

# “OBSTANOVKA” EXPERIMENT ONBOARD INTERNATIONAL SPACE STATION FOR SPACE WEATHER RESEARCH

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## Abstract

The evolution of the dynamic processes in magnetosphere and ionosphere leads to the appearance of a set of electromagnetic (EM) phenomena. The realization of their electromagnetic monitoring onboard the International Space Station (ISS) needs both the working out of the observation methodology and the design of corresponding experimental equipment. The methodology of electric and magnetic measurements onboard spacecraft was developed intensely at early stages of space investigations, also with input of the authors of the present proposal. But some theoretical problems connected with super-large body's interaction with space plasma, charges and noise of active experiments influence estimation still wait their investigation. To achieve this goal we shall compile the requirements for the Plasma-Wave Complex (PWC) of scientific instrumentation for wave and plasma parameters measurements in the ISS environment, which will be implemented in the OBSTANOVKA (ENVIRONMENT in English) experiment planned onboard of Russian segment of ISS.

## 1. INTRODUCTION

Natural plasma emission has become object of interest since first observation on the orbit of spacecraft has been done. The HF frequency range emissions are characterised by the whistler, Cerenkov, electron cyclotron emissions, Langmuir, Bernstein, upper hybrid, Z-mode or broadband wave activity at the ionospheric altitude. On the other hand Earth ionosphere undergoes also various man-made influences. Electromagnetic emissions observed in the nearest Earth environment are superposition of natural emissions and various types of man-made noises. A variety of observed phenomena connected with human activity like wave particle interaction, precipitation of radiation belt electrons, parametric coupling of electromagnetic whistler waves,

triggering emissions, frequency shifting and wave spectrum broadening has been detected and analysed. Also the electromagnetic emissions are detected on the board of low orbiting satellites as a consequence of thunderstorm activity and earthquake or volcanic eruption. The level of electromagnetic radio noises observed on satellite board strongly depends on properties of satellite environment and noises generated by payload system, as well as geophysical conditions. Most of these disturbances were observed at lower frequencies and only a few were correlated with the disturbances of HF electromagnetic emissions.

Some ground-based experiments were performed and consisted in controlled heating of the ionosphere by powerful electromagnetic waves. Synchronous detection of HF waves on the board of Coronas-I satellite over SURA heating facility exhibited enhancement of background radiation together with the appearance of radiation at the 3rd and 5th order of electron cyclotron harmonics [Klos et. al., 1997]. Latest experimental results from ionosphere HF pumping experiments in the night-side aurora region show the triggering of local aurora activation. The observations of HF emission in the topside ionosphere from the boards of low orbiting satellites - INTERCOSMOS -19; COSMOS-1809, ACTIVE and APEX - reveal the same features, i.e. a significant increase in emission intensity over some geographic areas. This remarkable intensity enhancement was observed even in the frequency range below the critical foF2 frequency, mainly at local night time [Klos et al., 1990]. As this enhancement took place mainly over populated areas of Europe and Asia, it was correlated with anthropogenic activity. This type of registration was also performed on the board of low orbiting satellite CORONAS-I. Here, parallel to the registration of emission in the range 0.1-30 MHz, high energy fluxes of electrons and protons were detected.[Klos et al., 1997; Rothkaehl et al., 1999; Rothkaehl and Klos 2003]. The past experiment

provided on the board of AUREOL-3 satellite permit to construct the map of electric and magnetic field emissions and examine an influence of the man-made activities on the natural waves [Parrot, 1990]. These measurements give a new picture to the scenario of the HF emissions in the topside ionosphere and interaction with the VLF frequency radiation as well as with particle precipitation. Permanently pumped to the ionosphere the electromagnetic waves by the system of broadcasting stations can disturb the nearest space environment too. Thus this activity can create in the topside ionosphere local Langmuir turbulence or ion-acoustic turbulence. It seems that the observed enhancements of background radiation in the HF frequency band are driven by natural changes in the geomagnetic system as well as by human activity and are related to VLF frequency plasma activity.

New design radio receiver for frequency band 0.1-15 MHz, with three electric and magnetic field component of antenna system on board ISS can be used to understand ionosphere processes and to select the emission related to human activity as well as to another artificial disturbances. The design experiment can be used for monitoring of the electromagnetic ecosystem for space weather forecast.

Fundamental problem of geophysical research as a part of space weather problem, is the study of interrelation of the plasma and electromagnetic phenomena in solar wind and magnetosphere with geomagnetic disturbance, observable at spacecraft, which orbits are on ionosphere heights. The special attention in this problem is given to questions of distribution and evolution of extremely low-frequency (ELF) magnetic disturbance. The ELF-VLF signals recorded earlier [Lichtenberger et al. 1991] showed various features including natural and man-made waves. The origin of some of these signals were unknown. In some cases the signals showed strange patterns. The accurate and controlled derivation

of the direction of propagation in complex media has some problematic and theoretically important topics, which might have consequences in practical application as well, e.g. the relation between the Poynting vector, the wave normal and the real direction of propagation of the wave energy [Ferencz, 1977, 1978]. The recent research concludes that the origin of a part of this ULF-ELF-VLF phenomenon may be due to seismic activity [Ferencz et al., 2001]. In these investigations the direction of propagation is extremely important.

The processes of the aurora ionosphere extension during substorm were investigated using data obtained in the SPRUT-VI experiment carried out onboard the MIR orbital station [Klimov et al., 2002]. The MIR instruments have measured periods of strong increases in magnetic variability and in energetic electron fluxes, especially at the highest latitudes covered by the MIR orbit. Co-ordinated measurements from ACE in the solar wind and from INTERBALL-1 at a variety of locations around the magnetosphere describe the development of a magnetic substorm at the time of these MIR observations. The occurrence of these MIR enhancements as a function of time, and as a function of geomagnetic co-ordinates through the relevant orbits, are consistent with a lowering of the low latitude aurora boundary into the MIR range of latitudes during this substorm.

Data from MIR has enabled us to study the near Earth aspects of magnetic substorms. We suppose that the International Space Station can be used to provide a direct monitoring of space weather effects at ionosphere heights, especially during times of relatively strong disturbances.

