ASPECTS OF ELECTROMAGNETIC COMPATIBILITY AT REMOTE SENSING OF IONOSPHERE IN RADIOPHYSICAL OBSERVATORY OF KHARKIV NATIONAL UNIVERSITY

I.I. Magda[1], *L.F. Chernogor*[2]
[1]*National Science Center "Kharkov Institute of Physics and Technology", Kharkov, Ukraine;*
E-mail: magda@kipt.kharkov.ua;
[2]*V.N. Karazin Kharkiv National University, Kharkov, Ukraine*
E-mail: leonid.f.chernogor@univer.kharkov.ua

Specific responses of radio receivers of various type and frequency range under conditions to receiving of both a sole intense ultrashort signals and combination of information and interference ultrashort signals are studied. A possible scenario of functional upset of radio receivers at the V.N. Karazin Kharkiv National University Radiophysical Observatory during remotely sensing the ionosphere with new radar transmitting a few hundred MW ~10 ns pulse has been analyzed. In the tests of receivers, the characteristics of interference signals well enough meet the conditions of planned experiments to probe the ionosphere. It is expected that the research results will contribute to the development of various preventive measures for the electromagnetic protection of the radio facilities at the Radiophysical Observatory.

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INTRODUCTION

For successful implementation of the scientific project "Ionosat-Micro" [1], set by the National Target-Oriented Scientific and Technical Space Program of Ukraine for 2013-2017, the ground-based sub-satellite monitoring of the geospace environment with the remote sensing facilities located at the V.N. Karazin Kharkiv National University (KhNU) Radiophysical Observatory (RPO) has been planned [2], which required a metrological verification and certification of the instruments. This work was accompanied by a detailed investigating an impact of different radio electronic systems (RES) on radio receivers. On-site measurements were preceded by vast laboratory studying the electromagnetic fields impact on radio receivers (RR) and their components. The work was carried on within the framework of well-known and described in scientific literature methods of electromagnetic compatibility and strength (EMCS) against the impact of stationary or relatively long-pulse interference (see, for example, [3 - 5]).

The present work aims at analyzing a possible scenario of the RRs functional upset during a new cycle of remote radio sensing of the ionosphere at the KhNU RFO. A modernized multi-purpose UHF sensing system based on the UHF radar has been proposed to be used in these experiments. This up-grade supposes providing a pulse compression in the master oscillator in order to increase its pulse power to several hundred megawatts. In this case, the pulse width should be reduced from 1 μs to 10 ns. In this concern, the investigation of the RRs response to the impact of ultrashort pulse (USP) ~0.1…10 ns [6 - 8] interference, which previously had not been carried out due to the lack of technical means, becomes relevant.

It is known that under the impact of interference signals (IS), depending on their amplitude, a wide spectrum of phenomena (from functional upset to total failure) arises in the RR operation caused by changes in the characteristics of the components. At the same time, if the interference is the USP signal with the pulse width τ_p and pulse rise time τ_r of $10^{-9}…10^{8}$ s and $10^{-10}…10^{-11}$ s, respectively, the character of the arising effects is significantly different in comparison with the steady-state or long-pulse impact [9 - 12].

The specific responses of the receivers of different type and in different frequency ranges irradiated by the USP IS either solely or in combination with the RF information signal (IFS) are presented below. The selection of types of the receivers, as well as of the test signals characteristics quite fully reflects the conditions that can arise in the planned experiments on radio probing the ionosphere. The test results can be useful for providing the preventive technical and organizational measures for electromagnetic protection of the RES, which operate in the KhNU Radiophysical Observatory.

1. BRIEF INFORMATION OF THE KHNU RADIOPHYSICAL OBSERVATORY

From the beginning of the 1950s to the present time, the geospace researches have been carried out at KhNU (see, for example, [13 - 15]). Since the 1960s, the Radiophysical Observatory equipped with automated and computerized systems for remote sensing the geospace environment in a wide range of altitudes ($z \approx 60...1000$ km) had been put into operation. A complex investigation along with modeling, and predicting the fundamental geospace physical and chemical processes of natural and anthropogenic origin (which can affect on functional stability of the telecommunication, power and machinery systems as well as on human health and wellbeing, etc.) have been run in the framework of ground support for the scientific project "Ionosat-Micro" [1]. The facilities for remote radio-sensing the ionosphere has been continuously improved and upgraded. The Facility for Remote Sensing the Near-Earth Space Environment at the Kharkiv V. N. Karazin National University Radiophysical Observatory is included in the State Register of Scientific Research Instruments that Constitute a National Asset. Table 1 presents a brief description of the receiving devices included into basic tools of the remote radio-sensing of the ionosphere [2] in RPO.

