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A Comparative Analysis of Strong Scintillation II: Calculations of Transionospheric High Frequency Wave Propagation

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Abstract

Two methods for description the effects of propagation through the quasi-random spatial distribution of the electron density in the ionosphere are discussed. Comparison of the results of solving the same problem employing both techniques is presented, and the range of validity of the methods is outlined based on the results obtained.

1. Introduction

Simulations of wave propagation through the deterministically specified quasi-random distributions of the electron density perturbations generated employing the technique, developed in [1], have been performed employing two different approaches. The first one is the solution to the appropriate parabolic equation, obtained utilizing the split-step technique, which may be considered as the rigorous solution to the problem under consideration as this solution, according to formal mathematical theorems, converges to the true solution as the spatial resolution is unlimitedly increased. This is then compared to the solution to the same problem, alternatively obtained employing the Hybrid Scintillation Propagation Model (HSPM) [2].

As the HSPM contains the Complex Phase Method (CPM), being the extension of the classic Rytov's approximation to the case of the inhomogeneous background medium, which is employed to describe the field in the inhomogeneous ionospheric layer, then according to the CPM the stochastic field within the inhomogeneous ionosphere should be characterized by the scintillation index satisfying the inequality $S_4 < 0.6$ - 0.7 (corresponding to the inequality of $\sigma_\chi^2 < 1$ for variance of the field log-amplitude fluctuations) [2, 3]. This means that the stochastic wave field inside the inhomogeneous ionospheric layer should be of weak or moderate scintillation type. Note, however, that the strong scintillation type stochastic wave field may well be developed when propagating from the bottom of the ionosphere down to the Earth's surface [2, 3].

2. Results and Comparison

In the following figures the results of simulations obtained utilizing both the methods are presented graphically and discussed. The top panels in all the figures demonstrate the results obtained by the HSPM, and the bottom panels are for the split-step technique.

Two regimes of scintillation at the exit from the layer were simulated by specifying different values of the scaling parameter in the code: 1) weak scintillation: S_4=0.09 at the bottom of the ionospheric layer, and 2) moderate scintillation: S_4 =0.66 at the bottom of the ionospheric layer.

In the first Fig. 1 the spatial dependence of the scintillation index S_4 along the path of propagation through the layer with local inhomogeneities is presented for the case when the value of the scintillation index at the bottom of the ionospheric layer (transition from the red color to the blue one) is 0.09.

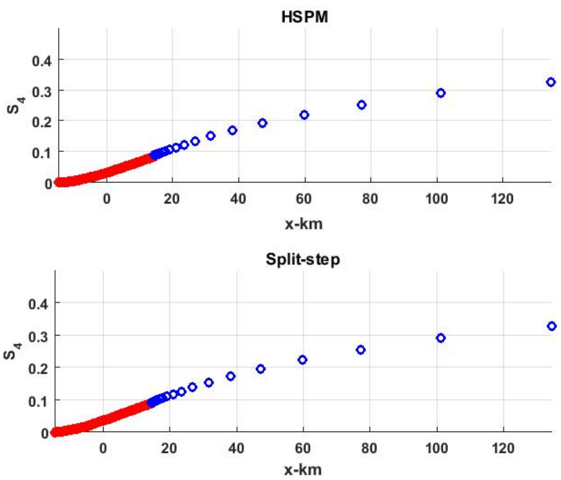

Figure 1. The spatial dependence of the scintillation index S_4. Top panel: the curve obtained within HSPM. Bottom panel: the curve obtained within the split step technique.

Both the techniques produce the identical dependence of the scintillation index S_4 on the distance along the path of propagation.

In the next Fig. 2 random series of the field amplitudes obtained by the two methods under discussion are presented. As is seen, both the curves are practically identical with no visible discrepancies.

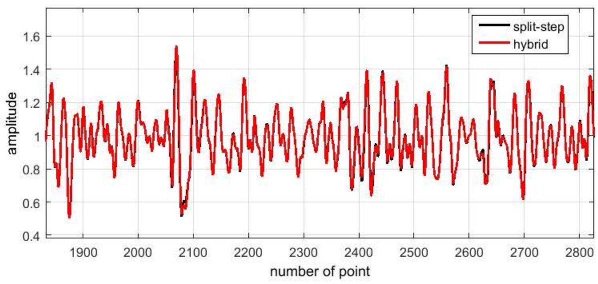

Figure 2. Random series of the field amplitudes: the red curve obtained by HSPM; the black curve obtained within the split step technique.

