Test of the Qualification Model of UG electronics for the AMS TRD Gas System

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Contents

1 Introduction

We report here the results of the space qualification of the UG electronics, i.e. the electronics that controls the gas circuit for the Transition Radiation Detector of the AMS-02 experiment [1]. The UG electronics rôle in the TRD gas system is shown in figure 1.

The tests date to the period february–march 2008. Aim of the tests is to demonstrate that the UG electronics, as it is projected and built, is suitable for space operation.

Two versions of the crate were built: the Qualification Model (hereafter, *the QM2 UG electronics*), that underwent environmental stress screening (ESS), thermo-vacuum stress (TVT) and electromagnetic interference (EMI) tests (*qualification*

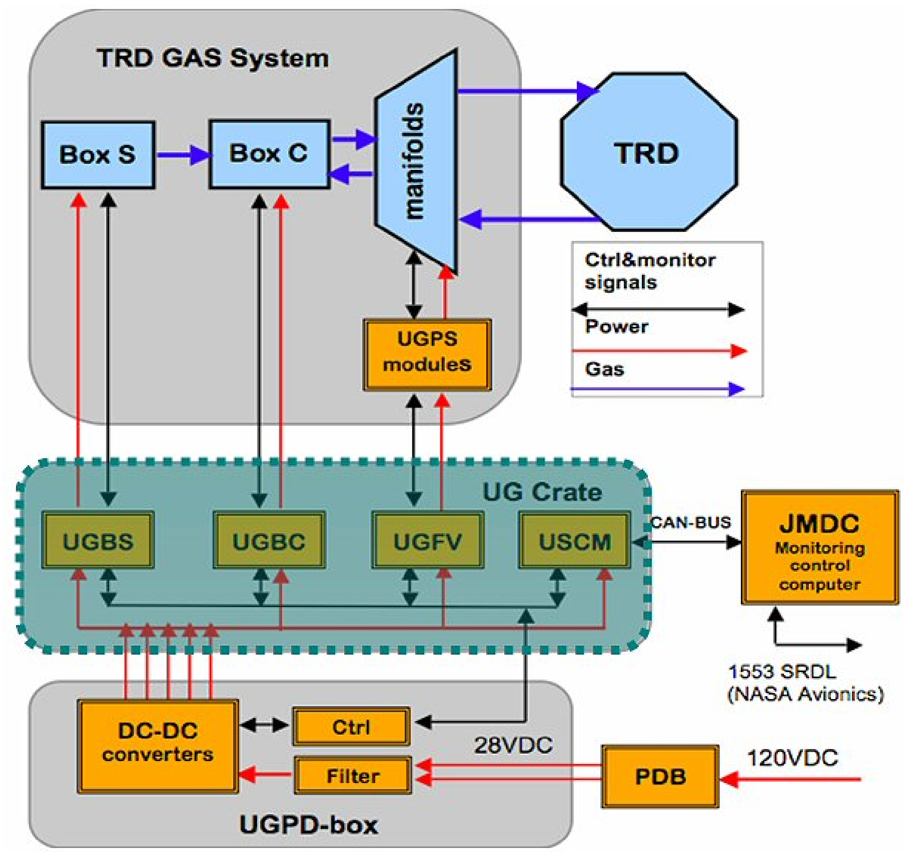

Figure 1: *The UG electronics in the Transition Radiation Detector gas circulation system.*

tests); and the Flight Model (hereafter, *the FM*), i.e. the hardware that will actually fly, which only underwent environmental stress and thermo-vacuum stress tests (*acceptance tests*). A second, spare, set of flight electronics, (hereafter, *the FS*), was built and tested like the FM one. This document describes the test procedure and results of the QM2 UG electronics.

The UG electronics construction and test is responsibility of INFN Roma. The space qualification and acceptance tests of the crate were performed according to the official procedures described in the experiment guidelines [2]. A preliminary discussion of the UG electronics FM acceptance tests was already released [3].

1.1 The UG-crate

The crate is equipped with a total of eight boards of four different kinds ("A" and "B", redundant for safety reasons):

1. two UGSCM (S/N A1 and A2)
2. two UGBS (S/N 001 and 002)
3. two UGBC (S/N 001 and 002)
4. two UGFV (S/N 001 and 002)

plus a backplane (UGBP) to which the boards are connected.

Except for the UGSCM's, which are provided by the AMS electronics team, INFN Roma projected, engineered and tested all the boards . The mechanics of the crate were built by G&A Engineering [4], following the drawings provided by Carlo Gavazzi Space [5]. The UG electronics is sketched in figure 2.

1.2 Test setup

The qualification of the UG electronics was performed using the test facilities of the "Laboratorio per lo Studio degli Effetti delle Radiazioni sui Materiali per lo Spazio" (SERMS), Terni, Italy. The "Electromagnetic Compatibility Laboratory" (CEM) of Perugia University conducted the electromagnetic compatibility tests. Technical test reports are availble at [6].

In the electromagnetic compatibility test, in addition to the UG electronics, also the UGPD crate, provided by CSIST, Taiwan [7] was included in the setup, supplying the power by DC-DC converters and powered by external 28 V commercial power supply. When the UGPD was not present, i.e. in the environmental stress test and in the thermo-vacuum test, external power supplies have been used also to power the UG electronics. However, in both power supply setups, part A or part B of the UG electronics have been powered one at a time, as prescripted.

