Improvement of the electromagnetic compatibility of multi-port waveguide structures based on artificial neural networks and genetic algorittm

The head of scientists teams

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PROJECT PROPOSAL

Project Title:

Improvement of the electromagnetic compatibility of multi-port waveguide structures based on artificial neural networks and genetic algorittm

Participants:

	Number	Person - Days of Efforts
Weapon Scientists	21	3724
Total Participants	22	4044

Project Summary:

A huge number of problems of mathematics, technology, science, medicine and economics may be considered as the optimization problems. Exactly to the application of the methods of optimization in the problems of designing the devices of super high frequencies (SHF) and antenna systems is devoted the proposed project. The target of the project is development of the strategy of optimization for geometric and physical parameters of multi-port waveguide junctions (both opened and closed), containing the system of matching heterogeneities of different types (system of inductive diaphragms, system of inductive tapes, system of inductive rods), which will help to manage practically more easily the electrodynamic characteristics of the systems in question.
Growing requirements concerning an increase in the effectiveness of functioning of radio-electronic and communication systems as a whole and their structural, transmitting and converting elements cause the need of creating new adequate mathematical and numerical algorithms for their computer design.

Within the framework of the project the following works will be executed:
A strict electrodynamic analysis of the closed multi-port waveguide junctions (branchings) with included system of different type artificial heterogeneities will be carried out;
A strict electrodynamic analysis of the open multi-port waveguide junctions (branchings) with included system of different type artificial heterogeneities will be carried out;
A package of programs with improved attributes for the visualization of the geometry of structures and calculation of different physical characteristics and field distributions (2D, 3D drawing) will be created.
As a result of optimization of the parameters of systems concrete recommendations for creating the basic elements of SHF devices and antenna systems will be proposed.
Electromagnetic analysis of complex metal-dielectric double-periodic frequency-selective and polarization-selective structures to design artificial planar meta-layers for applications in open radiating systems.
Electromagnetic analysis of open circular patch multi-port radiating structures

It is intended to accomplish optimization of the parameters by the method of artificial neuron networks and genetic algorithm; it will be given out concrete recommendations of application of each of them in the specific problem.
In solution of the problems within the framework of the project the following methods will be used: method of partial regions, the method of images, the theories of complex variable functions and generalized functions.

The results, obtained after the realization of this project can be used for creation of basic elements of SHF devices (based on planar and volumetric integrated circuits) and antenna systems (especially for creating integrated antenna systems of flight vehicles).

1.8 Project Facilities:

Computers;

Printers.

1.9 Project Science and Technology Areas:

Primary: Industrial Technologies

Secondary: Physics

1.10 Total Estimated Project Cost by Year:

Cost Estimate (in USD)	Year1	Year2	Year3	Total
Grant Payments				
Equipment				
Materials				
Other Direct Costs				
Travel				
Overhead				
Total STCU Financing Requested				**269000**

1.11 Project Description:

1.11 Introduction

What's the problem?

A huge number of problems of mathematics, technology, science, medicine and economics may be considered as the optimization problems. The aim of optimization algorithm is to find such a solution, which satisfy the set system of restrictions and maximize or minimize the objective function.

This project intends to perform the multi-parameter optimisation of constructive and material properties of multiport waveguide junctions based on a conception of neuron networks [1-6] and genetic algorithm, original approaches of which applied to digital telecommunication problems have been found in works [3-6] of the supposed Project participants. So, the multiport waveguide junctions with a system of artificial inclusions and one-port and two-port waveguide branchings with open ends are taken as investigated objects, and the problem is to optimize the respective objective function assembled on the base of constructive and material parameters of the junctions and branchings.

1.12 Literature Search

What are other people doing?

The advanced trends in radio-electronic and communication systems development make the increased demands to the effectiveness and electromagnetic compatibility (EMC) of these systems as a whole, and their constructive, transmitting and transforming elements as well. These demands, in a large extent, also concern of multiport (three and higher order) waveguide junctions, that are widely used in microwave and fiber-optic engineering, microwave integrated circuits, photonic crystals based devices and other ranges as directional

couplers, power dividers, multiplexers, duplexers, phase shifters, filters, and other devices. [7-12].

