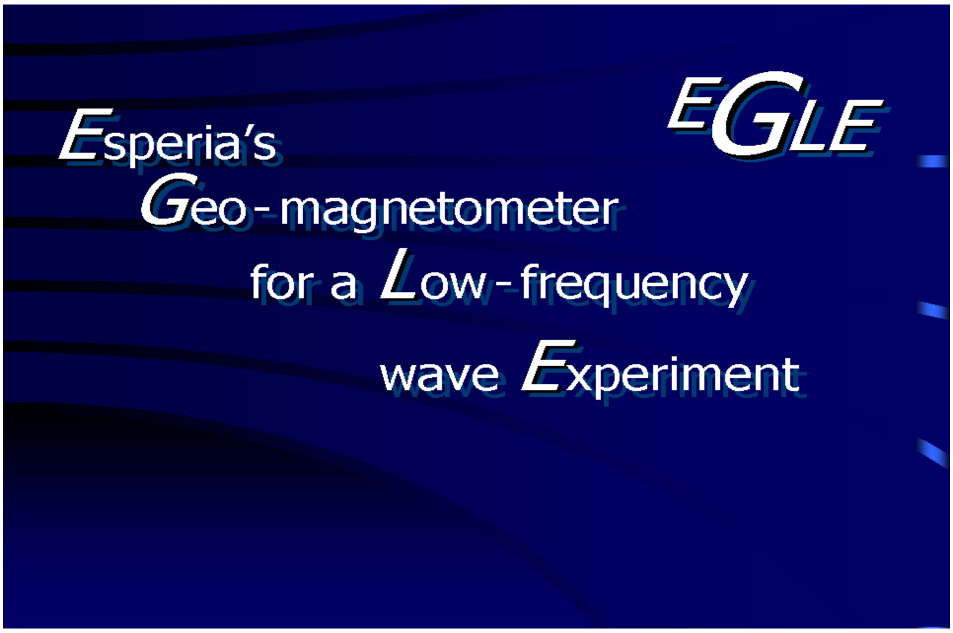
# The EGLE experiment

**E**speria's **G**eo-magnetometer for a **L**ow frequency wave **E**xperiment






## 1. Introduction

Electromagnetic emissions (EME) observed in the near-Earth environment are the superposition of natural and man-made emissions. Perturbations in the ionosphere caused by EME produced by human activities and radiated from the Earth's surface are mainly constituted by power line harmonic radiation (PLHR), VLF transmitters, and HF broadcasting stations. 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 analyzed. Also the EME are detected on board of LEO satellites as a consequence of thunderstorm activity and earthquakes or volcanic eruptions. The EM radio noise level observed on board of satellite strongly depends on properties of the surrounding satellite environment and noises generated by the payload system, as well as on geophysical conditions.

The monitoring of the electromagnetic environment on board the International Space Station (ISS) needs both of an appropriate observation methodology and of the corresponding experimental equipment design. The continuous monitoring of EM environment on board of the ISS by an advanced magnetic experiment in the ULF-HF band is important in the following areas:

a) Search of space weather conditions in equatorial, middle-latitude and sub-auroral ionosphere.
b) Geophysical research of plasma-wave processes connected to solar - magnetosphere - ionosphere - atmosphere -lithosphere interactions.
c) Investigation of the possible relationships between seismic activity and ULF-VLF phenomena that may be related to earthquakes.
d) Continuous monitoring of ULF-ELF-VLF activity in the near-Earth space including ELF-VLF pollution.
e) Monitoring of natural and man-made variations of the plasmasphere caused by whistlers.
f) Investigation of EM background and space weather phenomena.
g) Investigation of the effects of the large ISS structure on the propagating wave-front.

LAZIO experiment aims to perform measurements involving
- the radiation environment
- the magnetic environment inside the ISS.

LAZIO is equipped with a high precision low frequency magnetometer EGLE (Esperia's Geo-magnetometer for a Low frequency wave Experiment).
EGLE will be used to measure the intensity and variations of the magnetic field within the ISS, and to correlate these measurements with those of particle fluxes. A very interesting idea has been recently proposed, on the possible detection of electromagnetic seismic emissions in space. These electromagnetic waves has been supposed to interact with Van Allen trapped particles inducing they precipitation. The study of these effects is important to detect electromagnetic field variations and particle pitch angle distribution of the precipitating particles.

EGLE experiment is also the first test in space of a data acquisition system based on the 1-Wire® technology.

The EGLE magnetometer is constituted by:
- a single axis search coil probe, the EGLE Magnetometer Head (MH),
- an electronic interface with amplifiers, filtering and data acquisition unit (EGLE MB box),
- a 2m long cable to connect LAZIO MEB and EGLE MB,
- a 1-Wire® to RS232 serial adapter on the LAZIO pc tower.

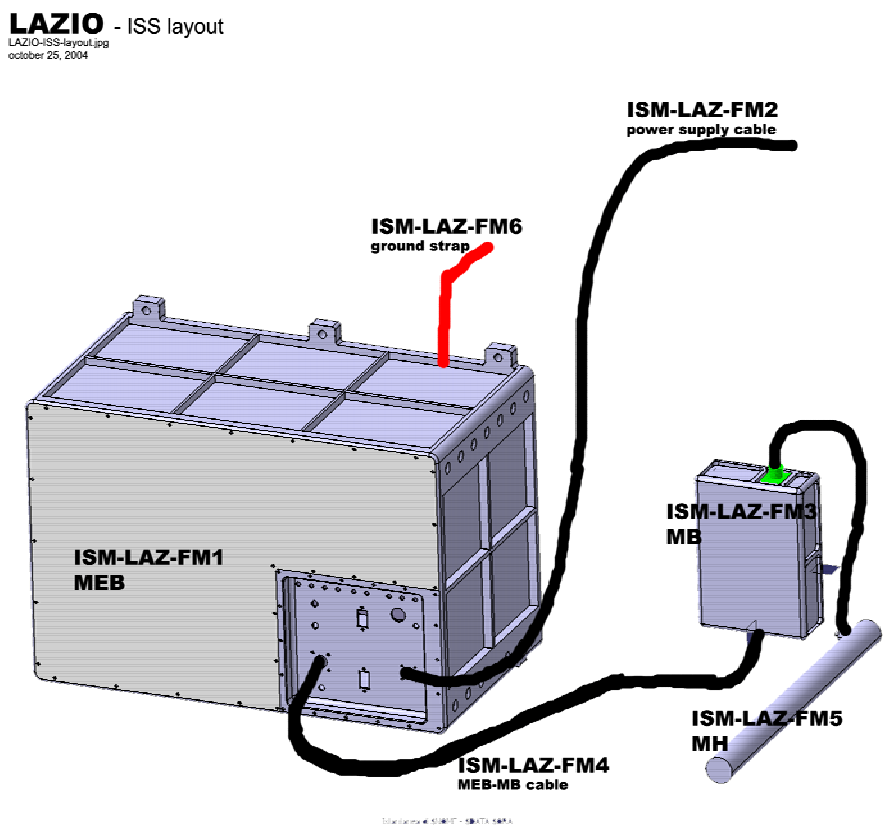


**Figure 1.** LAZIO MEB box, EGLE MB box , and MH probe connection.

The EGLE magnetometer is intended for automatic measurement of low frequency magnetic field component. The instrument performs high accuracy measurements. The advantages in using such a device are:

- small dimensions and mass; low power consumption;
- data acquisition via 1-Wire® technology;
- standard power supply of the device.

## 2. EGLE magnetic probe (MH)

Search-coil magnetometer LEMI-106I consists of search-coil sensor (SCS) and electronic unit, both located inside protective housing. The housing of the search-coil magnetometer has tubular shape and is made of fibreglass tube with inner electrostatic screen. Output cable of the magnetometer has the connector for the coupling to the registration unit. Schematic diagram of the LEMI-106I magnetometer is presented on Fig. 1.

