A fast method for the design of azimuth radiation characteristics of shaped beam rectangular waveguide slot antennas

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***Abstract*—In this paper we present a fast calculation method for the calculation of azimuth radiation characteristics of shaped beam rectangular waveguide slot antennas. The basic idea of the method is the segmentation of the original problem into two subproblems: an internal one, formed by the slotted waveguide, and an external one, consisting of the beamforming arrangement. Both subproblems are solved using the finite element method, however, the external model is based on the two-dimensional approximation of the geometry, resulting a significant improvement on computational resources required. The novelty of the paper is that quantitative criteria are defined for the validity of the segmentation, and these criteria are easy to be evaluated based on the calculation results of the internal subproblem.**

***Index Terms*—slot antennas, antenna radiation patterns, optimization.**

I. INTRODUCTION

Application of slot antennas in wireless communication is widespread in the microwave frequency range as they usually represent a trade-off between production cost and performance.

The simplest rectangular waveguide slot antenna is shown in Fig. 1. It consists of a hollow rectangular waveguide that has several slots on the board. Analysis methods of this traditional arrangement are given in [1], [2] and [3], while design considerations are also available in [4] and [5].

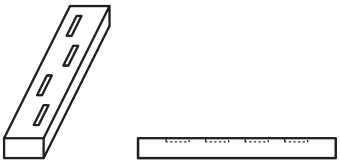

Fig. 1. Rectangular wavegude slot antenna:
3D-view (left) and side-view (right)

In this paper we study the shaped beam rectangular waveguide slot antenna shown in Fig. 2.

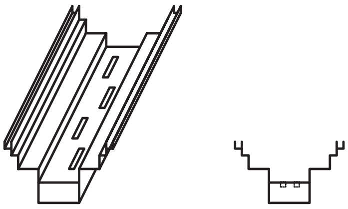

Fig. 2. Shaped beam rectangular waveguide slot antenna:
3D-view (left) and top-view (right)

One may depict that the geometry is changed—metallic sheets are attached to the outer wall of the waveguide in order to modify the radiation parameters of the antenna, and to achieve improved characteristics required for the given application.

The investigated configuration is the shaped beam rectangular waveguide slot antenna described above. We assume that the excitation of the waveguide is known.

Our goal is to calculate the radiation parameters of the device, focusing on the azimuth plane radiation pattern. Calculation of the elevation plane characteristics is given in [6].

II. THEORY

The basic idea of the analysis of the shaped beam slot antenna is the segmentation of the problem into internal and external subproblems. Both subproblems are set up by simplifying the geometry: internal calculations are performed on the waveguide only, while external calculations are performed on the two-dimensional model of the beamforming arrangement (the cross section perpendicular to the waveguide) to determine the azimuth radiation pattern.

A. Internal Subproblem

The investigated configuration of the internal problem is the rectangular waveguide slot antenna. The problem is solved by the finite element method. To perform the calculations the following considerations are made (Fig. 3.):

1. The excitation of the rectangular waveguide is known.
2. The walls of the waveguide are perfect electric conductors with finite thickness.
3. The investigation volume is closed by a perfectly matched layer (PML).

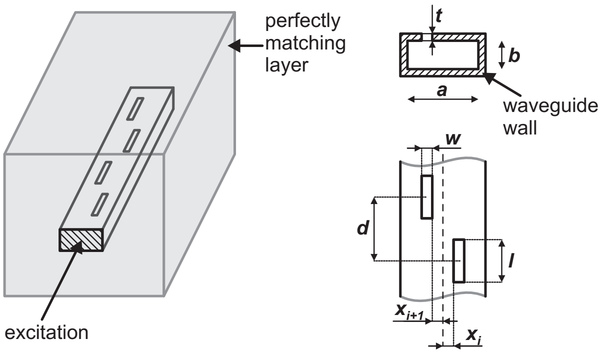

Fig. 3. Internal (3D) model of the antenna:
3D-view (left), cross-section (top-right) and front-view (bottom-right)

From the design point of view, one should minimize the return-loss of the antenna. This problem typically means a minimum search of a function whose independent variables are the slot parameters describing the slot dimensions and location.

