DESIGN AND MANUFACTURING OF NON-CIRCULAR SPLINE-PROFILE HORNS

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ABSTRACT

The latest improvements of feed horn design tools allow to fit better and better with a wide range of specifications : wide or multiple frequency bands, smooth profiles, phase center stability over the band, etc. With new computational capabilities come opportunities to create more efficient designs that take into account both RF performances and manufacturing constraints.

The aim of the current work is to design spline-profile, high-efficiency horns, the first application targeted being for an Array Fed Shaped Reflector (AFSR) antenna. In order to achieve the highest possible gain, the section of the horn is chosen so as to overlay as much as possible the cell of the array lattice. This constraint leads to use square or hexagonal sections, combined with triangular or square lattice. As most feed horn optimization softwares are restricted to circular sections, the design of such horns has required a specific tool.

In the frame of this work, a script has been developed over an existing optimization algorithm to fulfill the design of non-circular horns. The algorithm is based on mode-matching technique (Mician µWave Wizard) and allows to cope with any possible section. The horn profile is discretized and optimized iteratively to meet several main constraints : aperture efficiency, return loss over the frequency band(s), cross-polarization. Manufacturing constraints can also be taken into account : for example, a positive slope all along the profile might be sought depending on the manufacturing process.

This original tool has been used for the design of a spline-profile high-efficiency Ku-band Tx/Rx square horn. A very compact geometry has been obtained with very good return-loss and cross-polarization levels. Moreover the aperture efficiency achieved is similar to those of traditional circular high-efficiency horns. Simulated performances have been crosschecked with ICARE (Method of Moments) and CST Microwave Studio (Finite Integration Technique). The feed horn is manufactured, and will be measured in CNES antenna measurement facilities for validation.

This work has been done by IEEA in the frame of a CNES R&T study.

1. SPECIFICATIONS

The aim of the presented study is to design a dual frequency band high efficiency square horn. While the aperture efficiency is the primary goal, the other performances must be kept at acceptable levels. Tables 1 and 2 show the required performance levels.

Table 1 : Performance objectives for the Tx frequency band (11.7 GHz – 12.75 GHz)

Description	Objective
Aperture Efficiency	> 85 %
Return Loss	< -23 dB
Xpo/copomax θ<15°	< -33 dB
Xpo/copomax θ<20°	< -25 dB
Ohmic Loss	< 0.1 dB

Table 2 : Performance objectives for the Rx frequency band (17.3 GHz – 18.4 GHz)

Description	Objective
Aperture Efficiency	> 75 %
Return Loss	< -20 dB
Xpo/copomax θ<6°	< -33 dB
Xpo/copomax θ<20°	< -25 dB
Ohmic Loss	< 0.15 dB

The following notes apply to tables 1 and 2 :

- Aperture efficiency is defined as the ratio of the maximum gain and the gain of a uniformly illuminated aperture.
- Cross polarization (Xpo) is normalized by the maximum gain (copomax). The objective is defined for a θ angle range. θ is the angle between the observation direction and the axis of the horn.

The size of the square aperture is 66.7 mm (about 2.6 wavelength at 11.7 GHz). The length must be below 180 mm, but should be as short as possible, with an objective of 130 mm. The input waveguide has a square section of 15.5 mm.

2. DESIGN TOOL

The methodology of the design is based on [1]. The inner profile of the horn is described by a spline function. A fixed number of control points are used to define the spline. These points are the variables of the design. Actually, there positions along the axis of the horn are fixed. The variables are their distance from the axis. A design is evaluated with a cost function taking into account the difference between the objectives and the simulated performances. An optimization process is used to find the variables leading to the lowest cost function.

The number of variables may be important to reach an acceptable level of performance. However, the greater is this number, the longer is the optimization. To perform this optimization within a reasonable amount of time, the simulation of the horn must be very fast. The fastest and still very accurate method to simulate a square horn seems to be the Mode Matching method. In addition, there are several commercial and mature software packages using this method. For this study, µWave Wizard [2] is used.

In addition to the Mode Matching solver supporting most of the waveguide section geometries, this software provides an integrated optimization algorithm. Another attractive feature is its macro editor : the user can write a script to control most of the software functionalities. For example, a square horn with a spline inner profile is not a native element of the software. A macro has been developed to automatically create and connect the waveguide sections that are the components of the horn.