The LEMI-106I magnetometer construction allows to use it onboard the spacecraft in space. It is designed to withstand accelerations during the active phase of the launch and vacuum and temperature gradients during operation in space.

Search-coil sensor consists of magnetic core, main winding W1 and feedback winding W2. The cylindrical magnetic core is made of a number of longitudinal convex ferromagnetic high permeability amorphous tapes, insulated one from another. Two outer tapes of the core are electrically connected to the “ground” electric line, and work as a shield against possible outer source of disturbances. Main winding consists of 20 sections, tuned to achieve an uniform amplitude-frequency response with 20 capacitors C1 – C20.

Electronic unit U1 consists of one printed board. Output signal of main winding W1 is coupled to ultra low-noise input amplifier DA1 (AD743). The main local feedback loop R4R3 of DA1 amplifier fixes its total amplification coefficient at low frequencies equal to 600 approximately. Additional high-frequency correction circuit C22R5 decreases amplification coefficient at high frequencies up to 40 approximately, what guarantees stable operation of all the system “SCS - preamplifier” in full frequency band.

Output of DA1 through the R1C21R2 correction circuit is coupled to the magnetic flux feedback winding W2. Magnetic and local feedback circuits form the flat part of the magnetometer transfer function within frequency band 5 – 50000 Hz.
Output of DA1 amplifier is also connected to the input of the first output amplifier DA2:1 (AD822). Resistor R12 in main feedback circuit of DA2:1 amplifier is used for exact tuning of magnetometer nominal transfer function at in-phase output terminal OUT I. Output inverter - second output amplifier DA2:2 with amplification factor equal to minus 1 - forms the counter-phase output signal OUT C.
Additional high-frequency (C26R7) and low-frequency (C30R11) correction circuits form extra-flat resulting amplitude-frequency response in the frequency band 5 – 5000 Hz with deviation from nominal value (20 mV/nT) no more than ±0.25 dB.

DA1 preamplifier is protected from input overloading signals with Zener diodes VD1, VD2. Both DA2 amplifiers are protected with resistors R14, R15 from damage if overload at their outputs will occur.

The ultra-low noise preamplifier (AD743) has itself too low power supply ripple rejection ratio for high frequencies, especially at negative power voltage. To improve this parameter up to necessary values across full frequency band the built-in power supply filter C29,C30,C31,C32,R16,R17 is used. Relatively big resistors R16,R17 assure additional protection of electronic unit from overloading by ripples in supply voltage and from continuous overloading at the outputs, up to short connection. Safety diodes VD3, VD4 protect electronic unit from accidental connection of each power supply with wrong polarity.

**Figure 2.** EGLE magnetometric probe MH with 0.7m cable connected.

**Figure 3.** Bag for EGLE MH probe.

The structural parts of the sensor and of the magnetometer probe is made of modern constructional materials and provides reliable operation in outer space conditions after severe launch time stresses.

## 2. Technical specifications of the EGLE probe MH

Basic technical specifications of the EGLE probe MH are summarized in the table 1.

| **Basic technical specifications of the EGLE probe MH** | |
|---|---|
| Frequency band of receiver signals | 0.5 ÷ 50000 Hz |
| Shape of transfer function | linear – flat |
| Type of output | Symmetrical |
| Transformation factor at both output terminals:<br>▪ at linear part (0.5 – 5 Hz)<br>▪ at flat part (5 – 50000 Hz) | f*4 mV/(nT*Hz)<br>20 mV/nT |
| Transformation factor error:<br>▪ at flat part of band pass without edges<br>▪ at flat part band pass edges | ≤ ±0.25 dB<br>≤ 3 dB |
| Magnetic noise level, $pT*Hz^{-1/2}$:<br>▪ at 5 Hz<br>▪ at 100 Hz<br>▪ at 5 kHz<br>▪ at 50 kHz | ≤ 0.4<br>≤ 0.02<br>≤ 0.004<br>≤ 0.02 |
| Nominal output load | ≤ 200 pF<br>≥ 50 kΩ |
| Power supply voltage | ± (15 ± 0.2) V |
| Power consumption | 300 mW |
| Temperature range of operation | -30 °C ÷ +50 °C |
| Outer dimensions (without prominent parts) | l = 400 mm<br>d = 32 mm |
| Length of the output cable | 0.7 m |
| Weight | ≤ 320 g |

**Table 1.** Basic Technical Specifications of the EGLE probe.

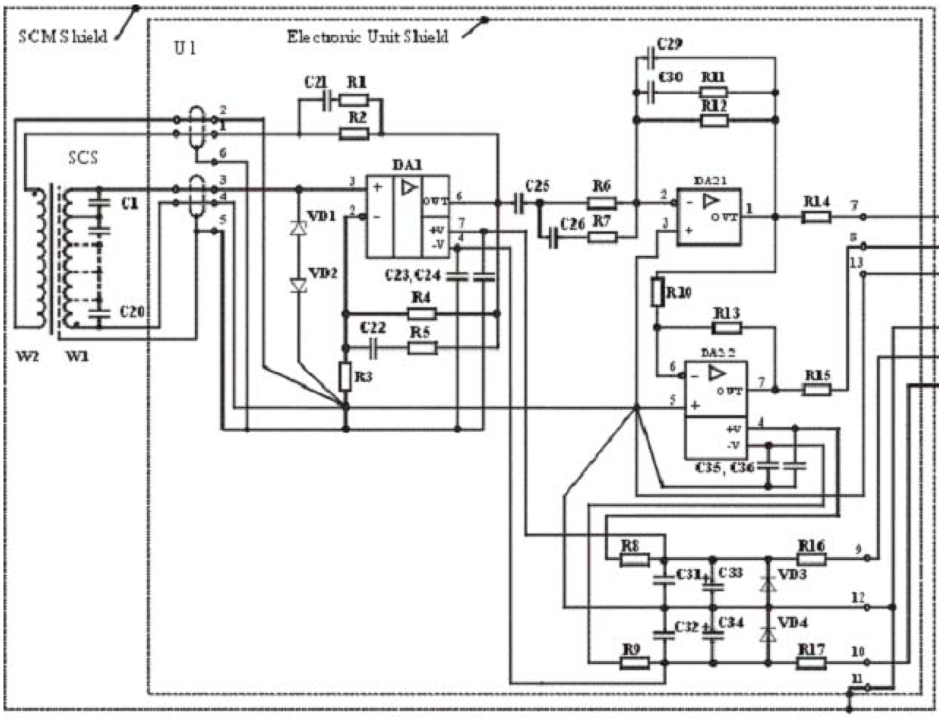



**Figure 4.** EGLE magnetometric probe MH schematic diagram

The magnetometer has "PC7" connector at the output. The layout of the MH cable connector pins description is shown on Fig .4 and Fig 5. Length of the coupling cable has to be not longer than 5 m.

CONNECTOR

(plug, soldering face)

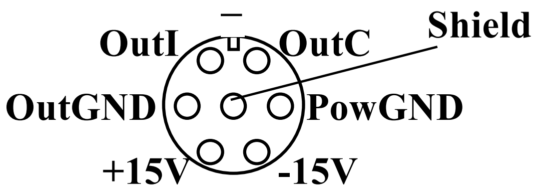



**Figure 5.** EGLE MH cable connector layout

The normal conditions of LEMI-106 I magnetometer shelf life are:

- temperature -20°C ÷ +50 °C
- humidity up to 80%
- pressure 100 ÷ 2000 hPa

Avoid the shocks of the magnetometer more than 20 g and vibrations in frequency band 1÷1000 Hz with accelerations more than 5 g during transportation.

