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**DROP-SHAPED ANTENNA RADIATION AND ITS
INTERACTION WITH THE USER**

SPECIALITY 01.04.03 - RADIOPHYSICS

**ABSTRACT
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Scientific-Attestation Council’s Scientific secretary,

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Actuality.

1. Personal Communication devices have become an important part of everyday life. It is hard to imagine today's society without computers, TV and radio. Mobile phones enlarge communication abilities between people significantly and make the work of emergency services easier. There is a strong competition between manufacturers due to wide selection of mobile phones. Consequently, demand for convenient portable devices that are light and small in size is ever increasing. Antenna is an important part of such devices. The future of electronic devices depends on future improvements and modernization of antennas.

The geometrical, mechanical and electromagnetic characteristics of modern antennas should satisfy many important and in many cases contradictory requirements. Particularly, antennas are desired to be small in size (especially for mobile phones) and well matched with the feeding cable and the free space. At the same time, antenna is desired to have wide range of operation frequencies and good radiation capabilities in this frequency band. In addition, antennas should have directed radiation to provide maximum user security from the radiation of antenna. Unlike electronic chips, size of antennas of mobile devices is mostly determined by the laws of physics, rather than by capabilities of modern technology. Size of an antenna as a function of wavelength influences antenna radiation parameters the most. Actually, antenna is used for conversion of directed waves to radiation waves and vice versa. To do this, antenna must have a size of the same order as the wavelength. This requirement provides a resonance frequency for antenna. Of course, Antennas can be smaller than the wavelength, but such antennas will have low efficiency of radiation and narrow frequency band. So, some compromise has to be made between antenna's size, frequency band and efficiency. The main goal is to create antenna that is small in size and compatible with given device, considering its radiation characteristics. For production, investigation and optimization of new antennic devices numerical experiments have to be made before real ones. Real (laboratory) experiments are expensive and don't enable smooth variation of some characteristics of antenna to determine the best values of those characteristics.

2. It is well known, that antenna characteristics undergo undesirable variation due to influence of the nearby objects. In particular, working resonance frequency and antenna's radiation efficiency changes significantly and sometimes even deviates from the norm. Therefore, when modeling antennas, it is important to get exact

picture of diffraction of radiated wave on large body located nearby antenna. Till now, computational technology allowed to investigate antennas only in low frequency areas. Today we can do such modelling in wider range of frequencies, including high frequencies too. Level of difficulty of modelling increases as the importance of taking into account interaction between antenna and nearby located electromagnetic structures becomes greater. It's especially important to consider antenna's interaction with the human body. Solving 3D electromagnetic problems is very important from the practical point of view, since 2D tasks give only qualitative pictures of a physical process. We have used The Method of Auxiliary Sources (MAS) in our task. In contrast with other methods, this one allows us to conduct complex study of antenna's characteristics. However, considerable increase of the number of unknowns in 3D problems restricts such investigations due to limited computing resources. Despite this problem, optimization of MAS provides efficient solution of antenna problem as it is shown in the presented dissertation.

The aim of the dissertation is to

1. Create a real antenmic structure with directed radiation that satisfies modern demands. The first step is creation of the computer model of antenna considering its axial symmetry. This fact is important for optimization of numeric calculations and modelling;
2. Develop numerical algoritms and create a software package with the user friendly interface for computer simulations of antenna operation. Software package allows easy and smooth variation of antenna's geometric and physical characteristics in order to conduct its numeric investigations. In addition, the software should allow multiple investigations of antenna characteristics for getting optimal parameters needed for construction of a real antenna;
3. Get optimal geometric and electromagnetic characteristics for antenna prototyping, based on numerical experiments; Create prototype of antenna; Make experimental measurments and compare obtained results to those from numerical experiments;
4. Study interaction between antenna and the user and create an antenna model with directed radiation that minimizes penetration of radiation in user's body. Create a prototype of antenna with directed radiation and conduct a real experiment.

Propriety of results.

We have used MAS algorithm in our work. This algorithm allows us examine and audit accuracy of solution, with consideration of boundary conditions on cable's and antenna's surfaces; from point of view of energy conservation law; with theoretical analysis of received data; with comparison of numeric results to analytical solutions. In addition, in cases of different shapes of antenna, obtained numerical results agreed with those of experiments. This fact also shows propriety of the used algorithm. Error of Electromagnetic characteristics of antenna obtained from numerical results is bounded to 4-5%.

Novation of dissertation.

1. New, drop shaped antennic structure is introduced. Diffraction problem on this new structure has been solved. Dependence of diffraction characteristics on the geometry and electromagnetic characteristics of the structure has been investigated using MAS. It is shown, that this EM structure can trap and reradiate electromagnetic field in free space at the resonance frequency. Thus, this structure can be used as effective antenna.

2. 3D computer model of drop shaped antenna fed by the coaxial cable is considered. Electromagnetic characteristics of antenna have been investigated using both, MAS and the hybrid method. The latter includes MAS and coaxial cable eigenfunctions' expansion method (EFEM). Based on numerical results, optimal parameters of antenna have been found.

