Full Wave Analysis of a Planar Reflector Antenna

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Abstract— **The theoretical analysis of a planar reflector antenna consisting of dipoles printed on a conductor backed dielectric sheet illuminated by a waveguide feed horn is presented. The characteristics of the antenna is analysed using the spectral domain method for open structures. Theoretical and experimental results are compared.**

I. Introduction

In a parabolic reflector, the correct phase angle for plane wave operation is guaranteed by the parabolic contour of the reflector. Although this gives excellent results, the production of a parabolic reflector is not as easy as often required, while, on the other hand, planar antennas are too lossy for sufficiently high gain. As a consequence, planar reflector antennas have been investigated providing the necessary phase angle by structures printed on a planar substrate. Partly, a rather strong discretization of the phases is used [1], [2] or a more continuos phase adjustment is attempted by small reflecting elements varying in size, e.g. rings [3] or dipole-like structures [4], [5].

However so far the performance of the entire antenna could not be calculated. We present a full wave analysis of a planar reflector antenna by using the spectral domain method. Using this technique, the far field pattern of the reflector as well as the phase distribution of the scattered wave is obtained. This can be used as a new way for optimization.

For an approximate design of the planar reflector, the phase angle of the reflection coefficient of a plane wave with normal incidence on an infinite periodic array of dipoles is investigated using spectral domain techniques applied to frequency selective surfaces [6], [7]. A unit cell for this arrangement, the obtained result and the resulting layout are shown in Fig.1.

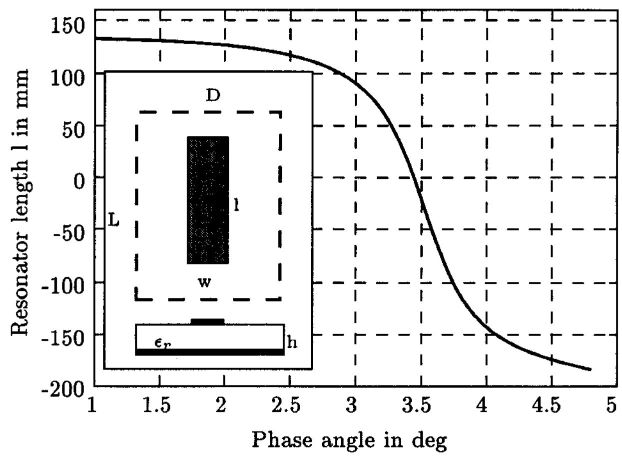

Fig. 1. Phase angle of reflection coefficient of plane wave incident on periodic structure (w=1.5 mm, h=0.76 mm, $\epsilon_r = 2.5$, L=D=5 mm, f=24 GHz).

II. Full Wave Analysis

The full-wave calculation method used here is a two-dimensonal, spectral domain immitance approach [6] for open structures. The configuration under investigation is shown in Fig.2.

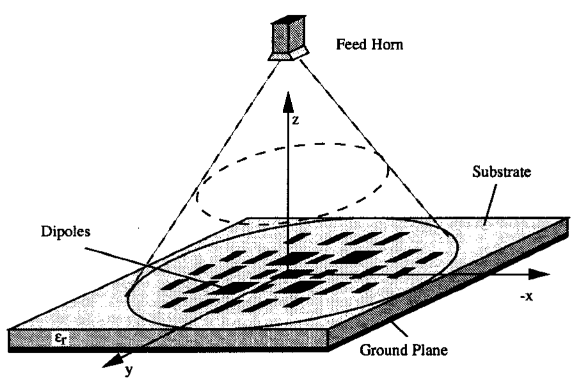

Fig. 2. Basic configuration used for the full wave analysis.

Assuming that the radiated electric field of the feed antenna is parallel to the y-direction, the tangential electric field E_x and the current J_x in the x-y-plane can be neglected for narrow dipole structures.

