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# Design and development of spaceborne scientific devices at the Institute of Experimental Physics SAS

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**Abstract.** Design and development of spaceborne scientific devices for operation on board of the spacecraft rank among to special science & technology activities due to extraordinary challenging demands for high reliability in hostile space environment. The development requires experienced and qualified personnel, expensive space-qualified components and expensive qualification testing in compliance with requirements of individual space agencies. „Centre of Space Research: Space Weather Influences" (CSR), established with the support of funds of EU in the frame of Operational program Research and Development, project ITM 26220120009", significantly contributed to enhancement of Department of Space Physics IEP in procurement of space qualified components and materials for space experiments under development and in technological abilities for developing and testing infrastructure.
**Key words:** scientific spacecraft – space technology – scientific devices

## 1. Introduction

The space science & technology activities of Department of Space Physics (DSP) of IEP started in the early seventies of the last century when the laboratory was involved in the INTERKOZMOS programme. The very first detectors of space energetic particles were for DSP developed at the Charles University in Prague and at the Faculty of electrical engineering of Technical University in Košice; however, the DSP soon started its own development in a small technical group under leadership of Ing. Jozef Rojko, CSc. The first significant success of the Košice-group is related to launch of a detector of neutrons and gamma rays SK-1 on board of the spacecraft INTERKOZMOS-17 in 1977. Since that time DSP has developed or participated in development over 20 scientific space devices. The most recent device on the orbit is an imaging detector of energetic neutral atoms NUADU, launched in 2004 (McKenna-Lawlor et al., 2004, 2009), also the detector of energetic electrons PEEL, launched on board of the suborbital sounding rocket HotPay-2 in 2008 is a kind of spaceborne device. Ready for launch is a programmable particle spectrometer MEP-2 and a new spectrometer DOK-M for project RESONANCE is just under development.

Development of spaceborne instrumentation belongs to most demanding technical human activities, focused on assurance of extremely high long-term reliability and stability in the open space environment, where the instruments are exposed to hard ionisation radiation, extreme temperature excursions, ultra-high vacuum and also to very strong vibrations and accelerations during the launch of a space rocket. Moreover, hard limitations are incurred with regard to mass, dimensions and available power supply. A relevant limitation is related to the narrow band for data download to a ground segment that requires data pre-processing and compression on board of the spacecraft.

## 2. Means and methods for assurance of high reliability of spaceborne devices

With regard to high financial demands of space missions and an inherent impossibility of satellite maintenance on orbit (also shortly before the launch), an extreme reliability of the space instrumentation is of great importance. The basic means to assure the reliability include usage of space-qualified components and materials, qualified and certified technological procedures and qualification testing of finished spaceborne devices. Important is also a redundant multi-level design, from individual functional blocks up to full dual redundancy (two identical systems).

### 2.1. Space qualified components

Space qualified components and materials are prepared already by the manufacturer for high-reliable space systems. The manufacturer modifies production technology for this task (purity-level of semiconductor material, packaging to ceramic and ceramic-metal packages, etc.), screening of best manufacturing batches, burning-in at harsh environmental condition (temperatures, vibrations, radiation) to exclude less reliable pieces. By the level of the testing, the components are sorted out to different qualification levels. Renowned space agencies issue the so-called „Qualified Part List“ (ESA-QPL, NASA-QPL) for this purpose. The minimum qualification level for spaceborne devices should meet the American military standard MIL-STD-883B.

#### 2.1.1. Contribution of the CSR project in procurement of space qualified components

A significant contribution of the CSR project concerns particularly the procurement of ion-implanted semiconductor detectors of ionizing radiation for spectrometers of space energetic particles under development at IEP. The detectors were procured from the reputable manufacturers ORTEC and CANBERRA.

Other important items are electronic space-qualified components necessary to build the spaceborne devices. The first period of the CSR is focused particularly on hybrid integrated circuits for analogue pre-processing of the signals from semiconductor detectors, supplied from the reputable manufacturer AMPTEK. The second period concerns mainly microcircuits for A-D conversion and informatics parts of the devices (processors, memory chips, interfaces).

