Design of optimal constructions of open and closed inhomogeneity multi-port waveguide systems

The head of scientists teams

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Summary of the project

The urgency of the purposes of accomplished work is caused by the contemporary trends of development of radio-electronic and communication systems facing increasing requirements of improvement in the effectiveness of functioning as systems as a whole, and, also, as their component elements.

The urgency of purposes of the offered project is caused by the contemporary trends of development of radio-electronic and communication systems facing increasing requirements of improvement in the effectiveness of functioning both of the systems as a whole and their component element s.

Functioning of antennas and antenna systems of complex construction occurs against the background of interferences, that adversely affects the quality of radio communication between transmitter and receiver. Elimination or lowering in the energy level of such undesirable influence is one of the fundamental problems in the theory and practice of antennas, known by name electromagnetic compatibility (EMC).

To one of the fundamental classes of antenna gratings belong gratings formed from the open ends of waveguides. Such gratings are basic for those working in communication systems characterized by the high level of delivered power. Gratings from the open ends of waveguides are widely used in flight vehicles, because they do not form excessive protuberances on the housing and, therefore, they do not create additional problems and inconveniences in the aerodynamics of vehicles.

For the quantitative estimation of EMS of antenna systems it will be introduced so called compatibility function, which is the modulus of energy radiated by the system the side directions.

This function depends on the relative values of main geometric dimensions of the antenna system, it means that we have to find such necessary values of these parameters, for which the energy level radiated in the lateral sides would be minimum.

Multi-port waveguide junctions are widely used in the SHF technology as power dividers, antenna switchers, filters, phase inverters, etc.

For increasing the effectiveness of the functioning of multi-port waveguide junctions within the framework of radio-electronic and communication systems it is necessary first of all to increase passband and to decrease energy losses. Furthermore, during the branching, division and transformation of signal in such systems it is necessary to ensure acceptable agreement between the arms, i.e. sufficiently high level of transmission into the necessary arm and attenuation in the rest. And finally, for guaranteeing the stable work of a waveguide junction it is necessary to reach stable characteristics in the sufficiently broadband.

The SHF devices have no tuning elements; therefore their experimental study must be preceded by the machine design of such devices.

Machine design unites 3 stages: 1) Mathematical simulation; 2) Analysis; 3) Optimization.

Within the framework of the project it will be considered the following tasks:

a) waveguide tees (WT) with included system of heterogeneities of different types (system of inductive rods, diaphragms and tapes);

b) four-port waveguide junctions (FWJ) with included system of heterogeneities of different types;

c) open waveguide tees (OWT) with included system of heterogeneities of different types;

d) open four-port waveguide junctions (OFWJ) with included system of heterogeneities of different types.

In the process of mathematical modeling it will be used the methods of partial domains, mirror images, calculus of residues, generalized functions, and also original procedure of the conversion of multipole spectrum into the diffractive.

In the process of analysis it will be given the graphs of dependence of the fundamental characteristics of structures on the parameters of problems in question, and also the figures of field distribution in the neighbor zone. It will be carried out physical analysis of the obtained results; optimization will be carried out on the basis of wide use of artificial inclusions with application of the methods of structural synthesis and models of artificial neural networks (genetic algorithm, Boltzmann machine, PSO algorithm).

Finally, the authors of the project are intended to conduct the algorithmization of the above-enumerated tasks in the form of calculation program package with convenient interface and advanced elements for selection and visualizations of the geometry of structural elements, 2 D and 3D drawings of electromagnetic fields in the sections of waveguide, and also to give out concrete recommendations for the practical realization of systems with properties given beforehand.

Detailed Project Information

1. Introduction and Overview

The aim of presented project is elaboration of optimal constructions of open and closed inhomogeneous waveguide structures using the systems of artificial inclusions (SAI) of different kind (the system of inductive rods, diaphragms and bands), extrinsic photonic crystals (PhC) of the finite size, together with the application of the models of artificial neuron networks (MANN).

The actuality of the suggested project is provided by the modern tendencies of development of radio-electronic and communication systems, which assert more and more increasing requests pointing to the improvement of effectiveness of functioning as of the systems as a whole, as of their component elements.

