TE_{11} to HE_{11} Mode Converter in Corrugated Horn Antenna

Prashant D. Sachaniya[1] B.J.Makwana[2] Maulik Patel[3]
[1]M.E Student (Communication System Engineering) [2,3]Assistant Professor
[1,2]Department of Communication System Engineering [3]Department of Digital Communications
[1,3]H.G.C.E, Vehlal, Ahmedabad [2]G.E.C. Bhavnagar

Abstract— In this paper, basic concept and design process of the TE_{11} to HE_{11} mode converter in corrugated horn antenna is presented. In order to obtain optimum illumination at the aperture of a dual mode conical horn, as in the open cassegrain antenna it is necessary to control the relative amplitudes and phase of the TE_{11} and TM_{11} modes. The mode combination is established by exciting the dominant mode (TE_{11}) in the circular wave-guide that feeds the horn, and converting into HE_{11} using variable-pitch-to-width-slot mode converter. It has advantage of low return loss and pattern symmetry for design frequency range.

Key words: Mode Converter, Corrugated Horn, TE_{11} to HE_{11}

I. INTRODUCTION

One of the simplest and probably the most widely used microwave antenna is the horn antenna. The horn antenna is nothing more than a hollow pipe of different cross sections, which has been tapered (flared) to a larger opening. Horn antennas consist of a flaring metal wave-guide shaped like a horn to direct radio waves in a beam. They are used as feeders (feed horns) for larger antenna structures such as parabolic antennas and as directive antennas for such devices. They are used as a feed element for large radio astronomy, satellite tracking and communication dishes. Its widespread applicability stems from its simplicity in construction, ease of excitation, versatility, large gain, and preferred overall performance. Horn antennas are popular in the microwave band (above 1 GHz). They provide high gain, low VSWR (with wave-guide feeds); relatively wide bandwidth and they are not difficult to be made.

In the 1960s, the idea of corrugated horns was first considered by Kay [1], Simons and Kay[2] and Minnett and Thomas[3],[4]. This was due to the specific interest in achieving symmetric radiation patterns so that low-side lobe and high efficiency reflector antennas could be produced. It was also realized in the 1970s by Parini, Clarricoats, and Olver[5] that corrugated horns radiate very low levels of cross polarization, which is essential for dual-polarization operation or frequency re-use. This is the situation where two signal channels are transmitted on orthogonal polarization at the same frequency, and no interaction takes place between the two channels. Therefore the channel capacity is doubled for a single antenna.

Corrugated horns supporting so-called hybrid modes have become well established as feeds for reflector antennas, and even as direct radiators. It is not difficult to trace the popularity of the corrugated horn, given the ability of certain hybrid modes to produce radiation patterns having extremely good beam symmetry with low cross-polarization levels, high beam efficiency with very low side lobes, and the potential for wide-bandwidth performance. Why they are called "corrugated" is clear from the typical example of a horn shown in Figure1, where the inside wall is manufactured in a succession of slots and "teeth." The purpose of the corrugated surface is to provide the means to support the propagation of hybrid modes within the horn [8].

Hybrid modes are basically a combination of TE and TM modes. For this combination to propagate as a single entity with a common propagating velocity, the horn or wave-guide must have isotropic surface-reactance properties: properties that are satisfied by the corrugated surface. It is worth pointing out that hybrid modes can also be supported by other means, such as wave-guides or horns partially filled with dielectric. However, these alternative possibilities are outside the scope of this design note [8].

We begin with some practical considerations. The bandwidth of a horn is usually defined by the frequency range over which the horn is required to have a suitable beam width and beam symmetry for a return loss usually better than 15 to 18 dB, and with a cross polarization maximum better than -20to -25 dB. These values are typical, but many high-performance applications have much tighter specifications [8].