### 2.2. Qualification testing of spaceborne devices

The main task of the qualification testing of spaceborne devices involves their thorough verification and demonstration of reliability at a prescribed environmental condition (temperature cycles, vibrations, impacts, accelerations and optimal burn-in to exclude unreliable parts).

#### 2.2.1. Vibration – acceleration qualification testing

Although the spaceborne device is operating on the orbit without any mechanical load (microgravity), it is endangered during the launch of the space carrier. With regard to optimal energy balance of the rocket launch, a huge energy is released during minutes, causing strong vibration levels (including aerodynamic vibrations in a denser atmosphere) incurred also to the scientific payload. An additional load is caused by a linear acceleration in the thrust vector and intense impact loads from jettisoning of the lower rocket stages and releasing various mechanisms and covers by explosive pyropatrons. All those accelerations endanger the integrity of the space devices, so they have to have a very compact and rugged design. The pc-boards require lot of supporting points to suppress dangerous low resonance frequencies, electronic components have to be additionally fixed by qualified structural glues (e.g. ScotchWeld 2216 B/A).

Qualification testing is defined for a specific space project, depending mainly on the space launcher used. To perform the vibration testing, a special computer-controlled testing apparatus (shaker) is used, with ability to deliver the required vibration load to the device under test. The standard loads consist of a sinus vibration defined by the frequency range, acceleration levels duration and random vibration test defined by the frequency-amplitude spectrum and duration. The load testing is preceded by the so-called low-level sinus scan of resonance spectra that is repeated after the load test. If there is no damage to the tested device during the load test, the first and second scan gives the same resonance spectra.

As an illustration of vibration qualification tests, a prescription from the project ESA-BepiColombo is used (carrier Ariane-5).

- Computer simulations (FEA – finite element analysis),
- sinus test (10 Hz – 3000 Hz, 24g, 2 minutes in each axis X,Y,Z,),
- random spectrum (10 Hz – 3000 Hz, 22g-rms, 2 minutes in each axis X,Y,Z),
- impact test (1000g, 5ms, 2 x for each axis and orientation, i.e. 12 impacts),

– linear acceleration (20g, on centrifuge, 10 minutes).

#### 2.2.2. Contribution of the CSR project to testing infrastructure of DSP-IEP for qualification vibration testing

An important contribution of the CSR project involves the procurement of a complete system for vibration qualification testing from the reputable manufacturer Brüel & Kjær / LDS consisting of: Vibration system V780, power amplifier HPAK, control system Laser USB with control software LAS-200 and 4pc of acceleration sensors IEPE 100 mV/g.

The basic parameters of the system:

– action force (sinus peak): 5100 N,

– action force (random-rms): 4200 N,

– action velocity (sinus peak): 1.9 m/s,

– action acceleration (sinus peak): 1050 m/s$^2$,

– action acceleration (random-rms): 480 m/s$^2$,

– frequency range: DC – 4000 Hz,

– resolution of the control system: 24 bit,

– interface to control computer: USB 2.0.

The system for vibration tests allows the IEP to perform the vibration qualification tests of the spaceborne devices that is directly under development at IEP and also for testing of the devices of partner institutions in the frame of international collaboration in space research.

### 2.3. Thermal-vacuum qualification testing

An important requirement to spaceborne devices involves reliable operation in an extreme wide temperature range (operational range), eventually to survive without permanent damage even a wider temperature range in a non-operational mode (e.g. strong under cooling during a long-term Earth eclipse, or overheating during some attitude manoeuvres of the spacecraft. Even more complicated is the temperature regime of deep space probes as their Sun thermal income power may vary in an extreme wide range. Special attention should be paid to the high vacuum environment as there is no component cooling by the air natural or forced circulation. More power dissipative components that would be easy cooled in the “Earth environment” can be easily overheated and destroyed in space vacuum. So that it is of importance to provide a satisfactory heat sink by thermal convection (thermal bridges to cooler parts of equipment) or by radiation – by a radiation heat sink.

