Design of Conical Corrugated Horn Antenna

Prashant D. Sachaniya[1], B.J.Makwana[2], Maulik Patel[3]

[1]Student: M.E. (Communication System Engineering), H.G.C.E, Vehlal, Ahmedabad
[2]Assistant Professor, M.E. (Communication System Engineering) G.E.C. Bhavnagar
[3]Assistant Professor, M.E. (Digital Communications) H.G.C.E, Vehlal Ahmedabad

Abstract: *In this paper, basic concept and design process of the Conical Corrugated horn antenna is presented. The mode combination is established by exciting the dominant mode (TE11) in the circular wave-guide that feeds the horn, and converting into HE11 using variable pitch-to-width-slot mode converter. It has advantage of low return loss and pattern symmetry for design frequency range.*

Key words: *Corrugated Horn, Mode Converter, TE11 to HE11, Conical Corrugated Horn*

I. INTRODUCTION

The design of Conical Corrugated horn antennas is a combination of two modes, input is excited by TE11 mode and the output of the horn is HE11 mode. It is well known that this hybrid mode can be made up of approximately a combination of 85% TE11 and 15% TM11 smooth circular waveguide modes with an appropriate relative phasing between them. The starting field distribution is usually the TE11 mode of the circular waveguide under mono-mode operation, and by means of a proper step or taper in the horn radius, the right amount of TM11 (amplitude and phase) is excited (Potter type horns).

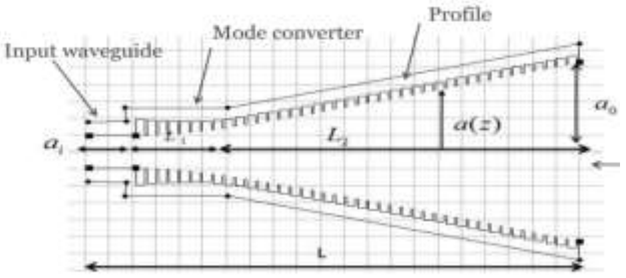


Fig.1 Conical Corrugated Horn Antenna

This technique, firstly used in non-over-sized horns, was later extended to over-sized ones, using long and smooth conical tapers after the step, which provided the appropriate mode mixture at the aperture (85%-15%). To get this mixture with radiating features, two main parameters have to be considered: the output diameter and the horn length. Since the coupling coefficient between waveguide modes is directly related to the waveguide slope change, for a given output radius that fixes the desired beam-width. the change in horn length allows the designer to select the appropriate phasing in the 85% of TE11 and 15% of TM11 mode mixture obtaining the appropriate side lobe and cross polarization minimum levels. Therefore, the only parameter to adjust is the taper length. This type of horn antennas were extensively used in the past decades and were known as Potter type horns, its drawback was the reduced bandwidth a design of this type could cover. Another technique is based on corrugated circular wave-guides and takes profit of the fact that this mode mixture corresponds to the fundamental mode of a circular corrugated waveguide, the HE11 mode. This technique reported in involves a gradual matching of the smooth circular guide to another corrugated one wherein the corrugation depth is smoothly tapered from λ/2 to λ/4.

These two outlined techniques are combined in the so-called conical corrugated horn antennas with a matching device at their input port. In principle, corrugated horn antennas presents a wider frequency response than Potter type horns. Their design parameters are basically: corrugation parameters (period, duty cycle, depth, shape, etc...); length and profile of the λ/2-to-λ/4 impedance matching device; and the horn geometry in order to optimize the global performance of the horn.

Directivity, gain, side lobe and cross polarization levels are important design parameters for many applications involving horn antennas. Additional design parameters, relevant to satellite applications are length and weight, which need to be minimized. During the last 20 years, many of the applications involving high performance horn antennas have been equipped with conical corrugated horn antennas.

II. DESIGN PARAMETERS[8]

First, we have the following four frequencies to aid in the design:

f_{min}: lowest operating frequency
f_{max}: highest operating frequency
f_c: center frequency
f_o: output frequency

The other main parameters to consider are:

a. Choice of the input radius

b. Choice of the output radius

c. Choice of the depths of the slots

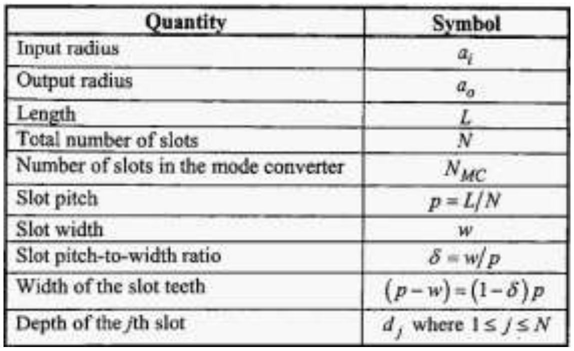
d. Choice of corrugation pitch and pitch-to-width ratio

e. Choice of the mode converter

f. Choice of horn length

g. Choice of the corrugated-surface profile

h. Phase-center position.



