RESEARCH OF THE POSSIBILITY TO USE MIR AND INTERNATIONAL SPACE STATION INFRASTRUCTURE FOR GEOPHYSICAL AND ANTROPOGENIC ELECTROMAGNETIC EXPLORATION

S.I.Klimov, V.A.Grushin, I.A.Dobrovolskyi Yu.V.Lissakov, M.N.Nozdrachev, A.A.Petrykovich, V.I.Prokhorenko, A.V.Prudkoglyad, V.G.Rodin, S.A.Romanov, V.S.Romanov, S.P.Savin, A.A.Skalsky, N.A.Eismont, L.M.Zelenyi (Space Research Institute RAS, Moscow, Profsoyuznaja 84/32, Russia), O.R.Grigoryan, (NPI, Moscow), N.A.Bryukhanov, I.V.Churillo, O.V.Lapshinova, A.V.Markov, S.B.Ryabukha, I.V.Sorokin, (RKK ENERGIJA, Korolev), M.P.Aphanasenko, V.E.Korepanov (LC IKI, Lviv), G.Berghofer, W.Magnes, W.Riedler, K.Schwingenschuh (IWF, Graz), H.U.Auster, K.-H.Fornakon (IGM TU-B, Braunschweig), J.Juchniewicz (CBK PAN, Warsaw), M.Parrot, J.L.Rauch (LPCE, Orleans), V.A.Gladyshev, O.A.Pokhotelov (UIP, Moscow).
sklimov@mx.iki.rssi.ru; Fax: +7 (095) 310-7023; Tel: +7 (095) 333-1100

The research program of the International Space Station (ISS) includes the geophysical researches. The scientific program includes the exploration of the ionospheric disturbances by OBSTANOVKA experiment (plasma waves) and SPRUT (energetical particles) due to anthropogenic activities and due to the natural geophysical effects. The altitude of the ISS (about 400 km) is near the maximum of the ionospheric electron density (F-layer) at the ionosphere/magnetosphere interface. First result of the SPRUT-VI experiment onboard MIR station are presented. This work has been supported by grants Minmauki-Veter and INTAS 96-2064.

ST4 Open session on the magnetosphere
Convener: M.J. Rycroft (Illkirch), Co-Convener: I. Sandahl (Kiruna)

Introduction

The electromagnetic effects are of the great interest for the natural geophysical phenomena connected with e.g. earthquakes and volcanic eruptions. Wave emissions and electron density perturbations could be connected with the ionosphere by a variaty of mechanisms. Only long term statistical studies will reveal the general features of the ionospheric perturbations and help to find their specific signatures for the earthquake predictions. Most previous satellite experiments have operated at heights above 800 km. The unique feature of the proposed experiment on the ISS is that regular observationsfor the first time will be performed at much lower heights, namely at about 350 km, at the ionosphere/ magnetosphere interface. The altitude of the ISS (about 400 km) is near the maximum of the ionospheric electron density (F-layer). Therefore this experiment has a good opportunity to study the natural ionospheric perturbations in-situ. Global monitoring of electromagnetic radiation in the range from DC to tens of MHz can be carried out only aboard satellites which allow to control the total Earth surface for a long time (more than 5 years) in the continuous automatic mode. It is very important that the obtained information will be immediately transmitted to the powerful computers which are used in space researches and analyzed by wide community of scientists. The ISS, with life time 10-15 years, is the good candidat for the usage for the global electromagnetic monitoring.

The following topics have been discussed out in phase A of this experiments:

- analysis of geophysical processes which determine the electromagnetic environment around the ISS orbit;
- analysis of the processes resulted from the interaction between the ISS like superlarge spacecrafts (SLSC) and surrounding plasma;
- approach to the design of the sub-satellite of the ISS (SS-ISS) which allow to improve its electromagnetic cleanliness for the extraction of lithospheric and anthropogenic perturbations in the ionosphere and realization of ecological low-frequency electromagnetic monitoring.

The process resulted from the interaction between the SLSC and surrounding plasma

1. Effects of SC interaction with surrounding ionosphere. Analysis of problems connected with most important interaction effects allows to make a conclusion about *the existence of five groups of interaction of SC with plasma.* They include effects:

a).induced by supersonic motion of spacecraft relative to background ions in plasma;

b).connected with irradiation of high energy electron fluxes; c).influence of solar radiation in dense plasma in NES;

d).contamination of SC surrounding space (both neutral and plasma components);

e).leading to generation and emission of plasma waves and electromagnetic radiation.

