Design of High Performance Wideband Corrugated Horn*

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Abstract

We present results of investigations in order to design wideband horn antennas both with respect to the return loss and the cross polarisation level.

1. Introduction

Corrugated horns have been studied at large mainly for space applications. The work reported here was intended to design a microwave source with less than –40dB VSWR, less than –50dB cross polarisation and low sidelobes over 20% bandwidth. Two analysis techniques may be used for the simulation of such antennas : the method of moment (MoM) based on solution of integral equations, and the scattering matrix technique. Results presented in this paper have been obtained using the MoM technique by means of 1D integral equations.

The most complete reference on this topic is the book by Olver and Clarricoats [1] who presented an extended analysis varying independently the most important parameters and giving information on the return loss and the cross polarisation. The additional problem of the synthesis of wide band corrugated horns was first addressed by Dragone [2] and more recently by Zhang [3]. The corresponding design allows to obtain comparable low levels of VSWR and cross polarisation over a large bandwidth.

2. State of the art

In [1] is outlined a methodology for designing corrugated horns, and a number of useful charts are provided, with a set of qualitative rules which are derived from the theory of modes in corrugated guides and conical horns, completed by numerical computations either semi-analytic or based on mode-matching. The numerical solution of exact integral equations by MoM was not in use for such problems at that time and is yet only practical if one takes full advantage of the symmetry of revolution. It is explained in [1] why the larger the diameter of the horn, the wider will be the bandwidth for a given x-polar level. It is also indicated that for long horns especially, the pattern is controlled mainly by the additional spherical phase factor, and thus depends more on the flare angle than on the aperture radius. Specifically the beamwidth may be calculated from the hypothesis that the field is that of a pure HE11 mode. As we shall show this is not always true.

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Olver and Clarricoats have shown that there is a limit of about 3°5 for the beamwidth and that the corresponding flare angle is below 15°. we used this value of 3°5. As for the flare angle, if it is too small the horn will be large ; if it is increased we obtain higher values of cross polarisation levels. A value of the flare angle between 10° and 12° provides a good solution

Zhang [3] studied large bandwidth corrugated horns both in terms of return loss and cross polarisation, and indicates how to choose the dimensions in order to have a wide band horn. Only the HE11 mode is wanted in order to have a low cross polarisation level. This sets a geometrical domain such that the dimensions allow HE11 to exist and EH11 to vanish. So the teeth to groove width has to be modified in order to meet requirements on both a low cross polarisation level and a large bandwidth. According to [3], the slots width has to be very thin at the beginning of the corrugated section (t / g = 7) (with t the tooth width and g the groove width) and becomes larger at the end of the corrugated section (t / g = ½). This way to modify the groove to tooth width ratio seems to be the only way to increase the bandwidth and maintain the cross polarisation level to a low value.

3. Parametric study

Influence of the input taper section

We found that the best transition from the waveguide to the horn is a parabolic profile with continuity of the derivative maintained at both ends The best VSWR is obtained for a value of approximately 10.2 times the waveguide radius for a flare angle of 10 degrees. For a flare angle of 14° the optimal taper length is approximately 14. , and 22 for 22°

Influence of the corrugation depth

According to Toral et al [4], one solution consists in setting the first corrugation depth to a particular value between λ/4 and λ/2. The optimal value seems to be 0.43 λ. Another solution consists in varying regularly the depth (following an exponential function), starting from a value close to λ/4 to a value equal to λ/2, as indicated in [4]. These two cases have been studied. The best solution we obtained consists in varying linearly the depth from λ/2 to λ/4. If the decrease in depth is achieved over a shorter length, it results a higher VSWR.

Number of corrugations per wavelength

For values of the size of a corrugation varying from 0.1 λ to 0.3 λ, no significant differences are observed on the VSWR. Variations on co – polarisation and x – polarisation levels were studied for a 20 corrugations length horn. A size of the corrugations of 0.15 / 0.2 λ , approximately 5 corrugations per wavelength, seems to be optimal.

Bandwidth consideration

Two series of results were obtained : results for the return loss vs frequency show a bandwidth close to 10 % at – 45 dB and 17 % at – 40 dB, using an input taper. Varying both depth and width of the slots inside the waveguide section and without input taper, there is a clear benefit with 35% of bandwidth at – 40 dB for the x-polar and 22% at – 45 dB.

