
PROJECT TITLE:

DESIGN METHOD FOR LEAKY-WAVE BASED NEAR-FIELD FOCUSING SYSTEMS

Scientific Report on the Research Activity within the framework

of the ESF program entitled "New Frontiers in Millimetre/Sub-Millimetre

Waves Integrated Dielectric Focusing Systems"

SENDING INSTITUTION:	HOST INSTITUTION:
Dipartimento di Ingegneria dell'Informazione Universita' degli Studi di Siena Via Roma,56 53100, Siena, Italy	Institut d'Electronique et des Télécommunications de Rennes (IETR), UMR CNRS 6164, Université de Rennes 1 35042, RENNES, FRANCE
People Involved: Matteo ALBANI	**People Involved:** Massimiliano CASALETTI Mauro ETTORRE Guido VALERIO Ronan SAULEAU

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1. INTRODUCTION AND MOTIVATIONS

In antenna applications leaky-wave modes and synthesis techniques have been extensively used for focusing the radiation pattern in far-field zone. However, in several applications such as near-field probing and radiometry, medical imaging, etc. [1]-[3], it is important to focus the energy in the near-field or Fresnel zone of an antenna. The basic theory for focusing in the Fresnel zone of antenna can be found in [4]-[6]. In brief, in the focal plane near the axis of a focused aperture, the field will have all the properties of the far field radiation if a quadratic phase taper is adjusted on the aperture of the antenna. This is strictly valid as along as the focal plane is placed at distance larger than one aperture size. However, no consideration can be made on aperture efficiency, size, pattern shaping, losses, etc.
Recently, a new algorithm has been proposed for the design of efficient tapered leaky-wave antennas [7]. The algorithm deals with a special kind of leaky-wave antennas, namely radial line slot arrays (RLSAs). In this project, the procedure has been extended for shaping the near field of RLSAs. The proposed approach extends and overcomes the limit of standard approaches based on the seminal works in [4]-[6].

2. PROBLEM STATEMENT AND METHOD

The design methodology we propose here for near field focusing systems is divided in two main steps: (1) derivation of the aperture field generating the required focal pattern in a 2D or 3D domain; (2) automatic design of the near-field focusing system based on RLSAs.
In the first step, the required pattern or field distribution is provided based on the particular application or needs. In particular, as test case, we will consider the possibility to control the side lobe level of focused beams within the near field of the structure as in [1]. A priori, such pattern may also not be a physical solution of the problem at hand. The goal of any synthesis procedure is to derive the aperture field distribution that generates the required patterns. Here we propose a new technique for shaping the near field of a focusing aperture based on a set theoretical approach and alternate projection method [7]. In these approaches, each requirement or relevant information (fabrication tolerances, synthesis error, etc.) is expressed as a set of constraints for the possible solution. The solution of the problem will belong to the intersection of all these set of constraints or will the closest one, according to a provided measure criterion. The alternate projection method is an iterative procedure used to find the solution of the problem. In details, the required near field is defined along a focusing plane in front of the aperture in terms of the desired axial pattern around the focal point and/or transverse plane patterns. In addition, several constraints may be provided at different planes for 3D field shaping. Circularly- and linearly-polarized fields are considered. Once the required near field pattern is defined, the aperture field distribution is found thanks to a combination of the alternate projection method and a Fast Fourier Transform (FFT) algorithm. The FFT algorithm is used to evaluate the field at the focusing and aperture plans avoiding unnecessary approximations of previous works. At each iteration, the squared error of the derived field distribution with respect to the needed one within the focusing domain is evaluated and used to modify the aperture distribution for the next step. The procedure is stopped after a predetermined number of iteration or when an acceptable approximation to the desired distribution is achieved [S2].
In the second step and as difference with previous works [4], the optimization tool is linked to in-house Method of Moment (MoM) to derive the antenna structure having the required aperture profile [8], [S1]. The required aperture field is achieved by properly designing the

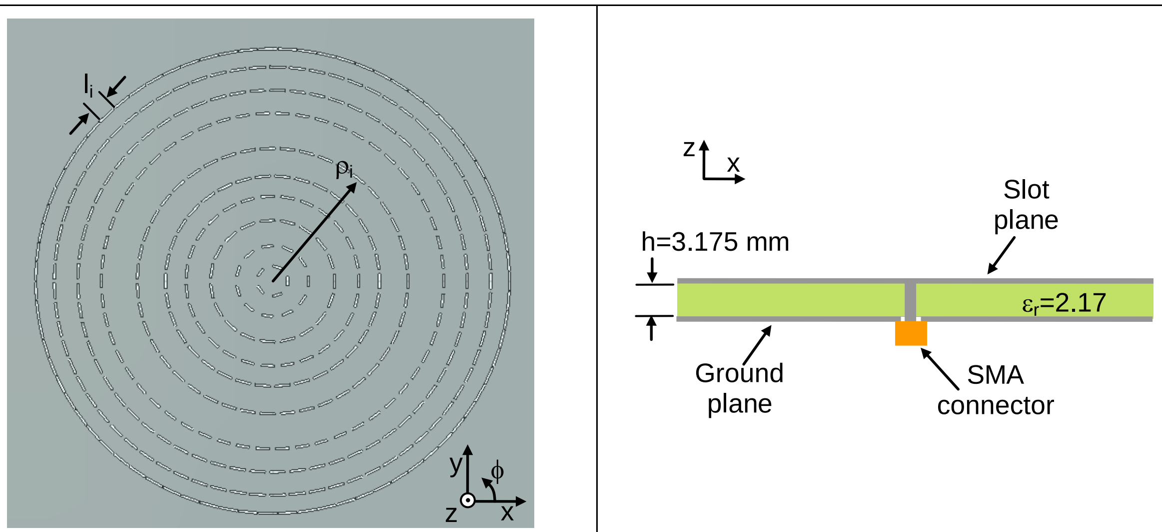
slot dimensions and locations across the radiating aperture. This avoids the use of cumbersome and lossy beam forming networks as in previous designs [1].

