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On the reconstruction of multiplet antennas from basic resonators

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Abstract. In this paper, we consider the possibility of reconstructing the geometry of an unknown multiplet antenna from the geometries of elementary radiators by combining their spatial far-field spectra when decomposed into spherical harmonics. We propose a simple step-by-step algorithm that allows us to combine a set of basic resonators for implementing a non-trivial radiation pattern.

Keywords: antenna, telecommunications, multipolar decomposition, radiation pattern, beam forming, computational electrodynamics

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О восстановлении многомодовых антенн из базисных резонаторов

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Аннотация. В данной работе рассматривается возможность восстановления геометрии неизвестной многомодовой антенны из геометрий элементарных излучателей путем совмещения их пространственных спектров дальнего поля при разложении на сферические гармоники. Представлена простая последовательность действий, позволяющую получить набор простейших антенных элементов для реализации нетривиальной диаграммы направленности.

Ключевые слова: антенна, телекоммуникации, мультипольное разложение, диаграмма направленности, формирование луча, вычислительная электродинамика

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Introduction

One of the most important tasks in modern telecommunication systems is to create a selective radiation pattern [1, 2]. Such diagrams may have slits, punctured points, and other features and singularities predetermined by the purpose of the communication channel (radar, satellite communications, smart beam control). To achieve this goal (enabling a controlled feature), in an arbitrary radiation pattern, in the general case, an antenna we modify must have a permitted harmonic of such an order that is capable of forming an electromagnetic field of similar dimension [3]. For example, a punctured point in the diagram can be provided by turning on a convenient dipole antenna with a fundamental minimum in the plane of the vibrator. In this paper, we consider an algorithm that can be used to accurately build a multiplet antenna with specified characteristics. The potential development of such a method may make it possible to improve existing beam control methods such as metasurfaces [4, 5] and antenna arrays [6, 7].

Discussion

At the first stage, the requirements are imposed on the radiation pattern of the multiplet antenna being reconstructed: its polarization and energy characteristics. The resulting electric field is then converted into a spectrum of multipolar contribution coefficients of spherical harmonics [8, 9]. Let us call this spectrum the required vector state of the reconstructed antenna.

Having performed the decomposition procedure for various trivial antennas, which we will call basic (e.g. electric dipole with pure electric response, split ring with both electric and magnetic responses, omega particles with coupled magnetoelectric response), one can obtain linearly independent non-orthogonal non-unit vector-states in which the system exist whenever the corresponding basic antenna is turned on at some normalized frequency f_n. It is assumed that by linear combination of such basic state vectors, it is possible to obtain, among other things, the required vector state of the reconstructed antenna.

Naturally, this decomposition still does not take into account the relative position and rotation of several antenna elements, so that we have only been able to decompose spectra of the same symmetry as the basic antennas. To introduce rotations into the algorithm, one has to recall that the modified spherical functions which coefficients we study generate the basis for irreducible representations of the SO(3) symmetry group. Introducing the antenna rotation $R(\lambda,\beta,\gamma)$ in Cartesian system of coordinates $\{x\to x', y\to y', z\to z'\}$ through Euler angles $\{\lambda,\beta,\gamma\}$ in *ZYZ* order, for the spherical harmonic $Y^m_l(x',y',z')$ of order *l, m* one can obtain [10]:

$$Y_l^m(x',y',z') = \sum_{k=-l}^{+l} [D_l^{mk}(R(\alpha,\beta,\gamma))]^* Y_l^k(x,y,z), \tag{1}$$

where $D_l^{mk}\left(R(\alpha,\beta,\gamma)\right)$ stands for the element of Wigner D-matrix. Based on this, the corresponding multipolar (either electric or magnetic) coefficient of the rotated antenna can be calculated as:

$$\begin{aligned} A_l^m(\alpha,\beta,\gamma) = \sum_{k=-l}^{+l} e^{im\alpha} e^{ik\gamma} \sqrt{(l+m)!(l-m)!(l+k)!(l-k)!}\,\times \\ \times \sum_{s=\max\{0;k-m\}}^{s=\min\{l+k,l-k\}} \frac{(-1)^{m-k+s}\cos^{2l+k-m-2s}(\beta/2)\cdot\sin^{m-k+2s}(\beta/2)}{(l+k-s)!s!(m-k+s)!(l-k-s)!} \cdot A_l^m(0,0,0). \end{aligned} \tag{2}$$

The corresponding examples of the rotation of the basic harmonics are shown in Fig. 1. Here the basic electric dipole antenna oriented along the *Z* axis was rotated 90 degrees so that the *Y'* axis coincided with the *Z* axis and the *Z'* axis coincided with the −*Y* axis.

With using this calculation it is possible to obtain a complete space of vector states of the basic antennas, which makes up the resulting multiplet structure. After this stage, it is necessary to set up an iterative search by iterating according to the following algorithm: (i) the most unbalanced multipole contribution is selected, i.e. the one that gives the largest amplitude to the required vector state, (ii) the base vector states being iterated are phased and normalized relative to the selected unbalanced contribution, (iii) the normalized one is subtracted from the required vector state. and a phased vector, which leaves behind a smaller difference, (iv) the steps (ii) and (iii) are repeated until the required convergence is achieved.

Finally, after achieving convergence, the sets of subtracted vector states, along with amplitudes, phases, and Eulerian rotation angles, can be compared with real prototypes of basic antennas and configured into a multiplet antenna.

