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A Dual Polarized Near-Field Focusing Plate at Microwave Frequencies Providing Sub-Wavelength Focusing in Two Dimensions

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Abstract—**In this work we introduce a novel near-field focusing plate able to provide sub-wavelength focusing in both directions, parallel to the plate, as well as for both polarizations of the illuminating plane wave at microwave frequencies. Two similar designs are proposed: the first one is made of a thick metallic plate, whereas the second one is made of a thin copper plate fabricated on top of a Rogers 5880 dielectric substrate. The focusing behavior of these structures is analyzed with Ansys HFSS and CST Microwave Studio full-wave simulators.**

Keywords-near-field focusing plate (NFFP); dual polarized NFFP; near-field microscopy; sub-wavelength structures

I. INTRODUCTION

Sub-wavelength near field focusing plates (NFFPs) have been investigated in previous works for near-field microscopy [1-7]. A patterned plate, consisting of only capacitive elements, has been introduced to achieve focusing beyond the diffraction limit in one direction at 1 GHz, by Grbic et al. in [1]. In [2], the theoretical analysis, the design procedure of grating-like near-field focusing plates and their implementation-details have been discussed at microwave frequencies. In [3], a metal meta-screen made of sub-wavelength spaced slots has been designed with focusing in one direction with size of $0.25\lambda_0$ (for a lens made of three slots) and $0.144\lambda_0$ (for a lens made of nine slots), for a single-polarized field at distance of $0.25\lambda_0$ from the lens, at 10 GHz. A single-polarized NFFP with focusing in two dimensions has been then proposed by Markley et al. in [4], with the asymmetric focusing spot of $0.27\lambda_0 \times 0.38\lambda_0$ at a distance of $0.25\lambda_0$ from the lens, at 10 GHz. In [5], a silver NFFP has been proposed at 360 THz providing a focusing size of $0.22\lambda_0$ (lens made of three slots) and $0.14\lambda_0$ (lens made of nine slots) at a distance of $0.25\lambda_0$ from the plate. A near-field antenna array probe has been discussed in [6], for sub-wavelength focused imaging at a distance of $0.25\lambda_0$ from the lens at 2.4 GHz (providing also measurement results). Most recently, in [7], a coax-fed two-dimensional near-field probe has been proposed at 2.4 GHz; it was able to produce a sub-wavelength focal spot of $0.217\lambda_0$ in two dimensions defining the lens plane at quarter wavelength distance away from the lens. However, the lens in [7] was not a planar device and it has been fed by a coaxial cable and thus it cannot be used at higher frequencies (i.e. optics).

In this work, a new meta-screen dual-polarized near-field focusing plate (DP-NFFP) with focusing in two dimensions is introduced at the operating frequency of 2.4 GHz (notice that this design can be scaled to higher frequencies). A general design is proposed and two possible implementations are here analyzed. The first one is a meta-screen made of a thick brass plate, whereas the second one is a lens made of a very thin copper layer placed on top of a dielectric substrate. The focusing behavior of both structures is simulated by using both Ansys HFSS and CST Microwave Studio. The frequency behavior of the mentioned structures is investigated around the designed operating frequency of 2.4 GHz.

II. PROPOSED DESIGNS

The top view of the layout of the lens is shown in Fig. 1. It presents a central cross hole, and two lateral slots at an angle of 45 degrees with respect to the principal axes of the plate. The two analyzed designs are shown in Figs. 1(a) and (b).

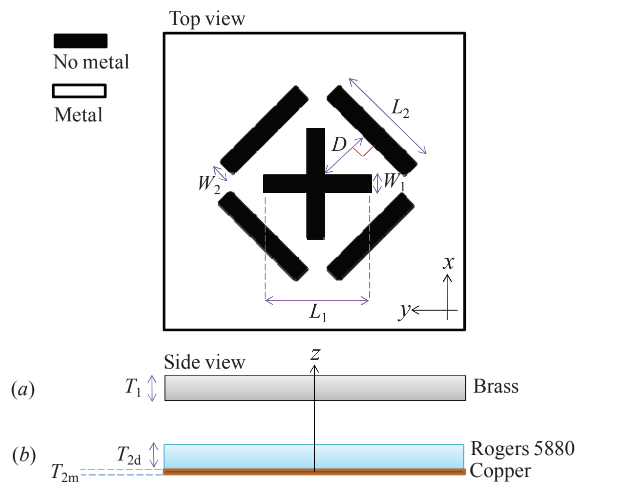

Figure 1. The geometry of the DP-NFFP with the main dimensions, (a) made of a brass plate, (b) made of a thin layer of copper on a dielectric susbstrate.

