# Modeling of Low-profile Reflect Array Antenna

**M. S. Gashinova and O. G. Vendik**
St.-Petersburg Electrotechnical University, Russia

**Abstract**—The theoretical analysis of a planar reflect-array antenna consisting of a rectangular microstrip patch radiators is presented. Such an antenna is to be designed to convert spherical wave radiated by feed horn antenna into plane wave by phasing of reflected wave due to adjusting the patch sizes and arranging them by principle of Fresnel mirror. The modelling of array antenna is based on the modelling of elementary equivalent waveguide cell consisting patch radiator at the interface between superstrate and grounded substrate layers. Spectral Domain Approach (SDA) of Method of Moments is used to analyse the characteristics of elementary waveguide cell. Theoretical and experimental results are compared.

## 1. Introduction

Microstrip reflectarray antenna exploits operational principles of traditional parabolic reflector antenna and microstrip patch phased array [1–4]. Such a combination allows eliminating two disadvantages of both standard antennas. For microstrip patch antennas there is a common difficulty to overcome a 30 dB gain limit of phased array because of lossy feeding network. The conventional high-gain antennas are the parabolic reflectors. Being the very efficient radiators they are bulky and massive. A flat microstrip refletarray is being developed as a compact high-gain antenna [2]. Low loss is conditioned by the sizes of most radiators are far from ones of resonant half-wavelength radiators (used usually with transmission lines for phase adjustment) as well as by absence of feeding networks. Feeding of the printed radiators is realized quasi-optically.

Such an antenna is to be designed to convert spherical wave radiated by feed horn antenna into plane wave by phasing of reflected wave due to adjusting the patch sizes and arranging them by principle of Fresnel mirror.

The basic configuration of antenna includes a feed horn antenna and a printed reflectarray. Rectangular patches arranged in a planar aperture based on metal backed substrate will reradiate illuminated energy into space. Each radiator's phase is adjusted to make total reradiated field cophasal and concentrated in a specific direction. The phasing method is to use a variable size patches to form the front of reflected wave.

A folded version of such reflectarrays has been proposed and realized [1]. The dual polarization properties of rectangular patch array enable to remove the feed element from the focal point in front of antenna and to place it at the backside of antenna with polarizing grid for reradiation.

In present paper we describe a code developed for the design of multilayer printed reflectarrays, which adjusts the sizes of patches to achieve a progressive phase for dual linear polarisation according to both twisting and focusing requirements.

## 2. Theory

To build a procedure for calculation of a reflection coefficient of linear polarized wave normally incident on a patch radiator we assume that no coupling between adjacent patches takes place. Such a situation is valid for normal incidence on infinite periodical array and gives us a reasonable approximation for most part of finite nonperiodic array if the distance between adjacent radiators is big enough.

Figure 1 illustrates the normal incidence of the plane wave on a single microstrip patch. With two pair of opposite perfect electric and magnetic walls corresponding to the case of non-interacting radiators we can consider the whole structure as a stack of elementary TEM (in $z$ direction) waveguides. Due to partial filling of such a waveguide with dielectric substrate, air superstrate and current carrying layers an existence of pure TEM mode represents another assumption and such a waveguide could be called as a quasi-TEM waveguide. To calculate the reflection coefficient of fundamental TEM mode we use a standard Spectral Domain Approach of Method of Moment.

General relation between electric fields in the plane of microstrip radiator is

$$\tilde{\bar{\mathbf{E}}}_{tot} = \tilde{\bar{\bar{\mathbf{G}}}} \cdot \tilde{\bar{\mathbf{J}}} + \tilde{\bar{\mathbf{E}}}_{inc}(1 + \tilde{\bar{\bar{\mathbf{\Gamma}}}}) \tag{1}$$

where $\tilde{\bar{\mathbf{E}}}_{tot}$ is vector of total tangential E-field (superposition of scattered and incident field), $\tilde{\bar{\bar{\mathbf{G}}}}$ is Green's dyad for elementary waveguide, $\tilde{\bar{\mathbf{J}}}$ is surface current density excited in microstrip dipole, $\tilde{\bar{\mathbf{E}}}_{inc}$ is vector of incident

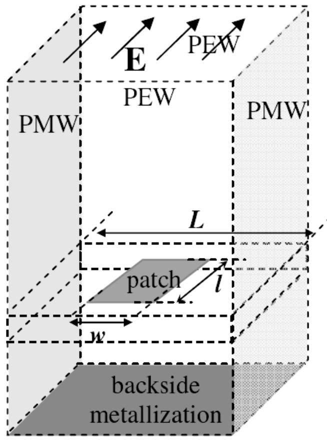



Figure 1: Equivalent elementary wavegude.

linear-polarized along the microstrip radiator side and $\tilde{\bar{\bar{\Gamma}}}$ is a tensor of reflection coefficients. Tilde denotes operating in Fourier domain. $\tilde{\bar{\bar{\Gamma}}}$ can be easily derived by analogy with determination of Green's dyad using standard immitance approach.

To approximate unknown current density one has to expand both components of $\tilde{\bar{\mathbf{J}}}$ by series of chosen basis functions.