More and more increasing requests pointing as to diminishing of the size, mass, overall dimension, as to increment in mobility, effectiveness and EMC of SHF devices and antenna systems, finally arrive to the tendency of miniaturization and optimization as of geometric, as of physical parameters of systems used in these constructions. This, in turn, provides the necessity of accounting of the waves of higher types (non-penetrating harmonics) appearing at the diffraction on different discontinuities. Therefore, it should be noted that one more factor determining the actuality of the project consists in aspiration of the authors to diminishing and optimization of the geometric parameters of functional and component elements as of SHF devices themselves, as of antenna systems.

In modern radio-electronic and communication systems the different types of antennas and antenna systems are applied, having different destinations and often located rather close to each other [1-6]. Functioning of antennas and antenna systems of complicated construction takes place against the background of the mutual noise that negatively influences on the quality of radio-communication between transmitters and receivers. Exclusion or reduction of the energetic level of such undesirable influence is one of the basic problem in the theory and practices of antennas, known as electromagnetic compatibility (EMC).

Accomplishment of far cosmos communication, development of radio-astronomy is mainly determined by the creation of optimally huge, big antennas. Highest saturation of surrounding by the radio-signals tends to adaptation to presented conditions, particularly, to creation of the adaptive antenna systems. Different objects (ex. aircrafts) hold dozens antenna devices of different range and purpose, thus, it is necessary to create the compatible electromagnetic systems, whose effectiveness is greatly dependent on the characteristics of the antenna devices. From the other hand, the antenna systems should provide the extreme characteristics, namely, rather low level of the side lobs, the maximal effect of utilization of the surface, wide band conditions, fast rule of radiation pattern etc. [7].

To one of the fundamental classes of antenna gratings belong the gratings formed of the open ends of waveguides [8-12]. Such gratings are the basic for the functioning of communication systems characterized by the high level of transmitted power (such antennas are widely used, for example, in cosmos communication and in radio-astronomy). The gratings formed of the open ends of waveguides are widely used in aircrafts, as they do not perform additional unnecessary lugs on the body of an aircraft and, thus, create no additional problems and inconveniences in aero-dynamics of the aircrafts.

Increment in flying speed, in maneuverability of aircrafts as well, as growth of the intensity of their movement within the operating zones of rule, greatly increase the area of the problems solved by radio-

technical apparatuses of aircrafts. During the design and construction of aircrafts arises the problem of location of great number of antennas within the body and provision of the needed vision zones for them and mutual communication. One of the solutions of the signed problem is creation of multifunctional (complex) log antenna-feeder systems, consisting of antennas, filters, switchers, couplers, rule blocks, making possible to radiate (receive) electromagnetic energy and to distribute it between different kinds of radio-apparatuses [13].

The effectiveness of utilization and scientific-technical application of achievements in spheres of radio-techniques, radio-physics and radio-electronics for applied purposes greatly depends on possibilities of an elements base (the sources of transmission and reception, the channel and oscillating systems). Thereupon the special importance is taken on the new methods of construction of SHF devices, based on planar (PIS) and volume (VIS) integral schemes. [14]. 3D construction of location of the basic elements and processing of the signal though its total volume, from the one hand, performs the wide possibilities for improvement of radio-physical, climate, radioactive and other parameters of the apparatuses, while from the other hand – requires creation of new adequate physical and mathematical models of basic elements. At the same time, the adequate models should be rather exact (electro-dynamic level of exactness) and make possible to determine the parameters within the time intervals convenient for automatic rule systems.

As the VIS in SHF so-called multi-cascade waveguide systems may be used, while the transfer between the cascades is carried out by waveguide fragments. Generally, VIS in SHF represents itself as rather complicated diffraction system and, thus, the analysis even of the simple functional junction at times turns to be very difficult and complicated problem. Way out is preliminary decomposition of the scheme into the compound elements (decomposition method) [15]. Usually, such elements are the discontinuities in VIS, holding the definite obligations (turning of the transmission line, transfer between the cascades, T-joint, break of a conductor etc.). Therefore, for the analysis of VIS rather definite meaning receives the investigation of the properties of multi-port waveguide couplings (including WT and FWC with SAI) [16-35].

For increasing of the effectiveness of functioning of multi-port waveguide couplings within the range of radio-electronics and communication systems, first of all, it is necessary to increase the bandwidth and to decrease the energy losses. Besides that, at the branching, division and transformation of the signal, in such systems it is necessary to provide the convenient compatibility into the needed arm and damping in others. And, finally, in order to provide the stability in the work of the waveguide coupling, the stabile characteristics within rather wide frequency band should be reached [36-38].