In the two panels of the following Fig. 3 the spectra of both the field phase and intensity are shown, which were obtained by the two different methods

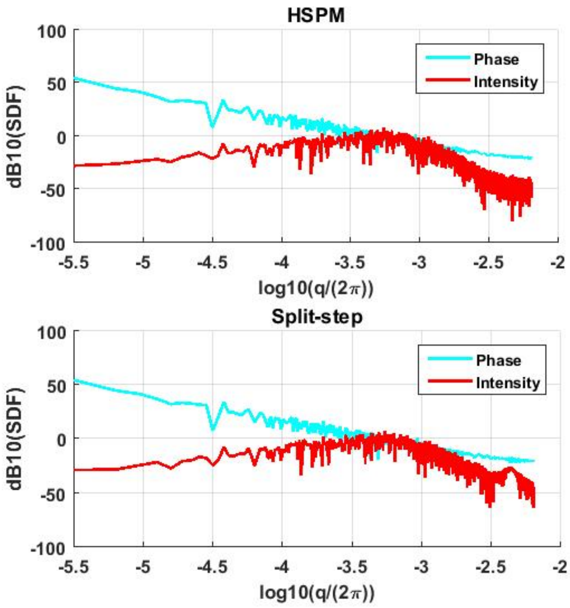

Figure 3. Spatial spectra of phase and intensity: the results obtained within the HSPM are shown in the top panel; those obtained within the split step technique are given in the bottom panel.

As is seen, according to Figs. 1 -3 above, both the techniques under discussion produce the same results for the case of propagation through the channel with the ultimate value of the scintillation index at the bottom of the ionospheric layer of S_4= 0.09.

In the next series of Figs. 4-7 below the results are shown for the greater ultimate value of the scintillation index at the bottom of the ionospheric layer of S_4=0.66, which is close to the limit of the range of validity of the HSPM.

The scintillation index S_4 , as in the previous case, demonstrates the same behavior within the both techniques under discussion (see Fig.4).

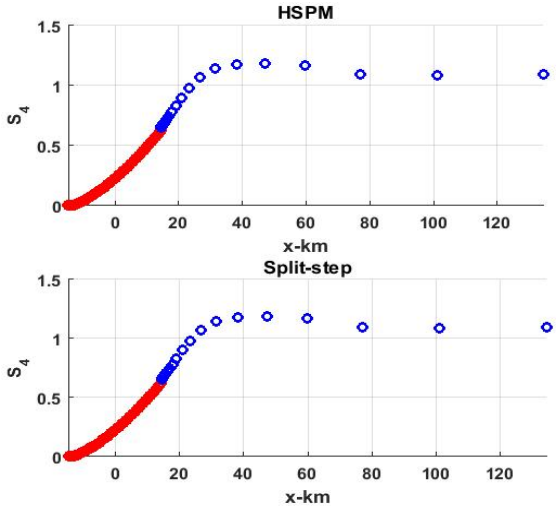

Figure 4. The spatial dependence of the scintillation index S_4. Top panel: the curve obtained within the HSPM. Bottom panel: the curve obtained within split step technique.

Next we present more detailed information about the field amplitude and phase, produced by two different propagation techniques.

In the following Figs, 5a and 5b quasi-random series for the field amplitude and phase on the distance of 120 km behind the layer are shown, which were produced employing both techniques.

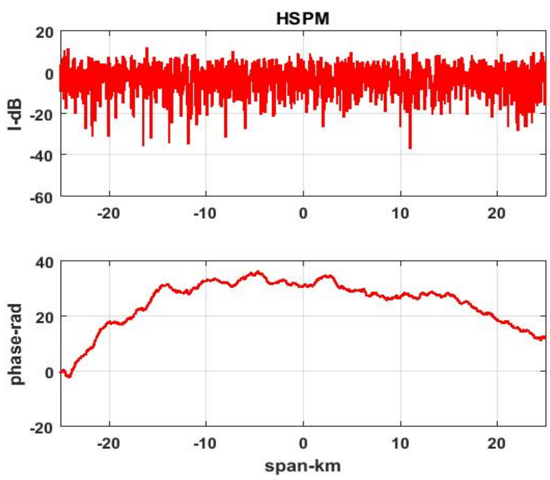

Figure 5a. Random series for the field amplitude (upper panel) and phase produced employing the Hybrid model.