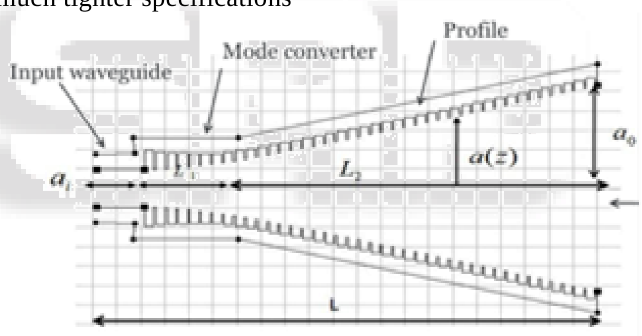

Fig. 1: A Typical Corrugated Horn Antenna with Mode Converter

As illustrated in Figure 1, it is usual for the corrugated horn to be connected to a circular, smooth-walled, input wave-guide. The fundamental mode of this guide is the TE_{11} mode, and there is the need for a so-called "mode converter" at the transition between the smooth-walled input wave-guide and the body of the corrugated horn. This mode converter is designed to provide a smooth transition from the TE_{11} to the HE_{11} mode supported by the corrugated horn[8].

II. DESIGN

A. Design Parameters:

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:

1) Choice of the input radius
2) Choice of the output radius
3) Choice of the depths of the slots
4) Choice of corrugation pitch and pitch-to-width ratio
5) Choice of the mode converter
6) Choice of horn length
7) Choice of the corrugated-surface profile
8) Phase-center position.

Parameter	Symbol
Input radius	a_i
Output radius	a_o
Length	L
Total number of slots	N
No. of slots in the Mode converter	N_{MC}
Slot Pitch	$p=L/M$
Slot Width	w
Slot Pitch to Width Ratio	$\delta=w/p$
Width of the slot teeth	$(p-w)=(1-\delta)p$
Depth of the jth Slot	dj where $1 \le j \le N$

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

B. 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:

- Variable-Depth-Slot Mode Converter for $f_{max} < 1.8*f_{min}$
- Ring-Loaded-Slot Mode Converter for $f_{max} \le 2.4*f_{min}$
- Variable-Pitch-to-Width-Slot Mode Converter for $f_{max} \le 2.05*f_{min}$

1) Variable-Depth-Slot Mode Converter[8][9]

When $1 \le j \le N_{MC}+1$, then the slot depth of the jth slot is

$$d_j = \left\{\sigma - \frac{j-1}{N_{MC}}\left(\sigma - \frac{1}{4}\exp\left[\frac{1}{2.114(k_c a_j)^{1.134}}\right]\right)\right\}\lambda_c$$

Where σ (0.4 ≤ σ ≤ 0.5) is a percentage factor for the first slot depth of the mode converter

When $N_{MC}+2 \le j \le N$, then the slot depth of the jth slot is

$$d_j = \frac{\lambda_c}{4}\exp\left[\frac{1}{2.114(k_c a_j)^{1.134}}\right] - \left(\frac{j-N_{MC}-1}{N-N_{MC}-1}\right)$$
$$\left\{\frac{\lambda_c}{4}\exp\left[\frac{1}{2.114(k_c a_o)^{1.134}}\right] - \frac{\lambda_o}{4}\exp\left[\frac{1}{2.114(k_o a_o)^{1.134}}\right]\right\}$$

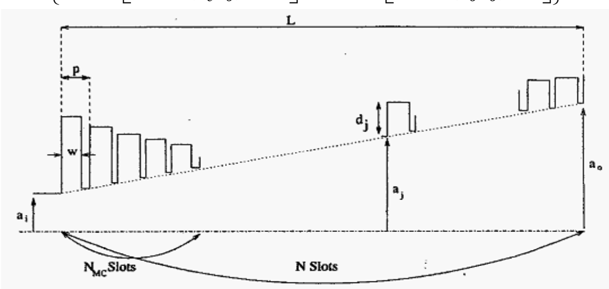

Fig. 2: The Geometrical Parameter of Variable-Depth-Slot Mode Converter [8]

2) Ring-Loaded-Slot Mode Converter[7][8]

