Scientific session of the Division of General Physics and Astronomy of the Academy of Sciences of the USSR (21 December 1988)

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A scientific session of the Division of General Physics and Astronomy of the USSR Academy of Sciences was held on 21 December 1988 at the S. I. Vavilov Institute of Physics Problems of the Academy of Sciences of the USSR. The papers listed below were presented at this session.

Scientific session dedicated to the hundredth anniversary of the experiments of H. Hertz

1. V. V. Migulin. Hundredth anniversary of the work of H. Hertz on the experimental proof of the existence of electromagnetic waves.

2. G. I. Makarov, V. V. Novikov, and A. B. Orlov. On the propagation of kilometer and longer radiowaves.

3. V. I. Baĭbakov, V. N. Datsko, and Yu. V. Kostovich. Experimental discovery of Zenneck's surface electromagnetic waves.

A brief summary of the papers is given below.

V. V. Migulin. Hundredth anniversary of the work of H. Hertz on the experimental proof of the existence of the electromagnetic waves. The year 1988 marks the hundredth anniversary of the publication of the remarkable papers by Heinrich Hertz in which he on the basis of brilliant experiments proved the validity of the theory of electromagnetism created by Maxwell and demonstrated the possibility of exciting electromagnetic waves of the same physical nature as light waves by electrical oscillations at radio frequencies.

Having initiated at the suggestion of Helmholtz a search of experimental confirmation of the existence of displacement currents introduced by Maxwell Hertz began his research by developing devices capable of generating high frequency electrical oscillations and exciting electromagnetic waves. The vibrator constructed by him excited by a spark discharge, which later acquired the name of a Hertz vibrator, enabled him for the first time to obtain in laboratory conditions electromagnetic waves in the meter and decimeter ranges. In his experiments H. Hertz demonstrated the physical identity of electromagnetic waves obtained by him and light waves by establishing their transverse nature, polarization, possibility of refraction and by determining their speed of propagation equal to the velocity of light.

This incontrovertibly proved the validity of Maxwell's theory and laid the foundation for practical means of exciting electromagnetic waves at radio frequencies which several years later were utilized for transmitting information, i.e., for radio communication.

On the basis of Maxwell's theory H. Hertz developed a method of making calculations concerning the process of radiation of electromagnetic waves by means of a special vector introduced by him into the theory which is now known as the Hertz vector and which is used until the present time in designing antennas and making calculations concerning the propagation of radio waves.

H. Hertz was born in 1857, and his brilliant work which has been acclaimed worldwide was carried out when he was only 31 years old.

It should also be pointed out that Hertz in 1887 was the first to discover the phenomenon of the photoeffect, but H. Hertz having noted this phenomenon of the photoeffect, but H. Hertz having noted this phenomenon could not undertake its detailed study having devoted all his energies to the investigation of the electromagnetic waves.

He died early–in 1894 at the age of 37 and in his untimely death world science lost one of its most brilliant representatives. Hertz's name is now associated with the unit of frequency.

G. I. Makarov, V. V. Novikov, and A. B. Orlov. On the propagation of kilometer and longer radiowaves. The paper presents a brief discussion of the problem of predicting the propagation of radiowaves in the range of ultralong waves (ULW). A large number of papers has been devoted to the experimental and theoretical investigations of the laws of propagation of radiowaves in the ULW-range. References to them can be found in the review articles of Refs. 1–3 and the papers of Refs. 4, 5.

In order to improve the reliability and accuracy of the operation of radiotechnical systems in the frequency range under consideration it is necessary to have a global forecast of electromagnetic waves taking into account both the regular variations of the properties of the ionosphere (daily, seasonal, latitudinal ones corresponding to cases of different solar activity), and also the large-scale ionospheric disturbances of the VIV(SID) and PPSH(PCA) type.[1] Forecasting of electromagnetic fields can be carried out on the basis of a numerical solution of the direct problem of the field in a waveguide channel of given properties.

By now there has been developed a theory of the propagation of low-frequency radiowaves in a spherical waveguide channel with an anisotropic ionosphere whose properties vary both according to altitude and in the direction of propagation (in the longitudinal direction), and also according to the properties of the earth which is inhomogeneous both in depth and in the longitudinal direction. For the analysis and the numerical calculations of the electromagnetic field at distances from the source greater than 500-1000 km a representation of the solution is used in the form of a number of

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normal waves (NW), which is obtained as a result of applying to the solution of the Maxwell equations the method of cross sections. The NW series is essentially an expansion of the solution in eigenfunctions of the radial (altitude) operator of the problem whose coefficients (the complex amplitudes of the NW) are governed by a system of waveguide equations which consists of an infinite system of coupled ordinary differential equations along the longitudinal coordinate. In the case of a weakly irregular waveguide, the relative variation of the properties of which along a wavelength is small, in the absence of the phenomenon of degeneracy (the coincidence of the eigenvalues of the NW at a certain point of the propagation trajectory) the local transformation coefficients of the NW due to the irregularity of the waveguide turn out to be small, and one can restrict oneself in solving the waveguide equations with sufficient accuracy to the well-known WKB approximation which corresponds to neglecting the transformation of the NW. However, in some situations (at the day-night transition at frequencies of the order of 5 kHz, in nighttime conditions of propagation near the geomagnetic equator at frequencies close to 10 kHz, etc.) the phenomenon of degeneracy arises which leads to a strong transformation of the NW subject to degeneracy, and the conditions for the applicability of the WKB approximation are violated. In the case of local degeneracy along the trajectory of propagation taking into account the interaction of the NW undergoing degeneracy a single approximate solution of the waveguide equations has been constructed which is valid in the neighborhood of the point of degeneracy and which goes over into the WKB approximation outside it. Transformation matrices for the NW have been found in the case of passing through the degeneracy region, which demonstrate that beyond the degeneracy region splitting of the basic incident NW into two occurs which leads to appearance of interference effects.

