STUDY OF CAVITY RESONANCES IN QUASIOPTICAL GRID AMPLIFIER WITH HARD-WALLED WAVEGUIDE SECTION

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SUMMARY

Professors Zirath and Kildal's groups at Chalmers have started a cooperation on developing a spatial quasioptical grid amplifier. Initially most work is done by guest researcher and Master students. The waveguide components are studied in Kildal's group, whereas the active grid is being studied in cooperation between Zirath's group and Dr Weikle's group in Virginia. The present paper describes the initial study of the waveguide components, involving the development of a hard horn transition from a standard waveguide to a quadratic quasi-TEM hard waveguide.

INTRODUCTION

In the millimeter wave region single transistors become so small that they cannot produce much power. Therefore, in order to get some Watts output power, there must be several transistors in an array. Power distribution/combination networks realized as microstrip transmission lines or similar are very lossy at these frequencies at the same time as the amplification in the transistors is small, so there will be small or no net amplification. Therefore, some research groups in the US are working to realize millimeter wave amplification by locating a grid of amplifiers transverse to a wave inside an oversized waveguide, and amplify this wave, see [1]-[4]. The cross sectional waveguide dimensions are normally a few wavelengths, so that horns are used on both sides of the grid to make a transition between standard rectangular waveguide input at one end and a standard waveguide output at the other. Thereby, a large oversized waveguide cavity is formed around the amplifier grid, causing a lot of problems. The horns as well as the oversized waveguide are made to have so-called hard walls, thereby enabling a plane wave incident on the grid. The uniform illumination makes it possible to get more power out of the grid. The hard horns were originally proposed for antenna applications in 1988 [5]. Since then several theoretical studies of hard horns has been done by Skobelev. In particular he has developed a mode matching code for dielectric loaded loaded hard horn antennas [6].

The present work describes a numerical design of two hard horn transitions and a hard waveguide section for use in a grid amplifier. The work is reported in more detail in [7] and [8], and have been performed by the commercial computer codes HFSS (based on FEM) and QW-3D (based on FDTD) as well as Skobelev's mode matching code. One of the hard horn transitions have also been manufactured and measured to verify its performance. Much of the numerical work is related to the study of resonances in the waveguide cavity. Different ways of moving or removing the resonances awas studied, but the resonances still remain a fundamental limitation of such grid amplifiers. The bandwidth is strongly limited by their presence. The numerical study has so far been done without including the active grid.

