Transition between gap waveguides for use in multilayer structures at millimeter-wave frequencies.

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Abstract—A compact twist to connect a ridge-gap waveguide and a groove-gap waveguide in the Ka-band is presented. Measured insertion loss for a single twist is around 0.5 dB between 37.5 GHz and 39 GHz. Return loss for a double twist is better than 12 dB in the same frequency range.

Index Terms—Gap waveguides, twist, millimeter-wave circuits.

1. INTRODUCTION

Commercial applications at millimeter-wave frequencies have experienced a significant growth during last years. Several wireless systems in outdoor environments, e.g. local multipoint distribution systems (LMDS), operate in the 20-40 GHz range [1]. At 60 GHz, a high data-rate can be achieved, but the strong atmospheric absorption limits the communications to the short range of wireless personal area networks (WPAN) [2]. However, in the 70/80 GHz band, a smaller attenuation takes place, what opens the possibility to implement automotive radars at these frequencies [3].

Commercial applications require high-gain antennas to concentrate the power within a narrow beam in one or more directions. Additionally, in many cases, low-profile multi-beam antennas with small area become necessary due to space restrictions. In these cases, a multilayer structure is a suitable solution for size reduction.

During last years, main efforts have been focused on developing transmission lines capable of combining the low losses of metal waveguides, and the flexibility and low cost of printed lines. New types of waveguides, the so-called gap waveguides, have been recently proposed as an alternative to conventional transmission lines at high frequencies [4-6].

In this letter, the design of a compact twist from ridge-gap waveguide (RGW) to groove-gap waveguide with horizontal polarization (GGWHP) is presented at 38 GHz. The proposed twist is suitable for feeding compact slot-antenna arrays in multilayer structures, similarly to the model presented in [7].

In order to verify the operation of the proposed twist, a prototype consisting of a double transition RGW-GGWHPRGW has been designed, fabricated and measured.

2. DESIGN OF THE TRANSITION BERTWEEN GAP WAVEGUIDES

In antenna arrays implemented with multilayer structures, the feeding network is usually placed below the array. Consequently, the design of transitions to interconnect the different layers of the structure becomes necessary. Recently, the design of a compact twist between a RGW and a GGWHP has been presented in [8]. In that case, both waveguides were free of dielectric materials.

In [9], the advantages of using a GGWHP to simplify the fabrication of slotted waveguide arrays were discussed. Moreover, it was presented a new way to excite untilted slots in the narrow wall of the waveguide by means of parasitic dipoles located inside the waveguide on a plane parallel to the slots. The top cover of the GGW was fabricated with a thin foil of dielectric material having the slots etched on the upper side, and the dipoles on the lower side.

Since a perfect contact is not needed between the waveguide parts, the RGW presents important advantages at high frequencies [4]. The use of RGW also simplifies the routing of paths in the feeding network, allowing compact structures. The aforementioned advantages of the GGWHP to design slot-antenna arrays, and the RGW to design the feeding network, let conclude that a system combining both technologies in a multilayer structures may provide an efficient antenna in a low profile shape. In this work, a transition between a RGW and a GGWHP in different layers is proposed.

In this design, a dielectric material between the bed of nails of the GGWHP and the upper metallic cover is used for the final location of the slots and dipoles of the antenna array. A substrate Neltec NY9220 with $\epsilon_r = 2.2$ and 0.508 mm of thickness was selected.

