

Hungarian Participation in JUICE Project of European Space Agency

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Abstract: JUICE - JUPiter ICy moons Explorer - is the first large-class mission of ESA (European Space Agency). Planned for launch in Sept 2022 and arrival at Jupiter in 2029, it will spend at least three years making detailed observations of the giant gaseous planet Jupiter and three of its largest moons, Ganymede, Callisto and Europa. Space technical team developed power supply unit for PEP (Particle Environment Package) instrument. PEP and its sensors will examine the plasma environment in the Jovian system. PEP will measure density and fluxes of positive and negative ions, electrons, exospheric neutral gas, thermal plasma and energetic neutral atoms. The nominal onboard voltage is 28 V on the space probe. Space technical team had a job to develop power supply unit DCC (Direct Current Converter) for the sensors of PEP. The job was a great challenge because of the required high reliability and that reliable operation had to be ensured in extreme circumstances. We present in this article the realization of DCC. The DCC required for its tests to develop a special test equipment called EGSE (Electronic Ground Support Equipment). The EGSE was developed by the SGF Ltd. and supports checks of DCC. In this article we present the DCC, the quality insurance methods and the tests carried out by EGSE.

Keywords: JUICE; Icy moons; Jupiter; ESA; DCC; EGSE

1 Overview

The results of this project will be used in the upcoming phases of JUICE mission. The JUICE (JUPiter ICy moon Explorer) is the first large-class mission of ESA.

The icy moons of Jupiter are in the focus of this science mission. It investigates the Jupiter system as an archetype of gas giants and investigates habitability around gas giants. JUICE will be launched in 2023, arrive at Jupiter in 2031, and the end of the mission is foreseen around 2035. JUICE is a European-led mission to the Jovian system. The spacecraft will go on to spend many months orbiting Jupiter and will have orbits around Ganymede, 2 Europa flybys and will have a new Callisto phase. The payload consists of 11 research instruments, e.g., imaging instruments, optical spectrometers, in-situ field and particle detectors, sounders and radio science instruments. One of the 11 instruments is the PEP (Particle Environment Package) containing 6 sensors and 3 DPUs (Digital Processor Unit controlling sensors) located in two groups PEP-Lo and PEP-Hi. The tasks of the Hungarian participants include the following

- designing, manufacturing and testing (including a few technological and a flight test model) an on-board common power supply system (DCC) for PEP-Lo experiment. Our DCC provides power for sensors belonging to PEP-Lo.
- designing and manufacturing EGSE for PEP instrument sensors, (both software and hardware). In this article, we present only the EGSE of DCC unit.

The launch of JUICE is planned in 2023 on board of an Ariane-5 rocket from French Guyane. The start mass of Ariane-5 is 777,000 kg. The launch mass of the payload is 4800 kg containing 3.000 kg propellant for maneuvers in the area of Jupiter. The scientific payload mass is 1,800 kg including solar panels and an antenna for communication with Earth. A significant amount of fuel is needed for the spaceship to be delivered to the target, so weight issues were very important in the development. The team started development in Wigner Research Center for Physics, but in 2021 the team was moved to the Centre for Energy Research.

The main task of onboard power supply unit is the conversion of the onboard 28 V according to the needs of the sensors. There are few references in the literature, mostly application examples from chip manufacturers [1]. What is common between them is that they all use a separate converter for each sensor to fulfill voltage requirements. This provides high precision power supply, but the number of converters per sensor can be 3-5. Our solution generates all required 3-6 different voltages for every sensor with one PWM (Pulse Width Modulation) converter and one transformer with common primary and several secondary windings. It is a component and space-saving solution, thereby reducing the number of chips. This method controls all outputs of a sensor together and reduces weight and component number.

2 Overview of the DCC Unit

The power supply of PEP is ensured by solar cells. The use of solar array power generation in combination with the large distance from the Sun, with a worst-case solar constant of 46 W/m², results in a large area solar arrays, of typically about 60-75 m². The onboard voltage is 28 V for experiments, which is provided by a nominal line of 28 V and a redundant line, which is 28 V as well. The DCC Unit is presented by its blockscheme in Figure 1. It receives both onboard 28 V power by nominal and redundant lines, and the incoming power is transformed to voltages according to the needs of fed units, which are main and redundant DPU and the sensors called JDC, NIM, JNA and JEI. This provides high precision power supply, but the number of converters per sensor can be 3-5. If the nominal line drops, the onboard electronics switches DCC to the redundant power line to ensure the power for PEP-Lo experiment. The power requirements of the sensors were determined for different operation modes with 20% contingency for 6 modes of operation (see Table 1). During team meetings a centralized DC/DC converter configuration was proposed, followed by individual, galvanic isolated DC/DC down converters for each subsystem and sensor (S&Ss).

