5G Antenna in Inverted Microstrip Gap Waveguide Technology Including a Transition to Microstrip

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***Abstract* - A 28 GHz four-beam antenna based on the combination of a 4x4 Butler matrix and a Fabry-Perot superlayer is the final goal of this work. The matrix is designed in the low loss inverted microstrip gap waveguide technology, including the design of a transition to microstrip to enable measurements. Multibeam antennas with high efficiency are of interest for the future 5G communication systems to be used for instance in MIMO systems.**

***Index Terms* — Antenna, AMC, Butler matrix, Fabry-Perot, gap waveguide, transition.**

1. Introduction

Gap waveguide technology [1] can be easily combined with classical designs to provide improved performance in terms of efficiency in antenna systems at millimeter-wave frequencies. In the 28GHz-band, which is of interest for the future 5G mobile communications, the use of feed networks based on this technology is convenient. A particular case of these feed networks is the Butler matrix, that is useful to generate multibeam systems. A preliminary design based on gap waveguide technology was already proposed in [2]. We propose here to use that matrix not only with a conventional slot array (that produces directive beams just in one plane) but with slots feeding a Fabry-Perot cavity, building up a so-called superstrate or superlayer. In this way, pencil beams are obtained in a simple and integrated design. However, the use of a superlayer produces an increase in the mutual coupling, forcing us to separate the slots close to or more than lambda. The cavity itself attenuates the grating lobe, but as the phase distributions provided by a conventional Butler matrix are fixed, the combination of those phases with very separated elements causes the four beams to be distributed in a small angular range. Consequently, a compromise between mutual coupling and angular range is needed.

In this paper, we will focus on the potential of the Fabry-Perot array antenna design itself and on the development of a transition to microstrip, as the design of the Butler matrix was already presented in [2].

2. Antenna design and preliminary analysis

The feed network for the antenna has been designed in inverted microstrip gap waveguide by using the dimensions shown in Fig.1 and Table 1, where the dispersion diagram is also shown. The employed substrate material is Rogers RO4003 with permittivity $\varepsilon_r = 3.55$ and loss tangent $\tan\delta = 0.0027$. As a first step, a wideband slot antenna has been created in this technology and presented in Fig. 2.a. Next, the design of the array of slots was accomplished and the effect of the use of a superlayer has been evaluated. In Fig. 2 we can see the effect in the radiation pattern when adding the superlayer in the structure (Fig. 2.b, 2.c and 2.d) i.e., how the beam from the slot array (2.b) is transformed into a pencil beam. We can also observe a corresponding improvement in the directivity with the increase of the permittivity of the superlayer. The effect of the dielectric superlayer on the antenna gain as a function of the frequency has been studied and is shown in Fig. 3.

3. Design of transition from microstrip line to inverted microstrip gap waveguide

In order to measure the antenna with a conventional vector network analyzer, a suitable transition from inverted

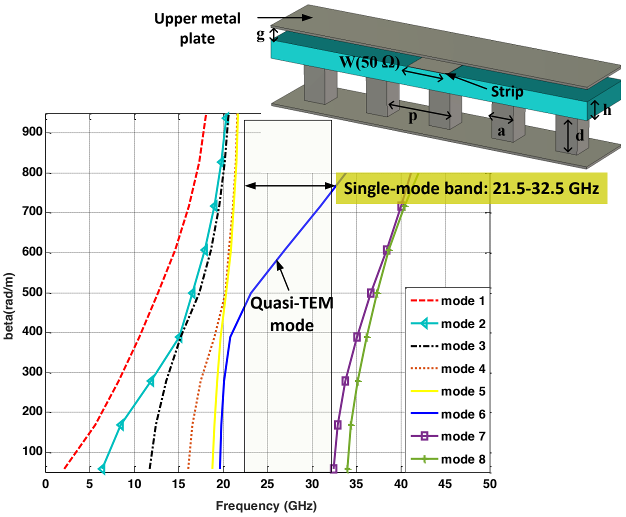

Fig. 1. Dispersion diagram of the infinite periodic unit cell with metal strip on the top of the substrate material.

TABLE I
Dimensions of the gap waveguide structure (referred to unit cell shown in Fig. 1)

Parameter	Value
Air gap, g	0.535 mm
p	3 mm
a	1 mm
Height of the pin, d	2 mm
Thickness of RO4003 substrate, h	0.813 mm
W (50 Ω)	1.9 mm

