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Automatically Optimized Near-Field Focusing Radial Line Slot Array

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***Abstract*—We present an automatically optimized near-field focusing radial line slot array (RLSA) antenna. The side lobe level and beamwidth of the normal component of the radiated electric field are controlled during the design process. A set theoretic approach is used to derive the RLSA aperture field distribution generating the required near field over a focusing plane at a given distance from the radiating aperture. The position and size of the slots of the RLSA antenna are automatically controlled to synthesize the derived aperture field distribution. The design approach is validated by measurements at 12.5 GHz.**

I. Introduction

RLSA antennas are well-known antenna solutions for far-field applications. Their main features are high efficiency, planarity, and compactness [1]-[3]. The possibility to automatically design and optimize such antennas has recently provided new directions for performance enhancement [3]. The efficiency, simplicity and automatic design of RLSA structures make such antennas extremely attractive for near field applications as near-field probing, radiometry, non-invasive medical imaging, etc. [4]-[6].

Here we propose the design of a RLSA antenna focusing the normal component of the electric field in the near field with reduced side lobe levels and defined beamwidth. The design methodology is divided in two main steps. In the first step, the required near-field pattern is defined over a certain plane parallel to the RLSA aperture. The aperture field distribution generating such near-field pattern is then derived based on a set theoretic approach and alternate projection method [7]. In the second step, the derived aperture distribution is synthesized on the RLSA aperture by properly tuning the positions and sizes of the slots of the RLSA. The automatic design procedure proposed in [3] is extended to the near field and linked to an in-house Method of Moment (MoM) [8] to speed up the computational time and optimization process.

II. Design procedure

The geometry of the problem is shown in Fig. 1. An aperture of size S_A is located at $z = 0$ and is radiating in free space. The required pattern is defined over a focusing plane (S_F) located at a distance $z = h$ and parallel to the radiating aperture. Transverse magnetic (TM) modes with respect to the z-direction and with ϕ invariance are considered. In the present case, the requirements on the near field are expressed on the normal component of the electric field (E_z) in the focusing plane (S_F) providing a mask for the near field as:

$$\text{Mask} = \begin{cases} \frac{|E_z(x,y,h)|}{\max(|E_z(x,y,h)|)} > c_1 & \text{in } A_1, \\ \frac{|E_z(x,y,h)|}{\max(|E_z(x,y,h)|)} < c_2 & \text{in } A_2, \end{cases} \quad (1)$$

where $0 < c_2 < c_1 < 1$ are fixed limits for the normalized module of E_z in some space domains A_1 and A_2 over the focusing plane, respectively and $\max(|E_z|)$ indicates the maximum value of the z-component of the electric field. A set theoretic approach and alternate projection method [7] are then used to derive the aperture field distribution that generates the required pattern. A Fast Fourier Transform (FFT) algorithm is adopted to evaluate the fields at the focusing (S_F) and aperture plane (S_A). In addition, at each step (n) of the iterative procedure only the module of the electric field is modified for the next step ($n+1$) accordingly to the defined mask as:

$$|E_z^{(n+1)}(x,y,h)| = \begin{cases} \max(|E_z^{(n)}|)c_1 \text{ if } \frac{|E_z^{(n)}|}{\max(|E_z^{(n)}|)} < c_1 \text{ in } A_1, \\ \max(|E_z^{(n)}|)c_2 \text{ if } \frac{|E_z^{(n)}|}{\max(|E_z^{(n)}|)} > c_2 \text{ in } A_2. \end{cases} \quad (2)$$

The procedure is repeated until E_z lays within the imposed requirements in the focusing plane or the error with respect to the defined mask is lower than a certain threshold.

For the second step of the design procedure, the tangential aperture field distribution is required to synthesize the RLSA structure. This distribution is evaluated from the normal component of the electric field following similar steps of those proposed in [6]. The position and size of the slots of the RLSA antenna are then automatically optimized by using an automatic design procedure as in [3].