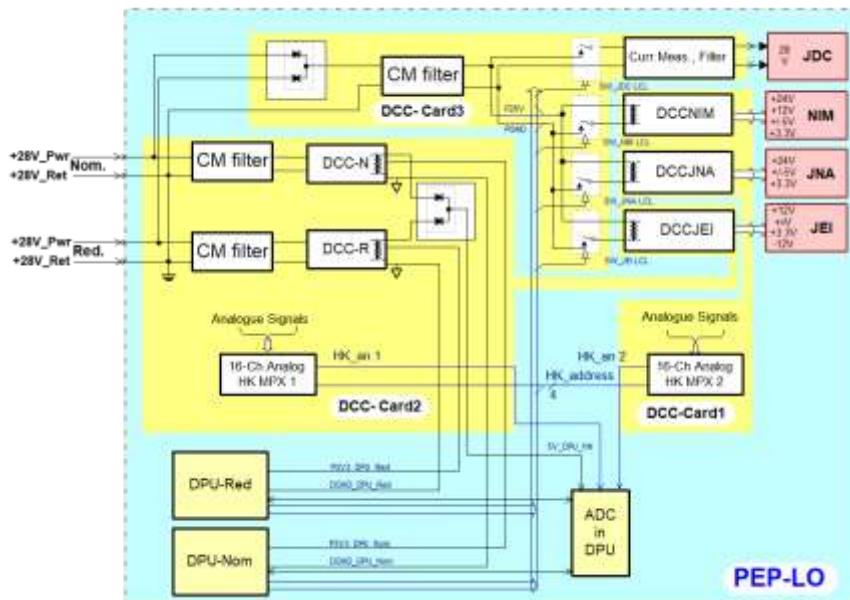


Figure 1

Blockscheme of DCC Unit is in yellow background, supplied sensors are in pink, redundant DPU is in blue background

This solution minimizes the cross coupling and the number of switching elements, and the output units can be tested individually. Due to the typically required 3 to 4 outputs for sensor voltages, a flyback type converter topology is proposed.

The required output power level of the individual converters is between 5 to 15 Watt. In order to minimize the possible voltage drop between the converters and the supplied subsystems, specific attention needs to be paid to the selection of the harness and cabling system. EMC requirements could be fulfilled easier by separation of DC/DC converters for subsystems and sensors.

Table 1

Total Power need of PEP-Lo experiment in different operation modes with 20% contingency

1-Off	0.0 Watt
2-Init	34.7 Watt
3-Standby	18.2 Watt
4-Service	18.7 Watt
5-Cal/Diag	38.7 Watt
6-Peak Science	49.5 Watt

The realized DCC was prepared by series of iterations with sensor teams, experiment PI (principal investigator), engineers responsible for the thermal balance and radiation shielding of instruments on space probe. At the beginning, DCC was aimed to contain full redundancy, which had to be reduced because weight reduction was introduced in the meantime. Several circuit topologies have been studied. With galvanic isolation requirement in view, only transformers with two or more windings should be used. (The circuits can be flyback topology, forward topology, push-pull and bridge.) Our choice is the flyback topology. It is advantageous for smaller power requirements and has a smaller number of components. When used for multiple output, the individual output voltages follow each other quite well, when either the input voltage or the output load changes. Their disadvantage is that their main switching element, typically a MOSFET, is stressed by voltage spikes, higher than primary voltage. The degree of this stress varies depending on output voltage and load. Worst case values can be several times the primary voltage. The voltage transient has to be neutralized by so-called "snubber network" which in the transient energy will be dissipated to heat. This decreases efficiency and may require cooling. Flyback transformers need a certain amount of gap in the core, which requires careful selection from the catalogue.

The configuration of a flyback converter in operation Figure 2: In the on-state, the energy is transferred from the input voltage source to the transformer (the output capacitor supplies energy to the output load). In the off-state, the energy is transferred from the transformer to the output load.

The PWM continuous conduction mode is reached when the current in the charging/discharging coil never drops to or crosses 0. For continuous operation, the operation can be described by solving linear equations instead of differential equations.

$$V_o = N_2/N_1 * (t_{on}/T_s) / (1 - t_{on}/T_s) * V_i$$

where V_o and V_i are output and input voltages, and N_2 and N_1 are windings of transformer. The t_{on} is the switch on time, and T_s is the period time. Based on this formula, we can determine the transmission ratio of PWM not only by transformer windings but by duty cycle. [2]

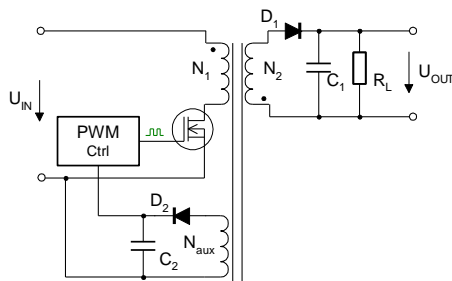


Figure 2
Simplified blockscheme of flyback converter

Even if the input voltage changes, the output voltage can be controlled by feedback coming from output. The transformer is energy storage in the circuit. When the PWM output is on, it is charged with energy, which is released if the PWM output is off. The energy storage capacity of a transformer can be increased by air gap.

The design of PWM converters was done for a nominal load in continuous mode. At low loads, they may operate in dis-continuous mode. Since the transformer for PWM has one common primary N_1 and several secondary windings $N_2, N_3, ..N_x$ are designed to the required voltages. In the design ISL78440 chip was used, its RadHard version exists for space application. Its datasheet is given in [3]. The original manufacturer of this chip was Intersil, the present manufacturer is Renesas.