PWC instrument will be composed from multiple units, which are integrated into two blocks installed outside ISS and the third one (BSTM, see Table 1) inside ISS:

Table 1. PWC composition

Unit	Responsible Institute
Combined wave sensor – CWS-1, CWS-2	LC ISR
Flux gate magnetometer – DFM-1	IKI
Flux gate magnetometer – DFM-2	LC ISR
Langmuir probe - LP-1, LP-2	STIL
Spacecraft potential monitor - DP-1, DP-2	IKI BAS
Plasma discharge stimulator – SPP	SKB
Correlating Electron Spectrograph (10eV – 10KeV) CORES	Sussex University
Radio Frequency Analyzer – RFA (Scorpion)	SISP; SRC
Signal Analyzer and Sampler – SAS3	SRG, BLE
Data Acquisition and Control Unit - DACU-1, DACU-1	KFKI RMKI; Sheffield University
Block of Storage of Telemetry Information – BSTM (inside ISS)	KFKI RMKI; Sheffield University
Grounding support equipment – GSE	KFKI RMKI; SRC

The “OBSTANOVKA-1” stage will be carried out to provide a databank of electromagnetic fields and of plasma-wave processes occurring in the ISS near-surface zone (NSZ) to study the plasma component factors of near-Earth space (NES). The results will be

used in the field of applied geophysics, ecology, space weather monitoring, and also for the updating of operational requirements used in space engineering and technology.

The PWC instrument will be developed and constructed within the framework of the given international cooperation under the scientific and technical management of Space Research Institute (IKI) of Russian Academy of Sciences. In the year 2002 the OBSTANOVKA experiment was agreed by Russian and Ukrainian Space Agencies to have a status of Russian-Ukrainian experiment with international participation. The internal cooperation given in Table 1 allows not only to decrease the cost of instrumentation for every participating party but to raise scientific and technological level of the experiment.

To study the plasma environment parameters, including electromagnetic conditions (EMC) in the vicinity of ISS, PWC will measure fluctuation and gradients of magnetic field, parameters of electrostatic and electromagnetic fields, density and temperature of thermal plasma, thermal electron flows in the ISS NSZ, and also electric potential of the ISS itself.

The measurement of all of these parameters will allow us to investigate the interaction of a superlarge spacecraft (SC) with NES plasma.

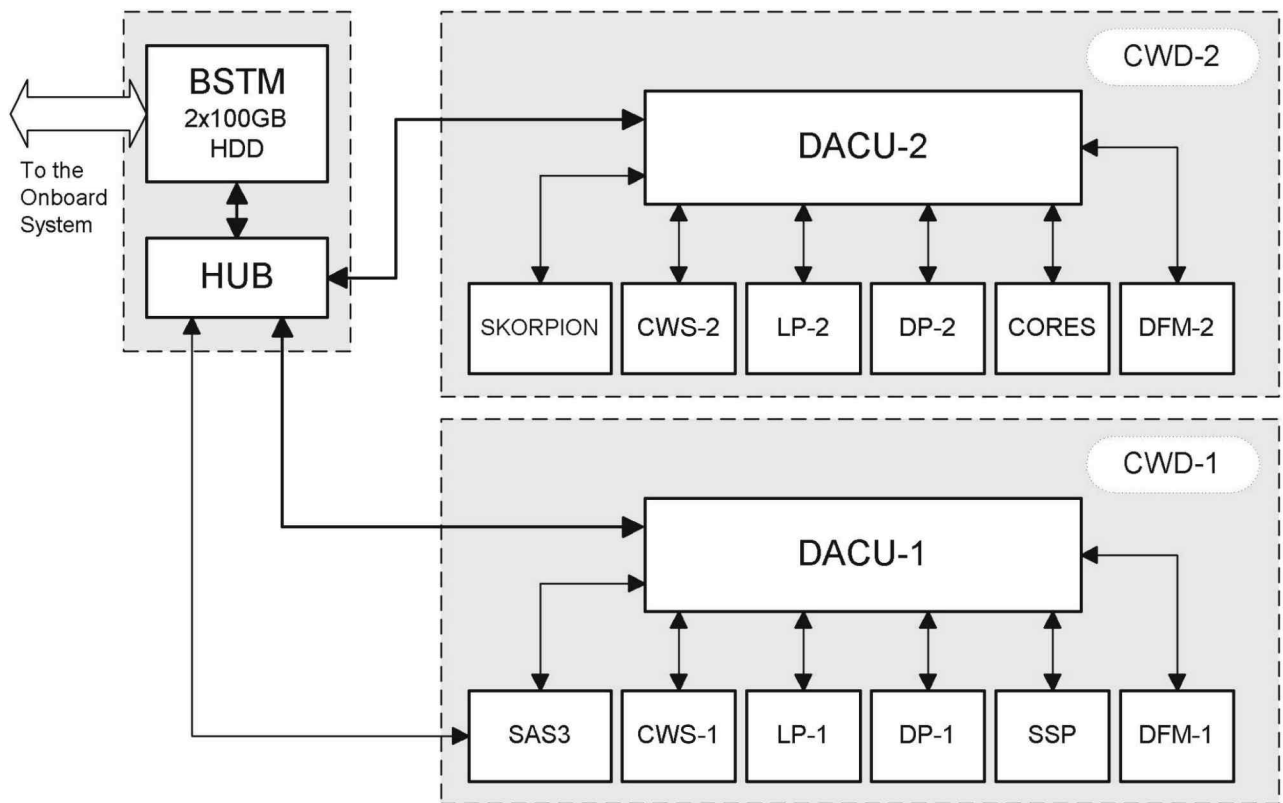


Figure 1. PWS block-scheme.

The PWC is implemented as two measuring blocks with nearly identical sensors, the distance between which (3-15 m) will enable us to carry out simultaneous point-to-point measurements necessary for the measurements of DC electrical fields and small-scale gradients in magnetic field. This will also increase the PWC reliability and, accordingly, the “OBSTANOVKA-1” experiment success. The detailed description of the experiment goals and instrumentation is given below.

## 2. THE CRITICAL REQUIREMENTS TO THE PWC

The specific oscillations range for NES is from DC fields to a few tens of megahertz. The evolution of dynamic processes in Earth’s magnetosphere and ionosphere plasma regions leads to the appearance of a set of electromagnetic phenomena which may be detected in NES and on the Earth’s surface. For example, extreme change of magnetospheric structure in 1972 resulted from its interaction with catastrophically

accelerated plasma flow from the Sun led to the failure of some important electric transmission lines and pipe lines in Canada and US. The coronal plasma outburst from the Sun on January 6-11, 1997 probably caused the failure of the Telstar-401 satellite. Up to now the influence of solar activity and magnetic storms on the human organism is insufficiently studied (frequencies about several hertz).

