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Horn Antenna Design: The Concepts and Considerations

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***Abstract*--The horn antenna is widely used in the transmission and reception of RF microwave signals. It is usually an assembly of flaring metal, waveguide and antenna. Beyond the fundamental knowledge of microwave propagation, it is essential in the design of horn antenna to understand the intricacies and design considerations at two important ends: the points of propagating microwaves and points of intercepting microwaves. Great care must be taken at the receive ends especially if it involves astronomical applications where the microwaves to be intercepted are from extra terrestrial sources extremely far away and hence very weak. This paper highlights the design considerations of a horn antenna which are fundamental principles employed in the design of a compact horn antenna that will be suitable for astronomical application at L – Band.**

***Keywords*-- Antenna, Cut – off, Gain, Horn, Impedance, Optimal, Probe, RF, Waveguide.**

I. INTRODUCTION

Horns are among the simplest and most widely used microwave antennas and they find applications in the areas of wireless communications, electromagnetic sensing RF heating and biomedicine [1]. The horn antenna may be considered as an RF transformer or impedance match between the waveguide feeder and free space which has an impedance of 377 ohms by having a tapered or having a flared end to the waveguide. Horn antenna offers several benefits when employed in that besides matching the impedance of the guide to that of free space or vice versa, it helps suppress signals travelling via unwanted modes in the waveguide from being radiated and it provides significant level of directivity and gain [2]. While it serves as entry medium for signal interception for processing in the case of receiving systems, it serves in the case of transmission to illuminate dish antenna from its focal area estimated from the f/d parameters of the parabolic dish [3]. Dual mode feedhorns often provide excellent performance over wide range of microwave bands. [4]

II. TYPES OF HORN ANTENNA

The two basic types of horn antenna are the pyramid and conical horn antenna. Other modifications include Sectorial (E or H plane), Exponential, Corrugated, Ridged and Septum Horns.

Figures of pyramidal and Conical horns are shown below [2].

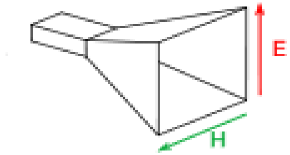

Figure 1: Pyramidal Horn

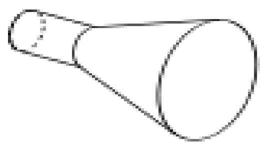

Figure 2: Conical Horn

III. HORN ANTENNA DESIGN CONSIDERATIONS

Impedance matching is very desirable with radio frequency transmission lines. Standing waves lead to increased losses and frequently cause the transmitted to malfunction [5].When one considers a waveguide without a horn in operation, the sudden interface of the conductive walls or free air as the case may be for interception or transmission of microwaves cause an abrupt change in impedance at the interface. This often results in reflections, losses and standing waves. Also when the flare angle becomes too large as it tends to 90 degrees, the operation tends to assume that of a hornless antenna thereby resulting in losses, reflections and standing waves. In design, there is an Optimum flare angle for different horn types where all the aforementioned problems remain very minimal. Such horn antenna designed with considerations to the optimum flare angle is often referred to as the optimum Horn.

IV. APERTURE AND SLANT LENGTH CONSIDERATIONS

To realise an optimum pyramidal horn, the width of the aperture in either the E-field or the H-field direction is dependent on the intended wavelength and the slant length of the aperture in either direction as shown below.

$$A_E = \sqrt{2\lambda L_E} \qquad \text{Eqn (1)}$$

and

$$A_H = \sqrt{3\lambda L_H} \qquad \text{Eqn (2)}$$

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Where:

A_E = width of the aperture in the E – field direction

L_E = Slant length of the aperture in the E – field direction

A_H = width of the aperture in the H – field direction

L_H = Slant length of the aperture in the H – field direction

λ = wavelength

To realise an optimum conical horn, the diameter of the cylindrical horn aperture is dependent on the slant length of the cone from the apex as shown below.

$$d = \sqrt{3\lambda L} \qquad \text{Eqn(3)}$$

Where:

d = diameter of the cylindrical horn aperture

L = slant length of the cone from the apex

The bandwidth for practical horn antennas can be of the order of 20:1 for instance, operating from 1 GHz-20 GHz and while optimum horns give maximum gain for a given horn length, they do not give maximum gain for a given aperture size.

The gain *G* of a pyramidal horn antenna is the ratio of the power intensity along its beam axis to the intensity of an isotropic antenna with the same input power.

The gain (G) of pyramidal and conical horn are expressed below [8].

For pyramidal horn:

$$G = \frac{4\pi A}{\lambda^2} E_a \qquad \text{Eqn(4)}$$

For conical horn:

$$G = \left(\frac{\pi d}{\lambda}\right)^2 . Ea \qquad \text{Eqn(5)}$$

Where:

A = area of the aperture

d = aperture diameter for conical

λ = wavelength

Ea = aperture efficiency, usually btw 0 and 1. Dimensionless.

