S E S 2 0 1 2
Eighth Scientific Conference with International Participation
SPACE, ECOLOGY, SAFETY
4 – 6 December 2012, Sofia, Bulgaria

THE EXPERIMENT ON ELECTRIC FIELDS MEASUREMENT IN A BROAD BAND "AMEF-WB/IESP-3R" AND ELECTROMAGNETIC WAVE ANALIZER "ELMAVAN" FOR "RESONANCE" PROJECT

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Key words: *electromagnetic emission, waves, electric field, sensors, measurements, analyzers*

Abstract: *This article describes two scientific instruments for measuring electric and magnetic fields from the board of 4 high apogee satellites in the RESONANCE project. They are the experiment of electric fields measurement in a broad band AMEF-WB/IESP-3R and the electromagnetic wave analyzer ELMAVAN. There are represented all basic parameters of the devices, their scientific tasks, the proposed solutions for the main hubs and blocks and a protocol of the tests and a joint calibration of both devices.*

The structure of the "wave complex" in the RESONANCE project

To solve scientific problems in project RESONANCE for measurement of electric and magnetic fields on board of satellites is developed "wave complex" composed of:

- Device AMEF-WB/IESP-3R and electric field sensors operating in a wide frequency range 0 - 1 MHz
- Electromagnetic wave analyzer ELMAVAN for the 3D measurements of the electric and magnetic field fluctuations in the frequency range 10 Hz - 20 kHz
- Device High Frequency Analizer HFA for measurements of fluctuations of electric and magnetic fields in the frequency range of 10 kHz - 1 MHz;
- Magnetic field sensors in the relevant frequency bands;

This report discusses the first two units and their interconnections.

Scientific objectives of the "wave complex" in the RESONANCE project

Studies of the auroral zone of the magnetosphere at heights of 1-2 terrestrial radii and above have already been conducted by different probes including S3-3, DE-1, VIKING, FAST and INTERBALL-2. Determination of acceleration region location has become one of the most interesting results of these studies. On the basis of the required data, the authors decided the acceleration region was situated near the probe i.e., at heights of 1-3 terrestrial radii. Analysis of the distribution function of electrons and ions shows that at these heights the upward electric field accelerates descending electrons and ascending ions [1]. Article [2] informs about measurements of a quasistatic longitudinal electric field with significant amplitude. Its existence is interpreted by the authors in terms of large-scale accelerating structures. Small-scale electrostatic structures, solitons and double layers are described in articles [3,4]. The majority of wave and small-scale structures measurements were interpreted as electrostatic, however, in some cases the authors come to a conclusion about existence of electromagnetic waves in the auroral zone that may appear as a result of interaction between waves and particles[5,6]. Studies performed by the probes S3-3 and VIKING in the region of low frequencies were insufficient due to absence of measurements or a limited sensitivity of magnetic sensors in the frequency range of 0.1÷10 Hz. For example, the inductive antenna used in the VIKING mission was designed principally for measurements in the range of tens of kHz.

As it is known from articles [7,8] electromagnetic waves with a limited longitudinal electric field, the so-called Kinetic Alfven Waves can be generated in the auroral zone [9] and contribute to both longitudinal and lateral acceleration of charged particles. Confirmation of theoretical models is connected with experimental difficulties, because lasting homogeneous measurements are necessary in the points shifted along a magnetic field force line. This possibility is going to be realized in the framework of the project RESONANCE.

Another important objective of auroral magnetosphere physics is to determine the role of small-scale electrodynamic structures in the global dynamics of auroral plasma. It was reported in a number of articles that electrostatic structures dynamics could influence heating and acceleration of charged particles which resulted in formation of regions with low concentration of plasma [10]. An interest in these regions is connected with development of a cyclotron maser instability and generation of auroral kilometric radiation - AKR [11, 12].