At present phased antenna gratings are one of the most promising types of beam antennas. The possibility of rapid and flexible control of the parameters of phased gratings makes it possible to use them in the systems of space communication and in radioastronomy.

To some of the fundamental classes of phased gratings relate flat gratings composed of the open ends of waveguides. Such gratings are the fundamental type of scanning antennas in the radio systems, characterized by the high level of delivered power. Gratings from the open ends of waveguides are widely adapted as the antenna systems in flight vehicles, since they lack flanges and consequently they do not create additional problems in the aerodynamics of vehicles.

However, phased array potentialities can be realized with the availability of special high-frequency devices such as phase changers, switchers as well as various units of control and signal processing. The use of phased arrays with an electronic beam control implies the solution of a set of purely antenna problems, among which is a major problem of eliminating **t**he antenna parameters deterioration when scanning with a directional diagram.

The mutual influence of the emitters of scanning grating leads to such an unpleasant phenomenon as a "blinding" of grating at specific angles. It is known that this phenomenon is connected with three-dimensional resonances, which appear in the aperture of gratings, whose existence cannot be revealed without a strict electrodynamic analysis. This emphasizes the need for a strict statement and an exact (as it is possible) solution of boundary-value problems for phased antenna arrays [13].

Obtaining of new solutions should be based on application of new methods in analyzing and developing phased arrays. In spite of considerable progress in the field of phased array theory and design and widening their potentialities there still are some limitations for wide application of phased arrays with an electronic scanning in various systems and devices. These limitations are associated with complexity of design.

In the work [14] it is proposed the modified method of residue, by help of which the authors made it possible to solve the infinite system of equations, obtained in the problem on a grating of rectangular waveguides with dielectric coating. Calculations based on the method proposed in the work showed that with dielectric coating it is possible to reach an improvement in the characteristics of grating over a wide range of the angles of scanning.

For reaching the optimum agreement, selection of the parameters in antenna gratings with matching elements and dielectric substrate is the best when it is implemented by multiparameter optimization.

In comparatively early works [13-15], the theory of antenna gratings was considered in the approximation of an infinite periodic structure. Later appeared works dedicated to the development of the effective numerical methods of calculation for a final antenna grating from the plane-parallel waveguides under the dielectric layer [16].

However, it is necessary to note that the rigorous strict solutions of such problems are extremely useful for evaluation of the accuracy of results, obtained by numerical methods. Furthermore, without strict theoretical solutions it was not possible to reveal such an essential phenomenon as so-called complex waves along the dielectric surface with impedance.

In the work [17] a rigorous strict electrodynamic theory of the E- planar branching of waveguides in the form of the open end with infinite flanges and dielectric substrate is developed; and it is numerical results are obtained.

In order to efficiently utilize the modern communication systems, it is essential to create the communication lines with large carrying capacity and low energy losses. In brunching, dividing or transforming of signal energy in such the systems, it is necessary to provide an acceptable matching of waveguide arms, i.e. to provide a high enough quality of delivering of principal wave energy to a desired arm and its suppression in other arms. This task becomes even more important when maintaining stable characteristics of multiport waveguide junctions in a wide frequency band.

Multiport waveguide junctions with homogeneous filling do not fully satisfy the modern claims to their effectiveness and electromagnetic compatibility with other elements. Thus, investigation of three-port, T–junctions (waveguide tees), and also forth–port, cruciform waveguide junctions in E or H planes has shown [13-32], that practically applicable matching of waveguide arms can be achieved only in a narrow frequency band, and only for the certain cross-section size ratios of waveguide arms. Therefore, the problem of acceptable matching in a wide frequency band, all the more in multiport waveguide junctions, cannot be solved without constructional modification of junction geometry. This problem may be solved by including artificial inhomogeneities in the junction construction.