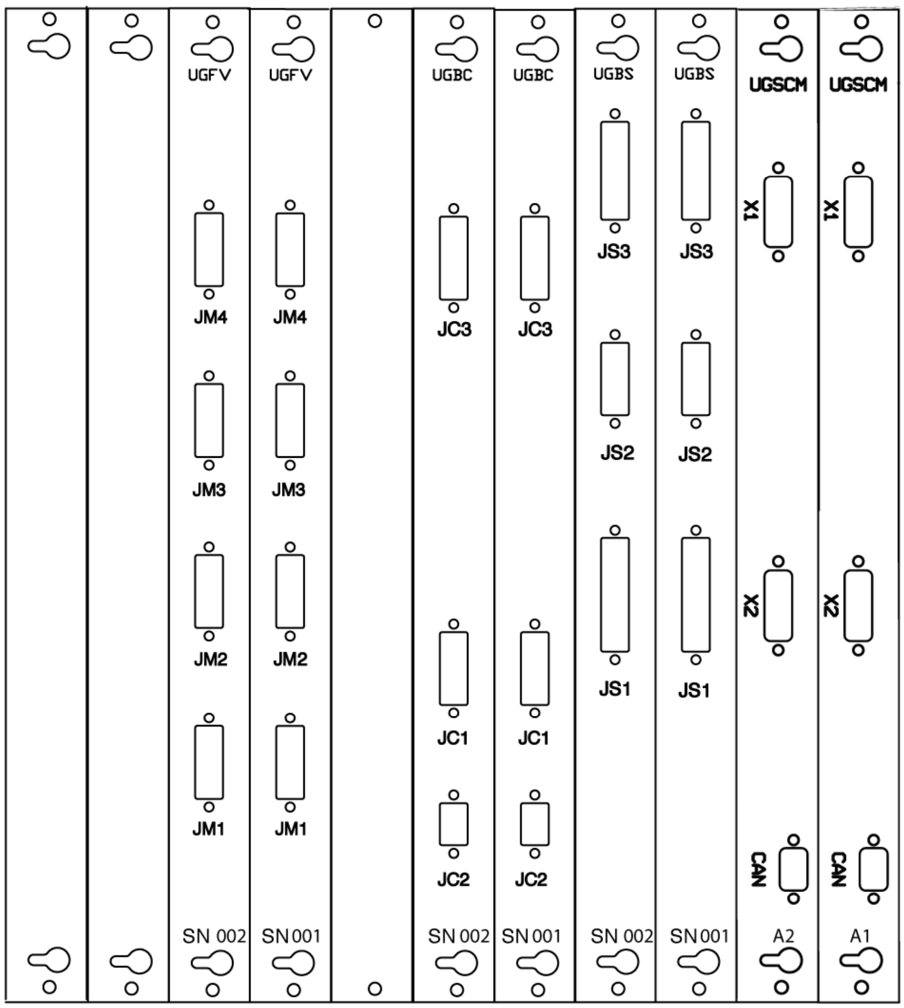

Figure 2: *The UG crate. From right to left, two UGSCM boards, two UGBS boards, two UGBC boards, one dummy metal panel and two UGFV boards.*

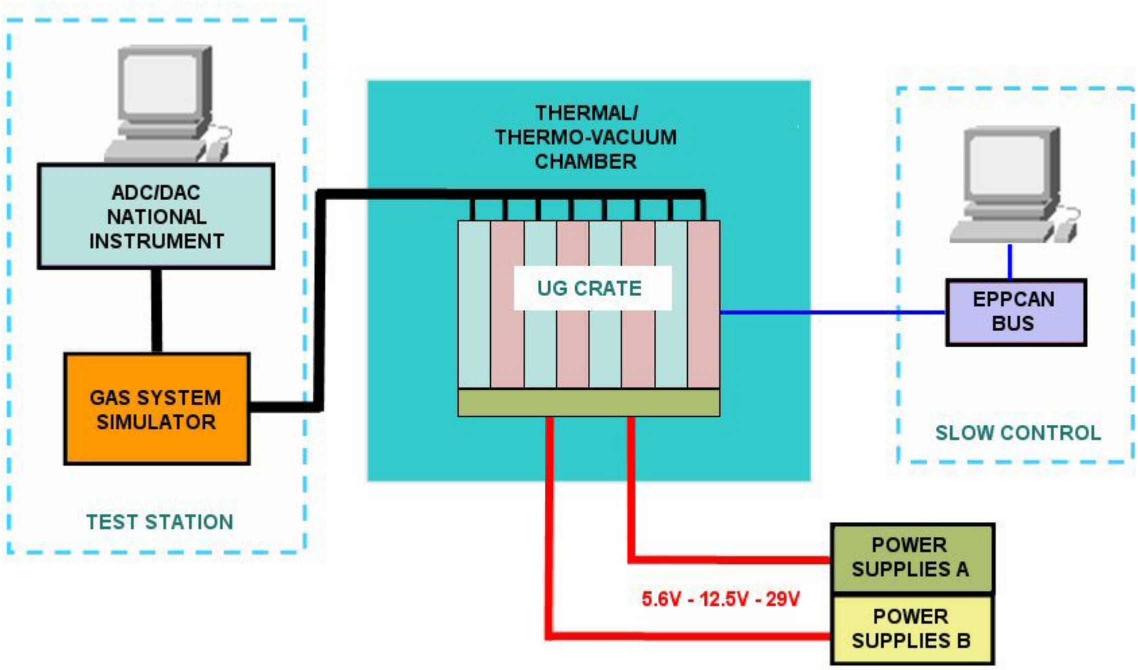

Figure 3: *Setup used in the environmental stress and thermo-vacuum tests.*

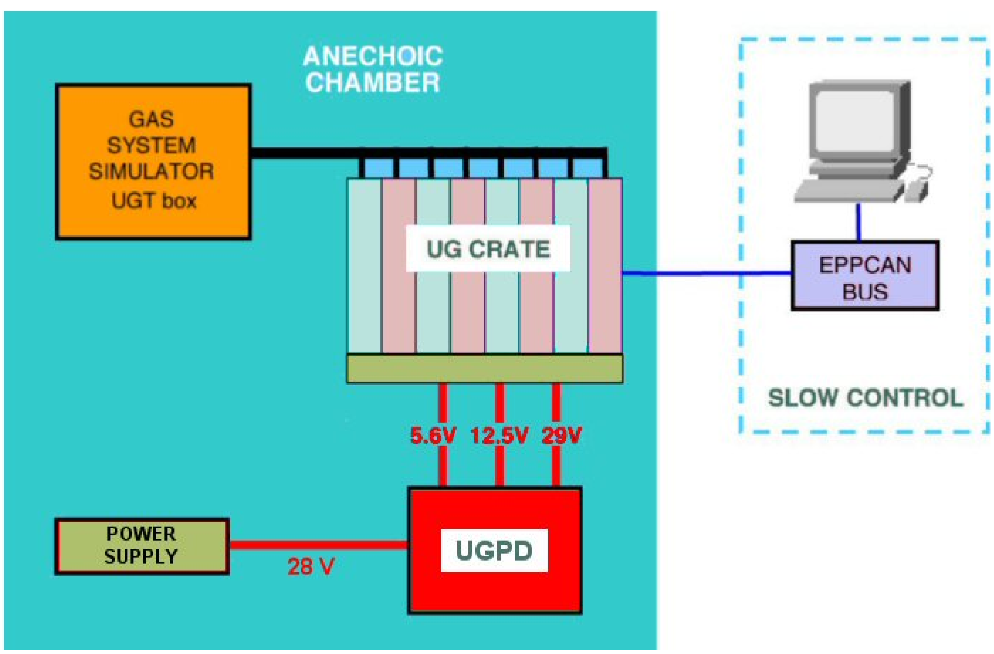

Figure 4: *Setup used the EMI tests.*

ESS and TV tests were performed while checking the full functionality of the electronics. For this reason, a Test Station (UGTS), with a set of six boards simulating the input/output operations of TRD gas circuit, was connected to the UG crate. Electromagnetic compatibility test was performed with a simplified Test Box, UGT Box, simulating valves and circulation pumps.

