Design of a Slotted Substrate Integrated Waveguide Antenna using a Metasurface

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Abstract – **In this paper, the use of a metasurface to improve the radiation properties of a Substrate Integrated Waveguide based slotted antenna is proposed. The design process of a metasurface covered 8 element slot antenna array following a Chebyshev distribution is presented and its performance is compared with that of a conventional one. The results demonstrate the improvement in the radiation performance that can be achieved, without affecting the bandwidth.**

I. INTRODUCTION

During the last decade, the use of metasurfaces (MTS) has arisen large interest for antenna applications [1],[2]. These periodic structures allow to tailor the radiation pattern of the antennas built with them and improve their performance. Different versions of metasurfaces can be found in the literature, ranging from modulated impedances [3] to Huygens metasurfaces [4].

In this case we propose the use of a metasurface to enhance the radiation properties of a slotted substrate integrated waveguide array. The used metasurface is described in [5] and consists of 2 layers of dipoles and a wire grid in between them, see Fig. 1a, all of them printed on a Rogers RT5880 dielectric substrate. The table in Fig 1a shows the dimensions of the metasurface, adjusted to have a transmission band around 24 GHz.

This metasurface has been used in previous works to improve the radiation properties of dipole [5] and Slotted Waveguide Array (SWA) antennas [6]. In the last case, the gain improvement with respect to a conventional SWA was close to 4 dB, while keeping the same operational bandwidth.

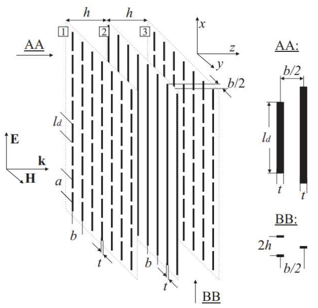
In this work we will use this metasurface on a low-profile configuration, using a slotted Substrate Integrated Waveguide (SIW) array. Thanks to its planarity, SIW technology allows reducing the manufacturing complexity and the overall volume of antennas. However, given the shorter wavelength of this waveguide, the slot separation is smaller than in [6] and the metasurface dimensions had to be modified in order to fit this shorter separation. In addition, coupling between MTS sections is stronger and the antenna design must take into account this effect.

II. DESIGN OF THE MTS COVERED SUBSTRATE INTEGRATED WAVEGUIDE

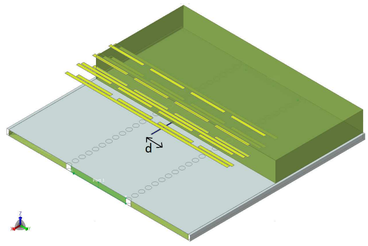
A. Slot conductance calculation

The dimensions of the SIW can be obtained following the standard procedure [7]. In particular, using a 508 µm thick Rogers RT5880 circuit board, the dimensions shown in Fig. 1a were obtained for a SIW working around 24 GHz. The SIW channel is 6.19 mm wide and the 0.5 mm diameter metallic vias are separated 0.7 mm.

The conductance created by a slot on the top wall of a SIW depends on the displacement of the slot with respect to the waveguide axis and will be used to adjust the design to the intended Chebyshev distribution with -20 dB sidelobe level. For these calculations, we will use the structure in Fig. 1b. The slot in the top metal plane is covered by the afore described metasurface. The slot is perpendicular to the MTS dipoles, so that they are properly excited. The response of the waveguide is analyzed for each of the positions of the slot, indicated as *d*. Note that the MTS is moved along with the slot, so that the position of the slot with respect to the MTS is the same in all cases.



h	0.508
t	0.27
b	1.678
l_d	3.517
a	4.22



a) b)

Fig. 1. A) Schematic of the metasurface used in this work. The dipoles and the wire grid are printed on a dielectric substrate, not shown in the drawing. B) Structure analyzed to obtain the slot conductance. Half of the substrate was removed to improve visibility.

For a resonant dipole, the equivalent conductance associated to each slot position can be computed as [8].