On the other hand, some natural electromagnetic phenomena in the Earth’s atmosphere have some influence on the electromagnetic fields registered in the magnetosphere (usually strongly modified by the ionosphere). A classic example of terrestrial radiation registered on the SC are atmospheric whistlers generated by lightning discharges.

The industrialization of society is connected with the consumption of significant quantity of energy, including electromagnetic. Up to now insufficient attention has been given to identifying the extent of the influence of

this radiation into NES in the range from several hertz to several kilohertz on the environment (including biosphere) [Grigorjan et al., 1996]. Phenomena on the Earth's surface (for example, earthquakes, typhoons and so on) also may be connected with the structural change of spatial electromagnetic fields and with its generation.

Launch of superlarge spacecrafts - Orbital Station MIR and ISS – may also become a significant factor in the anthropogenic influence to environment [Klimov et al., 1995]. Therefore a long-term global ecological monitoring of electromagnetic radiation in the range from DC fields to tens of megahertz is necessary (higher frequencies are in the region used by telecommunication networks where the control system of the radiation levels works) [Grigoryan et al., 1997]. This monitoring should be carried in space because only satellite allows us to monitor large section of the Earth and to work in durable (more than 5 years) continuous automatic mode. It is very important here that the obtained information will be immediately transmitted to powerful computers used in space research and available for analysis by the wider scientific community.

Project design studies were made taking into account the requirements to space experiment structure and technology of manufacturing. Studies considered instrument compactness, modularity and electromagnetic compatibility of all onboard service systems and scientific payload. This ensures that the natural electromagnetic condition in the NSZ plasma will be not strongly disturbed and provides us with a high level of measurements reliability in the surrounding plasma.

The goals of “OBSTANOVKA-1” experiment can be formulated as follows:

- study of plasma-wave processes arising in NSZ from the interaction of superlarge SC with the ionosphere;
- improvement of Combined Wave Diagnostics (CWD) method of ionosphere plasma flows fluctuation on superlarge and long-lifetime SC;
- identification of plasma flows disturbance sources and electromagnetic fields in NSZ;
- geophysical research of plasma-wave processes connected to solar - magnetosphere - ionosphere - atmosphere - lithosphere interactions;
- ecological monitoring of low-frequency electromagnetic radiation of anthropogenic character, and also connected with global hazard;
- study of environmental plasma and electromagnetic fields disturbance levels from the injection of electron and plasma beams from ISS and mechanisms of artificial electromagnetic waves distribution;
- study of the mass characteristics of heavy molecular ions ( $\text{NO}^+$  and  $\text{O}_2^+$ ) in NSZ of ISS on the basis of the measured VLF noise and plasma concentration data;
- research of space weather conditions in equatorial, middle-latitude and sub-aurora ionosphere.

The performance of the “OBSTANOVKA-1” experiment will permit us also to solve the following tasks of applied and fundamental importance:

- to determine spectral density of electromagnetic, electrostatic and magnetic fields fluctuations in a range of frequencies from fractions of hertz up to tens megahertz resulting from the influence of the various natural NES factors and also from an artificial origin;
- to measure vectors of intensity of magnetic fields and field-aligned currents (FACs);
- to determine spectral fluctuation of the charged particles flows and density;
- to estimate the change of distribution of electromagnetic waves in the disturbed ionosphere, caused by an ISS electromagnetic background and influence of active means, and also to estimate the range of electromagnetic disturbance of ionosphere around ISS;
- to estimate the conformity of measured electromagnetic fields to the operational requirements of space engineering products and technology, service systems and useful payload;
- to analyze the concentration of ionosphere plasma close to ISS.

The developed PWC scientific equipment is designed to measure in NES the following physical parameters:

- current parameters of thermal plasma (in two points):
  - electrons and ions temperature,  $T_e$ ,  $T_i$ ,
  - electrons and ions density,  $N_e$ ,  $N_i$ ;
- current electromagnetic parameters (in two points):
  - DC electric and magnetic fields and currents;
  - AC electric and magnetic fields and currents;
  - current plasma potential and ISS potential;
  - electrons spectra with energy range 0,01-10 keV;
  - spectra of VLF electromagnetic fluctuations.

For the study of discharge effects in NES plasma the PWC structure includes also the device for discharge stimulation.

### 3. The PWC SENSORS STRUCTURE

#### 3.1. Langmuir Probe (LP)

The main task of LP is to study the thermal plasma in the vicinity of the ISS and the potential of the ISS structure. The measured parameters are the electron and ion concentrations  $N_e$  and  $N_i$  in the range  $1 \cdot 10^9 - 1 \cdot 10^{13} \text{ m}^{-3}$ , the electron temperature  $T_e$  from 1000 to 6000 K, and the space station potential  $U_s$  in the range  $\pm 200 \text{ V}$ . Its main characteristics are given in Table 2. There are two main modes of operation: “full”, for measuring  $T_e$ ,  $U_s$ ,  $N_e$  and  $N_i$ , with time resolution 1 s, and “fast” for measuring the fluctuations of the plasma concentration, with frequency of 200 Hz. The presence of two identical instruments LP1 and LP2 mounted on each of the CWD units allows the determination of space variations of  $N_e$ ,  $N_i$ ,  $T_e$  and  $U_s$  in the NSZ.

LP experiment consists of two identical instruments, LP1 and LP2. Each of them contains an electronic block and a measuring monoblock consisting of a sensor and a

multi-range current meter (Fig. 2). The electronic blocks are situated in the CWD-1-1 and CWD-1-2 units. The sensors are cylindrical electrostatic probes. The electronic blocks provide the sweep voltages applied to the sensors and measurement of the current collected by them, and include microcomputers for controlling and optimizing the measurement process, processing and preparing information for the Telemetry, interfacing to the telemetry, Telecommand (TM/TC) and the On-Board Data Handling Unit, OBDH.

Electrons and/or ions, depending on the voltage applied, are collected by the cylindrical sensors, and the current

generated by them is fed to the multi-range current meter, converted there to voltage and, after the A/D converter, read out by the DPU into the TM stream together with information about the voltage applied, at a rate dependent on instantaneous LP instrument mode.

The LP development is funded by National Space Program of Bulgaria. It is scheduled to be available for flight to the end of 2004. The given electrostatic probes have operated aboard numerous "Intercosmos" satellites, heavy geophysical rockets "Vertical", and have been included in the payload of Mars-96 mission.