Both the generation and effects of whistler-mode chorus pose fundamental research problems. In particular, the generation mechanism of chorus emissions is now under active study. It is still unclear how particles with usually smooth distribution functions, characteristic of natural conditions, generate highly coherent discrete emissions with rapidly changing frequency. A model of chorus generation based on the backward wave oscillator (BWO) regime of magnetospheric cyclotron maser was suggested by Trakhtengerts et al. The aim of the ELMAVAN instrument is to study VLF chorus emissions and verification of the chorus generation mechanism. We will analyze the characteristics of chorus elements inside the generation region, i.e., the amplitudes, frequency spectrum, the frequency sweep rate, the time intervals between chorus elements. Using simultaneous measurements of warm and cold plasma we will estimate these chorus parameters from the BWO model, and compare quantitatively with observed characteristics of chorus emissions.

Equatorial noise consists of electromagnetic plasma waves propagating in the close vicinity of the geomagnetic equatorial plane at frequencies from a few hertz to several hundreds of hertz. These emissions occur in the outer plasmasphere within about 10 degrees from the equator, at frequencies between the local proton cyclotron frequency and the lower hybrid frequency. Wide-band time-frequency spectrograms showed that the noise consists of many spectral lines with different frequency spacings. These waves possibly also can interact with the energetic electrons trapped in the radiation belts and accelerate them to relativistic energies. The spatio-temporal variability and propagation of equatorial noise are still unknown as well as the exact nature of wave-particle interactions responsible for the generation of these emissions.

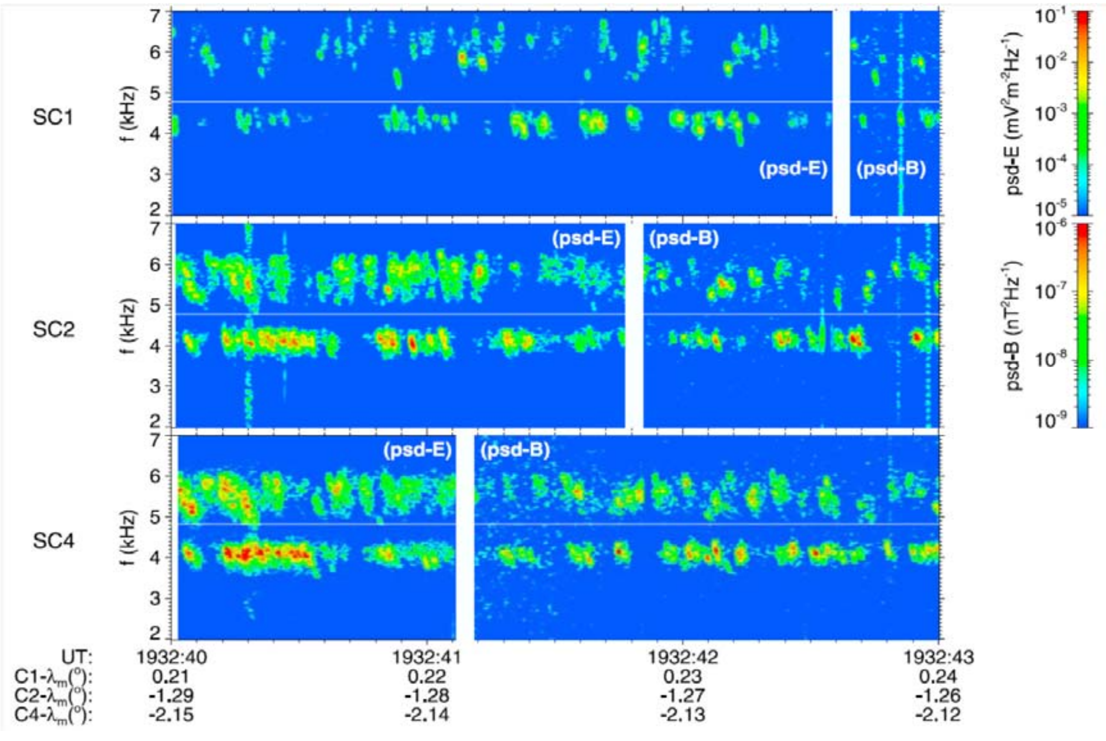

Fig. 1: High-resolution spectrograms of the power spectral density of whistler-mode chorus calculated from the electric field (psd-E) and magnetic field (psd-B) data recorded by the WBD instruments on board the Cluster 1 (SC1), Cluster 2 (SC2), and Cluster 4 (SC4) spacecraft on 20 January 2004. (From Santolik et al., J. Geophys. Res., doi:10.1029/2009JA014586, 2009)