The complete setup used for the sub-tests, described in detail in the corresponding section, are sketched in figures 3 and 4.

1.3 Functionality test sequence

At fixed stages of ESS and TV tests a functional check of the UG electronics was performed in order to ensure that the boards were behaving correctly. Commands were sent to the UG electronics from the external control computer communicating with the boards via EPPCAN bus (see again figures 3 and 4). The communication among the boards and between the UG electronics and the UGPD occurres via a LeCroy bus.

The operation sequence, together with temperatures, pressures, status flags that were read out during the test, were stored in a disk together with the output from the Test Station.

The operation sequence is the following:

1. UGSCM A and B are initialized;
2. all valves controlled by UGBS (V1a, V2a, V3a, V4a, V10a, V20a, V1b, V2b, V3b, V4b, V10b, V20b, Sp1, Sp2) are enabled and opened for 5 s one at a time, and status is read, then disabled;
3. all pressure sensors controlled by UGBS (P1a, P2a, P1b, P2b, Pk1c, Pk2c, Pk1d) are read out;
4. all heaters controlled by UGBS (H1, H2, H3, H4, H5) are enabled and started for 1 minute, then disabled, one at a time;
5. operations 2 to 4 are repeated four times: [UGSCM-A + UGBS-A], [UGSCM-A + UGBS-B], [UGSCM-B + UGBS-A], [UGSCM-B + UGBS-B];
6. all power supplies (29V, 12V, 5V, 8.5V) controlled by UGBC are enabled, and the status is read out;
7. all valves controlled by UGBC (V6a, V18a, V6b, V18b, V6a&V18a, V6b&V18b) are enabled and opened for 5 s one at a time, and status is read, then disabled;
8. all pressure sensors controlled by UGBC (P3, P4) are read out;
9. all circulation pumps controlled by UGBC (CP1, CP2) are enabled at H speed, started and stopped after 5 s, then enabled at F speed, started and stopped after 5 s then disabled, one at a time;

10. all UGBC serial ports (RS232_1, RS232_2, RS232_3, RS232_4) are enabled and the status is read, read/write operations are checked, then the ports are disabled;

11. all power supplies (29V, 12V, 5V, 8.5V) controlled by UGBC are disabled;

12. operations 7 to 11 are repeated four times: [UGSCM-A + UGBC-A], [UGSCM-A + UGBC-B], [UGSCM-B + UGBC-A], [UGSCM-B + UGBC-B];

13. all power supplies controlled by UGFV (12VPS, 12VFV, 21V, MUX) are enabled;

14. modules 1 to 4 are selected one at a time, and for each module, valves V1 to V5 are opened then closed after 5 s;

15. multiplexers 1 to 4 are selected one at a time, and for each multiplexer all pressure sensors (P1, P2, P3, P4, P5) are read out;

16. all power supplies controlled by UGFV (12VPS, 12VFV, 21V, MUX) are disabled;

17. operations 13 to 16 are repeated four times: [UGSCM-A + UGFV-A], [UGSCM-A + UGFV-B], [UGSCM-B + UGFV-A], [UGSCM-B + UGFV-B].

The time needed to perform these tests is of the order of 40 minutes.

At each run, after the computer controlled procedure, we read out the Dallas temperature sensor, i.e. the one present on the UGSCM, and the one connected to bus 8 through the UGBS, located on the gas system simulator. The readout was repeated for A and B modules.

The operation sequence of the EMI test includes opening and closing valves, operating circulation pumps, establishing communications between UGSCM and UG modules and between UGSCM and UGPD.

2 QM2 qualification test

This section describes the qualification tests performed on the QM2 version of the UG electronics.

2.1 Environmental stress test

The ESS test consist in a cycle of thermal stress followed by a vibration cycle, again followed by a thermal stress cycle, all in air.

The thermal profile is shown in figure 5. During the phases called *cold storage* and *hot storage*, the crate was not powered. During *cold operating* and *hot operating*

Thermal stress test phase	Temperature
Cold storage	−45 °C
Cold operating	−25 °C
Hot operating	+55 °C
Hot storage	+85 °C

Table 1: *Temperature levels for the thermal stress test.*

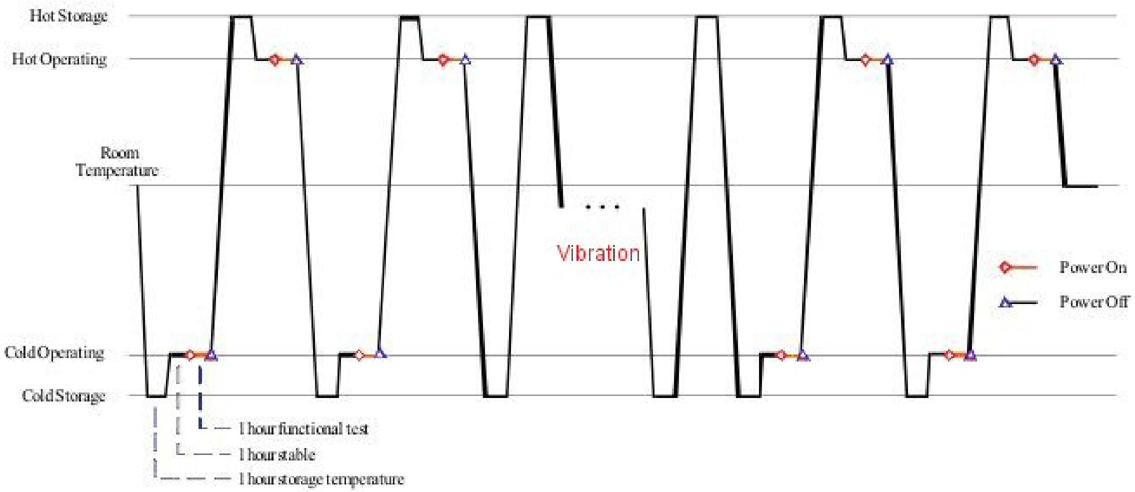

Figure 5: *Nominal temperature profile for UG electronics thermal stress test. The red dots correspond to crate power up and execution of the functional tests, while the blue triangles correspond to power off. Between the first and the second thermal cycle, the vibration test was executed.*

phases, after a stabilizing period of one hour, the crate was powered and the functional test was executed. Table 1 shows the temperatures corresponding to the test phases. Between the first (10 cold–hot cycles) and the second (5 cold–hot cycles) thermal stress, the vibration test was executed.

The UG electronics showed no malfunctioning at any temperature during the tests, either before or after the vibration.