A. Design #1: thick metallic plate

The design proposed in Fig. 1(a) is made of a thick metallic plate made of brass. The dimensions are shown in Table I.

For mechanical stability the thickness of the plate is selected to be 2 mm (i.e., to avoid bending and other distortions to the plate), and $D = 2.3$ cm. However, it should be mentioned that by selecting smaller values for D, the focusing behavior of the lens can be further improved as will be shown for the second structure.

TABLE I. DIMENSION OF DESIGN #1

Dimension for Design #1	
L_1	5.925 cm
L_2	4.825 cm
W_1	5 mm
W_2	5 mm
D	2.3 cm
T_1	2 mm

B. Design #2: thin metallic plate with substrate

The design proposed in Fig. 1(b) is made of a thin layer of copper on a Rogers duroid 5880 substrate, whose permittivity and dielectric loss tangent are $\varepsilon_r = 2.2$ and $\tan\delta = 0.0009$, respectively. The substrate and copper thicknesses are selected equal to standard values $T_{2d} = 1.575$ mm and $T_{2m} = 35$ µm, respectively. The design dimensions of this structure are shown in Table II. With respect to the design shown in Fig. 1(a), the metallic plate is supported by the thick dielectric substrate. Therefore, the thickness limitation discussed in Sec. II-*A* is not critical in the mechanical stability of the plate.

TABLE II. DIMENSION OF DESIGN #2

Dimension for Design #1	
L_1	5.22 cm
L_2	4.1 cm
W_1	5 mm
W_2	5 mm
D	2.1 cm
T_{2d}	1.575 mm
T_{2m}	35 µm

III. FIGURES OF MERIT

In this section, we define two parameters that will be used to evaluate the performances of the focusing behavior of each designed lens.

A. Field transfer ratio F

By field transfer ratio F we refer to the amount of field that is transferred from one side of the plate to the other side (focusing side). Assuming that the lens is illuminated by a plane wave with the electric field polarized in either the x or y direction with magnitude E_0, and that E_T is the peak of the focused field, as shown in Fig. 2, right under the center of the NFFP, F is defined as

$$F = \frac{E_T}{E_0}. \tag{1}$$

B. Full width half maximum FWHM

The full width half maximum refers to the width of the focused intensity spot, i.e., it is defined as the difference of the two scanning distances in x and y directions when the focused field intensity (i.e. $|E_x|^2$ or $|E_y|^2$, where E_x or E_y is the field concentration due to the x- or y-polarized field illumination, respectively, in x and y directions) drops to half of the maximum value E_T, according to Fig. 2. Since it cannot be stated a priori that the *FWHM* will be the same for both x and y directions, then we define

$$FWHM_x = \left(\frac{x_2 - x_1}{\lambda_0}\right)\lambda_0 \quad , \quad FWHM_y = \left(\frac{y_2 - y_1}{\lambda_0}\right)\lambda_0, \tag{2}$$

for x and y direction, respectively.

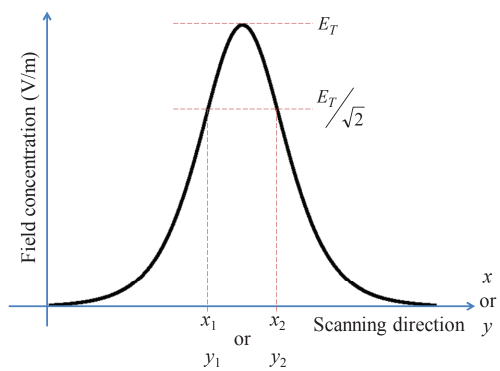

Figure 2. Example of focused field by a lensing device.

IV. FOCUSING BEHAVIOR OF THE PROPOSED DESIGNS

In this part, the focusing behavior of the proposed structures will be simulated by two full-wave simulators, Ansys HFSS and CST Microwave Studio at a fixed distance of $0.25\lambda_0$ from the plates. In the following sections, the normalized concentrated field intensity values are compared on both x- and y-directions due to an x-polarized plane-wave illumination on both mentioned structures. Because of symmetry, analogous results are obtained for a y-polarized plane-wave illumination.