**Egle magnetometer (MH) components list**

# Principal Diagramme

| Designation | Value | Type | Note |
|---|---|---|---|
| R1 | 56 k | 0805 | 1% |
| R2 | 4,3 k | 0805 | 1% |
| R3 | 91 | 0805 | 1% |
| R4 | 56 k | 0805 | trim. |
| R5 | 3,6 k | 0805 | trim. |
| R6 | 62,4 k | 0805 | 1% |
| R7 | 200 k | 0805 | |
| R8, R9 | 22 | 0805 | |
| R10, R13 | 11 k | 0805 | 1% |
| R11 | 750 k | 0805 | trim. |
| R12 | 75 k | 0805 | 1% |
| R14, R15 | 91 | 0805 | 1% |
| R16, R17 | 330 | 0805 | |
| | | | |
| C1-C20 | | 1206 | trim. |
| C21 | 5600 | 1206 | |
| C22 | 0,022 mF | 1206 | |
| C23, C24 | 0,1 mF | 1206 | |
| C25 | 10,0 mF | 1206-X5R-16 | |
| C26 | 22 | 1206 | |
| C29 | 12 | 1206 | |
| C30 | 150 | 1206 | |
| C31, C32 | 1,0 mF | 1206-X7R-25 | |
| C33, C34 | 100,0 mF | 1206-X7R-25 | |
| C35, C36 | 0,1 mF | 1206 | |
| | | | |
| VD1, VD2 | KC 191 | | |
| VD3, VD4 | 1N4148 | | |
| | | | |
| DA1 | AD743 | | |
| DA2 | AD822AN | | |

## 3. EGLE magnetometer probe (MH) features

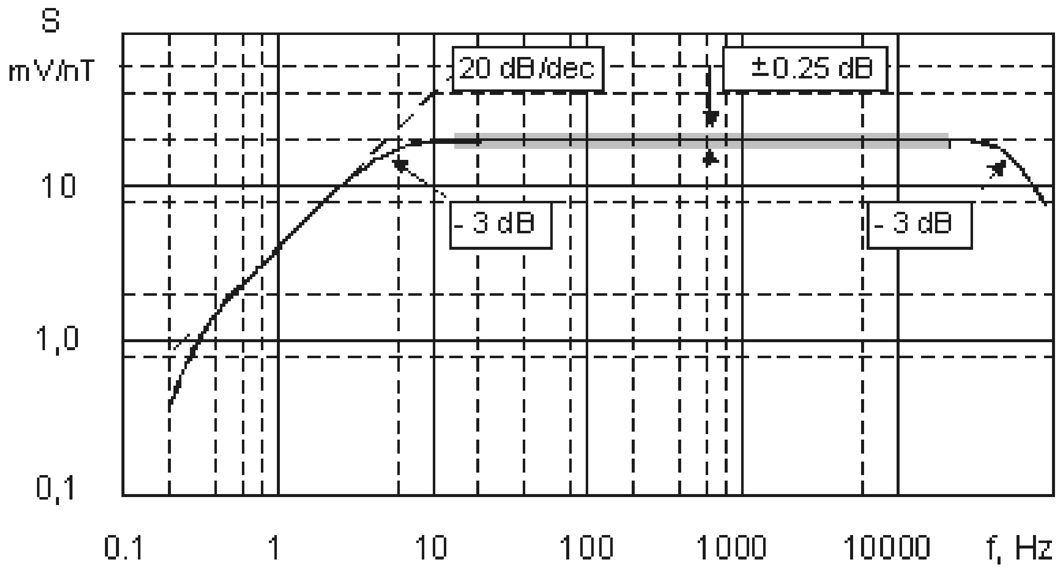



**Figure 6.** Amplitude-frequency response of the EGLE magnetometer.

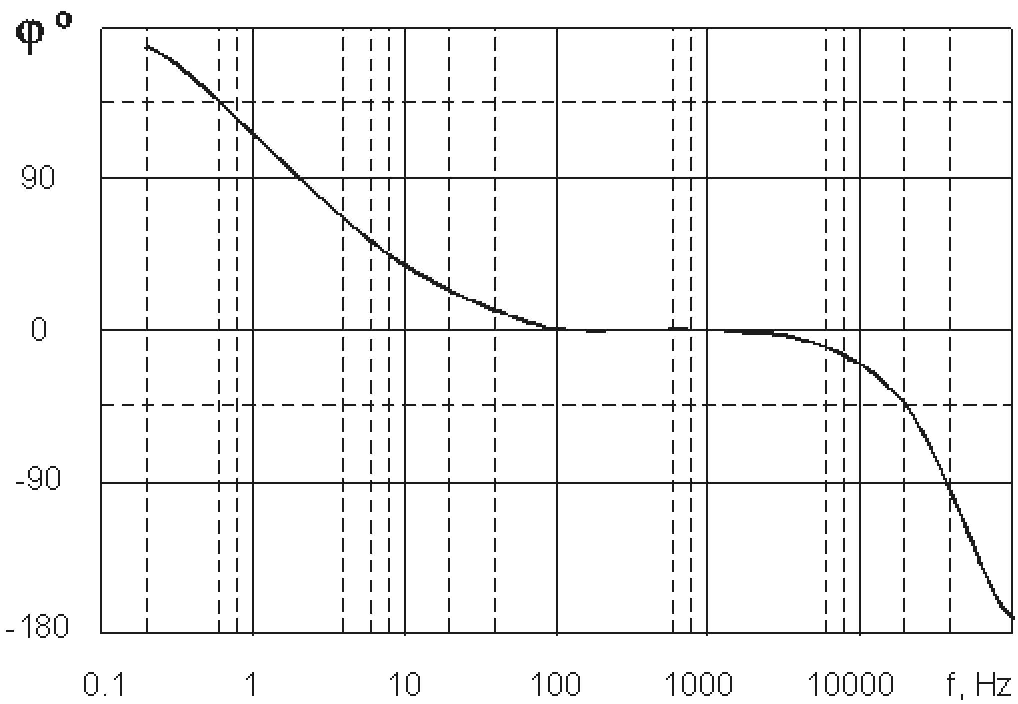



**Figure 7.** Phase-frequency response of the EGLE magnetometer.

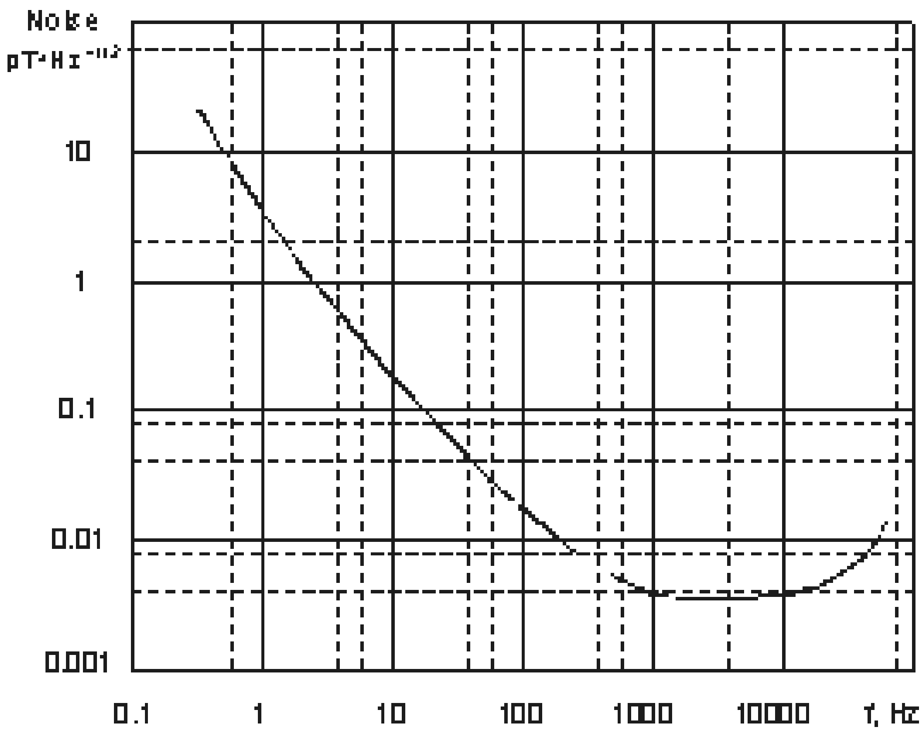



**Figure 8.** Noise spectral density

## 4. Search-coil magnetometer Laboratory Thermal Tests Report

**1 Item name -** search-coil magnetometer

**2 Type of tests** – function tests at high temperature.

**3 Methods of tests** – ***according to "ISS, Integrated Russian Segment/Section. Initial Technical Requirement to Equipment and Accessories. ИТТ КЦН РС МКС П34240-515" and "Program of tests of LEMI-106I".***