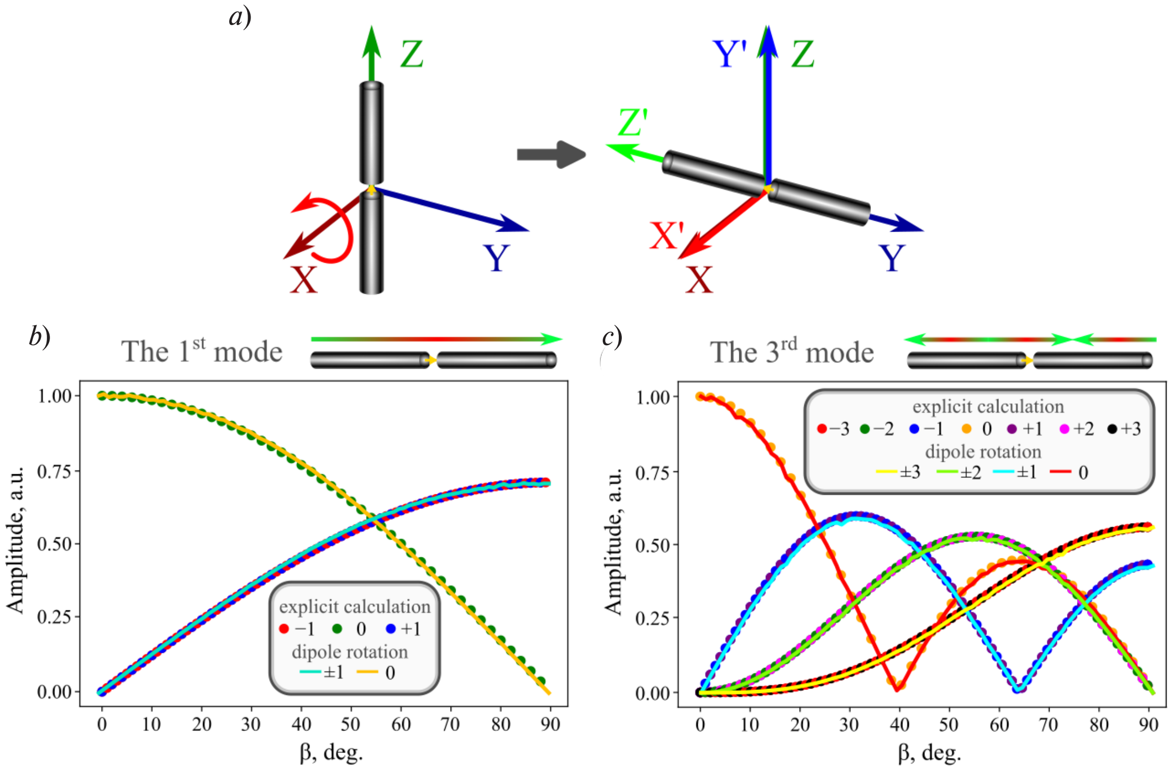

Fig. 1. Transformations of the basic antenna vector state during rotation: the axes rotation (*a*); comparison of the results of direct calculation using equation (2) with multipolar coefficients of the far field of a rotated dipole antenna at 1st (*b*) and 3rd (*c*) order mode

Conclusion

Within the framework of this study, the generalized algorithm for constructing a multiplet antenna corresponding to a complex radiation pattern with features using spherical harmonic decomposition was described. A method for numerically obtaining the space of basis vectors to ensure the convergence of the algorithm is considered, as well as the inclusion of asymmetric diagrams by adding states corresponding to Eulerian rotations.

The use of such an algorithm in modern communication networks in the design of antenna terminals can help to develop selective radiation patterns applicable in a wide range of tasks from space and defense industries to household multi-user networks.

REFERENCES

1. **Kammoun A., Alouini M.S.,** Elevation beamforming with full dimension MIMO architectures in 5G systems: A tutorial. IEEE Communications Surveys & Tutorials. 21 (4) (2019) 3238–3273.

2. **Ali E., Ismail M., Nordin R., Abdulah N.F.,** Beamforming techniques for massive MIMO systems in 5G: overview, classification, and trends for future research, Frontiers of Information Technology & Electronic Engineering. (18) (2017) 753–772.

3. **Jackson J.D.** Classical electrodynamics, John Wiley & Sons. (2021).

4. **Sayanskiy A., Belov A., Yafasov R., et al.,** A 2D-programmable and scalable reconfigurable intelligent surface remotely controlled via digital infrared code, IEEE Transactions on Antennas and Propagation. 71 (1) (2022) 570–580.

5. **Ma H., Kim J.S., Choe J.H., Park Q.H.,** Deep-learning-assisted reconfigurable metasurface antenna for real-time holographic beam steering, Nanophotonics. 12 (13) (2023) 2415–2423.

6. **Zhao D., Gu P., Zhong J., et al.,** Millimeter-wave integrated phased arrays, IEEE Transactions on Circuits and Systems I: Regular Papers. 68 (10) (2021) 3977–3990.

7. **He G., Gao X., Sun L., Zhang R.,** A review of multibeam phased array antennas as LEO satellite constellation ground station, IEEE Access. (9) (2021) 147142–147154.

8. **Burtsev V.D., Vosheva T.S., Sedov A.P., et al.,** On the Far Electric Field Extraction. In 2024 IEEE International Conference on Microwaves, Communications, Antennas, Biomedical Engineering and Electronic Systems (COMCAS) IEEE, (2024) 1–5.

9. **Burtsev V.D., Nikulin A.V., Seregin G.M., Filonov D.S.** (in publication). Geometry designing for an antenna with the given radiation pattern, Nanoindustry, Issue 11s, (18) (135) (2025).

10. **Schwinger J.,** Angular momentum, Springer Berlin Heidelberg, (2001).

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