Model-based requirements-verification lifecycle

Merlin Bieze
RHEA Group

Model-Based System Engineering (MBSE) is increasingly being adopted in industry in favor of a document-centric approach. This improves efficiency, provided more transparency in design choices and improves the communication of engineering information between the different stakeholders. Many MBSE tools are being used by industry to create a wide variety of digital models, but the exchange of information between the customer and supplier is often still very much document centric. At almost every stage there is a conversion from models to documents and vice-versa rather than a model exchange. This is time consuming, costly and can lead to loss of information and loss of traceability. The Model-based Requirements Verification Lifecycle (MARVL) project aims to address these problems by developing a methodology and supporting infrastructure, called the Common Information Platform, to improve the processes and the related information exchange.

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Localisation of Objects in Space through rf Tags (LOST)

Christophe Craeye
University Catholique de Louvain (UCL)

The activity aimed at studying, developing the principles and algorithms, and finally implementing and testing a prototype of simultaneous localization of multiple passive RF tags with the use of multiple receivers.
The ESA/LOST project allowed to demonstrate the first full system for accurate and medium-range localization of passive RFID tags in the ultra-wide band (UWB) regime. Achieving a few centimeters localization accuracy in the range of 10 meters for several tags. All basic requirements have been satisfied, within some minor modulations. A final demonstration at ESTEC Robotics laboratory in December 2017 showed the actual capabilities of the prototype applied to a real case.
Even if a long way still needs to be covered toward actual space-based applications, we believe that the system developed under the ESA/LOST project is sufficiently complete and flexible to allow a constant and well-controlled evolution toward very high standards in terms of accuracy, range, rate, robustness against non-line of sight conditions, and ease of deployment and use.

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Earth Observation Image Librarian (EOLIB)

Mihai Datcu
DLR

The EOLIB prototype, developed and implemented during the project activity, provides advanced functionalities for Image Information Mining (IIM) and Knowledge Discovery (KD) within huge EO image archives. In this framework, ESA and DLR enlarged the generic data mining functions to recent satellite missions like e.g. TerraSAR-X, TanDEM-X, Sentinel-1, Sentinel-2 and Sentinel-3, and similar SAR and optical missions.
The EOLib prototype has been delivered and integrated into the DLR PDGS at Oberpfaffenhofen. Over one thousand radar (TerraSAR-X) images were made available to the system. Additionally, a stand-alone demonstrator, capable to handle both radar and optical data, has been implemented, to provide an easy-to-use system deployable at user premises.

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Data Mining for Analysis and exploitation of next generation of Time Series (DAMATS)

Adrian Stoica
Terrasigna

The developed DAMATS prototype provides general analytical methods for the exploitation of the information contained in Satellite Image Time Series (SITS), in particular for the extraction of information in terms of categories of evolution, and the classification of evolution processes in the observed scenes. The prototype permits the: (1) quick and effective generation of SITS; (2) definition and categorization of classes having the same evolution in time; (3) fast semantic searches of defined classes within huge image archives. The system has been demonstrated in typical use cases like e.g.: multi-temporal analysis for annotation of a scene, search for specific information directly on the SITS, bi-temporal analysis for change detection, multi-temporal analysis applied on a change map.

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Session 1B / CD 5: End-to-end RF and Optical systems and products for navigation, communications & remote sensing

Interference Mitigation by Signal Processing Cancelation & RF Front End

Francisco Amarillo Fernandez
ESA/ESTEC

Intentional and unintentional interference is a relevant error source affecting the accuracy, integrity, continuity and availability of GNSS services. The Project has established promising DSP algorithms enabling a visibly superior interference detection and rejection capability for GNSS receivers. In order to assess and demonstrate their capability in detection, identification, and mitigation of interference sources, a hardware Concept Demonstrator (CD) has been designed, developed and tested very successfully according a comprehensive verification plan.
The CD is based on a commercial high-performance software receiver (SX-NSR from IFEN GmbH) with an improved RF-FE hardware and a new detection, identification, and mitigation software architecture. The RF-FE has been modified to enable the handling of high signal dynamics and a unique out-of-band signal rejection capability. The CD has been designed for L1/E1 with the potential of extension to other GNSS bands and alternative front-ends.
A comprehensive and extensive field campaign with life GNSS signals, received in a real environment was executed with excellent practical results.