A spline function is coded to define the size of each section. Finally, the macro prepares the optimization by creating the variables and the cost function.

In order to take into account the user inputs, the macro displays a graphical user interface (Fig. 1). The following comments apply to this user interface :

- The explanatory picture presents the available sections : square, hexagon, octagon, circular. However µWave Wizard is not limited to regular polygons.
- This picture also shows an optional linear output for the horn. This feature is introduced to take into account manufacturing constraints (see part 4.).
- The control points can be regularly placed along the axis of the horn, or the user can position them. This feature is introduced to increase or decrease the points density in some regions.
- The slope of the profile can be forced to be positive. Actually, the decreasing parts of the spline are just ignored. This may be required by the manufacturing process.
- By default, natural conditions are applied at both ends of the spline. However, it is possible to force its derivative to zero at the input. This may help to achieve a smooth transition from the input waveguide to the spline horn.

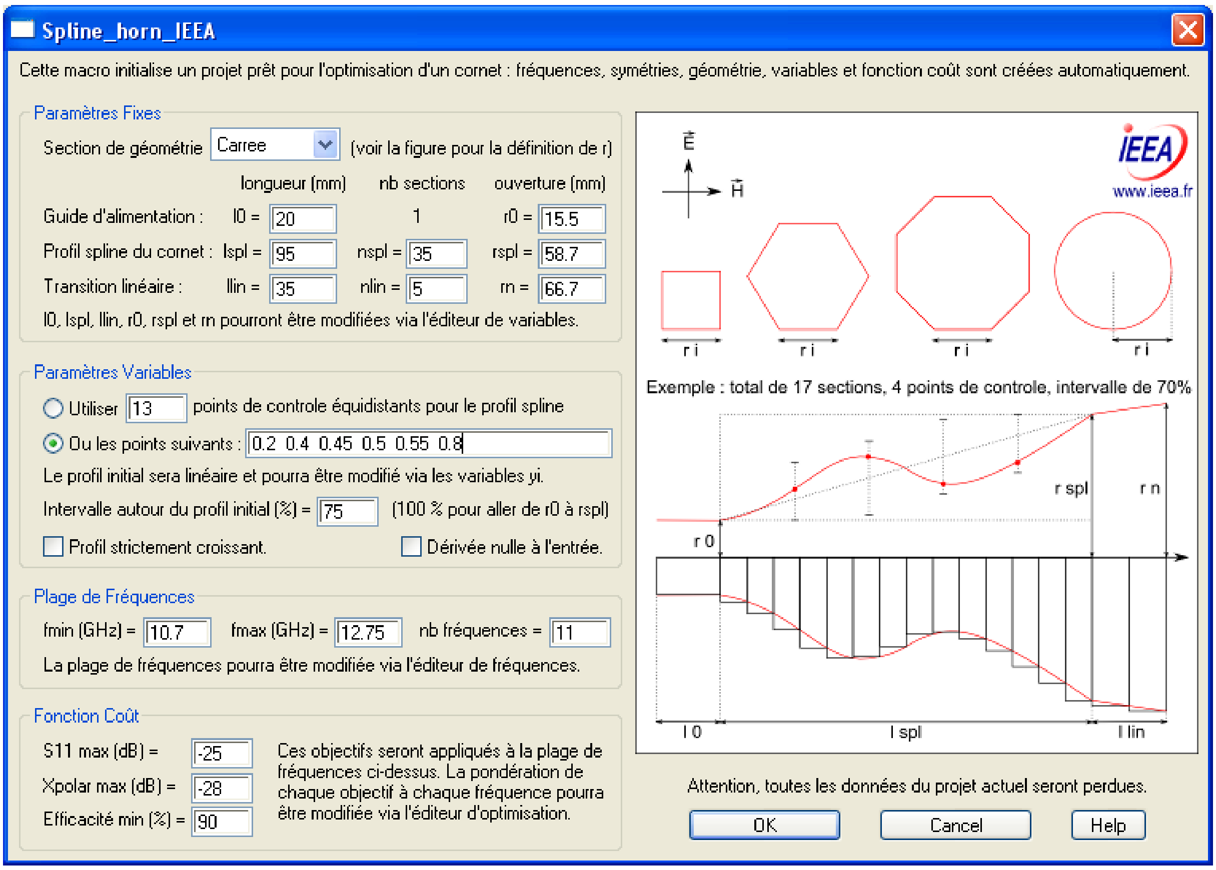

Figure 1 : GUI of the macro steering µWave Wizard in order to prepare the optimization of a spline profile square horn.