When $1 \le j \le N_{MC}+1$, then the slot depth of the jth slot is

$$d_j = \frac{\lambda_c}{4}\exp\left[\frac{1}{2.114(k_c a_j)^{1.134}}\right]$$

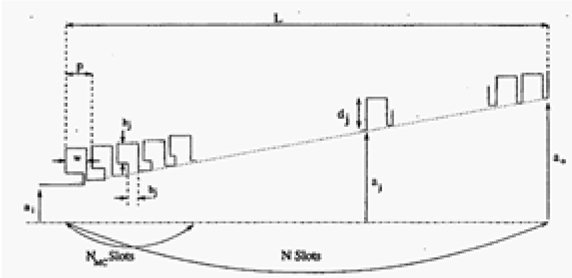

Fig. 3: The Geometrical Parameter of Ring-Loaded-Slot Mode Converter[8]

When $N_{MC}+2 \le j \le N$, then the slot depth of the jth slot is

$$d_j = \frac{\lambda_c}{4}\exp\left[\frac{1}{2.114(k_c a_j)^{1.134}}\right] - \left(\frac{j-N_{MC}-1}{N-N_{MC}-1}\right)$$
$$\left\{\frac{\lambda_c}{4}\exp\left[\frac{1}{2.114(k_c a_o)^{1.134}}\right] - \frac{\lambda_o}{4}\exp\left[\frac{1}{2.114(k_o a_o)^{1.134}}\right]\right\}$$

When $1 \le j \le N_{MC}$, then the width of the bth slot is

$$b_j = \left[0.1 + (j-1)\frac{\delta - 0.1}{N_{MC}}\right]p$$

And the height of the h_jth slot is

$$h_j = \frac{2}{3}d_j$$

3) Variable-Pitch-to-Width-Slot Mode Converter[6][8]

When $1 \le j \le N_{MC}+1$, then the slot depth of the jth slot is

$$d_j = \left[\sigma\frac{\lambda_c}{1.15} + \frac{j-1}{N_{MC}-1}\left(\frac{\lambda_c}{4} - \sigma\frac{\lambda_c}{4}\right)\right]$$
$$\exp\left[\frac{1}{2.114(k_c a_j)^{1.134}}\right]$$

When $N_{MC}+2 \le j \le N$, then the slot depth of the jth slot is

$$d_j = \frac{\lambda_c}{4}\exp\left[\frac{1}{2.114(k_c a_j)^{1.134}}\right] - \left(\frac{j-N_{MC}-1}{N-N_{MC}-1}\right)$$
$$\left\{\frac{\lambda_c}{4}\exp\left[\frac{1}{2.114(k_c a_o)^{1.134}}\right] - \frac{\lambda_o}{4}\exp\left[\frac{1}{2.114(k_o a_o)^{1.134}}\right]\right\}$$

When $1 \le j \le N_{MC}$, then the width of the w_jth slot is

$$w_j = \delta_{min} + \frac{j-1}{N_{MC}-1}(\delta_{max} - \delta_{min}),$$

With 0.125≤δmin ≤ δ and δmax≈δ (the nominal pitch-to-width ratio) As before, 0.4 ≤ σ ≤ 0.5

III. SIMULATED RESULT

The simulated results of TE_{11} to HE_{11} mode Converter at 10GHz using Variable Pitch to Width Slot Mode Converter Method (Figure.4) are given. The horn with smooth edges Variable Pitch to Width Slot Mode Converter has the output in terms of HE_{11} (Figure.6) with the directive gain 14dB is achieved for cross-polarization (Figure.5) less than -21 dB and improved Radiation Pattern symmetry.