2. Modification of neutral atmosphere. SC surface is an important source of contamination of spacecraft surroundings. Absorbed by SC surface on Earth gas evaporates in space partly because of high vacuum, and partly because of surface heating during SC irradiation by solar light. Moreover the water outburst from life support system and gas plumes from thrusts during SC maneuvers generate artificial atmosphere with size up to 300 m from OS. This artificial atmosphere has density fluctuations and masks the pressure difference between forward and backward directions.

3. Effects of forward and backward directions. Main interest is connected with the form of tail region and its variations with SC orientation and plasma parameters. It was supposed that the existence of convective electric fields may move the tail from geometrical symmetry axis to several degrees. For the SLSC a problem of differential charging became important, especially when large ion current, induced in nose part, exists in combination with large tail region, free from ions. If this situation combines with *existence of large fluxes of energetic electrons precipitated to the surface in tail region then the catastrophic charging level may exist* when photoemission is blocked in the shadow.

4. SC electric charge. SC potential relative to surrounding plasma is controlled by the equilibrium between electron and ion currents flowing from SC surface and backward currents from plasma. This plasma heterogeneity should generate heterogeneous currents at SC surface, and if *nonconducting surfaces exist* then they would have charged. In fact, induced electric field $v \times B$ totally dominates in this region. For SC velocity 8 - 10 km/s this field is usually equal to 0.2 - 0.3 V/m. Therefore potential difference on SLSC is 10 - 30 V. Current charge probably much less. It must be noted that v x B field makes difficulties in measurements of thermal electrons on OS with plasma sensors.

Analysis of physical situation near the ISS allows to make a conclusion that for the study of the processes resulted from the interaction between the SLSC and surrounding plasma it is necessary to organize the experiments:

1. **Directly on the ISS:**

- **on the outer surface**

  OBSTANOVKA (ENVIRONMENT**), ELECTROPHYSIKA, SPRUT-F, PHOKUS.**
- **on the boom**

  OBSTANOVKA, ELECTROPHYSIKA, PHOKUS.
- **with the use of the buoy**

  OBSTANOVKA.

2.On the sub-satellite.

The SLSC generate the perturbations which to propagate to several hundred meters and for tether systems - to distances larger than several tether length, or several kilometers. Therefore it is necessary to have sub-satellite at the same distances. The possibility to use such orbit was shown during this work.

SUBSPITNIK (SUB-SATELLITE**), SPIRAL'.**

3.On the ground observatories.

INSPIRE and POETRY Projects

Global monitoring in the frame of **Space Weather Program (SWP)** of the space plasma parameters and of the electromagnetic radiation in the range from DC fields to tens of **megahertz should be carried by spacecraft (SC)** because only they allow to monitor near-Earth regions and to **work in durable (more than 5 years) continuous automatic mode.** ***It is very important here that obtained information has to be immediately transmitted to powerful computers used in space research and may be analyzed by wide circle of scientists and other consumers.***

The plasma wave studies onboard SC is one of the important diagnostic methods of space studies. But because of the limited number of SC's these studies are made episodically and often only in definite fields. Especially, **ULF/ELF region was badly studied because such investigations are connected with main methodical and technical problems.** One of them is that **the electromagnetic environment (EME)** of existing SC impedes measurements of electromagnetic fields which have low local energy density. This is connected with SC electronic and electromechanical equipment operations which are sources of electromagnetic radiation, including above mentioned frequency range. Certainly the increasing of number of equipment on SC (or, more precisely, its power consumption) worsens EME.

Electromagnetically clean nano-satellite (EMCNS).

Therefore there is a need of performing the electromagnetic monitoring at SC with power consumption less than 5-15 W, - ***electromagnetically clean nano-satellite (EMCNS)*** - **with the weight 3-15 kg.**
The above problem can only be resolved by monitoring the system in its entirety, both locally and globally. **The launch of few/few tens EMCNS by one launcher must ensure low-cost orbital grouping for multi-points monitoring of the space weather parameters in magnetosphere and ionosphere.** The autonomous the EMCNS will be to perform continuos, in-situ measurements of the magnetospheric plasma parameters with sufficient resolution to resolve the spatio-temporal ambiguities associated with the driving microphysical processes. **The EMCNS can be thought of as the "pixels" of a syntetic magnetospheric image.**

The EMCNS concept is presented based on the experience of the instrument design for space plasma parameters measurement onboard the high elliptical orbit satellite (projects **INTERBALL**, **RELICT-2**), the interplanetary space stations (**Vega-1, -2, Phobos -1,-2, Mars 94/96),** and **especially balloons** (Vega-1, -2) and **small station** (Mars 94/96) where very big limitations of a mass, power, bit-rate, and etc existed.

International Space Station (ISS) will be included in SWP like mother-SC for EMCNS by use of the fixed in few points on outer surface buoys (modification of the EMCNS) with multi-purposes sensors.