**4 Working Conditions:**

| | |
|---|---|
| - temperature of ambient air, °C | 20 - 30; |
| - humidity, % | 65 - 80; |
| - atmospheric pressure, mmHg | 630 - 800. |

Temperatures of the magnetometer and air in the climatic chamber are specified in Tables 2,3.

**5 Test equipment** – Helmholtz Coil w/o no., climatic chamber w/o no., Multimeter HP3440A serial no. US36111520, Programmable Functional Generator HM8131-2 serial no. 131023P 03030.

**6 Place and time of test** – LC ISR, Lviv, 04.08.04.

**7 Test results –** are shown in tables 2, 3.

LEMI-106 I Amplitude Frequency Response S(f)/S(1200Hz) during high temperature test.

Table 2.

| f, Hz | 5 | 10 | 40 | 90 | 200 | 600 | 1200 | 1600 | 2k | 4k |
|---|---|---|---|---|---|---|---|---|---|---|
| normal temperature (before test) | 0.700 | 0.888 | 1.025 | 1.038 | 1.038 | 1.013 | 1.000 | 1.000 | 1.000 | 1.038 |
| $t_{mag}$=50°C | 0.700 | 0.888 | 1.025 | 1.038 | 1.038 | 1.013 | 1.000 | 1.000 | 1.000 | 1.038 |
| normal temperature (after test) | 0.700 | 0.888 | 1.025 | 1.038 | 1.038 | 1.013 | 1.000 | 1.000 | 1.000 | 1.038 |

Cont. Table 2.

| f, Hz | 6k | 8k | 10k | 16k | 20k | 25k | 30k | 35k | 40k | 50k |
|---|---|---|---|---|---|---|---|---|---|---|
| normal temperature (before test) | 1.013 | 0.988 | 1.000 | 0.988 | 0.975 | 0.950 | 0.925 | 0.900 | 0.863 | 0.750 |
| $t_{mag}$= 50°C | 1.013 | 0.988 | 1.000 | 0.988 | 0.975 | 0.950 | 0.925 | 0.900 | 0.850 | 0.738 |
| normal temperature (after test) | 1.013 | 0.988 | 1.000 | 0.988 | 0.963 | 0.938 | 0.913 | 0.888 | 0.838 | 0.725 |

Table 3.Amplitude Frequency Response S(f)/S(800Hz) during low temperature test.

| f, Hz | 5 | 10 | 20 | 60 | 120 | 400 | 800 | 1600 | 2k | 4k |
|---|---|---|---|---|---|---|---|---|---|---|
| normal temperature (before test) | 0.713 | 0.900 | 1.000 | 1.025 | 1.025 | 1.013 | 1.000 | 1.000 | 1.006 | 1.038 |
| $t_{mag}$= -38°C | 0.713 | 0.900 | 1.000 | 1.038 | 1.038 | 1.013 | 1.000 | 1.000 | 1.006 | 1.025 |
| normal temperature (after test) | 0.713 | 0.900 | 1.000 | 1.025 | 1.025 | 1.013 | 1.000 | 1.000 | 1.006 | 1.038 |

Cont. Table 3.

| f, Hz | 6k | 8k | 10k | 16k | 20k | 25k | 30k | 35k | 40k | 50k |
|---|---|---|---|---|---|---|---|---|---|---|
| normal temperature (before test) | 1.038 | 1.013 | 1.025 | 1.000 | 1.000 | 0.950 | 0.900 | 0.875 | 0.863 | 0.788 |
| $t_{mag}$= -38°C | 1.038 | 1.025 | 1.013 | 0.988 | 1.013 | 0.950 | 0.875 | 0.850 | 0.825 | 0.775 |
| normal temperature (after test) | 1.038 | 1.013 | 1.013 | 1.000 | 1.000 | 0.950 | 0.875 | 0.863 | 0.838 | 0.775 |

**8 Detected errors** – no.

**9 Conclusion** – magnetometer LEMI-106 I passed climatic tests successfully.

## 5. Search-coil magnetometer Laboratory Vibration Tests Report

**1 Item name -** search-coil magnetometer

**2 Type of test** – vibration-survival test.

**3 Methods of test** – according to "ISS, Integrated Russian *Segment/Section*. Initial Technical Requirement to Equipment and Accessories. ИТТ КЦН РС МКС П34240-515" and "Program of tests of LEMI-106I".

**4 Working Conditions:**

- temperature of ambient air, °C 20 - 30;
- humidity, % 65 - 80;
- atmospheric pressure, mmHg 630 - 800.

**5 Test equipment** – Helmholtz Coil w/o no., climatic chamber w/o no., Multimeter HP3440A serial no. US36111520, Programmable Functional Generator HM8131-2 serial no. 131023P 03030, vibration stand V-806 serial no. 155.

**6 Place and time of test** – LC ISR, Lviv, 08.08.04.

**7 Test results –** are shown in table 4.

LEMI-106I Amplitude Frequency Response S(f)/S(1200Hz)
before and after vibration-survival test.

Table 4.

| f, Hz | 5 | 10 | 40 | 90 | 200 | 600 | 1200 | 1600 | 2k | 4k |
|---|---|---|---|---|---|---|---|---|---|---|
| before test | 0.700 | 0.888 | 1.025 | 1.038 | 1.038 | 1.013 | 1.000 | 1.000 | 1.000 | 1.038 |
| after test | 0.700 | 0.888 | 1.025 | 1.038 | 1.038 | 1.013 | 1.000 | 1.000 | 1.000 | 1.038 |

Cont. Table 4.

| f, Hz | 6k | 8k | 10k | 16k | 20k | 25k | 30k | 35k | 40k | 50k |
|---|---|---|---|---|---|---|---|---|---|---|
| before test | 1.013 | 0.988 | 1.000 | 0.988 | 0.975 | 0.950 | 0.925 | 0.900 | 0.863 | 0.750 |
| after test | 1.013 | 0.988 | 1.000 | 0.988 | 0.963 | 0.938 | 0.913 | 0.888 | 0.838 | 0.725 |

