

NEAR-FIELD FOCUSING IN ONE PLANE USING A LOADED SECTORAL HORN ANTENNA

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Abstract—A near-field focused antenna used as a feed for linear array is presented in this paper. This antenna is an H -plane sectoral horn with a biconvex dielectric lens placed in its aperture. This antenna focuses the beam in one plane (H -plane) to illuminate a linear array with a small width and provide a large aperture on the other plan to illuminate the length of the array. The simulated field distribution on the array is found to be in good agreement with the measurement of a prototype at 9.41 GHz.

1. INTRODUCTION

Today, near-field focusing is a well-known technique used for several applications such as imagery sensing, characterization of materials or in biomedical devices.

The design of a near-field focused antenna is based on the adjustment of the phase of the field along the aperture of the antenna in order to obtain a locally plane wave-front at a focal point. Considering the field generated by the antenna as a Gaussian beam, it is possible to evaluate the width of the focus beam, i.e., the beam waist.

Many systems enable beam focusing in near-field region. It can be obtained using a planar patch array [1, 2], a slotted rectangular waveguide [3], a horn with metal plate lens [4, 5] or with a dielectric

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lens. In the latest case, the dielectric lens can be placed in front of the horn [6] or inserted in the horn aperture [7, 8].

All these near-field focused antennas generate a 2 dimensions spot. In [9], authors use a sectoral horn with a dielectric lens in its aperture but to adjust the beam properties in the far-field region. However, a near-field focusing antenna with a focused beam in one plane and a broad beam in the orthogonal plane can be interesting in several applications. Such as optic for testing long material with a low width or for microwave applications as a feeding system for a linear reflector or transmit-array antenna.

This paper presents an H -plane sectoral horn antenna loaded by a dielectric lens dedicated to the illumination of an array with a length of 320 mm and a width of 58 mm, located in the near-field region of the feed. This structure focuses the E -field along one plane in order to illuminate the width of the array and provides a broad beam along the orthogonal plane to illuminate the length of the array. This antenna has been simulated and measured at 9.41 GHz and has been developed as a part of the development of an innovative navigation radar.

This paper is organized as follows. In the first part, we carry out the theory of the near-field focusing technique. In the second part, we present the results of an optimization of the sectoral horn loaded by a dielectric lens with HFSS. Finally, these theoretical results have been compared with the measurement.

2. THEORY

2.1. Estimation of the Lens Shape

To introduce the near-field focusing theory, an aperture (A) of length L is considered as depicted in Figure 1. The electrical field $\vec{E}_{AP}(x, z)$ is linearly polarized where x and z are the coordinates of the aperture.

$$\vec{E}_{AP}(x, z) = E_0(x, z) \cdot e^{-j\varphi(x, z)} \vec{x} \quad (1)$$

The electrical field radiated by the distribution (1) is expressed as follow [10]:

$$\vec{E}(P) = \frac{1}{4\pi} \iint_{(A)} \vec{E}_{AP}(M) \cdot \frac{e^{-jkr}}{r} \cdot \left[\left(jk + \frac{1}{r} \right) \vec{i} \cdot \vec{r} + jk \vec{i} \cdot \vec{s} \right] dx dz \quad (2)$$

where:

M a source point located on the aperture (A),

P is the observation point,

r is the distance from the source point M to the observation point,

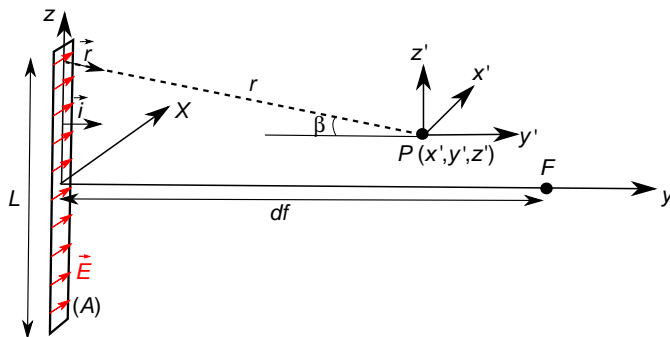


Figure 1. Parameters for the calculation of phase in the aperture for near-field focusing.