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Integrity for navigation land users (INLU)

Ioana Gulie
Airbus

Integrity for Land Users (INLU) is an ESA TRP project in which the options to provide integrity for land users are assessed. While in the aviation domain integrity algorithms with a sufficient maturity are available, this is not the case for land users due the significantly different threat space, which is dominated by multipath and non-line-of-sight tracking. In order to assess the integrity performance of the algorithms under test in various land user scenarios, a versatile simulation environment is developed. It contains a software signal generator for baseband sample generation, which is able to reflect trajectory dynamics, multipath propagation, and interference. Additionally, a highly configurable software receiver implementing state-of-the-art and new tracking techniques and integrity algorithms is developed, which also offers blended solutions of satellite navigation, inertial sensors, and odometry. As one of the main outcomes, a novel odometry-based integrity concept for railway applications will be demonstrated.

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Enhanced methodology and tools for system performance evaluation

Nabil Jardak
M3 Systems

The use of GNSS in constrained (sub and deep-urban) environment is increasing and it is important to be able to assess the GNSS performance in various conditions with a high level of fidelity. In this context, the GUEST tool is developed. It is a GNSS enhanced performance assessment tool for GNSS characterization in diverse environments.
The GUEST tool is highly configurable. It supports 4 GNSS constellations and models the relevant error sources (atmosphere, OTDS, TGD, multi-path). The receiver propagation environment (multi-path, shadowing) is based on ray tracing tool and 3-D virtual scenes. As outputs, the tool provides relevant Performance Figure of Merits.
The GUEST tool was validation by comparison to the COTS receivers (mass-market and professional), both in controlled scenario simulations (GNSS simulator) and in-field campaigns on real SIS signals collected in diverse environment. In the presentation, the GUEST tool will be presented (its architecture and capabilities), then we will show its performance focusing on the validation methodology and results.

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Session 1B / CD 5: End-to-end RF and Optical systems and products for navigation, communications & remote sensing

Advanced Payload Architecture for GNSS

Lionel Ries
ESA

This study puts forward the renewed interest in Mega-Constellations to initiate investigations on Position-Navigation-Timing (PNT) capabilities in LEO. These capabilities would aim at complementing a GNSS backbone in areas of possible caveats of GNSSs.
The first phase concentrated onto the identification of uses cases (improved resilience, very low energy positioning, indoor), identification of high-level candidate architectures and preliminary evaluation of PNT performances. A hosted payload concept was retained, beside a primary Navigation payload and use of SATCOM signals of opportunity. Performances have been evaluated for different configurations representative of large constellations (from 72 to 648 satellites), for different carrier frequencies (from VHF to Ka-Band) and positioning technologies (range-based, Doppler-based and Two-Way ranging).
Following the establishment of the mission and system concepts, the second phase addressed the primary objective of the study, namely the payload architecture and suitability of Low-Cost technologies to fulfill LEO-PNT targets. Special focus was given to technologies (antenna, amplifiers, SDR) derived from Cube-sat and low-cost LEO segments.