**8 Detected errors** – no.

**9 Conclusion** – magnetometer passed vibration-survival test successfully.

# 6. EGLE  interface board (MB)

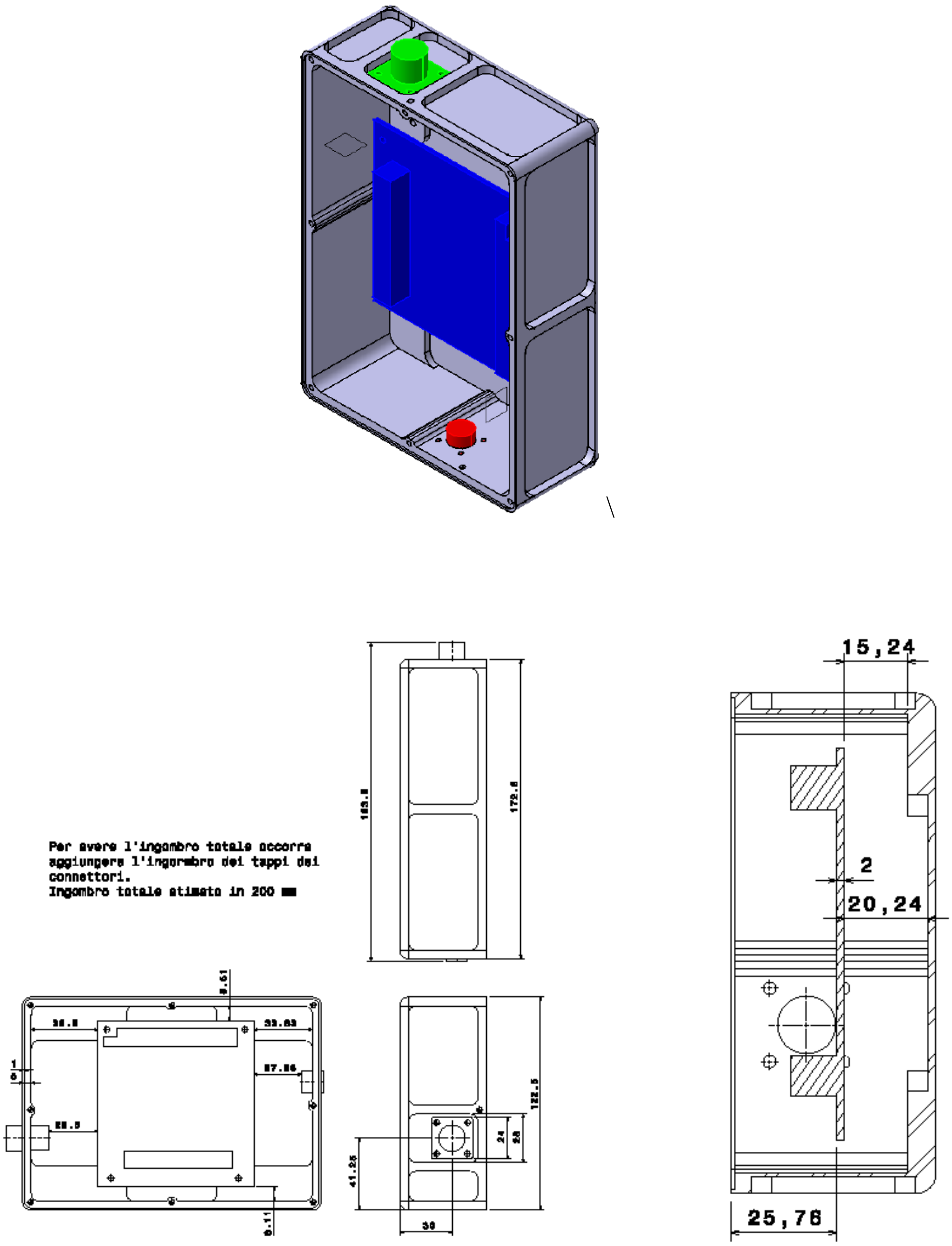



**Figure 8.** EGLE MB box scheme.

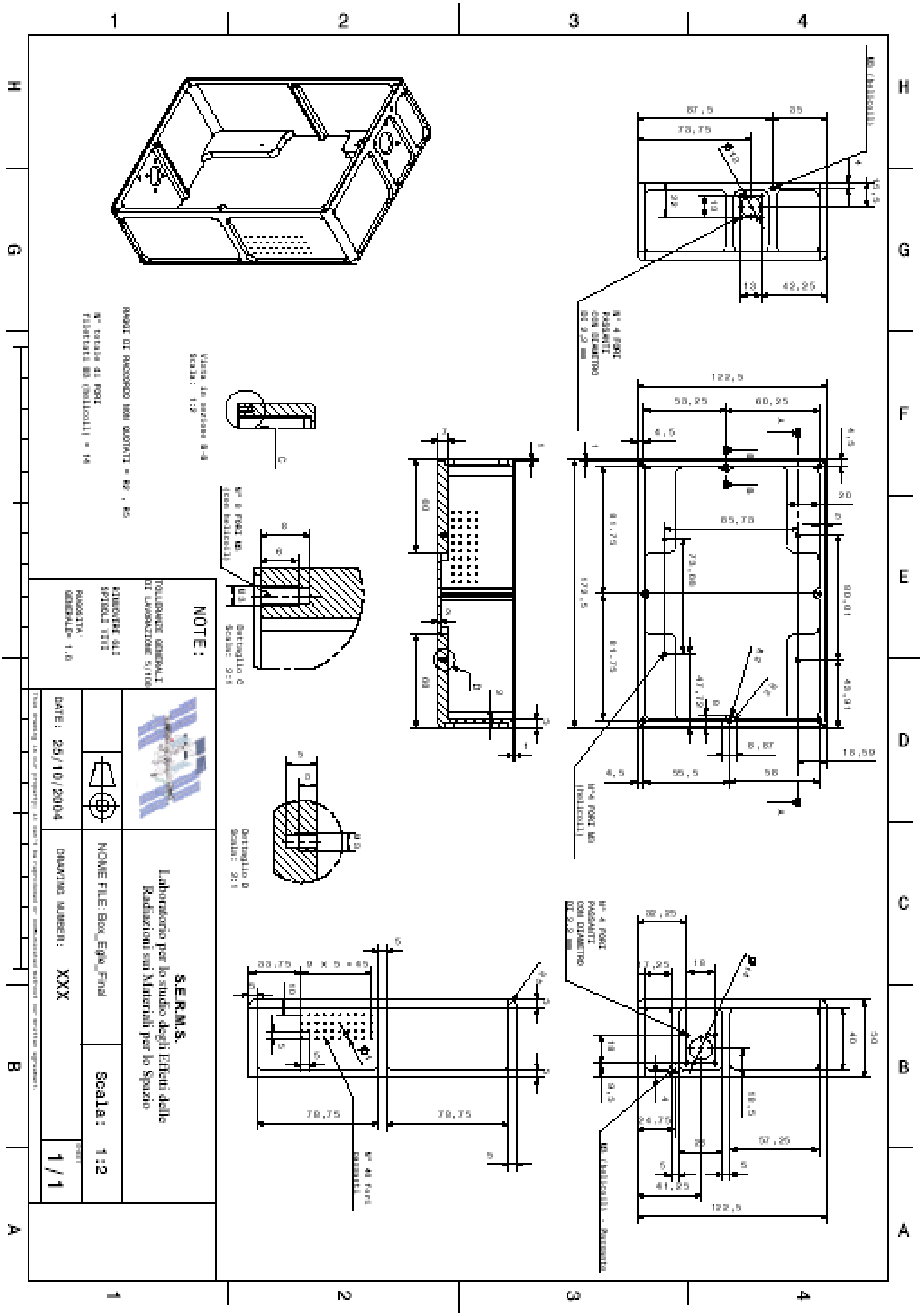



**Figure 9**. The project of the EGLE MB box.

Magnetic field signals detected by the EGLE MH probe are amplified, filtered and acquired by the the EGLE acquisition and data handling board located into the EGLE MB box.

