JUICE instrument workshop, 9-11 November 2011

The first Jupiter Icy Moons Explorer (JUICE) instrument workshop was held in Darmstadt, Germany, on 9-11 November 2011. The goals of workshop were to inform potential instrument providers about the recent changes in the mission profile and radiation environment, to update them on technology development activities of potential interest, which are currently being funded by the European Space Agency in support of the JUICE mission study activities, and to discuss and describe the radiation environment and transport modelling. In addition, the workshop gave potential instrument providers the possibility to discuss technical aspects with ESA experts and to discuss among themselves topics such as resource sharing, critical items and development experiences.

(An introduction to the workshop can be found in the presentation of A. Wielders – see table of presentations on the website: http://sci.esa.int/jump.cfm?oid=49858)

Day 1: Mission, payload and technical development activity presentations

During the first day of the workshop an update of the mission profile was given, as defined during the ESA reformulation study of JUICE. The JUICE mission profile is an evolution of the JGO spacecraft of the Europa Jupiter System Mission (JGO/EJSM), where two main additional elements were introduced: (a) two Europa flybys, and (b) a high inclination phase around Jupiter (up to 30°). In parallel to these updates, a new radiation environment tool was introduced. (*See the presentation by C. Erd for further details.*)

The updated radiation environment model includes all relevant observations of the radiation environment in situ, and also ground-based observations obtained with radio telescopes. The updated model predicts a Total Ionising Dose (TID) two times higher compared to the previous model. Similar radiation model improvements in the USA have led to similarly increased exposure levels. The inclusion of Europa flybys adds ~ 25% of the TID. As a reference, the new radiation model predicts - for the current baseline mission profile - a TID of 240 krad behind 10 mm of solid sphere of aluminium. (*See the presentation by G. Santin for further details.*)

At the request of participants a presentation about resource sharing was included in the workshop. The potential benefit of resource sharing is to reduce the amount of resources per instrument by sharing some general services, such as data processing and power conversion. After the presentation, the audience requested a splinter session on day 2 of the workshop to discuss the resource sharing issue further. During the remaining six presentations of day 1 ongoing technology development activities were introduced, in preparation for the splinter meetings to be held on day 2. These included radiation hardened electronics design, radiation modelling, ASIC development and potential on board payload data processing.

Day 2: Splinter sessions

ASIC development (splinter session)

The progress to date on the basic technology development of the two ASICs with potential applications for instrument front-ends was described. The ASICs are targeting readout for high frequencies from 50 MHz down to 5 MHz and medium frequencies from 5 MHz down to 50 kHz. The latest specifications were presented during the workshop. The building blocks, the architecture and operation were described and possible instrument applications presented. (*See the presentations by G. Thys and R. Jansen for further details.*)

Concerns were raised (i) whether the ASIC performance could rival that of equivalent discrete commercial components that have been refined over the years, (ii) how a single ASIC could serve a multitude of sensors, and (iii) how it could effectively be designed for its application instrument. For the latter point, it was noted that for the medium frequency Instrumentation ASIC, the input voltage range should be extended from 2 V peak-to-peak to 4 V peak-to-peak and the power consumption minimised for it to be useful. This information will be fed back into the ASIC development.

Architectures for the following four basic instrument types were presented as possible applications: a radiation detector, a radiation spectrometer, and two control loops (see presentations by Jansen and Thys). Subsequently three Instrument ASIC usage scenarios have been shown. The first envisages the ASIC to be used without modifications in the instrument, the second considers the re-use of the intellectual property (IP) blocks of the ASIC together with dedicated digital circuitry in a new ASIC, and the third details the re-use of the IP blocks of the ASIC together with dedicated digital and analogue circuitry in a new ASIC. The architecture of the Instrument ASIC has been constructed such that the complete functionality and performance can be attained for the engineering models for the first two scenarios by employing the Instrument ASICs in parallel or series with dedicated Field Programmable Gate Array (FPGA) control.

As these developments are still ongoing, the currently preferred approach by instrument designers is to rely on radiation hardness designs based on components that have already been refined, debugged and improved over a long time. To avoid technology risks, instrument proposals will not rely on the output of the ongoing radiation tolerant Instrument ASIC

development. Instrument teams would first need to be provided with proven performance before committing themselves to using the ASIC for optimizing their design taking advantage of the increased radiation tolerance and increased level of miniaturisation. It was agreed that the aim would be that a limited number of samples would be made available in 2012 to potential end users within the instrument teams, such that the ASIC could be preliminarily validated in preparation for its integration into the sensors at the earliest possible opportunity. Furthermore, a limited number of the instrument sensor designs could be used as verification and validation cases for the ASIC during its development, provided they would be made available to ESA on time. In return, the respective instrument teams would receive a sensor reference design with the Instrument ASIC, including a prediction of its performance and later its simulated performance. First steps in this direction have been successfully initiated during this workshop splinter meeting. Other instrument teams interested in this development are invited to contact Richard Jansen at ESA (richard.jansen[@]esa.int)
ESA contact person: Richard Jansen (richard.jansen@esa.int)

Payload Processing Technologies (splinter session)

A summary presentation of the ESA perspective on payload data processing technologies was provided, including data compression algorithms and standards, microprocessors available in Europe, and ongoing and completed technology developments in the area of support for payload data processing such as Digital Signal Processing (DSP) IP, high bandwidth network on chip technology, and prototyping activities using IMEC's 1 Mrad DARE 180 technology. A LEON/NoC/DSP-based data processor chip based on demonstrated IP and DARE 180 chip prototyping activities was described with a peak performance in the range of 1 Giga operations per second (GOPS). This could be considered as a generic data processor to be used by several instruments in either a standalone configuration (one processor per instrument) or as part of a processing array (for a shared payload data processing unit (DPU)).

