

PATTERN SYNTHESIS USING PHASE-ONLY CONTROL RADIATED BY PLANAR ARRAYS WITH A LARGE NUMBER OF ELEMENTS

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Abstract. (COST 284 contribution). *A method for synthesizing antenna patterns from planar arrays with a high number of elements is presented. This method allows to synthesize antenna patterns radiated by planar arrays with a fixed amplitude distribution using just the phase of the radiating elements. An example of a shaped-beam pattern radiated by a rectangular grid, circular boundary planar array with more than 11.000 elements will be shown.*

1. Introduction. Spacecraft antennas are commonly designed to provide coverage to a specified portion of the earth's surface while minimizing the radiation to the remainder of the earth's surface. The most popular designs for producing shaped contour radiation patterns are the array-fed parabolic reflector, the direct radiating planar array and the parabolic reflector having small surface perturbations with a single feed. The direct radiating planar array has a number of advantages over reflectors: distribution of power amplification at the elementary radiation level, higher aperture efficiency, no spillover loss, no aperture blockage, and the possibility of implementation of deployment in large arrays. Main disadvantages are complexity, and also how to design the feeding network in order to minimise losses and mutual coupling. Parabolic reflectors with surface perturbations present also drawbacks, being some of them, for example, the existence of a size limit that is imposed by the launcher, and the necessity of use one manufacturing tool per application. Some of these drawbacks can be overcome using reflectarrays. They are composed by a feeder which excites an array of radiating elements, without interconnections, comprising a reflecting surface to produce the reflected and desired radiated field. If the reflecting surface is a plane, it is apparent that many of the design advantages for reflectarrays are joined with direct planar arrays. However, reflectarrays have an additional problem: the amplitude distribution has to be necessarily fixed because it depends on the feeder (usually a horn antenna) and on its position. In other words, synthesis of radiation patterns for planar reflectarrays can be accomplished as a phase-only synthesis procedure for planar arrays.

Antenna array radiation patterns designed for space applications must have narrow main beams. Due to the well-known link of beamwidth and number of elements of planar arrays, for this kind of applications arrays composed by many elements are needed. However, the pattern synthesis of planar arrays with a large number of elements is a challenging task and many methods used to obtain footprint patterns from planar arrays, e.g. [1], are not capable of attaining good results for these huge arrays. On the other hand, methods commonly applied to synthesize radiation patterns from large arrays, that is, aperture pattern synthesis techniques and subsequent sampling procedures [2] are not suitable since they are not able to undertake phase-only synthesis.

For all these reasons, a method for synthesizing shaped-beam patterns of large arrays with phase-only control is needed. Here, we apply our previous work [3] to rectangular grid, circular boundary arrays to obtain circular footprint patterns with controlled side lobe and

ripple levels. The procedure is illustrated by synthesis of a 11304 element planar array that radiates a flat-topped pattern with a circular cross section of radius 1.4° and with low sidelobe and ripple levels.

2. Method. Given a planar array of radiating elements arranged in a quadrangular grid with circular boundary on the XY-plane with fixed amplitude excitations (denoted as $|I_{0pq}|$ for the pq -th element), the modified Taylor expressions developed by Elliott [4] that relate the complex zeros of a radiation pattern with their excitation distribution are used to calculate the phase of the excitation of the radiating elements that generates the desired pattern.

Starting from an initial set of complex zeros ($u_{m0}+jv_{m0}$) we seek to synthesize a desired radiation pattern F_d by iterative perturbation of the ($u_{m0}+jv_{m0}$). In iteration i we apply complex perturbations δ_{im} to define zeros ($u_{im}+jv_{im}$) = ($u_{0m} + \text{Re}(\delta_{im})$) + $j(v_{0m} + \text{Im}(\delta_{im}))$, we calculate the excitation distribution $h_i=|I_i|\exp\{j\psi_i\}$ that produces the pattern with these zeros:

$$h_i(p) = \frac{2}{\pi^2} \sum_{m=0}^{\bar{n}-1} \frac{F_i(\gamma_{1m}) J_0(\gamma_{1m} p)}{[J_0(\gamma_{1m} \pi)]^2} \quad (1)$$

where $p = \pi a / \rho$, $\pi \gamma_{1m}$ is the m -th root of J_1 , the first-order Bessel function and where

$$F_i(u) = \frac{2a^2}{\pi} \frac{J_1(\pi u)}{\pi u} \frac{\prod_{m=1}^{\bar{n}-1} (1 - u^2 / (u_{im} + jv_{im})^2)}{\prod_{m=1}^{\bar{n}-1} (1 - u^2 / \gamma_{1m}^2)} \quad (2)$$

being $u = (2a/\lambda)\sin\theta$ (λ is the wavelength of the radiation and θ the polar angle).

The resulting phase distribution is sampled to obtain the phase associated to each radiating element, thus, ψ_{ipq} will denote the pq -th element corresponding phase. The phases ψ_{ipq} are combined with the previously fixed amplitudes $|I_{0pq}|$ to afford the complex excitation $I_{ipq} = |I_{0pq}| \exp\{j\psi_{ipq}\}$. We calculate the pattern F_i^* produced by these excitations:

$$F_i^*(\theta, \varphi) = \sum_p \sum_q I_{ipq} e^{jk(x_{pq} \sin\theta \cos\varphi + y_{pq} \sin\theta \sin\varphi)} \quad (3)$$

where k is the wave number, and (x_{pq}, y_{pq}) is the location of the pq -th element on the plane. We compare F_i^* with the desired pattern F_d , using an appropriate cost function $C(F_i^*)$. This cost function is minimized using the hybrid simulated annealing (hybrid SA) algorithm described in [5], which applies the SA approach to simplex optimization.

