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Investigation of Transitions for Use in Inverted Microstrip Gap Waveguide Antenna Arrays

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***Abstract*— The main purpose of this work is to create good transitions for inverted microstrip-based versions of gap waveguide that are used to feed slot or horn antenna arrays. Two new millimeter-wave transitions from inverted microstrip gap waveguide to rectangular waveguide are presented. Both geometries are similar and consist of a planar probe, which contains a rectangular patch or T-section. The planar probe is inserted inside the rectangular waveguide through an opening made in the broadside wall of the waveguide. The main difference between the two geometries is that one of them extends upwards and the other one downwards with respect to the planar inverted microstrip gap waveguide circuit. The simulated S-parameters show promising results.**

***Index Terms*—Gap waveguide, Perfect Magnetic Conductor (PMC), Artificial Magnetic Conductor (AMC), Microstrip-to-rectangular waveguide transition, millimeter-wave circuits.**

I. INTRODUCTION

The gap waveguide technology has been proposed as a promising waveguide suitable at millimeter and submillimeter-wave frequency ranges [1]-[2]. This waveguide is created in the airgap (which must be smaller than a quarter of a wavelength) between two parallel metal plates. One of these plates is textured to contain a bed of pins that surrounds a metal ridge, groove or strip. The pin surface works as an Artificial Magnetic Conductor (AMC) [3]. The combination of the AMC and the top smooth metal plate establishes a stopband for parallel-plate modes [4] in any direction outside the metal ridge, groove or strip. The gap waveguide has inherently low loss [5], and good metal contact between the different metal pieces is not required since the pin surface removes any possible leakage of fields.

An important challenge of our research is the integration of active components and antennas in the same gap waveguide module operating at millimeter-wave frequencies. For this aim, it is important to develop good transitions from traditional technologies, such as planar structures (microstrip [6] and, coplanar waveguide [7]) or rectangular waveguide, to gap waveguide technology. A transition from a standard waveguide to a suspended-strip gap waveguide has also been previously investigated [8]. The present paper introduces a new type of inverted microstrip gap waveguide to rectangular waveguide transition. This idea has also been used to design a better transition from standard microstrip line to rectangular waveguide than what can be found in literature.

One of the most promising gap waveguide variants is the inverted microstrip gap waveguide. In this technology, the substrate is supported by a bed of nails that, in combination with the upper metal lid, ensures removal of all parallel-plate modes or surface waves. The propagation of a local wave is allowed in the air gap along a metal strip placed on the substrate. The inverted microstrip gap waveguide is a very convenient technology for the design of low loss feed networks for array antennas [9]-[10]. The reasons for the low loss are that there is no dielectric substrate in the region of the propagating microstrip modes, and that the conductive metal loss is reduced to a minimum by increasing the transverse dimensions of the microstrip lines. The latter can be done without losses due to both surface waves and radiation, provided if the inverted microstrip line is packaged by gap waveguide technology. Thereby, it becomes a microstrip gap waveguide.

In particular, it was found in [10] that there is a need for a compact wideband transition from inverted microstrip gap waveguides to rectangular waveguides that enters orthogonally to the microstrip circuit. This is a severe limitation when designing inverted microstrip gap waveguide antenna arrays at high frequencies, and the present work was started to overcome this limitation.

Because of the lack of wideband inverted microstrip gap waveguide transitions, the authors of [11] chose to realize their 60 GHz antenna in the related *microstrip-ridge* gap waveguide technology. In the *microstrip-ridge* gap version the pin surface is integrated in the substrate as via holes, instead of being located below the substrate like in the inverted microstrip version of the present paper. The transition from *microstrip-ridge* gap waveguide to WR-15 used in [11] is described in [12]. It is designed by using via-holes and shows good performance over 15% bandwidth. Therefore, the goal of the present work is to try to achieve the same wideband performance in the inverted microstrip gap waveguide technology. The results so far are described in the present paper, introducing both an upwards and a downwards transition from inverted microstrip gap waveguides to rectangular waveguide, both designed by means of pins and working within the F band (i.e. 90-140 GHz). We chose to design the transitions in F band because of some other parallel work in that band.

The transitions are designed in a back-to-back configuration in order to overcome the problem associated with the quality of the numerical ports used to analyze the inverted microstrip gap waveguide [13].

