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To cite this version:

Hussein Rammal, Charif Olleik, Kamal Sabbah, Mohammad Rammal, Patrick Vaudon. Synthesis of phased cylindrical ARC antennas arrays. International Journal of Antennas and Propagation, 2009, 2009 (ID 691625), 10.1155/2009/691625 . hal-00435703

HAL Id: hal-00435703

https://unilim.hal.science/hal-00435703

Submitted on 24 Nov 2009

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Hindawi Publishing Corporation
International Journal of Antennas and Propagation
Volume 2009, Article ID 691625, 5 pages
doi:10.1155/2009/691625

Application Article

Synthesis of Phased Cylindrical Arc Antenna Arrays

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Received 27 January 2009; Revised 12 May 2009; Accepted 9 June 2009

Recommended by Wei Hong

This paper describes a new approach to synthesize cylindrical antenna arrays controlled by the phase excitation, to synthesize directive lobe and multilobe patterns with steered zero. The proposed method is based on iterative minimization of a function that incorporates constraints imposed in each direction. An 8-element cylindrical antenna has been simulated and tested for various types of beam configurations.

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1. Introduction

The utilization of conformal antennas finds its interest, when the antenna is placed on nonplanar support [1] or when we desire to form specific lobes, which benefit from the geometry of array; the desired beam pattern can vary widely depending on the application. There are directional antennas with low level side lobes or with high gain [2, 3], and antennas with cosecant lobe [4] or double pencil beam [5]. Most of synthesis methods use complex excitation (amplitudes and phases) [6]; it allows better control of the quality of beam shape or sidelobe level. Some applications propose a phase adjustment in order to take into account coupling between elements [7]. Interferences can be rejected by placing nulls in theirs directions; in [8] the authors presents phase control methods for null steering with a broadside beam arrays.

In a linear phased array antenna, the beam can usually not be steered more than about 60°–70° from the normal of the array [9]. The limitation is due to beam broadening (reducing directivity) and element impedance variations due to mutual coupling, resulting in increased mismatch at large scanning angles.

The developed method that we use is an extension of minimax method applied for the linear arrays [10], and it will be applied for cylindrical antenna arrays synthesis.

As conformal array, the cylinder has a potential of 360° coverage. Today, the common solution is three separate antennas, each covering a 120° sector [6].

In our work, we propose a general approach only by phase adjustment, to synthesize steered beam and multibeam with steered zero using cylindrical antenna arrays. The idea of our work is based on tangential linearization by application of Taylor formula. The equation system formed by the radiated fields is calculated for all directions in space, and then we minimize the deviation of this system compared to amplitude of desired one. Optimization is performed with a minimax criterion. Specifications on the desired beam such as the maximum and minimum sidelobe level and the null depth level are considered by introducing a set of weighting factors in the function constructed for the minimax algorithm. With this formulation we are able to steer beams and nulls at the direction of interest and at the same time keep the average sidelobe level at its minimum.

2. Synthesis Problem Formulation

The radiation field of cylindrical array (Figure 1) is expressed as

$$E(\varphi) = \sum_{n=1}^{N} I_n e^{j\beta n} E_0(\theta, \varphi_n) e^{jkR\cos(\theta-\varphi_n)}, \qquad (1)$$

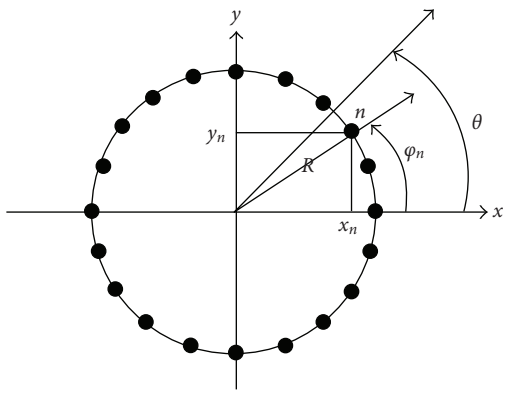


Figure 1: Geometry of cylindrical array.

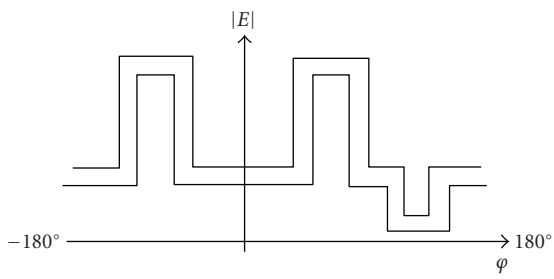


Figure 2: Desired beam definition.

where

(i) $I_n e^{j\beta n}$ is the complex excitation for the element n;

(ii) φ_n is the angular position of the element n;

(iii) E_0 is the elementary field.