These aims may be reached by utilization of the artificial discontinuities [39-51]. Tuning elements or artificial inclusions (such as inductive rods, diaphragms and bands are) are inserted into the traditional waveguide couplings [52-68]. However, the analysis of characteristics of such couplings shows that the singular inclusions often are unable to reach the convenient level of compatibility of the waveguide arms and of the sufficient bandwidth of multi-port couplings. Therefore, for optimization of multi-port couplings the systems of such inclusions are considered in presented project.

In short-wave range and in quasi-optical diapason, where the creation of the traditional micro-wave devices with metal walls meets the serious difficulties, the elaboration of the analogs of traditional devices is suggested on the basis of nano-technologies (using frequency-selective nano-materials [69-71] and photonic crystals [69-75]).

For the quantitative estimation of EMC of antenna systems considered in the problems within the frames of the project so-called *compatibility function* will be introduced, representing the energy radiated by the system in the side directions, i.e. the energy level in the side lobs. This function depends upon the relative values of internal geometric parameters of antenna systems, thus, it is

necessary to select these values in such a way that the energy level in the side directions should be minimal.

SHFУ devices are free from tuning elements, thus, their experimental investigation should be preceded by the machine design of the structures.

The machine design unites within itself three stages: a) Machine modeling; b) Simulation and analysis; c) Optimization.

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For realization of the stages of the machine design for the structures considered within the frames of the project the following methods will be used:

a) During the process of the mathematical modeling the methods of partial areas, Fourier-transformations, mirror imaging, theory of residues and generalized functions.

b) During the process of simulation and analysis the graphs of dependence of the basic parameters of the structures considered within the frames of the project on different geometric and physical parameters will be received as well, as the patterns of fields distribution in nearby zone (the calculation programs will compiled by the executors of the project), their physical analysis will be carried out.

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.

At present time for increasing the speed of managing of modern waveguide systems the new methods of solution of engineer problems oriented on the computing systems with the parallel architecture are elaborated, and neuro-computer methods are perfectly inserted into this tendency.

Elaboration and investigation of neuro-computer approaches is one of the perspective branches of creation of the waveguide systems of new generation.

Application of these approaches is completely grounded for the solution of the optimization problems, including these of un-traditional staging, in the cases, when the sufficient exactness and the fastness of determination of the optimal solution is needed as well, as the high confiding probability to the reliability of received results.

Consequently, the presented project will be oriented on creation of the program complex of an engineer-elaborator for design and optimization of functional devices based as on traditional, as on complex, composite nano-materials. The authors of the project are intended to elaborate the algorithms for all problems, listed above, and to create the computing program complex with the suitable interface, with developed elements for selection and visualization of the geometry of the constructive elements (2D and 3D graphs of the electromagnetic fields in the cross-sections of waveguides) as well, as to issue the concrete recommendations for practical realization of the systems with in advance adjusted properties.

The executors of the project possess the abundant experience in investigation of inhomogeneous waveguide structures and waveguide couplings (branching) [19, 24-26, 41-68], antenna gratings [78-91] and studying of EMC of antennas and antenna systems [92-105].

Besides that, the participants of the project possess the original experience in investigation of impurity photonic crystals of the finite size [69-70] and of their applications for creation of the analogs of micro-wave devices with adjusted properties [72-74]. The photonic crystal – it is per se the artificial dielectric representing itself as the periodic dielectric structure inserted into another dielectric. Electrodynamic properties of such artificial material are considered by the crystallography of used dielectric grating, the geometry of its separate elements, the contrast between materials of the dielectric grating and the basic dielectric and the resonance properties of elements of the grating. Therefore, the photonic crystal is some analog of the real atomic grating but of the other scale. Moreover, as in the common crystals, in the photonic one exist so-called band gaps [69-70] − the diapason of frequencies, where penetration of waves of some polarizations inside the crystal is impossible.

If some defects are inserted into the photonic crystal – substitutions, insertions, dislocations or vacancies – then the wave can penetrate along the waveguide composed by them – and only along it (nowhere else). Different types and configurations of inserted defects compose the waveguides with different properties, admitting the waves of different polarizations and wavelengths [69]. Therefore, changing the kind of a material, and also the shape, character, location and intensity of impurities (inclusions) into the primitive cell of the photonic crystal, it is possible to rule the structure of band gaps in the photonic crystal, changing the character of penetration of electromagnetic waves inside them, in order to create the different analogs of the traditional micro-wave devices [72-77].