The main computational difficulty of the method of cross sections is finding the eigenvalues of the radial operator. In this direction analytical investigations were carried out of the dynamics of eigenvalues involving asymptotic and direct variational methods and automated algorithms have been developed for calculating the eigen-values, eigenfunctions and electromagnetic fields which are relatively fast (5–10 s per eigenvalue, 4–8 min per typical inhomogeneous trajectory by using a computer of EC-1060 type).

The theory that has been developed of waveguide propagation of low-frequency radio waves does not take into account the variation of properties of the waveguide channel in the direction transverse to the propagation trajectory. The effect of this on the electromagnetic field can turn out to be essential when the incidence of NW on an inhomogeneity of the type of the day-night transition or the sea-land boundary is close to being tangental. The problem of evaluating the field in the presence of several degeneracy points also requires further development and creation of appropriate algorithms.

At small distances from the source it is convenient to use for calculating the field the representation of the solution in the form of a number of waves reflected from the earth and the ionosphere. One should only note that this series requires being augmented by waves of other types (in particular a wave of the "whispering gallery" type) and further analytical and numerical investigations of the role played by these waves at low frequencies are essential.

In solving the direct problem of the propagation of radio waves it is necessary to specify the properties of the waveguide channel, i.e., the map of geoelectric sections of the earth and the altitude profiles of the electron concentration and effective frequency of collisions of electrons in the lower ionosphere. Maps of the electrical properties of the earth based primarily on geophysical data are available for the greater part of the regions of the USSR. The construction of maps of the ionosphere presents a more complex matter. The reflection of radio waves of the frequencies under consideration is significantly influenced by regions of the ionosphere with a low electron concentration of the order of 10–200 electrons/cm^3, for measuring which the presently available local radio physical methods are not very useful. The empirical models of electron concentration constructed using the data of such methods as a rule do not determine the values of the concentration at altitudes below 65–70 km and therefore in fact cannot be used for forecasting the fields. Therefore a hybrid model has been developed in which the electron concentration above 70–75 km in the daytime and 95–100 km at night were obtained on the basis of the data of local methods and models generalizing them, while below that (up to 50 km)—on the basis of solution of the inverse problem using the data on electromagnetic fields measured at a number of points.[6] The model describes all the main regular spatial-temporal variations including the sunrise-sunset asymmetry in the regular daily variations at altitudes below 75 km, and also the auroral effects for a certain fixed average perturbation.

The comprehensive comparison that has been carried out of the ULW calculated according to the field model with the experimental data primarily for frequencies in the 10–30 kHz range for different geophysical conditions (solar activity, time of the year and day, geographical position and extent of the trajectories) showed that, as a rule, the discrepancies did not exceed the accuracy of the experimental data (0.3–0.5 rad in phase and 10–20% in amplitude).

In the case of large-scale ionospheric disturbances of SID and PCA type one should regard as the simplest, effective and promising method of forecasting ULW-fields the method based on the analysis of the current ULW-data, obtained using signals of radio stations at a number of control points and radiometric data. The basis for such a forecast is provided by the spatial-temporal models of the lower perturbed ionosphere[5] which enable one to recalculate the effects of perturbation in the ULW-field from one trajectory to another and from one frequency to another. The current correction carried out by this procedure reduces the effects of manifestation of perturbations by a factor of 3–5.

The materials of this report have been published in articles of Refs. 1, 4.

[1)]Transl. note. The Russian acronyms VIV and PPSh presumably stand for SID (Sudden Ionospheric Disturbances) and PCA (Polar Cap Absorption).

[1]G. I. Makarov, V. V. Novikov, and A. B. Orlov, Izv. Vyssh. Uchebn. Zaved. Radiofiz. **13**, 321 (1970) [Radiophys. Quantum Electron. **13**, 245 (1970)].
[2]A. B. Orlov and G. V. Azarnin, *Problemy difraktsii i rasprostraneniya voln*, Publ. by Leningrad Univ., No. 10, 3 (1970).
[3]G. F. Remenets, *ibid.*, No. 13, 3 (1974).

[4]G. I. Makarov and V. V. Novikov, *Abstracts of papers presented at the All-Union Conference on the Propagation of Radiowaves* (In Russian), Nauka, M., 1984, Part 1, p. 279.
[5]G. I. Makarov, V. V. Novikov, and A. B. Orlov, *Abstracts of papers presented at the XV All-Union Conference on the Propagation of Radiowaves* (In Russian), Nauka, M., 1987, p. 205.
[6]G. V. Azarnin, V. A. Kolsanov, and A. B. Orlov, *Problemy difraktsii i rasprostraneniya voln*, Publ. by Leningrad Univ., No. 21, 112 (1987).