The random vibration along the three orthogonal axes was executed according to the profile shown in figure 6. The crate was mounted on a fixture matching the crate axis with the slip table axis. Accelerometers were fixed on the crate by cyanoacrilic glue. The actual vibration profile measured for the three axes is shown in figure 7.

For all subtest (each single axis) performed, no damage has been reported, and all the subtests were normally completed. The full operation sequence 1–17 described in paragraph 1.3 was executed during the thermal stress without errors.

Figures 8 and 9 reports the readout of the pressure sensors as a function of the time, with the temperature varying in the chamber, for an applied voltage of 3 V to the Gp50 sensors, and 3 V and 600 mV to the (differential) Kulite sensors. At

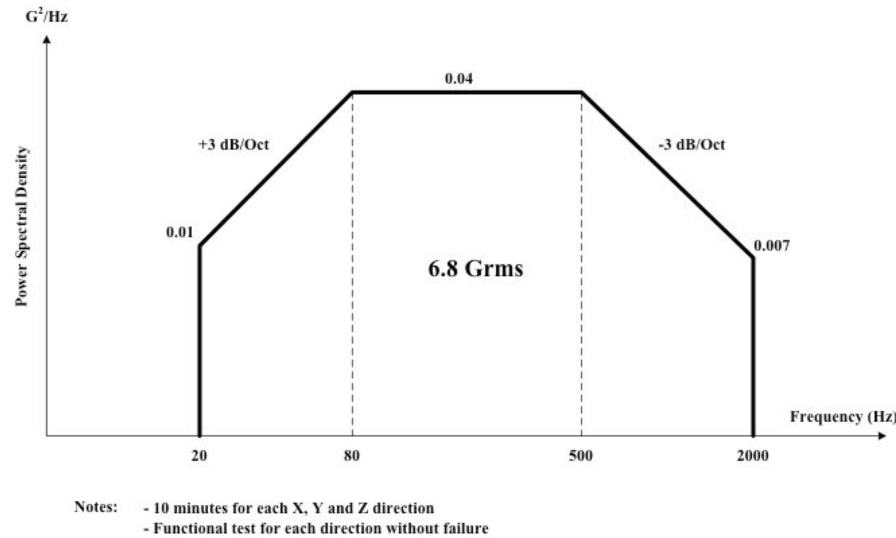

Figure 6: *Nominal vibration profile for UG electronics, to be repeated for each of the three axes.*

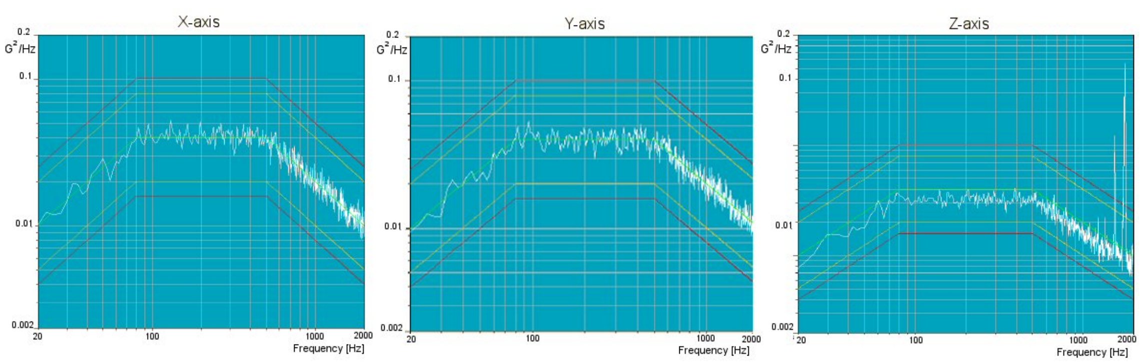

Figure 7: *Measured vibration profile for QM2 UG electronics: left to right, X-axis, Y-axis and Z-axis profiles.*

each temperature a resolution of less than 1‰ is achieved, while the sensor readout shows a temperature dependence of about 10 mV for a ΔT of 80 °C, and a readout channel dependance of about 1%.

2.2 Thermo-vacuum test

After passing the environmental stress test, the UG electronics was fixed to the lower cold plate of the the thermo-vacuum chamber through an aluminium alloy fixture with black surface treatment. Figure 10 shows the UG electronics positioned on the thermo-vacuum chamber's plate.

To optimize the thermal exchange, a layer of thermal conductive material (Cho-Term) was placed both between the crate and the fixture, and between the fixture and the cold plate. The crate was covered with MLI, to avoid thermal dispersion and to reproduce the flight conditions. Several PT100 thermal sensors were positioned in the chamber and on the electronics under test, to monitor the temperature variation in the chamber and at each board's location. The nominal temperature profile specified for the test is shown in figure 11. For the definition of the temperatures, see again table 1.

In order to start the first hot-storage phase, the pressure measured inside the chamber had to be below 10^{-4} hPa. The first switch-on operation could not start before the pressure had reached 10^{-5} hPa. The stabilization time was defined by the condition that the measured temperature T remained stable and within 1°C from the nominal temperature t for at least 1 hour, i.e. $|\Delta T|/\Delta t < 1°C$/hour for at least 1 hour.

Figure 12 shows the pressure profile measured in the chamber during the test. The temperature profile, as measured at three of the UG boards in the crate, is shown in figure 13.

No malfunctioning was observed during the test, at any temperature. The analysis of the recorded data showed that all the commands were issued successfully, and all the components responded as expected.

Figure 14 shows the readout of the pressure sensors as a function of the temperature in the chamber, for an applied voltage of 3 V to the Gp50 sensors, and 3 V and 600 mV to the (differential) Kulite sensors. The distributions agree with the ESS ones.

2.3 Electromagnetic compatibility

The EMI test was conducted in a Siemens-Matsushita semi-anechoic chamber. The UG electronics was powered with the QM UGPD connected to a commercial 28 VDC power supply, whose return lead was linked to the ground plane.

UG electronics , UGPD, 28V power supply and simplified UGT Box were all inside the chamber, while the slow control computer, placed outside the semi-anechoic chamber, communicated to the UGSCM via the EPP-CAN Bus.

