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Directivity and Bandwidth of a Dual-Sided Slotted Waveguide Array

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Abstract

Waveguide arrays normally have just one waveguide side supporting its slot elements in order to realize a high aperture efficiency for a directional beam. For different patterns in different applications, the other sides of the waveguide can also be used for the slots. This paper presents a simulation study for a dual-sided slotted waveguide array, where the same longitudinal-oriented slot array is deployed on the opposite broad-walls of a rectangular waveguide. Intuitively, the broadside array patterns will have their directivity approximately halved relative to the single-sided array, but the impact on the pattern in the direction around the waveguide structure is not clear. This paper presents a study of this pattern effect, and on the improvement in impedance bandwidth expected from this configuration of extra radiating slots.

1. Introduction

Waveguide slot array antennas have applications in radar and wireless communication systems, and recently in mm-wave applications using on-chip antennas. Their advantages include low loss, and good directional pattern properties, and the main disadvantage is the small relative bandwidth. Consequently, pattern properties and bandwidth are the main areas of design and research interest. In arrays, the waveguide slots are deployed on a larger ground-plane than the broad-wall of the waveguide. As stand-alone antennas - i.e., no ground plane other than the waveguide itself - the edge diffraction impacts the patterns both by direct contribution and by affecting the mutual coupling between the slots. This complexity means that simulation is required for studying the pattern and impedance during initial design. When there are slots on multiple sides of the waveguides, this complexity increases, and the modelling of the structure becomes extremely challenging, and a simulation-based approach becomes a critical part of the design process.

The dual-sided waveguide slot array has a low-gain pattern cut around its structure. This pattern finds application in some terrestrial communications antennas and in microwave heating. There has been previous work on the structure consisting of longitudinal slots on the opposite broad wall [1]-[4]. This structure is also called a “waveguide doublet”, which in particular refers to longitudinal slots on the opposing broad-walls.

In [4], a comprehensive analysis is presented based on a T-network model for the individual slots. It was demonstrated that an array of longitudinal slot doublets in a rectangular waveguide may be characterized by an equivalent single-slot array in a half-height waveguide. Modelling an array of longitudinal slot doublets in a rectangular waveguide compared well to a simulation, although the diffraction from a stand-alone waveguide structure was not included.

In [1], a configuration is used to produce two radiation nulls in the omnidirectional pattern cut, by adjusting the slot position offsets with respect to the waveguide center line. Resonance and radiation characteristics of the proposed doublet were also provided. The nulls were for interference suppression for fixed propagation conditions.

Analysis with simulation has been used in [2] and [3] for air- and dielectric-filled rectangular waveguides with single slots on the opposing broad-walls of the waveguide.

A particularly useful antenna is the medium gain (say ~8-15dB gain) with high aperture efficiency. The configuration requires several slots. The new contribution of this paper is the nature of the directivity and the impedance bandwidth of a medium gain configuration of the dual-sided waveguide slot array. For the study, we use a five slot configuration for both arrays, operating around 2.45 GHz (This ISM band is also used for microwave heating). The dual-lobed pattern has directivities, broadside to each array, of about 10.5 dB, compared to the single-sided array having a directivity of about 13.8dB.

2. Antenna Configuration

Our dual-sided slotted waveguide array is described in this section. There are 5 slots in each side of the waveguide, each arranged with opposite slot offset with respect to the center of the waveguide, see Figure 1. The waveguide is standard WR340 with a wall thickness of 2mm. The parameters indicated in Figure 1 allow us to “hand optimize”, through a parametric study, for various performance aspects of the antenna. After this “hand optimized” 5 slot design, we introduce the extra array element-by-element in our study. It is emphasized that no formal optimization is undertaken here. (Our experience has been that optimization is extremely time consuming - several hundred iterations, each requiring a full wave simulation solution – of course operating on a model of the antenna rather than the real-world antenna itself which always behaves differently to the model at specific frequencies. The parametric study is therefore a good trade-off for initial design.) With this in mind, our results presented here are limited to incrementing the number of slots in the second array for a match at 2.45GHz.

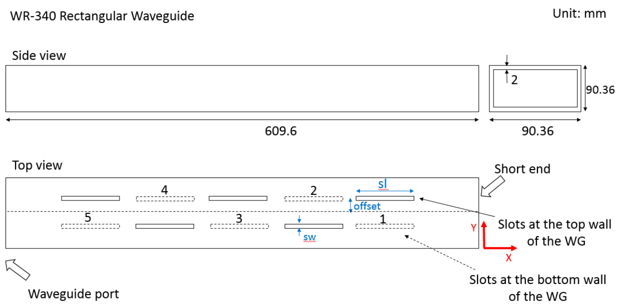

Figure 1. Dual-sided slotted waveguide array design parameters. The second array is introduced element-by-element in the simulation results.

3. Simulation Results

The forward and backward directivity of the antenna for different number of the slots added at the bottom of the waveguide are shown in Figure 2. Zero added slots refers to the single-sided 5 slot array. The directivity is about 13.8 dB. The associated high aperture efficiency is a major advantage of these slots arrays. This directivity indicates that the averaged per-slot directivity is about 6.8dB. Adding just a single slot on the opposite broad-wall has the relatively dramatic impact of reducing the broadside directivity by well over a dB, while bolstering the backward directivity (i.e. broadside to the single slot) by about 1.1dB. Similarly, two slots in the opposite broad-wall reduces the directivity by about 2 dB and changes the backward directivity is about 2.1dB. When both 5-element slot arrays are present, the forward and backward directivities are 10.5dB.

