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First data from the EGLE experiment onboard the ISS

EGLE is a wide frequency band search-coil magnetometer designed and built at the Roma Tre University. It has been installed onboard the ISS by the Italian astronaut Roberto Vittori on April 25, 2005 within the LAZIO-EGLE experiment carried out during the ENEIDE Soyuz mission. The scope of the experiment is to test EGLE in space and to investigate geomagnetic field variations. The main applications of EGLE are the study of electromagnetic environment inside the ISS, the correlation of magnetic field data with particle fluxes detected by LAZIO particle detector, and the monitoring of ionospheric perturbations possibly caused by Earth seismic activity. Since continuous electromagnetic field measurements on board the ISS are important for diverse space applications, a magnetometer with a suitable design is requested. Appropriate solutions for these applications, which have been adopted by EGLE, are in particular the use of 1-Wire technology and the possibility to detect by means of a search-coil magnetometer a large portion of the ULF frequency band, usually measured by flux-gate probes. To investigate the topside ionosphere electromagnetic environment and stability of Van Allen radiation belts in relation with seismic and anthropogenic electromagnetic emissions, a specific satellite mission (the ESPERIA project) has been designed for the Italian Space Agency (ASI), and up to now a few instruments of its payload have been built and tested in space. One of them is exactly the EGLE search-coil magnetometer. The first magnetic observations performed by this instrument reveal to be promising and demand for a further and deeper analysis based on a longer time series of data.

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1 Introduction

In recent times, ionospheric and magnetospheric perturbations of electric and magnetic fields and radiation belt particle precipitations, were detected on board of Low-Earth-Orbit (LEO) satellites [1,2] and reconciled not only with Sun and atmospheric effects but also with Earth's and anthropogenic activities [3]. Electromagnetic emissions (EME) radiated from the Earth's surface and generated by human activities or natural ground sources as earthquakes, demonstrated to propagate through the near-Earth space and cause perturbations in the topside ionosphere [1,2,3]. Within this framework, EME-waves have been considered as coupling elements in the lithosphere-atmosphere-ionosphere-magnetosphere interactions [4]. Sources of anthropogenic EME-waves are constituted by power line harmonic radiation (PLHR), VLF transmitters, and HF broadcasting stations. EME-waves in a large frequency band are generated as a consequence of earthquake preparation and occurrence [5,6]. All these waves can be detected onboard of LEO satellites.

To investigate these phenomena, a specific satellite mission (the ESPERIA project) has been designed at a Phase A Study level for the Italian Space Agency (ASI). Up to now two ESPERIA payload instruments (the LAZIO particle detector and the EGLE search-coil magnetometer) have been built and tested in space on board the ISS, within the LAZIO-EGLE experiment carried out during the ENEIDE Soyuz mission. The importance in carrying out simultaneous observations of electromagnetic and particle fluxes fluctuations is to investigate the phenomenon of particle precipitation from the inner radiation belt induced by seismic and anthropogenic EME-waves [1,6]. Continuous electromagnetic field measurements in a large frequency band inside the ISS are also important to study the physical behaviour of Van Allen radiation belt particles and to monitor the magnetic environment inside the ISS for biological applications. An example of biological application is the possible effect of magnetic field on bacteria growth [7].

LAZIO (Low Altitude Zone Ionizing Observatory) is a particle detector, constituted by several silicon detectors and plastic scintillators to detect ionizing particle from ~10 MeV to ~100 MeV [8]. It has been designed to detect cosmic ray and particle burst precipitation from the radiation belt. EGLE (Esperia's Geo-magnetometer for a Low-frequency wave Experiment) is a high precision search-coil magnetometer built to detect magnetic field fluctuations from ~0.5 Hz to ~40 kHz. LAZIO-EGLE experiment has been launched to the ISS on February 28, 2005 by a cargo Progress and successfully installed and tested on board the ISS on April 25, 2005 by the Italian astronaut Roberto Vittori within the ENEIDE Soyuz mission. The paper includes the description of the EGLE instrument and its location in the PIRS module of the ISS, together with first data collected after its installation inside the same orbital station.