It is worthy to emphasize that the use of the complex zeros as variables of the optimization procedure implies that the number of unknowns in the algorithm may remain unchanged for increasing number of elements and therefore a higher number of elements will affect the computational time but not the search convergence.

3. Example. The above procedure has been applied to a quadrangular grid, circular boundary planar array composed by 11304 total elements in order to obtain a flat-topped pattern of circular cross section. A maximum ripple level of 1dB within a radius of about 1.3° and the lower possible sidelobe level are its desired characteristics. The radiating elements are located

0.57λ apart leading to an array of radius 34.2λ and the magnitude of the elements' excitation was fixed as to simulate the feed of a horn: it is a sampled -15dB tapered \cos^q amplitude distribution. As either the amplitude as the phase distribution $h_i(p)$ are φ -symmetric, eq. 3 can be replaced by the array pattern with quadrantal symmetry so the summatory terms are reduced by four to 2826 and so the computational time. The resulting pattern (figs. 1a-1b) was obtained with $\bar{n} = 10$, presents a -18.2 dB side lobe level, and the flat-topped main beam has a radius of 1.4° at -3dB and a ripple level of 1dB .

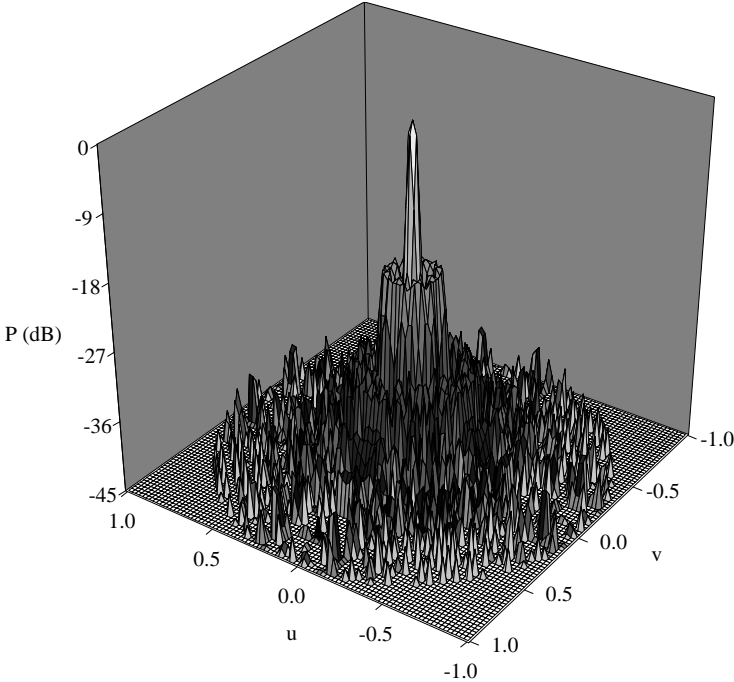


Fig. 1a. Three-dimensional plot of power pattern ($u=\sin\theta\cos\varphi$, $v=\sin\theta\sin\varphi$)

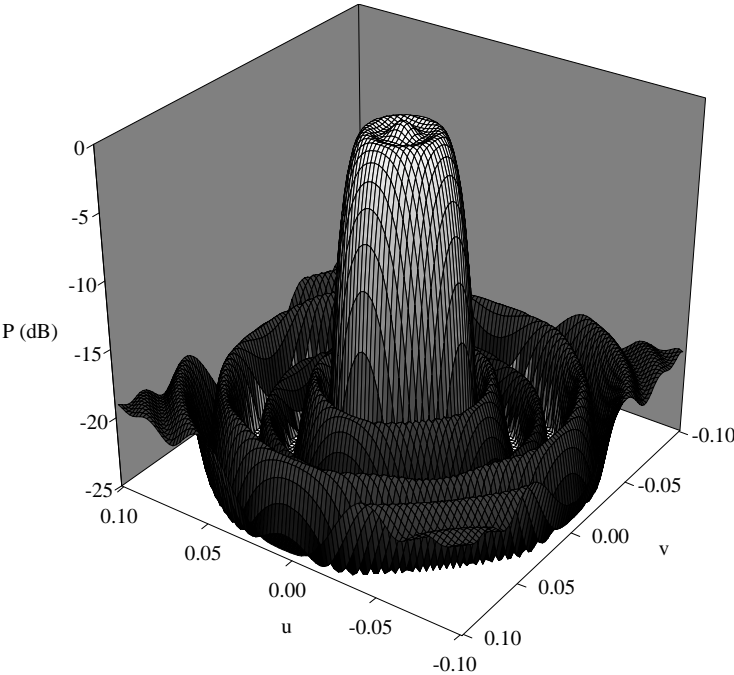


Fig. 1b. Zoomed three-dimensional plot of power pattern ($u=\sin\theta\cos\varphi$, $v=\sin\theta\sin\varphi$)

4. Conclusions. A method for synthesizing antenna patterns from planar arrays with large number of elements using just phase-only control has been presented. It allows the design of quasi φ -symmetric patterns with narrow beams and low side lobe and ripple levels. It is possible to extend this technique to non φ -symmetric patterns using the modified Taylor expression for undulating ring side lobes developed by Elliott [6].

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6. References

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