For conformal arrays, the element pattern plays an important role in the array pattern, because each element is facing a different direction. Therefore, the element pattern expression has a different value in each summand of (1).

The desired field is defined in amplitude throughout template (Figure 2), that indicates the direction and shape of the main lobes, the position, and the width of zero.

The optimization problem under consideration consists to minimize the error function:

$$\mathrm{ERR}\left(\underline{\beta}\right) = \omega_j \underset{j}{\mathrm{Max}} \left|\mathrm{ERR}_j\left(\underline{\beta}\right)\right|, \tag{2}$$

where

$$\mathrm{ERR}_j\left(\underline{\beta}\right) = \mathrm{ERR}_j\left(\beta_1, \beta_2, \ldots, \beta_N\right), \tag{3}$$

$j = 1, \ldots, M$ (M is the number of the sampled angular directions).

ERR_j is the deviation of an actual calculated field (1) $E_c(\underline{\beta}, \theta j)$, from a desired one $E_d(\theta_j)$:

$$\mathrm{ERR}_j\left(\underline{\beta}\right) = E_c\left(\underline{\beta}, \theta_j\right) - E_d\left(\theta_j\right). \tag{4}$$

ω_j is a weighting factor in the direction θ_j; it can be adjusted to control the beam in all direction, especially to create a deep zeros in the directions of interference sources.

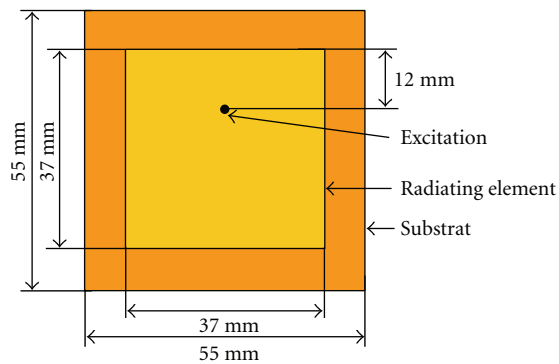


Figure 3: Patch antenna dimensions.

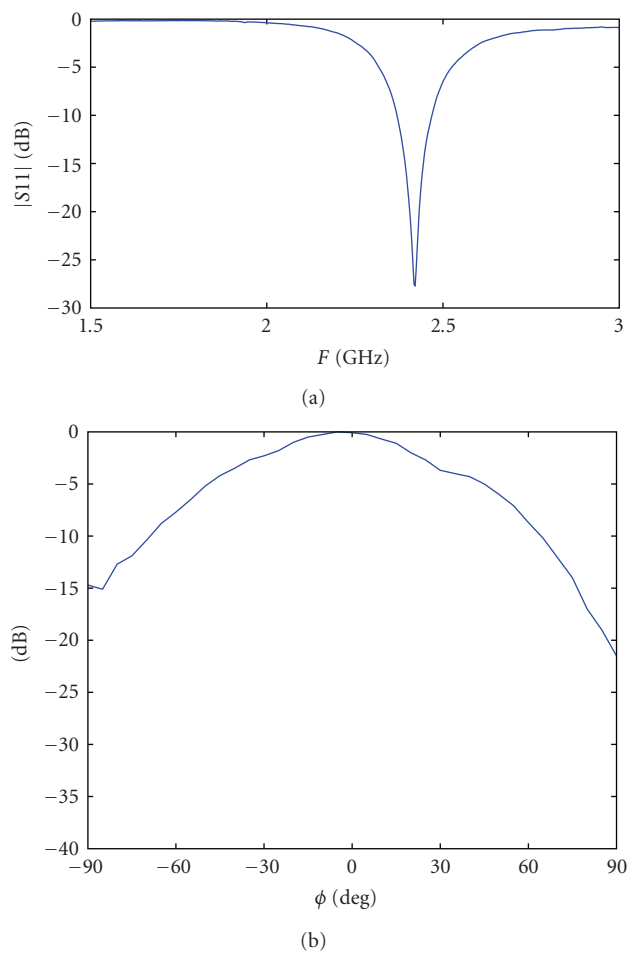
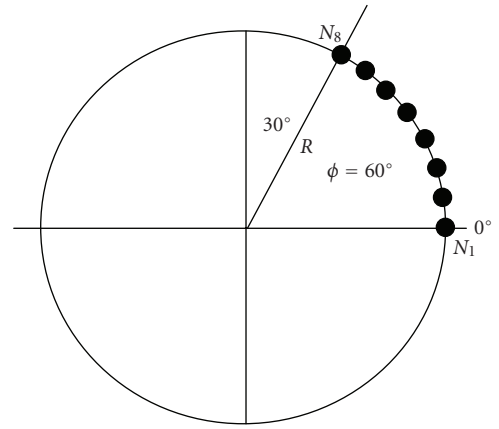