During discussions with some instrument study teams, it was found that the majority of teams are planning to use large (partially RAM-based) FPGAs or combinations of LEON chips with FPGAs. Radiation hardness appears to be an unsolved problem in many cases. Processing power, power consumption, and size/mass are additional concerns. Many proposed instruments have significant mass fractions spent on shielding materials. The envisaged intense use of FPGAs also leads to higher power consumptions, with obvious implications on system level. The development of a small set of interface-compatible radiation-hard ASICs (for both analogue front-end use and digital data processing back-end) that could serve multiple teams was perceived as an attractive solution.
Questions were raised by the participants about how such developments, that would serve a larger number of payload teams, could be funded and - equally important - be ready in time when needed by the instrument teams. It was suggested that instrument proposals could be based on a combination of existing LEON processor(s), FPGAs, and ADC/DAC/multiplexer components that could be completely or partially replaced by the newly developed chips once they become available, with associated increased radiation tolerance, reliability, and savings in mass and power.

The information on instrument data processing requirements discussed during this splinter session will be consolidated after the workshop in order to derive a first set of requirements for proposed component developments, and for supporting subsequent ESA direction of development efforts. (*See the presentation by R. Trautner for further details.*)
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DARE+ radiation design library (splinter session)

The "Design Against Radiation Effects" (DARE) ASIC library, developed by IMEC (Belgium) under several contracts with ESA, was described in detail. DARE is based on a commercial 180 nm CMOS technology of UMC (Taiwan). The radiation hardness of DARE results from the consistent application of cell design level methods as enhanced guard rings, enclosed layout transistors, and customisation of resistive and capacitive elements. The library includes RAM compiler, PLL, LVDS I/Os, 5 V tolerance, cold sparing, and single event upset (SEU) tolerant Flip-Flops. The efficiency of the DARE library has been demonstrated by comprehensive functional and irradiation tests of specific test vehicles and a 4.4 million transistor ASIC for telecommunications. DARE+ is the follow-on activity which will include more functionality and higher dose tolerance. (*See the presentation of B. Glass for further details.*)
ESA contact person: Boris Glass (boris.glass@esa.int)

Electronic radiation hardening - technology demonstration activities (splinter session)

The radiation constraints and implications of the JUICE mission were summarised at the component level, and the radiation hardness assurance for microelectronic parts was discussed. In particular, it was emphasised that, because of the high TID constraints, hardness assurance shall be supported by statistical analysis of the flight lot results in order to reduce the radiation design margins. The details of the on-going radiation testing activities on opto-couplers, sensors and detectors, mass-memories and power systems were presented. (*See the presentation by V. Ferlet-Cavrois for further details.*)
ESA contact person: Veronique Ferlet-Cavrois (veronique.ferlet-cavrois@esa.int)

Electrostatic charging (splinter session)

A brief summary was made of the types of charging effects that could be encountered on the JUICE spacecraft. It was emphasized that instruments should consider their potential electrostatic impact on the platform and on other instruments, and assess whether they may be influenced by charging effects or charged contaminants from other surfaces or from the electrostatic sheath and wake of the Jovian plasma. It was noted that solar arrays are potential sources of electrostatic disturbances due to the limited conductivity of the cover glasses and due to the wake expected in the co-rotating Jovian plasma.

A brief review was presented on available data and tools to assess charging effects. It was emphasized and demonstrated that first order estimates of average surface or ground

potential can be quickly obtained without the help of advanced tools. More advanced tools, taking into account a wide range of plasma-surface processes (Equipot) or 3D geometry (SPIS), are required to look at effects at smaller scales (which nevertheless may be critical). With reference to current publications on electrostatic charging in the Jovian environment it was noted that the environment of the moons may be somewhat different from current assumptions and that more detailed work on modelling of such environments may be needed. It was also noted that uncertainty of the assessments results from the lack of accuracy of surface material properties. (*See the presentation of A. Hilgers for further details.*)
ESA contact person: Alain Hilgers (alain.hilgers@esa.int)

Issues in modelling of radiation effects in the Jupiter environment (splinter session)

A new model of the Jovian radiation environment was developed by using all the latest data from spacecraft and ground-based observations. This JOSE model is the baseline for all JUICE radiation environment calculations and was summarized during this presentation. Radiation transport simulation tools such as GRAS/GEANT4 were also discussed and clear guidelines concerning particular issues in their application for performing radiation exposure estimates for instruments and subsystems were presented. (*See the presentation of G. Santin for further details.*)
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Issues in (very) radiation hardened systems (splinter session)

A number of on-board computer related developments were discussed in this splinter session. The choice of ASIC versus FPGA in a stringent radiation environment was discussed and potential pit-falls were identified. A detailed trade-off between ASIC and FPGA needs to be performed for each instrument before a decision can be made. The outcome of such a trade-off will be highly specific to each instrument. The potential use of soft-memory - like NAND Flash - was also discussed together with the radiation introduced effects in such a memory device. (*See the presentation of G. Furano for further details.*)
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Discussion on potential resource sharing possibilities (splinter session)

During this workshop, at the request of several participants, a discussion on practicalities about possible resource sharing was included in the workshop agenda. Several remarks, observations and suggestions were made, which may be of general interest to the community and which are therefore included in this summary.

