Joint-stock company «Research & production corporation
«Lianozovo electromechanical plant»

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Electrically small antenna radiators with using impedance matched materials

PhD Dissertation Summary
for the purpose of obtaining academic degree
Doctor of Philosophy in Engineering HSE

Academic supervisor:
Doctor of Technical Sciences
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GENERAL DESCRIPTION OF THE RESEARCH

Relevance of the dissertation. Currently, modern mobile telecommunications devices such as smartphones, tablets, laptops, etc., they include antennas of different wavebands: LTE, 3G, GSM, Wi-Fi, Bluetooth, Glonass-GPS. Modern radar systems that include an antenna sheet with a large number of antenna radiators, automatic compensation systems for active interference, information transmission antennas and control commands, all of these devices require a given level of isolation between the various information transmission and control channels. In antenna arrays are trying to place, within the same receiving and transmitting canvas, the transmission, and reception of signals of different frequency ranges. Wherefore is necessary to solve the problem of reducing communication between the radiators in the antenna array. This connection can be reduced by increasing the electrical distance between the radiators by increasing the dielectric and magnetic permeabilities of the material into which the antenna radiators are placed. At the same time, to minimize the reflection of electromagnetic waves from the material-vacuum interface, the impedance of such material must be matched with the vacuum impedance. All this determines the relevance of creating electrically small antenna radiators using impedance matched materials.

The term impedance of the medium was introduced by Schelkunoff S.A. The question of the propagation of the concept of impedance to electromagnetic fields was also considered by Stratton J.A. He considered the solution of the problem of matching impedances of media and showed that for the absence of reflection of a plane wave from the interface of two media, it is necessary to have equality of wave impedances of these media. Materials whose impedance (wave impedance) is consistent with the impedance (wave impedance) of the vacuum, i.e. impedance matched materials were used by Kevin Buell and Antti Karilainen to reduce the operating frequency of already existing patch radiators. It should also be noted that most of the studies on the simulation of electrically small antennas are carried out using universal electromagnetic programs. Works on creating electrically small antennas based on

impedance matched materials using universal electromagnetic programs have been conducted for more than 10 years. At present, the prospect of development in electromagnetic modeling and the development of electrically small antenna radiators using impedance matched materials is an important trend in antenna technology.

An object of the research. Radiators of antennas, including in their composition impedance matched materials, for navigation and communication antenna systems.

A subject of the research. Regularities, techniques, analysis and synthesis of antenna radiators, including impedance matched materials, for navigation and communication antenna systems.

The purpose of the research is to develop a radiator using impedance matched materials compatible with a vacuum to create antenna systems with the smallest possible overall dimensions and specified electrical characteristics for solving problems of navigation and communication.

Scientific problem. Development of an electrically small antenna radiator using impedance matched material compatible with a vacuum with the maximum achievable gain value for a given dimension.

To achieve this goal, the following **scientific problems** are solved in the dissertation**:**

1. Carrying out a numerical simulation of electrically small antennas using impedance matched material compatible with a vacuum.
2. Development of the method of synthesis of electrically small antennas using impedance matched material compatible with a vacuum.
3. Development of an automated software and hardware complex for multi-frequency measurements of directional patterns electrically small antennas.
4. Development of an electrically small antenna radiator using impedance matched material compatible with a vacuum.
5. Carrying out measurements and comparison with the calculated characteristics of an electrically small antenna radiator using impedance matched material compatible with a vacuum.

The scientific novelty of the results is as follows:

1. A radiator using impedance matched material compatible with a vacuum has two induction and two far-field zones, in which the limiting value of the gain for a given dimension according to the Chu criterion is achieved.

2. A method has been developed to increase the operating wavelength of existing radiators using impedance matched material compatible with a vacuum without changing their geometric dimensions.

3. An algorithm has been developed for managing the process and processing of measurement results for multi-frequency measurements of directional patterns electrically small antennas, which has reduced the cost of the software and hardware complex.

The theoretical significance of the research is:

1. A method has been developed to increase the operating wavelength of existing radiators using impedance matched material compatible with a vacuum.

2. The proposed radiator using impedance matched material compatible with a vacuum has two induction and two far-field zones.

3. On the universal electromagnetic programs, the properties of the proposed radiator are investigated and the maximum achievable characteristics by the gain factor are estimated for the given dimensions.

The practical significance of the research is:

1. For arbitrary radiators, by placing them in an impedance matched material compatible with a vacuum, the admissibility of displacement by 25% of the operating frequency range in the region of the long-wavelength range is shown.

2. The possibility of achieving the limiting value of the gain for a given dimension’s radiator when using impedance matched material compatible with a vacuum is shown.

3. An automated software and hardware complex for multi-frequency measurements of directional patterns electrically small antennas has been developed, which provides the required accuracy of antenna characteristics measurement at a reduced cost in 7 times, compared with the existing systems on the market.