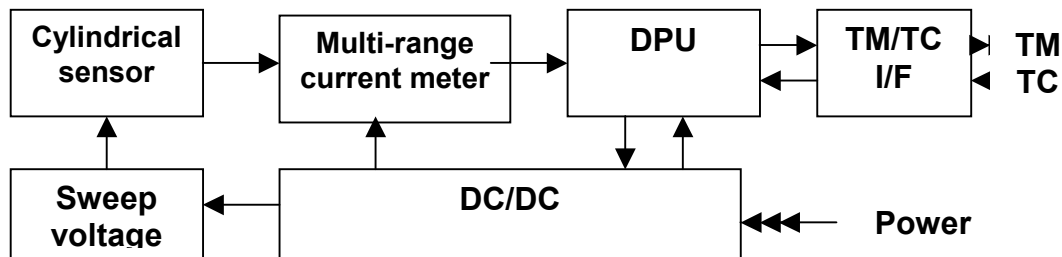


Figure 2. The LP functional block diagram

Table 2. LP main characteristics

Parameter	Value
<i>General</i>	
Mass of the measuring monoblocks, kg	2 x 0.35 (TBC)
Mass of the electronic block, kg	2 x 0.3 (TBC)
Power, W	2 x 3
Voltage, V	27.0 (+/- 4.0)
Dimension of the monoblocks, mm	245 x 95 x 52
<i>Functional</i>	
Electron concentration range, m <sup>-3</sup>	10 <sup>9</sup> to 10 <sup>13</sup>
Ion concentration range, m <sup>-3</sup>	10 <sup>9</sup> to 10 <sup>13</sup>
Electron temperature range, K	1000 to 6000
Potential, V	-200 to +200
<i>Operational</i>	
Discrete Commands	1 Command [ON/OFF]
TC Stream (Serial Interface)	Bytes [Various-TBD]
TM Stream (Serial Interface)	Bytes [Various block sizes- TBD]
TM Rates (Mode dependant)	200bps to 10kbps

### 3.2. The potential difference measurements instrument (DP)

The potential difference measurement between a probe and ISS body is the main scientific aim of the device DP. This allows us to study of the ISS electric charging processes and the time variation of the electric potential. The existence of two identical devices DP1-1 and DP1-2, which are mounted on every block CWD, allows us also to measure the spatial electric field in NSZ. The potential difference can be measured in the range  $\pm 200$  V. The existence of such high potential values admits charging mechanisms, different from collecting of conducting particles in the plasma. The device DP also provides an estimation of the contact layer resistance of the system plasma – probe. If there is an opportunity for the probe to be replaced by an astronaut, this will permit the study of the influence of the probe geometric and constructional characteristics on the potential difference measurement.

The device DP is an electronic module which measures the potential difference in range  $\pm 200$  V, which is divided in two sub-ranges:  $\pm 20$  V and  $\pm 200$  V. The sub-ranges are switched automatically.

A 12-bit ADC (Fig. 3) provides potential difference measurements with resolution 10 mV ( $\pm 20$  V) and 100 mV ( $\pm 200$  V).

The device DP has three main operational modes:

- 'monitoring' - measurement frequency of 1 Hz;
- 'event' - measurement frequency OF 512 Hz;
- 'research' - a selectable frequency of the measurements.

A possibility for external command is provided, to choose measurement frequency, in the range (1 Hz – 2048 Hz). A measurement mode slower than 1 Hz is also possible. The measurement duration in the modes

‘event’ and ‘research’, as well as the switching on/off of the modes, is synchronized with plasma device SSP.

The device DP communicates with storage and data telemetry module BSTM through RS422 or RS485 interface. The data exchange speed is 115.200 kBit/s. There is a possibility for the transmission of measured value of the potential difference through BSTM to a standard personal computer in RS ISS or/and to other devices of CWD.

The device input is protected in cases of voltages higher than  $|200\text{ V}|$ .

The signal is obtained from a sensor – a conducting sphere with  $R=40\text{ mm}$ . The boom part adjacent to the sphere is biased forming an ‘equipotential electrode’. It is isolated from the sphere, but is maintained at a potential equal to the sphere potential. Thus, the deviation from the spherical symmetry of potential is minimized. The part of the boom closer to the block CWD, is isolated and maintained at a potential - 10 V lower than the potential of the sphere – ‘decelerating electrode’. This diminishes the influence of the photoelectrons current from the block CWD body and

from the ISS body, on the potential difference measurement accuracy.

A preamplifier (PA, Fig. 3) with gain equal to one is mounted inside the probe. Its high input resistance assures the probe potential is very close to the sphere floating potential. Its task is to minimize the error from parasite capacitive influences. The input currents of the preamplifier, which flow from the sphere to PA, will be smaller than 10 pA and will be determined by the elements ensuring PA input protection. As a part of the device self - test procedure, PA input is short-circuited by a shunt, which allows the estimation of the layer resistance. The spherical probe and the equipotential electrode are realized as replaceable monoblock. The monoblock is mounted on a boom with length  $\sim 120\text{ cm}$ .

The secondary power supply source has galvanic insulation between primary power lines and the secondary power lines and the equipment structure. The connection with the main power supply will be designed so that no instrument failure can influence other units. The mass budget of DP unit is given in Table 3. The instrument total power budget is  $\sim 4.7\text{ W}$ .

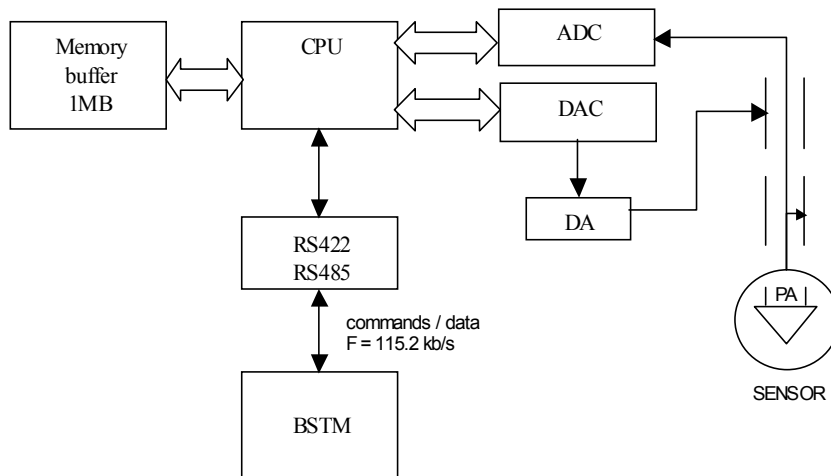


Figure 3. Functional block-diagram of DP device

Table 3. Device DP mass budget

Unit	Mass, kg
Monoblock	$0.180 \pm 10\%$
Boom	$0.350 + 10\% - 20\%$
Electronic Block	0.440
Total	$0.97 + 10\% - 20\%$