For the design steps of the PWM controller in Table 2, equations can be found in various application notes [4]. Snubber design solutions are given in [5]. The task of the snubber is to reduce overshoot and spikes caused by inductors due to switching so as to protect semiconductors.

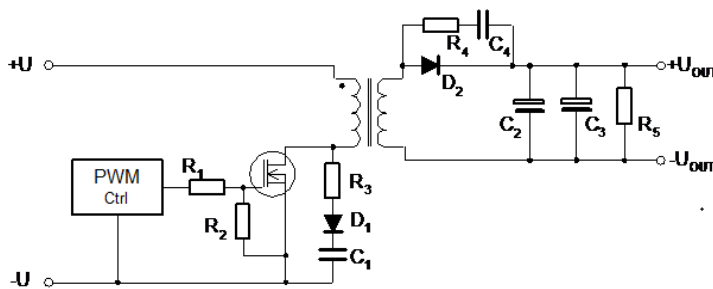


Figure 3
Snubbers parallel with power MOSFET and rectifier diode

The application of snubbers by reducing transients reduces the EMI electromagnetic interference effects as well. Snubber design details are described in [5]. Figure 3 shows snubbers at a diode D2 and MOSFET. Snubber at diode consists of a capacitor and a resistor. The capacitors limit the rise of voltage on diode, so transients are suppressed. In reverse operation of inductance the capacitors hold the voltage on the diode, and the resistor helps to dissipate the energy stored in the inductance. The energy stored in inductance fills capacitance at switching off. In sizing the capacitance this energy should not cause higher voltage than the maximum allowed reverse voltage of the diode. Driving inductive loads with transistor switches, often results in high voltage resonant spikes when the coils are switched off from their current source by the driver transistor. When the MOSFET shuts off, the current is at its peak value. The capacitor limits rising voltage, and energy stored in inductance is dissipated through the resistor. The drain of the MOSFET snaps back to the rail voltage in dt seconds.

Table 2
Design steps of an PWM controller

1. Determine the input parameters:	V_{in} , V_{out} , P_{out} , Ripple, f_{sw} , η
2. Count turn ratio and primary inductance	L_p (primary inductance), n_s (turn ratio)
3. Count converter parameters	I_{MOSFET_PEAK} , V_{MOSFET_MAX} , V_{DIODE_PEAK} , V_{C_MAX} , V_{OUT_RIPPLE}
4. Select the MOSFET	<i>To chose MOSFET with 20% margin</i>
5. Select the rectifier diode	<i>To chose diode with 40% margin</i>
6. Select the output capacitor	<i>To chose capacitor for optimal ripple</i>
7. Transformer design	A_{AREA} , $N_{PRIMARY}$, $N_{SECONDARY}$
8. Snubber design	Calculate turn on snubber components to protect MOSFET and diode.

$$C = I_{pk} \cdot dt / V_{rail}$$

The time constant (TC) of the RC element must be a fraction of the period. We use the time constant formula for choosing R.

$$RC = TC$$

A rule is to choose TC to be 1/10th of the switch on time.

The results were built on a protoboard and fine-tuned base on lab measurements.

The PWM converters contain feedback from output transformers. The feedback loop should be designed with suitable fast transient response and stability to avoid oscillation, overshoots in voltages, big ripples and possible damage of load device. When the output load changes, the control circuit must modify the duty cycle by an appropriate phase margin. A power supply feedback bandwidth and stability can be examined by widely used Bode plots whether it complies Nyquist criteria of feedback loop stability [6]. A negative feedback loop system stability is

illustrated according to Nyquist criteria in Figure 4. where polar coordinates are used. Assuming the open-loop gain transfer function is $T(s) = s = j\omega = j2\pi f$ in complex plain, as the frequency ω goes from 0 to infinity. Loop is stable if the plot does not encircle $(-1, 0)$ point according to Nyquist criteria. The stability margins are determined by the distance of $T(j\omega)$ plot from $(-1, 0)$ point. The phase margin (PM) is defined as the phase angle of the point where $T(j\omega)$ crosses unit circle, and the gain margin (GM) is determined where $T(j\omega)$ crosses Re axis. In Bode plot in Figure 4, phase margin and gain margin are indicated by vertical lines.

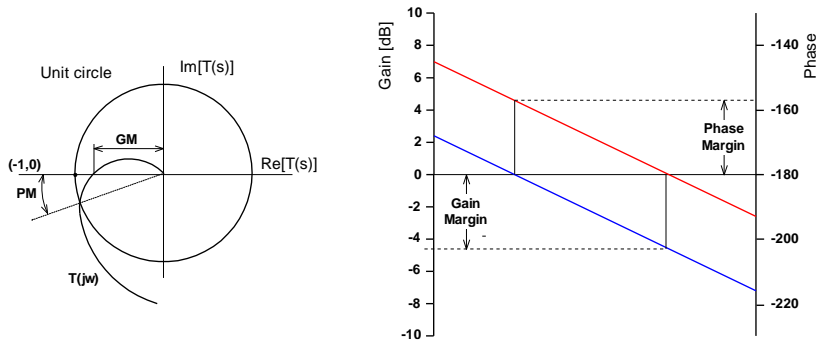


Figure 4

Phase margins (PH) and gain margin (GM) of a stable system according to Nyquist criteria on complex plain and in Bode plot