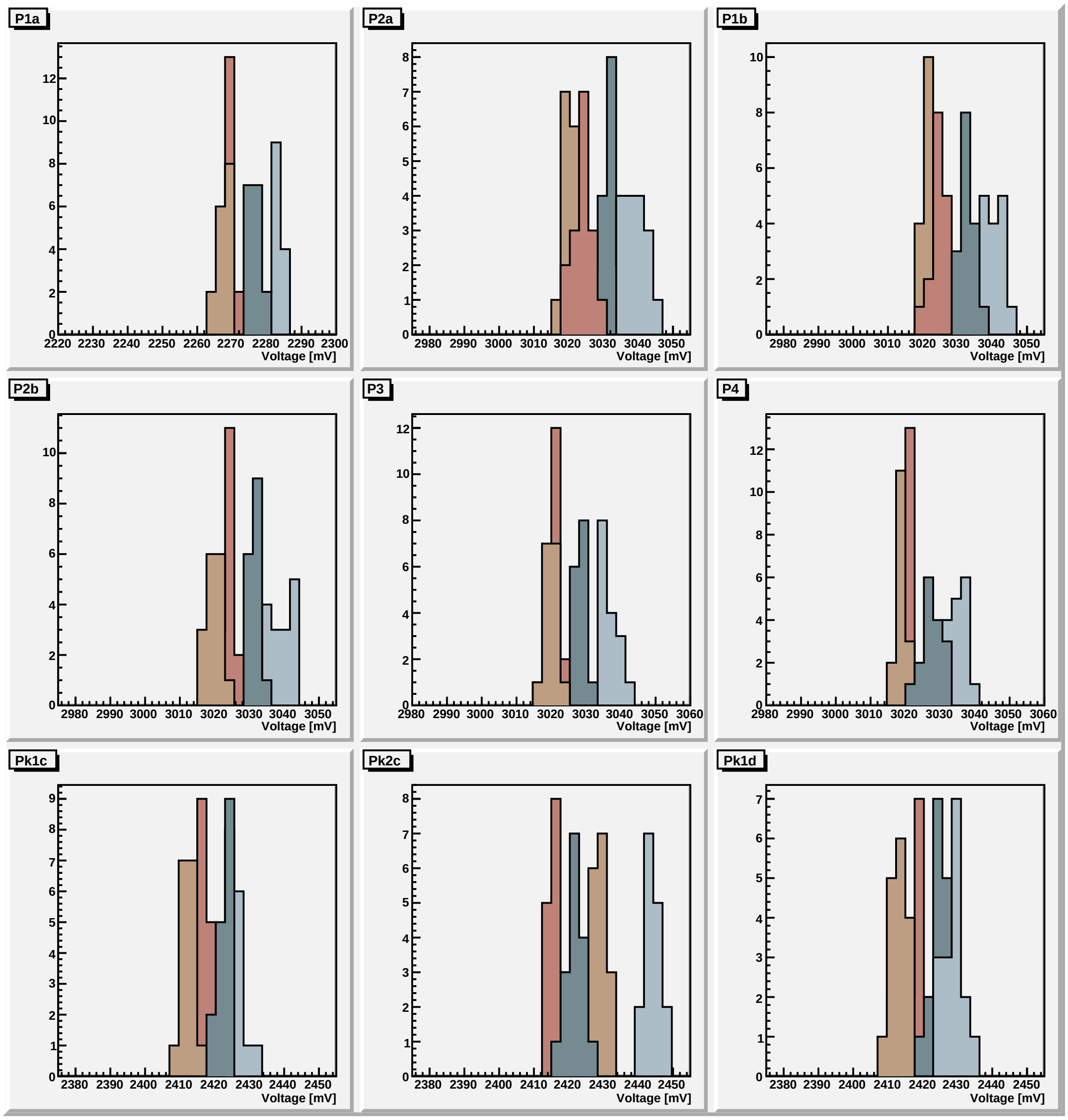

Figure 8: *Response of the pressure sensors in the ESS test before the vibration to an applied voltage of 3 V for GP50 pressure sensors (P1a to P4) and 3 V and 600 mV to the Kulite sensors (Pk1c to Pk2c). Light red: A-channel, +55 °C; Light blue: A-channel, -25 °C; Dark red: B-channel, +55 °C; Dark blue: B-channel, -25 °C.*