III. Prototype and Experimental Results

A RLSA antenna has been designed with a shaped z-component of the electric field (E_z). The operating frequency is equal to $f_0 = 12.5$ GHz. The focusing plane is placed at a distance equal to half the antenna size ($h = 150$ mm). The following mask is imposed on the normalized E_z profile over the focusing plane:

$$\text{Mask} = \begin{cases} \frac{|E_z|}{\max(|E_z|)} > -3 \text{ dB} & \text{for } \rho < 10 \text{ mm}, \\ \frac{|E_z|}{\max(|E_z|)} < -14 \text{ dB} & \text{for } \rho > 20 \text{ mm}. \end{cases} \quad (3)$$

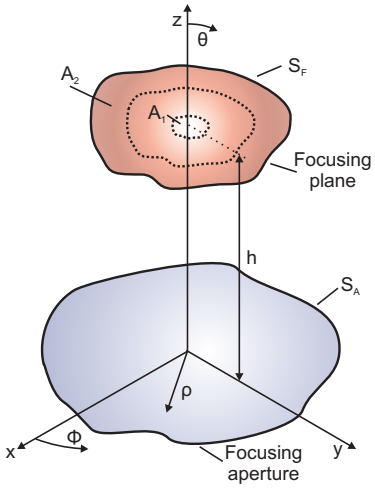


Fig. 1. Geometry of the problem with two generic surfaces defined on two parallel planes orthogonal to the z-axis. The focusing aperture S_A is located at $z = 0$. The focusing plane S_F is at $z = h$.

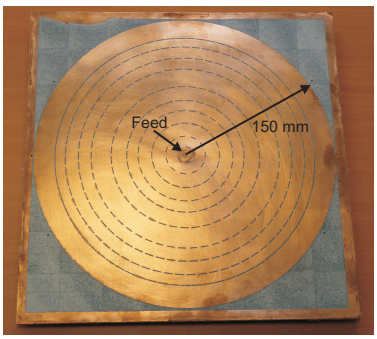


Fig. 2. Final prototype. The slots have been etched by laser ablation.

A prototype has been manufactured and tested at IETR and is shown in Fig. 2. The slots of the RLSA are etched on the upper face of a double grounded Neltec NY9217 substrate with permittivity 2.17 and height 3.175 mm. The prototype is centrally fed by a coaxial probe attached on the back side of the prototype to a SMA connector.

The E_z component of the electric field was measured above the prototype using a short electric probe attached to an automatically controlled 2D translation stage. The normalized E_z component at the operating frequency f_0 along the x- and y-axis is shown in Fig. 3 (a) and (b), respectively. 2D plots of the fields are also provided in Fig. 3 (c) and (d). Good agreement is achieved between the measured and simulated results [8]. A good circular symmetry of the pattern can be also appreciated.

IV. Conclusion

The design and measurement results for a RLSA antenna focusing in the near field have been presented. The possibility to control the side lobe level and beamwidth of the vertical component of the electric field has been considered. The RLSA structure is automatically generated by a novel

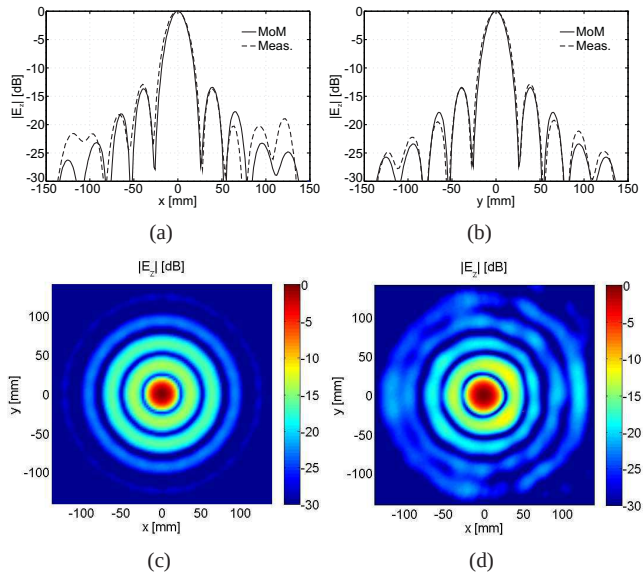


Fig. 3. Normalized E_z component of the electric field at f_0 on the focusing plane. (a) Comparison between measured and MoM results along the x-axis. (b) Comparison between measured and MoM results along the y-axis. (c) 2D MoM electric field plot. (d) 2D measured electric field plot.

design procedure using as inputs the requirements on the near field. 2D measurements validated the proposed approach and realized prototype. The proposed structure and design technique may find application in areas such as radiometry, wireless power transfer, and medical imaging.

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