MULTIMODE HARD HORN ANTENNAS WITH PARTLY CORRUGATED WALLS FOR 20/30 GHZ DUAL-REFLECTOR ANTENNAS WITH MULTIPLE BEAMS – FULL 3D SIMULATIONS AND MEASUREMENTS

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ABSTRACT

We introduce a partly corrugated hard horn, consisting of a smooth-walled horn with an attached longitudinally corrugated outer section. This is used and controlled to design better and shorter single-band horns than otherwise possible. Furthermore, it enables the design of dual-band horns with low cross-polarization and high gain, for multi function use at Ka-band with transmit and receive frequencies in the same antenna. A model of such a dual-band horn was manufactured at Saab Ericsson Space and measured. The design was done by using efficient in-house mode matching code based on homogenized asymptotic boundary conditions for the corrugations. This has been verified by heavy computations using a 3-D FDTD code. The measured laboratory model had too large cross polar sidelobes, but the later extensive computations showed that these sidelobes would have been in agreement with the mode matching results if the number of corrugations was doubled.

I. INTRODUCTION

Hard horns were already in [1] suggested to be advantageous elements in cluster-fed reflector antennas. In [2] a parametric study of the corrugated hard horn was made based on a classical aperture model using the dominant quasi-TEM mode. The model accounts for the radiation from the wall region, which in the model is homogenized to a parallelplate medium, i.e. corrugations of zero period. It was shown that the single mode hard horn could potentially cover very wide bandwidth, over which it was better than a normal smooth wall conical horn with respect to aperture efficiency and cross polarization. This bandwidth was limited at the lower end by the cut-off of the feeding waveguide and at the upper end by the so-called TEM frequency. These conclusions were somewhat in contrast to previous studies in [3] indicating narrow bandwidth for best performance of crosspolarization and efficiency.

We have in the last two years worked with application of the longitudinally corrugated hard horns as feeds for Ka-band (17.7-20.2 GHz and 27.5-30.0 GHz) cluster-fed multibeam antennas. We are trying to find solutions in which the same feed-cluster and reflector covers both bands of operation. In this application it has been shown [4] - [5] that it is not really the very high efficiency which is the crucial factor, but rather the cross polar levels which have to be kept low over both bands, both in the same beam and in adjacent beams [5]. The use of medium efficiency horns were discussed in [4] and shown to give promising results for the 4-cell frequency reuse scheme. In the manufacturing of a traditional single mode conical hard horn with large aperture radius, a problem has been identified associated with the continuation of the corrugations from the aperture towards the apex of the horn (see [2]), where the acute pitch angle of the corrugations enforces one or more changes of the number of corrugations in the horn section. Not only does this change of corrugation number introduce difficulties in manufacturing, but potentially also affect the return-loss performance of the horn. Thus there is a need for simpler hard horns solutions in terms manufacturing. In the present work we introduce a new type of dual-band hard horn, see Fig. 1, where the hard surface only is used in part of the horn in order to alleviate the complexity in its manufacturing.

Furthermore, the hard walled section has a conical shape with a very low tapering angle, and with a direct transition between the metal to the hard wall (i.e. without any tapering). The transition between the metallic surface and the hard surface appears at a large diameter, and therefore the horn becomes a multimode horn.

The present paper explains the design of the horn, and presents measurements and simulations on a laboratory model. More details can be found in [12].

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II. DESIGN OF THE HARD HORN

Conventional multimode horns are designed using a smooth metal surface with one or more radial steps along its longitudinal section. The steps create higher order modes which combine in the aperture to give an almost uniform aperture distribution. In [6] a multimode horn with 4λ diameter is designed to give 10 % bandwidth, and in [7] a dual band (8.6-9.8 GHz and 10.75-11.15 GHz) multimode horn with smaller than 3λ diameter is described. In the present paper we introduce the hard surface in a multi-step multimode horn. The inherent characteristic of the hard surface is a strong factor in the operation of this horn. However its mechanical design is also important and in this case the horn is designed to be as wide band as possible.

We have for the design of the hard multimode horn used an in-house mode-matching code (MM), [8]. In short, the MM approximates the horn as a cascading of a number of cylindrical sections. The radiation from the currents on the outside of the horn is included in the radiation pattern computation as explained in [9]. For our design 12 TE modes and 12 TM modes are taken into consideration at each cylindrical section and the radial step between each section is kept under λ/100 in order to ensure correct matching of the fields. In addition to initial parametric studies, further optimization of the horn was conducted using a simple genetic algorithm subroutine, developed according to the theory in [10]. For the initial design of the horn the parameters L1, L2 and t from Fig. 2 were optimized for low cross-polar performance using a population of 20 individuals.

