Better Multiband Horn Antenna Design by Using the Real Modal Content at Input

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***Abstract*—By taking into account the real modal content coming from the connected stage, instead of the fundamental waveguide mode only, a horn antenna can be designed to cope with the imperfections at its input. Unwanted higher order modes are often responsible for performance degradation and hence bandwidth limitation. The design procedure is applied for two types of horns, dedicated to different applications, but both with a wideband objective.**

***Index Terms*—horn antenna, multiband, wideband, modal content.**

I. Introduction

A major constraint for onboard satellite antennas is weight and accommodation. To increase the number of functionalities without additional apertures, more and more payloads include multi-frequency horn antennas. The lowest and highest operating frequencies may be separated by more than one octave. The input waveguide diameter of such antennas is set to allow the propagation of the fundamental mode at the lowest frequency. At the higher frequencies, higher order modes of this waveguide tend to move from evanescent to propagative. While the horn antenna is classically designed by assuming that the part connected at its input (transition, polarizer, diplexer, OMT, …) generates only the fundamental mode, the higher order modes are practically unavoidable. A typical effect is a cross polarization level higher than expected at those frequencies due to higher order modes propagating through the input waveguide.

A literature review was performed to identify possible ways to suppress the unwanted modes in the input waveguide. Solutions like [1] may be used, but they are limited to particular modes and aren’t suited for circular polarization. The bibliography study has also shown that wideband operation can be achieved with horns classically used for space applications, like the profiled smooth wall horn (spline in [2] or piecewise linear in [3]) or the corrugated horn ([4]). Both horn technologies will be used in the application part of this paper. The work presented is applied to circular horns, but it might easily be extended to any horn section shape.

II. Workflow Description

A horn antenna is classically designed with the assumption that it is fed with the fundamental mode. The feeding circuit is concurrently designed to produce a field distribution as near as possible from the fundamental mode. The final step is the simulation of the entire feed chain to validate the assembly. While this is common for regular narrow band operation, it can be challenging for wideband applications. In that case, higher order modes are transmitted to the horn and affect its radiation characteristics. The entire assembly may require long transitions or extra parts to reduce the level of those unwanted modes.

The approach proposed here is to consider the higher order modes as an input of the horn design procedure. The modal content at the output of the feeding circuit may be measured or simulated with another tool. However, in order to show the benefits of the method without the implementation details (different mode definitions, different file formats, experimental setup, …), the software µWave Wizard ([5]) is used to simulate the entire feed chain. This mode matching simulation tool is well suited for the optimization of waveguide structures and horn antennas. In addition, the solving technique directly provides a valuable insight into the modal content.

Since µWave Wizard is able to simulate the entire feed chain, it is possible to optimize the horn antenna inside the system, without any assumptions. However, taking into account all the modes is time consuming, whereas µWave Wizard can use the symmetry properties of the TE11 mode to significantly reduce the computation resources. It has been observed that a preliminary design assuming a TE11 feeding leads to a good starting point for an optimization of the horn within the entire feed chain. In that case, very few iterations are required to improve the performances. This result might be limited to cases with a realistic level of higher order modes (around –20 dB below the fundamental mode).

These comments lead to a straightforward workflow, summarized as following:

- Optimize the horn assuming a TE11 mode in the input waveguide.
- Get the S-parameters file describing the RF circuit connected to the horn (all the modes propagating in every access of the circuit are the ports of this multiport element).

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- Evaluate the horn performances when connected to the RF circuit, simulated as a black box multiport.
- If the horn radiation is affected too much, optimize the horn when connected to the RF circuit.

III. Application Examples

A. Telecommunication Mission

The antenna described in this part is designed to be a part of a communication system. TABLE I. shows that there is a 2.9 ratio between the lower and the higher frequencies. The RF circuit intended to feed this horn wasn't available at the time of the study. The alternative chosen to illustrate the proposed method is a coaxial to circular transition (visible in Fig. 2). Such an element simplifies the input into a single TEM mode and allows to realistically reflect higher order modes coming from the horn. It can be designed within µWave Wizard to produce typical levels of higher order modes. These modes are mainly TM11, TE31 and TE12 (Fig. 1).

The spline profiled smooth wall horn has been reported in the literature ([2]) as a design able to operate on several frequency bands distant by more than one octave. The variables of the geometry are the positions of the control points of the spline function. Fig. 2 shows that very few modifications were required to improve the preliminary design optimized with a pure TE11 mode in order to cope with the actual source imperfections. However, without these minor modifications, the XPD would be unacceptably high in the V frequency band (Fig. 3). The improved design brings the XPD level below the specifications. The tradeoff leads to a lower aperture efficiency at the higher frequency (Fig. 3).