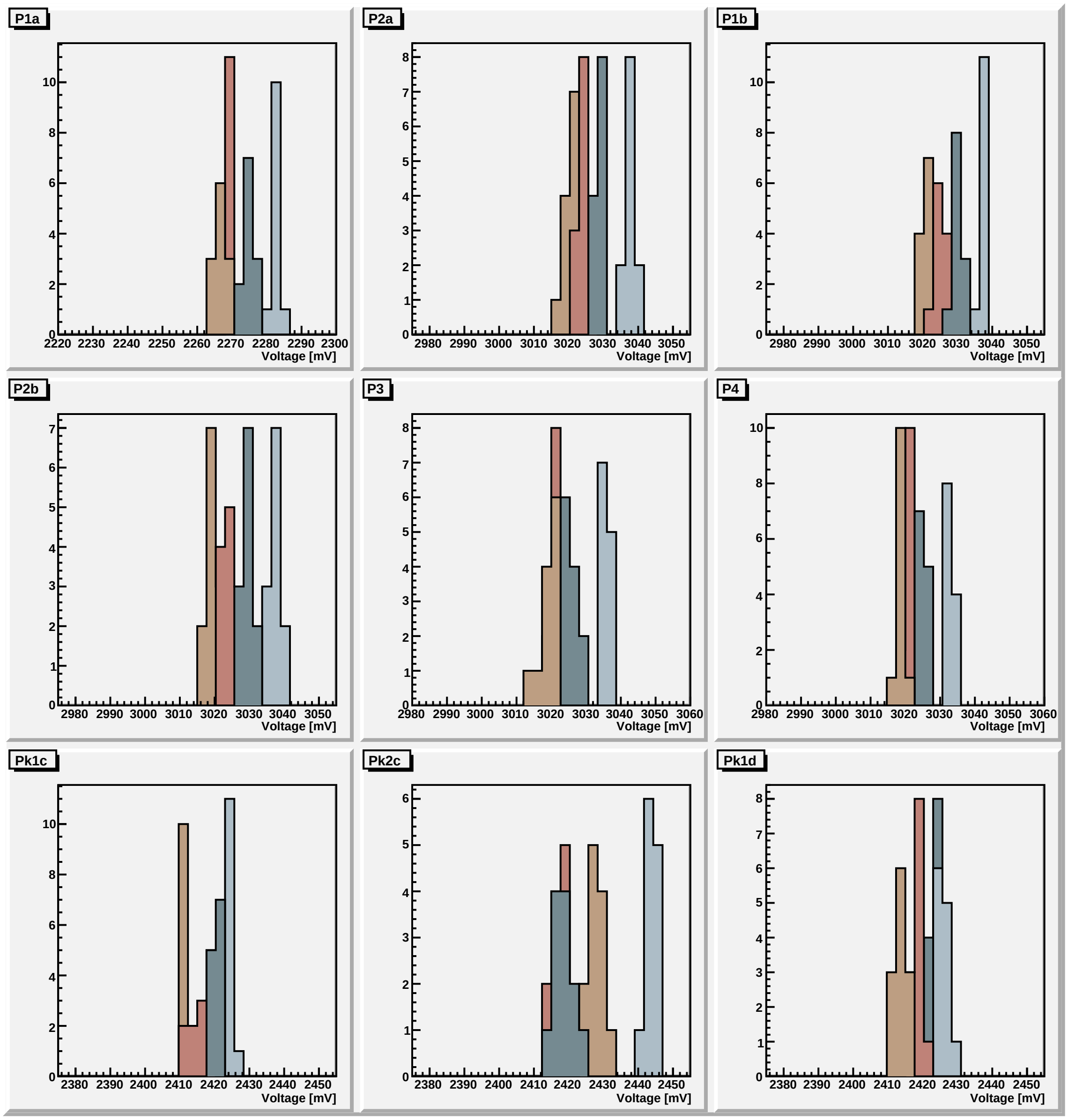

Figure 9: *Response of the pressure sensors in the ESS test after the vibration to an applied voltage of 3 V for GP50 pressure sensors (P1a to P4) and 3 V and 600 mV to the Kulite sensors (Pk1c to Pk2c). Light red: A-channel, +55 °C; Light blue: A-channel, -25 °C; Dark red: B-channel, +55 °C; Dark blue: B-channel, -25 °C.*