Table 1

Characteristics of the receivers in the radio systems at the RPO

System	Radio frequency band (bandwidth)	Critical level, U_{in}
MF radar	1.5…24 MHz (40 kHz)	0.02…0.2
HF Doppler radar at vertical incidence	1…24 MHz (10 Hz)	0.02…0.05
Digisonde	1…15 MHz (1…16 kHz)	0.05…0.1
Multi-frequency passive radar	3…30 MHz (300 Hz), 30…300 MHz, 300…3000 MHz, 3…30 GHz (10 kHz)	0.02…0.05
Fluxgate magnetometer (based on IM-II magnetometer)	0.001…1 Hz	10…100 nT
GPS/GLONASS receivers	150/400 MHz 1.2…1.6 GHz	0.01…0.03 0.003…0.03

* special fabrication

2. RF POWER AT THE INPUT OF THE RECEIVER DISPOSED CLOSE TO HIGH-POWER RADIATOR

The supposed interference signal levels produced by radar with the RF power output of 100 MW have be estimated for various distances and decrease factors as a function of the antenna directivity. It is well known, the RF power at the input of the receiving antenna is

$$P_{in} = P_T \frac{G_T G_R \lambda^2}{(4\pi R)^2},$$

where P_T is the transmitter power, G_T and G_R are the transmitting and receiving antenna gains, respectively, λ is the wave-length, R is the distance between the antennas.

Table 2

Power P_{in} (top line, W) and voltage U_{in} (bottom line, V) at receiver input (R_{in}=75 Ω) versus the distance to and side-lobe levels of transmitting antenna

G_T dB	R, m				
	15	45	150	450	1500
0	$3.2{\cdot}10^6$	$3.2{\cdot}10^5$	$3.2{\cdot}10^4$	$3.2{\cdot}10^3$	320
	$2.2{\cdot}10^4$	$6.9{\cdot}10^3$	$2.2{\cdot}10^3$	690	220
–10	$3.2{\cdot}10^5$	$3.2{\cdot}10^4$	$3.2{\cdot}10^3$	$3.2{\cdot}10^2$	32
	$6.9{\cdot}10^3$	$2.2{\cdot}10^3$	690	220	69
–20	$3.2{\cdot}10^4$	$3.2{\cdot}10^3$	$3.2{\cdot}10^2$	$3.2{\cdot}10^1$	3.2
	$2.2{\cdot}10^3$	690	220	69	22
–30	$3.2{\cdot}10^3$	$3.2{\cdot}10^2$	$3.2{\cdot}10^1$	3.2	0.32
	690	220	69	22	6.9
–40	$3.2{\cdot}10^2$	$3.2{\cdot}10^1$	3.2	0.32	$3.2{\cdot}10^{-2}$
	220	69	22	6.9	2.2
–50	$3.2{\cdot}10^1$	3.2	0.32	$3.2{\cdot}10^{-2}$	$3.2{\cdot}10^{-3}$
	69	22	6.9	2.2	0.69

The amplitudes of the power P_{in} (and voltage U_{in}) at the receiver input with the input resistance R_{in} calculated for P_T = 0.1 GW, $G_T = 5.10^4$, G_R = 1, R_{in} = 75 Ω, and λ = 0.15 m are given in Table 2. Apparently, such high impulse amplitudes at the RR input are sufficiently higher than those indicated in Table 1, and can result in functional upsets and even destruction. To better understand possible effects in receiving devices of the Observatory, the results of laboratory tests of various types of receivers on functional upset under the exposure to the USP IS are described below.

