Fading Phenomena in Ionospheric Communication Links Occur During Magnetic Storm with Applications to Satellite Communications and Ionosphere Monitoring

N. Blaunstein [1] , ***E. Mishin*** [2]

[1] Department of Communication Systems Engineering, Ben-Gurion University of the Negev, Beer Sheva, Israel, nathanb@cse.bgu.ac.il

[2] Boston College, Institute for Scientific Research, Chestnut Hill, MA, USA, evlpaem@verizon.net

Abstract

This paper presents the intensity and phase fluctuations dependence on the degree of ionospheric plasma perturbations occur during magnetic storm based on experiments by GPS monitoring of the ionosphere. During this natural phenomenon, anomalous absorption caused by decrease of the total electronic content, and fast fading of GPS radio signals caused by generation of plasma small-scale irregularities are observed experimentally. In order to present the effect of scattering caused by plasma irregularities generated during magnetic storm, 2-D phase-screen model is introduced. A satisfactory explanation of fading phenomena observed experimentally is presented based on the corresponding theoretical framework.

1. Introduction

One of the key parameters in designing a global low-earth-orbit (LEO) or median-earth-orbit (MEO) land-satellite personal or mobile radio communication system is the propagation of radio waves in various media, in particular, the fast fading phenomena which has direct ramification on the attributes of land–satellite-land communication links parameters [1-3]. As a result, interest to satellite communications has stimulated investigations of ionospheric properties, in particular, the analysis of the spatial-temporal distribution of ionospheric irregularities [4-6]. At the same time, electromagnetic and plasma disturbances associated with natural phenomena occur due to coupling between the magnetosphere and the ionosphere, such as the storm-time ring current in the plasmosphere and topside (e.g., polar) ionosphere [7, 8]. The effects of ion-molecule kinetics on the plasma density trough associated with sub-auroral polarization streams (SAPS) were considered [9, 10]..When radio waves are propagated through irregular ionospheric plasma, small-angle scattering causes signal intensity scintillations [11, 12]. A main goal of this work is to determine the intensity and phase fluctuations depending on degree of perturbation of ionospheric plasma during the magnetic storm based on measurement outcomes made by different satellites, where fast fading of radio signals was observed.

2. Theoretical Background

Following the proposed in it approach; we introduce an analysis of intensity fluctuation in the frequency domain based on the 2-D screen-phase screen model which improves the 1D-screen model [11]. Within the framework of small-scale scintillation, we introduce tractable expressions for the intensity spectrum, and an achievement of simplicity and tractability of the fading phenomena was made. Thus, for a given frequency, high spectral index p causes an increase in the signal intensity fluctuations by use Ricean *K*-parameter as a ratio of coherent and incoherent components of the total signal intensity:

$$K = \left\langle I_{co} \right\rangle / (\sigma_I^2)^{0.5} \tag{1}$$

from which it is easy to predict the signal-to-noise ratio (SNR). Here σ_I^2 is the signal intensity fluctuations (e.g., the intensity of signal fast fading) defined as

$$\sigma_I^2 = \frac{\langle I^2 \rangle - \langle I \rangle^2}{\langle I \rangle^2} = \frac{\langle I^2 \rangle}{\langle I \rangle^2} - 1 \qquad (2)$$

As was shown in [12], the signal intensity scintillations depend on the spectral index p as follows:

For p=2: $$\sigma_I{}^2 = \frac{2\sqrt{2}}{\sqrt{\pi} \cdot L_0} \overline{(\Delta\Phi)^2} \cdot F \qquad (3a)$$

For p=3: $$\sigma_I{}^2 = \frac{\pi}{2 \cdot L_0{}^2} \overline{(\Delta\Phi)^2} \cdot F^2 \qquad (3b)$$

For p=4: $$\sigma_I{}^2 = \frac{8\sqrt{2}}{3\sqrt{\pi} \cdot L_0{}^3} \overline{(\Delta\Phi)^2} \cdot F^2 \qquad (3c)$$