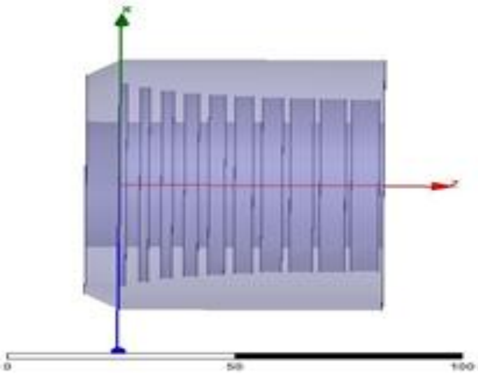

Fig. 4: Side View of Variable Pitch to Width Slot Mode Converter in Corrugated Horn Antenna at 10GHz

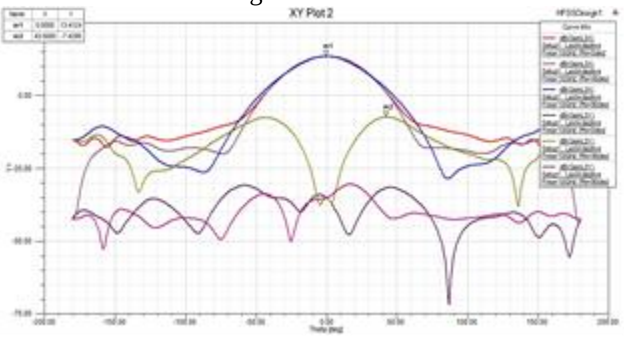

Fig. 5: Directive Gain and Cross Polarization of Variable Pitch to Width Slot Mode Converter in Corrugated Horn Antenna at 10GHz.

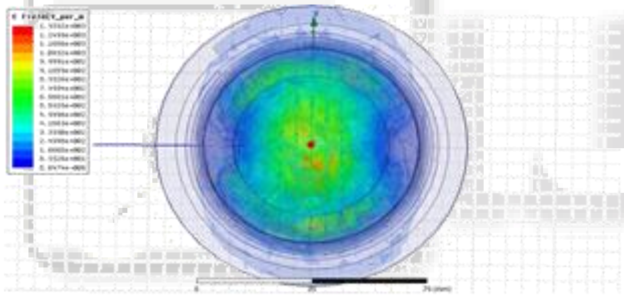

Fig. 6: HE_{11} generated at output of the Variable Pitch to Width Slot Mode Converter

REFERENCES

[1] A. F. Kay, "A wide flare angle horn. A novel feed for low noise broadband and high aperture efficiency antennas," US Airforce Cambridge Research Laboratories, Rep. 62-757, October 1962.

[2] A. J. Simons and A. F. Kay, "The scalar feed – a high performance feed for large paraboloidal reflectors," in IEE Conference, 1966, pp. 213-217.

[3] H. C. Minnett and MacA. B. Thomas, "A method of synthetising radiation patterns with axial symmetry," IEEE Transactions, AP-14, pp. 654-656, 1966.

[4] H. C. Minnett and MacA. B. Thomas, "Propagation and radiation behaviour of corrugated feeds," in Proceedings of IEE, 1972, p. 1280.

[5] C. G. Parini, P. J. B. Clarricoats, and A. D. Olver, "Cross-polar radiation from open-ended corrugated waveguides," Electronic Letters, 11, p. 567, 1975.

[6] Schwerthoeffer, U. ; Adel, H. ; Wansch, R. **"**Design and implementation of a Ka-band corrugated feed horn for reflector antennas",Antennas and Propagation Society International Symposium (APSURSI), IEEE 2013

[7] K. B. Parikh, S. B. Sharma, J. V. Dave"Asymmetrical Sine Squared Profiled Corrugated Horn offers Enhanced Bandwidth", IEEE, 2012.

[8] Christophe Granetand Graeme L. James, "Design of Corrugated Horns: A Primer",Antennas and Propagation Magazine, Vol. 47, No.2, April 200

[9] E.R. Nagelberg, J.Shefer, "Mode Conversion in Circular Waveguide",1965.

[10] A.W.Rudge, Nurin A. Adatia, "Offset Parabolic Reflector Antenna", Proceedings of IEEE, Vol-66, 1978.

[11] A. Balanis, Antenna Theory, analysis and Design, Second Edition,pp 796-800

[12] Getting Started with HFSSv9 for Antenna Design v0.pdf

[13] M. Kulkarni, Microwave and Radar Engineering, Fourth Edition,2010,pp 74-137