Ionospheric scintillations: impact on the HF subsurface radar sounding

Yaroslaw A. ILYUSHIN

Moscow State University
Russia Moscow 119992 GSP-2 Lengory phone +7 (495) 939-3252 e-mail ilyushin@phys.msu.ru

At present, the space-borne ground penetrating radars (GPR) [1] are successfully used for exploration of the planetary interiors (Fig. 1). The need of deep subsurface penetration and high depth resolution of the instrument determines low operational frequency and wide frequency band of the radar signals. There are two well known effects which destructively impact the GPR measurements: distortion of the signal due to the ionospheric propagation and side echoes coming from rough planetary surface. Both mentioned subjects together in fact limit the capability of the radar instrument. To partially eliminate them, various signal processing techniques, including aperture synthesis and so on, are typically used.

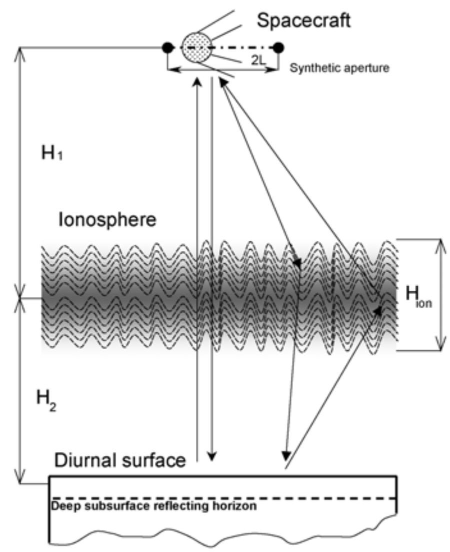

Fig.1. The general sketch of the GPR experiment geometry

The systematic signal phase distortions, introduced in the signal by the regular layered ionosphere, is the most studied at the moment. This subject is discussed in many papers, and various adaptive correction schemes are proposed to compensate the ionospheric phase shift. The side clutter is now less investigated, because of great complexity of the problem of wave scattering on the rough surface and lack of computing resources, sufficient for rigorous solution of the problem in wide spectral band.

The small scale fluctuations of the ionospheric plasma density, which can produce effects similar to the surface clutter, still remain almost not investigated. Qualitative discussion of them can be found in some papers. However, in the shortwave frequency band, where most GPR instruments operate, the characteristic spatial scale of the fluctuations is comparable to the fresnel zone size, so the diffractive effects caused by them should be accounted for. In addition, rigorous numerical simulation of the aperture synthesis in GPR sounding presents certain computational difficulties, so that many authors make use of various simplifying assumptions. Some published papers present results of numerical modeling where the aperture synthesis has not been simulated at all. This restricts the generality of conclusions, at least to a certain extent.

To address the questions sketched above, several mathematical models have been considered, including numerical scheme for equation of Markovian approximation for coherence function, phase screen approximation for two-frequency correlation function, Kirchoff approximation for scattering from the rough surface etc. Rigorous simulation of the synthetic aperture technique has been performed in most our calculations.

On the basis of this approach, destructive impact of the ionospheric plasma density fluctuations have been estimated. Role of various parameters, including the synthetic aperture length and so on, has been figured out. Effects of the anisotropy of the correlation function of the plasma density fluctuations have been taken into account. Several measurement schemes are considered, including classical unfocused synthetic aperture radar and the step frequency radar. Combined impact of the systematic and stochastic signal phase distortions in the ionosphere is analyzed, and the functioning of known phase correction algorithms is simulated thoroughly. An example of simulated subsurface radargram is shown in Fig. 2.

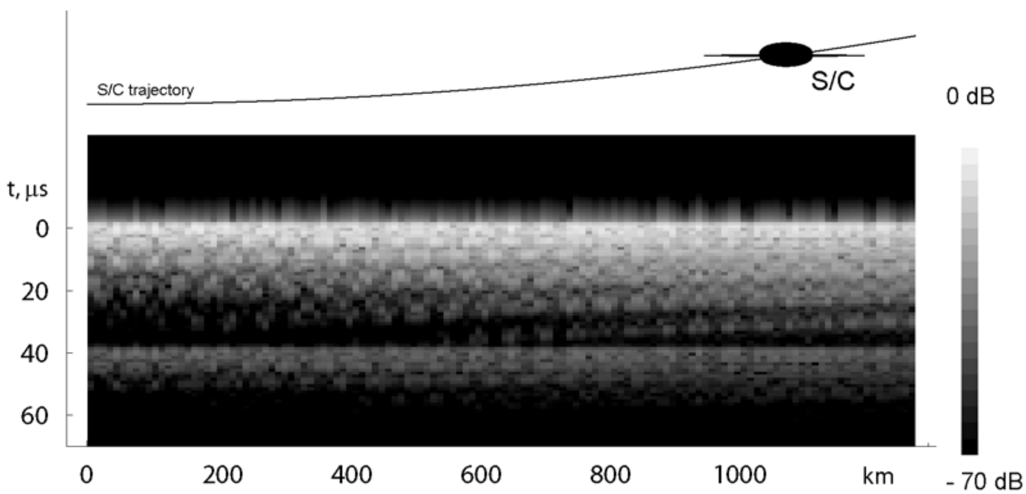

Fig. 2. An example of simulated subsurface radargram. LFM frequency band 2500 – 3500 kHz.

It has been shown that the random signal phase fluctuations can severely distort the signal, especially at the frequencies close to the critical plasma frequency of the ionosphere. This can lead to additional increase of the minimal frequency applicable for subsurface radar sounding compared to the case of smooth ionosphere.

At frequencies well above the critical frequency of the ionosphere, the impacts of the systematic and stochastic phase fluctuations can be regarded as independent ones.

It turns out that the step frequency radar is very unstable relative to the surface clutter, so that the applicability of this scheme is restricted to the surfaces smooth enough.

Different frequency response of the random phase perturbations due to ionospheric irregularities and surface roughness can be used to detect and estimate the ionospheric turbulence in the planetary ionospheres in the case of multi-frequency radar measurements.

2. Acknowledgements

This study was partially supported by Russian Fundamental Research Fund (RFFI grants 05-05-65145 and 06-05-64988). The author is grateful to the MSU computing facility (SRCC) for granting access to the computational resources.

3. References

1. G. Picardi, J. J. Plaut, D. Biccari, et al. “Radar soundings of the subsurface of Mars,” Science, 310, 2005, p. 1925.