PLATFORM FOR ACQUISITION OF ACCELERATION DATA II – PAANDA II: PRELIMINARY CONCEPTS

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Abstract. *Characterization of the acceleration environment provided by a microgravity platform during sub-orbital flight is essential to the experiments carried aboard. The knowledge of the acceleration profile is important to validate the processes involved on those experiments. It also permits the characterization of the vehicle performance and its mechanisms during flight. This article presents and discusses the concepts involved in the development of Platform for Acquisition of Acceleration Data II (PAANDA II), which will be carried by the Microg1 microgravity platform and boosted by a VSB30 sounding rocket. This instrument was designed to characterize accelerations during all flight stages of the microgravity platform, including launch, microgravity and reentry. The instrument was designed with two operational scales allowing acquisition of acceleration values above 18 g downto 1 µg. At the low acceleration scale the system can reach resolution bellow 1 µg. The flight has a high temperature variation characteristic, which restricts the choice of components that can be used at the instrument's analog-to-digital conversion system. To reach the desired thermal characteristics some components have to be temperature monitored for later digital compensation. As any aerospace system, the instrument is subject to failure. One way to assure the system's proper operation is to add physical redundancy and failure detection. The PAANDA II was designed to operate with four pendular accelerometers mounted over a tetrahedrically shaped frame. With this configuration as many as four tridimensional orthogonal acceleration information can be calculated, which assures the system correct operation even if one of the sensors fails.*

Keywords: *PAANDA II, microgravity, physical redundancy*

1. INTRODUCTION

One possible, but not viable, method to expose experiments to an acceleration-free ambient is to carry then to region in space far enough from any celestial body, so the gravitational attraction experienced by the experiments is considered null. At earth vicinity, the only way to simulate an ambient free of the gravitational field is to put a body in free fall. Essentially, a falling body with no reaction forces to gravity action on it, such as the atmospheric drag, experiences no thrust and the acceleration "felt" by the body is null. One example is a satellite in earth's orbit. The centripetal force generated by the satellite velocity cancels the gravity attraction force and this is similar to the condition where the satellite is in an infinite free fall state.

A microgravity environment is defined as an ambient that accelerations due to reaction forces, such as thrust and centripetal, is close to zero. There are several methods to produce a microgravity ambient. The most common are a sub-orbital parabolic flight using a rocket launched microgravity platform, an orbiting vehicle, such as a specifically designed satellite or the international space station, a parabolic flight using an airplane and a drop tower. These techniques differ by the microgravity level reached, the time in which the microgravity ambient can be maintained, their complexity, availability and cost. They are suitable depending on the application needs. An orbiting vehicle can be used to generate a microgravity ambient that can last for years but with a very limited availability, high complexity and high cost. A drop tower can generate an ambient with acceleration levels better than 10^{-6} g, which is compatible with an orbiting vehicle, but limited to seconds of duration. Therefore, its complexity, availability and cost are much better than the previous one. Experiments can be repeated within hours of preparation delay, making it suitable for testing and demonstrating the feasibility of experiments that will undergo other complex and more expensive microgravity methods.

The rocket launched microgravity platforms can produce a microgravity environment at moderate cost and complexity. From simple sounding rockets to multi-stage and guided rockets can be used to propel such platforms that will perform a parabolic sub-orbital flight. At the upper portion of its trajectory, in space, the platform will be in free-fall. During this, the microgravity platform will rotation stabilize to null the centripetal forces acting on it, so the residual acceleration felt by the platform will be caused by aerodynamic drag, which will produce a microgravity ambient around 10^{-6} g. This will last until the falling platform reaches the upper portion of the atmosphere, where a reaction force due to the rising drag, the thrust, starts to build up, also rising the acceleration "felt" by the platform.

These platforms can produce microgravity environments that could last several minutes, depending on the altitude reached after launch.

A microgravity environment is an important tool to study certain natural phenomena that preferentially occur or not in the absence of gravity. Gravity is one of a number of experimental parameters which effect can be isolated to help understand certain basic mechanisms blurred by it. The objective is to understand fundamental mechanisms that will help improve processes and add knowledge to help elucidate more complex phenomena or problem that occur on earth. Many areas benefit from microgravity, such as medical, biological, aerospace, physics, chemistry, materials, electronic instrumentation and others. A great number of studies investigating the effects of microgravity have been reported. Some examples include studies of bone demineralization, immune responsiveness for space travel, DNA repair, angiogenesis, root growth, metal solidification, crystal growth, multiphase flow, radiation effects in humans, imaging techniques, electronic control, etc.