At the higher power dissipation, heat tubes are necessary to remove the heat from the exposed parts. The maximum operational range of most of the space qualified semiconductor devices is -55°C to +125°C, however, for the sake of extreme reliability it is not recommended to operate above +80°C. The temperature regime of space devices is of extraordinary importance and deserves a special attention of space thermal engineering experts.

Qualification thermal vacuum testing usually consists of a prescribed number of well-defined temperature cycles in operational and non-operational modes of the device under test at the atmospheric pressure well below $10^{-5}$ mBar, when conduction thermal exchanges are negligible. Typical temperature cycles for spaceborne devices are in the range from -40°C to +50°C in the operational mode and -50°C to +70°C in the non-operational mode, however, some retractable parts (e.g. sensors on the booms) may require a much wider range. The device under tests is during the testing in the vacuum chamber connected to the spacecraft simulator through vacuum feedthrough insulators.

#### 2.3.1. Contribution of the CSR project to testing infrastructure of DSP-IEP for thermal-vacuum qualification testing

Although DSP-IEP has built the main parts of the thermal vacuum facilities (vacuum chamber, vacuum pumps) from alternative funds, the thermal testing facilities have not been finished yet and require delivery of additional parts. The CSR project has contributed with Dewar vacuum flasks to storage the liquid Nitrogen and in second period with thermal exchange devices to cool the temperature controlled table inside the vacuum chamber.

### 2.4. Qualification testing of electromagnetic compatibility (EMC)

As there are a plethora of various scientific and service electronic devices on board of the spacecraft, a minimum mutual electrical interference is of extraordinary importance.

The main task of the EMC qualification testing is to prove that the device under test:

- emits interference signals below the level that is required in the entire frequency range of investigated electromagnetic spectra (emission testing).

- is not sensitive to interference from other sources at the level that is expected on board of the spacecraft (immunity tests, susceptibility).

So far, DSP-IEP has had no own equipment to perform the EMC testing and had to rely on testing at the laboratories of the partner institutions.

### 2.4.1. Contribution of the CSR project to testing infrastructure of DSP-IEP for electromagnetic compatibility (EMC)

A complete set of testing devices for EMC testing is provided by the CSR funds. The system allows testing of conductive (on powering line) and radiated emission and also immunity conductive testing (immunity against injected interference on power line).

The testing workplace consists of:

- EMI receiver 10Hz – 30MHz certified to standard CISPR 16-1-1,
- extension unit 30 MHz - 3 GHz, certified to standard CISPR 16-1-1,
- set of antennas for radiated emission testing,
- active rod antenna 9kHz-30MHz,
- bi-conical antenna 30-200MHz,
- logarithmic-periodical antenna 200MHz-2700MHz,
- artificial network V 150 Ohm for conductive emission testing,
- system for conductive immunity testing 10kHz to 230MHz,
- RF power meter 1 GHz,
- set of injection elements,
- set of binding elements for conductive immunity testing.

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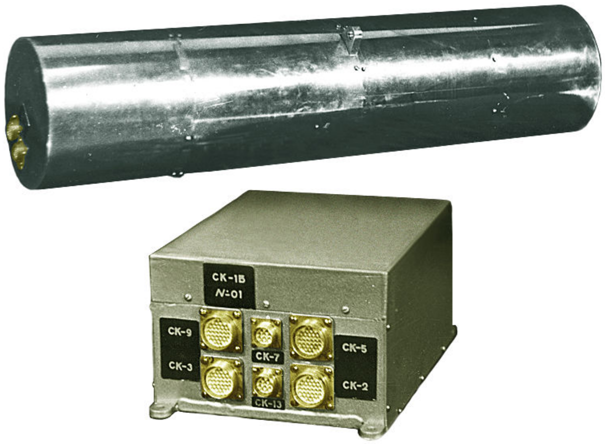