TABLE I. ANTENNA SPECIFICATIONS

Band	**User Tx Ka**	**User Rx Ka**	**Gateway Tx Q**	**Gateway Rx V**
Freq. min Freq. max	17.30 GHz 18.75 GHz	28.40 GHz 28.90 GHz	37.50 GHz 38.50 GHz	47.20 GHz 50.10 GHz
Return loss	< -23 dB	< -23 dB	< -23 dB	< -23 dB
Aperture efficiency	> 88 %	> 75 %	> 65 %	> 60 %
XPD[a]	< -7 dB	< -7 dB	< -12 dB	< -12 dB

[a] XPD is defined as the maximal value of the ratio cross polarization over co polarization, for the angular sector illuminating the reflector (19°)

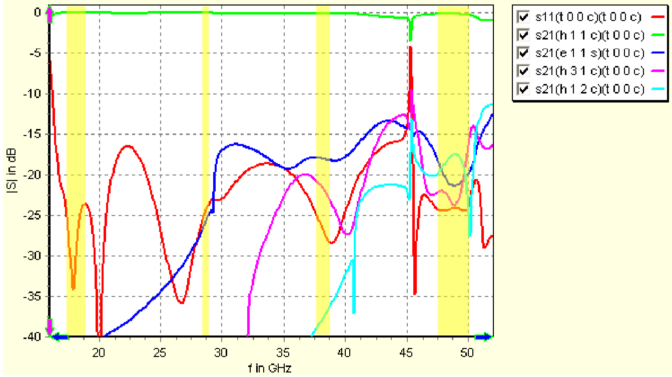

Fig. 1. S-parameters of the coaxial to circular transition (only the parameters with a significant level). The frequency bands are yellow. Port 1 is the coaxial waveguide. Port 2 is the circular waveguide. Mode naming conventions in µWave Wizard : h for TE mode, e for TM, c and s for polarizations.

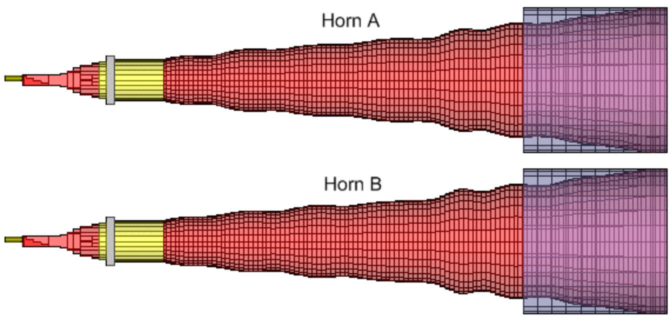

Fig. 2. Horn A has been optimized for a pure TE11 mode feed. Horn B was connected to the real feed during the optimization. The grey part between the transition and the horn is an ideal polarizer used to simulate a circular polarization.

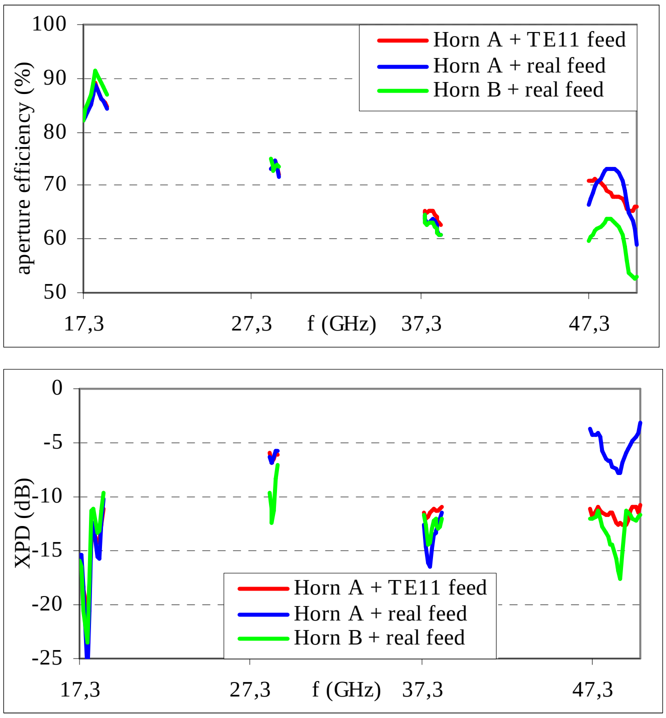

Fig. 3. Aperture efficiency and cross polarization of the horns optimized with a pure TE11 feed (Horn A) or with a real feed (Horn B).

B. *Radiometer Mission*

A dual band corrugated horn antenna has been designed during another study. Details are available in [6]. The operating frequency bands and the main objectives are reported in TABLE II. . This antenna is fed by a diplexer on a rectangular waveguide followed by a long rectangular to circular transition. This long RF circuit produces a near perfect TE11 mode even at the higher frequencies. For the work presented in this paper, this transition was shortened to reduce bulkiness, leading to an increased higher order modes level. Fig. 4 shows that mainly the TM11 and TE31 modes are transmitted to the horn input. It is visible on Fig. 6 that these modes affect significantly the cross polarization level in the second frequency band. However, the optimization of the horn within the feed chain was able to greatly reduce the cross polarization degradation.