GRID AMPLIFIERS WITH HARD HORN TRANSITIONS

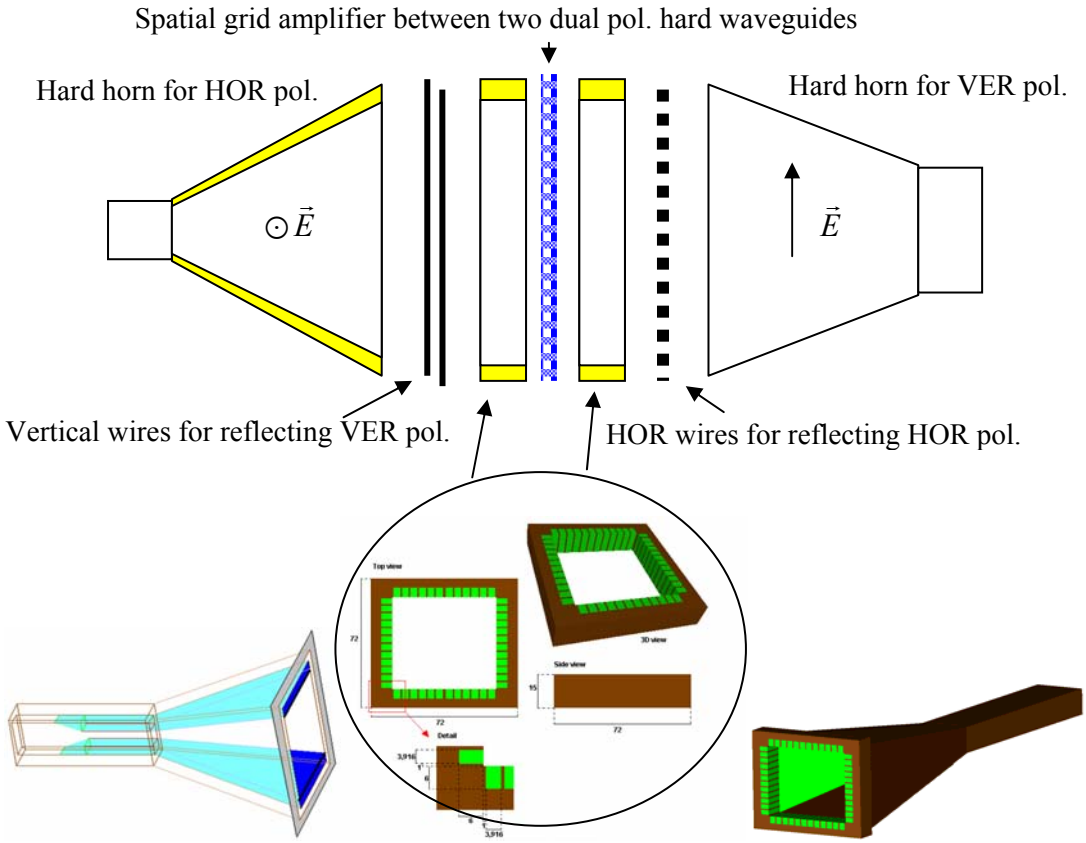

Figure 1 Illustration of the different components in a spatial grid amplifier (upper), for horizontally (HOR) polarized input port and vertically (VER) polarized output port. Drawings of hard horn transition with transparent walls to reveal the dielectric loaded walls (lower left), longitudinally corrugated hard walled waveguide (lower center), and hard horn transition with hard waveguide in front (right). The polarization grid is not shown in the lower figure.

A grid amplifier with two hard horn transitions is illustrated in Figure 1. The centrally located spatial grid amplifier consists in principle of an array of horizontally polarized receive antennas and vertically polarized transmit antennas with an array of amplifiers between the receive and transmit antennas, all located on the same narrow plate. The horn transitions have dielectric loaded E-plane walls, to allow a quasi-TEM wave of the appropriate linear polarization to propagate. The hard cylindrical waveguide pieces between the two wire grids have longitudinal dielectric-filled corrugations to allow quasi-TEM waves of arbitrary polarization to propagate. The horizontal and vertical wire grids work as ground planes for the horizontally and vertically polarized receive and transmit antennas.

RESULTS OF STUDY OF HARD HORN TRANSITION AND WAVEGUIDE CAVITY

We decided to design a grid with 2 by 2 wavelengths size, and we chose to initially work at 10 GHz, because it then would be easier to realize the transistors for the grid, even though grid amplifiers are a preferred technology only above 20 GHz. The hard horn transition was designed using Skobelev's code. It was anticipated problems with resonances in the central cavity of where the grid amplifier is located. Therefore, the hard horn transition was designed to give as much power as possible in the basic desired quasi-TEM mode in the aperture. Skobelev's code could provide the amplitude distribution between the different modes, so this factor was easy to calculate. The longer horn the better from this point of view, but we also found out that the dielectric loaded walls should start

already inside the rectangular waveguide input to the horn, in order to improve performance, see the lower left drawing in Figure 1 and Figure 2. This was a new finding, as Skobelev previously had considered a linear increase of the wall thickness from zero at the horn throat to the aperture as being the best. The thickness at the aperture must be $\lambda/\left(4\sqrt{\varepsilon-1}\right)$ to support the TEM wave. We chose polystyrene with $\varepsilon = 2.54$.

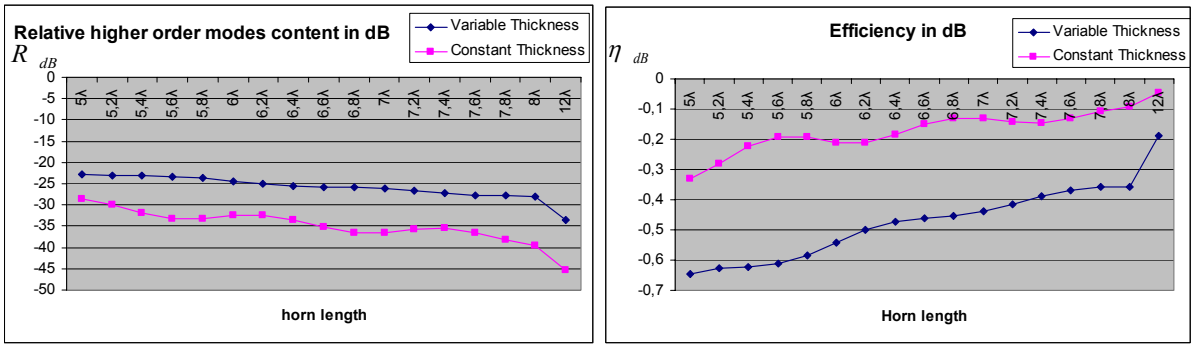

Figure 2. Relative power in higher order modes and aperture efficiency of dielectric loaded hard horn when the dielectric wall varies from zero to its full thickness in the aperture, and when it has constant thickness inside the whole horn.

In order to validate the simulations we manufactured a horn transition, see Figure 3, and measured and computed the radiation patterns. Such results really has no significance for the actual grid amplifier application, but is a good indication of how accurate the computations are. The computed and measured sidelobe levels and beam widths are plotted in Figure 3, and the agreement is good except for the beam width around 10 GHz. We do not know why yet.