The Brazilian Space Agency (AEB) regularly provides infrastructure and financial support for rocket launched microgravity flights to selected experiments form Brazilian and foreign universities and research centers. The flights occur at the two launching bases available in Brazilian territory: The Alcântara Launching Center (CLA) and the Barreira do Inferno Launching Center (CLBI). The vehicle used for microgravity missions is the VSB30, a dual stage solid propellant sounding rocket. The vehicle carries a Microgravity platform called Microg1, which is developed by the German Aerospace Center (DLR) and is based on the Texus payload. The missions are accomplished as a result of cooperation between the Institute of Aeronautics and Space (IAE) from Brazil and DLR.

The Platform for Acquisition of Acceleration Data (PAANDA) project is an effort to develop an instrument capable to measure the acceleration ambient of a rocket launched microgravity platform during all flight phases, with emphasis on the microgravity period. The characterization of the acceleration ambient, in which scientific experiments are exposed, is important for the analysis of results since their data can be correlated with the observed accelerations. Also the vehicle's and microgravity platform's mechanisms can be monitored through the analysis of the acceleration data, as a possible way to ensure their proper operation. A first version of this instrument, the PAANDA I, flew at the Cumã II mission. The PAANDA II is a second version and it is under development. Its design is based on the PAANDA I with added redundancy and failure detection. It is expected that improvements in its acquisition system and better calibration procedures enhance its accuracy and resolution. PAANDA II will fly in a future microgravity mission yet to be scheduled.

2. PAANDA I

The PAANDA I was the first version of an instrument built to measure the accelerations of a rocket launched microgravity mission with emphasis on measuring the residual accelerations on the microgravity period. The PAANDA I was integrated with nine other scientific experiments and launched in July 19 2007 at CLA, Alcântara, Brazil. Due to recovery problems the instrument was lost at the Brazilian north shore. Fortunately, most of its data was recovered through telemetry.

Basically, the instrument consists of three orthogonally mounted accelerometers, an acquisition system, a processing and storage system and a communication system. Sensors and other system electronics are mounted in a rigid aluminum support frame that ensures the sensors' orthogonally and also serve as a calibration tool to measure their turn-on offsets. As a basic design criterion, the acquisition scheme employed should be as simple as possible to minimize problems with temperature drift and noise. Figure 1 illustrates the Cumã II mission resultant acceleration calculated from the instrument data.

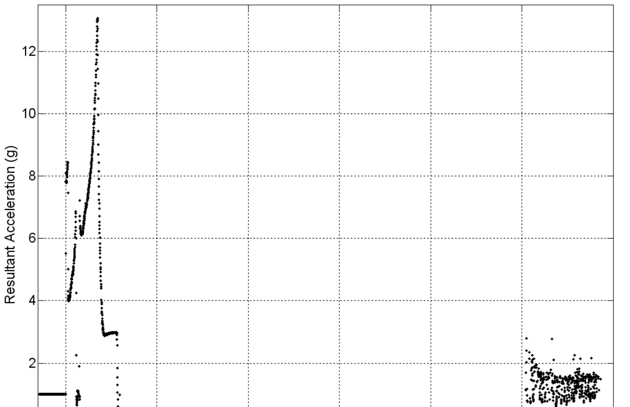

Figure 1. Resultant acceleration for the Cumã II mission (Tosin *et al.*, 2010)

The acquisition system, basically composed by a resistor and an integrating type analog-to-digital converter, was employed to read acceleration signals from closed-loop pendular force-rebalance accelerometers reaching resolution of 1.5 µg (Tosin *et al.*, 2010).

3. PAANDA II

PAANDA II, the second version of the inertial instrumentation experiment PAANDA (Tosin *et al.*, 2010), seeks to measure residual accelerations of a microgravity platform. However, we propose that the new experiment include physical redundancy in acceleration information and telemetry data transmission, greater autonomy, and centralized processing and instrument control.

3.1. Experiment description

The experiment seeks to measure tridimensional accelerations during the complete flight of a microgravity platform launched by a VSB-30 sounding rocket, including launch and reentry. Acceleration monitoring is very important for the remaining scientific experiments aboard the microgravity platform, since certain physical, chemical and biological process are observed only in the absence of forces. Therefore, the results obtained by these experiments can be correlated to perturbations observed by PAANDA II during this period, also known as the microgravity period. To that end, the instrument must be capable of measuring accelerations down to 1 micro-g resolution with an 18 g full scale.