Table 3

Test conditions of receivers of different frequency bands

Test signals mode		Receiver frequency band	Test signals characteristics	
			τ_p/τ_r, ns	U_{in}, V
I,a I,b	UWB VP or transient process	HF, UHF, VHF, SHF	1…500/ 0.3…20 1…5/0.2…1	10^{-6}…10 10^{-4}…100
II	NB RF in frequency band of RR	SHF	6…15/3	10^{-4}…20
III	Combination NB RF and UWB VP with 5 ns delay time between signals	HF/UHF, VHF, SHF	NB RF 15/3 UWB VP 1.2/0.2	10^{-3}…10 10^{-3}…10

3. EXPERIMENTAL STUDY OF FUNCTIONAL UPSETS IN RECEIVERS AFFECTED BY USP IS

From the above, it follows that the efficiency of the USP interference should depend substantially on the time (frequency) characteristics of IS and the receiving circuit. This has been studied in the tests of RRs, which had significantly different frequency bandwidth of the input components [16 - 18]. For this purpose, conventional HF, UHF, and VHF receivers, as well as mock-ups of SHF receivers have been used (Fig. 1).

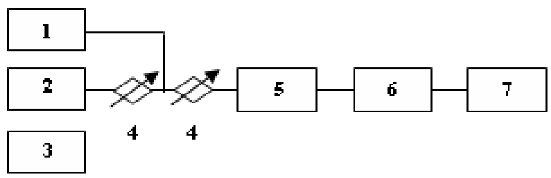


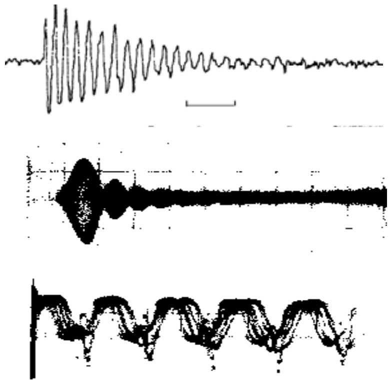
Fig. 1. Diagram of RR test: 1 – G4-116 signal generator; 2 – G5-78 impulse generator; 3 – impulse generator G5-54; 4-5 – 30 dB attenuator; 5 – RR under test; 6 – S1-70 sampling oscilloscope; 7 – personal computer

In the first case, the RRs had a narrow input frequency band due to the presence of a resonant tunable input RF circuit. In the second case, the input filters were removed in a RR, and the bandwidth of the receiving circuit was determined mainly by the properties of the low-noise amplifier (LNA), which usually has slightly varying characteristics over a wide (up to several octaves) frequency range.

The test conditions of the receivers differed in the signal composition – the combinations of RF harmonics and USP signals, as well as in the USP IS mode (Table 3). The modulated narrowband harmonics signals (NB RF) played the role of the IFS. The ultra-wideband video pulse (UWB VP) signals simulated the USP IS. The difference in the UWB VP signals was determined mainly by the pulse and rise-time durations. Thus, the following signals were applied to the input of the radio receiver units: (1) NB RF with $\Delta f << f_0$; (2) UWB VP with $\Delta f \sim f_0$; (3) combined NB RF and UWB VP.

3.1. RF RECEIVER RESPONSE

In view of the fact that different NB receivers in HF, UHF, and VHF bands have identical responses to the IS, the test of a conventional 3rd-class R-323M receiver is considered below as an example. The RR test was carried out using a close-type test-bed in conditions of direct injection of USP IS and IFS to the RR input, Fig. 1. The specific characteristics of the RR output signals were determined, which corresponded to the nonlinear response of the device (see Table 3, mode I,a): (1) the RR nonlinear response width τ_{res} at the output of the units: RFA, IFA, and LF; (2) the minimum width of the USP IS $\tau_{p\ min}$, when the impact on RR can be interpreted as a shock-like, producing a specific nonlinear response; (3) the critical repetition frequency of the USP IS, $F_{r\ cr}$, when the individual responses at the RR output are overlapped and perceived as a continuous signal (reception blocking).



a 50 ns/div

b 0.05 ms/div

c 1 ms/div

Fig. 2. Typical responses of the output units of HF/UHF band RRs: (a) HFA, (b) IFA, (c) LFA in the modes of single IS (a and b), and combination of IS and IFS (c). IFS (f_0 = 22 MHz, AM, F_{AM} = 1 kHz), USP IS (τ_p = 5 ns, τ_r= 0.45 ns, F_r = 1 kHz)

Fig. 2 demonstrates the response at the receiver HF, UHF, and VHF units (a – HFA, b – IFA, and c – LFA) obtained in the mode of single IS, Fig. 2,a,b), and of combination of IS and IFS, Fig. 2,b. The IFC was a continuous harmonic signal with the carrier frequency f_0 = 22 MHz, and modulation on amplitude at F_M = 1 kHz. The IS was a periodically repeating transient process with the pulse width τ_p = 5 ns, rise-time τ_r = 0.45 ns, and with an exponent-like decay. The IS repetition frequency, F_r = 1 kHz.