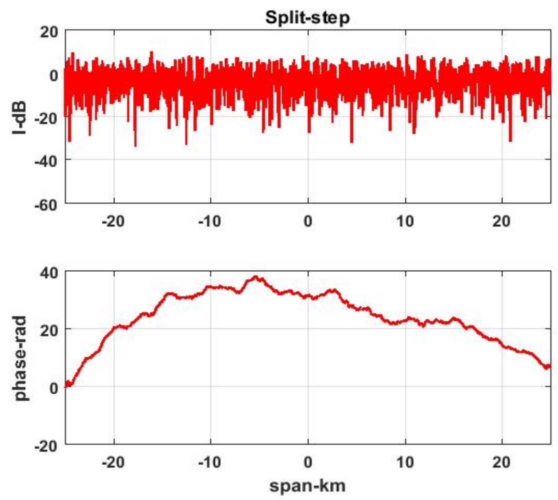

Figure 5b. Random series for the field amplitude (upper panel) and phase produced employing the split step technique.

Obviously, two pairs of curves for the amplitudes and phases correspondingly are not distinguishable as they are shown in Figs. 5a and 5b. To make small discrepancies visible, below the fragment of both the amplitudes produced by two different techniques are put together on the same plot. Then in Fig. 6, minimal discrepancies can be observed.

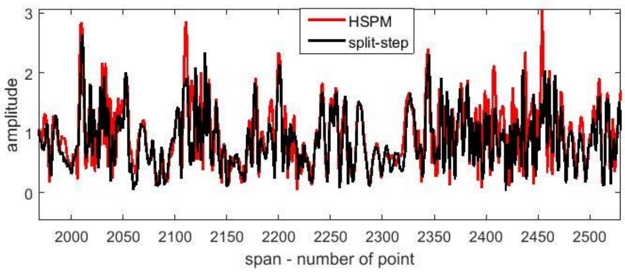

Figure 6. The amplitude, produced by the Hybrid Technique, is given in red color.

Finally, the probability density function of the intensity fluctuation can also be produced by both the techniques discussed here.

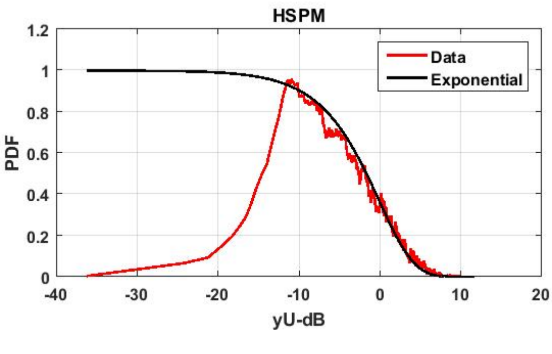

Figure 7a. PDF produced by the Hybrid Method.

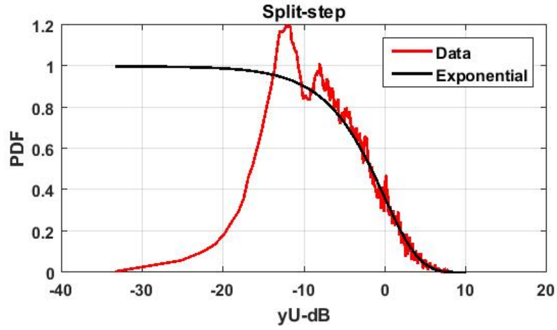

Figure 7b. PDF produced by the split step technique.

To conclude, the results presented here additionally validate the HSPM and outline its range of validity, as it was formulated in [2, 3]. Pure numerical split step technique allowed performing this validation.

It would also worth pointing out that, once it is clear that the problem of propagation is within the range of validity of the HSPM, the latter provides much faster calculations, as it does not require generating the 3-D random (quasi-random) inhomogeneities of the electron density, which is highly time consuming.

It would, finally, worth pointing out that in many cases the alternative to the split step technique for the case, when the HSPM does not work may be recently developed semi-analytic technique based on Markov's momenta equations [4, 5].

3. References

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