Existence on the EMCNS of highly sensitive sensors with low noise level should allow to provide the new qualitative approach for the SWP problem solution.

The goal of this paper is to discribe the methodology and instrumentation for EME phenomena investigation by the EMCNS.

To fulfill this goal the **nano-satellites or automatic mini-buoys** ***(Figure 1, 2)*** will be designed, having full autonomy and relatively short-distance telemetry. The EMCNS fixed to the ISS surface (like mozer-satellite MZS), free floating near the MZS and tethered to the MZS, operation modes will be foreseen. In the last cases still one advantage will be the relatively easy realization of extremely high EM sensors sensitivity aboard of nano-satellites, what is not possible even using micro-satellites. **Besides technological goals of the proposed study there is very important to monitor electric and magnetic fields in the ionosphere for solving of a set of scientific and applied problems connected to plasma-waves processes reflecting solar-terrestrial connection.** It will be an important observation point for space weather study and forecast.

It is necessary to mention that the developed at early stages of space investigations conception of unique solitary experiments on spacecrafts launched in determined regions of near-earth space is now practically settled - no new results for fundamental physics development can be expected. The qualitative progress in our understanding of space processes could be obtained mainly with the help of regular study both in space and on the Earth during long period, at least of about one cycle of solar activity (11 years). The realization of the proposed project will make considerable input to such a study. **Using the opportunity of the ISS screw periodical coming out of station the search of both places-indicators of anomalous behavior and places with minimal level of interferences for monitoring system installation could be executed.**

The **methodology of electric and magnetic field measurements** aboard spacecrafts was developed intensely at early stages of space investigations [1-3], also with input of the authors of the present proposal [4-6]. But some theoretical problems connected with super-large bodies interaction with space plasma, charges and noises estimation, influence of active experiments still wait their investigation. Based on its results the requirements to the corresponding equipment have to be elaborated.

As a result of preliminary study and taking into account new possibilities of manned spacecraft a new conception of space buoys or the EMCNS is proposed. This conception includes the development of super-small (about 10 kg) fully autonomous measuring systems each of which will have following facilities ***(Figure.1):***

- flux-gate magnetometer (FGM);
- search-coil magnetometers (SC);
- wave probe
- electric sensors (ES);
- autonomous power supply (solar panels (SP) and inner long-term battery);
- short-range telemetry (TM);
- manually deployed booms;
- one-side fixator (F).

In the stowed position such the EMCNS will take very few place ***(Figure.1,b)*** and could be easily delivered to the MZS as piggy-back cargo. Then when the ISS (like MZS) screw will go outside, the EMCNS using special fixator F can be placed at any convenient place on the ISS surface. Its booms will be manually deployed and side SP properly oriented by the operator. Then **the EMCNS operation can be controlled from inside ISS control station using short-range TM.**

A set of such EMCNS along and across the ISS will give spatial structure of ISS electromagnetic environment and will allow to find proper places for its monitoring. For this the EMCNS have to be as cheap as possible and convenient in use. An optimistic estimation of both price and weight of the EMCNS is based on already existing achievements both in the structure construction and scientific payload.

The EMCNS structure is planned to be designed as miniaturized copy of micro-satellite structure [7]. It will be still simplified because any orientation system and no automatic booms deployment system are needed**. Preliminary estimation of total weight of all service structure in such conditions gives about 6 kg including 3 two-section booms of total length about 1 m each and lithium battery.**

The **scientific payload** composed from FGM sensor, 3 ES, 2 SC, 1 WP and electronics also is expected to be enough light and low powered. The sensors weight estimation together with their sensitivities based on present state of development is given in Table 1. The electronics is supposed to have **the weight about 2 kg and power consumption about 2 W.**

Table 1. Scientific Payload Proposed for the EMCNS

№	**Device**	**Measurement**	**Weight**
1.	Wave probe WZ	***Electric current density J***: Frequency range 0.1 Hz … 40 kHz, Noise 10^{-13} A.cm^{-2} Hz $^{-1/2}$ ***Magnetic field B***: Frequency range 0.1 Hz … 40 kHz Noise 10^{-13} T.Hz $^{-1/2}$ ***Electric potential φ:*** Frequency range 0.1 Hz … 40 kHz Noise 10^{-6} V. Hz $^{-1/2}$	240 gr
2.	Electric field probe ES	Frequency range 0.1 Hz … 200 kHz Noise 10^{-6} V. Hz $^{-1/2}$	120 gr
3.	Flux-gate magnetometer FGM	Frequency range DC - 20 Hz Noise 10^{-11} T	36 gr

4.	Search-coil magnetometer SC	Frequency range 10 Hz...200 kHz Noise 10^{-14} T. Hz $^{-1/2}$	110 gr

The short-range TM can be developed using the principles of already existing systems. The simplest realization seems to be based on cellular phone technology. If no additional electromagnetic interferences will be desirable, also very attractive TM realization can be based on infra-red communication systems, the possibility of using of which for this purpose is already investigated by RKK ENERGIA.