Aperture efficiency is a dimensionless factor that increases with the length of the horn.

In Practical horns its value ranges from 0.4 to 0.8 while in optimum pyramidal horns its value is 0.511and in optimum conical horns it is 0.522. However, an approximate value of 0.5 is generally used.

V. Frequency Considerations

For any waveguide to be operational at an intended frequency, it must as a critical condition pass the frequency cut – off tests for it to be operational. The horn low cut-off frequency is the lowest frequency below which the horn would not function or where cut-off phenomenon occurs while the horn high cut – off frequency is the highest frequency above which the horn would not function. The horn low – cut frequency can be estimated from Eqn(6) below.

$$\lambda_{LC} = 3.412 \times r \qquad \text{Eqn(6)}$$

Where:

λ_{LC} is the low cut-off wavelength,

r is the radius of the cylinder.

For pyramidal horn with square waveguide, the constant is divided by two, hence we have:

$$\lambda_{LC}(mm) = 1.706 \times base\ length\ (mm) \qquad \text{Eqn(7)}$$

Using standard wavelength formula, low cut off frequency is therefore:

$$F(GHz) = \frac{c}{\lambda} = \frac{300}{\lambda_{LC}} \qquad \text{Eqn (8)}$$

The horn high – cut frequency can be estimated from Eqn(9) below.

$$\lambda_{HC} = 1.3065 \times base\ length\ (mm) \qquad \text{Eqn(9)}$$

Then, equation (8) for high cut – off becomes:

$$F(GHz) = \frac{300}{\lambda_{HC}} \qquad \text{Eqn(10)}$$

The lower cut-off must be below the frequency on which you want to operate and the high cut-off must be above the frequency on which you want to operate. So if the two are 1.54GHz and 2.66GHz respectively, the horn antenna operates in the band of 1.55GHz to 2.65GHz and we have to choose a design frequency within this critical frequency range that we intend to operate the antenna.

While the intended frequency F′ of use is chosen, the wavelength for this intended frequency also known as free space wavelength can be estimated using the equation (8) which gives:

$$\lambda'(\text{mm}) = \frac{300}{F'(\text{GHz})} \qquad \text{Eqn(11)}$$

Physical Length Dimensioning

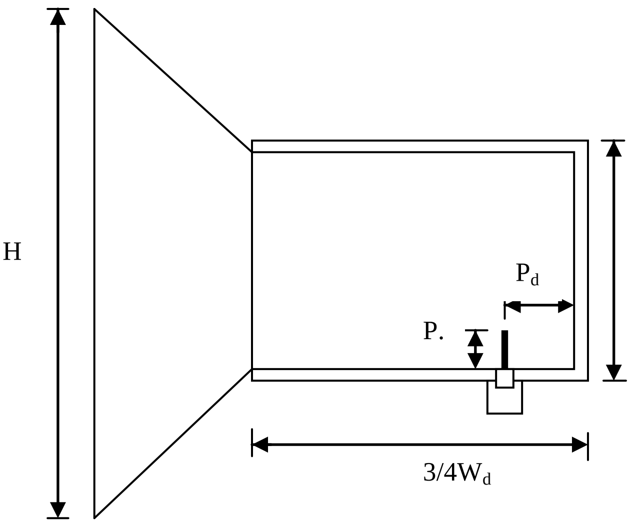

Figure 3: Critical dimensions of Horn Antenna

The waves travelling in the waveguide travel at slower than the speed of light; in estimating the overall length of the horn antenna, if the modified wavelength distance, the wavelength inside the waveguide is Wd, the waveguide length is cut to 75% of Wd.

$$\text{Wd} = \frac{1}{\sqrt{\left(\frac{1}{\lambda'}\right)^2 - \left(\frac{1}{\lambda_{LC}}\right)^2}} \qquad \text{Eqn (12)}$$

Hence, the length of the waveguide is:

$$\text{Waveguide Length} = 0.75 * \text{Wd} \quad \text{Eqn (13)}$$

The probe distance Pd on the waveguide from the close end where the N female connector is located is given as:

$$Pd = \frac{Wd}{4}\, mm \qquad \text{Eqn (14)}$$

The probe depth is then given by:

$$\text{P.} = \frac{\lambda'}{4}\, mm \qquad \text{Eqn (15)}$$

Another important design parameter to be estimated is the Hood size. The outer length of the hood H2 should be 1.5 times the free space wavelength λ'.

$$\text{H2} = 1.5 * \lambda' \text{ (mm)} \qquad \text{Eqn (16)}$$

VI. CONCLUSION

At either ends of microwave communication system where horn antennas are employed, it is clear that the integrity of signal intercepted or transmitted depends largely on the design considerations of the horn antenna. In all, 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.

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