Another characteristic of the experiment is the physical redundancy in the acquisition of acceleration data through the use of four Q-Flex accelerometers, laid on the faces of a tetrahedral frame with support and calibration purposes. The information from these sensors is acquired and managed by a single processor, as well as the information required for scale factor correction and thermal variation of critical components used in A/D conversion of the accelerometer signals.

PAANDA II is subdivided in four blocks: Acceleration Measurement Unit (UMA), Telemetry Coding Unit (UCT), Energy Unit (UE) and Control and Monitoring Unit (UMC), as shown on Fig. 2.

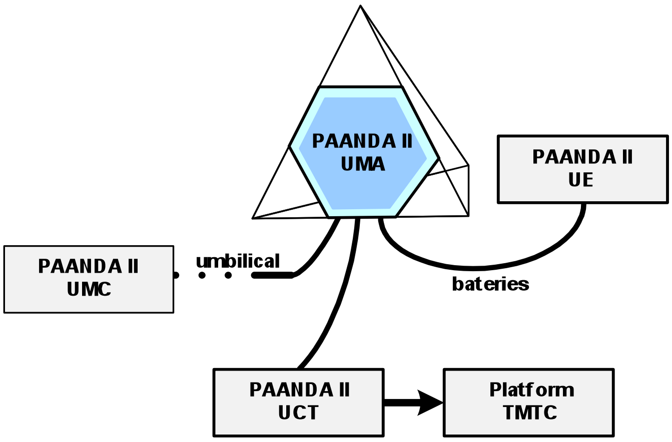

Figure 2. PAANDA II blocks: Acceleration Measurement Unit (UMA), Telemetry Coding Unit (UCT), Energy Unit (UE) and Control and Monitoring Unit (UMC)

3.2. Acceleration Measurement Unit – UMA

The Acceleration Measurement Unit is responsible for A/D conversion and storage of the acceleration and temperature data of four sensors, as well as obtaining the rocket module's internal pressure and the batteries' voltage. These informations are sent to the Telemetry Coding Unit or the Control and Monitoring Unit. The UMA is subdivided in three blocks: Acquisition Circuits, Embedded Central Computer and Support Frame.

3.2.1. Acquisition Circuits

The UMA is composed of four acquisition circuits, called Alpha (A), Beta (B), Gamma (G) and Delta (D), or ABGD for short. Each of these circuits is tasked with acquisition and A/D conversion of acceleration and temperature data from a Honeywell® QA2000-10 sensor, as well as the temperature of critical components involved in this process.

Q-Flex sensors, like the QA2000, are employed in commercial and military inertial systems, and also in space applications such as nutation control, microgravity measurements, among others (Foote and Grindeland, 1992). This kind of sensors uses a proof or seismic mass tied to a hinged pendulum manufactured in a single piece of quartz. Torque coils are mounted next to the pendulum, which can be coupled to the permanent magnetic field created by magnets tied to the sensor frame, allowing for torque generation over the proof mass movement. Surfaces perpendicular to the seismic mass movement create two capacitors with the frame in such a way that, after differential amplification, the amplified signals of the capacitors are proportional to the position of the proof mass inside the sensor, creating a position sensor for this mass (Foote and Grindeland, 1992), (Lawrence, 1998) e (Tritterton and Weston, 2004).

When acceleration is present, the seismic mass suffers a contrary reaction force, shifting it around the hinge. This shift produces a signal in the motion sensor that is amplified so as to produce a contrary torque in the seismic block using the coils. This closed-loop control system is designed to cancel out the movement of the pendulum, keeping it fixed in a central plane. Thus, an acceleration applied perpendicularly to the seismic mass' plane is proportional to the current necessary to cancel out the effects of acceleration on the proof mass.

The acceleration and temperature signals of the QA2000 sensor are supplied as current, and using resistors to sample these signals as voltage, it is possible to control the operating full scale -- the sensor's scale factor is given in mA/g. Thus, the resistors must have low resistance variation with temperature so that thermal errors aren't inserted in the accelerometer's signal. For the same reason, the A/D converter employed must have low offset variability and low temperature bias.

To meet these requirements, Vishay® VH102Z resistors, with 0.2 ppm/°C temperature coefficient and 0.005% tolerance are used to set the system's full scale to ±18 g and ±1.05 g. Scale change is accomplished through a biestable relay, controlled by the CCE, which connects a second resistor to the QA2000's acceleration signal. The voltage on these resistors is sampled and A/D converted by a Thaler Corporation® ADC180M A/D converter, with 26 bits maximum resolution, and maximum variations of 1 ppm/°C in scale factor and 0.2 ppm/°C in offset. Thus, in theory, using a 7320 Ω resistor to set the full scale at 1.05 g, and sampling the acceleration signal at 10 Hz and 21 bits with a 10 V full scale, the resolution of the instrument is 10 µV or 1 µg.