Up to recently, many efforts have been done to derive rigorous electrodynamics theories of homogeneous waveguide junctions, such as three-port, T–junctions [13-27], forth–port, cruciform waveguide junctions [28-32], Magic tee [33], and unsymmetrical three–port junction in E–/H–planes [34-35]. Also, many works are devoted to using artificial inhomogeneities, such as inductive pin, strips, diaphragms and so on, as adjusting elements for matching waveguide sections with different properties [36-45]. Inclusion of these inhomogeneities or their combinations into the construction is intended to transform wave impedances of waveguide sections to be matched. This initiates the intensive investigation of artificial inhomogeneities in multiport waveguide junctions [46-55], which indicates the topicality of this problem just today. However, since the most investigations in this topic concern of the single inhomogeneities, this does not allow obtaining the effective matching of waveguide arms in a wide frequency band. Also, electrodynamic analysis and optimisation should forego the serial production of multiport waveguide junctions with optimal matching characteristics.

Another promissing kind of antenna arrays are microstrip antenna arrays. Microstrip antenna arrays distinguish by design simplicity, small weight and manufacturability. On the base of the arrays the multi-feeder antenna system can be fabricated.

When exciting a microstrip array located on a grounded dielectric layer, considerable part of power can be reradiated into a surface wave. Selecting the array parameters one can obtain the phase front form close to linear, which makes possible effective and in-phase array exciting from rectangular waveguides.

Frequency-selective surfaces (FSS), representing double-periodic reflecting or transmitting screens, play an important role in contemporary antenna instrument engineering. On their base the microwave multi-frequency ground-based and space communication facilities, devices for signal transmission and processing were created and are in the design. To analyze physical properties of FSS in the form of doubly-periodic screens with openings the

development of new approaches and techniques for solution of three-dimensional diffraction problems is required. Creation of mathematical FSS models describing sufficiently rigorous their physical properties allows carrying out their in-depth analysis, revealing their inherent properties, determining the set of critical geometrical parameters, solving the questions of physical interpretation of resonance and abnormal phenomenon due to an electromagnetic wave scattering by such structures. Design of multi-element FSS and polarization changers in open transmission lines with new functions makes it possible to increase the capability of such devices and to create novel microwave devices with controlling characteristics.

In this project we plan to introduce and study novel artificial composite layered materials consisting of different kinds of metal-dielectric layers with periodically distributed densely packed complex-shaped slit discontinuities produced by inexpensive planar technology. We expect that it is possible to design materials for microwave applications with unique properties for frequency selective covers, polarization control, to prevent surface wave propagation along antenna substrates etc. These artificial layers are promised in the solution of problem of antennas compatibility improvement.

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1.13 Purpose and Objective

What are we going to do?

The most investigations in this topic concern of the single inhomogeneities, this does not allow obtaining the effective matching of waveguide arms in a wide frequency band. Also, electrodynamic analysis and optimisation should forego the serial production of multiport waveguide junctions with optimal matching characteristics.

The suggested Project is intended to fill up the existing gap in this area in the following directions:

to carry out the rigorous (full-wave) electrodynamic analysis of multiport waveguide junctions with including artificial inhomogeneities of various types (system of inductive pins, system of inductive strips, and system of diaphragms);

to carry out the rigorous (full-wave) electrodynamic analysis of a one-port and two-port waveguide branchings in the form of open ends with infinite flanges and the improvement of their electrodynamic characteristics by including different type matching elements in the waveguide parts of a system;

to create a user-friendly program package of common use with advanced attributes of visualization means for carrying out the numerical simulation, multi-parameter optimisation and physical analysis of the constructions under investigation;

to give the concrete recommendations on improving matching properties of multiport waveguide systems and a two-port waveguide branching in the form of open ends.

to carry out electromagnetic analysis of complex metal-dielectric double-periodic frequency-selective and polarization-selective structures to design artificial planar meta-layers for applications in open radiating systems;

to develop electromagnetic theory of open circular patch multi-port radiating structures.

1.14 Expected Significance

What's new?

We expect to carry out an electromagnetic analysis of novel meta-layers which are two-element thin periodic structures with a special regime of a trapped mode excitation as high quality factor FSS for application to improve antennas compatibility. For the first time we plan to study of eigenwaves of these meta-layers as well as layered periodic slabs for antennas applications to prevent propagation of surface waves excited by antenna elements.
It is planned to develop effective numerical algorithm of calculation of electrodynamic characteristics of open circular patch multi-port radiating structures, taking into account mutual coupling between the elements.