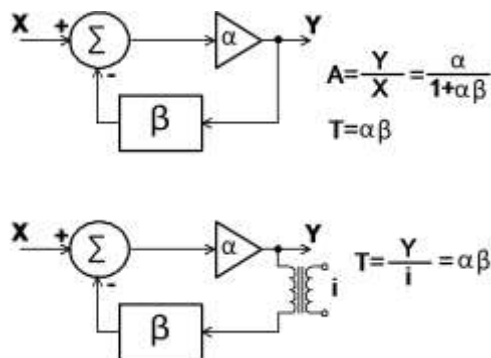


Figure 5

Typical Feedback Loop and breaking it to measure an injected signal i

A phase margin means how many degrees the phase can be changed before reaching -180° , the gain margin means how many dB can be added to it before reaching 1 (0 dB) while the phase is -180° . A power supply is actually a feedback amplifier (Figure 5). Since α and β are complex variables, their product T has magnitude and angle, too. If phase angle of T reaches -180° , and its magnitude is 1, the system transfer function reaches infinity meaning that the system will

produce output signal while Y is 0. The stability of the system can be measured by injecting an external signal in the loop, its name is *i* on the lower side of Figure 5. The loop is not broken, and this *i* signal is injected by galvanic isolation from outside by a transformer. The injected signal is driven by a frequency generator in sweep operation mode from 10 Hz to 100 kHz or to other upper limit which exceeds the crossover frequency where the gain goes below 1. The output response of the injected signal is measured by an oscilloscope, and the Bode plots of gain and phase results are printed out in frequency domain. [7] This test was done for all converters. Figure 6 shows the result of JNA converter having 50° phase margin and 20 dB gain margin, which comply with requirements defined as 50° for phase and 10 dB for gain.

The solution presented for consideration here contains separate converters for individual sensors of PEP (Nadir Unit) and redundant converters for DPUs.

The control of subunits is realized by two DPUs; they have redundant powering ensuring single point failure protection. There is further redundancy in the system, by overlapping measurement ranges of sensors. Fall out of one sensor would not result entire scientific loss, rather than fall of a part of energy spectra or FOV – field of view.

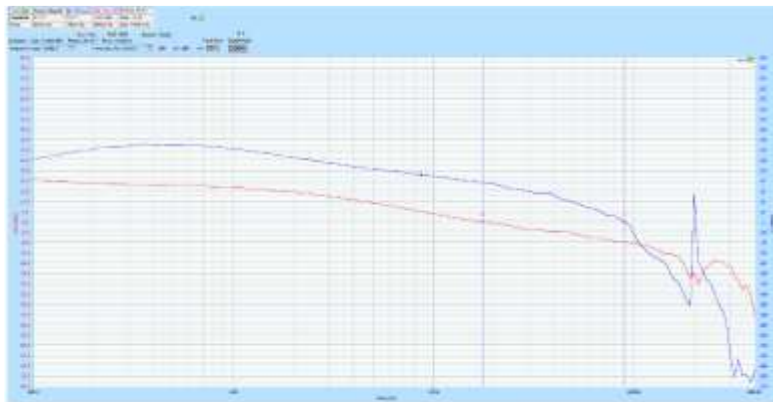


Figure 15 JNA converter control loop, zero load, min V_{in}

Figure 6

Test of control loop stability of JNA converter. Bode plots of phase margin and gain margin justify 76° phase margin and 10 dB gain margin

Since an individual power supply unit supplies every experiment, the sensors are isolated from each other. In this solution there is no need for a matrix of switches. Consequently, the switches connecting the power supply to instruments cannot generate crosstalk and transients. Semiconductor components will be implemented for the switching functions.

The converters will have different output voltages: +24, +12, ±5, +3,3 V and +1,8 V; these values in a limited range can be adapted to individual request of sensors

or other special power supply requirements. In the sensors electronics for low voltage FPGA down converter will be implemented (Point of Load). The down converters decrease current loss in wires and connector pins.

There is no common ground of sensor electronics. Transformers for each sensor ensure the isolation between primary and secondary power lines in both subunits.

If converters work at higher frequency, then the switching elements, transformers, power transistors and their overall size and weight can be less. 200 kHz operating frequency was the requirement coming from technical specifications. During design differential and common mode noise had to be suppressed. Figure 7 a) and b) The onboard power supply units and the switching elements of converters are the sources of noises. The source of differential noise is the onboard power. Switching components of DC/DC converter generate common mode noise spreading through power lines and on stray capacitances. As the frequency is increased, so the impedance of stray capacitances is diminished causing CM noise spreading especially in high frequencies. The switching transients can cause very high harmonic content in noise. Spreading noise can make interference to other circuits, and it can be the source of emitted noise and disturb operation of analogue sensors and other circuits. The DM noise spread can be reduced by a low pass filter, choosing a suitable cut-off frequency. The CM noise can be reduced by a choke coil working as an inductor against CM noise. The leakage inductor of CM filter can be part of DM filter to reduce component number in EMI (Electro-Magnetic Interference) filters. The EMI filters and converter subsystems are in cascaded connection. Stability of cascaded EMI filter and subsystem can be ensured based on Middlebrook criteria if $Z_{out} \ll Z_{in}$, where Z_{out} is the output impedance of EMI filter and Z_{in} is the input impedance of DC/DC converter [8].