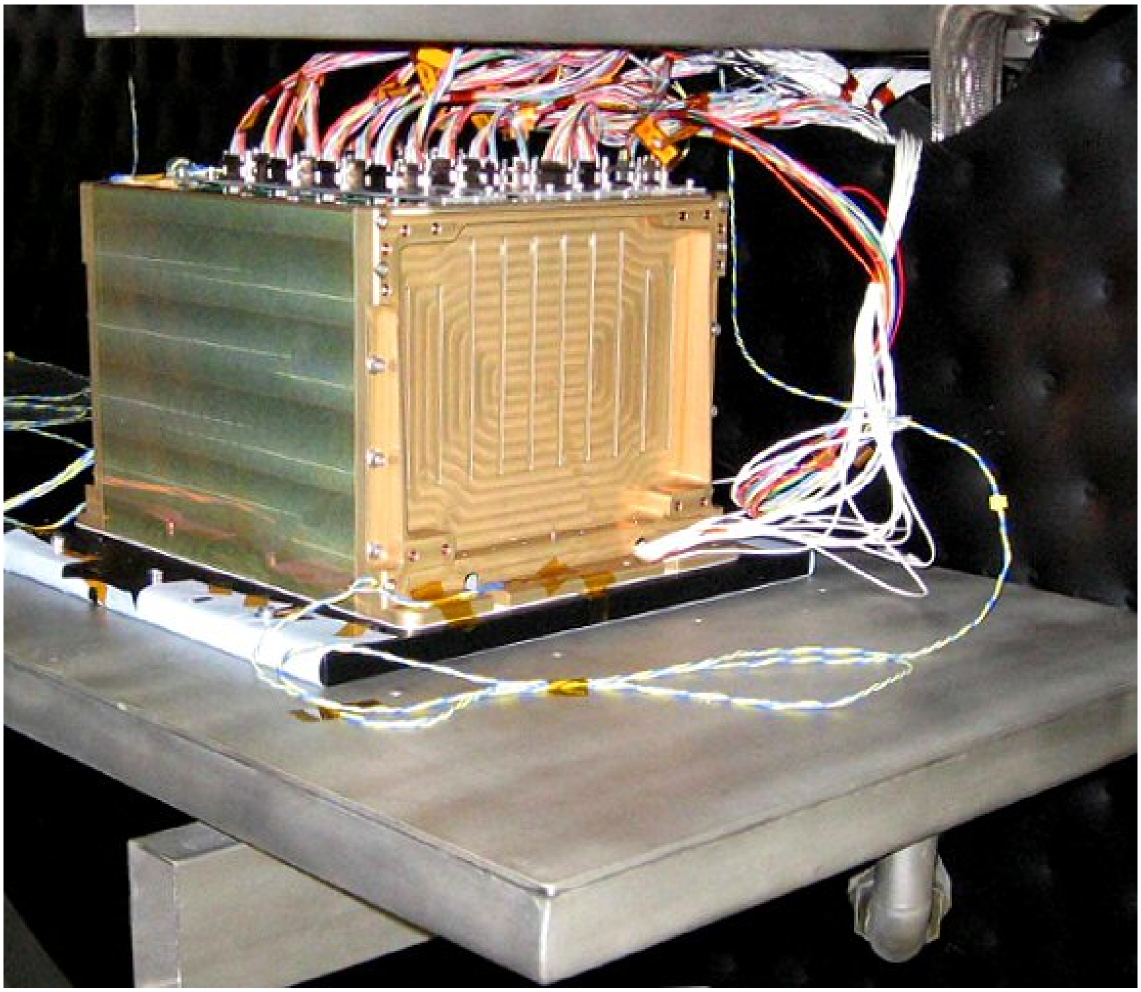

Figure 10: *The UG electronics in the thermo-vacuum chamber.*

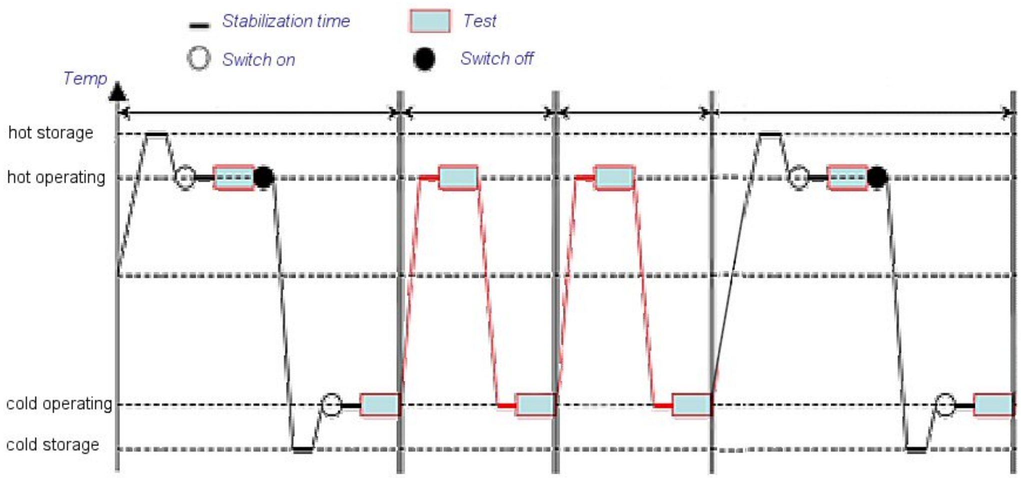

Figure 11: *Temperature profile to be applied in UG electronics TV test.*

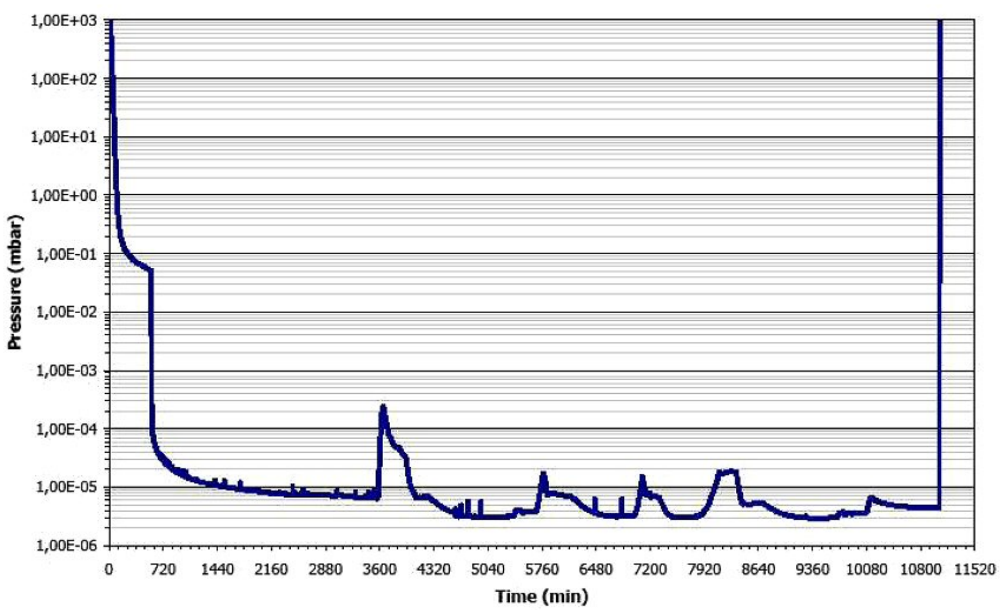

Figure 12: *Measured pressure profile in UG electronics TV test.*

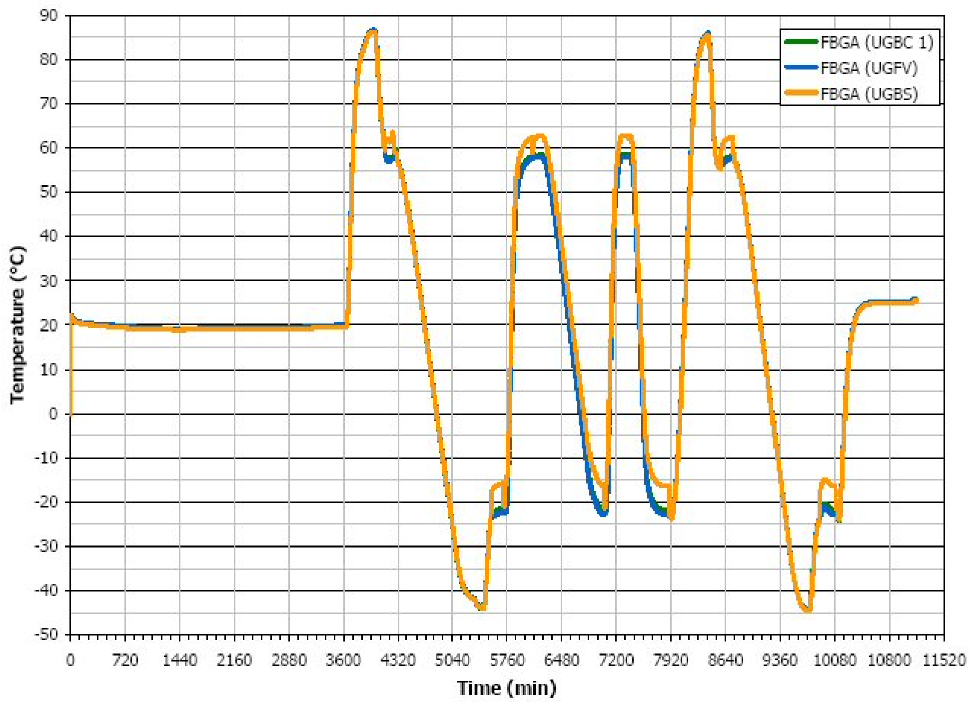

Figure 13: *Measured temperature profile in UG electronics TV test.*

The test included:

- conducted energy emission in the range 30 Hz ÷ 15 kHz (CE01) and 15 kHz ÷ 50 MHz (CE03);
- mode switching transient envelope (CE07);
- radiated energy emission in the range 14kHz ÷ 15.5 GHz (RE02);
- electromagnetic energy injection in the range 30 Hz ÷ 50 kHz (CS01) and 50 kHz ÷ 50 MHz (CS02);
- conducted pulse susceptibility with a 10 μs ÷ 150 ns source (CS06);
- radiated pulse susceptibility with a 10 μs ÷ 150 ns source (RS02);
- radiated electric field susceptibility in the range 14kHz ÷ 15.5 GHz (RS03).

During the conducted emission (CE03) test, while operating the Marotta valves, the specified emission limit was exceeded by about 3 db at a frequency of 15 kHz. The anomaly was cured inserting a 450 μF capacitor on the backplane at the 29 V line fed by the UGPD. Figure 15 shows the spectrum of the conducted energy