3.2. RF RECEIVER TESTS IN THE ABSENCE OF INFORMATION SIGNAL

The character of high-frequency amplifier (HFA) response. The HFA response to impact of a unipolar video-USP was qualitatively equal for IS with a wide range of characteristics ($U_{in\ i}$ = 0.001…0.1 V, τ_r = 0.45 ns, and τ_p = 1…500 ns). The amplitude of the RR response varied proportionally to the amplitude of the USP IS impact. In this case, the width of the response signals τ_{res} was practically unchanged and exceeded τ_p by more than 100 times.

The HFA response to single USP IS with a relatively small amplitude ($\tau_p < f_0^{-1}$, $U_{in\ i}$ < 0.05 V) had the form of damped sinusoid, which is a typical response of high-Q system to shock impact of USP IS with the decrement proportional to the system quality factor (Q ~ 25…30), Fig. 2,a. The period of the sinusoid signal corresponded well to the resonant frequency f_0 of the RR input RF circuit. Thus, τ_{res}(HFA) ≈ $Q/2f_0$. If the USP IS amplitudes was high enough ($\tau_p < f_0^{-1}$, $U_{in\ i}$ > 0.05 V), the shape of the damped sine was distorted, indicating the appearance of nonlinear distortions.

Variation in the unipolar USP IS width significantly changed the response envelope. The distortion of the HFA response was determined by the interference of the leading and trailing edges of the impact signal. For $\tau_p > \tau_{re}$(HFA), the impact of each edge of the IS had an independent character, so the efficiency of the interference from each edge was maximum. At smooth variation in the IS width τ_p, the phase of the response signals from leading and trailing edges could coincide at the time intervals of f_0^{-1}. For different IS widths, when the delay time between the pulse edges (measured in units of the reception frequency f_0^{-1}) were multiples of f_0^{-1}, a minimum(or maximum) efficiency of the impact on the receiver NB reception unit was observed.

The intermediate-frequency amplifier (IFA) response. The dynamics of the IFA response to the impact of short edges of USP IS was qualitatively consistent with the HFA response. The response width of the IFA to IS significantly exceeded the URF response. Fig. 2,b shows the response of the IFA when $\tau_p << f_0^{-1} << \tau_{res}$(HFA). Like the HFA excitation, the IFA response signal envelope suffered irregular changes due to the phase-shifted effect of the leading and trailing edges of the IS for its sufficiently long width, $\tau_p > \tau_{res}$(HFA). At the same time, the structure of the response at the IFA output was more complex than at the HFA output. It was distinguished by the presence of 2 components: (i) the response of the IF amplifier with the conversion frequency $f_{int} = f_0 - f_h$ = 10.7 MHz, where f_h is the local oscillator frequency, and (ii) the low-frequency amplitude modulation of the signal. Due to a high Q-factor of the IFA unit, its response width τ_{res}(IFA) >> τ_{res}(HFA) and reached 250 μs. The measured period, T_M ≈ 80 μs, of the LF modulation of the response corresponded to a frequency that was about a half of the passband frequency of the IF amplifier in the mode of the average passband (25 kHz), $f_M = T_M^{-1} \approx 1/2\Delta f$(IFA) = 12.5 kHz.

The dynamics of the receiver's low-frequency amplifier (LFA) response had significant differences in comparison with the responses of two previous RR units of HF and IF amplification. Under the impact of a series of USP IS, the LFA output to each of the signals had a characteristic aperiodic response, Fig. 2,c. In this case, the LFA response width was approximately equal to the whole width of the IFA response. An increase in the IS repetition frequency to a value comparable to the maximum frequency of the LFA spectrum led to the overlap of the response-signals and appearance of the LFA permanent failure.