The EGLE magnetometer gives the possibility to get  magnetic field data in four frequency band:

a) 1 Hz ÷ 40 Hz
b) 0.5 Hz ÷ 5 kHz
c) 20 kHz ÷ 40 kHz
d) 1 Hz ÷ 20 Hz

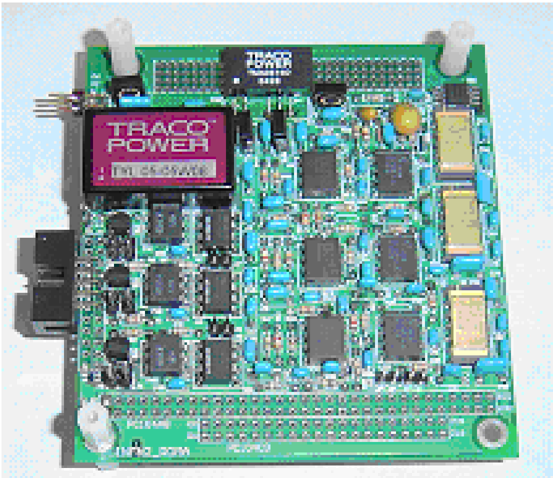



**Figure 10.** EGLE electronic interface board with amplifiers, filtering and data acquisition installed inside the EGLE MB box.

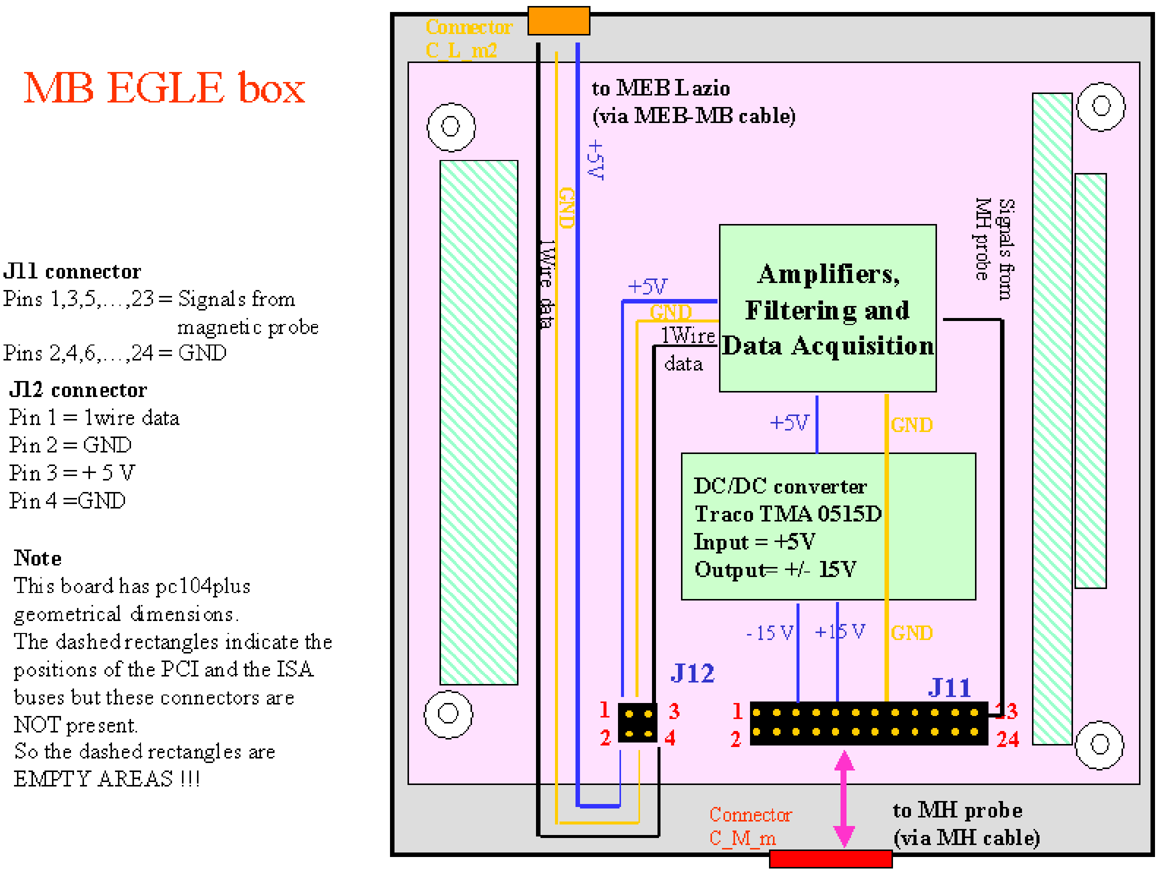



**Figure 11.** Scheme of the EGLE electronic interface board inside MB box

## 7. Connection of the EGLE magnetometer to the LAZIO MEB box

The EGLE magnetometer MB is connected to the LAZIO MEB through a 2m long cable. EGLE experiment is the first test in space of a data acquisition system based on the 1-Wire® technology.

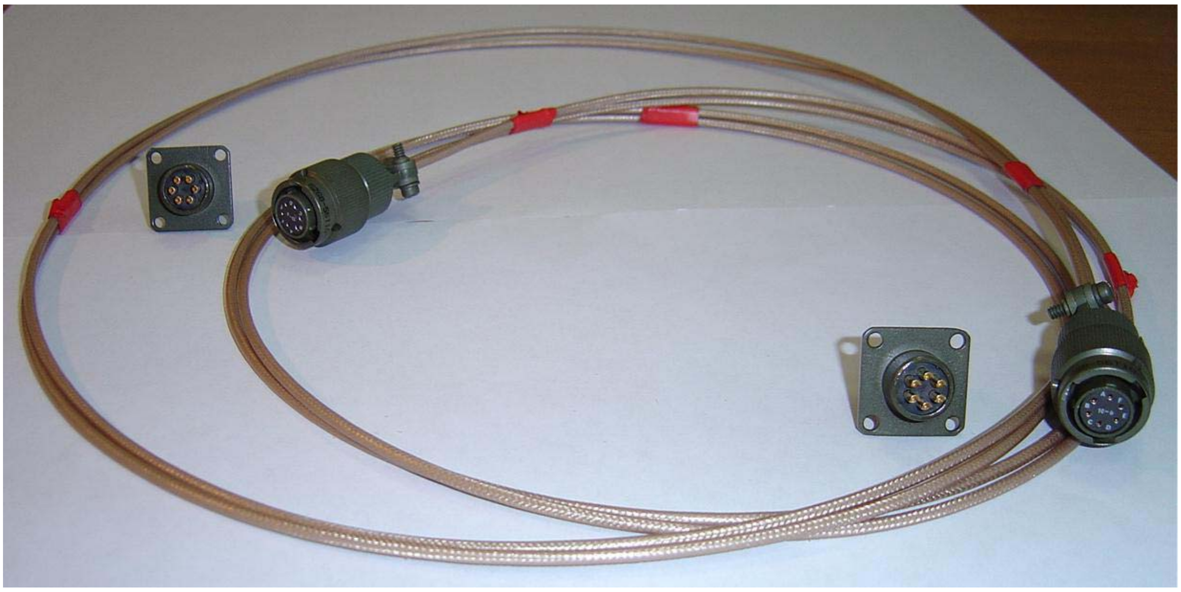
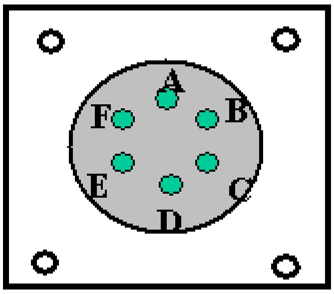


**Figure 12.** Cable for connection between LAZIO MEB box and EGLE MB box.




Pin A = NC
Pin B = 1 Wire data
Pin C = +5 V
Pin D = NC
Pin E = GND
Pin F = GND

**Figure 13.** Connectors on the LAZIO MEB box wall and the EGLE MB box.wall. Model: Amphenol Serie 62GB bayonet, male for wall 6 pins 62GB-16E-10-6P.