3. OPTIMIZATION RESULTS

The length of the horn is fixed during the optimization. Therefore, to minimize the length, several optimizations are launched with different length values. It is observed that the longer the horn is, the better is its efficiency. This behavior can be explained for a simple pyramidal horn : at the aperture, the phase front is almost a plane for a long horn, which provides a better aperture efficiency. As a consequence, the best design will be the shortest horn still compliant with the objective performances.

An example of an optimized horn is presented on fig. 2. The length is 130 mm (without the input waveguide). The number of control points to define the spline function is 13. In this study, this number appears to be a good compromise between the profile flexibility and number of iterations required for the optimization to converge.

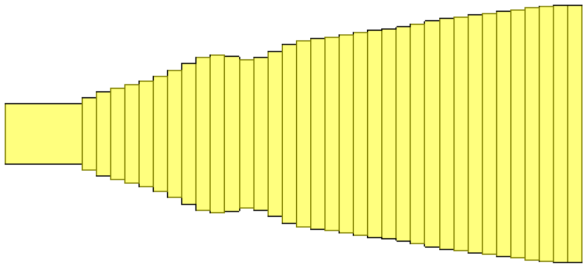

Figure 2 : Stepped profile of an example of an optimized horn.

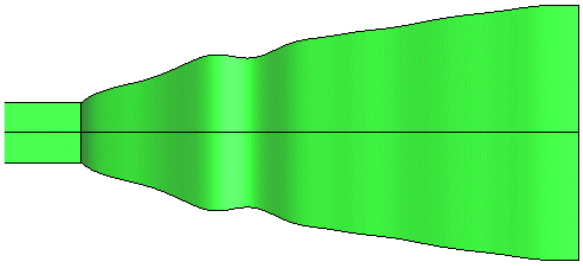

Figure 3 : Smooth wall version of the horn presented on Fig. 2.

Unlike in [1] where a stepped horn is actually manufactured, a smooth wall version of the horn is manufactured. For the example of fig. 2, the smooth wall version is presented in fig. 3. For validation purposes, the smooth wall version is also simulated with the tools ICARE (3D general MoM, developed by IEEA, [3]) and CST Microwave Studio.

After an extensive set of optimizations, a final design is obtained. Like the example of fig. 2, it is 130 mm long and 13 control points define its profile. Fig. 4, 5 and 6 are the simulated performances of this optimized horn. The first observation is that the three simulation tools provide similar results. This validates the design and proves that the stepped version of the horn used for the Mode Matching technique during the optimization was a good approximation. The second observation is that the results are compliant with all the specifications of tables 1 and 2.

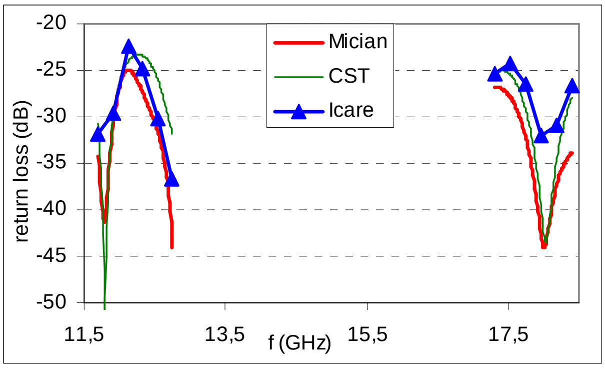

Figure 4 : Return loss of the final optimized horn.

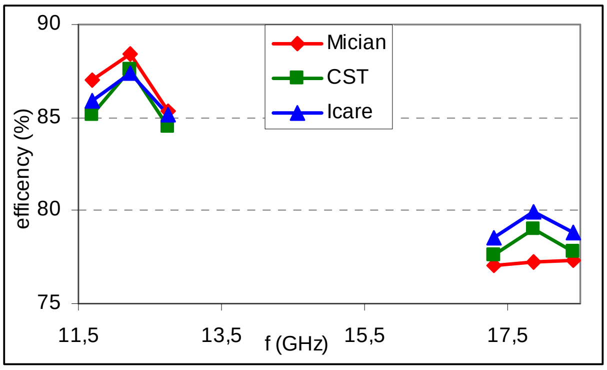

Figure 5 : Aperture efficiency of the final optimized horn.