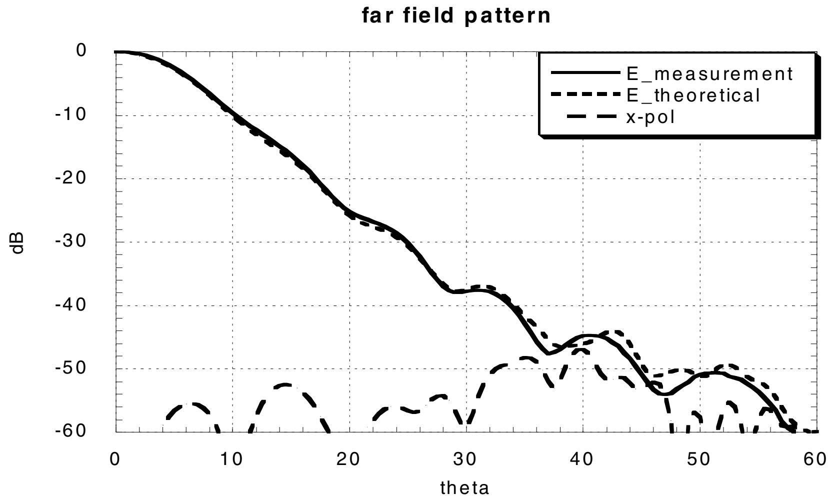
4. Results of optimisation

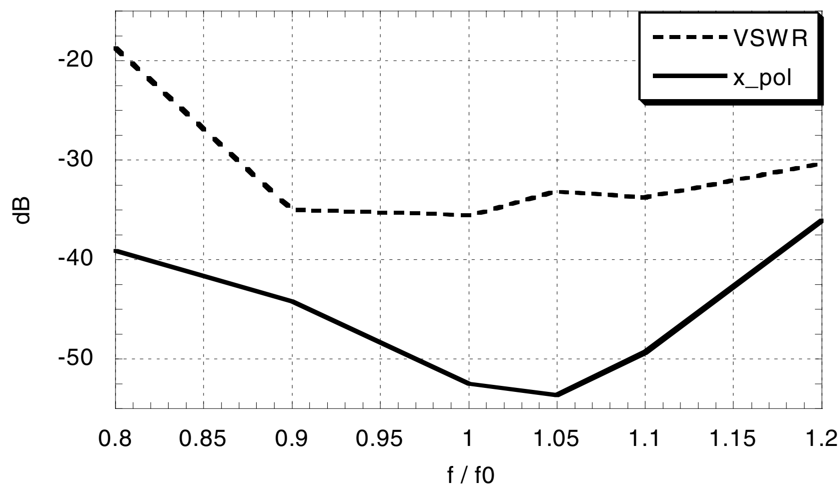
VSWR

Analysis of the simulations results of the study that we made shows that the VSWR is not affected by the length. It is in fact mainly related to the horn throat. A lower value (up to – 50 dB) may be obtained, using a very smooth throat profile, but not maintained over a large bandwidth. On the contrary the solution we obtained is not so good but it is usually acceptable (comparatively to the values corresponding to OMT and polarisers) and it is maintained over a large bandwidth.

cross-polarisation over the whole pattern

The cross-polarisation comes from the EH11 hybrid mode. This mode is evanescent in the profile we have synthesised and the horn length plays an essential role to decrease the cross-polarisation level. A value of - 45 dB seems to be the highest reachable level on a significant bandwidth. This low value has been obtained choosing an operating point regarding the different modes such that HE11 propagates and EH11 is attenuated. This operating point is defined in terms of teeth / grooves dimensions from which equivalent electrical properties may be deduced.





5. Synthesis and Conclusion

Our numerical studies have confirmed qualitative results like the relation between the minimum beamwidth and the aperture diameter, the fact that x-polar tends to increase with the flare angle and to decrease as a function of the frequency and to have a negative slope w.r.t. frequency at the operating frequency, and the fact that the depth of the corrugations should be decreasing or constant but not smaller than .25 λ. Other results are less simple. For instance it is generally agreed that the depth of the corrugations at large kr should be .25, but ref. [3] shows a result with very low x-polar for a depth equal to 0.33 λ. This means that the overall hybrid balance, that is the realisation of the balanced conditions on the aperture, may be achieved with different repartitions of impedance along the horn meridian. Similar remarks apply to the law of decrease of the corrugations depth and to the design of the input section.

There is no single general model for characterising horns having low VSWR and low X-polar over a wide frequency band. In terms of local equivalent surface impedances it may be stated that the VSWR depends on the smoothness of the impedance variation while the x-polar depends on the overall balance. Therefore the VSWR does not change significantly in general when the length is increased by addition of equal corrugations ; on the other hand the x-polar may change if the additional corrugations are not exactly adapted. But the x-polar may also be generated by abrupt changes in the profile and is finally sensitive to all details of the geometry. This may be understood intuitively by considering the requirements of the balanced hybrid conditions, which cannot be met in the transition region between guide and horn ; so the imbalance appearing in that region must be compensated by the subsequent corrugated region and it takes more or less length until one can consider that each new corrugation should meet the balanced condition. It is verified that this is more and more true when the flare angle increases.

In order to obtain a large bandwidth (with respect to both the VSWR and the cross polarisation), one of the best solutions consists in varying the teeth widths along the profile. The profile should not include an input taper. As a disadvantage the VSWR is higher than previously but it can be maintained to the same level (only a few dB variation) over a very large bandwidth. Moreover the solution is very stable. In particular increasing the number of corrugations does not affect the VSWR.

References

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