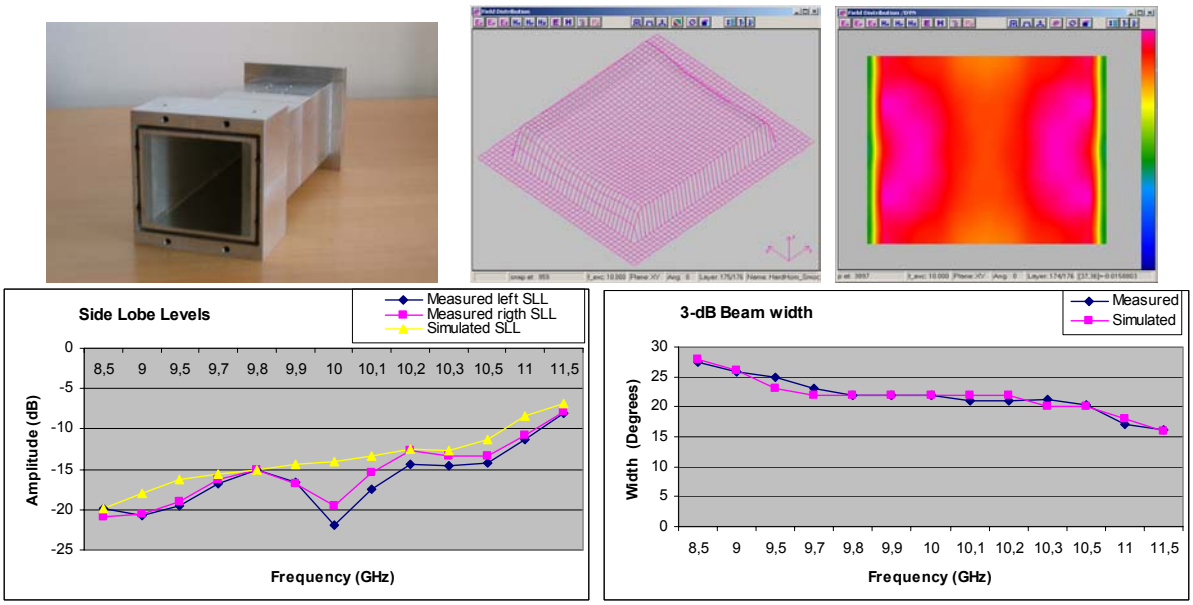

Figure 3. Photo of manufactured hard horn (upper left), aperture distributions simulated at the TEM frequency with FDTD (middle and right), and comparisons between computed and measured sidelobe levels and beamwidths(lower).

The next step was to model two opposing hard horns with a hard waveguide between them. We did not include any grid amplifier. The intention was to see if we would be able to avoid resonances inside the cavity, which we need to avoid also in the case when there is a grid amplifier inside. Simulations were done both with HFSS, QW-3D and Skobelev's code. Some results obtained with Skobelev's code are shown in Figure 4. The other codes showed similar results. We SEE a lot of peaks in S11 and

dips in S21. These are due to resonating cavity modes. In [8] we used QW-3D to investigate several ways of removing the resonances, such as metal plates and wires strategically located. We were able to move the resonances around, but the resulting best bandwidth did not improve significantly compared to that of the empty cavity, which can be seen to be up to 200 MHz between resonance peaks, i.e. 2 % bandwidth.

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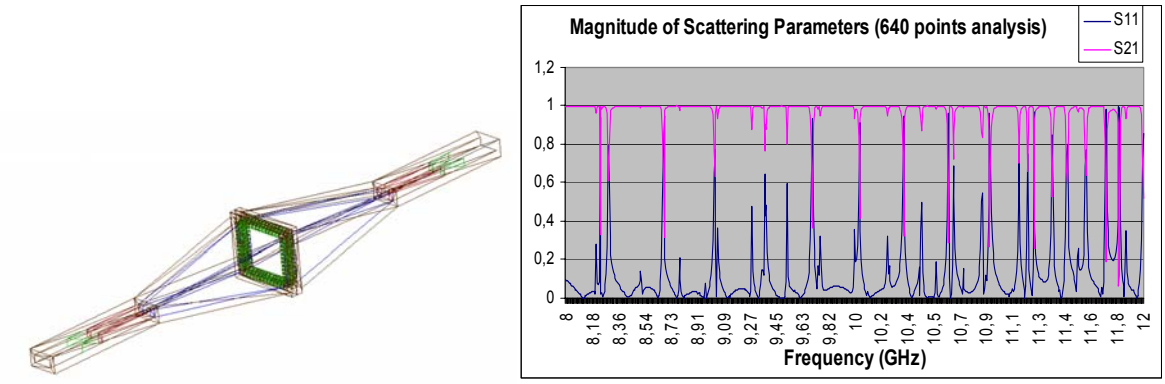

Figure 4. Drawing of complete cavity without grid amplifier, obtained from QW-3D (left), and computed results for S-parameters of the same cavity computed with Skobelev's code (right).

CONCLUSION

We have performed a numerical and experimental study of hard horn and waveguide components needed to realize so-called spatial grid amplifiers. The conclusions are that the horn transitions need to have a significant length in order to reduce cavity resonances, the dielectric loaded walls of the horns should preferably start already inside the standard rectangular waveguide inputs and outputs, and the bandwidth seems to be limited to a few percent due to cavity resonances. We are now in the process of investigating ideas of alternatives to the rather long hard horn transitions that can make the design more compact and thereby reduce the resonances.

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