Extremely low frequency (ELF) hiss is a broadband electromagnetic emission in the frequency range from a few hundred Hz up to several kHz. There are still a number of open questions because the properties of these waves are rather complex. Steady hiss can be found almost everywhere in the plasmasphere, but it also propagates on the dayside at high latitudes. The key questions about the origin of ELF hiss have not yet been clearly answered. Arguments have been given for the generation region off the equatorial plane, but successive amplification at multiple passes through the equatorial plane has also been proposed. Some researchers propose generation mechanisms acting on obliquely propagating whistler waves, as well as the theories based on accumulation of energy of nonducted whistlers. Refraction of these waves near the lower-hybrid resonance levels can result in their trapping and accumulation in the magnetosphere. Another hypothesis is based on propagation of chorus into the plasmasphere. Wave propagation studies can substantially contribute to the research on the hiss origin.

Auroral hiss is an intense plasma wave emission which frequently occurs at different altitudes in the high-latitude region of the Earth's magnetosphere. Observed by orbiting spacecraft it often appears with a characteristic funnel shaped envelope on time-frequency spectrograms (the lower-frequency cutoff first decreases and then increases). This envelope was explained by a limitation of ray angles for whistler-mode waves propagating from a localized source. Waves at higher frequencies thus can propagate across the field lines to larger distances from the source than waves at lower frequencies, creating the observed funnel shaped envelope. Auroral hiss is observed both downgoing and upgoing and is often associated with low-energy electron beams between 100 eV and several keV. It's generation and possible effects will be analyzed.

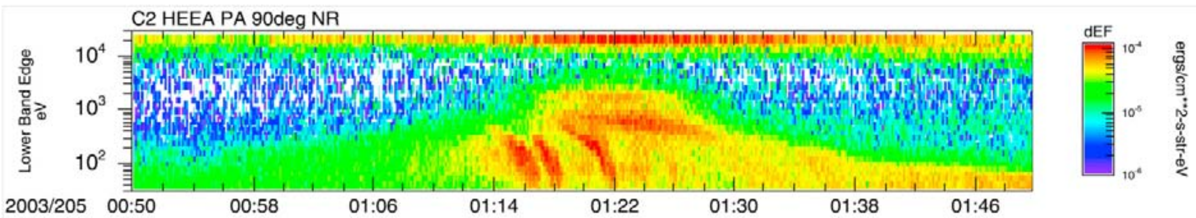

Fig. 2: Dynamic energy spectrograms of differential energy flux of electrons measured perpendicular to the magnetic field line by the PEACE instruments onboard the Cluster 2 spacecraft on 24 July 2003, in the equatorial source region of whistler mode emissions. (From Santolik et al., J. Geophys Res. doi:10.1029/2009JA015218, 2010)

Waves in plasmas are of crucial importance for dynamics of charged particles. The waves themselves are generated due to nonequilibrium distributions of charged particles, and this self-consistent process determines the energy balance. Some part of the wave energy can be re-absorbed by particles in other regions of phase space. In such a way, high-energy tails in the distributions of charged particles are generated. For example, it is now believed that one of the most important mechanisms of energization of relativistic electrons in the Earth's radiation belts is related to re-absorption of whistler-mode wave energy in ELF/VLF range (0.1-15 kHz) by high-energy (~1 MeV) tail of electron distribution. These waves are generated in the magnetosphere by nonlinear interactions with electrons at energies of 1-100 keV. A large part of the wave energy exists in the form of discrete emissions of chorus type, representing on average by two orders more total energy than the total energy of relativistic electrons in the outer radiation belt.

Principal of operation of the device AMEF-WB/IESP-3R

AMEF-WB/IESP-3R is a complex receiver of electric fields in a broad band. The instrument consists of 4 electric detectors and an electronics module. The block scheme of the device is shown in Fig. 3. and photo in Fig. 4.