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Finding interference threats

Ioana Gulie
Airbus

Radio frequency interferences, whether intentional or unintentional, are affecting the performance of the navigation receivers. The GNSS sensor stations (GSS) are key elements of satellite navigation systems and the detection and localization of the interference sources affecting the GSS receivers are very important. While interference detection, characterization and mitigation have been the objective of numerous studies, the problem of localization deserves further investigation.
During the Finding Interference Threats (FIT) project, interference scenarios and state-of-the-art RFI localization techniques relevant for GSS have been reviewed. A dedicated simulator has been developed, with elements ranging from the generation and processing of GNSS signals, to the generation of the interference sources taking into account real world characteristics like potential dynamics, propagation effects and antenna characteristics. The core of the simulator is the execution of selected detection and localization algorithms and the analysis of their performance. The performance of the various techniques is assessed and recommendations are made for their potential implementation in GSS.

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Can-Bus Interface for TT&C

Frans Thaller
SPDD System Techniek

For more than two decades, STT has been providing communication equipment for various space applications. Analogue interfaces for housekeeping and switching relays for high power commands prevailed. In recent years, some customers asked for a digital M&C-interface. It became obvious for STT that the trend towards digitization for M&C is irresistible. The first contracts with UART interfaces were signed, but STT gained the impression that this solution is not future prove and looked for more attractive alternatives. Encouraged by ESA's engagement in CAN-Bus STT decided to enter into this technology and applied for support to secure its market position. This has been granted by a contract. The efforts, struggles and achievements in this activity will be described. The evolution and availability of CAN transceivers for space, the test facilitation provided by industrial support equipment, the implementation in advanced FPGAs, and the experience with the space-specific CAN-Bus redundancy extension will be addressed.

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Mission On-Board Planning System

David Jameux.
ESA/ESTEC

The Planetary Mission On-Board Planner and Scheduler (PMOPS) project aims to allow missions to respond to changes in the current state through the use of on-board planning to maximise operational performance and science gains. It is built on software that has formed a basis for previous SCISYS-ESA contracts and raises the TRL by running on a rover in a representative environment. The need for greater on-board autonomy at a tactical mission level has been well established in a series of studies by various space agencies, with long round trip communications delays being the driving factor. Typically plans for these missions are conservative and therefore sub-optimal.
As part of creating a representative rover environment the ExoMars Rover Requirements were analysed and the software enhanced to comply with those deemed applicable. The platform was tested at Weston beach and executed various plans requiring intervention due to lack of resources and the opportunistic insertion of science activities.

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Integrated Payload Computer for Modular New Space Applications

Nuno Canto Brun
Syderal

The ongoing new space evolution calls for cost effective and recurrent products. In opposition to institutional one-shot projects, commercial space products will need to be highly modular and standardized to reach low costs. In this project, SYDERAL has developed an Integrated Payload Computer based on a mezzanine architecture, featured with a boot software and a software development support package. A Dual-Core processor with independent cache is used, running the Real Time Operating System (RTEMS). The HW includes a peripheral unit and a core computer running at 200 MIPS/200 MFLOPS. It has 8 MB of Non Volatile Memory and 256MB+128MB EDAC of Volatile Memory. IPC features a wide range of interfaces: MIL-STD-1553, SpaceWire, CAN, UART, SPI, GPIOs, 32bit peripheral bus and a debug interface. All components are ITAR-free and competitively priced. The IPC board can be used as a recurrent product in equipment as various as: On Board Computers, Payload Data Handling Units, Optical Instrument Control Unit and Video Processing Units.

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SpaceWire Network Bandwidth Performance Simulation Tool

Brice Dellandrea
Thales Alenia Space

MOST is a tool enabling simulations of complex networks based on SpaceWire or SpaceFibre technologies. It enables protocol evaluation and network design at early development phases, supports design of global systems, checks performance of real systems without the need for all physicals components, and helps studying the impact of unexpected situations. MOST is now being adapted for the NS-3 development environment to meet the need for a free, efficient and modular all-in-one simulator. This development is based on the open-source framework ns-3 and inspired by MOST on OPNET®.
MOST on NS-3 enables significant performance gain in terms of execution time and memory load, provides enhanced modularity for new protocol or component testing as well as for production of advanced statistics and enables automated scenarios to be simulated. MOST will soon enable hardware-in-the-loop simulations and new developments are made to extend its libraries (1553/CAN/Ethernet), for instance for the simulation of the novel DAHLIA SoC operation over next-generation avionics.

