CORRELATION-STATISTICS-BASED SIMULATOR OF PERTURBED PHASES TRIGGERED BY THE IONOSPHERIC IRREGULARITIES FOR HF RADAR SYSTEMS

Yongpeng Zhu, Yinsheng Wei and Peng Tong

School of Electronics and Information Engineering, Harbin Institute of Technology, Harbin, China

Overview

To simulate the perturbed phases of ionospherically propagated HF radio waves, the paper focuses on the following aspects:

- Analysis of the perturbed phases in space-time correlation and statistical distribution
- Derivation of the correlation-statistics-based simulator
- Effectiveness verification of the simulator

Mathematical Basis

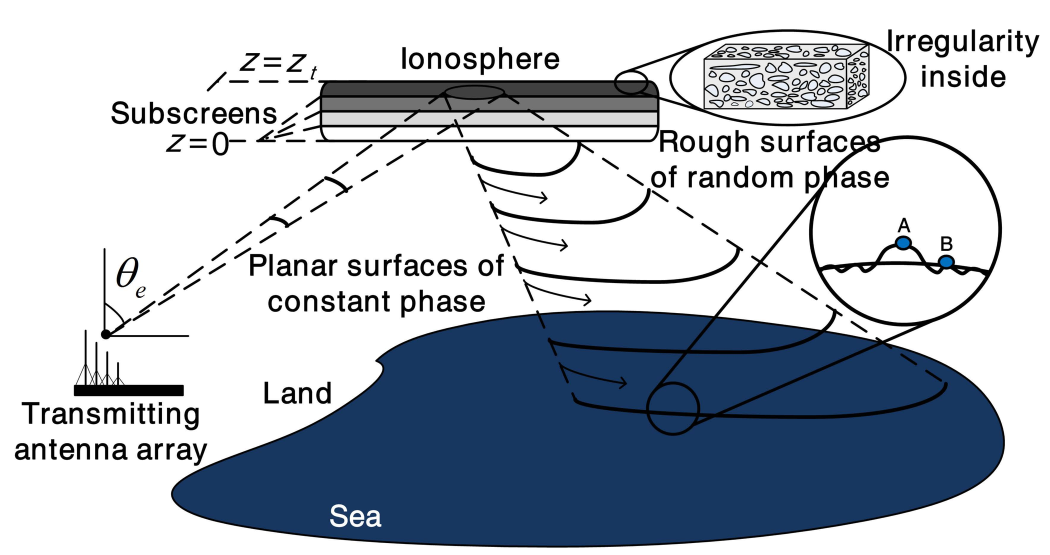


Fig. 1: Illustration of signal wavefront distortions.

- Space-time correlation function

$$R_{A_c}(\rho_c) \approx 1 + \langle \varphi_1^2 \rangle \frac{\kappa_0^2 \rho_c^2}{\pi} \ln \frac{\kappa_0 \rho_c}{2} \quad (1)$$

$$R_{A_c}(T_c) = \left\langle e^{-j\varphi_1(x,y,T)+j\varphi_1(x,y,T+T_c)} \right\rangle \approx 1 - \langle \varphi_1^2 \rangle \kappa_0^2 v_d^2 T_c^2 / 2 \quad (2)$$

$\langle \varphi_1^2 \rangle$ is the mean-square phase fluctuation;
κ_0 is the ionosphere outer scale parameter;
v_d is the plasma drift velocity;

- Amplitude statistics analysis of the perturbed phases based on multiple phase-screen method

$$\chi_c(\rho_l) = \sum_{i=0}^{M} \phi_i(\rho_l) \quad (3)$$

$\phi_i(\rho_l)$ is random phase changes at each phase screen;
M is the number of phase screen intervals;