II. UPWARDS TRANSITION FROM INVERTED MICROSTRIP GAP WAVEGUIDE TO RECTANGULAR WAVEGUIDE

We can distinguish between two main mechanical parts in the transition geometry: the substrate with the 50 Ω inverted microstrip gap line and the rectangular waveguide. The inverted microstrip gap line ends in a probe that is inserted into the rectangular waveguide. The probe contains a rectangular patch (or T-shape line), having certain dimensions and location inside the waveguide that are fine-tuned in order to achieve the desired matching.

The employed substrate material is Megtron6 with permittivity ε_r = 3.19, thickness h = 0.074 mm and loss tangent $tan\delta$ = 0.006. The thickness of the metal strip is t = 0.018 mm. The considered pin dimensions are: height d = 0.625 mm, width a = 0.21 mm, period p = 0.65 mm and airgap g = 0.125 mm. The achievable stopband by using the mentioned dimensions is shown in the dispersion diagram of Fig.1.

The considered rectangular waveguide has the same dimensions as the standard WR-8. The probe is inserted into the waveguide through an aperture which is made in the broad wall of the waveguide. Fig.2 illustrates the different parts of the transition geometry. This type of transition includes a waveguide short circuit or back-short which is placed about quarter wavelength away from the probe, i.e. establishing an open boundary condition under the substrate. Therefore, the rectangular waveguide enters orthogonally to the inverted microstrip gap waveguide and the patch faces the waveguide port (the opposite side to the waveguide backshort) as presented in Fig.2. Moreover, a pin is suitably placed under the probe which combined with the back-short ensures maximum coupling of fields into the rectangular waveguide and thereby the best field matching. The main parameters of the probe that determine the transition behavior are shown in Fig. 4. A preliminary sweep of these dimensions has been performed obtaining the indicated values.

Two back-to-back transitions from an inverted microstrip gap waveguide to a rectangular waveguide have been numerically analyzed to determine the S parameters by using CST Microwave Studio 2012 [14]. The results are shown in Fig. 4. The obtained return loss is better than 15 dB over 45% bandwidth, covering almost all the F band. This means that the corresponding S_{11} for a single transition will be 6 dB lower than the interference peaks that we see in the plots. This can be concluded by using theory of small reflections which is explained in Sec. 2.7 in [15]. The insertion loss is smaller than

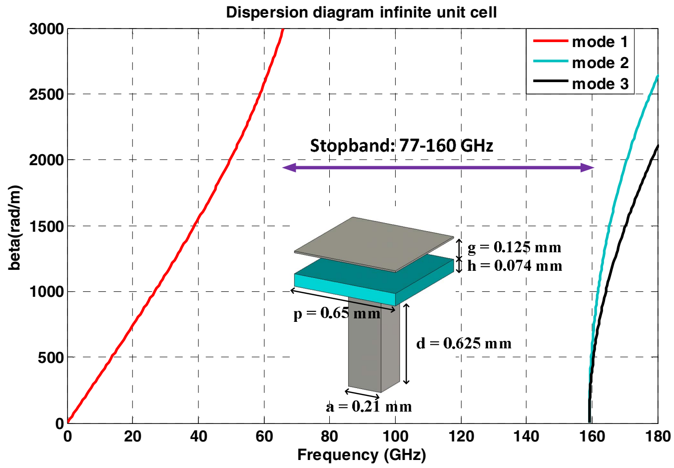


Fig. 1. Dispersion diagram for an infinite periodic unit cell.