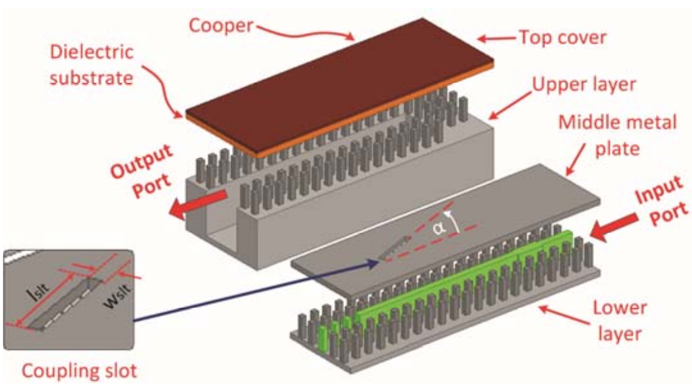

Figure 1. Proposed twist between Groove-gap waveguide and ridge-gap waveguide

The proposed transition (depicted in Fig. 1) consists of a GGWHP in the upper level, and a RGW in the lower level. The coupling between both levels is done through a coupling slot placed in the narrow wall of the GGWHP. The physical dimensions of the RGW's elements (see Fig. 2) at different central frequencies (f_0), and the lower (f_{CL}) and upper (f_{CH}) cut-off frequencies of their stop-bands, are summarized in Table 1.

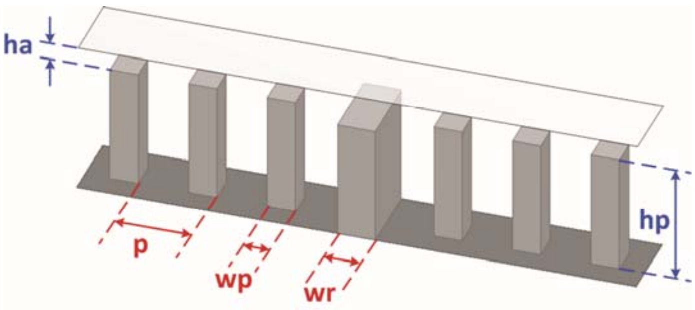

Figure 2. Geometrical parameters of the unit vell of a RGW

The current distribution in both waveguides is shown in Fig. 3. As observed, the current lines on the roof of the RGW are perpendicular to the current lines on the narrow wall of the GGW-HP. To allow coupling between both waveguides, a tilted slot is used to cut both current lines. Furthermore, because of the configuration of the electric fields in the waveguides, this transition acts as a twist from the vertical polarization of the E field in the RGW to the horizontal polarization of the E field in the GGWHP.

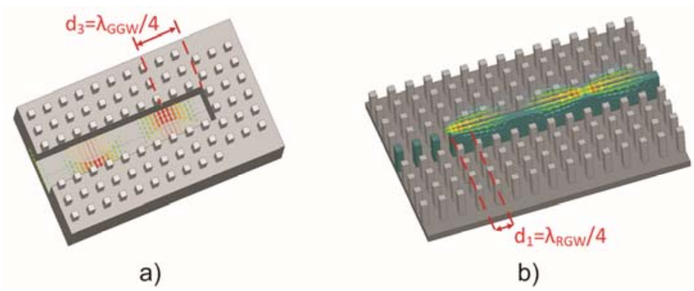

Figure 3. Current distribution in Gap Waveguides: a) Current lines in the lateral Wall of a GGW-HP, (b) CUrrent lines in a RGW.

The coupling between both waveguides can be controlled with the tilt angle α of the slot (see Fig. 1). The initial length and width of the slot were selected as $l_{slt} = \lambda_{GGW}/2$ (being λ_{GGW} the wavelength in the GGWHP at the central frequency) and $w_{slt} = l_{slt}/10$, respectively. Later, these values were optimized using ANSYS HFSS v.15.

Details of the transition can be observed in the longitudinal cut depicted in Fig. 4. In the lower level, the ridge is interrupted at a distance d_1 from the center of the slot, and more nails are used to fill the gap.

Since these nails present high surface impedance, they are equivalent to an open-circuit and, hence, the distance d_1 must be $\lambda_{gRGW}/4$. In the upper layer, the GGWHP ends in short-circuit; therefore, the slot is placed at a distance $d_3 = \lambda_{gGGW}/4$ from the end.

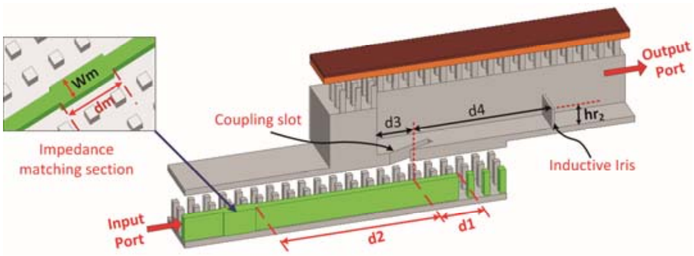

Figure 4. Details of the Twist between Gap Waveguides.