The accelerometer's temperature signal is A/D converted using the same methodology, however a 16-bit A/D converter with serial interface is employed, and its power is supplied by a Cirrus Logic® VRE305 voltage reference, with 0.6 ppm/°C thermal coefficient. The temperature of the acquisition circuit's critical components is monitoring using a network of 27 digital sensors, so that data can be corrected due to the thermal variation in each component.

3.2.2. Embedded central computer

Besides the data acquisition circuits, the UMA is composed of a monitoring, storage and communication circuit called the Embedded Central Computer (CCE). This circuit is tasked with requesting, reading and storing data from the various A/D converts and temperature sensors, as well as interfacing, packing and transmitting data, and regulating the instrument's voltages. A block diagram of CCE is shown in Fig. 3.

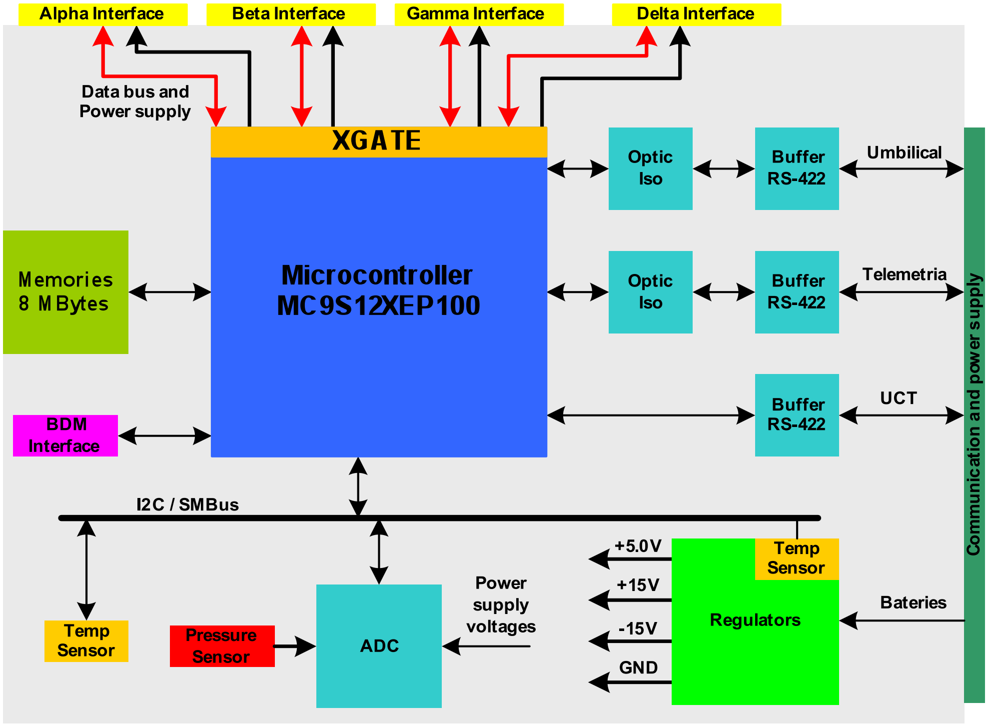

Figure 3 – CCE

Full system management of PAANDA II is performed by the dual core Freescale® MC9S12XEP100 microcontroller. The CPU12X main core is responsible for data processing, communications over the telemetry and umbilical cable, as well as communication with the A/D converters and I^2C and SMBus serial buses, voltage monitoring and data storage in non-volatile memory. The XGATE co-processor manages and reads the acceleration and temperature data from the four acquisition circuits, Alpha, Beta, Gamma and Delta, and controls the sampling periods.

The voltages from each of the acquisition circuits are individually regulated so that, in case of a regulator failure, a single circuit is affected and the rest of the system keeps working. Also, separate regulators are employed for digital and analog circuits, reducing the effect of noise produced in digital components on the performance of analog components. The same care is taken in communication interfaces, isolating the data transmission lines and supply voltages of these circuits, reducing the effect of noise coming from the microgravity platform and other experiments onboard.

The UMA is connected to the UE, UCT and rocket cabling through a micro-DB37 connector placed in the CCE. This ensures that the voltages supplied from the batteries, platform and umbilical cable, as well as the communication interfaces, go through this single cable, also employed during the calibration process. The connection of the CCE with Delta, and later with Alpha, Beta and Gamma, is done by stacking these boards using PC/104 standard connectors.