Also, the authors of the project possess the original experience in creation of MANN and their application in the digital telecommunication problems. As it is known, the neuron networks serve the calculation model, which conception is rather schematically inspired by the functioning of the real neurons (of humans or others), thus MANN may comfortably be used for solution of the optimization problems. Usually the neuron networks are optimized by studying methods of statistical kind. From the other hand, they keep within the frames of the family of methods of the artificial intellect, enriching them and allowing to get conclusions, based mostly on the perception, rather then on the formal logical deduction. It is known that the neuron networks were successfully used for the problems of classification, recognition, approximation of unknown function, for the fast modeling of known, but rather complicated functions, modeling of studying processes and improvement of teaching methods. Based on the results of the participants of the project and on the experience of studying of the problems of reliable transmission of the digital information at presence of the noise, the different MANN will be used for multi-parameter optimization and to discover the best constructive solutions, the elaborated antenna systems and the element base of radio-electronic devices.

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2. Expected Results and Their Application

The analysis of the characteristics of multi-port waveguide junctions shows that single inclusions do not allow to reach acceptable level of agreement between waveguide arms and sufficient broadbandness of waveguide junctions. Therefore, for optimization of multi-port waveguide junctions we consider the systems of such inclusions.

Within the frames of the project the following structures will be considered and optimized:

1. Waveguide triplets (WT) with SAI of different types;
2. Open WT (OWT) with SAI of different types;
3. Four-port waveguide couplings (FWC) with SAI of different types;
4. Open FWC (OFWC) with SAI of different types;
5. Multi-port functional devices based on the modern, frequency-selective nano-materials, including the devices, based on photonic crystals of the finite size. [69-75].

Within the framework of the project it will be studied the electrodynamic properties of considering structures, it will be built the graphs of dependence of electrodynamic characteristics on different geometric parameters of the problems, and also the figures of field distribution in neighbor zone. The algorithm for optimization of the geometric and physical parameters of the systems will be worked out for obtaining the best constructions with the properties given beforehand.

2.1. Sustainability Implementation Plan

2.1.1. Results to be promoted

The devices of SHF do not have tuning elements; therefore, their serial production and experimental study must be preceded by their theoretical and machine design of these structures.

The scientific value of the proposed project consists in the development of standardized methods of electrodynamic analysis and optimization of the constructions: irregular multi-port waveguide junctions

with included system of artificial heterogeneities, and also both free and irregular open two-port waveguide branchings.

The commercial significance of the project consists in the creation of competitive production, which will have wide area of potential application in the systems of emission of flight vehicles, radio-electronic and communication systems, antenna – feeders, microwave and fiber-optic technology, SHF integrated circuits, etc.

The economic and social significance of the project consists in the creation of scientific – technical production, which can be used for obtaining concrete products in different spheres of science and technology. Furthermore, scientific theories and packages of programs, obtained as a result of the realization of the project, can be used in the spheres of telecommunications, computer systems and networks, in the training processes of the university programs of corresponding specialties. The project will increase knowledge and habits of young doctoral candidates and student – programmers, it will help them in the independent setting and solution of scientific – technical problems.

2.1.2. Uniqueness of results

The structures considered in the project possess the following advantages: they may unite within themselves the purposes just of several number of functional elements, namely – in the case of closed waveguide structures (WT and FWC with SAI) at the same time they may serve as a filters (rejected and banded), wave types transformers, transitions between the cascades of VIS, power dividers and antenna switchers. While in the case of open structures (OWT and OFWC with SAI) they may be considered as multi-functional antenna-feeder systems, including antennas and filters. Changing the geometric and physical parameters of SAI it is possible easily, quickly and effectively rule the radiation pattern as well, as varying the types and parameters of SAI may be reached the retuning of antenna systems relative to the frequency parameter.

In the work the effective algorithms of solution of the optimization problems of open and closed waveguide structures, utilizing the system of artificial inclusions of different type, will be received. They are based on determination of the extremes of un-traditional generalized aiming functionalities, which may find in future the wide utilization in the applied electrodynamics for solution of the optimization problems.

The advantage of the given algorithm should become its universality probably it may be used for optimization of the waveguide systems through very different integral criteria.

2.1.3. Demand for results

The state and private companies, which deal with similar developments, are potential users of the developed technology.

2.1.4. Expected income

Main organization GTU plans to have profit from the results of the project by means of sale of technologies. Participants of the project have adequate experience in preservation of intellectual property and, then, sales of technologies. Participants have required infrastructure and prepared staff to manage with such activities.