A. Thick metallic plate

The focusing behavior of the structure shown in Fig. 1(a) is presented in Fig. 3. The results obtained by HFSS and CST are in good agreement. The *FWHM* values of the concentrated field intensity on both x- and y-axis are observed to be $0.206\lambda_0$

and $0.274\lambda_0$, respectively; also, the field transfer ratio F is observed to be 52%.

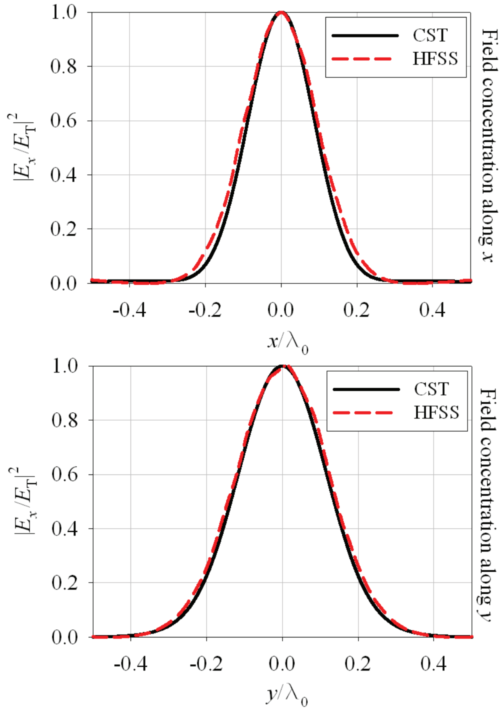

Figure 3. Normalized concentrated field intensity for the design #1, due to an x-polarized plane-wave illumination, at a quarter wavelength distance from the plate, at 2.4 GHz, on both x- and y-axis.

B. *Thin metallic plate with substrate*

The focusing behavior of the design shown in Fig. 1(b) is presented in Fig. 4. Again, the full-wave simulation results are in good agreement, and the *FWHM* values of the concentrated field at the mentioned distance on both x- and y-axis are observed to be $0.188\lambda_0$ and $0.247\lambda_0$, respectively; the field transfer ratio F is 37.2%.

C. *Summary of the results*

The comparisons between the focusing behavior of the two mentioned designs (#1 and #2), are shown in Table III. It can be seen that the design #2 shows a better focusing in both directions. However, the field transfer ratio of the design #1 is larger than the one for the design #2. An optimum design of a focusing plate could be based on maximizing F and minimizing *FWHM*. However, a tradeoff is observed between the design values of *FWHM* and F.

TABLE III. COMPARISON BETWEEN THE FOCUSING BEHAVIOR OF DESIGN #1 AND DESIGN #2

Design	***F*(%)**	***FWHM*$_x$ (*x*-pol)**	***FWHM*$_y$ (*x*-pol)**
#1	52	$0.206\ \lambda_0$	$0.274\ \lambda_0$
#2	37.2	$0.188\ \lambda_0$	$0.247\ \lambda_0$

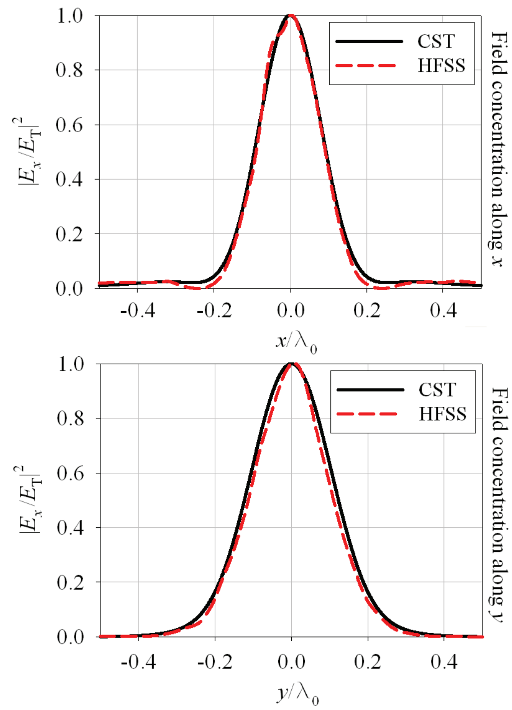

Figure 4. Normalized concentrated field intensity for the design #2, due to an x-polarized plane-wave illumination , at a quarter wavelength distance from the plate, at 2.4 GHz, on both x- and y-axis.