1.15 Organization, Qualification and Staffing

Who are we?

The suggested Project participants have a prolonged and productive experience in this area, which is justified by a number of publications [3-6, 24-26, 32, 39-45, 56-70]. First, the Project participants have developed the original theories of waveguide open branching with dielectric substrate[17]. and cruciform waveguide junctions [32]. Further, Project participants have been carried out the intensive investigation of artificial inhomogeneities in waveguides [39-45] and photonic crystals [56-58] and have experience in creation of advanced program packages [57,59, 67-70]. Finally, they have been developed the original theories of inhomogeneous waveguide junctions with single artificial inclusions [54-60], and multi-parameter optimization algorithms based on the conception of neuron networks [3-6]. The present Project is intended to develop and generalize the suggested earlier theories of inhomogeneous waveguide junctions on the case of sets of artificial inclusions, and thereby, to increase the number of degrees of freedom for the optimisation of matching properties and prediction of the most optimal constructions of waveguide junctions.

The project authors accumulate a great experience in investigation and calculation of microstrip antennas and arrays. Study was made of multi-element arrays of rectangular radiators; the procedure for constructive synthesis of microstrip antennas is developed [86, 87]. The characteristics are studied of low-profile asymmetric vibrator with a thin metallic disk on its top, which can be used as a microstrip array radiator [86, 88, 89].

The methods and codes have been developed by Ukrainian team's members to study electromagnetic properties of double periodic arrays of complex shaped metal strip particles placed on substrates [90-108]. They may be modified to solution the problems of antennas characteristics optimization.

Thus, the Project participants reveal all the necessary qualities and competence to successfully fulfill the tasks of the suggested Project, which is a continuation of the project of ISTC #G831 (2003-2005) and the project of STCU #4390 (2009-2011). The basis of this project is an accumulated theoretical, scientific, methodical, personal potential, and original works of the supposed Project participants on development of effective analytical and numerical methods of analysis of inhomogeneous waveguide problems.

1.16 Expected Results

What will be done in the framework of this project?

Within the framework of the project it will be received the follwing results:

Electrodynamic calculation of multi-port waveguide junctions with the included system of inductive strips, cylinders and diaphragms;

Electrodynamic calculation of open two-port waveguide branchings;

Neural algorithms of optimization for open and closed multi-port wave-guide junctions.

Creation of the user-friendly software package.

Electromagnetic analysis of complex metal-dielectric double-periodic frequency-selective and polarization-selective structures to design artificial planar meta-layers for applications in open radiating systems.

Electromagnetic analysis of open circular patch multi-port radiating structures.

1.17 Scope of Activities

How will the investigation be organized?

I Quarter

Formulation of the problem of diffraction of the principal wave on the system of cylindrical irregularities included in the basic arm of a wave-guide tee (WT). The system of integral equations;

2.1 Formulation of the problem of emitting electromagnetic waves (EMW) from the open end of an open two-port wave-guide branching (OTPWB) with included cylindrical heterogeneity. The system of integral equations;

3.1 Optimization as a problem of choice; objectives and problems of optimization; computational complexity of algorithms.

4.1 Problem Statement; creation of the object oriented conceptual model of the user-friendly software package software.

5.1 Statement of the problem of artificial planar metamaterials applications for improvement of antenna characteristics.

Statement of the problem of circular microstrip antenna with a dielectric substrate.

II Quarter

Derivation of the The system of algebraic equations in terms of with respect to the unknown coefficients of scattered field for the problem of diffraction of the principal waveguide wave by on the system of cylindrical irregularities included in the main basic arm of a waveguide tee (WT);

2.2 Derivation of the The system of algebraic equations in terms of with respect to the unknown coefficients of scattered field for the problem of radiation emitting electromagnetic waves (EMW) from the open end of an open two-port waveguide branching (OTPWB) with included cylindrical inhomogeneity heterogeneity; theoretical calculation of radiation pattern the directional characteristic function;

3.2 Imitation of annealing; growing neural networks; colony methods. Boltzmann Machine; consensus functions and maximization of consensus; synchronic and asynchronous functionality of Boltzmann Machine; travelling salesman problem.

