Design of Wideband Asymmetrical Sine Squared Profiled Corrugated Horn as Optimal Feed for Dual Reflector

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Abstract- The design methodology based on extensive parametric study and simulation is presented for asymmetrical sine squared profiled corrugated horn. The dominant mode, $TE_{11}$ has been converted into hybrid mode, $HE_{11}$, using an improved ring-loaded slot mode converter sections. Subsequently the asymmetrical sine squared profiled corrugated horn has been used to feed the dual reflector. The primary and secondary radiation characteristics are also obtained and presented. The pattern symmetry over desired beamwidth, cross-polarization less than 25 dB in both primary and secondary radiation patterns and the return loss better than 17 dB have been achieved over the bandwidth ratio of 2.5:1.

I. INTRODUCTION

The corrugated horns have well known properties like pattern symmetry and low level of cross-polarization. Due to above mentioned characteristics of corrugated horns, these horns are widely used as a feed for dual reflector antennas for satellite communication and radio telescopes. In the conventional corrugated horn the interior corrugated surface is tapered linearly while in the profiled corrugated horn the interior corrugated surface is asymmetrically sine squared profiled. The profiled corrugated horn offers higher gain and efficiency. As the flare angle at the aperture is zero, the phase center position remains constant over the bandwidth. There is a good impedance matching also at the input waveguide because of the small flare angle at the throat. The idea of profiled corrugated horn was first considered by Watson et al.[1]. The bandwidth ratio of up to 2.4:1 has been reported by G.L.James [2] in 1984. In 2012, K.B.Parikh et al. [3] have reported the bandwidth ratio of 2.22:1.

In the following section II the design principles of the profiled corrugated horn have been discussed. The optimized design of different parts has been discussed in Section III. The simulated results have been summarized in Section IV.

II. DESIGN PRINCIPLES

A circular waveguide with transverse circumferential grooves of appropriate depth called corrugated waveguide offers same boundary condition for both E and H field, means it radiates symmetrically in all directions. This fundamental principle was developed by Rumsey [4] in 1966. The present design deals with an improved profiled corrugated horn. It has been modified to asymmetrical sine squared profile such corrugated horn has three parts namely input taper, mode converter and profiled horn section. The cross-section view of asymmetrical sine squared profiled corrugated horn is shown in Fig.1. The corrugated horns are mostly fed by a smooth wall circular waveguide supporting the dominant mode, $TE_{11}$. The input taper smoothly transfers the input radius $a_i$ into mode converter radius $a_{i_c}$. The mode converter is used to convert the dominant mode, $TE_{11}$ into hybrid mode, $HE_{11}$. The mode converter of the horn is most critical part to design. The mode converter section is between smooth wall waveguide and corrugated waveguide. As smooth wall waveguide has zero longitudinal surface reactance and on the other side the corrugated waveguide has a longitudinal reactance of vary high value. One way to achieve this conversion of longitudinal surface reactance from zero to vary high value is to use slots of constant width, where the depth of the slots is gradually decreases from one half wavelength at the input to one quarter wavelength at output, this type of mode converter is called variable depth slot mode converter [5]. This mode converter offers narrow band conversion. To convert $TE_{11}$ mode into $HE_{11}$ mode over a wide bandwidth, the ring-loaded slot mode converter [6] is used in which the width of each consecutive slot gradually increases along the length of the converter. The ring-loaded slot mode converter has negligible amount mismatching and excitation of higher order modes. The mode converter parameters $a_l$, $b_l$ and the design frequency $f_l$ at which the slots are electrically one quarter wavelength deep are the critical design parameters so as to optimize the $TE_{11}$ into $HE_{11}$ mode conversion without generating the higher order modes. The profiled horn section accommodates necessary changes in flare angle as the flare angle at the input to the profiled horn section is equal to the flare angle of the mode converter, within the horn the flare angle reaches its maximum value and at the horn aperture the flare angle become zero.

III. DESIGN METHODOLOGY

A. Input Taper

The input taper provides an increase in radius from $TE_{11}$ cut-off to that required for $HE_{11}$ cut-off. The input radius of the taper is $k a_{i_{in}}= 2.4912$ and the output radius of the taper is $k a_{i_{out}}= 2.8999$. The length of the taper is $L_i = 1.2 ~ \lambda_i$. The input taper affects the performance of return loss. Therefore the input &
output radii and length of the taper are decided such that the horn gives improved return loss performance. The input taper is linearly profiled and shown in Fig.1.