All this makes the estimation of creation small low-price EMCNS very optimistic. For the following steps it is planned to complement the EMCNS by star imager [8] and use them in tethered or free floating around the ISS versions. Then the detailed structure of the ISS electromagnetic environment can be constructed and monitored [9]. By this the tiny and low-noise EMCNS will allow to realize full sensitivity of scientific instrumentation what is extremely important for the detailed study of microscale formations in ionosphere.

The "SPRUT-VI" experiment onboard "MIR" station.

The methodical and technical aspects of the EMCNS have been used in the frame of the "SPRUT-VI" experiment [10] onboard "MIR" station ***(Figure 3)***.

The "SPRUT-VI" allows to study the correlation between of varies factors of influence on the magnetosphere natural and artificial origin and arising of particle flows and electromagnetic radiation's bursts. Now it is shown, that practically any influence on the magnetosphere first of all result in a rise of varies energy particle flows and electromagnetic emission in a sufficiently broad frequency range. Therefor the "SPRUT-VI" devise is a combination of the independent complexes of scientific devises, united by the common ideology, power supply system, controlling system and system of the data accumulation and transmission.

The device allows to measure:
- vector DC - magnetic field +/- 60000nT;
- electron flows in the energy range from 50 keV up to 2.5 MeV;
- proton flows in the energy diapason from 50 keV up to 30 MeV;
- particle flows with the energy 1.5 MeV/nucleon;
- the flows of CNO-group nuclei with energies 1.5 MeV/nucleon;
- wave emissions in frequency range from 0.1 Hz up to 20 kHz;
- density electric current in the plasma from 10^{-8} up to 10^{-13} A.cm^{-2}.

The first result of DC and AC magnetic field are presented on ***(Figure 4 and Figure 5)*** respectively.

REFERENCES

1. Fahleson,U.V., et al. Investigation of the operation of a DC electric field detector. *Planet. Space. Sci.* Vol. 18, No. 11. p.1551. 1970.
2. Mozer,F.S. Analysis of techniques for measuring DC and AC electric fields in the magnetosphere. *Space Sci. Rev.* Vol 14, No 2, p. 272 - 313, 1973.
3. Pedersen,A., R.Grard. Quasistatic electric field measurements on the Geos-1 and Geos-2 satellites. *Quantitative Modeling of Magnetospheric Processes*, Washington D. C., pp. 281 - 296, 1979.
4. Soprunyuk,P. M., S.I.Klimov, V.E.Korepanov. *Electrical fields in space plasma (in Russian).* - Kijev, "Naukova Dumka", 190 pp., 1994.
5. Korepanov,V. Measurement of electrical field fluctuations by a method of Langmure double probe method. *Kosmicheskije issledovanija (in Russian),* Vol. XXII, No 3. pp. 421- 442, 1984.
6. Korepanov,V. Researches of electric field intensity in rarefied plasma. *Kosmicheskije issledovanija (in Russian),* Vol. XXYI, No 1. - pp. 152- 154, 1988.
7. Gladilin,V., V.Korepanov. Microsatellites for Earth observation missions. Small Satellites for Earth Observation. *Digest of the International Academy of Astronautics,* Berlin, - Nov. 4 -8, pp. 437 - 440, 1996.

8. Jorgensen,J.L., C.C.Liebe. The advanced stellar compass, development and operations. *Small satellites for Earth Observation. Digest of the International Academy of Astronautics*, Berlin, - Nov. 4 -8, pp. 140 - 143, 1996.
9. Klimov,S., O.Grigoryan, J.Juchniewicz, V.Korepanov, Yu.Lissakov, M.Parrot, O.Pokhotelov, V.Rodin and A.Chernjavski, The survey of anthropogenic and geophysical electromagnetic perturbation by use the micro-satellite integrated in ISS infrastructure. *Annales Geophysicae*, Part IV, Supplement IV to Volume 16, p. C1189 (1998).
10. Grigoryan,O.R., S.I.Klimov, Z.Klos, V.E.Korepanov, V.G.Rodin, S.B.Ryabukha, S.A.Pulinets, I.V.Churillo. Instrument for the ecologycal monitoring on "MIR" station. *Ingeniring ecology (in Russian)*, No.2, pp.44-51, 1997.