Thus the formulation of the problem in the spectral domain results in the following equation for the tangential electric fields $\tilde{E}_y$ in the plane of the printed dipoles:

$$\tilde{Z}_{yy}(\alpha,\beta) \cdot \tilde{J}_y(\alpha,\beta) + \tilde{E}_{y,exc}(\alpha,\beta) = \tilde{E}_{y,tot}(\alpha,\beta) \quad (1)$$

$\tilde{Z}_{yy}$ is Green's function, which can be easily derived using the immitance matrix approach, $\tilde{J}y$ is the current density on the microstrip patches, while α and β are spectral coordinates.

$\tilde{E}_{y,exc}$ is the exciting electric field in the x-y-plane. It is obtained here by calculating the electric field in the spatial domain using the far field distribution of the feed. Then the field is transformed into spectral domain by a Fourier transform to obtain $\tilde{E}_{y,inc}$. The superposition of $\tilde{E}_{y,inc}$ and its reflection by the configuration without the metallic structures leads to $\tilde{E}_{y,exc}$:

$$\tilde{E}_{y,exc}(\alpha,\beta) = \tilde{E}_{y,inc}(\alpha,\beta) \cdot (1 + \tilde{\Gamma}_{yy}(\alpha,\beta)) \quad (2)$$

$\tilde{\Gamma}_{yy}$ is the reflection coefficient, which can be determined using the immitance approach as well.

According to the standard spectral domain method, series representations for current densities on the strips are made and Galerkin's procedure is used to solve the problem. Sinusoidal entire domain functions supplemented by an edge term were used as basis functions. The lateral displacement of the respective metallic patches has to be considered by convolution with Dirac's delta function. Using Galerkin's procedure to solve equation (1) the following integrals are derived:

$$K_{yy}^{\mu\nu} = \int_0^\infty \int_0^{2\pi} \tilde{J}_y^{\mu}(\varrho,\omega) \tilde{Z}_{yy}(\varrho,\omega) \tilde{J}_y^{\nu *}(\varrho,\omega)\, \varrho \, d\omega \, d\varrho \quad (3)$$

with $\varrho = \sqrt{\alpha^2+\beta^2}$ and $\omega = \arctan(\beta/\alpha)$. J_y^{μ} and J_y^{ν} are basis functions.

The Green's function $\tilde{Z}_{yy}$ contains at least one surface-wave pole in the range of $1 < \varrho/k_0 < \sqrt{\epsilon_r}$ (k_0 is the free-space wave number). The location of the ring of poles can be determined numerically. Thus the integral can be solved by residue theorem [8].

The matrix elements of the resulting system of equations basically represent the interaction between the different dipoles. For simplification two elements at $y = y_u = y_v = 0$, $x = x_u$ and $x = x_v$ are regarded. The respective matrix element contains an expression $\exp\{-j\alpha \cdot (x_u - x_v)\}$ due to the lateral displacement of the dipoles. This results in a strongly oscillating behaviour of the term, if the distance $|x_u - x_v|$ of the elements is large, leading to severe difficulties with the numerical integration procedure. To avoid these difficulties the following procedure is used, which is outlined here only very briefly:

The basis functions and exponential expressions consist of two one dimensional separable functions. On the other hand, for greater α and β, the Green's function is rather smooth. Thus, parts of the integrand including the oscillating terms are separated and integrated analytically, while the Green's function is interpolated by a polynomial of low degree.

As a result of the Galerkin procedure the coefficients of the current basis functions are obtained. Relevant to the far field distribution is only the scattered electric field $\tilde{E}_{y,s}$, calculated by (4).

$$\tilde{E}_{y,s} = \tilde{Z}_{yy} \cdot \tilde{J}_y + \tilde{E}_{y,inc} \cdot \tilde{\Gamma}_{yy} \quad (4)$$

By using an inverse Fourier transform — again considering the poles in $\tilde{Z}_{yy}$ and $\tilde{\Gamma}_{yy}$ — the electric field in the spatial domain is obtained. Especially the phase of the electric fields can be used to determine errors and to adjust the respective patches. To use this new way of optimization will be the task of future work, especially for the design of small focal lengths. will be the task of future work.