### 3.3. CORRELATING ELECTRON SPECTROGRAPH 10eV – 10KeV (CORES)

The main purpose of the CORES is to study the electron population in the ISS vicinity. Electron velocity distribution functions are measured in fast time resolution as well as kilo-Hertz and Mega-Hertz modulations in the electrons resulting from wave-particle interactions. Electrons in the energy range 10eV up to 10keV are measured over a  $360^\circ$  field of view (FOV) with energy spectra resolved at typically at  $\sim$

0.1s time resolution with simultaneous measurements of electron modulations in the frequency ranges: 0-10MHz (HF); 0-10kHz (VLF); and 0-150Hz (ELF).

The CORES is a single module containing all of the components necessary for electron energy resolving and electron detection via microchannel plates (MCP) with associated High Voltage supplies (HV) and includes fast processing using field programmable gate arrays (FPGA) with a microcontroller Data Processing Unit (DPU) interfacing to the Telemetry (TM) and

Telecommand (TC) interfaces, I/F of the On-Board Data Handling Unit, OBDH (Fig. 4).

Electrons are accepted over a range of energies arriving in a 360° plane with an acceptance of +1 or -1° perpendicular to this plane. The electron distribution function is simultaneously sampled by a total of 128 energy-angle combinations, all processed by the FPGA in parallel with summed averages read out by the DPU into the TM stream at a rate dependant on instantaneous CORES instrument mode. Each of eight 22.5° sectors of the entrance plane measures electrons in 16 pseudo-logarithmic energy ranges that contiguously cover the

range from 10eV to 10keV. Its main characteristics are given in Table 4.

The main space scientific applications of the CORES are:

*Passive.* Measurement of natural space plasma electron spectra and wave-particle interactions at high time resolution.

*Active.* Identify the effects of electron/plasma guns/emitters and HF/VLF transmitters on the ambient plasma and under certain conditions can also provide a measurement of spacecraft potential.

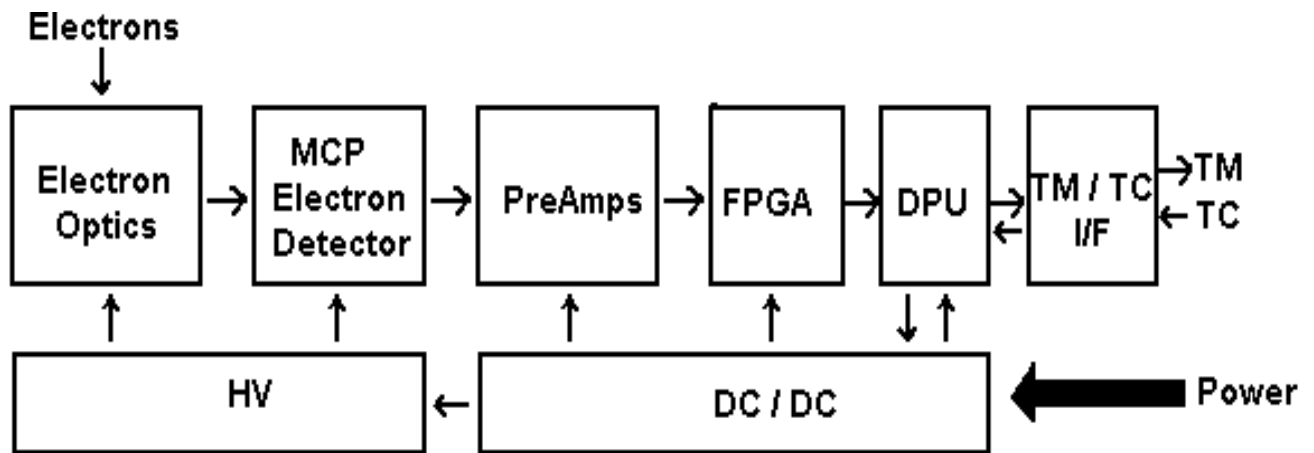


Figure 4. CORES functional block diagram

Table 4. CORES main characteristics

Parameter	Value
<i>General</i>	
Mass, kg	1.1 (TBC)
Power, W	2(+/- 0.2) (TBC)
Voltage, V	27.0 (+/- 4.0)
Dimension, mm	100 x 100 x 150
<i>Functional</i>	
Electron Energy Range, eV	10 <sup>1</sup> to 10 <sup>4</sup>
Frequency Ranges, Hz	HF:0-10 <sup>7</sup> ; VLF:0-10 <sup>4</sup> ; ELF:0-150
Frequency Resolution, % of range	3
Energy Resolution, % of each enter	50
<i>Operational</i>	
Discrete Commands	1 Command [ON/OFF]
TC Stream (Serial Interface)	Bytes [Various-TBD]
TM Stream (Serial Interface)	Bytes [Various block sizes- TBD]
TM Rates (Mode dependant)	100bps to 100kbps

The CORES Spectrograph development is funded by UK EPSRC. Scheduled to be available for flight from summer 2004. The Correlation aspects are derived from previous correlators on the SPREE instrument flown on STS-46, 1992, & STS-75, 1996. Sussex correlators were also included on the OEDIPUS-C Canadian sounding rocket, 1995 and on a NASA Sounding rocket, 1998. The Spectrograph is a 360° focusing design combined with a 2-D MCP Readout Electronics design recently validated in a vacuum chamber.

The instrument has a variety of possible modes but it is expected that most operation time will be limited to a few modes:

- OFF: The power supply to the instrument is switched off.
- STANDBY: The power to the instrument is on but HV supplies have not been commanded on. This mode is for uploading new software, and new FPGA configurations.
- CALIBRATION: This mode is for optimizing the MCP HV supply value.
- LOW DATA RATE OPERATION: This mode is primarily for energy spectra (no modulations information returned)
- MEDIUM DATA RATE OPERATION: This mode is for full spectra and modulation spectra, but summed over 10s.

- HIGH DATA RATE OPERATION: This mode is for full spectra and modulation spectra at the highest time resolution possible.