DM filter design equations are the following:

$$\text{Cut-off frequency} = \frac{1}{2 * \pi * \sqrt{LC}}$$

$$Z_{out} = \sqrt{L / C}$$

According to Middlebrook criteria Z_{out} must be at least one tenth of Z_{in} . From these equations L and C can be determined. Placing an electronic capacitor with a series resistor C4 an R5 parallel with C3 makes the filter damped, and high impedance resonance at cut-off frequency is avoided. $Z_{out} \ll Z_{in}$ equation can be ensured by damped filter.

At CM filter design inductors L1 and L2 can be chosen with a certain leakage inductance complying with the LC low-pass filter inductance value and substituting L3. Since the common mode noise appears at high frequencies, above 5-7 MHz, by choosing the CM filter cut-off frequency in the 500 kHz- 800 kHz range a good attenuation can be reached where noise appears. After choosing choke inductor the minimal value of C_1 and C_2 can be determined Figure 7 c).

Finalizing EMI filters they were built on PCB and DM and CM noises were tested whether they are below the level defined in requirements [9].

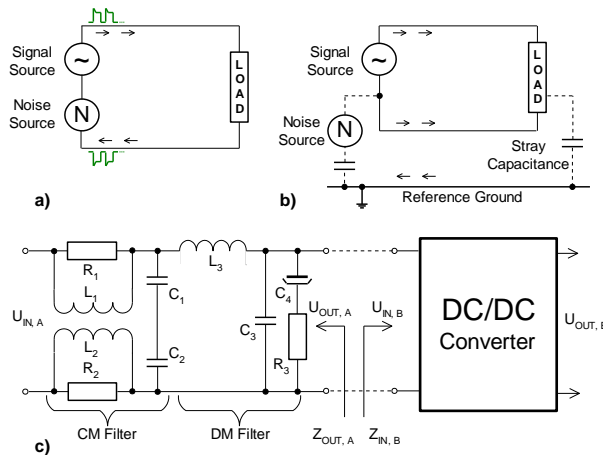


Figure 7

Differential mode noise (a), Common mode noise (b), Cascaded connection of EMI filter and DC/DC power supply unit

The 200 kHz is synchronized to quartz, which makes possible to distinguish space probe emission from scientific data. The efficiency of DCC units in all cases is higher than 73%. The basic mass of DCC is 1,365 grams, with frame, radiation shielding and three boards together are 125 x 130 x 50 mm. The height was reduced as well for significant reduction in shielding mass as well. The heat pipes are within the contingency. The DCC unit is placed in three cards; the cards have six layers – except JDC and card3, which have four layers – and they will be mounted double sided.

In design procedure functions, e.g., transient suppression, input current and inrush current limitation, overvoltage and undervoltage lockout and EMI – electromagnetic interference – filtering and noise damping are important requirements as well.

Inrush currents are peak currents created on the power bus when power is applied to the instruments by the LCL (latching current limiter). This current is usually due to the charge of the input filter but can also be due to the start-up of a DC/DC converter. When these currents appear on the power bus, the LCL will go into current limitation, potentially preventing not proper start-up of the instrument. If the LCL goes into limitation for too long, it will shut down itself eventually.

In space operation there is no atmosphere. The heat generated by components can be dissipated by mechanical heat sinks. Sizing heat sinks is a separate task to be solved. Calculation and design of heat balance in space is a very important part of development, as in the absence of the atmosphere, thermal fluctuation can be very significant.

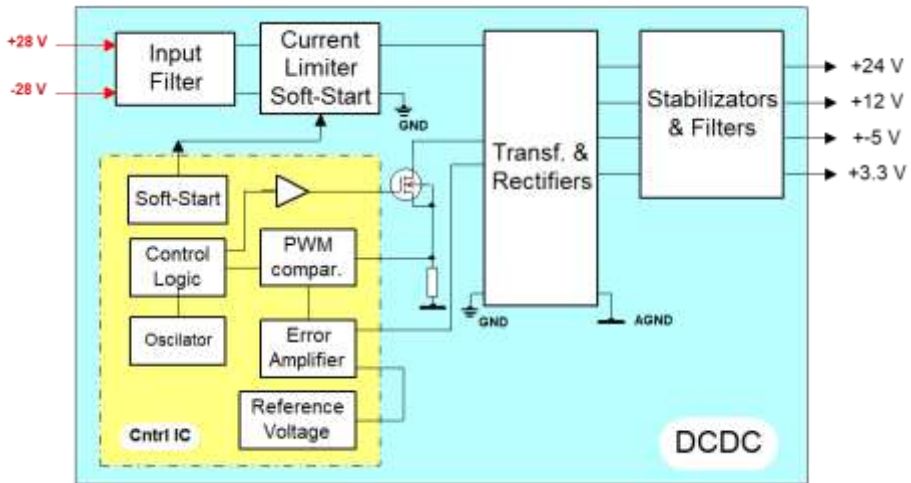


Figure 8

The functional circuit diagram of the power converters

Other environmental stress in space is the radiation effect of cosmic radiation, solar wind, charged particles, gamma radiation and electrons. The radiation can be characterized by TID total ionizing dose. The radiation charging is extremely high in the area of Jupiter. There is a third environmental effect as well, which is mechanical vibration caused by rocket launch. As a summary, in space the environment where the instruments have to work is extremely harsh comparing with Earth applications.