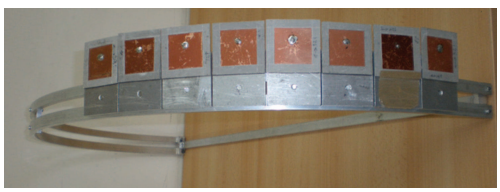
Figure 4: (a) Measured reflection coefficient. (b) Element radiation pattern.

At the kth stage of the minimization algorithm we solve a linearized system in minimax criterion:

$$\mathrm{ERR}_j\left(\beta_k\right) + \sum_{i=1}^{N} \frac{\partial \mathrm{ERR}_j\left(\beta_k\right)}{\partial \beta_i} h_{ki} = 0, \quad j = 1, \ldots, M. \tag{5}$$



(a)



(b)

Figure 5: (a) Geometry of antenna. (b) Realized antenna array.

$\underline{h}_k$ should satisfy a certain constraint: $\|h_k\| \leq \delta_k$, to ensure a good linear approximation of the set of linear system of equation.

δ_k is automatically adjusted during the process to find the inequality:

$$\mathrm{ERR}\left(\underline{\beta}_k + \underline{h}_k\right) < \mathrm{ERR}\left(\underline{\beta}_k\right). \tag{6}$$

The subproblem (5) is solved by a standard linear programming routine [11], that is, found very efficient for this type of problem. The convergence of the method is ensured by adjusting the value of δk at each iteration, so the point $x_{k+1} = x_k + h_k$ will be good if the decrease in the function $\mathrm{ERR}(\beta)$ exceeds a small multiple of the decrease predicted by the linear approximation. Otherwise the linear approximation is insufficient, and the value of δ_{k+1} will be reduced.

The iteration is stopped if one of the following criteria is met:

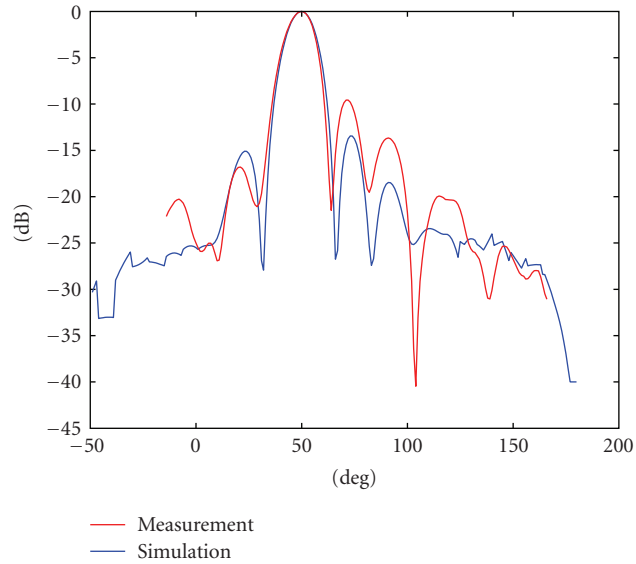
(1) the maximum of error function is below a certain value;

(2) the maximum of $\|\underline{h}_k\|$ is very small compared to $\underline{\beta}$.

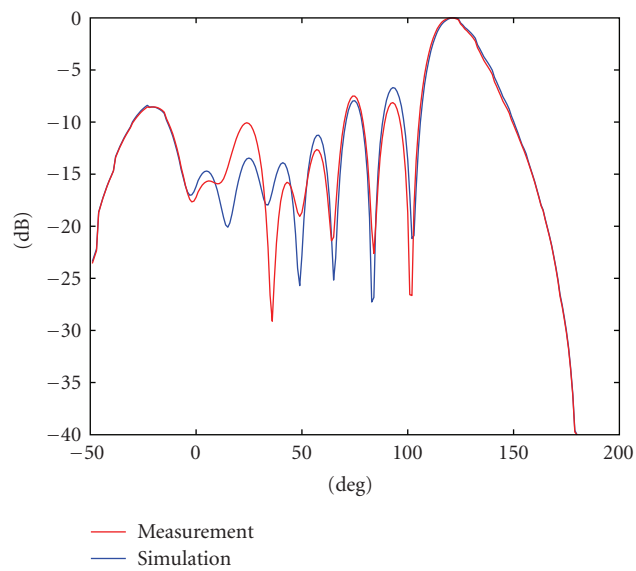
3. The Used Patch Element

The used antenna element is a square patch element. The substrate is made from PTFE Teflon ($\varepsilon_r = 2.55$, $h = 0.76$ mm). The patch element is represented in Figure 3.