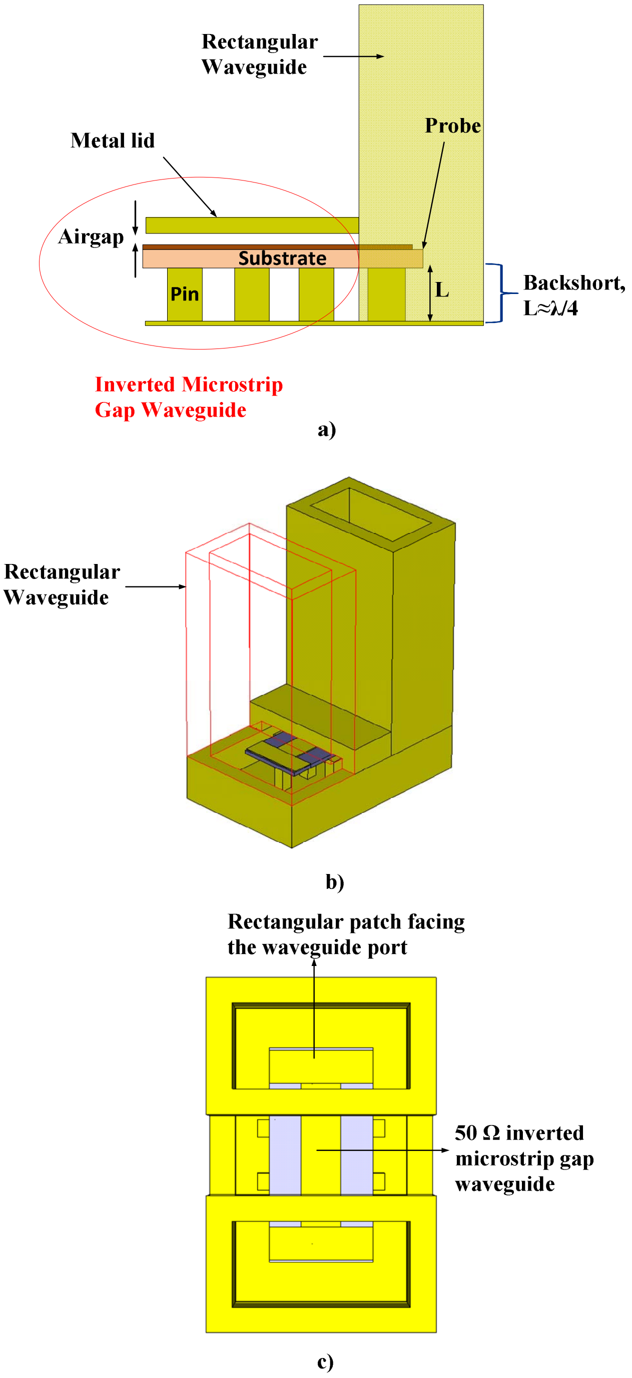


Fig. 2. Sketch of complete transition geometry (upwards case): a) side view, b) perspective view, c) top view.

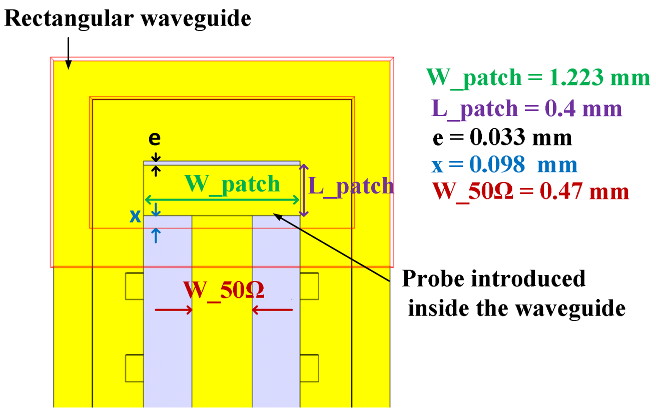


Fig. 3. Main parameters of the probe inserted inside the rectangular waveguide (upwards case).