3.3. COMBINED RECEPTION OF INTERFERENCE AND INFORMATION SIGNALS

The effect of USP IS changed significantly when a continuous harmonic IFS and USP IS were received simultaneously (see Table 3, mode III). The tests were carried out in conditions of receiving the amplitude and frequency modulated IFS. The effect of a stationary harmonic IFS ($F_{AM(FM)}$ = 1 kHz) led to the result qualitatively different from that of previous tests. Briefly, it can be considered as stabilization of the RR operation due to the action of automatic gain control. In this case, the modes of weak and strong IFS differed greatly. If the IFC level at the RR input $U_{in\ inf}$ exceeded the noise level U_n by 10…15 dB, the AGC suppressed the RR response to repetitive or single USP IS. For typical relation values $U_{in\ i}/U_{in\ inf}$ = 1000...2000, the interference signal at the IFA output was significantly lower (up to 20 dB) than the information signal. In this case, the RR functional upset did not occur. In the opposite case, when the IFS amplitude $U_{in\ inf}$ was below a certain critical level (≤10 dB U_n), the action of USP IS resulted in blinding the receiver for the time τ_{res}, which is characteristic of only a sole USP IS impact.

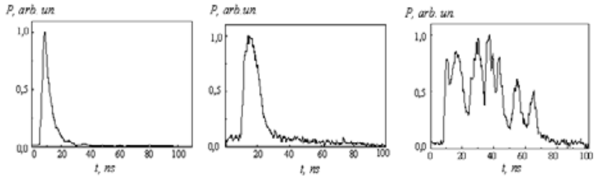
With the same amplitude of the responses to IS and IFS recorded at the RR output ($U_{out\ i}$ /$U_{out\ inf}$ ≈1), the ratio of the amplitudes of the input signals was high, $U_{in\ i}$ /$U_{in\ inf}$ =500…2000, see Fig. 2,c. This ratio set the minimum IS amplitude, which produced the RR functional upset in the combined mode of receiving the IS and IFS. Large value of the ratio was due to a low spectral power density of the interference in the IFS frequency range, which, because of the large frequency band of the USP IS (up to 2 GHz) did not exceed the level of 10^{-8} W/MHz. In spite of this, the USP IS energy equivalent was very small $W = \tau_p(U_{in\ i})^2/2R_{in} \sim 10^{-14}$ J in the tests indicating principally high energy efficiency of the USP interference in modern electromagnetic environment.

3.4. TESTS OF SHF RECEIVING UNITS

Testing the receivers with the operating frequencies of 2.0, 3.1 and 9.3 GHz affected by USP IS (see Table 3, modes I, b, II and III) showed that the character of their responses were qualitatively consistent with the picture of a functional upset described above, but the structure of the responses turned out to be much more complicated.

The parts of the SHF radio-tracts had a modular design and were manufactured as matched strip-lines with installed active and passive elements. At the USP IS amplitude exceeding the level of the RR linear operation mode, the output signal of the low-noise amplifier (LNA) demonstrated a complex nonlinear response. Due to short pulse width of the IS, the dimensional effects in the SHF modules turned out to be significant. This produced a condition for a multiple-path IS coupling to the parts of the radio-tract associated with delays of the reflected signals. In this case, several complex SHF active parts such as multistage solid-state protective devices (PD) and LNA or vacuum TWT demonstrated the appearance of the output signals with $\tau_{res} >> \tau_p$.

Fig. 3 demonstrates the RR response (f_0 = 9.3 GHz) to USP interference (τ_p = 1.2 ns, τ_r = 0.2 ns) at several characteristic points of the SHF radio-tract: panel (a) at the antenna output, panel (b) at the output of the LNA (in linear amplification mode), panel (c) at the output of the LNA (in non-linear amplification mode). As can be seen, there are several time scales (confirmed by spectral data) in the fine structure of the responses, indicating a non-stationary character of the signal transmission conditions, multiple scattering, and interference of the signal components in the radio-tract.



a b c

Fig. 3. The SHF receiver (9.3 GHz) response signals to USP IS (τ_p= 1.2 ns, τ_r = 0.2 ns): (a) antenna output; (b) LNA output, linear operation mode; (c) LNA output, non-linear operation mode

The detailed analysis of the RR response-signals dynamics due to the affect of USP IS of various types showed that their complexity was a result of simultaneous development of a number of effects [16]: (i) distortion of the intense input signals when its amplitude was limited in a PD that initiated the excitation of nonlinear oscillations; (ii) non-linear distortions of the UWB impulse signal and excitation of chaotic oscillations, caused by the radio-signal components interacting in the active element.