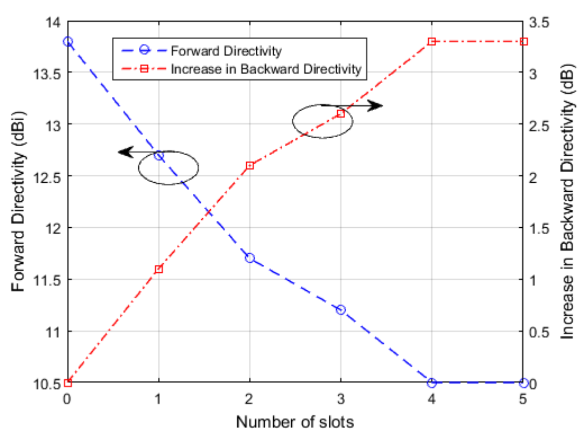

Figure 2. Forward (broadside) directivity for the 5-slot array of the dual-sided slotted waveguide array, and the change in the directivity in the backward direction as its array is populated with slots. "Zero" slots (left-most side) means that the array is the single-sided configuration.

The reflection coefficient in dB of the antenna is shown in Figure 3. The solid line is for the single-sided 5 element slot array and the dotted line is for dual-sided slotted waveguide array. The choice of configuration (parameters in Figure 1) allows the introduction of a second resonance-like minimum in the reflection coefficient, positioned to maximize the bandwidth. In this case, the -10dB impedance bandwidth has increased from 5.9% to 7.4% with the addition of the second array.

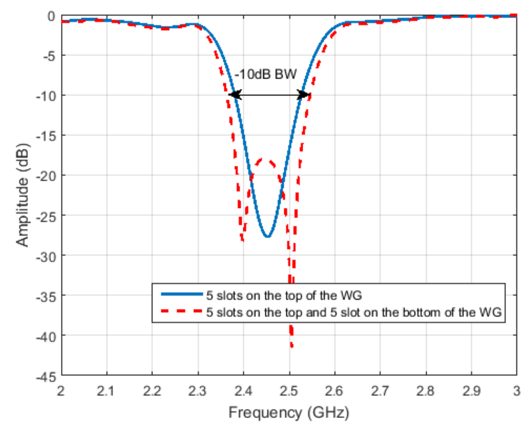

Figure 3. Reflection coefficient of the single-sided (solid line) and the dual-sided array (dotted line).

The pattern in the so-called "omnidirectional" cut (around the waveguide, orthogonal to the direction of the waveguide), is of particular interest because it is challenging to find from analytic and transmission line models. The normalized total power pattern cuts at $\phi=0^{\circ}$ and $\phi=90^{\circ}$ are shown in Figures 4 and 5 respectively.

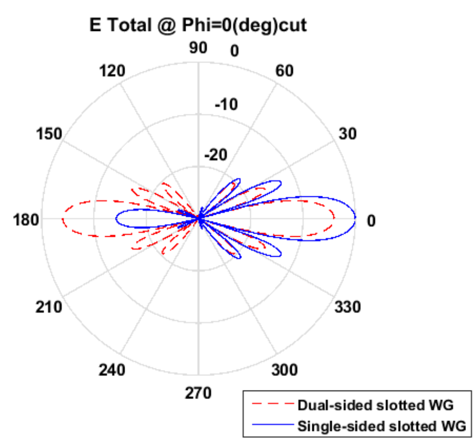

Figure 4. Normalized total power pattern cut at $\phi=0^{\circ}$ of single-sided slotted waveguide (solid) and dual-sided slotted WG (dotted).

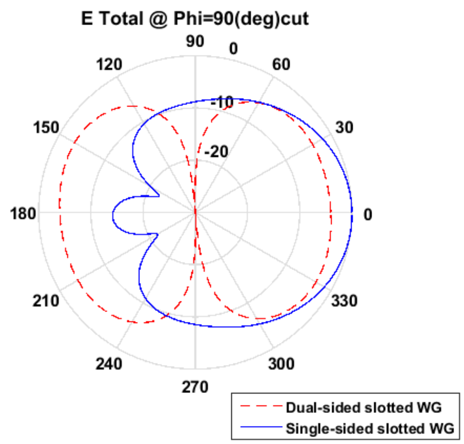

Figure 5. Normalized total power pattern cut at ϕ=90° of single-sided slotted waveguide (solid) and dual-sided slotted WG (dotted).

The introduction of the second slot array with this choice of offset can introduce pattern minima, as noted in [1], however, our interest is in the dual-lobe shape of the patterns. Finally, the incremental addition of slots is a useful study for gaining insight into reducing the voltage across the slots. For high power applications, and in vacuum or partial vacuum, keeping this voltage at a safe level is performance-limiting. In [6] it is shown how increasing the number of slots in a single-sided array decreases the E-field across each slot for a fixed power output from a magnetron, and here we can use the same approach of adding slots to reduce voltage without changing the primary radiator (single-sided slot array) configuration. Such extensions to this paper will be presented orally.

6. References

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