Autonomy is provided by a certain amount of artificial Intelligence included in package used to select energy-angle zones for correlation, or for high time resolution (high data rates) or for optimum instrument operation mode and optimum compression algorithms.

The experiment consists of a single unit contained in a box comprised of three parts milled from aluminium (dural). All voltage supplies and DC/DC convertors are situated within this box.

The DC/DC convertors have current limitation and short-circuit protection that will protect other on-board systems against any short circuit on the CORES instrument side. Any persistent voltage in the range between 24V and 32V (including a short circuit of the power line) is harmless to the instrument.

The CORES internal control units is based on a fast 8-bit microprocessor that configures and controls the operation of an FPGA responsible for fast processing (e.g. ACF) of electron arrival pulses.

The FPGA is responsible for:

- Data acquisition - receiving electron detection events from 128 energy -angle zones in parallel.

- Simultaneous HF, VLF and ELF frequency ranges modulation analysis via ACF algorithms.
- The DPU is responsible for:
  - Data Format and TM packet building
  - HK monitoring - obtain HK data (test point voltage and temperature), prepare HK-packet header
  - TM handling - sends formatted TM packets to telemetry subsystem
  - TC handling - receive TC packets, validate the contents and execute or reject
  - Instrument state control - control the execution of the mode changing commands and keep the instrument in a sensible state.
  - Configure FPGA on start up.

### 3.4.COMBINED WAVE SENSOR

Combined wave sensors CWS1, CWS2 (LEMI-603) are intended for measurement of one component of magnetic field variations (B-channel), current density (I-channel) and electric potential (E-channel) of ionosphere space plasma. An additional channel for measurement of the sensor block temperature is included. Each of probes consists of two units. The first unit is a block of sensors CWD-PS and the second one is the set of electronic unit CWD-SC. The CWD operation block diagram is given on Fig. 5.

Table 5. CWS1, CWS2 Basic Technical Specifications

Frequency band of all signals, Hz	0.1 ... 40000
Noise levels at frequency 1 kHz for:	
Induction of magnetic field channel, fT/√Hz	≤ 100
Current density channel, pA/cm <sup>2</sup> ·√Hz	≤ 1
Electric potential channel, nV/√Hz	≤ 20
Sensitivity:	
Magnetic induction channel, on plateau, V/T	10 <sup>8</sup>
Current density channel, V/A (effective surface area 78 cm <sup>2</sup> )	10 <sup>6</sup>
Gain of electric potential channel amplifier	10
Operation temperature range, °C	± 50
Stabilized supply voltages, V	± 5 (... 12)
Power consumption, W	≤ 0.3
Overall dimensions, mm	
Sensor w/o fasteners	∅27x300
Preamplifier	50x136x50
Weight, kg	0,18
Sensor	≤ 0.25
Preamplifier	≤ 0.3

### 3.5.Flux-gate magnetometer DFM2

According to project requirements, a new model of space magnetometer DFM2 (LEMI-012) is developed. The magnetometer LEMI-012 is intended for automatic measurement of three components of DC magnetic field induction. The instrument represents measurements results in the digital form, has high accuracy of measurements and linearity, and has built-in correction of temperature error. It allows receiving authentic information about temporal variations of the Earth magnetic field vector components in orbital flight.

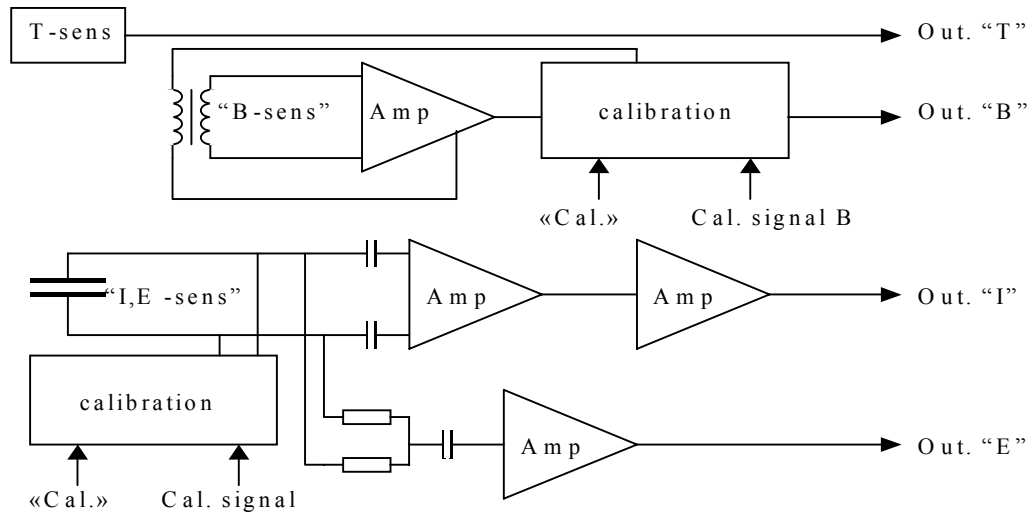
Advantages of the device:

- small dimensions, mass and power consumption ;
- series channel RS-485 of data exchange with external telemetry;
- availability of “TEST” command for in-flight verification of the device;
- standard power supply of the device, 24-34 V.

Structurally the magnetometer is executed as a monoblock comprising both sensor and electronic units. The structural parts of the sensor and the magnetometer is made of modern constructional materials and provides reliable operation in outer space conditions after severe launch time stresses. Special



sensor design maintains axial alignment after extreme shock loads.



**Figure 5. The CWS1, CWS2 Operation Block Diagram**

A user serial interface transmits output digital signals into the data acquisition and unit control. It maintains UART protocol and the communication channels are galvanically insulated from every circuit.

Further mass decreasing is possible (up to two times and even more) but it requires the use of much more expensive technology and component base. The DFM2 basic specifications are given in Table 6.

**Table 6. Basic Technical Specifications of DFM2 (LEMI-012)**

Measurement range, nT	$\pm 60000$
Resolution, nT	$\leq 1$
Axial non-orthogonality (without compensation)	$\pm 2^\circ$ of arc
Maximal offset, nT	50
Zero drift over temperature, nT/ $^\circ\text{C}$ (without compensation)	$< 2$
Gain drift over temperature, % of reading / $^\circ\text{C}$	$< 0.005$
Power consumption, W	$< 0.2$
Overall dimensions and mass	150x90x45 mm, 0.7 kg
Shockproof, till, g	150

### 3.6.FLUX-GATE MAGNETOMETER DFM1.

DFM1 is one of two magnetometer using in the PWC of scientific instrumentation. The instrument is three components flux-gate magnetometer measuring DC magnetic field induction. The measurement has high accuracy of measurements and linearity. Beside three

components DC field the instrument give possibility to get data about magnetic field pulsation and fluctuation (one component) in five frequency band: 55, 110, 165, 400 and 800 Hz. There is possibility to use additionally two bands. The wide of bands is 10 Hz. The measurements region in the band is 0.1 – 100 nT.

