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Versatility of MoM-FMP Technique for Designing Linear Arrays of Slots on Rectangular Waveguide

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1. Introduction

High frequency systems and techniques are becoming more and more common among the scientific community, like medical and diagnosis applications, military devices, and civil communications. These systems use to rely on slot-array antennas due to their properties of low loss and high gain. Even though this document continues a study specially focused on compound slot antennas, it shows arrays of different kinds of slots designed by means of the equivalent circuit representation explained in [1] and [2], following the procedure shown in presented on [3]. Despite the absence in the literature of a serially fed array of a large number of compound slots a fifteen-element design is proposed in this paper. Designed array performance match up with CST simulations.

2. Followed Methodology

All the examples presented here have been designed according to the same methodology, *Method of Moments – Forward Matching Procedure*, MoM-FMP. This method consists on the generation of a database of equivalent circuits of a single slot, for a finite number of possible configurations. According to the desired amplitude and phase distribution of the final array, the circuits are selected and forwardly assembled taking into account impedance matters, from the generator to the last element, which is always loaded with a short circuit. As a result, an input-matched array of N slots with a specific aperture distribution is obtained.

Some authors [4][5] separate the employment of a single shunt admittance or series impedance depending on the tilting angle of the slot, but this work does not make such distinction. The reason is that regardless of its inclination, offset or length, the scattering parameters of the single slot in a waveguide reveals a common reciprocal behaviour. When the slot is modelled as a two-port device with losses, the S matrix is always reciprocal and it can be represented as a circuit of three complex and independent elements [6], as the T or Π circuits. Some specific configurations like longitudinal, transverse or centred-inclined slots show symmetry besides reciprocity, so that they can be modelled by means of a single shunt or series element with two unknowns (real and imaginary parts). This can be demonstrated calculating the amplitude of the forward and backward, C_n and B_n respectively, scattered field from the slot [7] and calculating their ratio, $B_n/C_n = D_n$.

$$B_n = \frac{\int_{slot} \left(\vec{E}_{slot} \times \vec{H}_{slot}\right)\cdot d\vec{S}}{2\int_{S_1} \left(\vec{E}_{scat} \times \vec{H}_{scat}\right)\cdot d\vec{S}} \qquad C_n = \frac{\int_{slot} \left(\vec{E}_{slot} \times \vec{H}_{slot}\right)\cdot d\vec{S}}{2\int_{S_2} \left(\vec{E}_{scat} \times \vec{H}_{scat}\right)\cdot d\vec{S}}$$

where $\left(\vec{E}_{slot}, \vec{H}_{slot}\right)$ and $\left(\vec{E}_{scat}, \vec{H}_{scat}\right)$ are the electric and magnetic fields on the slot and scattered from it inside the waveguide, respectively. The numerator is identical but the denominator differs on the direction of propagation of the scattered fields, $+z$ and $-z$. S_1 and S_2 represent the internal faces of the waveguide, normal to the direction of propagation.

If the absolute value of D_n is equal to one, the slot shows this symmetry in its S matrix. The value of B_n and C_n is of course dependent of the structural properties of the slot under study.

According to Figure 1, fixing the offset and length for different cases, D_n is calculated and represented for a set of tilting angles, Figure 2. It can be seen that whichever the values of structural parameters are, when $\theta = 0^o, 90^o, 180^o$, $|D_n|$ becomes one, matching up to longitudinal or transverse cases. For the rest of the angles where the system is just reciprocal, the relation between reflected and transmitted scattered field is structure dependant and its value is a priori unknown.

3. Designed Arrays

In this section two arrays conceived to work at 12GHz with different kind of radiators are shown. Both systems have been designed exclusively using the Π-network, on a standard rectangular waveguide WR75 with internal dimensions $a = 19mm$, $b = 9.5mm$. Slots width and metal thickness are kept the same in both designs, $w_s = 1mm$ and $t = 1.25mm$, respectively. Once the array is obtained by means of MoM-FMP, its reflection coefficient is calculated from the response of the equivalent global circuit and compared to CST results. Structural and working properties of the slot in the arrays and are shown in Table 1 and Table 2, where slots are numbered from the generator to the short. P_{err} and ϕ_{err} represent the error from the ideal value in radiated power and the radiation phase of every slot, respectively. Tables also show the offset (D) and length (l) of the radiators.