4.2. Development of the Software package platform. Creation of the management panels and tools, geometry editor tools; CAD file import/export support for geometry objects.Development of the data Input/output tools.

5.2. Formulation of the problem of an electromagnetic wave scattering by a metal screen with a periodic set of complex shaped slits. The metal screen is placed on a dielectric substrate. Derivation of basic equations in the problem.

Development of algorithm of investigation of circular microstrip antenna with a dielectric substrate.

III Quarter

Processing, testing and verification of the programs of computer simulation of diffraction characteristics of WT with the system of cylindrical heterogeneities; Formulation of the problem of diffraction of the principal wave on the system of strips included in the basic arm of a wave-guide tee (WT). The system of integral equations;

2.3 Processing, testing and verification of the programs of computer simulation for the problem of emitting EMW from the open end of an OTPWB with included strip. Formulation of the problem of emitting EMW from the open end of an OTPWB with included strip. The system of integral equations;

3.3 Analysis of the algorithms for finding shortest paths; connectionist interpretation of transport problem; construction of energetic function. Genetic algorithm, efficiency of use of genetic algorithms and the ways of their improvement; applications of genetic algorithms and development directions.

4.3 Implementation of the Waveguide Tee (WT) with cylindrical irregularities in the software package. Creation geometry menu tools for WT. Implementation of the Open Two-Port Waveguide Branching (OTPWB) in the software package. Creation geometry menu tools for OTPWB. Development of Pre and Post Processing tools (2D graph plotting, scalar filed visualization tools).

5.3 Derivation of a set of equations for the solution of the problem of an electromagnetic wave scattering by metal screen with a periodic set of complex-shaped narrow slits.

Analysis of electromagnetic characteristics of a circular microstrip antenna with a dielectric substrate.

IV Quarter

Obtaining of the system of algebraic equations in terms of with respect to the unknown coefficients of scattered field for the problem of diffraction of the principal waveguide wave by on the system of strips included in the main basic arm of a waveguide tee (WT);

2.4 Obtaining of algebraic equations in terms of with respect to the unknown coefficients of scattered field for the problem of radiation of emitting EMW from the open end of an OTPWB with included strip;

3.4 Analysis of the algorithms for finding shortest paths; connectionist interpretation of transport problem; construction of energetic function. The generational genetic algorithm; adaptive genetic algorithm;multilayer genetic algorithm.

4.4. Creation geometry menu tools. Development of Pre and Post Processing tools (3D graph plotting, vector filed visualization tools).

5.4. Development of an algorithm for the solution of the problem of an electromagnetic wave scattering by metal screen with a periodic set of complex-shaped narrow slits.

Statement of the problem of phased arrays of circular patches.

V Quarter

Processing, testing and verification of the programs of computer simulation of diffraction characteristics of WT with the system of strips; Formulation of the problem of diffraction of the principal wave on the system of diaphragms included in the basic arm of a wave-guide tee (WT);

2.5 Processing, testing and verification of the programs of computer simulation of the problem of emitting EMW from the open end of an OTPWB with included strip. Formulation of the problem of emitting EMW from the open end of an OTPWB with included diaphragm;

3.5 Particle Swarm Optimization for a global optimization problem; description of PSO algorithm; the samples of solution of optimization problems by help of PSO algorithm and functional programming language Haskell.

4.5.1 Development of visual elements for the multiparameter optimization of open/closed multi-port wave-guide junctions/branchings.

4.5.2 Creation of the 3D object representation tools with OpenGL; EM field Animation tools.

5.5. Physical statement of a problem of eigenwaves of planar metamaterial consisted of periodic perforated metal screen placed on a dielectric substrate and main equations derivation in the problem.

Development of algorithm of investigation of phased arrays of circular patches.