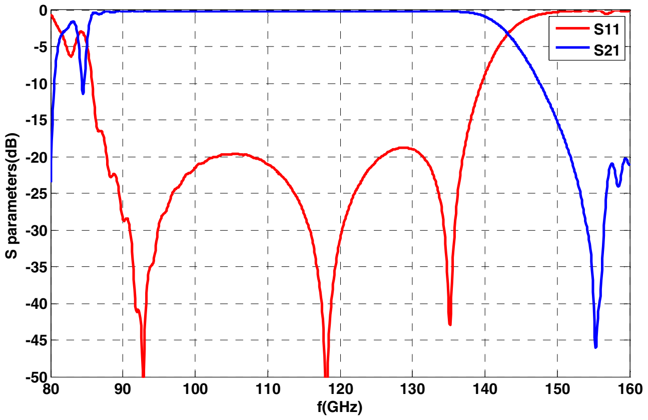


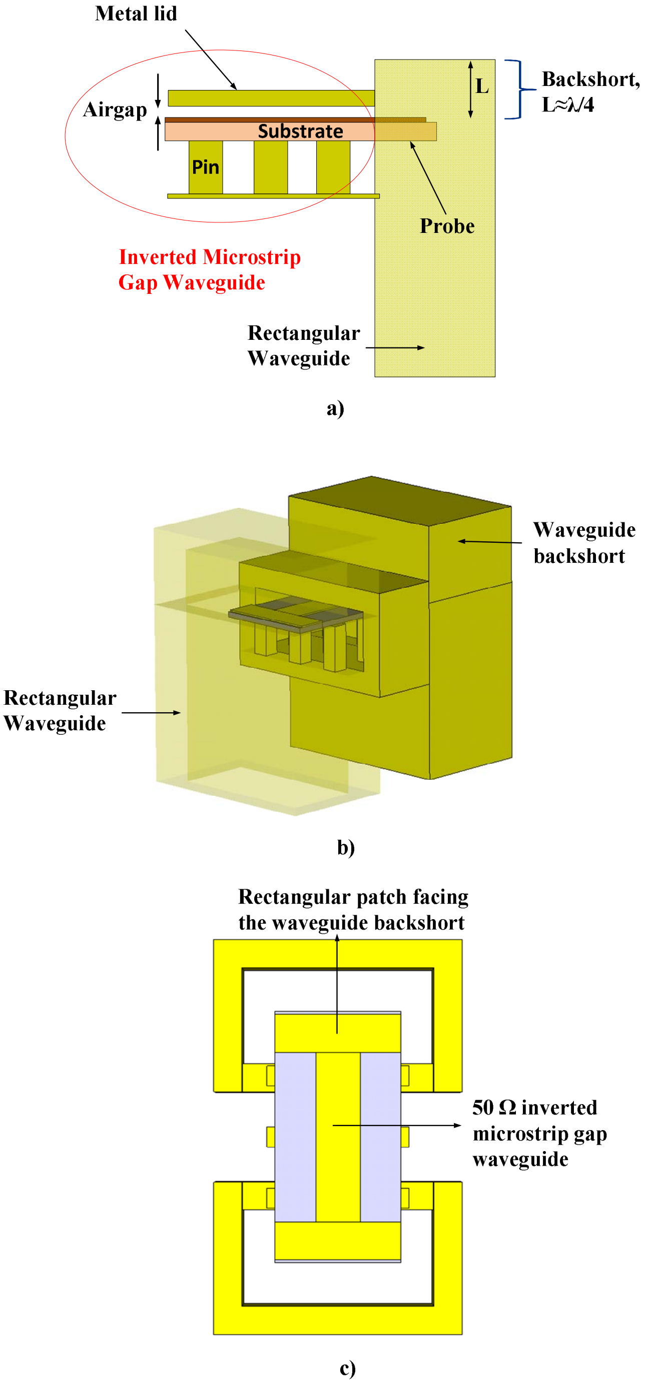
Fig. 4. Simulated S parameters for two back-to-back transitions from inverted microstrip gap waveguide to rectangular waveguide (upwards case).

0.5 dB over the same bandwidth, implying 0.25 dB for a single transition.

III. DOWNWARDS TRANSITION FROM INVERTED MICROSTRIP GAP WAVEGUIDE TO RECTANGULAR WAVEGUIDE

We will now introduce the downwards transition to rectangular waveguide. The material specifications and the geometry of the inverted microstrip gap waveguide are the same as explained in section II. In this design, the rectangular waveguide also enters orthogonally to the inverted microstrip gap waveguide circuit, but it extends downwards instead of upwards like in the previous case. The probe contains again a rectangular patch, but this faces now the waveguide back-short as illustrated in Fig. 4. This back-short establishes an open boundary condition in the upper plane of the probe forcing the fields to propagate down from the patch into the rectangular waveguide.

The obtained S parameters in Fig. 5 show that the return loss is better than 15 dB over the band from 120.3 to 133 GHz, i.e. 10.5%. Therefore, the S_{11} parameter for a single transition will be lower than -21 dB over the mentioned frequency band. The insertion loss is smaller than 0.46 dB over the same bandwidth, implying 0.23 dB for a single transition. The -10 dB bandwidth (approximately -16 dB of the single transition) is 118 to 134 GHz, corresponding to 13.5 %. This is very close to what is achieved for the *microstrip-ridge* gap waveguide in [12].



a)

b)

c)

Fig. 4. Sketch of complete transition geometry (downwards case): a) side view, b) perspective view, c) top view.