**Figure 1.** First spaceborne scientific device SK-1 was launched on board of the INTERKOZMOS-17 spacecraft in 1977.

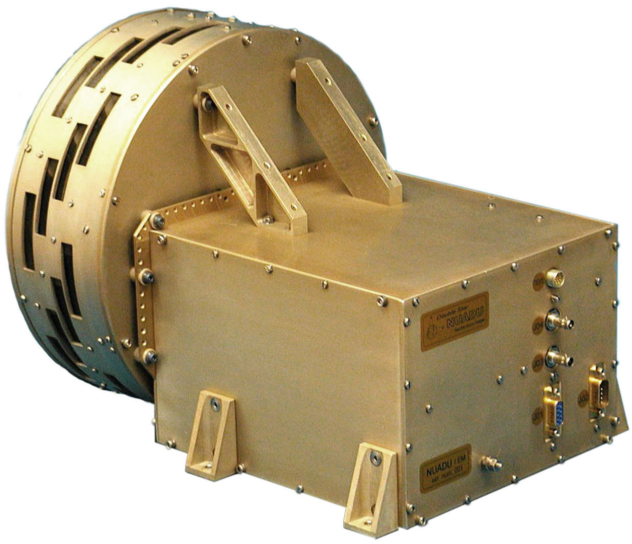

**Figure 2.** The most recent space device on the orbit: an imaging detector of energetic neutral atoms NUADU developed with IEP participation, operating on board of Chinese-European spacecraft Double Star TC-2.

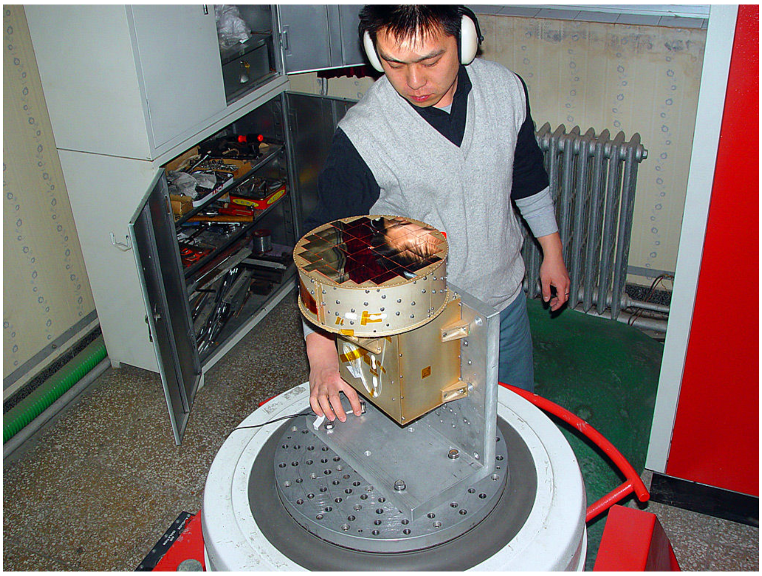

**Figure 3.** Vibration testing of the detector NUADU on electromagnetic shaker at Chinese Centre for Space science and Applied Research in Beijing.

