MODELLING OF WIDEBAND IONOSPHERIC HF CHANNELS

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ABSTRACT

Modelling of the wideband HF ionospheric sky wave channel of propagation is discussed, which is based on the results of solving the general problems of HF propagation in the three-dimensional fluctuating ionosphere rather than on developing empirical models. Statistical moments of the ionospheric sky wave are constructed to characterise the HF ionospheric fluctuating channels. They are employed, in particular, to produce random time sequences of the HF field in the ionospheric channel.

By contrast to the empirically based wideband models, where the input parameters are not necessarily directly linked with the parameters of the ionosphere and transmitter-receiver path, the present approach is based on the theory of HF wave propagation in the real fluctuating ionosphere. The main goal of the consideration is to produce an as general as possible technique to solve the problem of the HF ionospheric propagation for realistic models of the ionosphere. As is well known, the ionosphere is an anisotropic dispersive medium with a smoothly inhomogeneous background, but also containing local inhomogeneities with a wide range of scales, thus having deterministic as well as stochastic components. The appropriate equations governing the propagation of the wideband HF signals through this complicated medium do not permit the separation of variables and cannot be solved analytically so that asymptotic methods and numerical methods need to be employed in modelling the effects of HF propagation in the real ionosphere.

The first step in the technique of modelling is the numerical, or analytic ray tracing for the background ionosphere, which implies different levels of complexity. When the background medium is considered as stratified and isotropic, the ray equations can be integrated explicitly and then numerical calculation of the appropriate integrals can be performed for any given electron density profile. The presence of some local deterministic inhomogeneities (e.g. travelling ionospheric disturbances) can be taken into account within the scope of the perturbation theory applied to the ray equations. In this way, in particular, regular Doppler shifts due to bulk motion of the ionosphere can be accounted for. In the more general case of the background ionosphere including horizontal gradients of electron density, or the anisotropy

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introduced by the geomagnetic field, the ray equations can be solved directly by means of one of the available ray tracing codes (e.g. Jones 3D code). At the final stage, the oblique sounding ionograms are constructed which are further employed to specify possible paths of propagation between given transmitter and receiver locations, so that multi-path effects are taken into account.

Once tracing of rays for the background ionosphere has been accomplished and the oblique sounding ionograms have been constructed, the effects due to the ionospheric random inhomogeneities (ionospheric turbulence) are then taken into account. For each path of propagation they are accounted for in the approximation of the complex phase method, which is the extension of the classic Rytov's approximation to the case of an inhomogeneous background medium and the point source field. Initially [1] a generalisation has been accomplished for the case of a stratified background medium, and, more recently [2], the method was further extended to the most general case of a 3D smoothly inhomogeneous background medium. According to the complex phase method the appropriate integrals, representing complex phases, are written in curvilinear co-ordinates where ray trajectories constructed for the background ionosphere are employed as the reference rays of the ray-centred variables. The scattering effects are described in the Fresnel approximation for the forward scattering. As a result, the full-wave type solution of the problem of the HF propagation in the fluctuating ionosphere is constructed accounting for ray bending and scattering on the local random inhomogeneities including the contribution of the diffraction in the scattering.

When the complex phases of the field disturbed by random local inhomogeneities have been determined for a given realization of the properties of the medium of propagation, different order statistical moments of the complex phases are then constructed so that the moments of the full field are expressed through the moments of the complex phases [3]. In the numerical simulation of the statistical moments the model of the ionospheric turbulence is employed with the anisotropic inverse power law spatial spectrum having different outer scales of the inhomogeneities along and across the lines of the magnetic field of the Earth. The assumption of the "frozen-drift" of the turbulence is incorporated wherever necessary. As the result, the statistical moments of the field can be simulated for arbitrary given models of the background ionosphere and the parameters of the ionospheric turbulence, as well as the geometry of propagation with respect to the magnetic field of the Earth, and thus the variability with these parameters and geometries of signals propagating through real ionospheric HF channels may be studied.

When characterizing the HF ionospheric fluctuating channel of propagation different types of the statistical moments of the field are of interest. If fluctuations of the field phase, or level (log-amplitude) are studied, the power spectra of the appropriate processes are constructed [4]. When dealing with the properties of ionospherically propagated pulsed signals, the two-frequency correlation and coherence functions of the monochromatic components of the field should be constructed first [5] in order to describe the average properties of the signal.