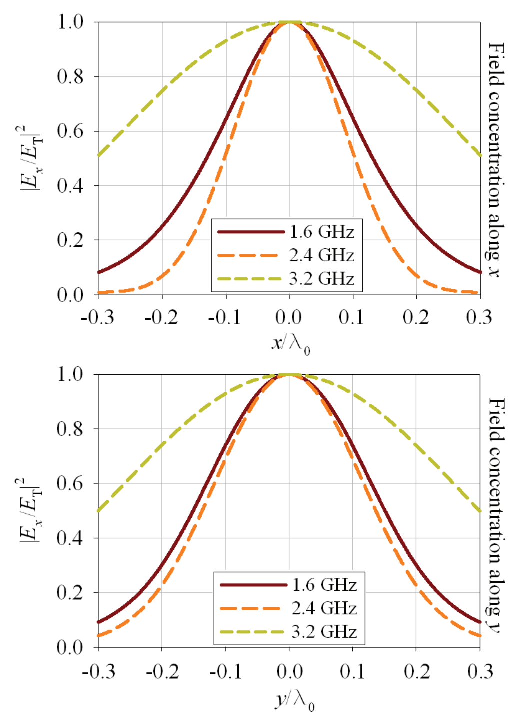

Figure 5. Frequency behavior of the design #1 around its designed operating frequency of 2.4 GHz , on both x- and y-axis, due to an x-polarized plane-wave illumination , at a quarter wavelength (at the central frequency) distance from the plate.

V. FREQUENCY BEHAVIOR OF THE PROPOSED DESIGNS

In this part, the frequency behavior of the proposed structures is investigated around the designed working frequency of 2.4 GHz. The analysis is performed at 1.6 GHz, 2.4 GHz and 3.2 GHz; the focusing behavior of the structure is obtained at the fixed distance of $0.25\lambda_0$ from the lens, where λ_0 is the wavelength at the working frequency of 2.4 GHz.

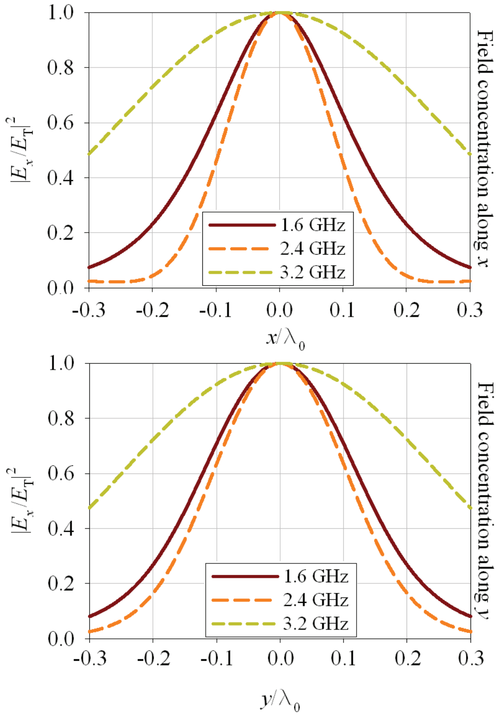

Figure 6. Frequency behavior of the design #2 around its designed operating frequency of 2.4 GHz , on both *x*- and *y*-axis, due to an *x*-polarized plane-wave illumination , at a quarter wavelength (at the central frequency) distance from the plate.

A. *Design #1*

The frequency behavior of the design #1 is shown in Fig. 5. The graphs show that the design has the best focusing at the designed working frequency of 2.4 GHz.

B. *Design #2*

The frequency behavior of the design #2 is shown in Fig. 6. The graph shows again the same conclusions observed for the design #1.

VI. CONCLUSION

A novel dual-polarized near-field focusing plate (DP-NFFP) with focusing in two dimensions has been proposed in this paper for the first time. Two different structures with the same general design have been shown. The focusing behavior of both structures has been simulated with both HFSS and CST and the results are in good agreement. This design can be easily scaled to be used at higher frequencies, i.e., optics, for near-field optical microscopy.

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