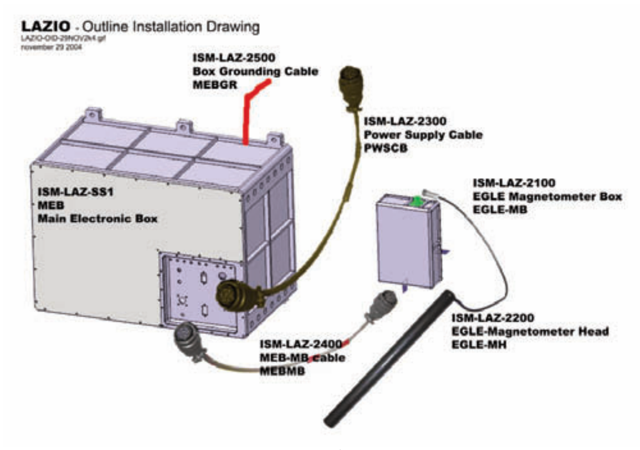

Fig. 1: LAZIO-EGLE experimental setup.

The EGLE magnetometer

The EGLE broad band search-coil magnetometer was constructed and tested on board of the ISS with aim at being installed onboard of small LEO satellites for the monitoring of geomagnetic field in the topside ionosphere. At this purpose, 1-Wire® technology was adopted as well as special attention was devoted in reducing mass and power budgets. 1-Wire® technology makes use of a single wire (plus ground) to accomplish both communication and power transmission. Data on the 1-Wire® net is transferred by time slots. A system clock is not required, as each 1-Wire® part is self-clocked by its own internal oscillator synchronized to the falling edge of the master. The use of 1-Wire® technology is justified by the fact that in satellite electromagnetic measurements the necessity to hold magnetic sensors far from the satellite body is an important factor for magnetic cleanliness. With standard multi-wires bus the problem of connecting remote probes, mounted at the end of deployed booms, with the central electronic unit, located in the satellite body, is a very serious concern. 1-Wire® technology allows to strongly reduce numbers of wires necessary to make these connections.

The LAZIO-EGLE hardware is schematically shown in the layout of figure 1 and consists of:

1. Main Electronic Box (MEB), containing the PC-104 onboard computer together with the particle detector and its electronic unit, data acquisition system and power supply.

2. EGLE-MB box (Magnetometer readout Box), a signal conditioning and data acquisition system.

Fig. 2: LAZIO-EGLE inside the PIRS module of the ISS. Arrows indicate MEB (left), EGLE-MB (front) and EGLE-MH (right).

3. EGLE-MH Magnetometer Head, a single axis search-coil sensor.

Magnetic field signals are filtered and digitized by a 1-Wire® AD Converter [9] installed in the EGLE-MB box. Data flow from EGLE-MB to MEB via 1-Wire® connection and are transferred to the LAZIO-EGLE PC-104 onboard computer via the 1-Wire®−RS232 serial adapter. Power for 1-Wire® ADC operations is derived from the bus during idle communication periods when the DATA line is at 5 volt by including a half-wave rectifier on each slave.

Figure 2 shows a picture of LAZIO-EGLE installation inside the PIRS section of the ISS. Arrows indicate MEB (left), EGLE-MB (front) and EGLE-MH (right) which are fixed by Velcro tags to the ISS wall. Characteristics of the EGLE probe, manufactured by the Lviv Center of Institute of Space Research [10] on the basis of our design, are reported in table 1 and figure 3.

As it is well known, to reconstruct the magnetic field intensity and direction three orthogonal single axis magnetometers are needed. Being an uniaxial search-coil magnetometer, EGLE probe should be pointed parallel to the geomagnetic field line, but this would ask for a continuous re-orientation of the magnetometer head inside the ISS. During the ENEIDE mission the EGLE magnetometer head was oriented along three orthogonal directions, each one for a duration of two days. Measurements are proportional to cos $(\alpha(\vec{r}, t))$, where $(\alpha(\vec{r}, t))$ is the angle between the magnetic field vector and the search-coil axis direction. This angle is varying in time and space as a function of the geomagnetic field fluctuation and the orientation of the ISS with respect to the Earth geomagnetic field. Even if the EGLE main goal is to carry out a technological experiment to test the general operation of the apparatus and the 1-Wire® data acquisition system, the EGLE orientation mode during the ENEIDE mission allows to test the full scale of the EGLE data acquisition system and to verify the variation of the time and space variation of $(\alpha(\vec{r}, t))$ as a function of the ISS position.

