ANALYSIS OF MODELING EFFORTS AND EXPERIMENTAL TECHNIQUES FOR IONOSPHERIC SCINTILLATIONS ASSESSMENT

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ABSTRACT

The global morphology of ionospheric scintillations related to satellite-to-ground links taking into account several satellite beacon experiments specially designed for scintillation studies (e.g., ATS-6, Wideband Satellite, HiLat, etc.) is given. A summary of the theoretical approaches used to describe scintillation mechanism in modeling efforts is presented. A general description of existing ionospheric scintillation models is given together with a discussion on their applicability to different links geometry. One of the most important application of scintillation studies is the satellite based navigation. Experimental techniques based on GPS signal scintillation monitors are discussed.

INTRODUCTION

Scintillation activity depends on the radio frequency, magnetic and solar activity, time of day, season of the year and magnetic latitude of the observation point in the case of satellite-to-ground links.

One of the most important areas where the knowledge of ionospheric scintillation effects is needed is satellite based navigation. Ionospheric scintillation is responsible for transionospheric signal degradation that can seriously jeopardize the performance of navigation systems. For this reason several studies about ionospheric scintillation effects on GPS signals have been carried out. Special GPS scintillation monitors have been projected by using commercial GPS receivers.

SCINTILLATION MORPHOLOGY

Equatorial Scintillations. Plasma irregularities and inhomogeneities in the low latitudes F region caused by plasma instabilities give rise to spread F echoes.

GPS radio signals have been used to investigate ionospheric amplitude scintillations [1, 2, 3]; in some cases the scintillations analysis is correlated to that of GPS TEC fluctuations during quiet and disturbed conditions. A clear relationship can be found between those struscures causing spread F and TEC fluctuations and those structures giving rise to scintillation on L band radio signals [4, 5, 6]. In these studies particular scintillation events have been analysed and compared with simultaneous TEC data or with backscatter radar information in order to visualize the irregularities giving rise to spread F, TEC fluctuations and scintillations.

A different approach to scintillation data analysis seems to be needed when the estimate of its effects on satellite based navigation systems is attempted. A different approach in such cases is requested by (1) the patchy structure of electron density irregularities giving rise to scintillation, (2) the usual availability of more than four GPS satellite signals in a receiver, (3) the analysis of scintillation impact at different system levels in order to estimate the global performance of a navigation system in presence of ionospheric irregularities, (4) single satellite availability.

Mid-Latitude Scintillations. At mid latitudes and for transmission frequencies around $150\,MHz$ two different types of ionospheric scintillations have been observed: random scintillations and quasi-periodic scintillations, the latter characterised by a regular 'ringing' similar to that associated with Fresnel diffraction [7]. Most of the studies about mid-latitude scintillations have been done using radio signals in the VHF band (around $150\,MHz$). Scintillation activity in L band (of interest for satellite navigation) at mid latitude is, in general, very low [8].

High-Latitudes Scintillations. Different zones having different physical mechanisms must be considered at high latitudes. Boundary and auroral blobs (i.e., regions of enhanced plasma density) can be located either inside or equatorward of the auroral oval. The auroral blobs are field-aligned structures often narrow in latitude ($< 100\,km$) but may be extended longitudinally along magnetic L-shells. Plasma instabilities operating on the steep gradients at the edges of the structures cause a cascade of irregularities of smaller scales [9]. There is experimental evidence of two irregularity components in the polar cap: intense irregularities within F layer polar cap arcs which produce more discrete ($\sim 1\,hr$ duration) intense scintillation events as the arcs drift through the raypath and anti-sunward drifting irregularities which produce a background level of weak to moderate scintillation [10].

MODELING TECHNIQUES

WBMOD. It is a worldwide climatology of the ionospheric plasma density irregularities which cause scintillation (i.e., environmental models) coupled to a model for the effects of these irregularities on a transionospheric radio signal (i.e., propagation model). The propagation model is a phase screen model in which the irregularities are characterized by a power law spectral density, pointed out by [11]. The model provides the amplitude scintillation index S_4 and the phase scintillation index σ_ϕ, computed by means of the propagation model under the specified conditions. The model can compute such scintillation indices at different percentiles or, conversely, it can compute the percentage of time that those indices exceed a specified threshold level for given conditions [12, 13]. This model describes in a probabilistic way the areas potentially suffering of scintillation events, but it does not seem so able to reproduce the patchy characteristics of the irregularities producing scintillation of radio signals.