3.2.3. Support frame

The support frame of the UMA is a single piece made from aeronautic aluminum, in the shape of a truncated regular tetrahedron, truncated for supporting the sensors and printed circuit boards, and instrument calibration. This block contains surfaces with precise orientation, lapidated finish and the use of saliencies in three points of each face for the calibration process, and insertions and drillings required to fasten the sensors and the boards that make up the UMA in its faces.

Since the accelerometers are laid out in the center of each hexagonal face of the truncated tetrahedron, and the boards containing acquisition circuits are mounted over them, the symmetry of this polyhedron allows for the development of a single acquisition board that can be used for all four faces of the instrument. Since the CCE is tacked over Delta, the board contain the management circuit is of the same shape and size as the acquisition boards -- a regular hexagon.

The constructive model of the idealized system doesn't employ connection cables, but a connection structure. This structure is integrated to the block itself, so as to interconnect the acquisition modules when these are fastened to the support structure. This is possible due to the use of insertions on the block, and a connector arrangement capable of interconnection the faces of the block. Fig. 4 illustrates the design of the polyhedron.

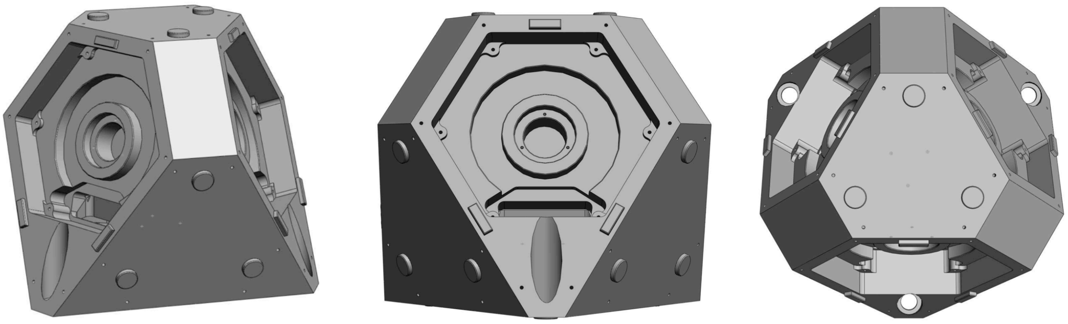

Figure 4 – Case of accelerometers

3.3. Telemetry Coding Unit – UCT

The Telemetry Coding Unit transmits data to the microgravity platform, which is later sent via telemetry through two communication channels. The first channel employs a simple coding scheme with no protection against channel transmission errors, but with the benefit of easily implemented coding and decoding algorithm, reducing the probability of unforeseen issues due to implementation errors. The second channel is a telecommunications experiment using error-correction codes.

In what follows, a *packet* is a packet of data received by the UCT from the CCE, and a *codeword* is a packet sent from the UCT to the telemetry system and received by the ground bases. Each packet is considered as a vector in a binary linear space. The XOR operation is used to construct a codeword from linear combinations of packets, according to a probability distribution that chooses which blocks are included. Now we turn to the issue of decoding. If the packets used to construct a codeword are known, then one can construct a binary matrix as follows: the i-th row corresponds to the i-th codeword, and the j-th column corresponds to the j-th packet. The bit in row i, column j will be 0 if the j-th packet hasn't been included in the linear combination that produced the i-th codeword, and 1 if it has been included. A single packet is a linear combination containing only itself, and hence is a valid codeword; in that case, a single bit is set in the row corresponding to that codeword, namely the row that corresponds to that packet. If enough rows (i.e. received codewords) are added to this matrix and it achieves maximal rank, one can apply Gaussian elimination to the matrix, and the result is a recipe for constructing linear combinations of codewords so as to obtain the original packets (Gazzoni Filho *et al.*, 2010).

The UCT is composed basically of an ST Microelectronics STM32 processor, based on an ARM Cortex-M3 core, NAND flash memory, voltage regulators, and driver and communications isolator. The processor handles the tasks of receiving data from the CCE, storing it in flash memory, coding and transmitting to the microgravity platform. The hardware is housed in an aluminum box and fastened to the rocket's plate, along with the battery box and the UMA.

3.4. Energy Unit – UE

The Energy Unit's purpose is to supply different voltage levels uninterruptedly to the UMA for a time period longer than 24h, since this is the estimated duration of the sounding rocket launch mission and the possibility of access to the instrument. The UE is highly important for PAANDA II, since some Q-Flex sensor parameters can only be determined by the calibration process, forcing the UMA to stay on after the calibration process.