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Session 2A / CD 9: Digital Engineering for Space Missions

Application of Virtual Reality for Mission Data Systems

Ruediger Gad
Terma GmbH

Virtual Reality Technology is maturing in the gaming industry. In order to spin-in the use of VR technology in operations, it is essential to integrate the VR with systems used for simulation, planning, monitoring and control of human and robotic mission operations. This activity has focused on doing such an integration and provide a Proof of Concept on the use case of a virtual Moon Base. The activity has run jointly by ESOC and EAC.
In the course of the activity, operational use cases for adoption of VR technology has been analysed by interviewing the stakeholder. A reference use case of a virtual Moon Base has been implemented, deployed and demonstrated as the Proof of Concept.

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SOCCI - Science Operations Configuration Control Infrastucture

Vicente Navarro
ESA/ESTEC

The European Space Astronomy Centre (ESAC) has been ESA's Science Operations Centre (SOC) since 2008. For each science mission ESAC hosts a number of operational systems typically related to mission planning, instrument handling, data processing and data archiving. As part of this role, ESAC is responsible for the management and implementation of Science Operations Systems throughout the software development lifecycle.
Therefore high quality software engineering flow-down from Mission Requirements to Science Operations represents a critical success factor for ESAC in particular, and any space project in general.
Although standards and principles for 'good' software engineering have been established for quite some time, over recent years more and better support tools have become available. These tools represent key enablers for increased efficiency, contributing to deliver higher quality software systems with less effort and time.
SOCCI provides a common software engineering environment where a core set of tools and procedures are shared across teams in Science Operations.

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ESA Architecture Framework Upgrade

Christian Philippe
ESA/ESTEC

The European Space Agency Architecture Framework (ESA-AF) was developed to address space based Systems of Systems (SoS) engineering. It is based on the standard methodologies TOGAF and MODAF, tailoring and extending these architecting methodologies to satisfy ESA's needs. Although ESA-AF meta-model is built on top of well-established open industry standards to foster adoption, ESA-AF modelling environment can be very challenging for end-users without the necessary background.
To address such end-users the ESA-AF Data Entry Framework (DEF) and associated tooling has been extended with a form-based modelling environment covering the complete ESA-AF meta-model. In addition, overview functionality has been provided offering a user-friendly entry into the form-based modelling environment based on standard architecture development workflows, organized along the logical different architecture viewpoints. Further, ESA-AF software has been upgraded to be compatible with the latest versions of MagicDraw and Eclipse, and include two System-of-Systems (SoS) components libraries.

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Session 2B / CD 5: End-to-end RF and Optical systems and products for navigation, communications & remote sensing

Optical inter-satellite links for Galileo 2nd Generation -1

Philipp Biller
Tesat-Spacecom

Connecting the satellites in a navigation constellation by intersatellite links offers a full range of new possibilities for ranging, timing and data exchange. Optical inter-satellite links (ISL) can achieve high ranging resolutions due to its short wavelength and provide in parallel duplex data transmission. As the optical beams are narrower than RF beams, no interference with other potential optical communication systems will occur and thus offer high operational security and immunity to jamming and eavesdropping. An obvious advantage of the optical ISL is the fact that the frequency usage is not regulated by ITU, which makes the planning and operation of a navigation constellation much easier.
In the frame of an ESA funded optical ISL program, TESAT and partners from DLR, Timetech and Synopta presented an optical ISL solution for Galileo based on a high TRL terminal of Tesat and demonstrated parallel ranging, timing and data transfer in a laboratory environment.

