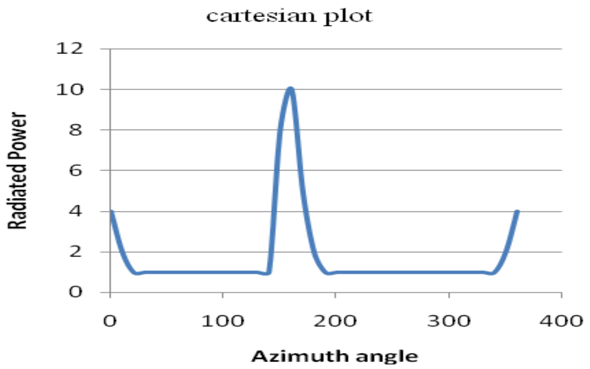


Figure10: Radiation pattern of Yagi-Yuda Antenna

Folded Dipole antenna



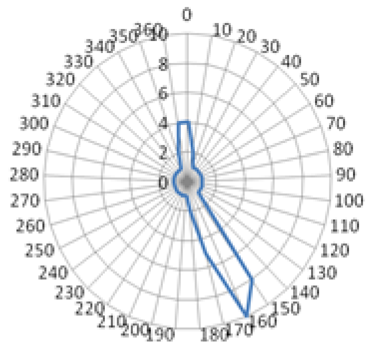


Figure 11: Radiation pattern of Folded Dipole Antenna

VII. DISCUSSION

The simulation results, Directivity as 18dB, Half Power Beam Width 26^0 and front to back ratio is 12 dBi and low cross polarization. By comparing the radiation pattern of horn antenna to the other antennait can be concluded that, the horn antenna combines several ideal characteristics such aslarge bandwidth, high directivity, high front-to-back ratio than the other antenna. Its side lobe and back lobe are so minimal compared to another antenna. As a result of experimental studies, it is evident that signal integrity be intercepted or transmitted depend on the design considerations of the pyramidal horn antenna. These antennas can be enhanced using dielectric lens, good conductive materials and ridges. They are used significantly where directivity of signal is of main concern.

VIII. CONCLUSION

At either ends of microwave communication system where horn antennas are employed, it is essential that while deciding on the intended frequency of operation, one need to define critical parameters upon which such design would be predicated such as the cut – off frequency, hence the bandwidth of the horn antenna, the physical length dimensions, the dipole distance and depth and the hood size. For any decent design, good judgements on these parameters are extremely essential to the realization of any sound horn antenna with a decent beam pattern.

In this research a coaxially fed standard gain horn antenna for the frequency range of 850-950MHz has been designed and during theresearch also two practical test samples were manufactured. In this paper, aspects of design for manufacture and assembly have been appliedto the design and also the possibilities to utilize cross-technologicalapproach method have been examined with successful results. Methods for calculating the required antenna dimensions have beenpresented. Some aspects of selectingsuitable aluminum alloy for laser processing have been discussed.

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