The UE is composed of three Ni-MH battery packs from Saft Batteries® and a circuit for acquiring and monitoring voltage and temperature signals from each of these packs. All of them are housed in a box that contains three DB9 connectors used for instrument maintenance, replacing and recharging the UE.

In the UMA design, linear voltage regulators are employed, and considering the limits of input voltage in the regulators, as well as the voltage range between charged and discharged cells, an arrangement was decided employing 9 series cells for the +V/2 pack and 17 series cells for the +V and -V packs. The voltages of these packs are regulated to +5 V, +15 V and -15 V, respectively. After estimating the power consumption of the components supplied by each of these voltage ranges, the chosen battery models were VHF16000XP, with 16 Ah capacity, for the +V/2 pack, and VHD9500XP, with 9.5 Ah capacity, for the remaining packs.

The battery box is tasked with housing, protecting and isolating the batteries, voltage monitoring system and its connections. The box is made of aluminum and has an "L" shape, inside the available space in the plate taken up by the UMA and UCT as well. In one of the side faces of the battery box, there are 3 holes for the DB9 connectors responsible for supplying power to the UMA and recharging the cells of the UE, as shown in Fig. 5.

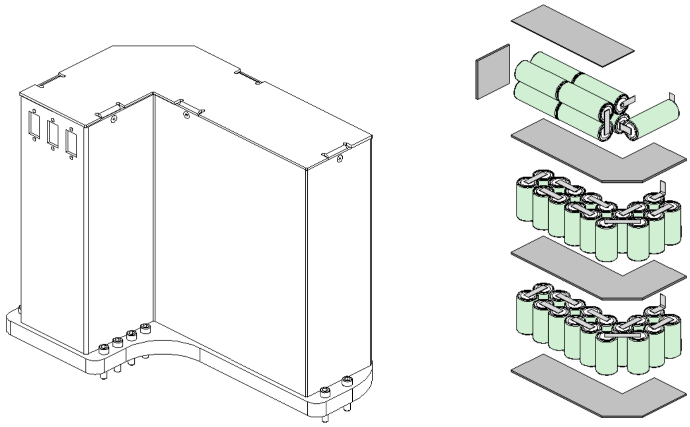

Figure 5: Box and cell arrangement of the UE

Inside the UE, the previously isolated packs are additionally protected and electrically isolated by rubber plates between the packs and in the upper and lower faces of the battery box, as shown in Fig. 5. The remaining internal space of the battery box is filled with silicon for electric/electronic device protection, allowing for some shock absorption from internal or external sources, as well as thermo-electrical isolation.

The connections between the UE and UMA are done through three DB9 connectors, two female and one male. The female connectors are used to replace a discharged UE by a charged one, ensuring the UMA stays on, while the male connector is used to recharge the battery packs. Diodes are employed to prevent a large flow of current to the discharged pack during the pack swap procedure, or a reverse current flow during battery charging.

The UE also contains an internal monitoring circuit for voltage levels and temperatures of the three packs. This monitoring is performed by an A/D converter with serial interface, in addition to a signal conditioning circuit for the sample voltage levels and digital temperature sensors. These data are used in the battery charging and maintenance process, following the characteristic curves for Ni-MH cells, so as to prevent overcharge and overheating.

3.5. Monitoring and Control Unit – UMC

The Monitoring and Control Unit is a computer connected to the umbilical cable through an RS-422 interface available to PAANDA II. This unit also supplies power to the optical isolation of this interface. The UMC performs, through a software in the Labview® environment via user commands, the monitoring and control of the UMA. It supplies, through a graphical interface, the parameters of PAANDA II such as acceleration, temperatures, battery voltage and currents, among others.

Another function of the UMC is to control the Energy Unit's charge and maintenance processes through symmetrical power supplies controlled over a GPIB bus. This process is highly important given that the experiment must not be turned off after calibration is performance. Through an RS-232 interface, the UMC also sends and receives data and commands through the telemetry, monitors and stores in real-time the received data, and is also capable of sending telecommands to the experience in mid-flight.

This unit is designed to be used either in a laboratory setting or in the PPCU (where the useful cargo is prepared), and later in the control bunker. The unit placed in the control bunker is controlled by the person responsible for supervising and executing the entire procedures prior to launch, when the instrument is inside the rocket and in the launch ramp.