The design of the horn antenna shown in Fig. 1 was found as a result of several steps: initially we simulated single band horn solutions with the outer hard walled part of the horn being cylindrical. It was found however that the inner smooth walled part needed to be very long to reduce the higher order mode amplitudes sufficiently. It was also found that if the outer corrugated wall section is made long enough, the horn gets two bands over which its cross-polar performance is fairly good. However, this final dual band horn became also rather long and it was therefore necessary to reduce its size. This was done by making the hard walled section slightly conical and thereby reducing the physical length of the horn. Finally a small step was added near the throat of the smooth-walled part of the horn in order to improve its performance at the high band. This step is placed at a radius where the higher order modes are under cut-off in the lower band and above cut-off for the first higher order mode in the higher band.

The geometry of the final dual band hard horn is shown in Fig. 1, and its dimensions are listed in Table 1. We have used 40 corrugations with a tooth thickness of 1 mm and a ratio between its groove width and period of approximately 0.7-0.8 depending on the axial position. This ratio is found acceptable from previous FEM studies of the infinitely long corrugated hard waveguide, [11]. It is also seen in Table 1 that the TEM frequency (calculated with the method in [2]) of the equivalent hard waveguide with the same dimensions as the horn aperture is placed at fTEM ≈ 37.2 GHz, which is well above the operation of the horn. This is an advantage for the present design since the effect of higher order φ – modes increase the closer the fTEM is to the operational frequencies, see [11]. The aperture efficiency and maximum cross-polar sidelobe level of the horn are shown in Fig. 2 and 3. As indicated in this figure the horn has a cross-polar level which is <-25 dB in the lower band and <-30 dB in the higher band, and high efficiency (72-82 %) in the lower band and medium efficiency (62-65 %) in the higher band.

III. MEASUREMENTS AND 3D FDTD SIMULATIONS OF EXPERIMENTAL MODEL

We manufactured the dual band multimode hard horn. This horn contains two separable parts: the inner rotational symmetric part which was manufactured in a turning process; and the outer corrugated part which was manufactured using electro erosion. The dielectric filling is Rohacell with relative permittivity 1.24 at 24 GHz. The dielectric rods inside the corrugations where cut and then inserted by hand.

The horn was measured in an indoor range at Saab Ericsson Space. The measured radiation patterns are plotted together with the simulated ones in Fig. 4. In the columns of Fig. 4 we present the E-plane, H-plane and 45˚ plane radiation patterns, from left to right, and the two rows are for the center frequencies of each band. We compare measured, MM simulated, and 3D FDTD simulations using QW3D. The most apparent in the Figure is the high -17 dB measured crosspolar sidelobe at 28.75 GHz. This is much higher than the theoretical -35 dB level predicted by the mode matching (MM) code based on the asymptotic corrugation boundary condition assuming zero corrugation period. Therefore, we started extensive and very time-consuming FDTD simulations with QW3D, to examine if an increasing number of corrugations would approach the theoretical MM results. Initially, we computed the case of N = 40 corrugations which corresponds to the measured horn and found that the simulated level was quite close to the measured one, see Fig. 16. We also increased the number of corrugations to 80, which required a finer grid and an even longer computation time. For this case we first kept the tooth thickness 1 mm (as in the 40 corrugations case) resulting in a w/p factor of 0.61 at the aperture. This gave virtually no reduction in the crosspolar level at the higher band. However, once the corrugation tooth thickness was reduced we started to observe a reduction in the crosspolar sidelobe levels at the higher band. For tooth thickness v = 0.6 mm the crosspolar sidelobe reduced to -22 dB, i.e. closer to the MM results (not included in Fig. 16), and for v = 0.4 mm and the resulting w/p = 0.84 (at the aperture) the FDTD results gave a cross polar sidelobe of -35 dB, exactly the same as the MM results, as shown in Fig. 16. Thereby, we had proven that the reason for the discrepancy between the measured and MM results is that the corrugation period and wall thickness was not small enough for the asymptotic corrugation boundary condition to be valid. Thus, the corrugation period should be 2.55 mm or smaller, and the tooth thickness 0.4 mm or smaller for good agreement with the mode matching code at 28.75 GHz.

IV. CONCLUSIONS

A dual-band hard horn was designed for Ka-band multi-beam satellite antennas, using a smooth wall inner section and an outer slightly conical hard wall section. A laboratory model of the dual-band horn was built and measured. In the higher frequency band there was a discrepancy between the measured cross polar sidelobes and the ones simulated with mode matching with asymptotic boundary conditions. Therefore, computationally expensive FDTD simulations were performed, and from these we were able to conclude that the corrugation period must be 2.55 mm or smaller and the tooth thickness 0.4 mm or smaller to give the same results as obtained with the asymptotic boundary conditions at 28.75 GHz.