$$P: r = \|\vec{r}\| = \|\overrightarrow{MP}\|,$$

k is the free space constant, $k = 2\pi/\lambda_0$,

\vec{i} is the unit vector in the y direction,

\vec{s} is the unit vector in the y direction,

β is the angle between the beam radiated by each source and the y axis,

when $r \gg \lambda$, $\vec{i} \cdot \vec{r} = \cos \theta$ and $\vec{i} \cdot \vec{s} = 1$, then Equation (2) can be simplified as follow

$$\vec{E}(P) = \iint_{(A)} K \cdot \vec{E}_{AP}(M) \cdot \frac{e^{-jkr}}{r} dx dz \quad (3)$$

where K is a constant equal to

$$K = \frac{jk(\cos \beta + 1)}{4\pi}$$

At a focal point $F(0, d_f, 0)$, the phase of the field generated by each source is equal to

$$\varphi = \varphi(\beta) + kr = \varphi(\beta) + k \cdot \frac{d_f}{\cos(\beta)} \sqrt{\left(1 + \frac{x^2 \cos^2(\beta)}{d_f^2}\right)} \quad (4)$$

As $x \ll d_f$

$$\varphi \approx \varphi(\beta) + k \cdot \frac{d_f}{\cos(\beta)}$$

At the focal point, the phase φ of the field radiated by each source located on the aperture must be constant.

$$\varphi(\beta) + k \cdot \frac{d_f}{\cos(\beta)} = C$$

where C is a constant. If we consider as a reference the phase of the field radiated from the source located at $z = L/2$, we obtain

$$C = \frac{d_f}{\cos(\beta_{\max})}$$

So, in order to focus the beam at a focal distance d_f , the variation of phase along the aperture, must be:

$$\varphi(\beta) = k \cdot d_f \left(\frac{1}{\cos(\beta_{\max})} - \frac{1}{\cos(\beta)} \right) \quad (5)$$

Such a phase variation can be synthesized combining a horn antenna and a dielectric lens. Indeed, by adjusting the thickness and the permittivity of the lens, the variation of phase given by Equation (5) can be obtained.

The determination of the lens shape is based on an optical analogy of the whole problem:

- The field illuminating the lens face inside the horn is considered to be generated by a source point S .
- The free space propagation model is considered on both side of the lens.
- No reflection and no refraction occur on the surface of the lens. It is obvious that such a simplification of the problem induces errors on the lens geometry determination.

The horn has a length of 281 mm. The aperture of the sectoral horn is equal to 325 mm in the H -plane and 55 mm in the E -plane (Figure 2).

The calculation of the lens shape is based on the lens topology reported in Figure 3. The source point S is placed at the excitation point of the horn antenna. The aperture length of the horn is called L and the desired focal point is called F . The calculation of the lens is divided in two parts:

- The first convex part of the lens is designed to obtain a plane wave on the plane corresponding to the horn aperture.
- The second convex part of the lens provides the appropriate phase distribution to focus the beam at the desired distance.

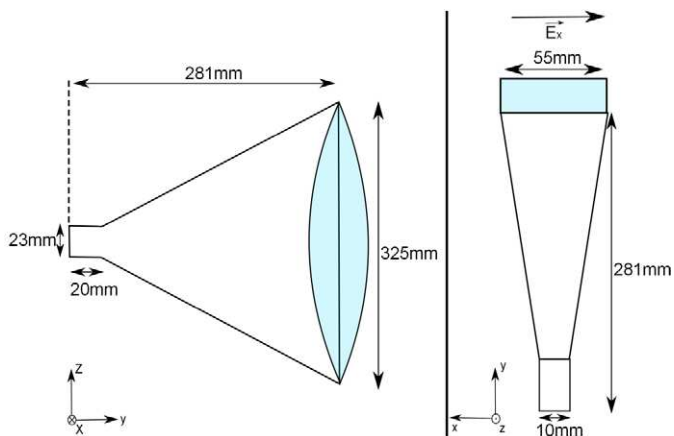


Figure 2. Geometry of the *H*-plane sectoral horn.

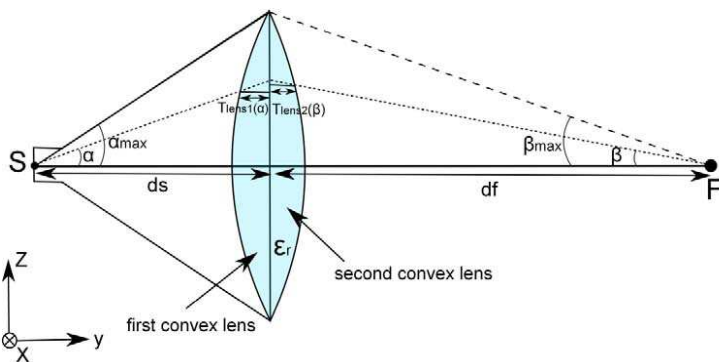


Figure 3. Parameters for the calculation of the lens shape.