3.1 Linear Array of Fifteen Compound Slots with Uniform Distribution

Arrays of compound slots are not common among the literature, although some good works can be found in [8]. The reason is that it is not possible to univocally ascribe radiation properties (radiated power or radiation phase) to a single structural parameter (offset, angle or length). The non-symmetrical condition of its scattering matrix makes known techniques [4] useless for this kind of radiator. The development of a specific design procedure for compound slots was considered as a challenge by Rengarajan in [8].

The circuit-based strategy shown in [3] represents a systematic methodology to design serially fed arrays of high number of elements. A fifteen elements array with a uniform distribution was designed and predicted return loss is compared with CST simulations. Figure 3 shows an excellent agreement. Radiation pattern is plotted in Figure 4, showing a side-lobe level of -13dB on a broadside radiation pattern. Due to the mutual coupling effect between radiators, which was not taken into account in the analysis stage, two lobes at ±49º are present.

3.2 Linear Array of Ten Longitudinal Slots with Taylor Distribution

For longitudinal slots, offset controls the radiated power and slot length fixes the radiation phase. Because of this, the method finds a solution where lengths are almost the same and the offsets vary to fulfil tapering requirements. This provokes a pick in the input matching at the designing frequency, Figure 5. Since all the slots have almost the same length, they radiate with the same phase and, consequently, the length of the connection waveguide remains regularly close to $0.5\lambda_g$. To point out the versatility of the method, a Taylor distribution has been applied, obtaining a -20dB side-lobe level. In order not to lose directivity, the selected distribution just fixes the amplitude of the first side-lobe.

5. Conclusion

This document shows the performance of two linear arrays of diverse kind of slots and different aperture distributions. Both of them have been designed by means of the same systematic circuit-based technique MoM-FMP, obtaining exceptional agreement with CST simulations. MoM-FMP gives the solution in less than 15 seconds for both cases at the designing frequency. Since all classes of slots can be represented by an equivalent network of three elements, MoM-FMP can be used to design any kind of linear slot-array.

Acknowledgments

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Table 1: Properties of the array of compound slots. Tilting angle is θ = 45º.

Slot	P_{err} [dB]	ϕ_{err} [deg]	D [mm]	L [mm]
1	-0.4	108.9	4.3	10.9
2	0.5	106.7	-0.5	13.5
3	0.5	112.3	4.5	11.1
4	0.1	109.4	-0.9	13.2
5	-0.6	111.5	3.5	11.1
6	-0.3	106.9	-1.9	13
7	0.4	110.5	1.9	11.2
8	-0.4	109.9	-2.1	12.7
9	-0.3	112.6	1.9	11.3
10	-0.2	109.9	-0.5	12.4
11	0.4	109.9	3.7	11.6
12	-0.4	107.8	-0.3	12.2
13	0.5	110.8	3.1	11.7
14	0.5	107.8	-1.1	12
15	0.1	106.7	1.7	11.8

Table 2: Properties of the array of longitudinal slots

Slot	P_{err} [dB]	ϕ_{err} [deg]	D [mm]	L [mm]
1	-0.2	-33.9	1.9	12.2
2	0	-31.7	-1.9	12
3	0.5	-31.6	2.3	12
4	0	-32	-2.9	12.2
5	-0.4	-31.5	3.3	12.3
6	-0.3	-31.1	-3.7	12.4
7	0.6	-34.3	4.5	12.6
8	0.1	-28.7	-4.1	12.5
9	-0.4	-31	4.3	12.6
10	0.1	-34.2	-4.5	12.7