2.2 Component Selection

In the design for space application the reliability is an important factor, which is ensured by using high reliability components to minimize the likelihood of failure events. In JUICE project components from the European Preferred Part List (PPL) of ESA were applied. The advantage of using components from the PPL list that these components have been investigated for the extreme application and they survive the environment stress. The components (transformers and chokes) that are not in the PPL are ordered from a qualified manufacturer. These components go through defined qualification process.

The DCC is mounted into the common shielded electronics box and the integrated radiation dose is shielded and the estimated radiation dose according to simulations is no more than 50 kRad. The passive components of DC/DC converters are not as sensitive for radiation as the integrated circuits or sensors. The semiconductor components in the DCC units: which have been proven to withstand two to three times higher radiation dose than expected.

The available radiation level in the case of PWM controllers and MOSFETs is up to 1 MRad, and in the case of comparators, opamps, voltage regulators and MOSFET drivers it is up to 300 kRads.

Diodes are radiation tolerant. The bipolar power transistors do not fully meet their specification after 100 kRad total dose. We also designed with parameter changes due to radiation.

Materials used in the spaceship have to be baked out since evaporating materials would have negative effect on measurements by condensing in critical points. Not all materials are suitable for space use after bake out, there is a list containing applicable materials.

2.3 Detailed Requirement list for High Reability

After team meetings the requirements concerning the DCC were summarized in a document. The DCC has to fulfill approximately 150 requirements. They cover the following types of areas of which some important ones are listed here:

- enviromental: temperature, min/max operational temperature: -50 °C +50 °C
- radiation: TID sensitive component tolerance ≥ 100 kRad
and lifetime: at least 13.5 (Earth) years.
- telecommand and telemetry: DPU swithes on/off sensor powers
- electrical design, applying ESA recommendations
- failure tolerance, Safety inhibits should be independent, verifiable, stable and stay in a safe position even in case of energy failure.
- input power requirements, +26,5 V to 31,5 V, max 5 A
- output power characteristics, different for each sensor
- current protection of individual sensors, different for each sensor
- power on and off transients, different for each sensor
- conversation efficiency, min 65% for DPU and 70% for sensors
- control loop stability, gain margin, phase margin, 10 dB, 50 Deg
- switching frequency of PWM controllers, 200 kHz
- synchronisation I/F from DPU to DCC DPU board at 200 kHz ± 400 ppm/week stability
- control I/F from DPU to DCC Power switches, active high

- requirements for EMC Testing, DM and CM conducted current emission according to requirements
- mechanical requirements (weight, size), 1.4 kg, 48.5 x 154.7 x 149.2 mm
- worst case analysis, verify the stability of DC/DC converters, current limiters by analysis under worst case conditions,
- mechanical tests and frequency range and level according to description
- thermal vacuum tests according to testplan

Reliability was a highly important subject of this project and its insurance was increased by different methods. Appropriate operation of DCC was justified by test, design review and analysis.

The schematics were subjects of several review meetings where outer experts study the details of circuit and help by advice and suggestions.

The first tests were performed by EM1 (engineering model) and EM2 models. The goal of EM models were to check design using industrial components in real operation. The first integrations were done by EM models. Beside EM models STM (structural thermal model) was prepared as well in which resistors simulated power dissipation in a case with the same flight model size. The goal of STM was to study the thermal behavior of the whole experiment.

2.4 Analysis Ensures Design Quality

During development of DCC different analyses were done to ensure reliability. They were: analyses

- the part stress analysis for all components,
- detailed analyses of critical circuits,
- simple circuit realizations checked by review,
- thermal analysis,
- FMECA Failure mode effects and critical analysis and
- radiation analysis.

The issues of analysis were investigated to avoid modifications in schematics during test.

In analysis the Pspice model was used. The Pspice model is available to determine the operational circumstances of components. They are used in stress analysis, where extreme values are investigated at minimum, maximum and max load + 20%. The goal was to determine the maximum possible stresses for all components and decide whether they tolerate stress or if not, then the component

had to be substituted. The stress values are temperature dependent. In stress analysis the temperature of cards was regarded uniformly 85°C. It was the hottest temperature on PCBs coming from thermal analysis.

The Pspice models of critical circuits were created and they were simulated by WCA worst case analysis, including aging examination. The WCA analysis resulted some issues, 2-3% uncertainty at some circuits switching on or off, but by changing key component values the uncertainty could be eliminated.