Quantity	Symbol
Input radius	a_i
Output radius	a_o
Length	L
Total number of slots	N
Number of slots in the mode converter	N_{MC}
Slot pitch	$p = L/N$
Slot width	w
Slot pitch-to-width ratio	$\delta = w/p$
Width of the slot teeth	$(p-w) = (1-\delta)p$
Depth of the *j*th slot	d_j where $1 \le j \le N$

Table 1: Corrugated Horn-Mode Converter parameters[8]

1. Center Frequency and Output Frequency

The choice of these frequencies depends on whether the horn is for narrow-band or broadband applications.

1.1 Narrow-Band Applications

Where $f_{\max} \le 1.4 * f_{\min}$

The center frequency, f_c, is usually chosen to be $f_c = \sqrt{f_{\min} f_{\max}}$ .the output frequency, f_o, (i.e., the last slot of the horn is optimized for a nominal $\frac{\lambda_o}{4}$) is usually chosen to be $f_c \le f_o \le 1.05 f_c$.

1.2 Broadband Applications

Where $1.4 f_{\min} \le f_{\max} \le 2.4 f_{\min}$

In this case, these frequencies are chosen to be $f_c \approx 1.2 f_{\min}$ and $1.05 f_c \le f_o \le 1.15 f_c$.

2. Input Radius

The fundamental mode in a circular waveguide is the TE,, mode, which has a cut-off wave-number

$$k = \frac{2\pi}{\lambda} = \frac{1.841}{\text{radius of circular waveguide}}$$

Therefore, the input radius, a_i, of a corrugated horn must satisfy the inequality $\frac{2\pi f_{\min}}{c} a_i \ge 1.84118$ (where c is the speed of light), and is often chosen to be such that $k_c a_i = \frac{2\pi}{\lambda_c} a_i = 3, i.e., a_i = \frac{3\lambda_c}{2\pi}$, This choice of a_i usually insures a return loss of the horn of over 15 dB at $f_{\min}$.

3. Output Radius

Typically, a corrugated horn is designed to have a taper of between -12dB to -18dB at an angle corresponding to the edge of the reflector or the edge of the target being illuminated. an estimate of the output radius, a_i, (in λ_c) at edge-taper values of -12, -15, and -18dB for half-subtended angles between 15° and 40°.

4. Nominal Slot-Depth Calculation

The corrugated surface of a corrugated horn represents a surface reactance, x_j, at a point along the horn where the radius is a_j and the slot-depth is d, , defined by

$$x_j = -\delta \frac{J_1(k_c a_j)Y_1\left[k_c(a_j+d_j)\right] - Y_1(k_c a_j)J_1\left[k_c(a_j+d_j)\right]}{J_1'(k_c a_j)Y_1\left[k_c(a_j+d_j)\right] - Y_1'(k_c a_j)J_1\left[k_c(a_j+d_j)\right]},$$

5. Pitch and Pitch-to-Width Ratio

The pitch, p, is usually chosen to be such that $\frac{\lambda_c}{10} \le p \le \frac{\lambda_c}{5}$ For narrow-band operation, a pitch closer to $\lambda_c/5$ is acceptable, while for broadband applications, a pitch closer to $\lambda_c/10$ is preferable. The pitch-to-width ratio, δ, is usually taken to be $0.7 \le \delta \le 0.9$.This parameter mostly influences the level of cross- polarization.

6. Design of Mode Converter

Usually, the input wave-guide is excited by a pure TE_{11} mode and a mode converter is required to do the TE_{11} to HE_{11}, mode conversion over a specified number of slots. There are basically three types of mode converters. They are as follows:

i) Variable-Depth-Slot Mode Converter for $f_{max} < 1.8*f_{min}$

ii) Ring-Loaded-Slot Mode Converter for $f_{max} \le 2.4*f_{min}$
iii) Variable-Pitch-to-Width-Slot Mode Converter for $f_{max} \le 2.05*f_{min}$