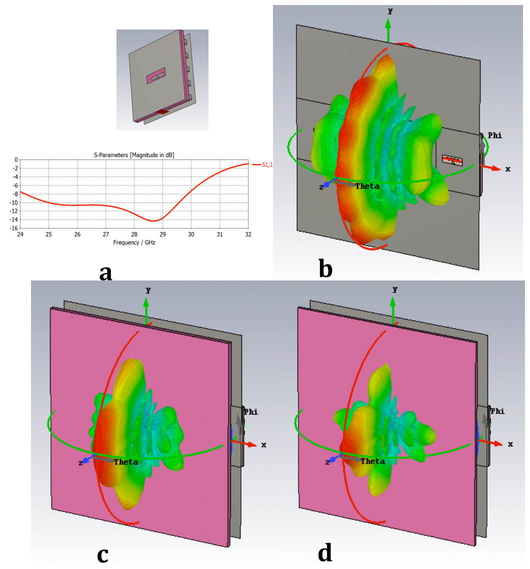

Fig. 2. Designed wideband slot antenna in inverted microstrip gap waveguide: (a) S_{11} of single slot, (b) Radiation pattern for the array of 4 slots, and when the superlayer is added on top (c) for $\varepsilon_r = 4$, and d) for $\varepsilon_r = 10$).

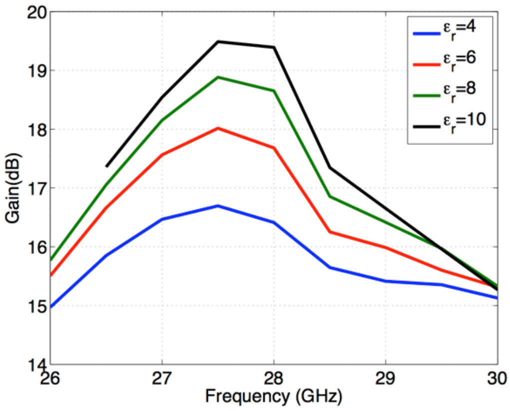

Fig. 3. Antenna gain as a function of frequency.

microstrip gap waveguide to a microstrip line is required. In this way, a coaxial connector can be soldered in the printed circuit board (PCB) where a 50 Ω microstrip line is etched. A suitable millimeter-wave coaxial connector is the mini-SMP from Rosenberger, which operates up to 50 GHz.

The proposed transition is based on the approach introduced in [1], where a microstrip line is connected to a certain section of a printed microstrip-ridge gap waveguide. The latter is made by means of circular patches grounded by using plated vias. The complete structure is composed of two main parts (see Fig. 4). First, the inverted microstrip gap waveguide interface contains a center line section of 50 Ω characteristic impedance in free space, which is around 2λ long. This center line is terminated in two narrower sections whose width corresponds to 50 Ω when the fields propagate through Rogers RO3003. Secondly, these input/output inverted microstrip gap waveguide sections make electrical contact with two microstrip lines of the same width. The two PCBs with the microstrip circuit are placed upside down and soldered in the upper metal lid of the gap waveguide. The simulated S-parameters are shown in Fig.5. The obtained return loss is better than 20 dB in almost 45% relative bandwidth, whereas the insertion loss remains better than 0.5 dB from 21 to 31.3 GHz. Therefore, the corresponding loss for a single transition would be 0.25 dB. Most of this loss comes from the input/output microstrip lines that stick out from the inverted microstrip gap waveguide prototype. It may be possible to reduce this loss if we extend the bed of nails in such a way that we package the input/output feeding microstrip lines.

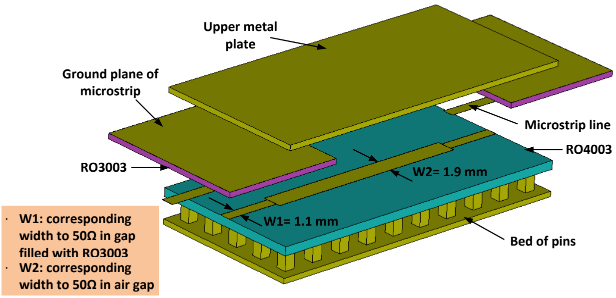

Fig. 4. Transition geometry

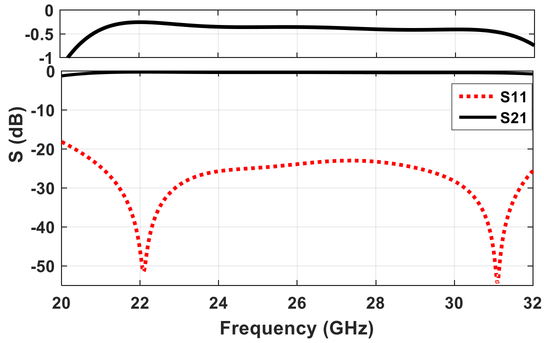

Fig. 5. Simulated S-parameters of two transitions in back-to-back configuration.

4. Conclusion

An evaluation of the use of a Fabry-Perot superlayer on an inverted microstrip gap waveguide slot array has been performed showing that it is possible to obtain directive pencil beams. Its combination with a Butler matrix feed will allow the multibeam operation. A wideband transition to microstrip is also proposed in order to enable accurate measurements of the 5G gap waveguide antenna.

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