Results

Magnetic field signals detected by the EGLE-MH probe are amplified, filtered and recorded by the EGLE acquisition and data handling board located into the EGLE-MB box. EGLE magnetometer allows to get magnetic field data in four frequency bands (~0.5Hz÷20 Hz raw data; and 0.5 Hz ÷ 40 Hz;

Table 1. EGLE probe technical specifications

Frequency band of received signals	0.5 – 50000 Hz
Shape of transfer function	linear – flat
Type of output	Symmetrical
Transformation factor at both output terminals - at linear part (0.5 – 5 Hz) - at flat part (5 – 50000 Hz)	 f*4 mV/(nT Hz) 20 mV/nT
Transformation factor error: - at flat part of band pass without edges - at flat part band pass edges	 ≤ ±0.25 dB ≤ 3 dB
Magnetic noise level, pT / (Hz)$^{1/2}$: - at 5 Hz - at 100 Hz - at 5 kHz - at 50 kHz	 ≤ 0.4 ≤ 0.02 ≤ 0.004 ≤ 0.02
Nominal output load	≤ 200 pF ≥ 50 k Ω
Power supply voltage	± (15 ± 0.2) V
Power consumption	300 mW
Temperature range of operation	(-30 ÷+50)°C
Outer dimensions	l=40cm Ø=3,2cm
Length of output cable	0.7 m
Weight	≤ 320 g

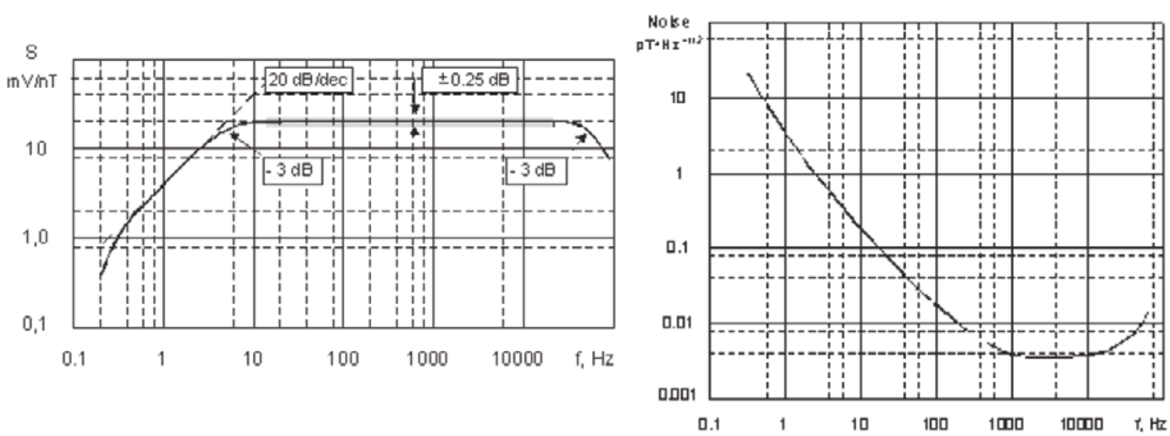

Fig. 3: Frequency response (left) and noise spectral density (right) of EGLE search-coil magnetometer.