Three electric sensors representing a sphere with preamplifiers inside are placed at the ends of a boom 15 m in length located in the probe's plane of rotation. The fourth sensor is mounted at a boom 4 m in length situated in the anti-sun direction. Such location of the sensors allows conducting measurements of the full vector of the electric field.

Signals from the sensors are transmitted to the electronics module placed at the probe's body, and then received by a differential amplifier where they are split in frequency for the purpose of the following processing. Signals in the frequency range from 10 to 20 kHz are transmitted to the device ELMAVAN, the ones in the frequency range from 10 kHz to 1MHz are transferred to the HFA device, and those in the frequency range from 0 to 10 Hz are processed in the electronics module in the following way:

- they are intensified by a factor of 1, 2, 4 or 8 depending on the amplitude of an input signal which is determined automatically. Information on intensification coefficients is stored in a telemetry frame.
- they are filtered by a second-order Butterworth anti-aliasing filter up to the frequency of 1 Hz.
- They are digitized by a 6-channel 16-bit synchronous A/D-converter of AD 7656 type. Digitizing frequency for each channel is 25 Hz.
- Processing results are saved into a frame measuring 224 bites containing information on measurements per second and service information. This frame is transmitted via a dual interface of *RS485* type to a control and information gathering unit (SUSPI). Normal operation mode provides for transmission of one telemetry frame per second simultaneously with a board time code signal. In accordance with the low-speed SUSPI interface bit rate, the bit rate is 9,600 bites per second.

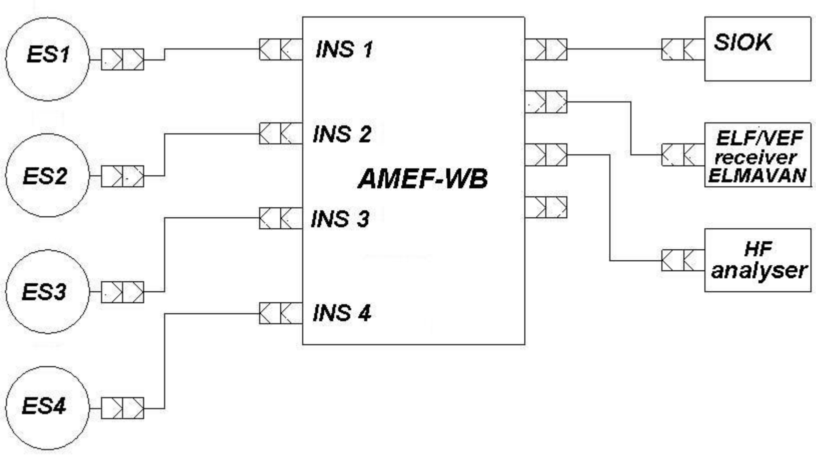

Fig. 3. The block scheme of the device AMEF-WB/IESP-3R

Fig. 4. Layout of the AMEF-WB/IESP-3R device and electric sensors

In case of a temporary loss of connection with SUSPI (SIOK), there is a possibility of storage of information in a buffer memory (up to 4.5 h of measurements without data transmission to SUSPI). To provide subsequent transmission of information from the buffer memory several telemetry frames should be transmitted to SUSPI per second.

A two-channel amplifier is used for sensors polarization current control in the electronics module. Control is realized automatically on the basis of earlier conducted measurements. Information on polarization current is saved into a telemetry frame.

Electromagnetic wave analyzer (ELMAVAN) will process the following input signals

- analog signals from 3 orthogonal magnetic search coil antennas with a sensitivity better than 10 fT /√Hz at f > 1kHz, and the maximum amplitude 10 nT at f > 100 Hz
- analog signals from 4 electric monopoles (AMEF-WB instrument) with a sensitivity of 0.1 μV/m /√Hz, and max. amplitude 1.2 V/m at f>100 Hz

Seven analog signals will be then derived from the inputs:

- three signals from magnetic antennas with a selectable gain
- three selectable differences of signals from four electric monopoles, with a selectable gain
- the sum of signals from electrical monopoles with a selectable gain