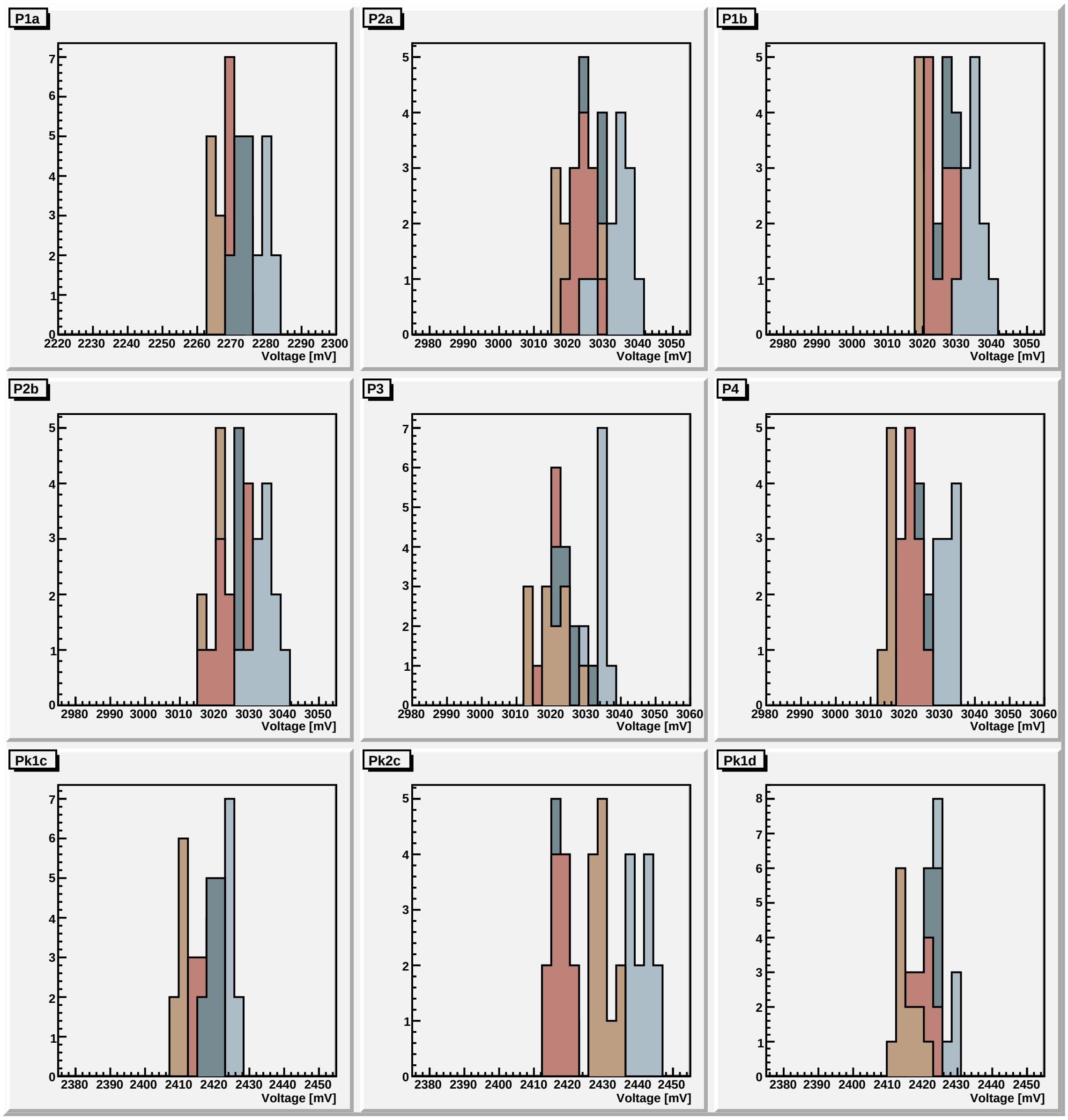

Figure 14: *Response of the pressure sensors in the TVT to an applied voltage of 3 V for GP50 pressure sensors (P1a to P4) and 3 V and 600 mV to the Kulite sensors (Pk1c to Pk2c). Light red: A-channel, +55 °C; Light blue: A-channel, -25 °C; Dark red: B-channel, +55 °C; Dark blue: B-channel, -25 °C.*

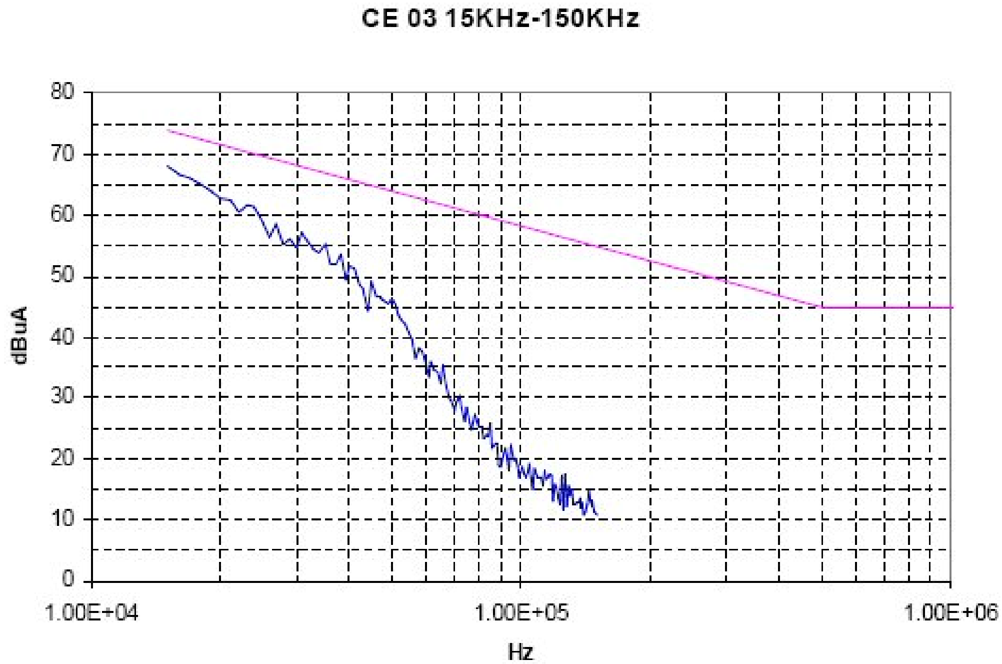

Figure 15: *Spectrum of the conducted energy emission (blue) of the UG electronics in the range 15 kHz ÷ 150 kHz, after the insertion of a 500 μF capacitor on the 29 V line from the UGPD to the backplane. The emission is well below the limit (red) in the whole range.*

emission of the UG electronics in the range 15 kHz ÷ 150 kHz, after the modification. The emission is well below the limit in the whole range.

During the radiated susceptibility (RS03) test, at an applied field of 60 V/m at 240 MHz, the LeCroy communication between the UGSCM and the UGPD was lost, while the communication between UGSCM and UG crate showed no anomalous behaviour. The problem was solved with the elimination of a ground loop on the LeCroy bus at the UGPD, and by shielding the 5.6 V, the 12.5 V and 29 V power cables connecting the UGPD to the UG crate.

No other anomaly appeared. After the modifications described above, all the parameters were below the expected limits.

3 Conclusions

In the period february–march 2008, the QM2 version of the UG electronics was space-qualified, undergoing environmental stress test consisting in thermal stress and vibration (ESS), thermo-vacuum test (TVT) and electromagnetic compatibility test (EMI). In ESS and TVT external power supplies distributed the nominal tensions to the UG electronics, while in the EMI test the UGPD crate was used.

The UG electronics fulfilled all the requirements specified in the experiment official guidelines, also showing full functionality at every stage of the space qualification test.

References

[1] http://ams.cern.ch/AMS/

[2] http://ams.cern.ch/AMS/electronics/SubD/qa/

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