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Design of a Butler Matrix at 60GHz in Inverted Microstrip Gap Waveguide Technology

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***Abstract*—A four-port Buttler matrix is designed at 60GHz in the new gap waveguide technology, inverted microstrip type. The simplicity of doing this circuit in a printed technology and the low loss characteristic makes this design very promising. All the different components of the matrix have been designed and optimized and the complete matrix is currently under optimization.**

I. INTRODUCTION

The growing amount of advantages that millimeter-wave bands can offer (increased bandwidth, larger transmission capacity or greater antenna directivity), can be complemented by the employment of beam-forming antenna feed networks such as the so-called Butler matrix. The Butler matrix has been already widely applied in this frequency range to feed switched-beam smart antenna arrays, with the aim of generating multiple beams in different directions [1], [2]. It is evident that for this particular circuit the losses at this frequency band are critical. So far, most promising examples in the literature in this band have been implemented using SIW technology.

However, the emerging technology known as gap waveguide has demonstrated to be a good candidate to develop low loss circuits [3], [4] in the millimeter band. Among the different versions of this technology, the known as inverted microstrip allows an easy translation of classical microstrip circuits but with improved performance due to both, the fact that the field is travelling on air and also the wider metallic lines. An example of this is the design of corporative feeding networks for array antennas that was reported in [5].

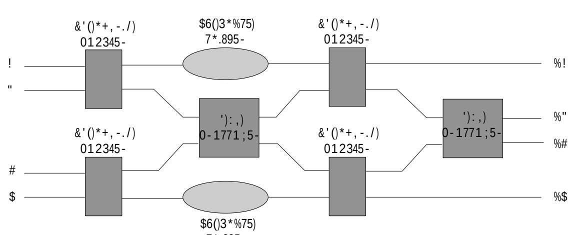

Fig. 1. Basic scheme of a Butler matrix.

As no previous research has been performed on realizing switched-beam gap waveguide smart antennas, the motivation of this work is to initiate the study of an inverted microstrip gap waveguide Butler matrix and in the future to integrate this type of feeding with a four-slot antenna array.

II. DESIGN OF THE BED OF NAILS

This technology requires the use of a periodic structure to provide an AMC condition. Typically, the bed of nails is employed to this aim because of its simplicity and wideband characteristic. Figure 2 shows the dispersion diagram of the bed of nails designed for this frequency band. The calculation includes the substrate layer where the circuit will be printed (Rogers RO3003 with permittivity ϵ_r = 3, h = 0.25 mm and tanδ = 0.0013) and the air gap of 0.25mm.

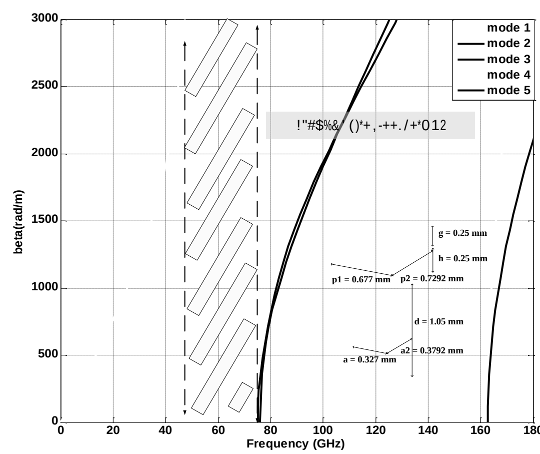

Fig. 2. Dispersion diagram of the bed of nails for the microstrip gap configuration for 60GHz.

III. DESIGN OF THE BUTLER MATRIX COMPONENTS

Basically the Butler matrix is composed of hybrid couplers, phase shifters and crossovers as shown in Figure **??**Butler. The first step in the design of the matrix is the individual design of each of these components. All of them have been designed and optimized initially using first an ideal PMC to save computational time and then replacing the PMC by the bed of nails of Figure 2. As an example, the performance of the designed wideband hybrid is shown in Figure 3. Here the simulations with PMC and pins are both included for comparison purposes. For PMC case, we can observe that return loss and isolation are higher than 20 dB between 52 and 68 GHz whilst S_{31} and S_{21} parameters show levels between -3 and -4 dB in approximately 8.5% bandwidth, and both parameters coincide at 57.77 GHz. The design with pins is a bit shifted in frequency as expected [5] and has slightly worse performance, but still good enough. The phase of the output S parameters is plotted in Figure 4.