TABLE II. ANTENNA SPECIFICATIONS

Band	**1**	**2**
Freq. min - Freq. max	49.5-55.5 GHz	109-128 GHz
Return loss	< -28 dB	< -28 dB
Aperture efficiency	Constant (around 60 %)	Constant (around 60 %)
Cross polarization (xpo max / copo max)	< -30 dB	< -30 dB

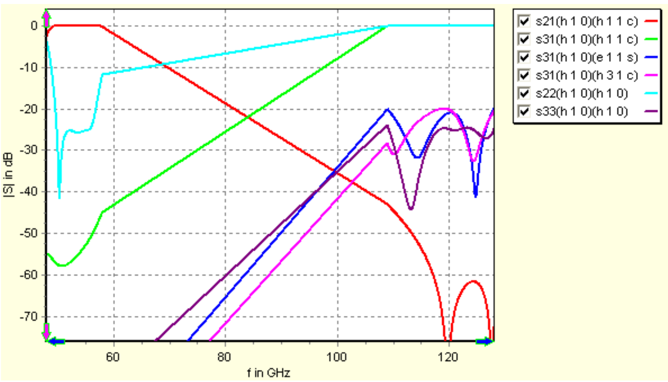

Fig. 4. S-parameters of the diplexer (only the parameters with a significant level, only computed within the operating bands). Port 1 is the common circular wave guide. Port 2 is the low frequency access (standard WR-15 rectangular waveguide). Port 3 is the high frquency access (standard WR-8 rectangular waveguide).

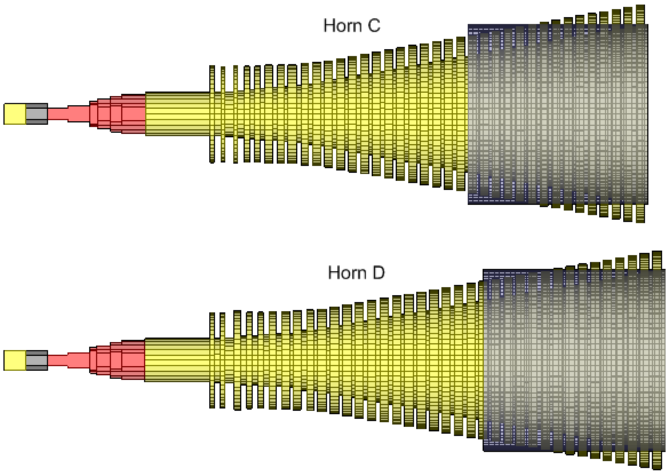

Fig. 5. Corrugated horn C has been optimized for a pure TE11 mode feed. Horn D was connected to the diplexer during the optimization. The grey part between the rectangular inputs and the rectangular to circular transition simulates the diplexer described with a S-parameters file.

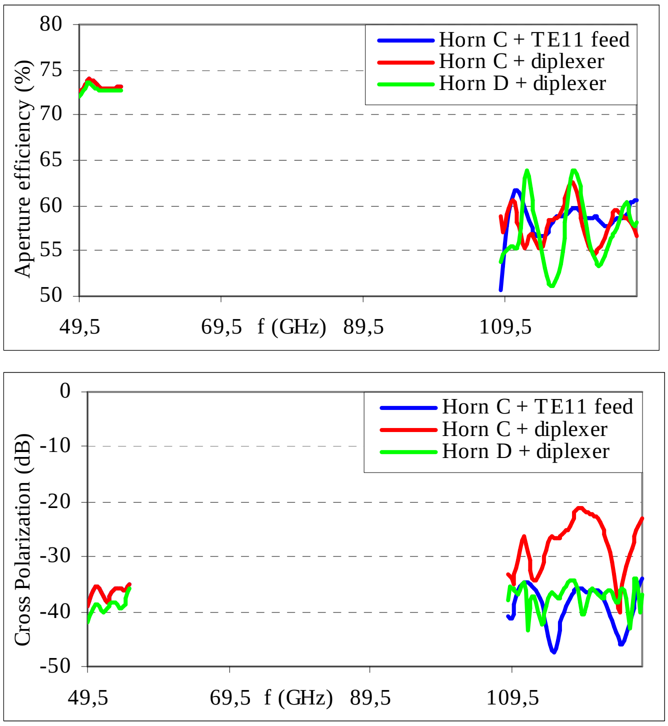

Fig. 6. Aperture efficiency and cross polarization of the horns optimized with a pure TE11 feed (Horn C) or with the diplexer (Horn D).

IV. CONCLUSION

The need for compactness and multi-functionality produces more and more wideband horn antennas for satellite applications. The advent of tools able to quickly simulate and optimize horns, connected to actual feed network, made it possible to overcome the negative effects of the higher order modes at the horn input.

The next step is to check the performance of the resulting horn in front of the reflector (special attention must be paid to phase center location and displacement versus frequency), and possibly to account for the reflector in the horn optimization process. Indeed, the rules applied to derive the horn specifications from the entire antenna system objectives are usually well suited for a narrow frequency band but may create unnecessary constraints on wideband designs.

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