The research method in the thesis, when considering electrically small radiators of antennas using impedance matched materials compatible with vacuum, it consisted of applying numerical simulations on modern electromagnetic calculation packages based on Maxwell’s equations and the principle of electromagnetic similarity

Thesis statements for defending

1. The maximum achievable for given radiator dimension, according to the Chu criterion the gain values are achieved in radiators with two induction and two far-field zones, which can be realized using impedance matched materials compatible with a vacuum.

2. The working frequency of the radiator can be reduced without changing the geometry when using impedance matched materials compatible with a vacuum.

3. The cost of automated software and hardware for multi-frequency measurements of the directional patterns of electrically small antennas using the positioning system and the developed software has been reduced by a factor of 7 as compared with existing on the market.

Conformity of work with a passport of specialty. The dissertation research is aimed at the development of electrically small antennas using impedance matched materials and contributes to the following areas of research "Engineering, electrical &

electronic; telecommunication" listed in the passport of specialty HSE "Engineering Sciences and Applied Mathematics":

1. Investigation of the phenomena of a passage of electromagnetic waves of different frequency ranges through media, their scattering, and reflection (first provisions for the defense).

2. Investigation of new processes and phenomena that make it possible to improve the efficiency of radio engineering, electronic and telecommunication devices and systems (second provisions for the defense).

3. Development of radio engineering, electronic and telecommunication devices and systems for their use in industry, biology, medicine, metrology and other branches of the national economy, including satellite systems (third provisions for the defense).

Approbation and implementation of the results a research. Within the framework of the dissertation research, two patents for the utility model were received: "Klimov's radiator" (RU No. 169311), "Godin's radiator" (RU No. 170118). The results of the research outlined in this dissertation were reported at the following conferences:

1. Konov K.I., Godin A.S. Complex for measuring radiation patterns of radiators APAR. // I International Symposium "Computer Measurement Technologies". 3 April 2015. Russia, Moscow.
2. Godin A.S., Gezha D.S., Drize A.D. Numerical electrodynamic modeling interior problem of the Sestroretskii cube. // II All-Russia Joint Scientific Conference "Problems of Microwave Electronics". 26-28 October 2015. Russia, Moscow.
3. Klimov K.N., Godin A.S., Kruglov A.I., Tsai A.B. Numerical electrodynamic modeling for the Huygens cube. // Moscow Electromagnetic Seminar IRE RAS. 1 September 2015. Russia, Moscow.
4. Godin A.S., Perfilyev V.V., Drize A.D., Klimov K.N. Using impedance matched material to measure the frequency range of radiators. // XXIII International Scientific and

Technical Conference "Radiolocation, navigation, communications". 18-20 April 2017. Russia, Voronezh.

5. K.N. Klimov, I.K. Epaneshnikova, A.M. Belevtsev, A.S. Godin, A.D. Drize, Synthesis of structures of electric small-sized radiators using impedance matching materials for millimeter waves, SPIE Security + Defence, 11-14 September 2017. Poland, Warsaw.

6. Godin A.S., Stepanov E.I., Matsayan M.S., Klimov K.N. Electrically small radiators for advanced radar systems. // III All-Russian scientific and technical conference "Problems of microwave electronics" V.A. Solntseva. 8-9 November 2017. Russia, Moscow.

7. Victor Perfilyev, Konstantin Klimov, Andrey Godin. Construction of distribution systems of multibeam active phased array antennas. // Moscow Workshop on Electronic and Networking Technologies (MWENT-2018). 14-16 March 2018. Russia, Moscow.

8. Godin A.S., Klimov K.N. The use of impedance matched materials for the expansion of the frequency band of the antenna radiators. // VII All-Russian scientific and technical conference on the exchange of experience in the field of creating ultra-wideband radio-electronic systems ("Microwave-2018"). 17-18 April 2018. Russia, Omsk.

9. Godin A.S., Klimov K.N. Expansion of the band of operating frequencies for antenna radiators using impedance-matched materials. // International Scientific and Technical Conference «Systems of Signal Synchronization, Generating and Processing in Telecommunications» (SYNCHROINFO-2018). 4-5 July 2018. The Republic of Belarus, Minsk.