These signals will be first passed though a set of analog low-pass active Butterworth filters of 8th order, with a passband frequency of 50kHz, passband ripple 1dB, and attenuation of 96 dB at 180 kHz to avoid aliasing of the signals. The filters are designed to avoid artificial phase differences between the signals. The signals will be then sampled by a set of 16-bit A/D converters, all of them simultaneously sampling at a sampling frequency of 200 kHz. The resulting set of digital signals is then passed though a 19-bit FIR low-pass filter with the passband below 20 kHz and attenuation of more than 96 dB at frequencies above 30 kHz. The output sampling frequency of this 4 times decimating filter is 50 kHz. Alternatively, an 8 times decimating FIR filter with a passband below 10 kHz can be used, with a final sampling frequency of 25 kHz.

The resulting digital data are then processed onboard using an FPGA. The digital processing includes:

- data buffering of the 7-channel waveforms in an on-board SRAM buffer (8x64 Mbit),
- multidimensional spectral analysis in a set of up to 1024 preselected frequency bands using an onboard MRAM (6x16 Mbit, also used as a backup for waveform buffer),
- onboard calculation of frequency-dependent polarization and propagation parameters

The final data products which are transferred to the spacecraft telemetry system:

- 7-channel digital 16-bit waveforms sampled at 25 or 50 kHz. The onboard buffer memory holds up to 2.5 or 5 minutes of continuous waveform data for 50 kHz or 25 kHz sampling rates, respectively
- averaged Hermitian spectral matrices of 7x7 components in a floating point format, for a set of up to 1024 preselected frequency bands
- propagation and polarization parameters in a floating point format, allowing us to obtain the power of the electric and magnetic field fluctuations, ellipticity, sense of polarization, polarization degree, wave-normal direction and Poynting vector direction for a set of up to 1024 preselected frequency bands

The instrument will be operated using a set of commands which will change the signal processing characteristics and settings of the onboard analysis algorithms. A flexible output telemetry rate is implemented, with maximum bitrates of 4 Mbit/s for multidimensional waveform data. The anticipated total telemetry volume is 1-3 GByte/day, with an average bit rate of 93-278 kbit/s.

Since non radhard components are used in the design of the analyzer, a wall thickness of 10 mm for the ELMAVAN aluminum box is chosen according to the total ionizing dose estimated for the Resonance orbit parameters and for a 4 years long mission.

Interaction between AMEF-WB/IESP-3R and ELMAVAN devices

Results of preliminary tests of devices to connect Instruments and AMEF-WB/IESP-3R ELMAVAN is a major part of "wave complex" which is designed to measure electric and magnetic fields on board satellites on project RESONANCE. At the moment, the two units are under development process instances. According to the program of testing the devices and their interaction were conducted partial testing of instruments and signaling interface between the two. Connection and tests took place at the Institute of Atmospheric Physics in Prague from 15 to 19 October 2012.

Connection and measurement technique

The device out AMEF-WB/IESP-3R was Connect the external precision signal generator was fed sinosuidalnie signals in the frequency range 10 Hz - 20 kHz measurement bandwidth device ELMAVAN. The signals were measured via a communications interface, accumulated and analyzed in the instrument ELMAVAN. These indulged on mobile computer visualization and recording of measurements. The dynamics of the last signal was 92 dB, the uneven sampling analogue - the frequency response of less than 1 dB, the suppression of common mode signals on the input differential amplifier device ELMAVAN above 60 dB. In Fig. 5 Minutes of the local test frequency 490 Hz, the signal amplitude 1 V, applied to the inputs E1 and E2 of unit with gain coefficient of 10. The left side of the figure shows the waveform of signals and on the right of the spectral analysis and assessment of the performance of the harmonics

Measurement results exceed the parameters laid down in the specification for the two units. They will take into account all the comments received in the course of their conduct in the further development of devices.