The thickness versus α of the first convex part (Figure 3) of the lens has been calculated as follow:

$$T_{lens1}(\alpha) = \frac{d_s \cdot \cos(\alpha)}{\sqrt{\epsilon_r} - 1} \left(\frac{1}{\cos(\alpha_{max})} - \frac{1}{\cos(\alpha)} \right) \quad (6)$$

The thickness versus β of the second convex part (Figure 3) of the lens has been calculated as follow:

$$T_{lens2}(\beta) = \frac{d_f \cdot \cos(\beta)}{\sqrt{\epsilon_r} - 1} \left(\frac{1}{\cos(\beta_{max})} - \frac{1}{\cos(\beta)} \right) \quad (7)$$

The shape of the lens is determined for a focal distance $d_f = 350$ mm. The horn has a length $d_s = 281$ mm and an aperture $L = 325$ mm.

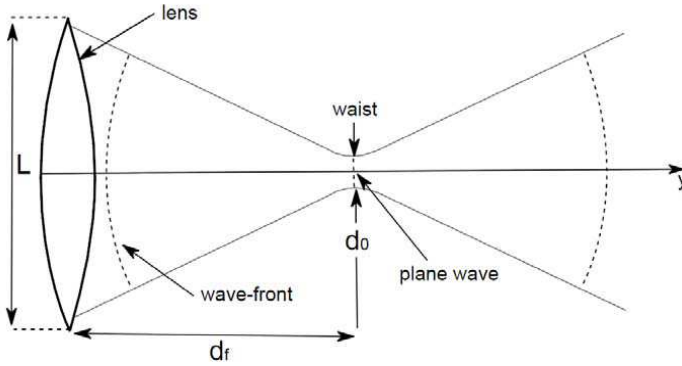


Figure 4. Properties of Gaussian beam near the focal.

And the lens has a permittivity $\varepsilon_r = 4$. Thus, the first convex lens has a thickness for $\alpha = 0$ equals to $T_{lens1}(0) = 43.6$ mm. The second convex lens has a thickness for $\beta = 0$ equals to $T_{lens2}(0) = 35.9$ mm.

2.2. Estimation of the Focus Width

If we consider that the distribution of the field at the output of the lens is closed to a Gaussian beam, its width near the focal point can be determined [10]. This width, called “waist” corresponds to the beamwidth at $20 \cdot \log_{10}(1/e) = -8.7$ dB.

As explained in introduction, the point where the beam width is minimal corresponds to the point where the wave-front is plane (Figure 4).

The waist can be calculated as follow [11]:

$$d_0 \approx \frac{2d_f \lambda}{L}$$

In our case, for a focal distance equals to 350 mm, the focus width is equal to $d_0 \approx 68.7$ mm.

3. SIMULATION AND MEASUREMENT RESULTS

3.1. Simulation Results

The lens dimensions determined analytically in the previous section have been optimized using HFSS. The optimization goal deals with a beam focusing constraint at a distance of 350 mm from the horn aperture.

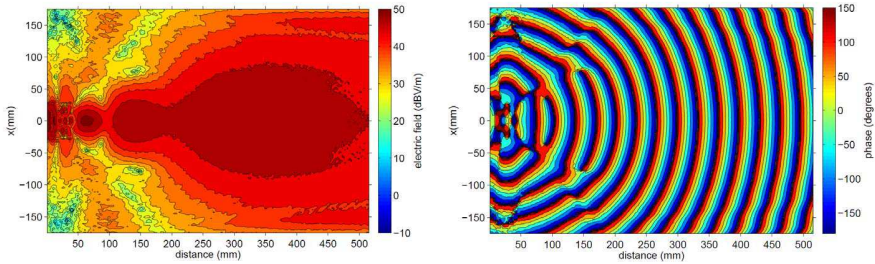


Figure 5. Electric field E_x in amplitude and phase in E -plane.

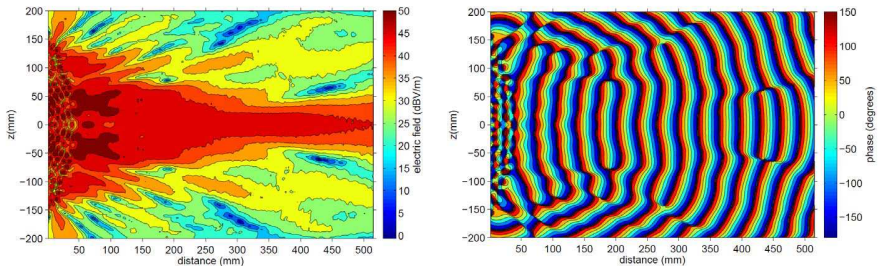


Figure 6. Electric field E_x in amplitude and phase in H -plane.