The Dallas Semiconductor/Maxim 1-Wire® technology uses a single wire (plus ground) to accomplish both communication and power transmission. A single bus master can feed multiple slaves over a single twisted-pair cable. The 1-Wire® net is a bus based on a PC or microcontroller communicating digitally over twisted-pair cable with 1-Wire® components. The network is defined with an open-drain (wired-AND) master/slave multidrop architecture that uses a resistor pull-up to a nominal 5V supply at the master. A 1-Wire® net-based system consists of three main elements: a bus master with controlling software; wiring and associated connectors; and 1-Wire® devices. Every slave has a globally unique digital address. The system permits tight control because no node is authorized to speak unless requested by the master, and no communication is allowed between slaves except through the master.
Both master and slaves are configured as transceivers permitting bit sequential data to flow in either direction, but only one direction at a time, with data read and written least significant bit (LSB) first. The 1-Wire® net is connected to the serial RS-232 CPU port via a 1-Wire® to serial adapter. 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. Power for chip operation is derived from the bus during idle communication periods when the DATA line is at 5V by including a half-wave rectifier on each slave.

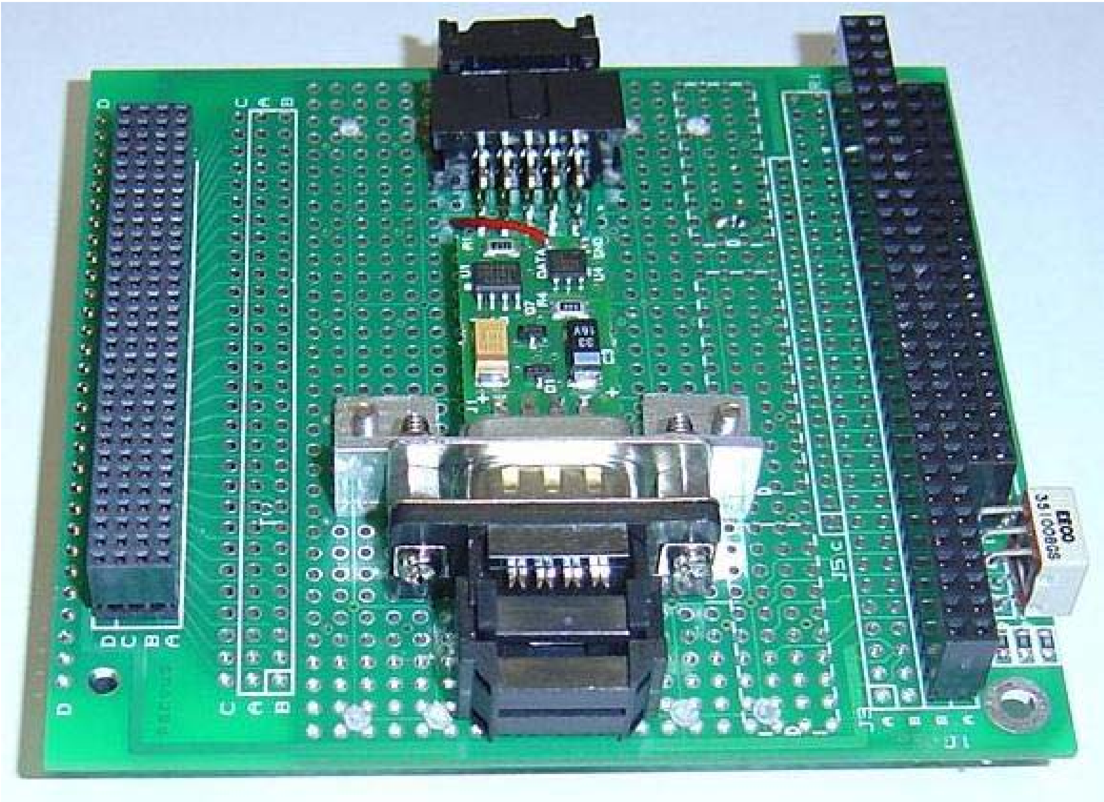


**Figure 14.**-Wire® to RS232 serial adapter installed on the LAZIO pc104 tower.

# 1Wire-serial board (on the PC tower)

**C_1W_m connector**
Pins 1 and 3 = 1Wire Data
Pin 5 = N.C.
Pins 7 and 9 = +5 V
Pins 2,4,6,8,10 = GND

**J1 = 120 pins ISA connector**
Pin B29 = +5 V
Pin B32 = GND

**J2 = 40 pins ISA connector**

**J3 = PCI connector**

**Fuse**
Restorable fuse RUE series
RS code = 183-9584
I max no stop = 0.9 A
I stop = 1.8 A
R = 0.07–0.12Ω

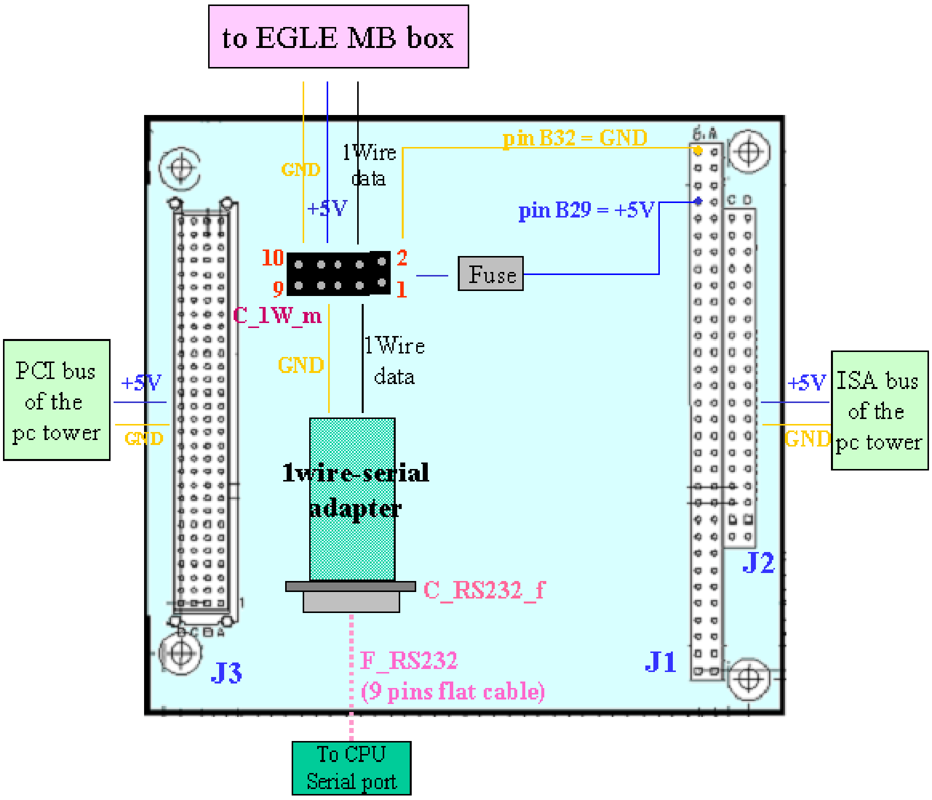



**Figure 15.** Scheme of the 1-Wire® to RS232 serial adapter installed on the LAZIO pc tower.

..