Assuming that polarization of the incident wave is parallel to one side of rectangular patch, along $y$-direction in instance, we can suppose that $y$-polarized electric field excite only y-component of current density:

$$\tilde{\bar{\mathbf{J}}} = J_y \cdot \bar{\mathbf{e}}_y \tag{2}$$

Then equation (1) transforms to scalar one:

$$\tilde{E}_{y,tot} = \tilde{G}_{yy}\tilde{J}_y + \tilde{E}_{y,inc}(l + \tilde{G}_{yy}) \tag{3}$$

where

$$J_y = \sum_n A_n \varphi_n(x,y) = \sum_n A_n \varphi_n^x(x)\varphi_n^y(y) \tag{4}$$

In order to take into account a priory known current density distribution with zero value at edges parallel to electric walls and singularity at the edges parallel to magnetic walls, we suggested a set of following separable expanding functions:

$$\varphi_n(x,y) = \begin{cases} \frac{\cos\left(\frac{4n\pi x}{w}\right)\sin\left(\frac{(2n+1)\pi}{l}\left(\frac{l}{2}-y\right)\right)}{w\sqrt{1-\left(\frac{2x}{w}\right)^2}} & |x| \le \frac{w}{2}, |y| \le \frac{l}{2} \\ 0 & |x| \ge \frac{w}{2}, |y| \ge \frac{l}{2} \end{cases} \tag{5}$$

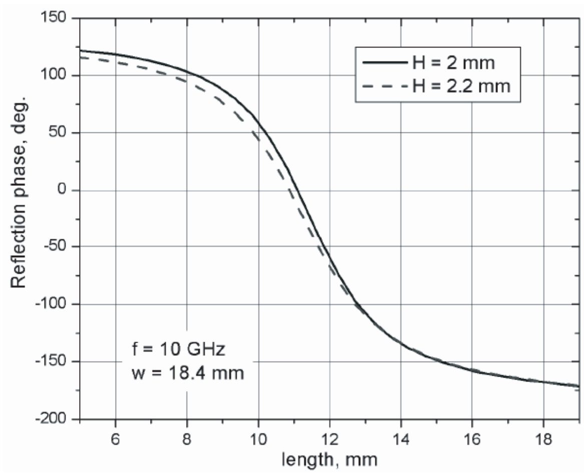
Here $l$ is the length of rectangular patch, i. e., the length of a side corresponding to the direction of polarization, $w$ is the width, and $n$ is the number of basis function.

In order to find the vector of unknown coefficient $\{A_n\}$, Galerkin's procedure has to be implemented with weighting functions the same as the expansion functions. Then the phase of reflected field can easily be found.

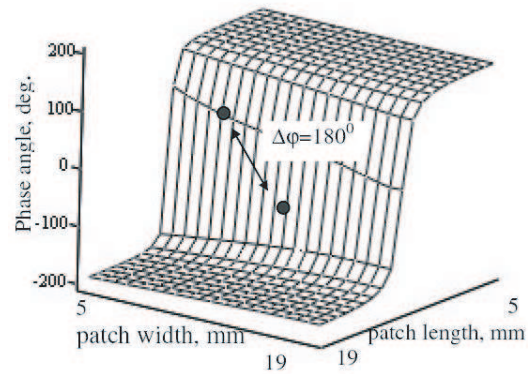
Modifying (1) by addition of electric field $\tilde{\bar{\mathbf{E}}}_{tr} = R_s \cdot \tilde{\bar{\mathbf{J}}}$ we can take into account the losses due to finite conductivity of patches by using of equivalent surface impedance $R_s$.

## 3. Result and Discussion

Figure 2 demonstrates the results of calculation of phase angle depending on length of patch for two different thickness of single substrate. In order to adjust the sizes of patches to achieve a progressive phase for dual linear polarisation according to both twisting and focusing requirements the calculation of phase for polarizations along the both side of patches has to be done. If the dimensions of the patches are chosen in such a way that the absolute difference between the reflection angle of the two perpendicular polarization is 180° then the polarization of the wave incident on the patch tilted by 45° with respect to polarization of incident wave will be twisted by 90°.




(a)




(b)

Figure 2: Results of calculation of phase angle depending on patch dimensions (a) Phase angle versus length of patch (different thickness of the substrate H), (b) Surface plot of phase angle in dependence on both dimensions of patch. Frequency 10 GHz, thickness of substrate $H = 2\,\text{mm}$, dielectric permittivity 1.06, $L = 21\,\text{mm}$, range of patch sizes 5–19 mm.

The phases of the reflected wave have to be attainable in the range of 0–360°. However the range of real array is, usually, less then 360 degree [4]. There are two opposite factor which influence the performance of antenna: the less the thickness of substrate and the bigger $\varepsilon$ the greater range of obtainable phase, but the greater slope of curve and the higher technological requirements for patch size precision. Besides, for twisting reflectarray there is a gap of unreliazable phases. In Figure 3 the results of calculation of phase for bilayered substrate ($H_{upper} = 0.12\,\text{MM}$ (dacron, $\varepsilon_r = 3.2$,), $H_{lower} = 1\,\text{MM}$ (foam, $\varepsilon_r = 1.06$)) at 25 GHz are presented. In order to cover these two gaps about 55° each, one needs to use near values of patch sizes what will result in general error of phase approximately of 28°.