3. NUMERICAL RESULTS

The test case considered in the present project considers the possibility to control the side lobe level of a focusing antenna within its near field [1]. In particular we have focused our attention on the normal component of the electric field (E_z as in [2], [3], see Figure 1). The operating frequency is chosen equal to $f_0 = 12.5 GHz$ and the focusing plane is fixed at 6.25 λ_0 (λ_0 is the wavelength in free space at f_0). Several constraints have been imposed on the aperture field and antenna:

1. Aperture size<6x6 λ_0^2;
2. Side lobe level (SLL) at the focusing plane < -13.5 dB for E_z.
3. Half power beamwidth (HPBW)< 20 mm for E_z.
4. Radiation efficiency >90%

The procedure outlined in Section 2 has been adopted to design the RLSA structure. A Neltec substrate NY9217 with thickness h=3.175 mm and relative permittivity ε_r=2.17 has been considered as supporting material. The final antenna structure and relative dimensions are provided in Figure 1 and Table 1, respectively. The RLSA antenna is made by 10 rings of slots. The slots are oriented along the ϕ-direction. The slots on each ring present the same length. The width of the slots is fixed to λ_0/20.



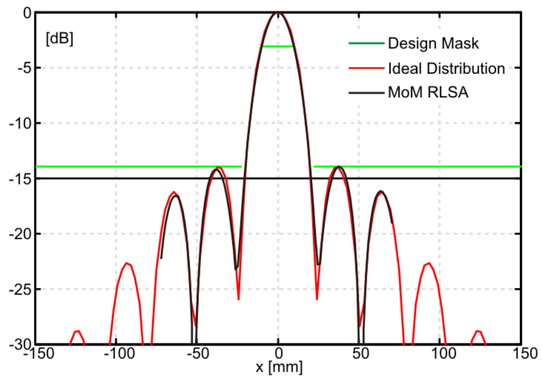
(a) (b)

Figure 1: RLSA structure. (a) Top view. (b) Lateral view.

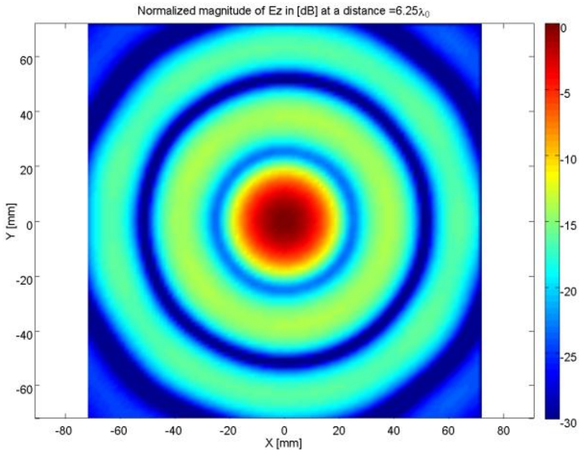
Ring	1	2	3	4	5	6	7	8	9	10
ρ_i [mm]	8.15	19.54	33.61	47.13	58.38	78.80	93.57	106.16	119.05	129.20
l_i [mm]	5.23	5.9	8.08	7.35	8.3	7.89	7.28	8.33	8.68	10.19

Table 1: Geometrical values for the RLSA structure.

The near-field of the RLSA is provided in Figure 2 (a). In green, the required masks with the limits imposed on the SLL and HPBW of the E_z component. As comparison, in red, it is shown the E_z component radiated by the ideal aperture distribution derived at the step 1 of our procedure (please refer to Section 2). It is clear from this figure that the designed RLSA satisfies the imposed constraints on the near-field pattern in terms of SLL and HPBW and agrees with the ideal pattern derived by our optimization procedure. In addition, in Figure 2 (b) shows the 2D-field plot in the xy-plane at the focal plane z=6.25 λ_0 for the normal component E_z. The focusing behaviour of the RLSA structure can be better appreciated. It is worth noting that all the fields shown in this section have been derived with our in-house MoM [8]. Commercial simulators can not be employed during the design process due to their long computational time. Besides, even an analysis a posteriori of the structure may be prohibitive.