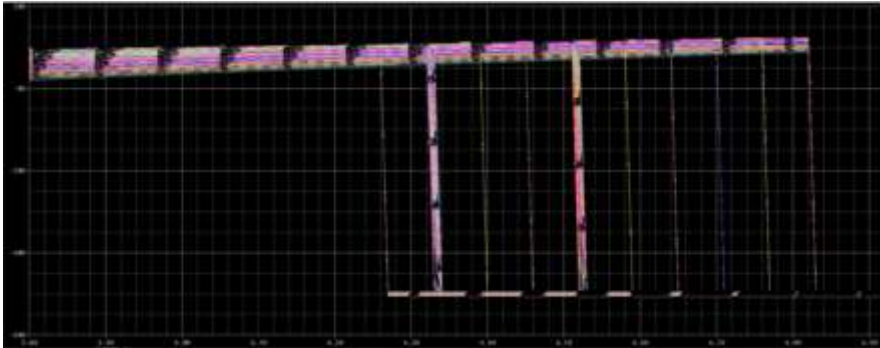


Figure 9

WCA simulation DPU-OVP (Overvoltage protection circuit) behavior from -55 until +80 C with shift of 15 C, 500 runs

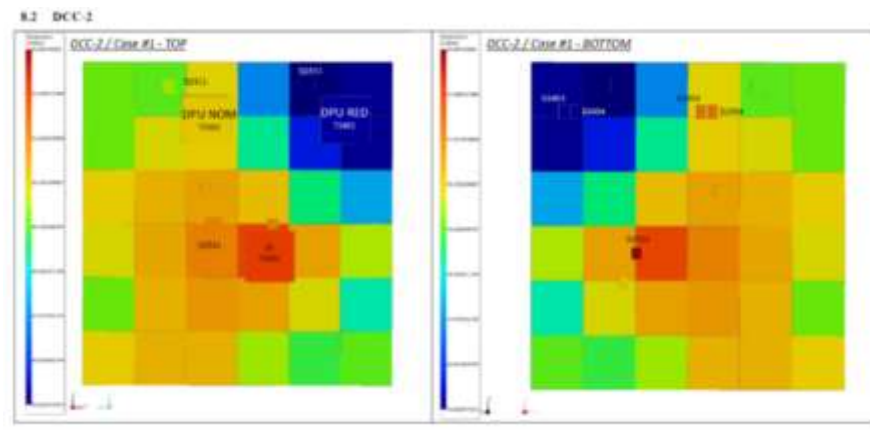


Figure 10

The simulated temperature of card2 for case #1 meaning average science operation

Thermal analysis and the power dissipation for all components were calculated. Thermal analysis determines how components meet design thermal requirements. In space power supplies work in vacuum, heat can be removed by conductive heater. The thermal analyses were simulated by Space Research Group of

University Bern for the whole PEP-Lo unit in different environmental circumstances during the planned flight. In Figure 10 temperature values are indicated by different colors. In thermal simulation the highest temperature on DCC was 85°C. In stress analysis of the DCC cards temperature was regarded 85°C.

According to radiation simulations the parts of DCC cards receive radiation between 12 krad and 27 krad with optimum placement of shielding material.

2.4 Manufacturing Flight Models

ESA regulates in standard the design and manufacturing flying PCB. Since the PCB (printed circuit board) is an important part of flight hardware, facing extreme stress, e.g., vibration and extreme temperature cycles, any humidity contained by PCB can cause failures in operation, radiation can damage hardware, so the requirements regarding PCB material would minimize risk of selection. The space agencies develop recommendations for both PCB design and manufacturing and accept the participation of qualified manufacturers for reliable operation.



Figure 11

Photo of one card of DCC

If the PCB is ready, soldering components is a determining task in flight assembly. Soldering fuses a pin to a metal pad and an electrically conductive connection is created. The surfaces to be soldered must be clean. Tin solder has to

cover the surfaces well. The tin, which can only be conventional lead, should flow properly during soldering and should not leave a residue of flux on the surface. Excess flux has to be cleaned after finalizing soldering. In assembly process space agency accept manufacturers with certificates for space qualified soldering. Soldering must be qualified by the manufacturer on a package-by-package basis to ensure that any inclusions and cracks do not reduce reliability. The greatest stress for heavy parts is shaking, for others it is thermal expansion.

3 EGSE for DCC

The blockscheme of EGSE for DCC is shown in Figure 12. It contains main power supply, variable loads for every voltage output, voltage and current meters. It can simulate any sensor or DPU and by adding external load it can simulate the full load for DCC. It contains a function generator which can modify loads with defined function. The DCC-EGSE also simulates the DPU interface by receiving HK housekeeping data and providing synchronous signal for 200 kHz DCC clock. By connecting wires shown on Figure 13 any sensor or DPU can be simulated. Loads are controlled and measured by microcontroller.