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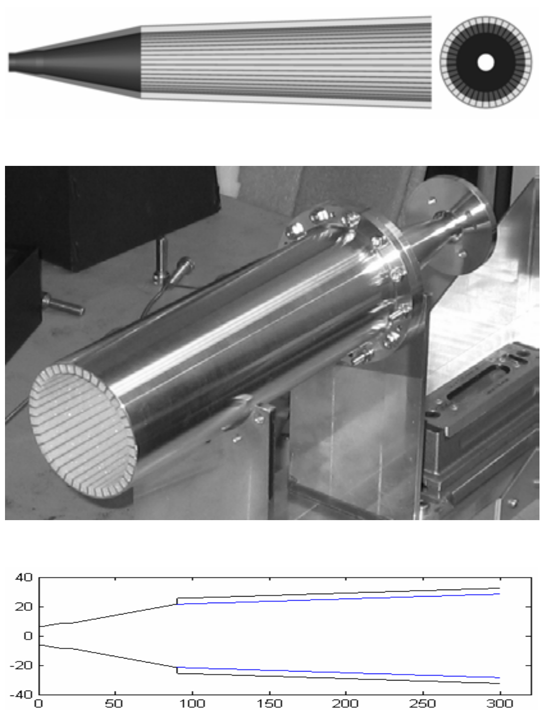

Fig. 1: Experimental dual band hard horn realized by longitudinal dielectric-filled corrugations, cross-section cut, top view, photo and dimensions.

Table 1: Dimensions of the dual band horn shown in Fig. 1. The measured horn has 40 corrugations. The table gives also dimensions of a horn with 80 corrugations, which has been simulated using a 3D FDTD program.

Parameter	Value	
Aperture diameter (mm)	$D = 65$	
Wall thickness (mm) Corresponding TEM frequency (GHz)	$t = 4$ $f_{TEM} \approx 37.2$	
Total length (mm)	300.5	
Relative permittivity in the corrugated wall region	$\varepsilon_r = 1.24$	
Number of corrugations N (*measured case)	40*	80
Corrugation tooth thickness (mm); v	1	0.4
Corrugation period (mm): $p = \pi{*}D$ / N At air interface, (at start of the hard section)	4.48, (3.39)	2.55, (1.69)
Corrugation opening (mm): $w = p - v$ At air interface, (at start of the hard section)	3.48, (2.39)	2.15, (1.29)
w/p: At air interface, (at start of the hard section)	0.78, (0.71)	0.84, (0.76)

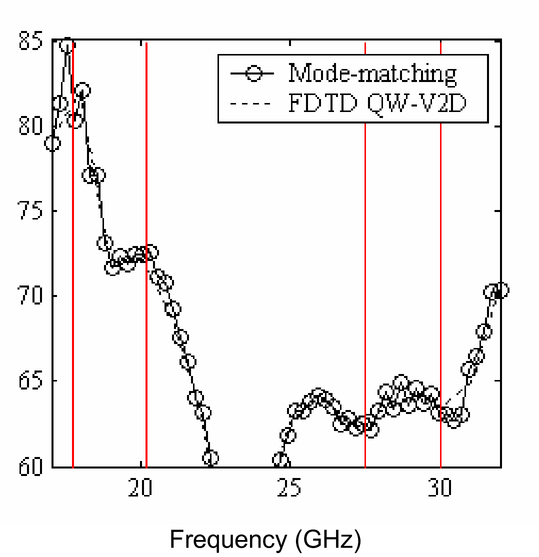

Fig. 2: Aperture efficiency (%) as a function of frequency for the dual band horn. Simulated with the mode-matching code (circles) and FDTD (QWV2D, dashed). The vertical lines indicate the frequency bands.

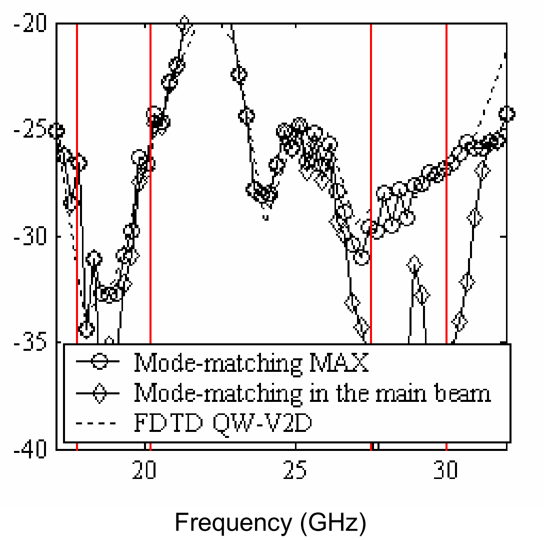

Fig. 3: Maximum cross-polar level as a function of frequency for the dual band horn. Simulated with the mode-matching code maximum cross-polarization in all angles (circles) and within the main beam (diamonds), and with FDTD QWV2D maximum in all angles (dashed). The vertical lines indicate the frequency bands.