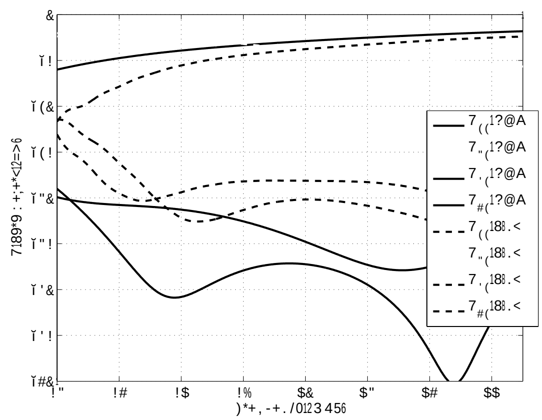

Fig. 3. S parameters of the wideband hybrid circuit.

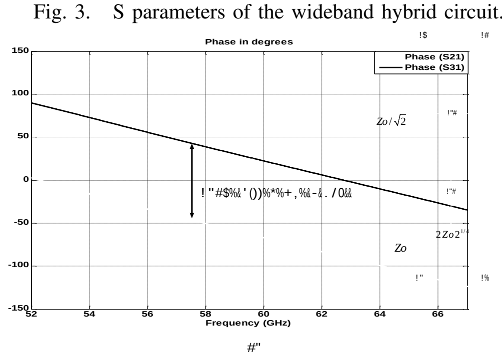

Fig. 4. Phase of the output S parameters of the wideband hybrid.

It is important to point out that the high impedance shunt lines of the different elements of the Butler matrix are difficult to be realized with standard microstrip lines at millimeter-wave frequencies since they become extremely thin. This is possible to be done with inverted microstrip gap waveguide since the field is mainly propagating in the air and the transversal dimensions of the circuit become wider.

A. Preliminary complete matrix

The designed Butler matrix in inverted microstrip gap waveguide technology is shown in Figure 5.

Once all the elements have been optimized, the complete circuit must be optimized again when all of them are put together. For the PMC case, the amplitudes in the ouput ports oscillate between -5.5 and -7 dB from 55.7 to 58.5 GHz. At 57 GHz all ouput amplitude values are close to -6 dB. When the pins are used instead, there is a shift in frequency as mentioned. The amplitude values are lower than in the PMC case and they get closer to -6 dB at around 62.7 GHz. The optimization of the phases is still under going.

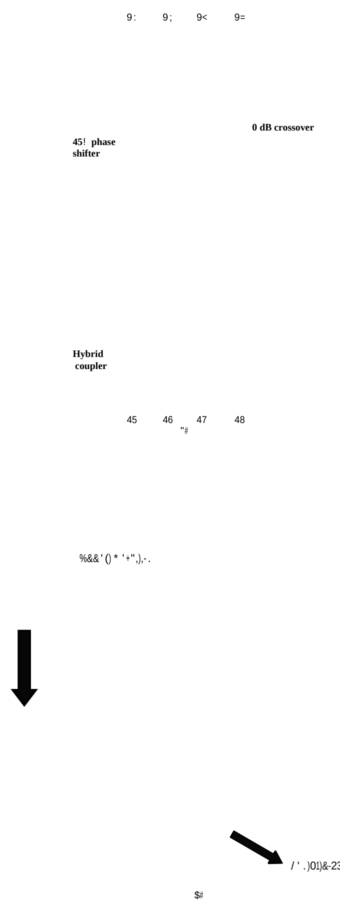

Fig. 5. Proposed Butler matrix in inverted microstrip technology.

ACKNOWLEDGEMENT

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