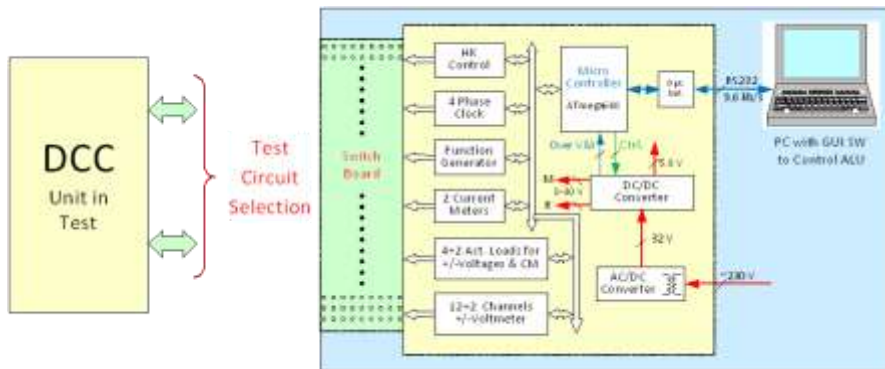


Figure 12

Blockscheme of EGSE for DCC

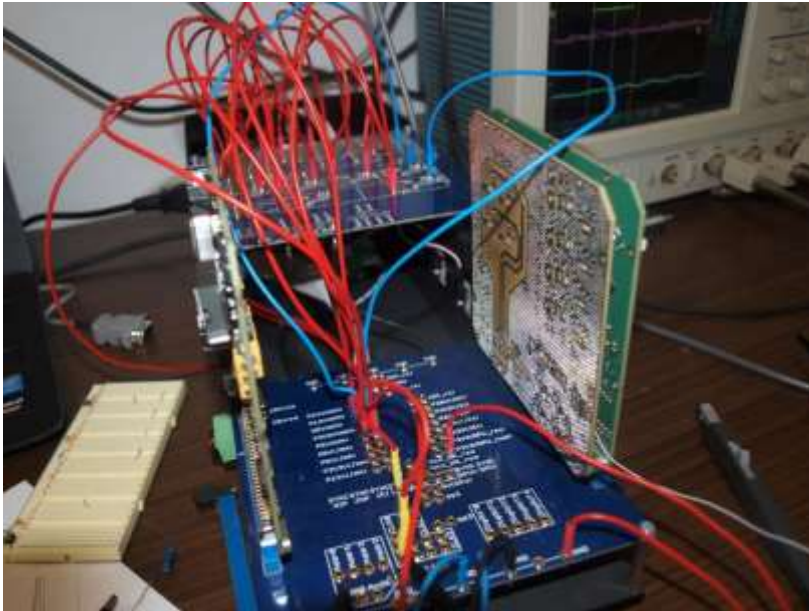


Figure 13

The DCC EGSE is in work. The blue cards are parts of EGSE for DCC. The two green cards are parts of the DCC in test

4 Details of DCC Acceptance Test

The blocks of the PEP instrument were tested individually according to the applicable requirement list. If all units went through the acceptance tests, they were integrated in the PEP instrument which had to go through the integration test procedure.

Appropriate operation of DCC was justified by design review, analysis, simulation and test.

Two flight models were done by qualified components surviving extreme circumstances in temperature and at least 100 kRad TID total-ionization dose. The assembly of flight blocks were done by manufacturers with ESA certificates for soldering. The assembly was preceded by meetings with manufacturers where all relevant questions of assembly were discussed in detail. The EM models were tested thoroughly. The components on EM and flight model were delivered by the same manufacturer using the same technology. So the tests of EM models meant a good chance that the flight models were going to work. There were some

deviations between characteristics of industrial and flight qualified components which caused different behaviour in some parts during tests.

The tests were done according to the detailed test plan which was determined priorly.

4.1 A Brief Description of Tests

The DCC test started by applying minimum load to all channels and peak load to one channel and results were recorded by EGSE. It was repeated for all sensors. A detailed table contains power requirements for all sensors in different operation modes, e.g., 1 off, 2 Initialization, 3 Standby, 4 Service, 5 Calibration/Diagnostics and 6 Science. The EGSE is available to switch different loads on every channels controlled by PC. The next test phase was to check LCL circuits for every sensor. A very detailed test series was done in thermo-vacuum chamber between -55°C and $+55^{\circ}\text{C}$. The Thermo-vacuum test was designed before implementation in detail. The number of thermo cycles were 4. The duration of dissipation and warming up the chambers required 4 days time.

The phase and gain margin of all the PWM control circuit were checked to justify the stability of control circuits. Vibration test is part of environment tests to justify that the circuits withstand the required shaking that occurs at the launch of the rocket.

After all tests was done the integration of hardware elements was started. In series the DCC, the DPU and the sensors were placed in the common rack. The integration began with the assembly of the DPU and DCC into a common mechanism. It happened in a clean room. After successful testing of the service units, the sensors were installed. After integration the whole PEP instrument was cooled down to -170°C in thermo-vacuum chamber to test the installed heaters to prove that the instrument will not cool down below -55°C .

Conclusions

After integration, the whole instrument set went through detailed testing. Some minor modification requests arose, but as these could be resolved, the first flight model of the instrument set was accepted and placed on the spacecraft, on which several more tests are still being performed. The international team is currently performing integrated tests of the FS flight spare model. By participating in the experiment, the Hungarian space instrument development as received a challenging task, and we had the chance of learning how a space agency, ESA works. It is a significant challenge for Hungarian space research to be able to participate in an interplanetary mission with flying hardware. In this way we can contribute to the exploration of the solar system.

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