We must stress that the UMC must not depend exclusively on grid power, besides being mobile so it can be transported to the launch ramp. This is achieved by a system containing a portable computer supplied by an UPS and battery bank with the required autonomy for the system.

4. Processing management

The main changes in the PAANDA II architecture, compared to its predecessor, were the use of a single dual core processing unit, as a replacement for the four processing units dedicated to data acquisition and experiment management, and the addition of a fourth unit of acceleration data acquisition. These changes enable the possibility of obtaining redundancy in the acceleration measurement, and the temporal decoupling of acquisitions and data processing.

In PAANDA I, data acquisition and processing were necessarily performed sequentially due to the lack of a temporary storage buffer between these two steps. Hence, the tasks of data acquisition from the acquisition modules, its processing and other instrument management tasks were temporally dependent. This limited task execution time to the maximum time between any two data acquisitions (Tosin *et al*., 2010).

Our new proposal is to employ the CPU12X main core to perform data processing, telemetry and telecommand, data storage in memory and other system management tasks. The XGATE coprocessor manages acceleration and temperature data acquisition from the four modules (Alpha, Beta, Gamma and Delta) and controls the sampling period.

Data acquired by the coprocessor is transferred to the main core in an asynchronous fashion using a circular buffer, which allows the two cores to perform their tasks independently. The data flow control in a circular buffer is a typical instance of the "producer-consumer" problem (Downey, 2007). The block diagram of Fig. 6 shows the design of the acquisition and processing structure.

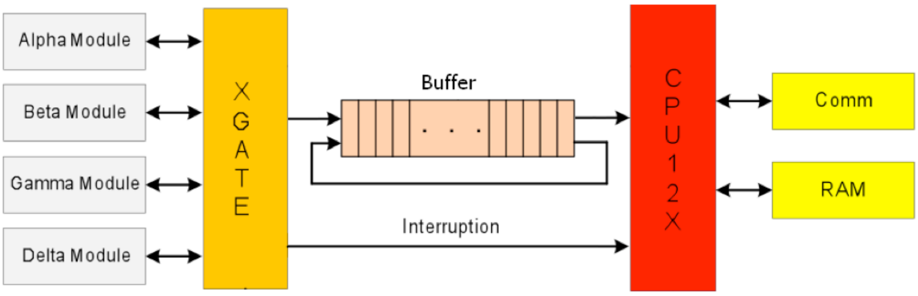

Figure 6 – Data structure with circular buffer

5. Calibration

The goal of PAANDA II is to measure residual accelerations in a microgravity platform with precision and accuracy close to 1 μg, however some error sources found in the Q-Flex accelerometers are much larger than the expected instrument characteristics. To correct the data, we must determine the parameters of the model of Eq. (1) by performing a multipoint static test (IEEE, 1972).

$$A = \frac{E}{K_1} = K_0 + a_i + K_2 a_i^2 + K_3 a_i^3 + d_o a_p + K_{ip} a_i a_p - d_p a_o + K_{io} a_i a_o \qquad (1)$$

The definitions and units of the parameters in Eq. (1) are: A is acceleration (g), E is the sensor output (mA), K_1 is the scale factor (mA/g), K_0 is bias (g), a_i is acceleration in the input axis (g), a_o is acceleration in the output axis (g), a_p is acceleration in the pendular axis (g), K_2 is the quadratic non-linearity factor (g/g^2), K_3 is the cubic non-linearity factor (g/g^3), d_o is the misalignment between the input and output axis, d_p is the misalignment between the input and pendular axis, K_{ip} e K_{io} are the cross-couplings (g/g^2).

Since PAANDA II is used in an environment with very small values of accelerations, some terms of Eq. (1) may be disregarded, resulting in Eq. (2) (Tosin *et al.* 2010).

$$a_i = \frac{E}{K_1} - K_0 \qquad (2)$$

For the required parameters, the static multipoint test, also known as tumble test, consists in positioning the sensor's input axis at angles of 0°, 90°, 180° and 270° with regards to the gravity vector. Then, the acceleration will be ±1 g when the input axis is positioned vertically, and nearly no gravitational component will be observed when it is positioned horizontally (Lawrence, 1998). It is then possible to calculate the sensor's scale factor and bias using Eq. (3) and Eq. (4), where E_0, E_{90}, E_{180} and E_{270} are the sensor outputs when the rotation between the output and pendular axes is 0°, 90°, 180° and 270° with regards to a vertical orientation.

$$K_1 = \frac{1}{2}\left(E_{90} - E_{270}\right) \qquad (3)$$

$$K_0 = \frac{1}{2}\frac{\left(E_0 - E_{180}\right)}{K_1} \qquad (4)$$

However, the acquisition circuit has other components that can insert errors in the acquired data due to thermal variations present during the mission, such as A/D converters, resistors and voltage references. To minimize this problem, the temperature of critical components is applied to a static model created through tests, allowing for an improvement in the system's accuracy (Souza, 2008).