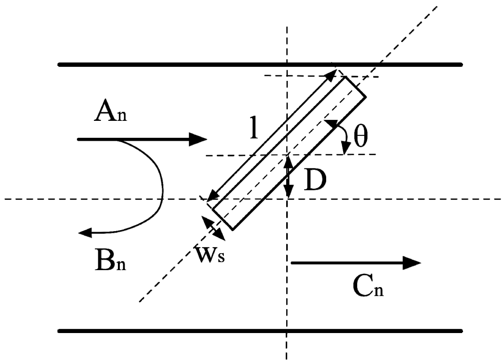

Figure 1: structural parameters of the compound slot

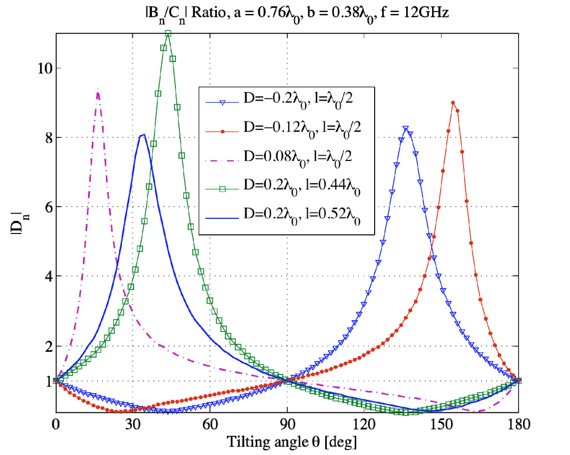

Figure 2: Ratio of reflected and transmitted scattered waves from a compound slot as a function of θ

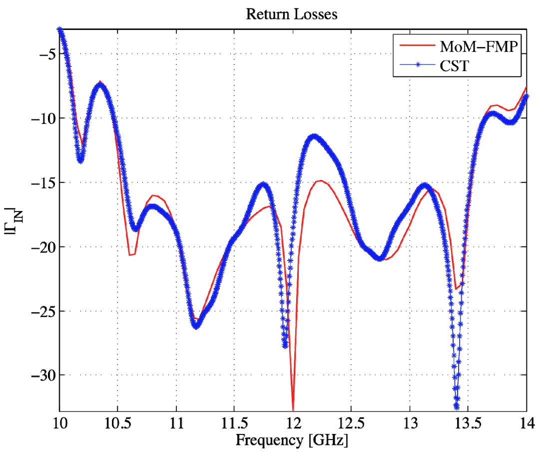

Figure 3: 15-elements compound slot array, return losses

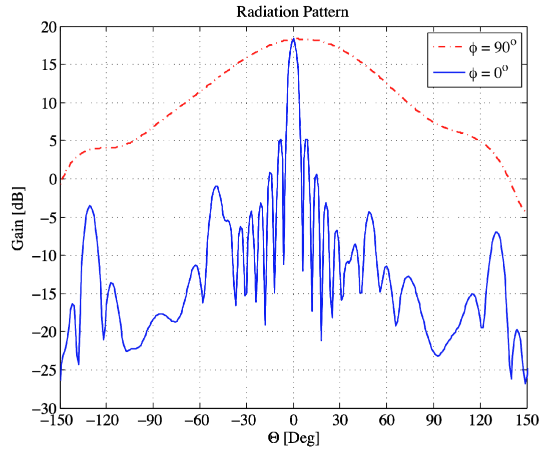

Figure 4: 15-elements compound slot array, radiation pattern

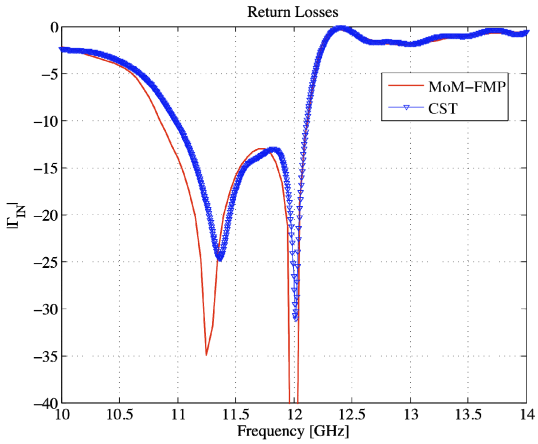

Figure 5: 10-elements compound slot array, return losses

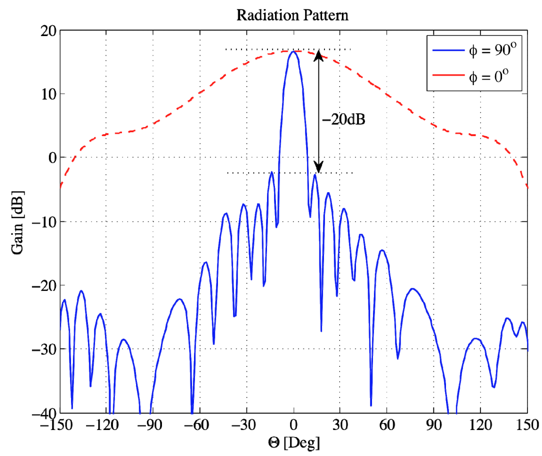

Figure 6: 10-elements longitudinal slot array, radiation pattern