**Table 7. Basic Technical Specifications of DFM1**

Measurement range, nT	$\pm 64000$
Resolution, nT	$\leq 10$
Bands for measurement of pulsation and fluctuation, Hz	55, 110, 165, 400, 800
Axial non-orthogonality (without compensation)	$\pm 2^\circ$ of arc
Zero drift over temperature, nT/ $^\circ\text{C}$ (without compensation)	$< 2$
Gain drift over temperature, % of reading / $^\circ\text{C}$	$< 0.005$
Power consumption, W	$< 0.7$
Overall dimensions and mass	150x90x45mm, 0.5kg

The DFM1 basic specifications can see in Table 7.

The results of measurements represent in the analog forms and before recording in memory data are sampling rate 2 Hz with 16 bit ADC for three components of DC field and 0.1 Hz for five frequency bands.

Structurally the instrument has two units: sensor block and electronic block. The instrument is developed as space qualification magnetometer so it is made of modern constructional materials and electronic elements and provides reliable operation in outer space conditions after severe launch time stresses.

### 3.7 SAS3 INSTRUMENT

The continuous monitoring of ULF-VLF electromagnetic environment on board of ISS by an advanced SAS system (SAS3-ISS) and by simultaneous ground based measurements in ULF-VLF bands is important in the following areas:

- Investigation and verification of the direction of Poynting vector, wave normal and wave energy propagation, using the whole SAS3-ISS configuration.
- The investigation of the possible relationship between the seismic activity and ULF-VLF phenomena that may be related to earthquake events.
- The continuous monitoring of general ULF-ELF-VLF activity in the near-Earth space – including ELF-VLF pollution.
- The monitoring of natural and man-made variations of the plasmasphere by whistlers.
- Investigation of electromagnetic background and space weather phenomena.

- Investigation of the effect of the large ISS structure to the propagating wave-front.

The SAS3-ISS is a complex measuring system containing five main parts in the final configuration. This system measures, digitizes the incoming ULF-ELF-VLF signals in the 1 Hz – 25 kHz frequency range (at the actual position of ISS) using high and low sampling rates.

The main parts are the following:

- Main measuring unit (MMU) measures and digitizes 1 magnetic and 1 electric components from CWS1, CWS2 sensors and operates in all operational modes.
- Central data managing and processing unit (CDMU) receives, processes and stores (transmits) the data flow produced by the main measuring unit and transfers the data to the BSTM.

**Table 7. Basic Technical Specifications for SAS3-ISS Instrument**

Frequency Band, Hz	1 - 25000
Size, mm	110 x 200 x 20
Mass, g	< 250
Power, max, W.	2
Operating temperature, °C	-40°C - +75
Acceleration, g	+/- 10 in 3 axes for all units

The operation of the instrument is controlled by the onboard DSP working in the following modes:

- High sampling rate: 2Ms/s. Detailed time function of the incoming signals. Low sampling rate: 50 ks/s. Time domain measurement and frequency domain investigation.
- Automatic event and/or whistler detector. Sampling rate: 50 ks/s.

- The default mode of operation is Mode 3.
- In modes 1 and 2 it is possible the continuous monitoring of the ELF-VLF activity.

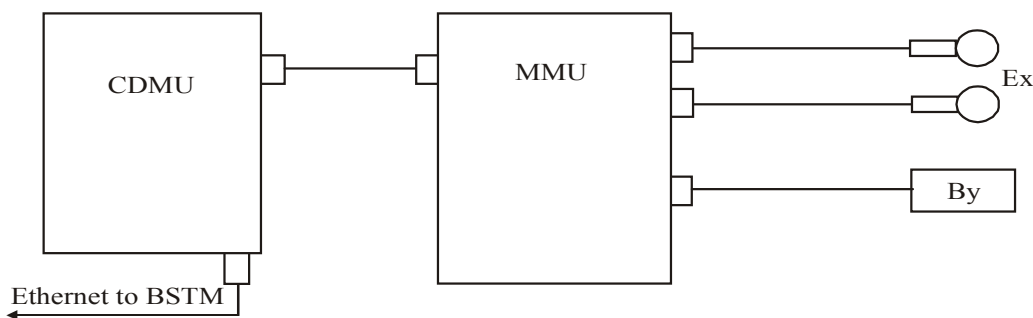


Figure 7. SAS3 block diagram.

### 3.8.DIGITAL RADIO - FREQUENCY ANALYZER (RFA)

The main purpose of this instrument is to measure natural and man-made electromagnetic emissions in the frequency range 100 kHz up to 15 MHz. This frequency range covers high frequency whistler waves, Langmuir and upper hybrid modes of the natural plasma. Thus, this instrument can be used as a versatile

device for studying nonlinear effects of local plasma resonances, radio transmissions from the ground, and ISS generated noise in the above mentioned frequency range. The station-generated noise is largely unknown, and therefore the investigation in this area could bring interesting results with both scientific as well as technical aspects. Particularly, it is expected that interference between station-generated electromagnetic emissions and natural local resonances in plasma could

provide new, unknown results. This instrument is a joint enterprise between the Space Research Centre in Warsaw, Poland and the Swedish Institute of Space Physics in Uppsala, Sweden. New digital technology of this instrument makes a fully programmable device that can be easily adapted to any scientific/technical objectives and telemetry capabilities.

The functional block diagram of RFA is shown on Figure 8. and instrument main characteristic is given on Table 8.