In order to enhance the bandwidth that can be achieved by only using the tilted slot (less than 1%), the use of additional tuning elements in both waveguides becomes mandatory. In the GGWHP, an asymmetric inductive iris is placed on the lower wall of the waveguide. In the RGW, an impedance matching element consisting in a widening of the ridge (similarly to a segment of a transmission line with different impedance) is used.

The simulation was performed defining the feeding ports directly in the RGW and GGWHP (see Fig. 4). The aim of the optimization was to obtain a return loss higher than 20 dB in the largest possible bandwidth. The optimized variables were: the angleα, the length l_{slt} and width w_{slt} of the slot (see Fig. 1), and also those variables indicated in Fig. 4. The thickness of the inductive iris was fixed to 0.2 mm.

With the inclusion of the tuning elements, a bandwidth of 3.4% (considering S_{11}<-20dB) has been achieved. Within this bandwidth, the insertion loss is below 0.4 dB (see Fig. 5).

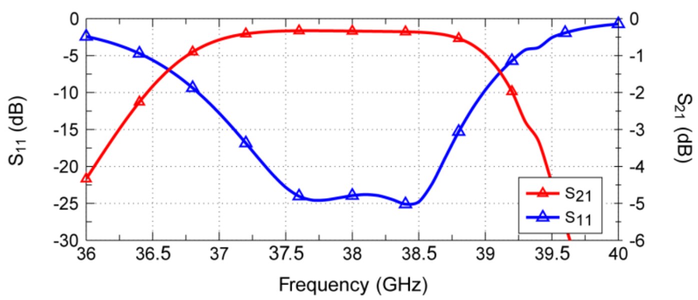

Figure 5. Simulated S parameters of the proposed twist

The optimized dimensions are: $d_1 = 4\,mm$, $d_2 = 12.1\,mm$, $d_3 = 2.5\,mm$, $d_4 = 11.35\,mm$, $d_m = 2.5\,mm$, $w_m = 0.9\,mm$, $h_{r2} = 1.65\,mm$, $\alpha = 22^o$, $l_{slt} = 4.22\,mm$, $w_{slt} = 0.57\,mm$. The dimensions for the RGW elements are those presented in Table 1 for 38 GHz.

fo GHz	*P* mm	*wp* mm	*hp* mm	*ha* mm	*wr* mm	f_{CL} GHz	f_{CH} GHz
38	1.25	0.45	1.95	0.39	0.6	33.00	59.00
60	1.23	0.38	1.60	0.32	0.6	38.53	72.91
77	0.94	0.28	1.17	0.19	0.6	52.08	101.31

Table 1 Geometrical parameters of the periodic structure

3. EXPERIMENTAL MEASUREMENTS

Using the optimized dimensions, a prototype of a double transition has been manufactured and measured. The prototype consists of two twists between RGW to GGWHP connected by a section of GGWHP (see Fig. 6). Standard WR28 flanges were used to connect the prototype to the vector analyzer. Thereby, a broadband transition from rectangular waveguide (RW) to RGW (at both ends) had to be included in the prototype [10]. The manufactured prototype is shown in Fig. 7. In this picture it is possible to identify the three parts in which the model has been divided for construction: the lower level has the transitions from RW to RGW in the input and output ports, the middle level has the coupling slot and the body of the GGWHP, and the upper level is the upper lid of the GGWHP.

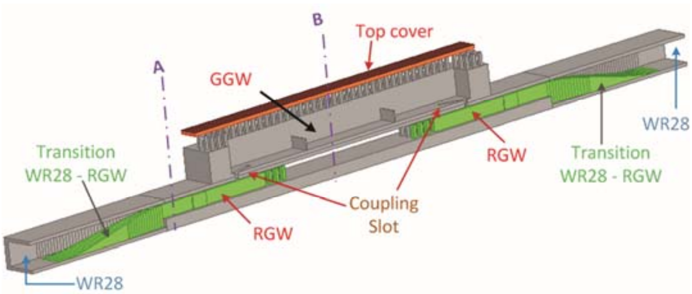

Figure 6. Longitudinal cut of the simulated prototype.