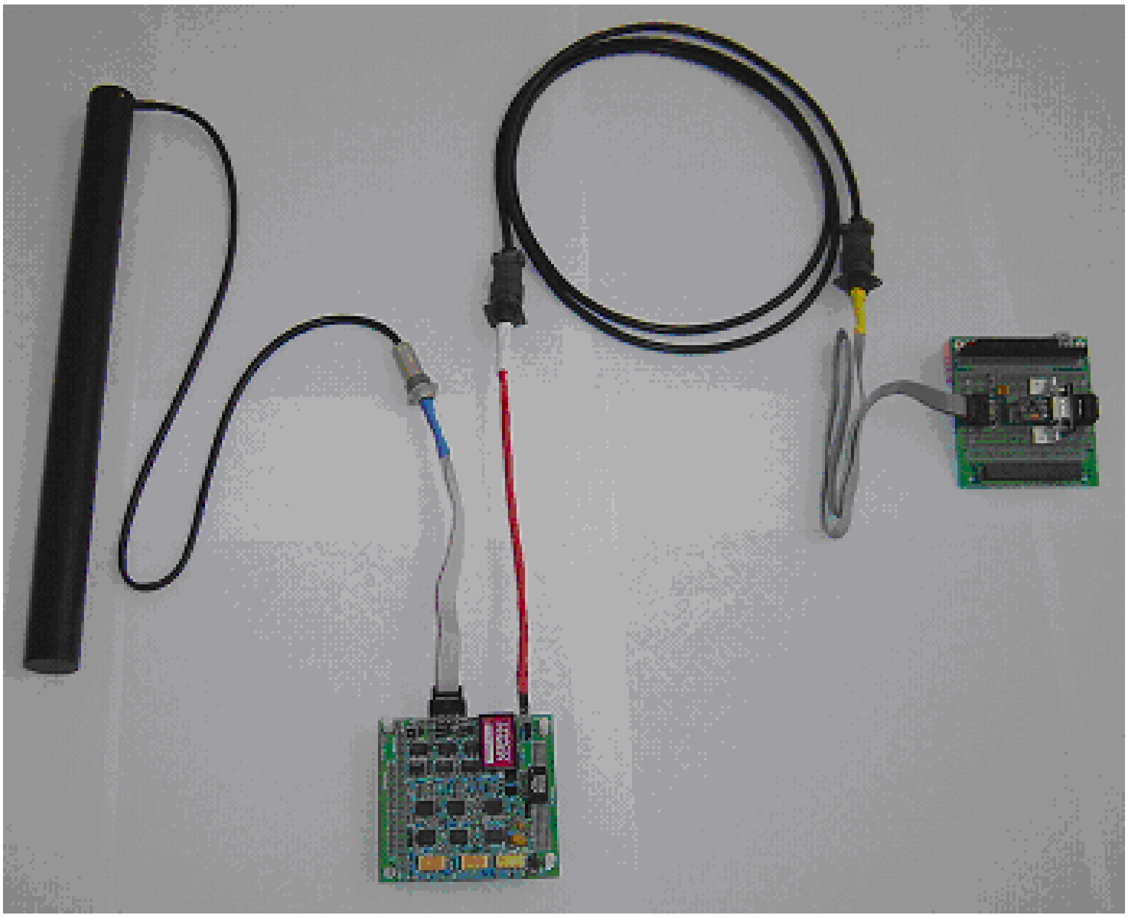


**Figure16.** LAZIO-EGLE connection scheme. Magnetic sensor (left), EGLE acquisition board mounted inside the EGLE MB box (bottom), Lazio MEB box - EGLE MB box connection cable (top), 1-Wire-Serial board mounted on the pc tower (right).

## 8. EGLE operations

EGLE includes a single axis search coil magnetometer, the EGLE Magnetometer Head (MH), so to better investigate magnetic field environment, during the operations of LAZIO, the EGLE MH will be put in different orientation according the following scheme.

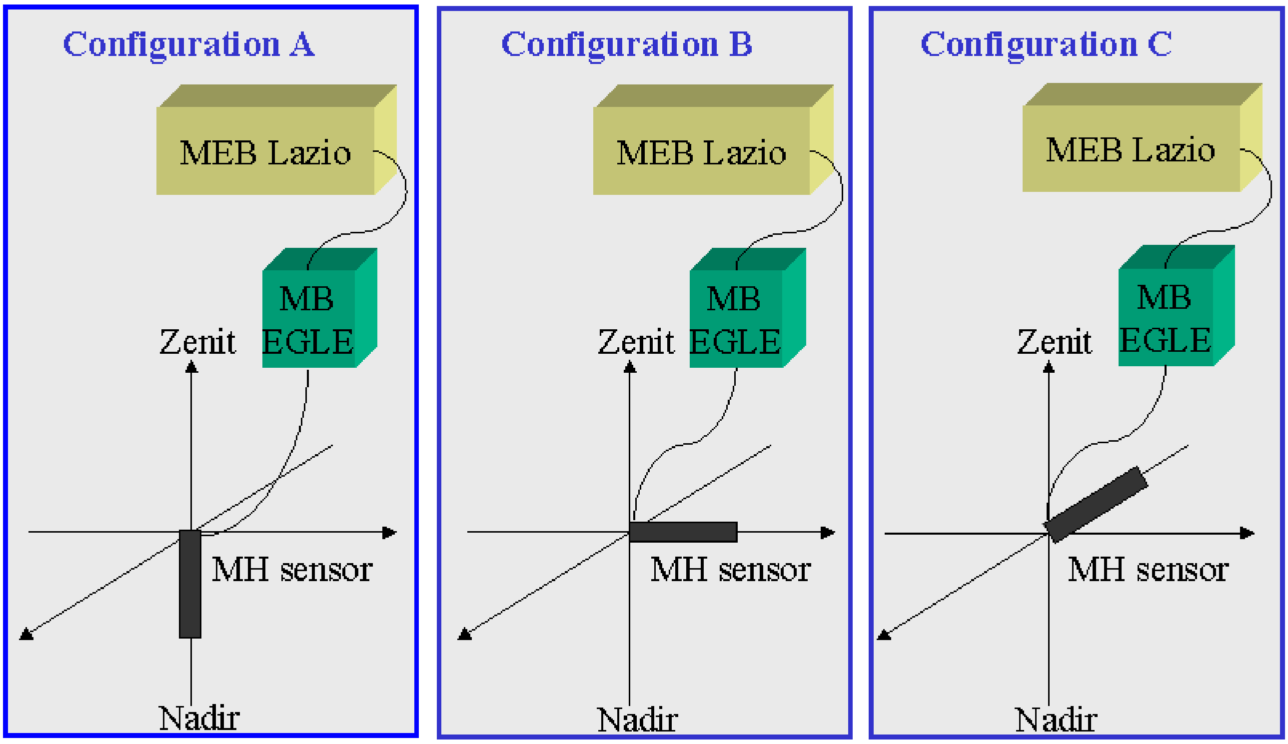



**Figure 17.** Orientation of the MH probe

During the Soyuz10 mission and the Increment11, the EGLE MH orientation will be changed with the following schedule:

- ✓ during Soyuz10 mission:
  - 3 days MH in position A
  - 3 days MH in position B
  - 3 days MH in position C

- ✓ during the Increment 11
  - 2 months MH in position A
  - 2 months MH in position B
  - 2 months MH in position C

Every time the MH position will be changed, it will be necessary:
• to take note of the MH axis orientation with respect the ISS and the MEB axes,
• to take pictures of the all MEB –MB – MH system.

Data of the relative orientation of the LAZIO particle detector axis and of the EGLE MH axis will allow to re-construct the particle pitch angle distribution v.s. the magnetic field data.

## 9. EGLE software

The EGLE software has two main operational modes:
-*'calibration'*: This mode is for optimising data acquisition in order to allow changes of the electronic gain at different frequency bands.
-*'monitoring'*: Continuous acquisition in the above mentioned 4 frequencies bands.
Data acquisition is done at 16 bits. Is possible to upgrade the EGLE acquisition parameters by re-installing the acquisition software on the MEB pc tower.

Magnetic field data will be recorded in the PCMCIA card of LAZIO MEB. EGLE magnetic field data will be analyzed on the ground and then correlated with the LAZIO particle detector measurements.