(a)



(b)

Figure 2: Radiated patterns for the RLSA structure at the focal plane z= 6.25 λ_0. (a) E_z component in xz-plane. (b) 2D-view in xy-plane.

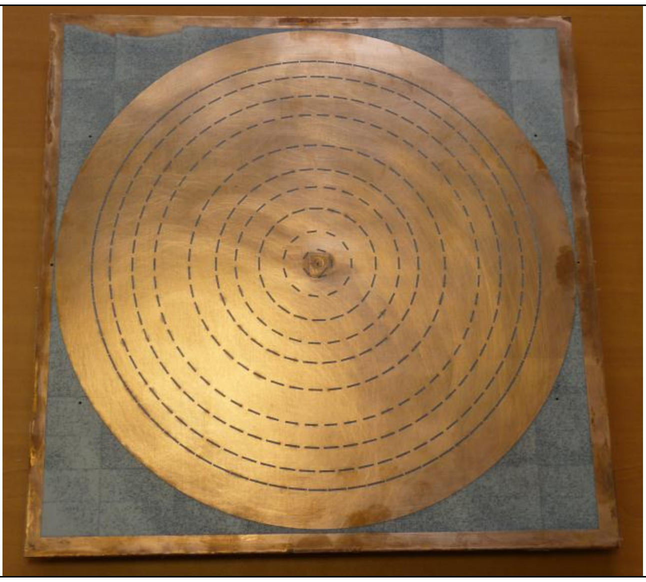


Figure 3: Prototype of the RLSA antenna designed during the project.

Finally, the test case considered in this section has been manufactured at IETR. The prototype is shown in Figure 3. Measurements results will be available in the coming months to further validate and enhance the impact of the present work.

4. CONCLUSIONS

During this project we have developed a new design tool for near-field focusing devices. This tool overcomes the previous limits on the design techniques for near-field focusing systems. The tool is based on an optimization techniques based on a projection alternate method coupled with an in-house MoM able to efficiently analysis RLSA structure.

The activity of the project has already provided 1 submitted paper in the 2013 IEEE Transaction on Antennas and Propagation [S1] and 1 communication at the IEEE International Symposium on Antennas and Propagation Symposium, held in Orlando, Florida, USA. Besides, at least 2 more publications are envisaged from the present works. In all these works the ESF program "New Frontiers in Millimetre/Sub-Millimetre Waves Integrated Dielectric Focusing Systems" is and will be acknowledged for the received financial support.

5. REFERENCES

[1] K. D. Stephan, J. B. Mead, D. M. Pozar, L. Wang, and J. A. PearceJ, "A Near Field Focused Microstrip Array for a Radiometric Temperature Sensor," *IEEE Trans. Antennas Propag.*, vol. 55, no. 4, pp. 1199-1203, Apr. 2007.

[2] M. Ettorre and A. Grbic, "Generation of Propagating Bessel Beams Using Leaky-Wave Modes," *IEEE Trans. Antennas Propag.*, vol. 60, no. 8, pp. 3605-3613, Aug. 2012.

[3] M. Ettorre, S. M. Rudolph, and A. Grbic, "Generation of Propagating Bessel Beams Using Leaky-Wave Modes: Experimental Validation," *IEEE Trans. Antennas Propag.*, vol. 60, no. 6, pp. 2645-2653, June 2012.

[4] J. W. Sherman., "Properties of focused apertures in the Fresnel region," IRE Trans. Antennas Propag., 1962, 10, pp. 399-408.

[5] W. J. Graham, "Analysis and synthesis of axial field pattern of focused apertures," IEEE Trans. Antennas Propag., vol. 31, no. 4, pp. 665–668, Jul. 1983.

[6] R. C. Hansen, "Focal region characteristics of focused array antennas," IEEE Trans. Antennas Propag., vol. 33, no. 12, pp. 1328–1337, Dec. 1985.

[7] M. Albani, A. Mazzinghi, and A. Freni, "Automatic Design of CP-RLSA Antennas," *IEEE Trans. Antennas Propag*., vol. 60, no. 12, pp. 5538 - 5547, Dec. 2012.

[8] M. Casaletti, R. Sauleau, M. Ettorre, S. Maci, "Efficient analysis of metallic and dielectric posts in parallel plate waveguide structures," *IEEE Trans. Microw. Theory Tech.,* vol. 60, no. 10, pp. 2979–2989, Oct. 2012.

6. SUMITTED PAPERS & CONFERENCE COMMUNICATIONS

The present project has already provided common publications of the team members. In addition at least 2 more publications are expected from the experimental results of the built prototype.

[S1] G. Valerio, M. Casaletti, J. Seljan, R. Sauleau, and M. Albani, "Efficient computation of the coupling between a vertical source and a slot," submitted to IEEE Trans. Antennas Propag.

[S2] M. Albani, M. Casaletti, M. Ettorre, G. Valerio, J. Seljan, and R. Sauleau "A new synthesis technique for near-field focusing systems," accepted at 2013 IEEE International Symposium on Antennas and Propagation 2013, Orlando, FL, USA.