VI quarter

Derivation of the The system of algebraic equations in terms of with respect to the unknown coefficients of scattered field for the problem of diffraction of the principal waveguide wave by on the system of diaphragms included in the main basic arm of a waveguide tee (WT);

2.6 Derivation of the system of algebraic equations in terms of with respect to the unknown coefficients for the problem of radiation of emitting EMW from the open end of an OTPWB with included diaphragm;

3.6 Optimization of WT with included system of irregularities using Boltzmann Machine, genetic algorithms and PSO;

4.6 Linking-up of the computational and optimizing programs for WT and CWJ with the system of cylindrical irregularities and free OTWB with the software package.

5.6. Development of an algorithm for the solution of the problem of eigenwaves analysis of artificial layers with complex-shaped periodic cells.

Processing, testing and verification of the programs of computer simulation of radiation characteristics of phased arrays of circular patches.

VII quarter

Processing, testing and verification of the programs of computer simulation of diffraction characteristics of WT with the system of diaphragms;

2.7 Processing, testing and verification of the programs of computer simulation for the problem of emitting EMW from the open end of an OTPWB with included diaphragm;

3.7 Optimization of OTPWB with included system of irregularities using Boltzmann Machine, genetic algorithms and PSO.

4.7 Analysis of thin periodic structures with trapped mode regime as high quality factor FSS for application to improve antennas compatibility. Study of eigenwaves of layered periodic slabs for antennas applications to prevent propagation of surface waves excited by antenna elements.

5.7. Analysis of electromagnetic characteristics of radiation of phased arrays of circular patches.

VIII quarter

1.8. Systematic System analysis of the diffraction and matching properties of inhomogeneous waveguide tees the structures considered in the project;

2.8. Systematic System analysis of the diffraction and matching properties of inhomogeneous open waveguides;

3.8 Comparative analysis of the considered methods of optimization for the problems within the framework of the project and recommendations for their use;

4.8. Elaboration of general recommendations on development and application of artificial metamaterial layers on the base of periodic structures of complex-shaped discontinuities in the antennas applications.

5.8. Investigations of electromagnetic characteristics of a surface wave excited in a dielectric substrate of a microstrip antenna composed of varied number of circular patch radiators. Elaboration of general recommendations on application of circular patch arrays for EMC in the microwave devices and antennas.

1.18 Technical Methodology

How will the science be done?

For realization of the stages of machine design for the structures being examined within the framework of the offered project it will be used the following methods:

In the process of mathematical simulation it will be used the methods of partial regions, Fourier transformations, mirror images, calculus of residues and generalized functions. As the result of using these methods it will be obtained the second kind infinite system of linear algebraic equations. In the problem of electromagnetic analysis of the complex-shaped element FSS and trapped mode meta-layers the method of integral equations on unknown electric fields in metallic screen openings will be used. To the research of electrodynamic characteristics of disk microstrip antenna and open circular patch multi-port radiating structures the rigorous Green's function method will be used. This approach will provide an ability to lead the considered tasks to the solution of integral equations related to unknown currents on the elements of considered structures.

B) For calculations the infinite system will be transformed into the finite system, for this purpose we use a method of reduction, for each problem the rank of reduction (and other parameters) will be determined individually. In the process of numerical simulation and analysis, there will be compiled programs for calculation of different characteristics; it will be built the graphs of dependences of these characteristics of considering structures within the framework of the project on different geometric and physical parameters, and also a graph of field distribution in the near zone; their physical analysis will be carried out. Solutions of the integral equations of the problem of electromagnetic field analysis in the periodic structures of meta-layers will be found by using the method of moments. The solutions of integral equations related to unknown currents on the circular elements of microstrip array antenna will be obtained with the help of the method of moments.

C) Optimization is suggested to be carried out based on the wide exploitation of SAI together with application of MANN (genetic algorithm, Boltzmann's machine and so-called PSO method). Particularly, the possibility of

application of neuron networks for solution of the problems of optimization of open and closed waveguide structures using the systems of artificial inclusions of different types will be considered; the effective algorithm for maximizing of the energetic parameters of such structures will be suggested; the numerical investigations will be carried out as well, as the comparison of the neuron algorithm with other, known algorithms.