This discussion is described here for information only and to encourage further discussions among potential instrument teams. It does not reflect in any way the official position of the European Space Agency or its strategy with respect to the future announcement of opportunity (AO) whose release is subject to the successful down selection of the JUICE mission.

The goal of sharing resources has to be a higher level of efficiency (being either technical (in terms of spacecraft resources) or cost). At the beginning of the discussion a warning was made, that combining efforts and sharing tasks should be approached carefully, and should only be proposed in areas where it actually achieves an improvement of efficiency. Obviously this may be easier to achieve with similar kinds of sensors and measurements.

An obvious way of sharing resources and at the same time reducing a multitude of unnecessary redundancies would be combining data processing efforts. Such a unit could be provided by a Principal Investigator (PI) or Co-PI for multiple sensors. A few critical issues requiring addressing were identified preliminarily and are discussed here following the example of a PI-level contribution for shared data processing (other possibilities, such as sharing of power conversion, etc., were also discussed at the workshop):

1. Should the involvement of a DPU for multiple front-end sensors be at the PI-level, then his/her team needs to be involved in the scientific output of the sensors, due to the fact that PI-teams have to lead science investigations. An agreement should be in place between the PI of the DPU and the PIs of the sensors on how to distribute data and scientific fields addressed by such a joint instrument.
2. The PI of the DPU needs to have the same 'visibility' as the other PIs of sensors in the JUICE Science Working Group, which will be established after the AO. This visibility is also helpful for convincing funding agencies about the added value of such a DPU.
3. A very detailed and comprehensive planning needs to be made between the PIs of the sensors and the DPU PI for a number of reasons:
    - DPU testing with sensors is more complex and more effort is needed to provide each sensor team with a DPU simulator for testing purposes.
    - Management of sensor requirements is more complex when more than one team is involved.

Such a PI-level service would however open a new interface to the spacecraft management (ESA) and to funding agencies, effectively introducing an additional management layer, and thereby increasing the complexity, which could be simplified by merging of such PI teams already at the time of response to the AO.

Suggestions were made about how the sharing of resources could be enabled for instrument teams in their response to the AO. The main concern raised by the participants is that one part of a larger consortium may not be selected and therefore other possible contributions are at higher risk. The suggestion was made that payload consortia should propose their instrument concept in full, and should indicate in their proposal whether they would be willing to share resources with other teams at all and, if so, whether they would be providing a service or using services. It was furthermore suggested that the AO text could include a clear description how the Payload Review and Selection Committee will handle any instrument proposals with an included resource sharing option.

It was also discussed whether the option could be of interest where instrument teams would be joining different competing consortia to increase their chances of selection. Such an approach was considered as increasing the workload for that team and also increasing complexity.

Additional potential resources, which could be of interest to instrument teams when being shared/provided, for example by the spacecraft, could include:

- Additional low voltages further to the standard 28 Volt power line.
- Optical bench for mounting cameras, laser altimeter & spectrometers.

(*For further details see the presentation of A. Wielders.*)

Disclaimer: The views presented in this section (Discussion on potential resource sharing possibilities) do not reflect the official position of the European Space Agency on this topic, but are the views of the individual participants of the workshop.

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Day 3: Instrument presentations

The final day of the workshop was devoted to the presentations by potential instrument teams. At the time of the workshop announcement a request for abstracts for this day was also released with the idea of giving instrument teams the possibility to present their instrument and related technical issues in order to encourage discussions on common issues and feedback from other instrument teams and ESA experts. In total, 23 presentations were given on possible instruments and instrument contributions to the JUICE mission. The topics discussed during the presentations ranged from radiation analyses and component testing to overall design and development issues of instruments. Due to the sensitivity of these discussions in view of the potentially upcoming AO, it was decided not to make these presentations publicly available.

Conclusions

The workshop was generally appreciated by the participants and continuation of discussions at technical level at similar meetings was requested. The potential members of instrument teams are invited to continue the discussions on technical matters with ESA experts off-line. The potential instrument teams are encouraged to continue the discussion on sharing and optimising their resources with interested teams.

Any general questions about the workshop can be directed to Arno Wielders (Arno.Wielders@ esa.int.

Acronyms
DARE: Design Against Radiation Effects
DSP: Digital Signal Processing
FPGA: Field Programmable Gate Array
IP: Intellectual Property
PI: Principal Investigator
TID: Total Ionising Dose