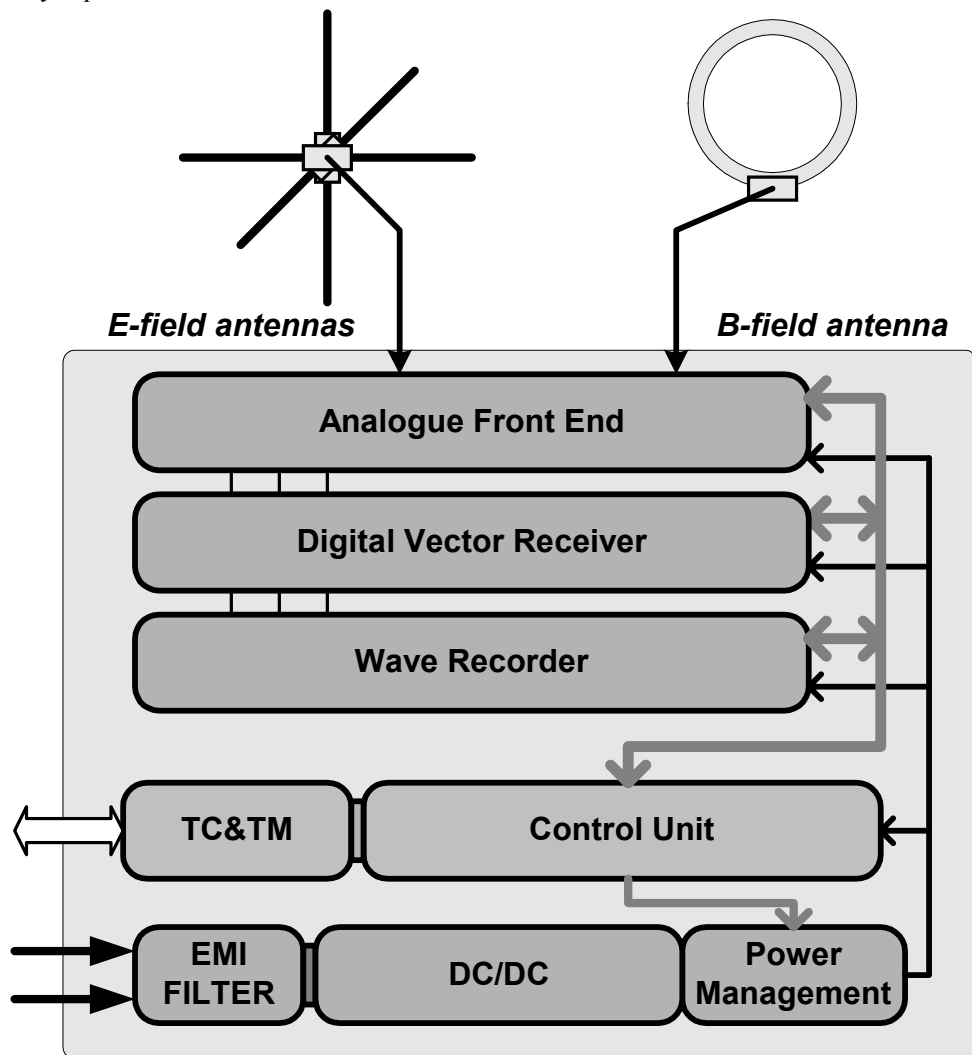


Figure 8. HF Vector Digital Receiver Block Diagram

Dipole antennas will receive electrical components of radio frequency noise signal. The second source of the measured signal will be a magnetic loop antenna (magnetic component). This antennas have its own, directly connected, low noise preamplifiers, which transform variable impedance of

antenna to constant ( $Z=50\Omega$ ) connection cable impedance. The gain of preamplifiers is fixed ( $\sim 10$  dB) to obtain relatively good signal-to-noise ratio and to avoid signal distortion or saturation. Next, the signals come to "Analog Front End" module where, after anti-aliasing filtration, are distributed to Digital Vector Receiver and Wave Recorder modules.

Table 8. Instrument main characteristic

Parameter	Value
<i>General</i>	
Mass [kg]	5.4 (+10% / - 30 %)
Power [W]	12.0 (+20% / - 30 %)
Voltage [V]	28.0 (+/- 4 [V])
Dimension [mm]	190.0x150.0x115.0 (TBC)
<i>Functional</i>	
Frequency range	100.0 [kHz] to 15.0 [MHz]
Spectrum resolution	10.0 [kHz] (0.1 to 1.0 MHz) 100.0 [kHz] (1.0 to 15.0 MHz)
Dynamic range [dB]	70.0 (TBC)

<i>Operational</i>	
Discrete commands	1 command (ON/OFF)
TC stream	2 - 3 commands /day (session)
TC packet length	16 bytes (TBC)
TM stream	~1 kb/ min (~20 bytes/sec)
TM packet length	256 byte (TBC)
Internal memory buffer	256 kB (min. 1 hours of measurement without TM dump)

### 3.9. PLASMA DISCHARGE STIMULATOR (SPP)

SPP is the original tool for realization of calibration practically of all PWC sensors. The electrical discharge gives a wide spectrum of electromagnetic radiation and also is a source of the accelerated particles. The concrete parameters SPP will be fulfilled during tests of laboratory models of the PWC sensors.

### 4. CONCLUSION

All scientific devices described upper are modern modifications of already used in space research instruments for plasma-wave measurements. Similar devices are used by the experiment participants in other space experiments providing a cost benefit to this project.

The devices of both spatial buoys CWD-1 and CWD-2 are designed for an uninterrupted operation onboard the ISS. Fortunately because the power supply is taken from the ISS structure, there is no serious power limitations. All devices have at least two operation modes: monitoring and event, which differ by the data volume transmitted to the onboard computer. The changeable hard disks with 100 Gbytes volume are foreseen for data collection and storage. It is estimated that this volume will be stored during ~ 180 days, i. e. each half year the hard disc will be changed and delivered to the Earth by nearest expedition.

Now many aspects of space weather begin to take root not only into a space science and technology, but also and in wider industrial and social spheres. Therefore prompt familiarizing of a society with these problems becomes the important task. Proceeding from this, tasks of experiment OBSTANOVKA are included also elements of the educational program. For these purposes it is supposed to use a radioline of a radioamateur range (145 and 435 MHz), now actively used for communication (connection) with the radioamateur of all world. System BSTM (look Table 1 and Figure 1) will form files of the information about characteristic parameters of space weather, measured in experiment and to transfer these data as to a wide network of the radioamateur, and School Centre of Reception of the telemetering Information formed now within the framework of realization of the Program of the Scientific-Educational Micro-Satellite [Klimov et al., 2001, 2003a]. Is important also to note, that simultaneously with realization of experiment OBSTANOVKA the work on orbits, close to the orbit the ISS, is supposed also operation of the Scientific-

Educational Micro-Satellite [Klimov et al., 2003b] with measurements some identical physical parameters.

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