IV. CONCLUSIONS

This paper has proposed two transitions from inverted microstrip gap waveguide to rectangular waveguide that have

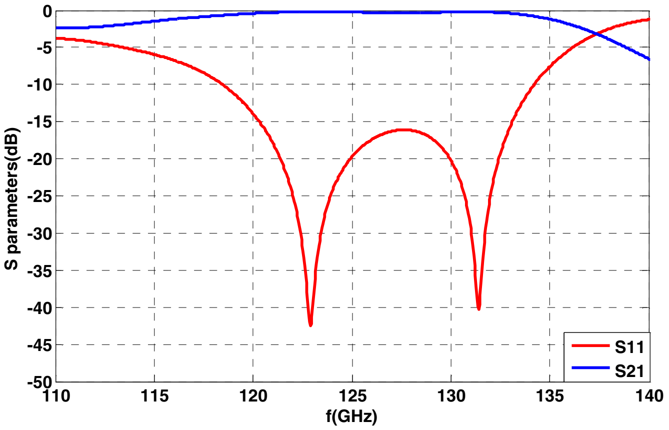


Fig. 5. Simulated S parameters for two back-to-back transitions from inverted microstrip gap waveguide to rectangular waveguide (downwards case).

been designed and simulated in back-to-back configuration. The numerical results for the first upwards case show that the return loss is better than 15 dB in 45% bandwidth (which means almost all F band). For the second downwards case the return loss is better than 15 dB in 10.5% bandwidth and better than 10 dB over 13.5 %. This is very close to what is required for the application described in [10] and [11]. It is more difficult to match the electromagnetic fields in the backwards configuration since the field needs to be forced to propagate downwards from the patch into the rectangular waveguide. This is done by adding a waveguide back-short placed a quarter of a wavelength above the probe. We should mention that the presented downwards design is just a preliminary version and same probe dimensions as used in the optimized upwards case have been employed to obtain initial results. Further optimization of the different transition parameters may increase the bandwidth.

Fig. 6 presents a preliminary sketch that illustrates how to connect the explained transition geometries to the inverted microstrip gap waveguide antenna array design introduced in [10]. The upwards geometry studied in this work shows a very wideband transition, but it is a problem that the rectangular waveguide port is located at the same plane as the radiating elements according to the geometry in [10], and also illustrated in the upper drawing of Fig.6. Therefore, we are not able to connect the transition to the array without destroying the radiation pattern. Nevertheless, it is possible that this type of T-shape microstrip line section can be used to feed a slot and a radiating element more broadband than the horn design presented in [10].

The downwards configuration (lower drawing in Fig.6.) constitutes the only possible alternative to connect the inverted microstrip gap waveguide antenna array to a rectangular waveguide flange. The return loss of this transition is very close to what is required for the application described in [11] and [12]. Thereby, this transition makes the inverted microstrip gap waveguide a very interesting solution for designing the distribution network of directive planar arrays in the 60 GHz band.

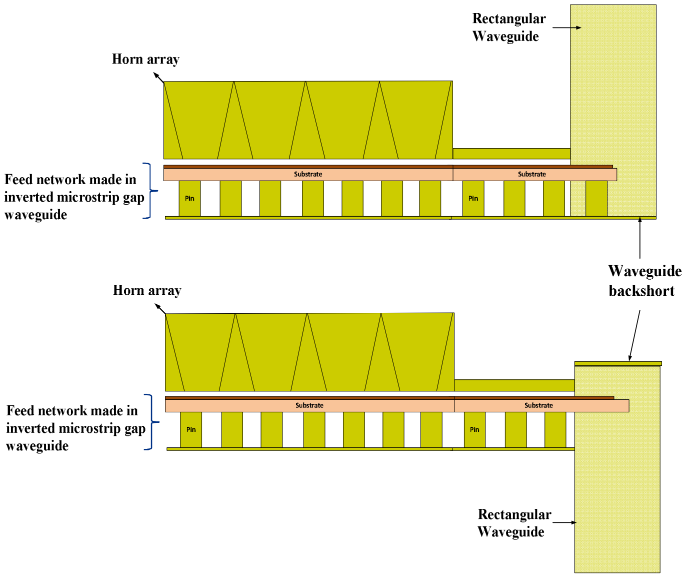


Fig. 6. Transition geometries integrated with inverted gap waveguide antenna horn array.

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