

Low Power Solutions for Rosetta Instruments: Finnish Contributions to an Exciting Project

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1. Introduction: The European comet mission Rosetta [1] was launched in March 2004 and reached the target comet 67P/Churyumov-Gerasimenko this summer. Around 11 November 2014 the landing vehicle Philae will be sent to the comet's surface to begin half a year of in-situ measurements of its surface material properties to shed light on the actual composition of these strange solar system bodies.

The Finnish Meteorological Institute (FMI) provided hardware or software for five different instruments and one system part of this exciting mission: The plasma instruments RPC/ICA, RPC/LAP and RPC/MIP, the dust analyzer COSIMA, all mounted on the satellite itself, the Lander's permittivity probe SESAME/PP and the autonomous mass memory of the Lander's command and data management system.

The common denominator was a robust design for a long-time mission with as low power consumption as possible at least for the Lander instrumentation. The main properties of the instruments and some technical implementation ideas will be presented here.

2. Control Electronics for Plasma Instruments:

Our institute developed and built the control electronics for two of the plasma instruments as part of the Rosetta Plasma Consortium (RPC): the Ion Composition Analyzer (ICA), PI-institute IRF-Kiruna, Sweden (Fig-1), and the Langmuir Probe (LAP), PI-institute IRF-Uppsala, Sweden (Fig-2). Both Data Processing Units are absolutely identical so that a third copy of the flight model served as flight spare for either of them. All tests were so successful that nearly identical copies with spare components from the Rosetta project were also used to control the ASPERA instruments on ESA's Mars orbiter Mars Express and ESA's Venus orbiter Venus Express.



Fig-1: RPC/ICA flight model

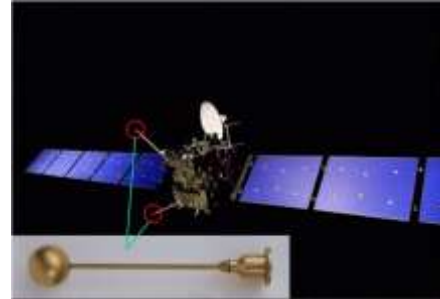


Fig-2: RPC/LAP positions and flight model

Figure 3 shows the development model of the electronics board with the same form factor as the final flight hardware. All interface details and the memory management system were implemented in a radiation hardened system were implemented in a radiation hardened FPGA. As non-volatile memory a 0.5 MByte radiation hardened EEPROM was used, while the boot software was implemented in a bipolar PROM, replaced on the shown board by four commercial EEPROMS with the same dimensions.



Fig-3: ICA and LAP DPU board

ICA is measuring the angular and velocity distribution of cometary and solar wind ions with sufficient resolution to detect protons, helium, oxygen, molecular ions and heavy ion clusters. LAP measures the density, temperature and flow speed of the plasma using its two spherical sensors mounted on the tips of separate booms. The Multi Impedance Probe (MIP) [2], PI-institute LPC2E/CNRS, Orleans, France, measures electron densities ($2 \cdot 10^0 - 2.5 \cdot 10^5 / \text{cm}^3$), temperatures (30 – 105K), velocities (100-1000 m/s) and plasma waves with 60 dB dynamic range. It can also use one of the two LAP electrodes to extend its measurement range from 0.5 cm up to 2 m Debye lengths. FMI pro-

vided the electronics ground support equipment for MIP.

2. Software for Dust Analyzer: The Cometary Secondary Ion Mass Analyzer (COSIMA), PI-institute MPS Göttingen, Germany (Fig-4 and 5), characterizes the dust grains released from the nucleus of comet and determines the molecular, elemental and isotopic composition of the grains. The grains are collected on an aluminium plate, interactively selected with a microscope, then bombarded with indium ions to strip one molecular layer after the other from the grain and accelerate the particles through a folded mass spectrometer. Our institute developed and built the control electronics which allows positioning the plate in two dimensions, collects the images and optimizes the spectrometer behavior. FMI also provided the ground support equipment and is in charge of operating the instrument throughout the mission.

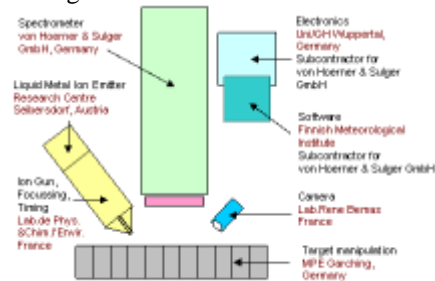


Fig-4: COSIMA structure and responsibilities



Fig-5: COSIMA flight model

The software is built around relocatable modules accessed by a common relocation address table which makes any software modification safe and efficient, as only the modified module has to be uplinked without interfering with the rest of the system.

The control system on ground is identical for software development, laboratory tests and flight operation. Built around a fault tolerant high-level operating system originally developed for control of international telephone traffic any part of the software can be changed without interrupting the system. Its secure port-based interfaces allows remote access to reference models situated in a clean-room environment from either standard laboratory environment or from team

members located at different sites or even in different countries

3. Permittivity Probe on Philae [3]: The Philae-Lander's Permittivity Probe follows the water ice content development at the landing site by measuring the complex permittivity of the sub-surface material in a frequency range below 10 kHz, which is mainly sensitive to changes of water ice content and temperature. By injecting alternating currents between two electrodes in contact with the comet surface and following the potential difference at two other locations on the comet surface one can measure the surface material's conductivity and permittivity (Fig-6). Additionally the receivers are sensitive enough to measure plasma waves caused by dust eruptions nearby and their interaction with the plasma above the surface. The PP electrodes are attached at each surface planned to be in contact with the surface material except for the drill: two of the three feet contain receivers; the third is used as one of the transmitter electrodes. As second transmitter electrode either a ring electrode underneath the APXS-detector lid or a mesh electrode around the insertion point of the MUPUS PEN can be used (Fig-7). The different resulting geometries allow getting a rough idea of the depth variation of water ice, as the measured depth depends on the distance of the used transmitter electrodes.