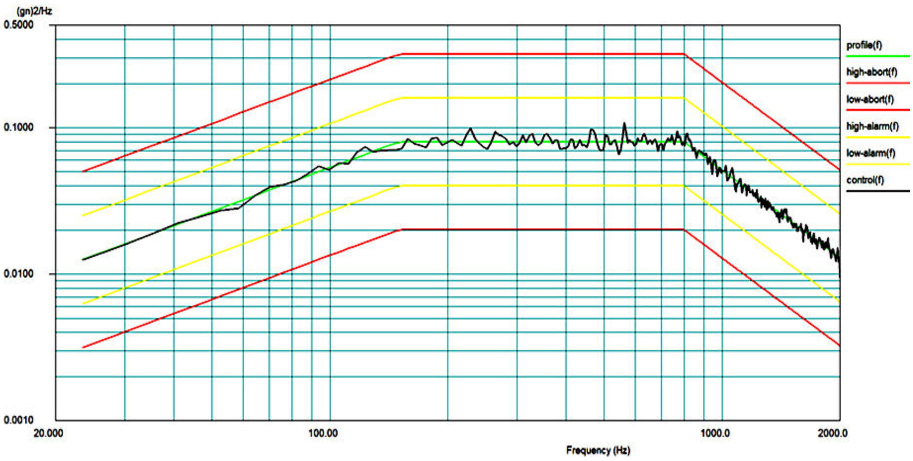


**Figure 4.** An illustration example of the spectral density of a load qualification test with a random spectrum (14g-rms, project Double Star, carrier Long March-2C).

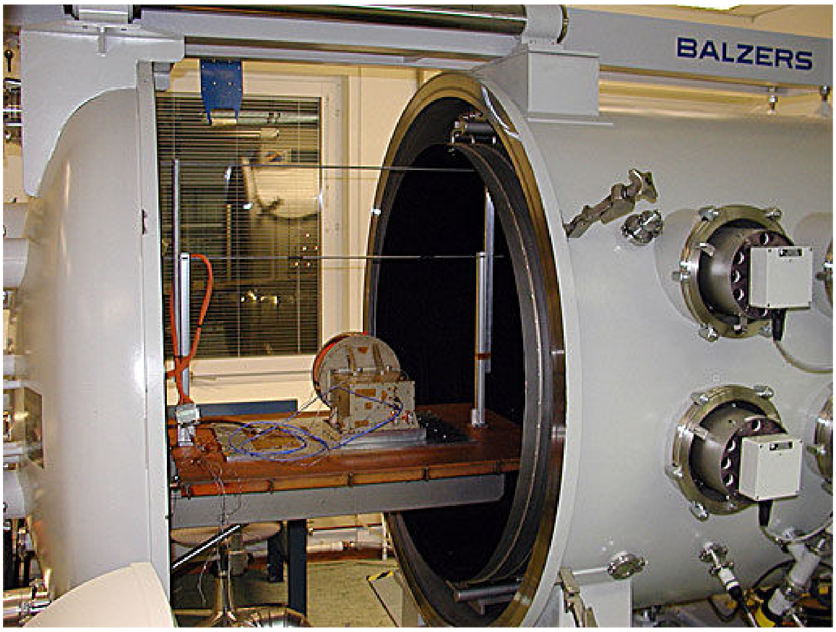


**Figure 5.** Thermal-vacuum testing of the NUADU detector in space environment simulator (IRF Kiruna, Sweden).

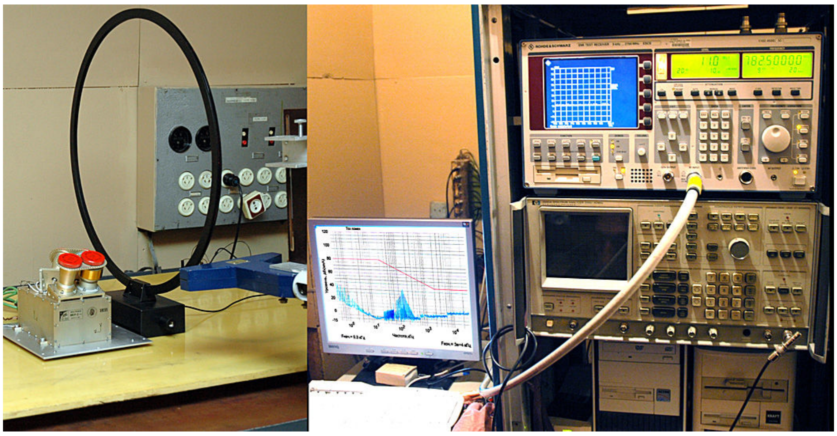

**Figure 6.** Testing of electromagnetic compatibility of the MEP-2 device at Space Research Institute in Moscow.