3. Prototype of symmetric antenna was created at LAE and appropriate measurements were made. Antenna's size was 6x6x13mm. Prototype was covered with 2mm layer of dielectric ($\epsilon=4$). As experiments show, antenna has a resonance frequency at 4.58Gh due to its geometry and dielectric permittivity. Radiation loss at the resonance frequency was -15db. This means that more than 80% of energy was radiated. At the same resonance frequency with radiation loss of -10db, radiation frequency band was 30% and 29% according to real and numerical experiments respectively. Numerical calculations coincided with experimental results. This gives us a good reason to continue our research using numerical methods. Antenna is able to get excited at the resonance frequency and radiate transmitted field from the feeding cable to free space. Antenna has a wide band of radiation frequency and is well matched with the feeding cable and free space. So, this kind of antenna meets requirements proposed in this dissertation.

4. The software package for engineering application was developed to carry out the numerical experiments. This software does not require from the user deep knowledge of mathematical apparatus and the method of solution used. Using this software the electrodynamic features of the antenna were investigated in the frames of Electromagnetic Compatibility (EMC) problems and its qualitative characteristics were found. The optimum parameters of the antenna were also found to provide its most efficient operation and recommendations were given for construction of a new type of adaptive antenna for cellular communications.

5. The next goal of our investigations was to study the influence of the antenna on the user's head. As a head model an IEEE standard head has been taken with material parameters $\epsilon = (45,9)$; $\mu = (1,0)$; $\sigma = 1\text{mho/m}$. Our research results agreed with results of other researchers, namely, energy absorbed in the head is approximately 70% of the feeding power of the corresponding radiation.

6. Characteristics of antenna with Directed radiation pattern were studied. One side of antenna was covered with metal. Using the metal cover we can preserve all necessary characteristics of antenna and in addition, we can decrease radiated power and optimize antenna parameters. In this case, influence of human head on antenna characteristics also decreases and user is better protected from undesirable influence of antenna radiation. Reason for having directed radiation in halfspace is the decrease of interaction of user's head with antenna and the rational use of radiated energy. Radiated field diagram was studied at distances of 4cm, 5cm and 1000cm from antenna. Those diagrams are similar in form, which means, that we don't have a reactive field in near field distribution and running wave is forming nearby the antenna. In other words, antenna is well matched with the free space.

7. Prototype of antenna with directed radiation was built for the real experiment. Antenna's sizes were 6x6x18mm. The prototype was covered with the 2mm dielectric layer ($\epsilon=4$). Dependence of radiation loss on frequency was measured. At the first resonance frequency (3Gh), radiation frequency band was 27% with -6db, while at the second resonance frequency (7.4Gh) it constituted 9.3%.

Practical value of the dissertation is mainly as follows:

1. Computer model of new type of antenna is introduced. Prototype of proposed antenna is created and its electromagnetic characteristics are studied. Experimental measurements show correctness of the proposed idea. This fact allow us to continue numerical research for finding optimal parameters of antenna. Model of

created antenna after some modifications may be used in several practical cases. For example, one may use such antennas in base stations of coaxial communications, in computer technologies for wireless communications and so on.

2. Proposed antennic structure is modified for mobile phones. Namely, one side of antenna is covered with the metallic layer, which allows to get directed radiation and preserve all necessary characteristics for better quality of communication, decreased radiated power and increased lifetime of energy sources (batteries). At the same time, it protects the user from undesirable influence of EM radiation. Prototype of directed antenna is created and appropriate experimental research is conducted. It's shown, that presented antenna can be used as a starting model for mobile phone production. The new type of adaptive antenna for cellular communications is presented.

3. The special software package intended for engineering applications was developed. It helps the antenna designer to simulate the operation of future antennas in different environments and study its EM characteristics. Software package enables to investigate the proposed antenna structure excited by the coaxial cable and study its radiation capabilities, with changing geometric and physical parameters of antenna. Interaction between user's head and antenna is also taken into account. This program can also be used as a demonstration tool in physics courses at the universities. Students can study antenna problems and make observations and measurements in a real time.

Contribution of the author: The main results presented in the dissertation are obtained by the author. In the publications made together with co-authors the author made the computer model, Antenna prototypes, found out the efficient algorithm, developed the computer code and took part in computer simulation as well as in interpretation of physical results.

Publication and approbation of the main results of the dissertation. The main results are published in 6 refereed proceedings of international conferences and symposiums and 1 refereed journal. Results were also presented at the following international conferences:

1. IEEE AP-S International Symposium, Boston, Massachusetts, July 8-13, 2001, pp.738-741.
2. IEEE AP-S International Symposium, San Antonio, Texas, June 16-21, 2002, pp.34-37.