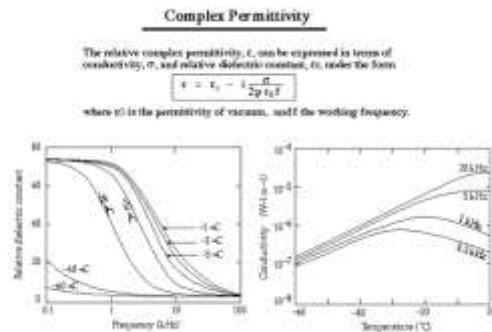


Fig-6: Complex permittivity of water ice

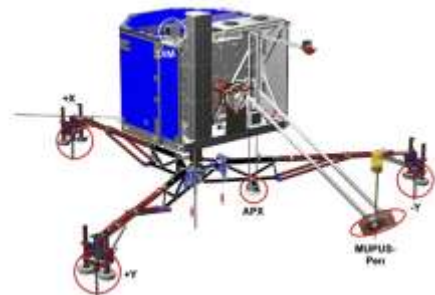


Fig-7: PP electrode locations on Philae

Measuring the variation of potential differences between the receiving electrodes embedded into the +Y- and -Y feet plasma waves between 20 Hz and 20 kHz can be measured. Fig-8 gives an example where 110 Hz noise generated by Philae's fly wheel during in-flight tests was picked up by the receivers.

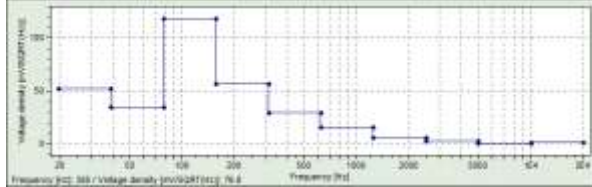


Fig-8: 110 Hz noise measured by PP in passive mode

Instrument parameters:

	+Y receiver	-Y receiver	diff. receiver	current monitor
minimum	-117 mV	-117 mV	-119 mV	- 2.2 μ A
maximum	+117 mV	+117 mV	+119 mV	+ 2.2 μ A
resolution	0.91 mV	0.91 mV	0.93 mV	17.4 nA
amplification	8.4 * 2.54	8.4 * 2.54	8.4 * 2.49	500

3. Resource Saving Means on Philae: Energy is a very scarce resource on Philae as is the telemetry budget. While during the first five comet days the energy is supplied by primary batteries, the extended mission has to survive on the 100 Wh the rechargeable batteries can store provided the solar panels provide enough energy. PP is optimized for both energy saving and telemetry reduction. All real-time aspects of the measurement are implemented in a radiation-hardened Field-Programmable Gate Array (FPGA). As it is CMOS-technology based its energy consumption depends critically on the clock frequency used. With a special design the external clock is blocked from any logic part currently not in used. The communication bus is monitored by a static gate design allowing also the programming of control registers without clock usage. On start of a measurement the clock signal is enabled for the sequencer design and disabled automatically when the predefined measurement sequence ends. The analog electronics is divided into separate functional blocks each powered independently. For example during passive measurements the current generator is not powered. [4]

The PP controller generates time series of currents and potential differences maintaining their phase relationship, typically vectors of 8 kByte each. To reduce the amount of telemetry needed, the data are analyzed by a software-implemented wavelet algorithm, which minimizes distortions from unwanted frequencies and

is able to extend the dynamic range of the system by synthesizing theoretical sine waves fitted to the measurement while maintaining the phase relation between the two time series. As a result the 16 kByte data vectors are reduced to just three numbers: the average amplitudes of both signals and the phase shift between them. This allows the measurement of many different frequencies and amplitudes without exceeding the allocated telemetry budget.

Similarly the passive measurement time series are translated into logarithmically binned power spectra with typically just 10 values which are transmitted to ground. As an example see Fig-8, measured during an interference test between Philae's fly wheel and PP to find the optimal fly wheel speed in 2010.

Similarly the autonomous mass memory of the Philae command and data management system (CDMS) is optimized for lack of energy: During nominal operations a small low-power interface FPGA is monitoring incoming serial data and command traffic. If data have to be stored in memory or should be read out, the fast and power consuming memory management FGPA is enabled by providing a clock frequency suitable for the intended task. Once the data transfer is handled and the data are stored or retrieved the clock is disabled again reducing the unit to low-power mode. If the battery level is getting critically low an EEPROM can be enabled by the interface FPGA and the complete RAM contents are transferred into it, programming pages on all EEPROM components in parallel by a complex address mapping process to reduce the transfer time as much as possible. Thereafter the complete mass memory module can be powered down and re-activated again when enough energy is available. Data transfer from the mass memory to the radio system is also handled autonomously: once start by command the data are formatted and sent to the radio link. In case of detected transfer or link problems the last data blocks are automatically re-sent without interaction from the main computer which can continue controlling the operation of the scientific instruments.

References:

- [1] Schulz R.. et al. (2009) *Rosetta, ESA's Mission to the Origin of the Solar System*, Springer
- [2] Trotignon J.G. (2007) *Space Science Reviews*, 128, 713-728
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- [4] Schmidt W. and Mälkki A. (2007) 5th *International Planetary Probe Workshop*, Bordeaux