The phase fluctuations are defined by the well-known parameter [12]:

$$\left\langle (\Delta\Phi)^2 \right\rangle = 4 r_e^2 N^2 \overline{(\Delta N / N)^2} \lambda^2 H^2 \sec \chi \qquad (4)$$

3. Experimental Observations of the Ionosphere during Magnetic Storms

Below, we present one from numerous characteristic measurements concerning real-time sequences referred to the plasma density fluctuations. Figure 1 refers to storm-time ionospheric irregularities in SAPS-related troughs which cause of GPS scintillations at middle latitude ionosphere [7-9]. It shows variations in total electronic content (TEC) and $\delta N/N$ parameter in a highly structured density trough situation. Experimentally observed the following features caused by magnetic storm are:

1)Small-scale plasma density and electromagnetic oscillations were detected by DMSP F13, 14, and 15 satellites while flying near the regions of intense radio-signal scintillations.
2)24-Hz Longmuir probe data show that during the scintillation intervals the amplitudes of density oscillations in the frequency range of 3-10 Hz increased by a factor of 100. The enhanced fluctuations appeared at the pole ward edges of large-scale density troughs, embedded within subauroral polarization streams.
3)Most likely these irregularities are responsible for radio-signal scintillations near 1GHz.

4. Results of Computations

Based on the phase fluctuations formula (4) and the measurements presented above, we computed the signal intensity fluctuation parameters which are varied by the changes in plasma density fluctuations $\delta N/N$. At the same time, as was mentioned above, the intensity of inhomogeneities is characterized by the spectral index p which shows degree of the dispersion of the radio wave intensity fluctuations. In our computations we introduce the parameter $\left\langle \Phi_1^2 \right\rangle$, according to [11, 12], which defines the disturbance of signal phase in the ionospheric layer containing small scale inhomogeneities.

$$\left\langle \Phi_1^2 \right\rangle = \pi^{1/2} k_0^2 l D \left\langle \left| N_1 / N_0 \right|^2 \right\rangle \left[\ln\left(8D/l\right) + C - 3/2 \right] \qquad (5)$$

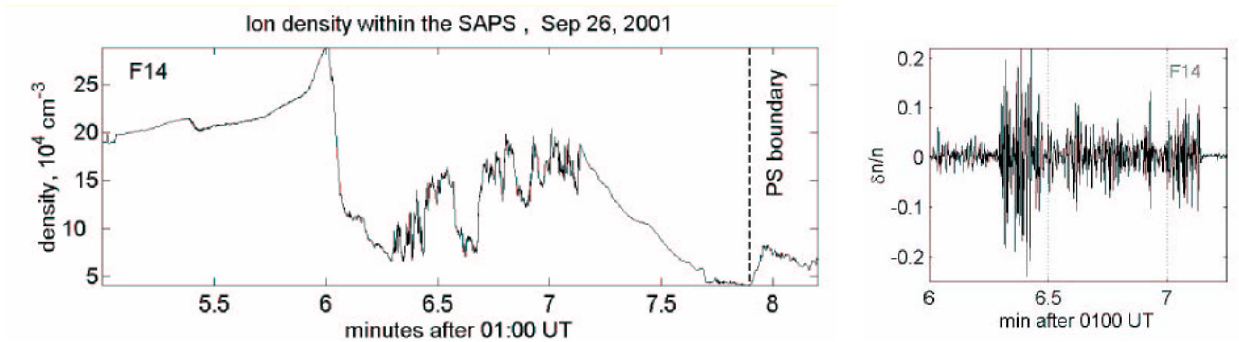

Fig. 1: Plasma density fluctuations (TEC and $\delta N/N$) during storm-time and Power Spectral Density (PSD) versus frequency registered during storm-time.