500Hz÷5 kHz, 20 kHz ÷ 40 kHz integrated r.m.s. data). Gaps between these frequency ranges have been chosen to filter well-known spurious artificial signals produced inside ISS. Data are stored without any astronaut intervention in the 4GB PCMCIA high-density cards installed in the onboard computer of the MEB box. Astronaut intervention is only requested to insert and replace PCMCIA cards. EGLE generates a daily file of ~80 MB. There are two possible configurations (EVENT / INTEGRAL mode) for collecting data. They can be controlled through a switch on the MEB front panel. Concerning first data obtained after EGLE installation, in figure 4 is reported a characteristic EGLE spectrogram. As it can be seen, also part of the ULF frequency band can be detected by this sensor. This is an unusual characteristic for a search-coil probe and characterizes EGLE as an original broad-band magnetometer, which in satellite applications can allow a significant mass reduction by avoiding the use of flux-gate instruments. In figure 5, EGLE geomagnetic data versus time appear to be clearly superimposed with the corresponding time variation of ISS latitude indicating that magnetic measurements exhibit the same time period of the ISS rotation around the Earth. This is due to the dependency of the EGLE data from $\alpha(\vec{r},t)$ which shows the consistency of measurements with movements of the EGLE magnetometer inside the dipolar geomagnetic field.

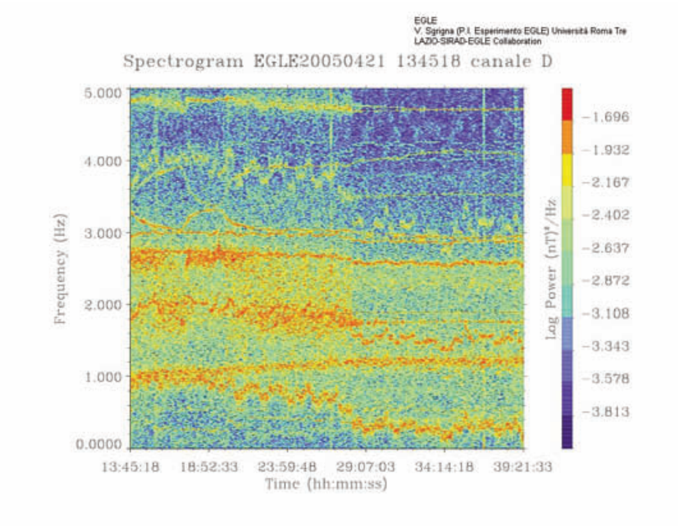

Fig. 4: Characteristic spectrogram of EGLE data.

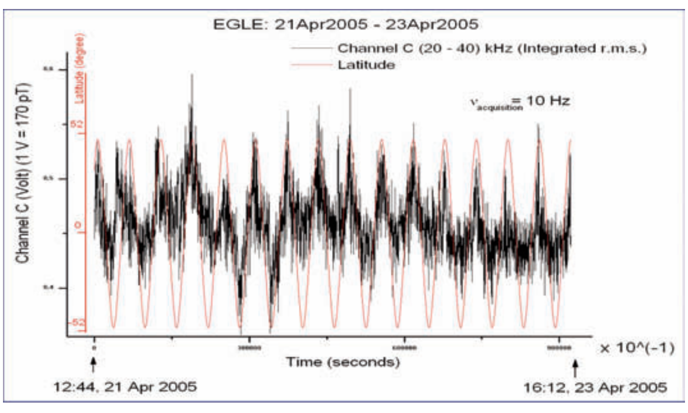

Fig. 5: EGLE magnetic field data and ISS latitude versus time.

Conclusions

The EGLE broad band search-coil magnetometer has been successfully installed and tested onboard the ISS within the ENEIDE Soyuz mission. It has been designed and constructed with aim at being installed onboard of small LEO satellites for the monitoring of perturbations in the topside ionosphere caused by seismo-associated and anthropogenic EME-waves. Other positive characteristics of EGLE instrument are its small dimensions and mass, low power consumption, and the use of a standard power supply system The main expectations from EGLE were:

- to evaluate its capability in detecting signals up to ULF frequencies (normally covered by flux-gate instruments),
- to test the operation of the 1-Wire® data acquisition system,
- to check the good quality of signal-to-noise-ratio in all the three frequency bands of the signal conditioning and data acquisition board.

Within the framework of the technological nature of the EGLE experiment all these expectations were satisfied.

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