The measurement of the reflection coefficient shows a satisfied adaptation at the operating frequency of 2.45 GHz (Figure 4(a)).



(a)



(b)

Figure 6: (a) Steering one lobe (50°). (b) Steering one lobe (120°).

Table 1: Steering one lobe.

N	Excitations (phase) 50° β	120° β
1	0.69	0
2	−95.8	−253.61
3	−174.75	−112
4	−230	−332
5	−272	−188
6	−285	−23.8
7	−272	−218
8	−240	−47.56

Table 2: Steering 2 lobes.

N	Excitations (phase) 20° and 80° β	30° and 100° β
1	0	0
2	272	98
3	23.8	88
4	330	234
5	126	248
6	95.8	98
7	332	120
8	307	30

Table 3: Steering one lobe and nulling.

N	Excitations (phase) Lobe (50°) and nulling (80°) β	Lobe (60°) and nulling (85°) β
1	−107.5	0
2	159.1	287.4
3	53.7	192.2
4	46.9	194.8
5	−10.3	195.8
6	−15.9	234.6
7	−12.2	200
8	9.0	308

The measured radiation pattern (H plane) (Figure 4(b)) is used directly in the calculation of the radiated field of the array. The field E_0 in (1) is adjusted for each element according to the desired spatial direction (θ).

4. Simulation and Measurement Results

The geometric of considered cylindrical antenna is represented in Figures 5(a) and 5(b), with radius $R = 41$ cm. 8 patch elements are distributed with equal spacing along the arc (the scanning angle is determined between ($\theta_{\min} = -60°$, element, and $\theta_{\max} = 180°$). In this case the theoretical maximum range, which could be scanned, is theoretically about 240°.

In our study we consider three types of lobes:

(1) antenna with steered lobe,

(2) antenna with two lobes,

(3) antenna with lobe and null.

The weighting factors give this technique greater flexibility to control the desired lobe, and they are automatically adjusted to find the best results (e.g., $\omega_j = 1$ in the region of main lobe and $\omega_j = 10$ in region of side lobe and 50 in the region of null). The synthesized array patterns have been carried out to illustrate this method's capabilities. Table 1 shows the result of synthesis phase excitation for steering one lobe at 2 different angles. Figures 6(a) and 6(b) represent the calculated field compared to measurements.