Significant computational resources can be saved during these calculations, because the large beamforming arrangement is not taken into consideration, therefore, the meshed volume can be shrunk to the waveguide itself.

The resulting field distribution in the slots gives important information about the usability of the external subproblem, which is based geometrically on the cross-section of the shaped beam antenna.

B. External Subproblem

The external problem is assumed to be a two-dimensional radiation problem. To calculate the radiation pattern in the azimuth plane the following considerations are made (Fig. 4.):

1. The excitation of the two-dimensional waveguide is a horizontally polarized plane wave.
2. The beamforming arrangement is made of perfect electric conductors with finite thickness.
3. The investigation area is closed by a PML.

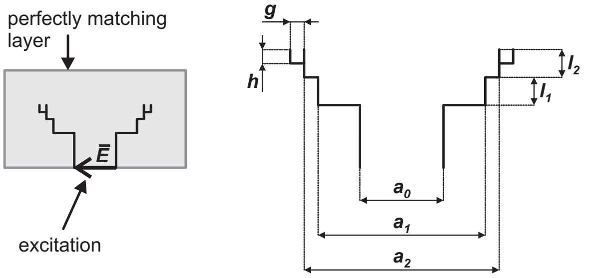

Fig. 4. External (2D) model of the antenna:
2D-view (left), main parameters (right)

The problem is solved by a two-dimensional finite element solver using negligibly small computational resources compared to the three-dimensional full-wave solution of the true antenna. This improvement is especially important from the design point of view, because beam shaping is a rather complicated optimization task (basically because the number of optimization parameters is large, and the problem is ill-posed), that requires many evaluations of the objective function.

C. Prediction of the Usability of Segmentation

It is evident that the segmentation described above cannot be used for the calculation of any shaped beam rectangular waveguide slot antenna. To get accurate and reliable results in any case, full-wave solution of the true antenna is needed. That solution requires relatively big computational resources (because of the large and complex geometry), therefore, prediction of the usability of segmentation is a key question during the design of such antennas.

Our investigations showed that *usability can be predicted by evaluating the field distribution of the internal subproblem, and these calculations are relatively simple.* In the full version of the paper, we will discuss in details the criteria of usability, which helps efficiently finding the quasi-optimum during the design process. The quasi-optimum can be then used for the 'fine tuning' of the antenna.

III. APPLICATION AND DISCUSSION

The method described above is used to calculate the azimuth radiation pattern of two antennas. The main parameters (waveguide dimensions, slot dimensions, beamforming arrangement) of both antennas are the same, therefore, they have a common 2D external model. However, the number of slots, and the field distribution in the slots (which mainly depends on parameters x_i, see Fig. 3.) are different.

The full-wave 3D solutions of the true antennas, and the common 2D approximate solution is given in Fig. 5.

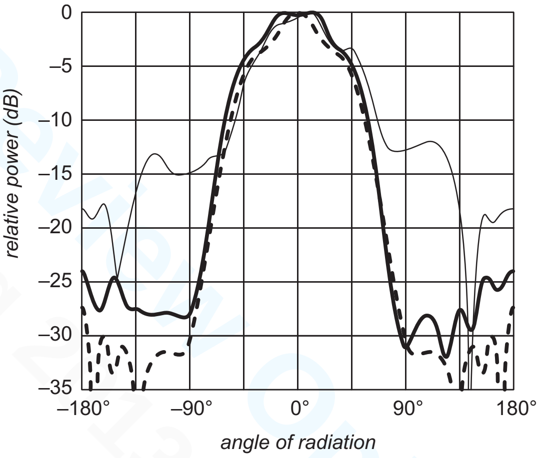

Fig. 5. Calculated azimuth plane radiation patterns:
3D full solution of the true first antenna (solid thick),
3D full solution of the true second antenna (solid thin),
common 2D approximate solution (dashed)

One may see that the two-dimensional approximation is valid in case of the first antenna (radiation below –25 dB relative power are practically out of interest), but not in case of the second one. The main message of the paper is that the validity of the approximation can be predicted from the evaluation of the solution of the internal subproblem only, without the full-wave analysis of the true antenna.

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