As it is a general procedure to characterise the fluctuating channel of propagation in terms of scattering functions, the consideration of different types of the scattering functions is of the particular interest. To construct the scattering functions, the two-time, two-frequency, two-position correlation and coherence functions should be constructed as the first stage [6,3]. Then the scattering functions are produced by means of the appropriate Fourier transforms. Necessary numerical procedures have been developed to simulate the scattering functions. Two types of scattering functions can be specified, viz. the pure and wideband scattering functions. The former characterises the distribution of the energy of the monochromatic field, propagating in the fluctuating ionosphere, in the domain Doppler spread - group-delay spread - angle of arrival spread [3], whereas the latter is introduced to characterise the pulse propagation in the fluctuating ionosphere. It is determined as the Fourier transform of the correlation function of the ionospheric pulse response in the slow time variable. This function describes the distribution of the energy of the pulsed signal through the ionosphere in the domain group-delay – Doppler spread. The analytic-numerical technique has been developed to simulate both the pure and wideband scattering functions [7] for a wide range of the following parameters:

(1) the transmission bandwidth
(2) the variance of fractional electron density fluctuations
(3) the speed and direction of the drift of the turbulence
(4) the anisotropy and outer scale of the irregularities
(5) the background ionosphere model
(6) the ratio of the transmission frequency to the MUF
(7) the orientation of the propagation path to the geomagnetic meridian.

In the case of multi-path channels, the multi-moded scattering functions are also constructed [8, 9], which take account of the contributions of the different modes of propagation to the full scattering function of the channel.

When random time series of the HF field through the ionospheric channel are of interest (e.g. when simulating a signal in the fluctuating channel), statistical moments of the field are then employed to produce these random series. Different approaches are possible to produce the field random realizations. If, in particular, random realizations of the phase of the monochromatic carrier signal are needed, the energy spectrum of phase fluctuations is first calculated and then employed to produce the series of random phase. But, to properly produce phase series, the energy spectrum of only the phase fluctuations is not sufficient, because the energy spectrum of the amplitude (log-amplitude) fluctuations also needs to be calculated so that the amplitude time series can be produced as well. Both phase and log-amplitude random series should be produced such that proper cross-correlation functions of the phase and log-amplitude fluctuations are provided. When dealing with pulse propagation through the fluctuating ionosphere and when random realizations of the pulsed signal are of interest, the wideband scattering function of the channel comprises the basis to produce random realizations.

To conclude this short review, it is clear that constructing the comprehensive solution for wave propagation in the real HF fluctuating ionospheric channel is a challengeable problem and employing any approximate asymptotic methods results in certain limitations of the validity of the approximation. The range of validity of the complex phase method comprising the theoretical basis of the present consideration is given by the condition of small or moderate fluctuations of the field amplitude. The method can handle satisfactorily propagation in the HF channel for the conditions of a weakly or moderately disturbed ionosphere. However, in the case of highly disturbed conditions that may occur, in particular, in the high latitude ionosphere, the method fails to give an accurate description of the channel. Other methods should then be applied to this case, which can deal with the problem of strong fluctuations and the saturated regime of propagation in particular. The approximation of Markov's parabolic equation and the path integral technique should be mentioned in this context. However, despite the many problems already solved in the scope of these methods, a good solution for the two-time two-frequency coherence function of the HF field propagating in the inhomogeneous highly disturbed ionosphere has not yet been accomplished. This problem is currently under intensive investigation.

REFERENCERS

[1] N.N.Zernov, "Scattering of waves of SW-range in oblique propagation in the ionosphere", *Radiophysics and Quantum Electronics*, vol. 23, pp. 109-114, 1980.

[2] Yu.A.Gogin, V.E Gherm, and N.N.Zernov, "Diffraction of the wave field on the weak inhomogeneities of the dielectric permittivity in a 3D smoothly inhomogeneous medium" (in Russian), *St.Petersburg University Herald*, *series 4*, issue 2 (No.12), 2001.

[3] V.E.Gherm, and N.N. Zernov, "Scattering function of the fluctuating ionosphere in the HF band", *Radio Science,* vol. 33*,* pp. 1019-1033, 1998.

[4] V.E.Gherm, and N.N. Zernov, "Fresnel filtering in HF ionospheric reflection channel", *Radio Science,* vol. 30, pp. 127-134, 1995.

[5] V.E.Gherm, N.N.Zernov, B.Lundborg, and A.Vastberg, "The two-frequency coherence function for the fluctuating ionosphere; narrowband pulse propagation", *Journal of Atmospheric and Solar-Terrestrial Physics,* vol. 59, pp. 1831-1841, 1997.

[6] V.E.Gherm, N.N.Zernov, and B.Lundborg, "The two-frequency, two-time coherence function for the fluctuating ionosphere; wideband pulse propagation", *Journal of Atmospheric and Solar-Terrestrial Physics,* vol. 59, pp. 1843-1854, 1997.

[7] V.E.Gherm, N.N.Zernov, B.Lundborg, M.Darnell, and H.J.Strangeways, "Wideband scattering functions for HF ionospheric propagation channels", *Journal of Atmospheric and Solar-Terrestrial Physics,* vol. 63*,* pp. 1489-1497, 2001.

[8] V.E.Gherm, N.N.Zernov and H.J.Strangeways, "Scattering functions for multimoded wideband HF channels", ICAP 2001, Manchester, UK, April, 2001, Conference Publication No. 480, pp. 393 – 396, 2001.

[9] V.E. Gherm, N.N. Zernov and H.J. Strangeways, "Multipath effects in wideband fluctuating HF channels", *Acta Geofizika e Geodetika*, vol. 37, 2002.