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Optical inter-satellite links for Galileo 2nd Generation -2

Jacques Haesler
CSEM

The 2nd generation of the European GNSS “Galileo” considers the potential use of inter-satellite links (ISLs) for ranging and communications, with an initial solution based on an RF microwave link.
This project investigates the alternative implementation of an Optical ISLs (O-ISL) considering potential advantages in terms of compact modular design, data rate, security, regulatory and bidirectional communication. A preliminary design of an optical terminal for communication and ranging (Optel-GNSS) between two GALILEO S/Cs has thus been elaborated. Functionally it is compliant with the requirements, the mass is 50% higher and the power consumption only 12% compared to the specification. Most of the technology has already been used in the Optel-µ®.
TAS-CH and CSEM are in a good position to develop an Optel-GNSS. The step from the Optel-µ® to the Optel-GNSS is rather big, but the step from the Optel terminal family to the Optel-GNSS is comparable to similar steps TAS-CH has made during the development of the Optel terminal family.

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Multi GNSS Reference Station

Margaux Cabantous and Raphael Petrau
CapGemini FR

Satellite navigation systems market is growing, leading to the necessity to provide performing and sustainable GNSS and SBAS Ground Segment infrastructure, in particular for Reference Stations.
The objective of this activity is to integrate and test a Prototype Multi GNSS Reference Station, based not only on selected COTS equipment but also on prototype developments, and to demonstrate the compliance of these equipment with regards to stringent performance specifications associated to DFMC SBAS context, including new GPS L5 and Galileo E1 and E5a signals.
To evaluate performances of the Reception Chain (involving both antenna and receiver), tests have been conducted. These tests showed that the proposed prototype has globally good performances in terms of acquisition and tracking of GNSS signals. Concerning the receiver, the prototype software allowing to track Galileo signals showed good results as no functional issue has been encountered during the characterization tests phase. A prototype antenna has also been developed with improved performance to meet challenging SBAS requirements.

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SPI4SPACE study

Daniele Rolfo
ThalesAleniaSpace Italy

A natural evolution of sensor acquisition methodologies is pushed by the need to increase the signal integrity and resolution of the transmitted signals, maintaining in any case very low power consumption. Those capabilities make the need for the definition of standards for digital transmission of sensor data in spacecraft. Previous TRP/GSTP activities have already performed an extensive trade-off of existing low speed digital networks, resulting in the proposed adoption of SPI and I2C for simple digital peripheral interconnects. This activity has prototyped SPI protocol(s) and physical layers for space applications. A specification taking into account existing solutions has been derived and Signal integrity techniques and also differential variants of the physical layer were investigated and prototyped in order to improve the communication quality and integrity. The SPI model(s) and code(s) for the demonstrator were developed and the test results will be presented together with the general methodology of the trade-offs performed.

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2nd Generation APS STR Breadboard, Step 2: Optical Head

Peter Hoffmeyer
Terma DK

The purpose of the study was, via manufacture and test of an engineering model, to design and demonstrate a second generation advanced, low cost and easily accommodated APS based optical head and baffle incorporating the technological advances identified in pre-cursor activities. Furthermore to produce an early BB based on the existing LCMS detector to provide early design de-risking in time for the CDR.
The fully integrated single chip APS sensor (Faintstar or LCMS) was designed

- For low cost, mass production and automated testing with high reliability using a minimum number of components
- With a miniaturized mechanical outline with outstanding thermo-mechanical stability suitable for integration in close proximity to the satellite payload
- For very low power consumption (< 0.75 W) with no need for thermo-electrical cooling
- To use a compact single stage straylight baffle completely mechanical decoupled
- With a SpaceWire interface and single 5 VDC supply

Design and qualification activities were completed September 2017.