- Wiener-Khinchin theorem

Methods

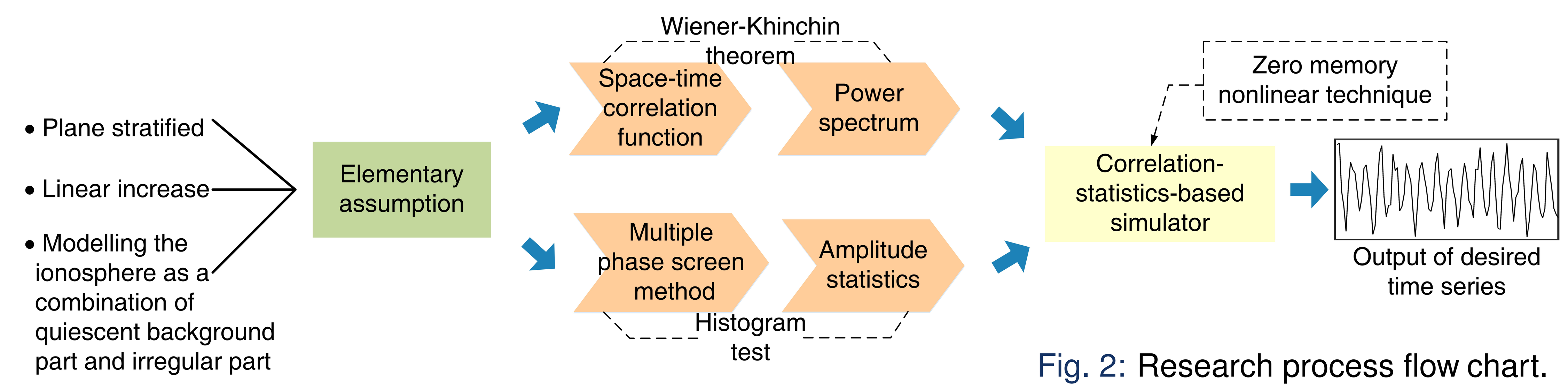
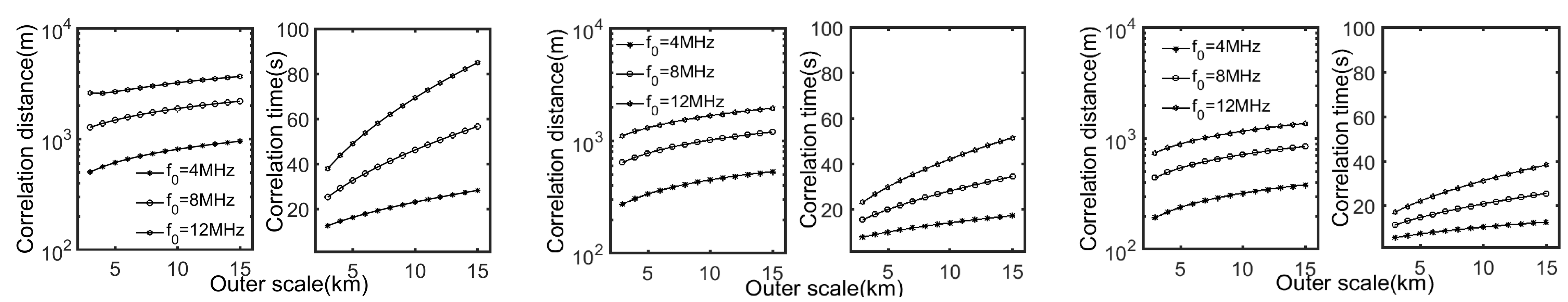


Fig. 2: Research process flow chart.