3. Proceedings of International Conference on Mathematical Methods in Electromagnetic Theory, MMET-2002, September 10-13, 2002, Kiev, Ukraine. pp. 485-487.
4. Seminar/Workshop on Direct & Inverse Problems of Electromagnetic & Acoustic Wave Theory, DIPED-2002, October 10-13, 2002, Tbilisi. pp. 61-64, pp. 102 - 105.

Author himself presented results at MMET-2002, where he received the first degree diploma and prize for the best presentation and at DIPED-2002, where the author received a diploma and prize.

Structure of dissertation. The dissertation consists of introduction, three sections, conclusion and the references to the used literature.

Overview of the dissertation.

In **introduction**, actuality of the dissertation, role of antennas today, antenna's requirements and lower limits of its size as well as antenna's size reduction methods and limitations are discussed. Influence of radiation on biological objects is overviewed. Brief overview of the main existing numerical techniques for solution of problems of electrodynamics is presented. The range of parameters for their efficient usage in particular problems is also discussed. Short overview of already completed research in antenna theory and experiments at the LAE and the future research directions are discussed.

8. **Section I.** In this section diffraction problem is solved on drop shaped antennic structure. As a model of feeding source an electric dipole located along z axis was chosen. Short description of MAS is given in the first paragraph.

In the real case it is required to use a coaxial cable as a feeding source. At the first stage it is more convenient to investigate new antennic structure using dipole source, which is a simplified model and its EM field describes radiation of open cable in some approximation. Dependence of diffraction characteristics on the geometry and electromagnetic characteristics of the structure is discussed and investigated. Near field dynamical distribution at the resonance frequency is given. It's shown that such antennic structure has the ability to trap field at the resonance frequency and to reradiate it in the free space. Obviously, such structure can be used as a real, effective antenna.

Section II. Electromagnetic characteristics of a drop shaped antenna fed by the coaxial cable are considered. Main attention is paid to matching antenna with the

feeding cable and the free space. It is shown that running wave is forming nearby the antenna, meaning that antenna is well matched with the free space. It is also shown, that this EM structure has a very good ability to trap and then reradiate electromagnetic field into the free space at the resonance frequency. This structure has wide band of radiation frequencies as well. Description of antennic structure is given in the first paragraph. We consider radiation of open coaxial cable using MAS and hybrid method in the second paragraphe. Both methods give identical results. Experimental results and their comparison to numerical ones are also presented. Near field distributions and Dependence of electromagnetic characteristics of antenna on geometric and and electromagnetic parameters are investigated. Experimental and numerical results for antenna's prototype are compared and presented. Antenna's characteristics at the working frequency (0.9-2GHz) are investigated and recommendations for coaxial base stations and designers of antennas for cellular handset are given.

Section III. We investigate antenna's interaction with user's head in this section. IEEE standard head model with $\epsilon = (45,9)$; $\mu = (1,0)$; $\sigma = 1\text{mho/m}$ is taken for this purpose. SAR distribution is investigated and presented in different cross sections of the human head. Also, radiation diagram is calculated (head antenna interaction was taken in account) and presented. Characteristics of directed radiation antenna are investigated for a SAR reduction. In this case, one side of antenna is covered with metal layer, that helps reduce power of radiation and optimize antenna parameters for user safety. Results of the real experiment conducted on the prototype of antenna with the direct radiation are presented. Namely, dependence of radiation loss on radiation frequency is shown. In separate pagargaph description of developed software is presented. The computer program was created for engineering applications, particularly for simulation of the antenna operation and for finding its best parameters. The development of the mentioned program is important from engineering point of view, because eases investigation and analysis of the antenna structure. The software is created in compliance with at the standards of existing similar packages and requires from the users the minimal knowledge of computers, mathematics and the physical method used for solution. The section describes the software in full.

Conclusion. The main results of the dissertation are presented.

The main results of the dissertation.

1. 3D Computer model of a drop shaped antenna fed by the coaxial cable is introduced. Electromagnetic characteristics of antenna are studied using MAS and hybrid method (includes MAS and (EFEM)). Based on results of the numerical research, prototype of antenna was made and laboratory experiment has been carried out. Numerical data is in good agreement with the experimental data. Antenna has a wide band of radiation frequencies and can trap field at resonance frequency and reradiate it in free space.

2. Interaction between antenna and user, namely, SAR distribution in user's head is studied. The new type of directed radiation antenna for portable cellular handsets is presented. It provides all necessary characteristics for reliable communication and at the same time reduces the total output energy, protects the users from unwanted EM radiation, forms the required pattern with useful redistribution of energy and prolongs the life time of feeding batteries.

3. The software package for engineering application was developed to carry out the numerical experiments. Software package allows investigation of the proposed antenna structure excited by the coaxial cable. This package eases variation of the geometric and physical parameters of antenna thus allowing us to conduct a detailed study of its radiation capabilities. Interaction of the user's head with the antenna is also taken into account. This program can also be used as a demonstration tool in physics' courses at the universities. Students can study antenna problems and make observations and measurements in a real time.

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უფასო

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