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Miniaturized Star Tracker developed for CubeSats

Nurcan Alpay Koc
Innovative Solutions in Space

ISIS Star Tracker was developed with funding from ESA in the scope of CubeSat Technologies Pre-Development (CubeTech) Project.
The objectives of the project were:

- Performing a detailed analysis on mission applications, and associated mission concepts and requirements.
- Defining the relevant CubeSat technical requirements to unit-level
- Evaluating the technologies needed for the defined missions with respect to the current state of the art and the requirements
- Trade-off and selecting technologies to be taken forward for development
- Designing and manufacturing a prototype model for each of the technologies to be developed.
- Validating the prototype model of each developed technology in a laboratory environment (TRL4) and in a relevant environment (TRL5) defined by ESA TRL Handbook.

CubeTech Project was completed successfully with the development of the miniaturized star tracker with the achievement of project objectives, and TRL 6 has been achieved at the end of the project.

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Session 3A / CD 2: Structures, Mechanisms, Materials, Thermal

Space based Optical Cryocooler development in Europe

Bauke Heeg
Lumium

Solid state optical cooling provides several distinct advantages for space applications, most notably being vibration-free and enabling cryocooler miniaturization. Despite being a relatively new cooling technique, research has enabled record cooling temperatures of under 90K using Yb:YLF materials. Moreover, the impact of many factors on the efficiency and power budget of the cooling process have been investigated in detail, such that device engineering of space based optical cryocoolers can now be considered in earnest. Here, an overview of the main R&D advances made in this technology will be presented, with emphasis on (i) critical device components including cooling medium, optical pump and thermal link; (ii) device architectures; (iii) system level performance estimates. This overview includes recent ESA ITI type A project results, previous research by the authors, and a significant amount of work to date in the USA. Finally, the prospects of optical cryocooler development in Europe will be placed in context of the general field op cryocooling.

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Impact analysis of piston alignment on key compressor performance characteristics

Edward Jansen
Thales Cryogenics

Under ESA GSTP, TCBV has performed a study in 2016 into the main causes of the Large Pulse Tube Cooler (LPTC) compressor (CPA) induced vibrations and the corresponding impact on CPA level. The goal of this study was to gain an understanding of the underlying root causes, verify them by analysis or test and to come to recommendations for the CPA design in order to make it less susceptible to integration and test influences with respect to induced vibrations.
The identified design changes and MAIT improvements have been introduced in the manufacturing process of the LPTC CPA for the for the MTG and IASI program. Formal qualification has been performed via the Proto Flight Model approach on CPA model and dedicated qualification test on CPA motor level in combination with required process qualification.
Four flight models have already been manufactured which show a large improvement with respect to the susceptibility against external influences which impact induced vibration and friction.

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Highly Efficient Stand Alone LHP based radiator system

Olivier Berder
Euro Heat Pipes

The purpose of HESAS is to provide to the market a qualified TRL6 generic and modular Highly Efficient Stand-Alone and scalable LHP-based Cold plate and Radiator thermal bus which can be integrated easily on existing satellites.
Add-on payloads in late project phases are one of the targeted applications. Another one are telecommunication satellites on which space, mass and power is often available for additional experiments but located far from the south/north radiators.
HESAS is based on modular and light-weight radiator panels, scalable cold plate with isostatic supports, scalable LHPs with flexible LHP tubing network allowing routing compatible with various accommodations and MAIT needs. Payloads of 10kg to 50kg dissipating 30W to 500W.
A Qualification Model using two modular radiator blocks and two redundant LHPs has been built and tested to cover most standard thermal and mechanical environment ranges. It demonstrates excellent performance like equipment temperature stability 1°C and an overall conductance between unit and radiator up to 15 W/K.