3. Identical input signal 490 Hz, 1Vp-p at E1 and E2; 0V at E3 and E4
Channel 3: 10xE1-10xE2, Channel 4: 10xE2-10xE3, Channel 5: 10xE1-10xE3, Channel 6: ½ (E1+E2+E3+E4)

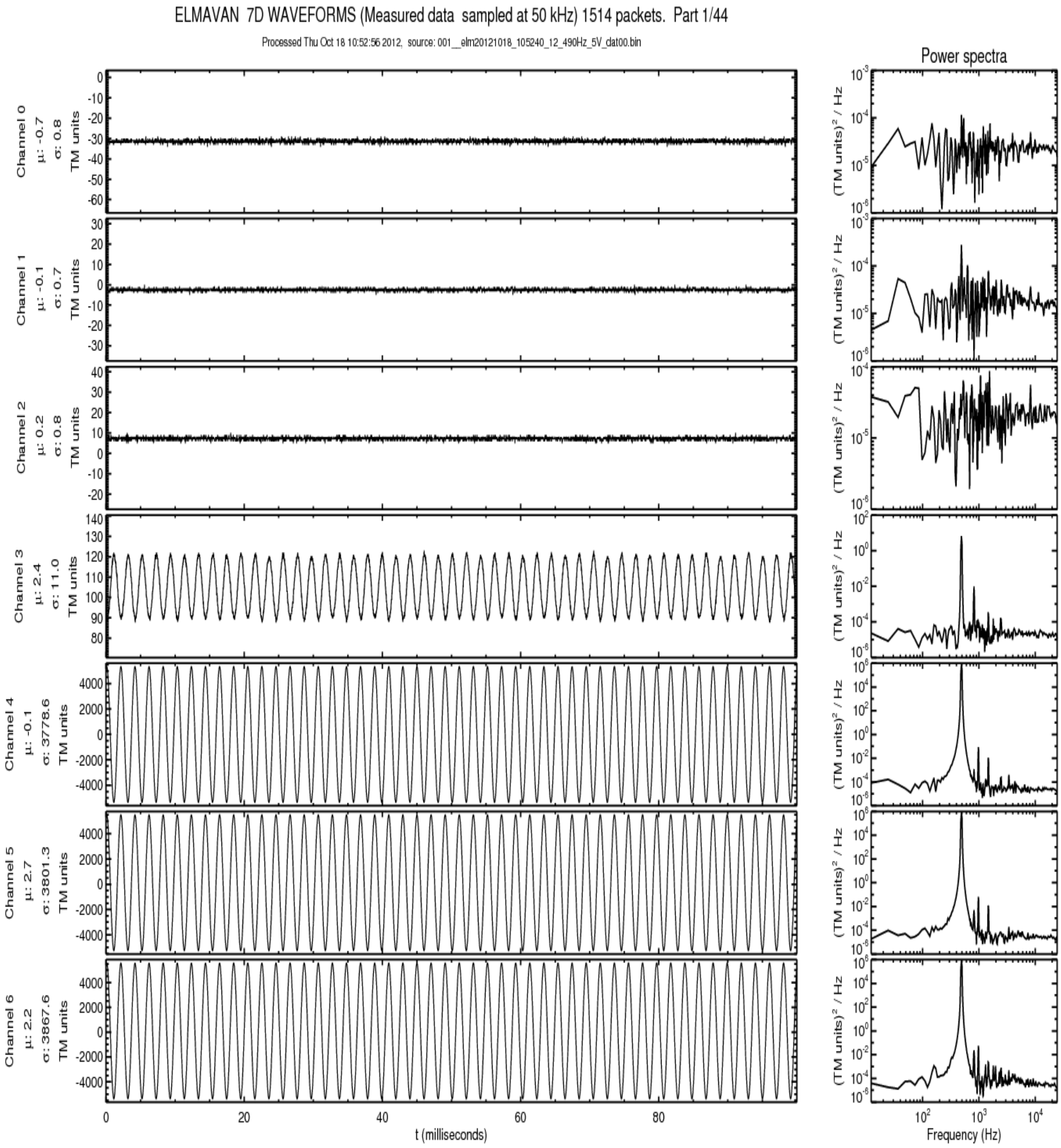

Fig. 5. Test protocol on the local frequency 490 Hz

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