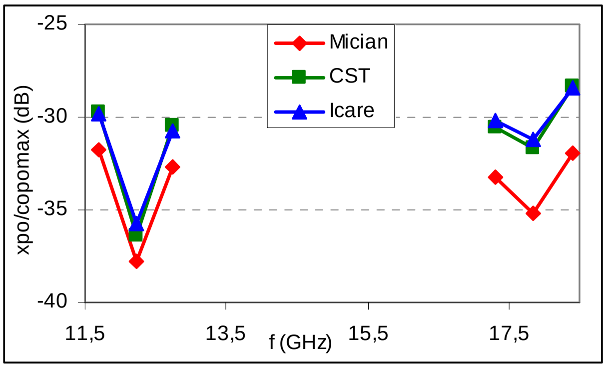

Figure 6 : Maximum cross polarization (for θ<20° and normalized by the maximum gain) of the final optimized horn.

4. MANUFACTURING

The main manufacturing constraint is the metal thickness at the output of the horn. It should be thick enough for mechanical stability, but thin enough to achieve a high horns density in an array. The objective thickness is 0.5 mm.

Most of the optimizations launched for this study converged to designs with output walls almost parallel to the horn axis. For example, fig. 2 shows that the last sections have almost the same size. As a consequence, the output section is fragile and may suffer from deformation. The first approach used to manage this constraint was to include a linear output (fig. 1). The slope of this part was fixed to be as small as possible and still compliant with the mechanical constraints. However, none of the optimizations of such structure led to an acceptable design. The obtained aperture efficiency was to low. The second approach explored was to use rounded corner as shown in fig. 7. Although the horn aperture is slightly smaller, the obtained performances (simulated with Icare) are very similar to the performances of its straight corners counterpart.

Fig. 7 presents the manufactured horn. The material is an aluminum alloy. The manufacturing process is classical drilling. The horn is actually divided into 4 slides along its axis. Each part is drilled separately from a solid aluminum alloy piece.

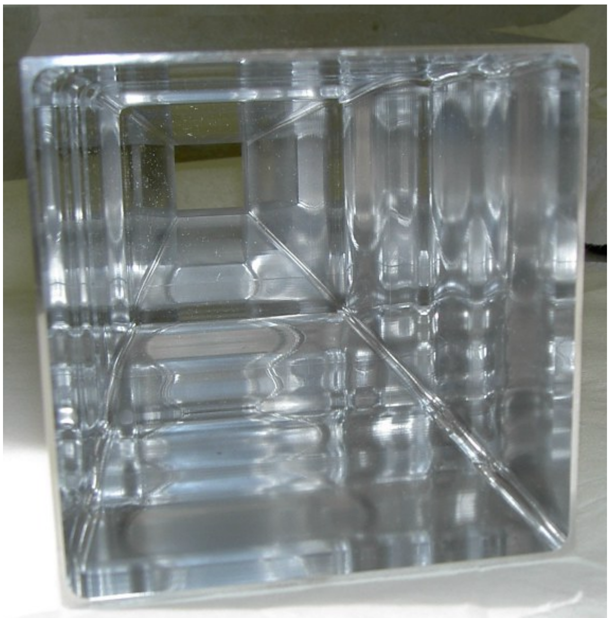

Figure 7 : View of the inside of the manufactured horn.

5. CONCLUSION

A high-efficiency dual band square horn has been design with an automated optimization process based on a commercial Mode Matching software. The variable of the design was the spline inner profile of the horn. The performances have been validated with three different simulation techniques. The horn has been manufactured and will be measured within the next weeks at the CNES facilities.

This work is another successful design resulting from the combination of modern computation power, fast simulation software and efficient optimization algorithm. However, it must be noticed that the design process wasn't entirely automated. Indeed, expertise and even trial and error were required to find the right parameters, for example the number of variables, the weights in the cost function, the starting point or the simulation parameters.

REFERENCES

[1] T.S. Bird, C. Granet , « Optimization of Profiles of Rectangular Horns for High Efficiency », *IEEE Trans. Antennas Propag.*, vol. AP-57, pp. 2480–2488, 2007.

[2] Mician µWave Wizard features description available online :
http://www.mician.com/cms/content/products/wave_wizard

[3] Icare description and user manual available online :
http://www.ieea.fr/en/softwares/icare-mom.html