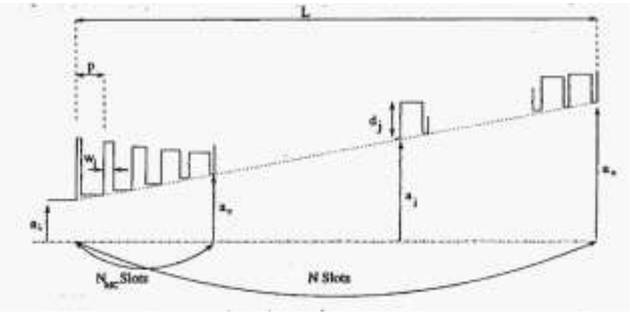


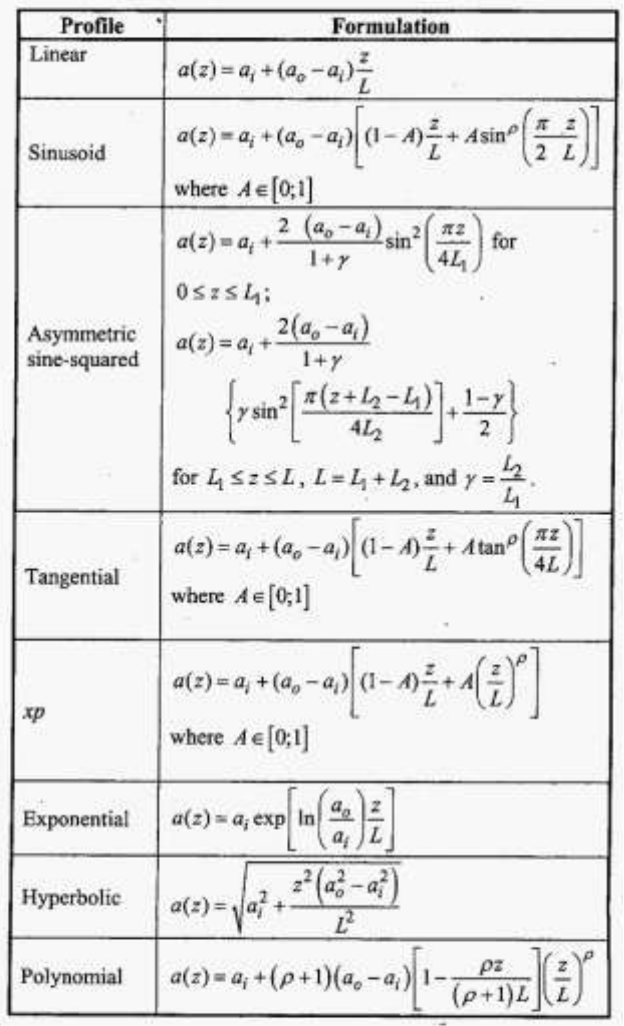
Fig.2 Variable pitch to width mode converter[8]

7. Choice of Horn Length

The length of the horn is usually set by the application, but around $5\lambda_c$ to $10\lambda_c$, is usually required, although some applications may need a horn $20\lambda_c$ to $30\lambda_c$ long. The length will have an impact on the side lobes and the stability of the phase center of the horn. Some experimentation is usually needed. In some cases, designs are optimized to be as compact as possible to reduce cost and weight, especially for on board satellite applications.

8. Choice of the Corrugated Surface Profile

In Table 2, we summarize a variety of profile options available to the feed-horn designer.



Profile	Formulation
Linear	$a(z) = a_i + (a_o - a_i)\frac{z}{L}$
Sinusoid	$a(z) = a_i + (a_o - a_i)\left[(1-A)\frac{z}{L} + A\sin^{\rho}\left(\frac{\pi}{2}\frac{z}{L}\right)\right]$ where $A \in [0;1]$
Asymmetric sine-squared	$a(z) = a_i + \frac{2\ (a_o - a_i)}{1+\gamma}\sin^2\left(\frac{\pi z}{4L_1}\right)$ for $0 \le z \le L_1$; $a(z) = a_i + \frac{2(a_o - a_i)}{1+\gamma}$ $\left\{\gamma \sin^2\left[\frac{\pi(z+L_2-L_1)}{4L_2}\right] + \frac{1-\gamma}{2}\right\}$ for $L_1 \le z \le L$, $L = L_1 + L_2$, and $\gamma = \frac{L_2}{L_1}$.
Tangential	$a(z) = a_i + (a_o - a_i)\left[(1-A)\frac{z}{L} + A\tan^{\rho}\left(\frac{\pi z}{4L}\right)\right]$ where $A \in [0;1]$
xp	$a(z) = a_i + (a_o - a_i)\left[(1-A)\frac{z}{L} + A\left(\frac{z}{L}\right)^{\rho}\right]$ where $A \in [0;1]$
Exponential	$a(z) = a_i \exp\left[\ln\left(\frac{a_o}{a_i}\right)\frac{z}{L}\right]$
Hyperbolic	$a(z) = \sqrt{a_i^2 + \frac{z^2\left(a_o^2 - a_i^2\right)}{L^2}}$
Polynomial	$a(z) = a_i + (\rho+1)(a_o - a_i)\left[1 - \frac{\rho z}{(\rho+1)L}\right]\left(\frac{z}{L}\right)^{\rho}$