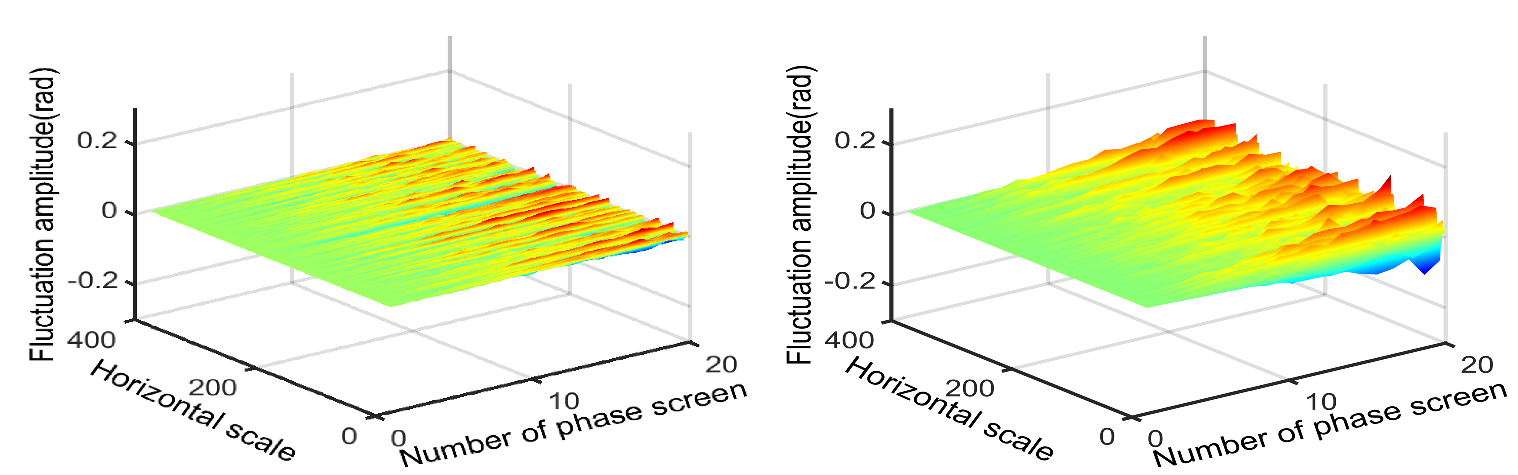
Important Results

- The space-time correlation of ionospheric perturbed phases depends on the outer scale length of plasma density irregularities, plasma drift velocity and mean square phase fluctuation strength.
- Histogram test results reveal that the amplitude of ionospheric perturbed phases follows Gaussian distribution.
- Ionospheric perturbed phases can be simulated with random time series whose power spectrum and amplitude satisfy the Gaussian distribution. And this can be realized through ZMNL technique.

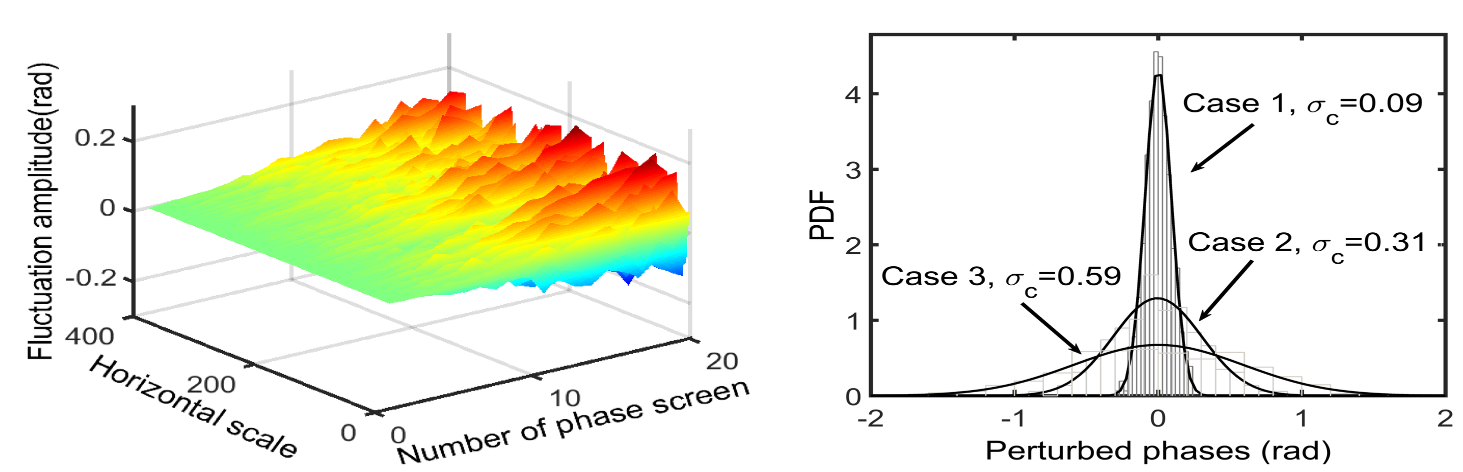
Results



(a) Case 1 (b) Case 2 (c) Case 3



(d) Case 1 (e) Case 2



(f) Case 3 (g) Histogram test

- (a)-(c): Illustration of space-time correlation
- (d)-(f) : Illustration of amplitude fluctuation at each phase screen
- (g) : Histogram test results

Table 1: Simulation parameters corresponding to different ionosphere irregular states.

Ionosphere parameters	Case 1	Case 2	Case 3
σ_{n_1}	0.8×10^{-3}	1×10^{-3}	1.2×10^{-3}
$N_e(m^{-3})$	2×10^{11}	4×10^{11}	5×10^{11}
$\theta_e(degree)$	60	50	40
$\nu_d(m/s)$	50	70	100
$z_t(km)$	19	60	120
$z_b(km)$	85	125	200