CONCLUSIONS

1. The Kharkiv V. N. Karazin National University Radiophysical Observatory includes a broad set of radar and radio instrumentation. The performance specifications of the instrumentation and the software employing modern signal processing techniques provide verified high temporal resolution measurements required for monitoring the highly variable space atmosphere interaction region. The Observatory can function both autonomously and be successfully used for ground-based support for space missions, and for the scientific project “IonoSat-Micro” in particular. In planned radio-sensing experiments, new radar with characteristics (pulse power of up to several hundred megawatts and pulse width of about 10 ns) can create an extreme electromagnetic environment. Thus, modern metrological verification and certification of remote sensing equipment is required to minimize the radar impact on radio-electronic equipment of the observatory.

2. The laboratory tests of radio receivers of different frequency range have shown that intense ultrashort electromagnetic impulses, due to a high penetrating quality and low upset threshold levels are the most dangerous factor of the modern electromagnetic environment.

3. The efficiency of excitation of nonlinear responses in unprotected radio receivers observed even for a small-amplitude interfering USP, is determined by combination of the their temporal and frequency characteristics: the pulse width, pulse rise-time, and the repetition frequency for video signals, as well as the carrier frequency for radio signals.

4. Taking into account the features of a receiver response to USP interference, it is possible to choose correctly the methods and means for the receiver protection, and also to optimize terrestrial layout of complex active radio-frequency electronics, such as, for example, radars for sub-satellite monitoring of geospace and ionosphere sensing.

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АСПЕКТЫ ЭЛЕКТРОМАГНИТНОЙ СОВМЕСТИМОСТИ ПРИ ИОНОСФЕРНОМ ДИСТАНЦИОННОМ ЗОНДИРОВАНИИ В РАДИОФИЗИЧЕСКОЙ ОБСЕРВАТОРИИ ХАРЬКОВСКОГО НАЦИОНАЛЬНОГО УНИВЕРСИТЕТА

И.И. Магда, Л.Ф. Черногор

Исследуются характерные виды реакций радиоприемных устройств различных типов и частотного диапазона в условиях приема интенсивных сигналов сверхкороткой длительности, а также в условиях комбинированного приема информационных сигналов и помеховых сигналов сверхкороткой длительности. Проведен анализ возможного сценария сбоев радиоприемных устройств радиофизической обсерватории ХНУ в условиях сеанса дистанционного радиозондирования ионосферы, в котором используется новое оборудование с импульсной мощностью до нескольких сотен мегаватт и длительностью импульса около 10 нс. В тестах приемных устройств использованы характеристики помеховых сигналов, которые достаточно полно отражают возможные условия предполагаемых экспериментов по радиозондированию ионосферы. Предполагается, что результаты исследований будут способствовать разработке различных превентивных мероприятий по электромагнитной защите радиоэлектронной аппаратуры обсерватории.

АСПЕКТИ ЕЛЕКТРОМАГНІТНОЇ СУМІСНОСТІ ПРИ ДИСТАНЦІЙНОМУ ЗОНДУВАННІ ІОНОСФЕРИ В РАДІОФІЗИЧНІЙ ОБСЕРВАТОРІЇ ХАРКІВСЬКОГО НАЦІОНАЛЬНОГО УНІВЕРСИТЕТУ

І.І. Магда, Л.Ф. Черногор

Досліджуються характерні види реакції радіоприймальних пристроїв різних типів і частотного діапазону в умовах прийому інтенсивних сигналів надкороткої тривалості, а також в умовах комбінованого прийому інформаційних сигналів і перешкоджаючих сигналів надкороткої тривалості. Проведено аналіз можливого сценарію збоїв радіоприймальних пристроїв радіофізичної обсерваторії ХНУ в умовах сеансу дистанційного радіозондування іоносфери, в якому використовується нове обладнання з імпульсною потужністю до декількох сотень мегават і тривалістю імпульсу близько 10 нс. У тестах приймальних пристроїв використані характеристики перешкоджаючих сигналів, які досить повно відображають можливі умови передбачуваних експериментів з радіозондування іоносфери. Передбачається, що результати досліджень будуть сприяти розробці різних превентивних заходів щодо електромагнітного захисту радіоелектронної апаратури обсерваторії.