Table 2. Types of corrugated surface profile[8]

9. Phase-Center Position

The phase-center position within the horn is determined from the variation in phase across the horn aperture, As a useful starting point, the phase-center position, as measured from the aperture towards the apex of the horn, is given by αL , where 0≤ α ≤1, and is approximated by

$$\alpha = 1 - \exp\left[-4.8\left(\frac{k_c a_o^2}{4\pi L}\right)^2\right].$$

10. Analysis Methods

There are several ways of analyzing the performance of a corrugated horn. The most widely used technique is the mode- matching method. However, if you do not have ready access to such a technique, more general programs are now becoming avail- able. These include (to name only a few, apologies for omissions) Ansoft HFSS, CST Microwave Studio, WASPnet, WIPL-D, and Mician Micro Wave Wizard. Using-the guidelines in this article, it is possible to generate a basic corrugated-horn geometry easily, and to follow this with a refined parameter study using one of the available software packages in an attempt to obtain the required performance specific to your application.

III. SIMULATION RESULT

The simulated results of Conical Corrugated horn antenna at 13.86 GHz (Figure.3) using Variable Pitch to Width Slot Mode Converter Method are given. The Conical Corrugated horn has the directive gain 17dB, cross-polarization (Figure.5) less than -30 dB (Figure.4) for bandwidth of 1.46:1 and improved Radiation Pattern symmetry.

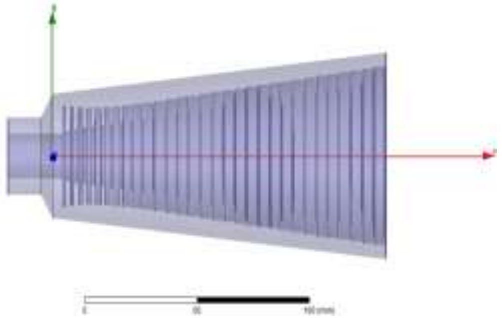


Fig 3. Conical Corrugated Horn with Variable Pitch to Width Mode Converter

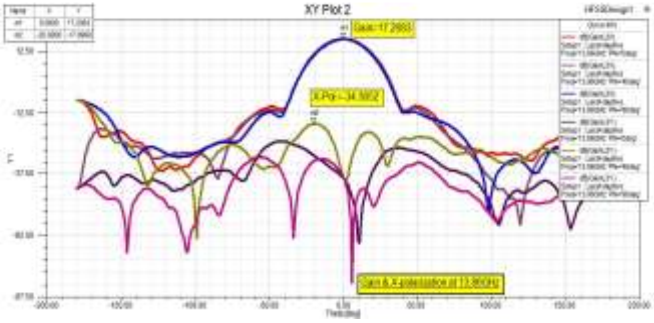


Fig. 4. Gain & Cross-Polarization in Conical Corrugated Horn using Variable Pitch to Width Mode Converter at 13.86GHz.

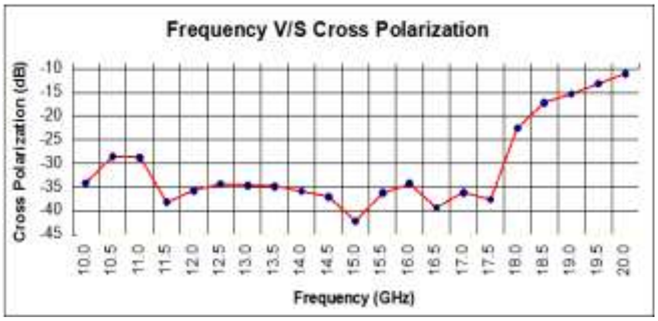


Fig. 5. Frequency V/S Cross-Polarization in Conical Corrugated Horn-Variable Pitch to Width Mode Converter

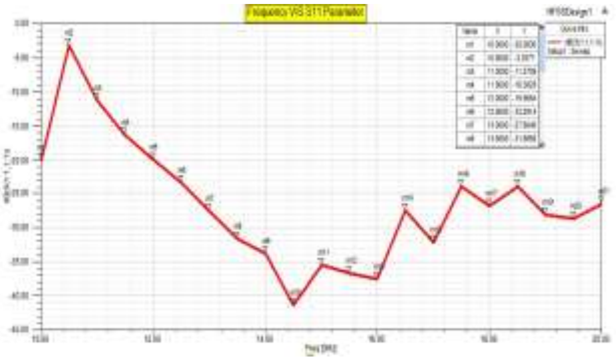


Fig. 6. Frequency V/S S_{11} parameter in Conical Corrugated Horn Variable Pitch to Width Mode Converter

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