6. Physical Redundancy

One of the largest improvements in PAANDA II is the redundancy enabled by the set of sensors used, increasing the reliability of instrument measurements and including the capability of detecting a possible failure. For a tridimensional system, a minimum of four sensors is required (Oliveira *et al.*, 2010), and (Sukkarieh *et al.*, 2000.

According to Pejsa (1974), an optimal configuration for any number of sensors with the same statistical uncertainty, and equally spaced in a cone, is given by the angle α. If one of the sensors is positioned along the cone axis, and the rest of them equally spaced around it, as in the PAANDA II support frame, the angle α is calculated by Eq. (5), where n is the number of sensors.

$$\alpha = \cos^{-1}\sqrt{\frac{n-3}{3n-3}} \qquad (5)$$

This angle, α = 70.529° for the case of four sensors, is used to determine the matrix of direction cosines ***H***, given by Eq. (6) (Shim and Yang, 2010), which relates sensor data with the main axes system. To simplify the analysis of the ***H*** matrix, we consider that one of the sensors is aligned to the z-axis and another sensor is aligned to the xz plane.

$$H = \begin{bmatrix} \frac{2\sqrt{2}}{3} & 0 & \frac{1}{3} \\ -\frac{\sqrt{2}}{3} & \frac{\sqrt{6}}{3} & \frac{1}{3} \\ -\frac{\sqrt{2}}{3} & -\frac{\sqrt{6}}{3} & \frac{1}{3} \\ 0 & 0 & 1 \end{bmatrix} \qquad (6)$$

The accelerations are calculated using the equation $\boldsymbol{A} = \boldsymbol{H}^* \boldsymbol{S}$, where $\boldsymbol{A} = [a_x \;\; a_y \;\; a_z]^T$ is the matrix with acceleration values in the orthogonal axes x, y e z, $\boldsymbol{S} = [s_1 \;\; s_2 \;\; s_3 \;\; s_4]^T$ are the data acquired by PAANDA II's four accelerometers and $\boldsymbol{H}^* = (\boldsymbol{H}^T \boldsymbol{H})^{-1} \boldsymbol{H}^T$ is the pseudo-inverse of the direction cosine matrix $\boldsymbol{H}$.

Even after compensating accelerometer data and correcting acquisition circuit data, the accelerations measured by PAANDA II may be invalid due to system faults. Such an error may originate in hardware or software, such as a sensor failure or processing errors. The number of errors that a system can support indicates its robustness, and it is expected for such a system to be intrinsically complex and possess numerous inscrutable and exotic characteristics (Lala and Harper, 1994).

The PAANDA II is not intended to detect errors or failures in real time, mainly by having limited amount of processing and being a scientific experiment. Therefore, it is interesting that the instrument acquires the largest possible number of information during the sub-orbital flight of microgravity platform. Subsequently, the data can be analyzed for determine the occurrence of system failures and their origin.

7. CONCLUSIONS

In this paper we present the preliminary design of an instrument capable of measuring residual accelerations of a microgravity platform. The experiment, called PAANDA II, is designed to comply with the technical and logistical requirements of testing, calibration, transport and launch. For these reasons, the design is not only composed of acceleration sensors and data acquisition and management circuits, but also systems that ensure the necessary support for the instrument's success.

The instrument is composed of four pendular accelerometers laid out in a regular tetrahedral frame, it has a resolution of 1 μg and better than 10 μg accuracy after calibration in the 1.05 g scale. The physical redundancy added to PAANDA II allows for a redundant measurement channel with single-fault tolerance, consequently increasing the reliability of the acquired data.

The remaining systems are designed for the experiment's use during the launch mission of sounding rocket in the Alcântara Launching Center (CLA), including restrictions on the charge time of batteries and access to the instrument. The launch of the PAANDA I experiment demonstrated the need for increased autonomy of the instrument, as well as preventing the corruption of data transmitted through telemetry. These problems were solved with the adoption of battery cells with higher charge capacity and the use of two coded channels for data transmission via telemetry, respectively.

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Brazilian Space Agency (AEB), National Council for Scientific and Technological Development (CNPq), National Institute of Space Research (INPE), Aeronautics and Space Institute (IAE) and State University of Londrina (UEL).

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