B. Mode Converter

The mode converter is the most critical part of the corrugated horn. The ring-loaded slot mode converter is used in the horn to achieve wide band performance. In this mode converter it is assumed that only dominant mode exits in the slots so the impedance of the ring-loaded slot to be capacitive over the bandwidth [7]. The mode converter can excite the unwanted highly cross-polarized EH_{11} modes, particularly the slow wave mode, EH_{11} at low frequency of the band and the mode, EH_{12} at the higher cut-off of the band. The mode converter is designed at frequency \( f_i = 1.228 \ f_{min} \). The input radius of the mode converter is chosen such that it satisfies the cut-off of the HE_{11} mode, \( k_a 1 = 2.8999 \). The flare angle \( \theta_0 \) is selected such that, at \( f_{min} \) the slow wave mode EH_{11} may not propagate and cross-polarization in \( \pm 45 \) degree planes can be minimized. The length of the mode converter is \( L_2 = \lambda \) and ten numbers of slots are selected as to ensure the return loss performance beyond the band. The pitch of each slot is \( p_0 = 0.1 \lambda \) and the width to pitch ratio is \( \delta = 0.75 \). The slot depth and slot width are given by,

\[
d_i = \frac{\lambda}{4} \left( \frac{1}{g} \sin \frac{\pi}{4} \right) (1)
\]

\[
b_i = 0.1 + \frac{(0.2 - 0.1)}{L_i} (2)
\]

The mode converter used in this paper has specially designed round edge ring-loaded slots. These round edge slots further reduce the excitation of the higher order modes, EH_{11} at the discontinuities and enhance the cross-polarized bandwidth as compared to the conventional ring-loaded slot mode converter. The round edge ring-loaded slot mode converter can be analyzed using well-known modal matching techniques [6]. The cross-sectional view of ring-loaded slot mode converter is shown in Fig.2.

C. Profiled Horn Section

The horn has asymmetrical sine squared profiled. It is necessary to choose inner radius of the profile and input profile angle such that HE_{11} mode smoothly transfers from mode converter to horn without significant amount of reflection. The maximum flare angle \( \theta_M \) is key parameter which decides the excitation of higher order mode, HE_{12} along the horn profile and this mode raises the co-polar side lobes. Therefore, the \( \theta_M \) is restricted to 18 degree. The design equation of the profiled is,

\[
a(z) = a_0 + \frac{2(b_0 e^{-0.02})}{2pr} \sin \left( \frac{z}{4a_0} \right) (3)
\]

For \( L_2 \leq z \leq L_1 \),

\[
r(z) = a_0 + \frac{2(b_0 e^{-0.02})}{2pr} \left[ \frac{\sin^2 \left( \frac{z}{4a_0} \right)}{2} + \frac{1-r}{2} \right] (4)
\]

For \( L_1 \leq z \leq L_5 \), \( L_5 = L_3 + L_4 \), \( r = \frac{L_4}{L_3} = 0.4 \).

The design frequency is \( f_i = 1.195 \ f_{min} \), the aperture radius is selected as \( a_0 = 2.24 \lambda_0 \), pitch \( p = 0.1 \lambda_0 \). Slot width to pitch ratio \( \delta = 0.75 \) and slot depths are same as chosen in mode converter section.

IV. SIMULATED RESULTS

The simulation has been carried out for asymmetrical sine squared profiled corrugated horn by using Ansoft HFSS. The asymmetrical sine squared profiled corrugated horn using HFSS is shown in Fig. 3. As dual reflector the cassegrain reflector system is used and the secondary patterns have been obtained using TICRA’s GRASP. The simulated results include gain, cross-polarization and return loss. The return loss is shown in Fig.4. The return loss performance is restricted by the low frequency. But the return loss better than 17 dB can be obtained at frequency 2.85 GHz whereas, it is better than 30 dB at the higher cut-off 7 GHz. Fig. 5 shows the radiation patterns of the horn over the frequency band of 2.85 to 7 GHz. Mainly the cross-polar component is restricted by high frequency. But the cross-polarization better than 25 dB can be obtained by the horn at 7GHz. The cross-polarization is shown in Fig.6. The cassegrain reflector system designed in GRASP is shown in Fig. 7. The secondary patterns after using the asymmetrical sine squared profiled corrugated horn as a feed for the cassegrain reflector are shown in Fig.8. As from Fig.8, it can be seen that the cross-polarization in secondary patterns over the frequency band is below 25 dB. The return loss is better than 17 dB and peak cross polarization is better than -25 dB over the bandwidth ratios up to 2.5:1.

V. CONCLUSION

The design methodology and simulated results of asymmetrical sine squared profiled corrugated horn are presented. The new design approach for wide band ring-loaded slot mode converter has been discussed. The radiating and transmission characteristics of asymmetric sine squared profiled corrugated horn as well as secondary radiation patterns using dual reflector are optimized and presented. The bandwidth of 2.5:1 is achieved for cross-polarization less than 25 dB and return loss better than 17 dB.

REFERENCES

Fig. 1. Cross-sectional view of asymmetrical sine squared profiled corrugated horn.

Fig. 2. Cross-sectional view of ring-loaded slot mode converter.

Fig. 3. Asymmetrical sine squared profiled corrugated horn using HFSS.

Fig. 4. Return loss Vs Frequency.
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Fig. 5. Radiation patterns, [A] 2.85 GHz, [B] 3.5 GHz, [C] 4.5 GHz, [D] 5.5 GHz, [E] 6.5 GHz and [F] 7 GHz.

Fig. 6. Cross-polarization Vs Frequency.

Fig. 7. Cassegrain reflector system designed in GRASP.

Fig. 8. Secondary Radiation patterns, [A] 3 GHz, [B] 5 GHz and [C] 7 GHz.