Here l represents the scale of inhomogeneity, D represents the layer thickness, $\left\langle |N_1/N_0|^2 \right\rangle$ is the relative fluctuations of the plasma density (average of a random process), and C represents the Euler constant. The intensity of plasma irregularities is defined to be Gaussian distributed:

$$I(k) = \sqrt{8\pi} \cdot \ell \cdot \exp(-\frac{1}{2}k^2 \cdot \ell^2) \tag{6}$$

where

$$\ell = \frac{L_0}{\{[2/(p-3)] \cdot \overline{(\Delta\Phi)^2}\}^{1/2}} \tag{7}$$

The graphs which will be shown below are based on the equations (4)-(7). Calculations of signal phase fluctuations $\left\langle \Phi_1^2 \right\rangle$, denoted as F_1, were made for three different frequencies and presented in Fig. 2 by different colors: a green line corresponds to 500MHz, a blue line is to 1GHz, and a red line is to 2GHz.

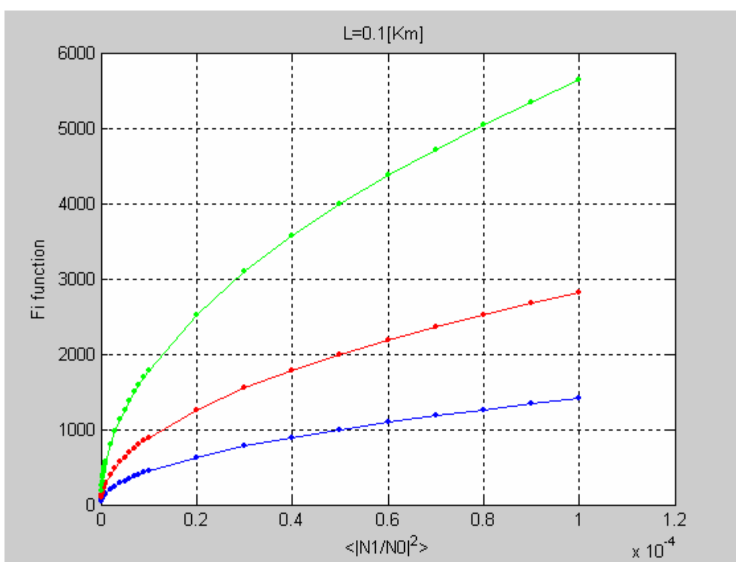

Fig. 2: Variations in $\left\langle \Phi_1^2 \right\rangle$ versus $\left\langle |N_1/N_0|^2 \right\rangle$.

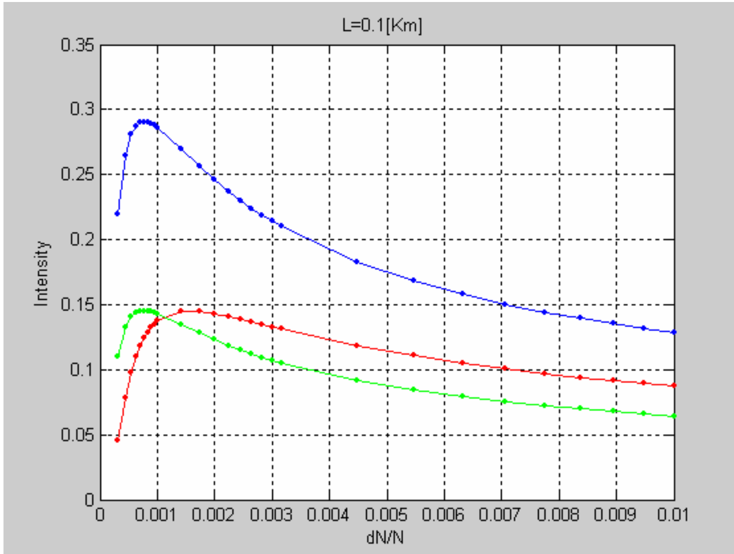

Fig. 3: Variations in intensity due to varies in $\delta N/N$.

Figure 3 presents variations of signal intensity with variations of $\delta N/N$ for different spectral indices σ_I^2: a green line corresponds to f=500MHz and σ_I^2 =0.0575, a blue line corresponds to f=1GHz and σ_I^2 =0.0242, and a red line corresponds to f=2GHz and σ_I^2 =0.0288.

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