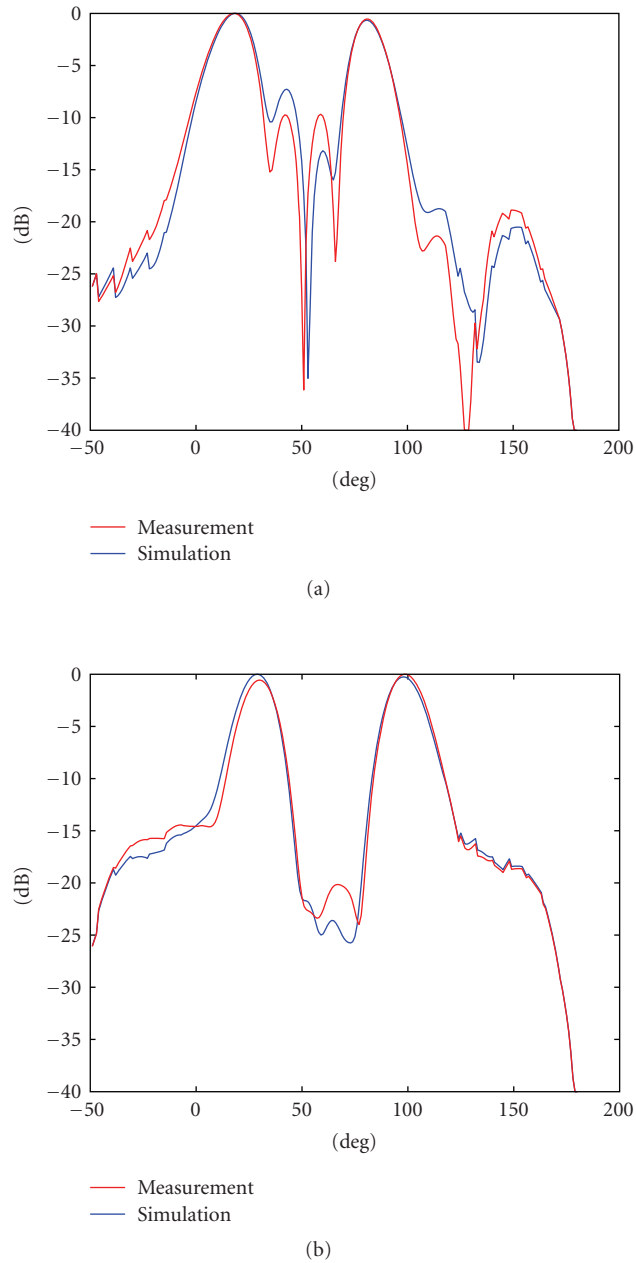


Figure 7: (a) Steering 2 lobes (20° and 80°). (b) Steering 2 lobes (30° and 100°).

Also this technique is able to compute the phases for multibeam arrays for 2 lobes. Table 2 shows the simulation results for multibeam steering lobes in two desired directions (first at 20° and 80°, the second one at 30° and 100° and its patterns in Figures 7(a) and 7(b)).

Table 3 shows the simulation results for steering one lobe and null.

We can observe from patterns, that this technique is very efficient for different cases of steered main lobe and imposed null in the direction of interference (Figures 8(a) and 8(b)).

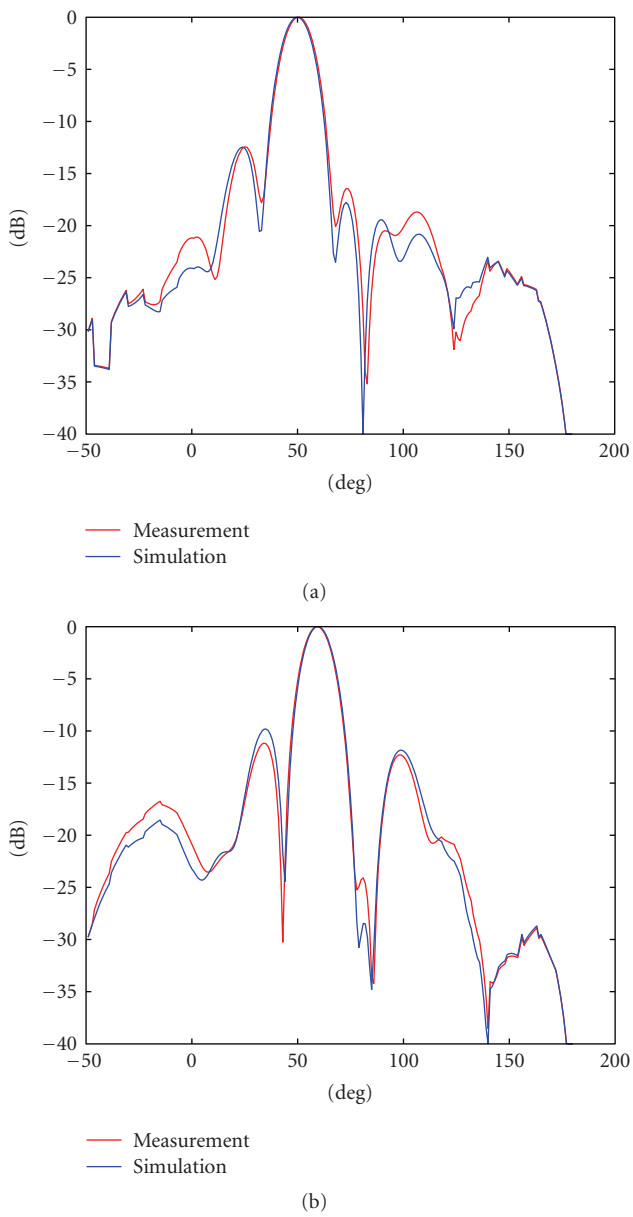


Figure 8: (a) Steering one lobe (50°) and nulling (80°). (b) Steering one lobe (60°) and nulling (85°).

5. Conclusion

In conclusion, we have described an iterative technique, which is able to compute the desired pattern for cylindrical antenna arrays by modifying only the phase excitations. The technique has shown its ability to generate reasonable results in all checked cases. This algorithm holds not only for the examples presented above, but also appears to be general for all cases of synthesized desired characteristics of steered beams.

Acknowledgment

This work has been supported by Lebanese University research grant.

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