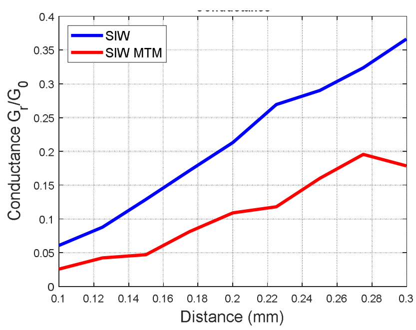
$$G = \frac{-2S11}{1+S11} \quad (1)$$

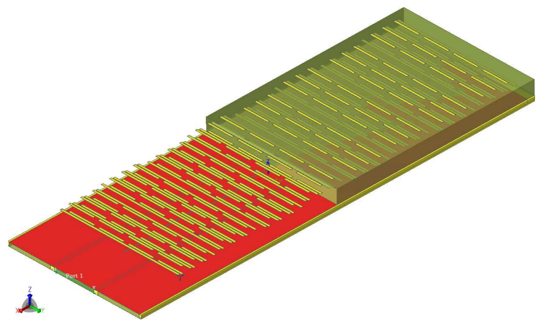
The comparison between the conductance obtained for a SIW slot and a metasurface covered SIW slot is presented in Fig. 2a. When the metasurface covers the slot, its conductance is lower, so that we would require larger displacements of the slot to obtain the same conductance that we would obtain without the use of the metasurface. In addition, when the slot is covered with the metasurface, the slot resonant length is shorter in comparison with the resonant length in the uncovered SIW case.

B. Antenna Design

In order to obtain the Chebyshev distribution, the data shown in Fig. 2a were used so that the required slot positons were determined. Moreover, these data show that the MTM covered SIW requires larger slots displacements to achieve the same conductance values.

A model of the complete antenna is shown in Fig. 2b, where the displacements of the metasurface following the slot positions can be noticed.





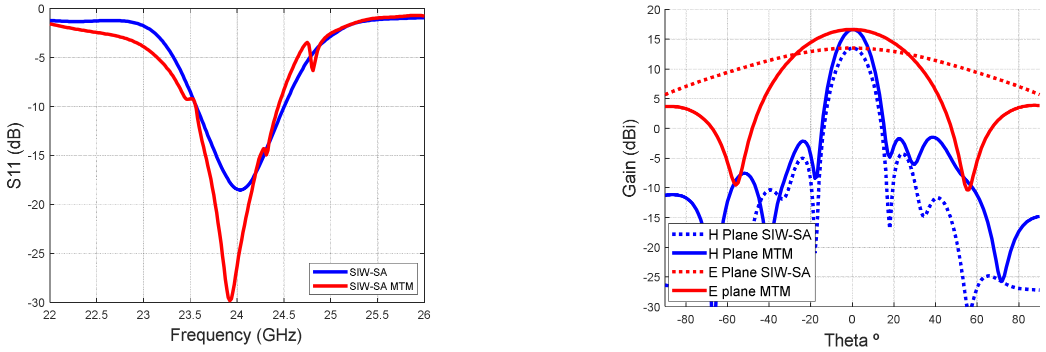
a) b)

Fig. 2. A) Normalized conductance of a slot in the wall of a SIW. Comparison between a MTM covered SIW and uncovered SIW. B) Schematic of the metasurface covered SIW-SA. Half of the substrate was removed to improve visibility.

III. ANTENNA PERFORMANCE

For the sake of comparison, the response of an uncovered slotted SIW array with a Chebyshev distribution was also analyzed. Regarding their impedance matching response, see Fig. 3 a, no significant differences are found between both antennas.

In Fig. 3b the radiation pattern of both antennas is shown. The H-Plane of the two antennas is similar, since it is dominated by the array factor of the Chebyshev distribution. However, there is a significant difference between their E-Plane cuts. The use of the metasurface increases the effective radiating aperture and, therefore, a narrower pattern is obtained in this plane when the MTS is used. Conversely, the radiation pattern of the uncovered antenna corresponds to the slots radiation, being much broader. As a consequence, the MTS covered slotted SIW achieves 3 dB higher gain than its counterpart.



a) b)

Fig. 3. A) Comparison of the performance of the SIW-SA and the MTM covered SIW-SA a) Matching; b) Radiation pattern.

IV. Conclusions

The improvement of the radiation performance of a slotted substrate integrated waveguide (SIW) array antenna when covered with a metasurface has been demonstrated. The metasurface increases the radiation aperture and allows narrowing the radiation pattern E-Plane, which increases the antenna gain. This solution can help simplifying the feeding networks of SIW slotted waveguide arrays.

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