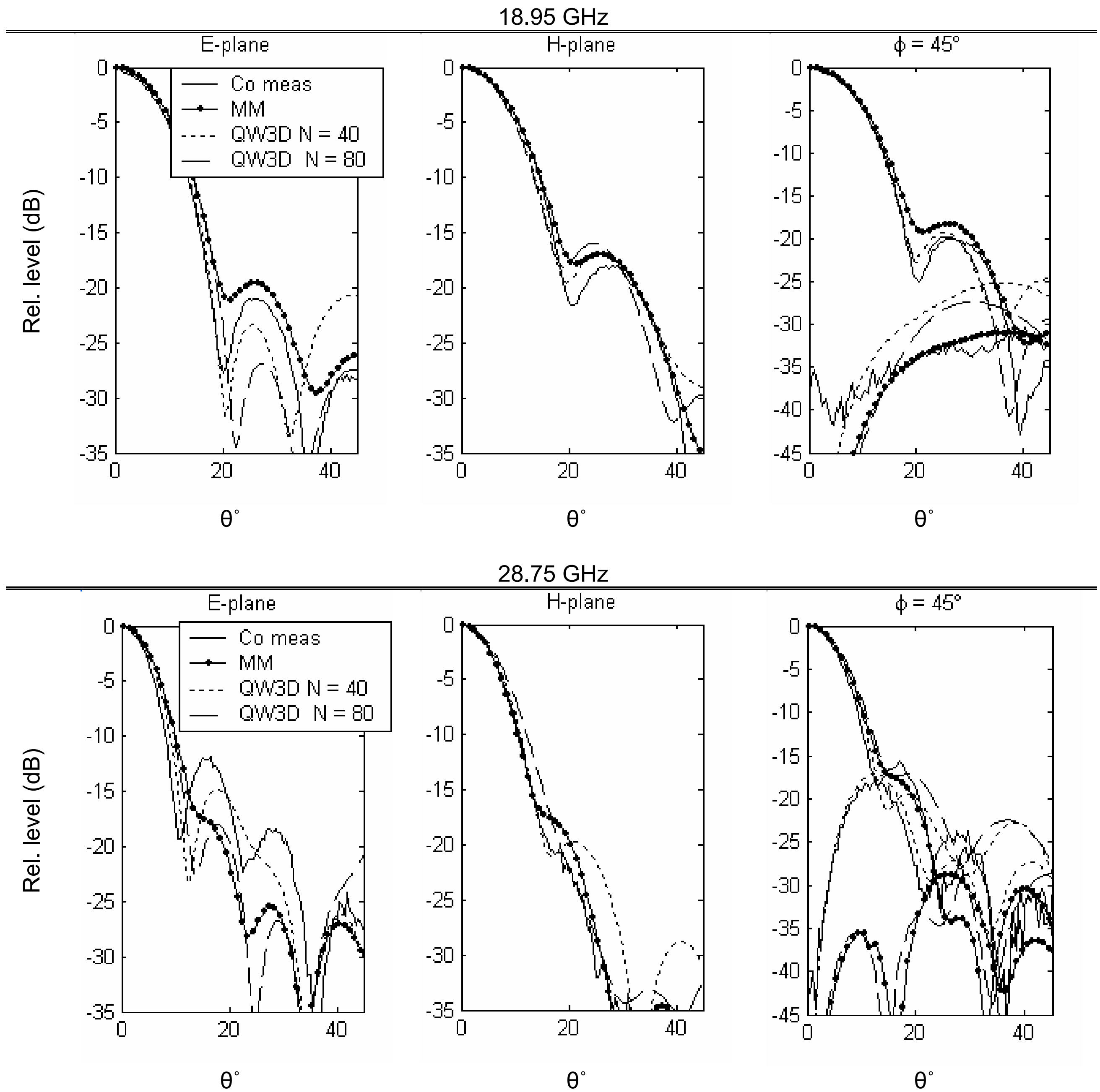

Fig. 4: E-plane, H-plane and $\phi = 45^\circ$ co- and cross-polar radiation field distributions of the dual band horn calculated using mode-matching (MM), 3D FDTD (QW3D) with 40 and 80 corrugations, and measurements (40 corrugations) at the center frequencies of the two bands.