The validity of presented approach is confirmed by comparison with results of simulation by MS CST and Ansoft HFSS (Figure 4). Small discrepancy between data may be explained by more accuracy of methods of simulation based on FE and FDTD. However for acquisition of large arrays of patch dimensions the using MoM based code is more efficient.

Finally the developed code has been used for design of reflectarray antenna with diameter 300 mm operating at 25 GHz. More than 400 radiators were used to form a designed gain of 36 dB. Measured gain is around 32 dB, half-power beam width 2.7°, sidelobes are around 16°. Difference between measured and calculated characteristics can be partly explained by mentioned deviation of patch sizes to cover the unreliazable phase gap. Another reason of discrepancy is due to loss of some part of energy at the edge region of antennas plate. Moreover, the quasi-optical method to build a Fresnel reflector requires considering the dependence of phase angle also on angle of oblique incidence of wave on the edge patches.

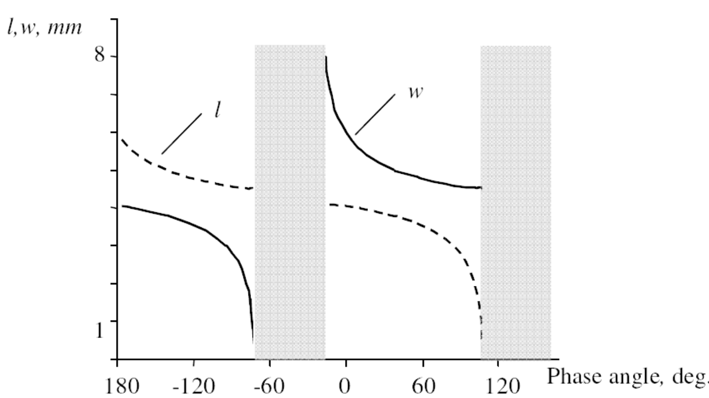



Figure 3: Dependence of phase angle on patch dimensions.

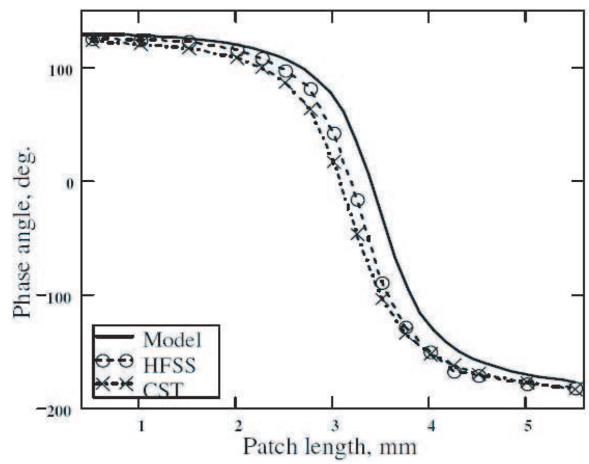



Figure 4: Comparison of simulation by presented model and by using microwave simulation packages. $H = 0.787\,\mathrm{mm}$, $\varepsilon_r = 2.22$, $L = 6\,\mathrm{mm}$, range of patch sizes from 0.6 to 5.6 mm, $f = 25\,\mathrm{GHz}$.

## 4. Conclusion

The design code based on the Spectral Domain Method of Moments (MoM) for lossy mutilayer periodic structures and normal incidence of a plane wave has been developed. Specific entire-domain basis functions have been proposed to achieve a high convergence and accuracy of MoM. Code developed is very efficient because it combines high calculation speed and high accuracy of full-wave analysis and is very promising for acquisition of large arrays of patch dimensions.

To validate the design method, a series of reflectarray antennas operating at different frequencies with and without twisting effect have been designed and manufactured [6]. A good agreement was obtained between predicted and measured radiation patterns for both polarizations. The measured gains were not less then 32 dB.

## REFERENCES

1. Pilz, D. and W. Menzel, *Electron. Lett.*, Vol. 34, No. 9, 832–833, April 1998.
2. Menzel, W., D. Pilz, and M. AI- Tikrit, *IEEE Antenna's and Propagation Magazine*, Vol. 44, No. 3, 25–29, June 2002.
3. Encinar, J. A., *IEEE Trans. Antennas Propagat.*, Vol. 49, 1403–1410, October 2001.
4. Tsai, F.-C. E. and M. E. Bialkowski, *IEEE Trans. Antennas Propagat.*, Vol. 51, No. 10, 2953-2962, October 2003.
5. Pilz, D. and W. Menzel, *Asia-Pacific Microwave Conference Proc.*, Hong Kong, 225–227, December 2–5, 1997.
6. Parnes, M. D., V. D. Korolkov, M. S. Gashinova, I. A. Kolmakov, Ya. A. Kolmakov, O. G. Vendik, and T. V. Rossii, *Radioelectronics*, Vol. 1, Russian, 56–59, 2005.