GIM. The model is composed of two models. The physical model for irregularities effects attempts to describe the background ion concentration by using continuity and momentum equations for the specified geomagnetic and solar conditions. The background electron density profiles are computed by the NeQuick model [14] that is coupled to GIM. The numerical model computes the first order errors by means of the results of NeQuick model; thus, scintillation errors and its statistical properties are obtained by using the phase screen technique for a power la spectral density of the ionospheric irregularities [15]. As in WBMOD this model seems to be able in reproducing the global morphology, but not the patchy characteristics of ionospheric irregularities.

MPC method. The starting point is represented by the multiple phase screen technique (MPS). In the MPS, the random phase screen is replaced by a series of thin diffractive screens perpendicular to the line of sight of the ray. Each screen imparts to the wave a phase change which is equivalent to the phase change within the region it represents. The complex spatially modulated wave front emerging behind the screen is then propagated to the next screen under free-space propagation conditions. The process is repeated until the complex field is computed at the receiver plane. From screen to screen, the free-space propagation is solved using the Fresnel-Kirchoff integral. The MPC method avoids the plane wave hypothesis and is especially designed for upward links, where the elctromagnetic wave source may be close to the turbulent medium and the receiver is far away (geostationary satellite case) [16].

Gherm and Zernov's theoretical approach. It is able to compute spectral density functions for both phase and log-amplitude for a signal propagating through the ionosphere. The model allows the calculation of phase and log-amplitude time series, simulating a typical received signal at the ground. The model takes into account a description of the background ionosphere, for given geophysical conditions, and a description of the irregularities by means of an anisotropic inverse power law spatial spectrum of electron density fluctuations (defined with respect to the local geomagnetic field) [17].

EXPERIMENTAL TECHNIQUES

During past decades several beacon satellite experiments have been designed to study in a classical way ionospheric scintillation and irregularities produginc it. More recently, attention has been focussed on the estimate of ionospheric scintillation effects on satellite navigation systems, as GPS (and then SBAS or GALILEO). In order to estimate system availability and accuracy during different ionospheric conditions knowledge of ionospheric scintillation effects on system like GPS as complete as possible is needed. For this purpose, so called ionospheric scintillation monitors have been designed by using commercial GPS receivers, modified in order to measure both intensity and phase of signals from GPS satellites.

Van Dierendonck's monitor. It has been obtained by using a C/A code receiver, modified in order to extract scintillation information both for intensity and phase of the received GPS signals [18]. In its last version, such scintillation monitor is a dual frequency GPS receiver, able to extract scintillation indices (S_4 over one minute periods and σ_ϕ over periods of 1, 3, 10, 30 and $60\,sec$) and TEC measurements every $15\,sec$. The received signal intensity and phase are sampled at $50\,Hz$ and then detrended by using a nominal cut-off frequency of $0.1\,Hz$. High frequency components are only used to compute scintillation indices. As optional ouputs such monitor can provide satellite C/N_0, azimuth, elevation, one-sigma code-minus-carrier pseudorange measurements and raw data for spectral analyses [19]. Anyway, such a scintillation monitor could have some problems in detrending received phase and intensity because of: (1) a fixed cut-off frequency when used at high-latitudes and (2) a not consistent intensity high-pass filtering in general.

Cornell monitor. It is a single frequency C/A code receiver coupled with a PC in order to extract scintillation information from GPS signals [5]. Such scintillation monitor measures amplitude scintillation only. The signal strength information, based on correlator output samples, for all available channels is recorded at a $50\,Hz$ rate. Signal strength measurements are synchronized to the broadcast GPS timing signals so that spaced receivers may be used in correlation studies [3]. Moreover, the Cornell scintillation monitor has an optional designation of a "noise channel" and allows for automated data collection. The crucial differences between the Cornell monitor and that by Van Dierendonck relies on: (1) the algorithm used to compute scintillation index S_4 seems to be more correct for the Cornell type, where a consistent high-pass filtering of intensity is made, (2) different signal strength estimators are used in the two monitors (wide band power in the Cornell type and difference between wide and narrow band powers in the Van Dierendonck's one) with a different way to treat the noise.

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