Correlation-Statistics-Based Simulator Derivation

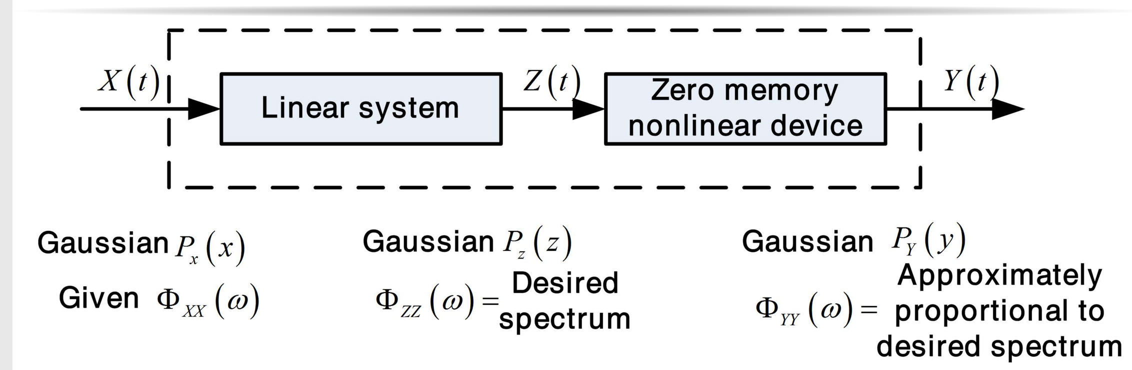
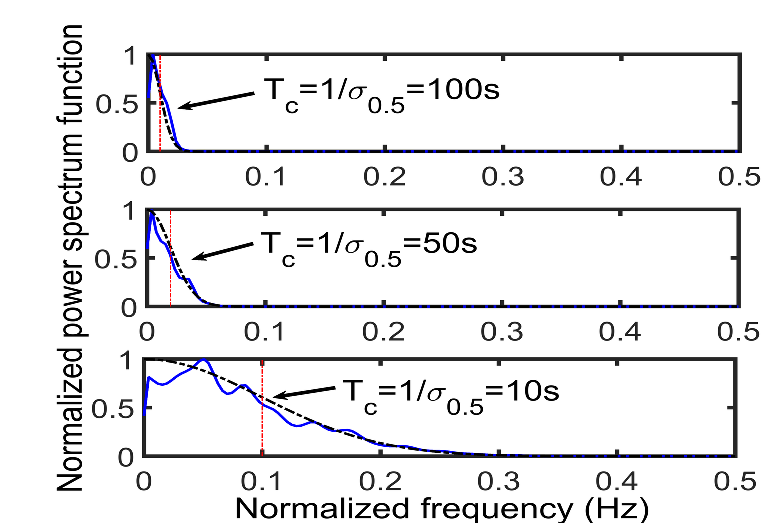
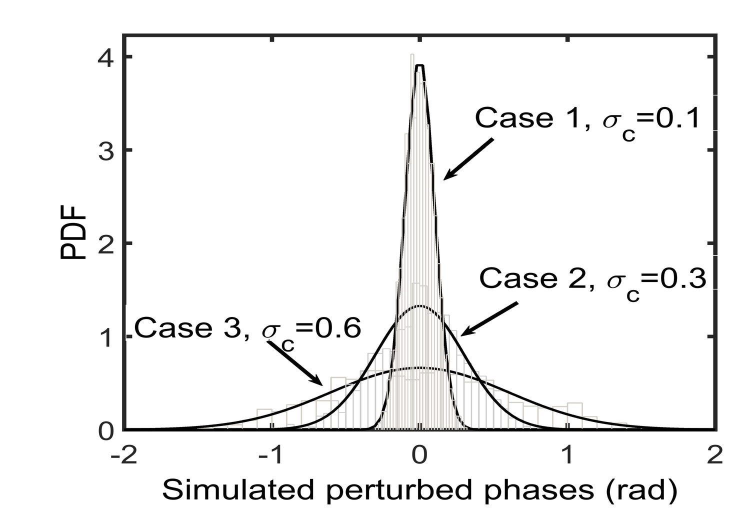


Fig. 3: Principle of ZMNL to generate desired time series.



(a) Power spectrum



(b) Amplitude statistics

- (a)-(b): Effectiveness of the proposed method

Summary

- The space-time correlation and amplitude statistics of ionospheric perturbed phases are studied.
- The essence of the proposed simulator is to guarantee the generated time series satisfying specific power spectrum and statistical distribution, which can be realized through the ZMNL technique.
- The results are helpful for understanding the spectral signatures of ionospherically backscattered echoes in HF skywave radar systems.

Contact Information

- Email: zhuyp@hit.edu.cn

哈爾濱工業大學

HARBIN INSTITUTE OF TECHNOLOGY