The main results of the dissertation work were implemented in the enterprise the design and production practice of JSC "R&P Corp. "LEMZ":

- An electrically small radiator was designed and manufactured using an impedance matched material compatible with vacuum, its electrical characteristics are measured;

- An automated software and hardware complex were developed for multi-frequency measurements of radiation patterns for electrically small antennas;

On the theme of the dissertation, prizes were awarded at the following competitions:

- Laureate of the Moscow Government Prize for Young Scientists for 2018 in the field of "Electronics and Communications";
- 1st place in the XX city competition government of Moscow professional skills "Moscow Masters" by profession electronics engineer;

The author's personal contribution consists in direct participation in the formulation of research problems and their solution, the creation of a method for increasing the operating wavelength of existing antenna radiators using impedance matched materials without changing their geometrical dimensions, which reduced the operating frequency of the radiator by 1.5 times and reached the maximum achievable according to the criterion Chu the values of the gain of the radiators. Personally, the author proposed and investigated two new electromagnetics objects: the external Huygens cube and the external Sestroretskii cube, which allow estimating the maximum achievable parameters of antenna radiators of given dimensions using numerical simulation using universal electromagnetic programs, which made it possible to determine the radius of a sphere (hemisphere) from an impedance matched material to increase working wavelength of existing radiators. Godin A.S. has developed a control algorithm for the process of conducting and processing the results for measuring the directional patterns of electrically small antennas, which provides the desired accuracy of measuring antenna characteristics while reducing the cost by 7 times compared to existing complexes on the market. Personally, the author and the participation of the author was prepared the main publications on the work performed.

As part of the dissertation research, Godin A.S. as an author and co-author received two patents for a utility model: № 169311, № 170118.

The reliability of the results and conclusions formulated in the research is confirmed:

- using numerical simulation methods based on Maxwell's equations;
- the corresponding results to fundamental physical principles;
- carrying out experimental research.

Main results of the research

In solving the problems posed in the thesis, the following results were obtained:

1. The maximum achievable for given radiator dimensions according to the Chu criterion the gain values are achieved in radiators with two induction and two far-field zones, which can be realized using impedance matched materials compatible with a vacuum.

2. The working frequency of the radiator can be reduced without changing the geometry when using impedance matched materials compatible with a vacuum.

3. The cost of automated software and hardware for multi-frequency measurements of the directional patterns of electrically small antennas using the positioning system and the developed software has been reduced by a factor of 7 as compared with existing on the market.

Thus, a radiator was developed using impedance matched materials compatible with a vacuum to create antenna systems with the smallest possible overall dimensions and specified electrical characteristics for solving problems of navigation and communication problems, i.e. the goal set in the thesis has been fulfilled.

This study will further allow miniaturization of antenna systems for advanced communication and navigation systems. The use of impedance matched materials in antenna radiators allows to increase the isolation between antenna radiators, reduce the thickness of the antenna sheet, increase the viewing area of the antenna array, reduce the backscatters of the antenna. Impedance matched materials may also be used to reduce the visibility, for example, of UAVs (unmanned aerial vehicles), since not only are the dimensions of the antennas are reduced, but their effective area of scattering is also reduced.

Publications

The results of the thesis submitted for defense are reflected in the publications listed below.

All these works are published in peer-reviewed scientific journals that are part of the Scopus and Web of Science citation systems

1. Godin, A.S., Tsai, A.B., Klimov, K.N. Numerical electrodynamic analysis of the interior problem for a Huygens element that is an interior Huygens cube. // J. Commun. Technol. Electron. Vol. 60, No 4, pp. 329-334, 2015.
2. Godin, A.S., Tsai, A.B., Klimov, K.N. Numerical electrodynamic analysis of the external Huygens cube. // J. Commun. Technol. Electron. Vol. 60, No 5, pp. 468-485, 2015.
3. Godin, A.S., Tsai, A.B., Klimov, K.N. Numerical electromagnetic investigation of patterns of the external problem for the Huygens element that is the external Huygens cube. // J. Commun. Technol. Electron. Vol. 60, No 7, pp. 695-704, 2015.
4. Godin, A.S., Matsayan, M.S., Klimov, K.N. Numerical electrodynamic analysis of the external Sestroretskii cube. // J. Commun. Technol. Electron. Vol. 61, No 5, pp. 453-468, 2016.
5. Godin, A.S., Matsayan, M.S., Klimov, K.N. Numerical electrodynamic investigation of the interior 3D problem of the Sestroretskii cube. // J. Commun. Technol. Electron. Vol. 61, No 6, pp. 574-586, 2016.
6. Godin, A.S., Matsayan, M.S., Klimov, K.N. Numerical electrodynamic analysis of the far-field patterns of the external Sestroretskii cube. // J. Commun. Technol. Electron. Vol. 61, No 7, pp. 776-782, 2016.
7. Klimov, K.N., Godin, A.S., Matsayan, M.S. On the possibility of existence of a self-consistent solution for an electromagnetic field in vacuum. // J. Commun. Technol. Electron. Vol. 61, No 10, pp. 1091-1094, 2016.
8. Godin, A.S., Klimov K.N. Expansion of the band of operating frequencies for antenna radiators using impedance-matched materials. // International Scientific and Technical Conference «Systems of Signal Synchronization, Generating and Processing in Telecommunications» (SYNCHROINFO-2018). 4-5 July 2018. The Republic of Belarus, Minsk.