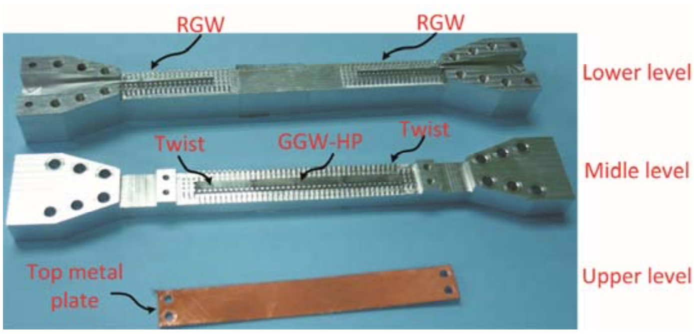

Figure 7. Picture of the manufactured prototype.

Simulations and measurements of the prototype present good agreement, as can be observed in Fig. 8. The measured S_{11} parameter of the double transition is below -10 dB from 37.2 to 39.3 GHz and the S_{21} parameter is above -1 dB within almost the same frequency band.

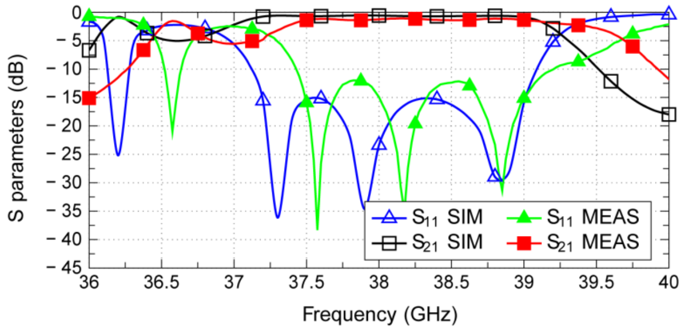

Figure 8. Measured and simulated S parameters of the prototype

The insertion loss of a single twist (section A-B in Fig. 6) has been evaluated taking into account the symmetry of the structure and using a TRL calibration to extract the losses caused by the transitions between the RW and the RGW.

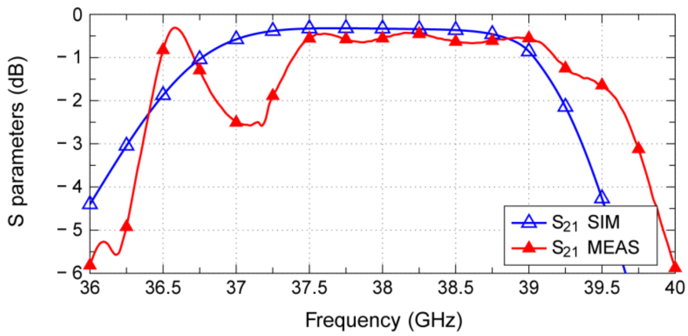

Figure 9. Measured and simulated insertion loss of a single twist.

As can be seen in Fig. 9, insertion loss is around 0.5 dB in the frequency range from 37.5 to 39 GHz. The differences with the simulations are produced by inaccuracies in the manufacturing process and, also, by differences between the considered permittivity of the dielectric substrate and the real value of the material at 38 GHz.

4. CONCLUSION

A novel compact twist for the interconnection of two different gap waveguides in multilayer structures, at millimeter-wave frequencies, has been presented. This twist can be used, for instance, as a feeding network in antenna arrays implemented in GGWHP. To confirm the correct operation of the transition, a double twist has been manufactured and measured.

Measurements of the S parameters of the complete prototype show good agreement with simulations. Also, the insertion loss of a single twist presents a bandwidth of 3.9% similar to that obtained in simulations.

5. ACNOWLEDGEMENT

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