III. Results

A 24 GHz offset reflectarray with a diameter of 200 mm, a focal distance of 150 mm, and an offset of 216 mm was built. The resulting layout is shown in Fig.3.

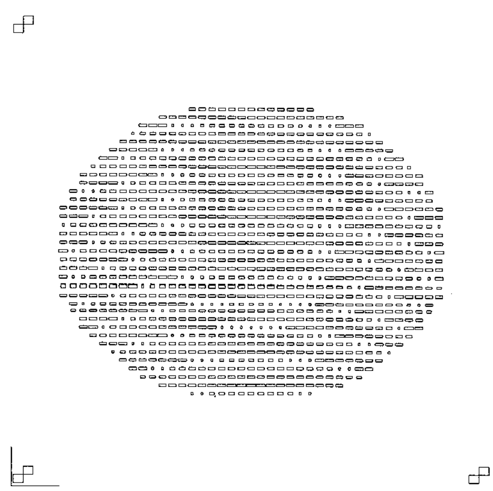

Fig. 3. Layout of the reflectarray under investigation.

The calculated and measured radiation pattern of the investigated reflectarray are shown in Fig.4 and Fig.5. The results agree well in gain, half-power beam

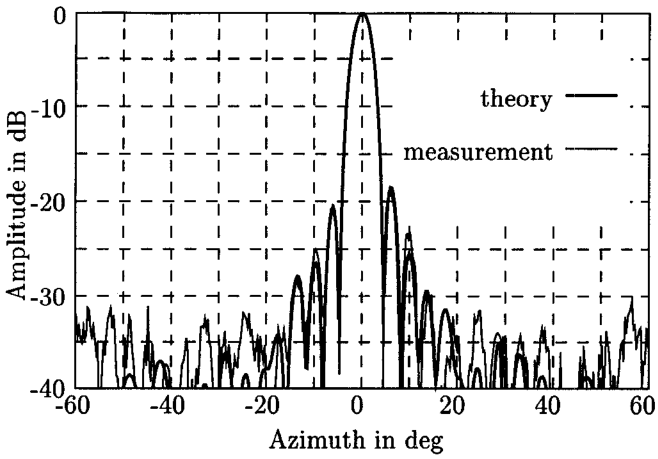

Fig. 4. E-plane pattern of the reflectarray.

width and in the first sidelobes. Some differences occure only in the H-plane due to aperture blocking caused by the feed structure and direct radiation of the feed horn (Fig.5).

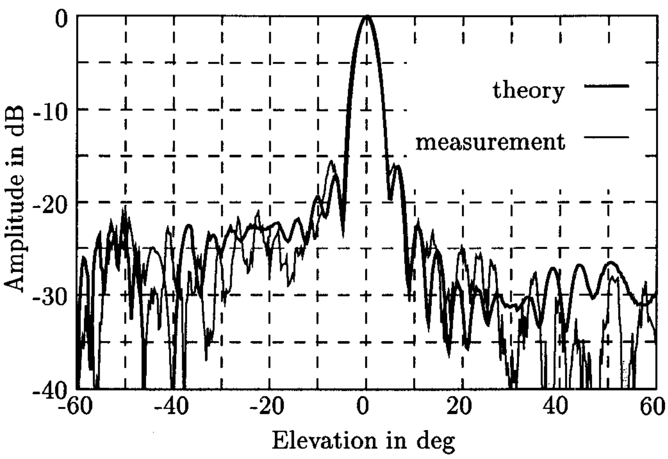

Fig. 5. H-plane pattern of the reflectarray.

IV. Conclusion

A planar offset reflectarray has been investigated by the spectral domain method. The theoretical results agree with the measurement. In future work this method can be used for further improvement of reflectarray antennas regarding gain, bandwidth and sidelobes.

References

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