The optimal thicknesses of the lens obtained are $T_{lens1}(0) = 36$ mm for the first convex lens and $T_{lens2}(0) = 40$ mm for the second convex lens. In the simulation, the lens is positioned in the aperture of the horn and reflection and diffraction effects are taken into account. It explains the differences of thicknesses between theory and simulation.

Figures 5 and 6 show the E_x -field in the E and H planes in both magnitude and phase at 9.41 GHz. We notice that in the E -plane the field is not focused, because the lens has no impact on the phase propagation behavior. As expected in the H -plane, the field is focused with a focal point located at 350 mm from the aperture of the horn. Moreover, at the focal point, the wavefront is locally plane (Figure 6). Simulation results are compliant with the theoretical model used for the calculation, which validate the design process.

3.2. Measurement Results

A prototype of this antenna has been manufactured as depicted in Figure 7. This antenna has been measured at 9.41 GHz and the E -field has been evaluated at 350 mm from the horn.

Figure 8 shows the mapping of the E_x -field in simulation and in

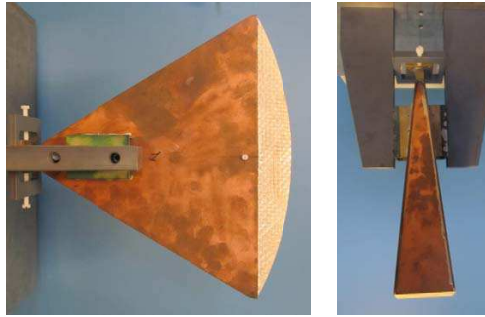


Figure 7. The proposed horn antenna with dielectric lens.

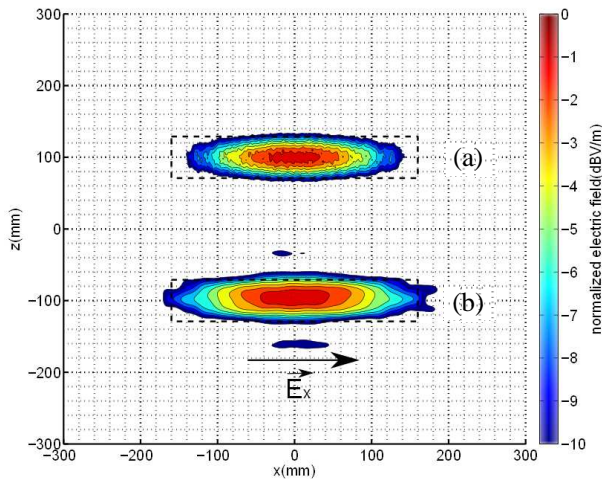


Figure 8. (a) Simulated and (b) measured mapping of the normalized E_x -field at 350 mm from the horn at 9.41 GHz.

measurement with in dashed line the contour of the desired -10 dB area. Small discrepancies are noticed between the theoretical and the measured mapping of the E_x -field. The simulated field magnitude on the edge of the contour equals to -7.6 dB in the H -plane and -11.2 dB in the E -plane. In measurement, these values are different (-4.6 dB in the H -plane and -7.7 dB in the E -plane). These differences are partly due to a slight tilt of the beam. This tilt (5 mm in the H -plane and 2 mm in the E -plane) can be explained by a slightly misalignment of the antenna in the measurement setup. By correcting this tilt, the field magnitude on the edge would be equal to -6 dB in the H -plane and -8 dB in the E -plane.

Table 1. Value of the waist at 350 mm from the horn in theory, in simulation and in measurement.

	Theory	Simulation	Measurement
Value of the waist	68.7 mm	60 mm	66 mm

Concerning the waist, the Table 1 provides the comparison for the values obtained in the theory, in the simulation and in the measurement. These results are in good agreement.

4. CONCLUSION

A near-field focused antenna providing a one dimension focused beam has been investigated. A theoretical approach enables to determine, in a simple way, the lens shape used to focus the beam. The final structure, i.e., an H -plane sectoral horn with a dielectric biconvex lens placed on its aperture, has been optimized using full wave EM software. The simulation and the measurement are in a very good agreement. As shown, this near-field focused antenna can be used as a feed for a linear array with a ratio length/width equal to 5.5. The focal point is located at 350 mm from the horn aperture with a waist equals to 66 mm.

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