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Session 3B / CD 5: End-to-end RF and Optical systems and products for navigation, communications & remote sensing

Micro-optoelectronic FGU

Dr. Stefan Kundermann
CSEM

Currently photonics based payloads for optical microwave distribution suffer from complexity and are still comparatively big, heavy and power hungry. In a typical LO distribution implementation the microwave frequency is generated in the RF domain and then transposed to the optical domain. The goal of the present funded TRP activity has been to generate the microwave frequency directly in the optical domain and with emphasis on miniaturization by using approaches based on photonic integrated circuits.
Micro resonators, possessing both a high quality factor and an appropriate free-spectral range, have been fabricated and packaged. The fabrication delivered a high yield, and the packaging was mechanically, thermally and optically stable and robust. Two different operational approaches of the fabricated photonic-integrated micro resonators have been explored. The first approach (hyper-parametric oscillation did not achieve the desired performance requirements; the second approach (solitons) shows great promise in numerical studies and indirect experiments but could not be implemented as the micro resonator quality factor was currently not yet sufficiently high.
Once achieved, the micro-photonic frequency generation unit (FGU) will enable compact and efficient generation of low noise microwave signals that can directly be distributed optically. Such sources are not only of interest for space applications but also for ground-based time-synchronization applications or optical channel generation for high-bandwidth optical communications.

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Mm-wave mixers with low-barrier diodes

Matthias Hoefle
ACST GmbH

Conversion loss and noise temperature for low-barrier Schottky diodes in a test jig of a fundamental 183GHz mixer were studied. Measurement results of standard ACST 3DSF5 diodes shown good conversion loss of below 5dB (DSB) and noise temperature of below 3000K at LO power levels down to 100µW.
Two modified diodes were also evaluated. Measured conversion loss and noise is higher than simulated. Excessive noise may be attributed either to effect of two or more competitive current mechanisms at the Schottky interface or to mixer assembly issues.
Even if the noise temperature of standard 3DXF5 diodes is not as low as desired, reaching 100µW LO pump level brings considerable advantages in heterodyne receivers with LNAs in the front. Since LO generation is typically power-consuming, its considerable reduction is important from DC power budgets of space missions but also from reliability point of view. Less LO power would also importantly bring down the cost and complexity of the LO chain.

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Generic frequency converter unit for spaceborne lidar instruments

Myriam Raybaut
ONIRA

In the context of global climate monitoring the technique of differential absorption lidar (DIAL) is used to measure the concentration of atmospheric trace gases (e.g. carbon dioxide, methane, water vapour) with high accuracy. The DIAL instrument is required to emit simultaneously a minimum of two laser wavelengths positioned with very high precision and stability inside and outside the chosen absorption feature of an atmospheric constituent. Nanosecond-pulsed lasers in the near-infrared wavelength range are in the focus of technology developments for this purpose. One generic scheme to generate the desired laser emission, applicable to a variety of target species, is frequency conversion and subsequent amplification of a Nd:YAG laser at 1µm wavelength by use of an optical parametric oscillator-amplifier (OPO-OPA). A versatile OPO-OPA laser system has been developed and its performance demonstrated for the particularly challenging case of measuring CO2 in the 2µm band. The development comprised a dedicated engineering effort and environmental testing to validate a space-worthy instrument design.

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Integrated Tile Demonstrator

Grzegorz Adamiuk
Airbus

Next generation C-Band SAR based on digital beam forming (DBF) will push the performance of the instrument and allows swath width improvements by a factor of 5 (400km) compared to current Sentinel 1 while still maintaining the resolution of 5m x 5m. This is achieved by azimuth DBF processing and on-board scan-on–receive functionality in the digital domain. In the activity Integrated Tile Demonstrator a partial antenna element (Tile) of the phased array antenna has been designed, built and tested. The DBF is performed in a FPGA in fast time. In addition, the FPGA handles the calibration of the system and the full antenna can be calibrated in fractions of a second without imaging interruption. A full antenna will have 56 units and is therefore a graceful degrading system. The presentation gives an overview of the achievements in activity aiming at next generation of C-band SAR instrument in the Copernicus Program: Sentinel-1 Next Generation (S1 NG).

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Generic AOCS/GNC techniques and design framework for Failure Detection Isolation and Recovery

Domenico Reggio
Airbus Defence and Space

The study was motivated by the commonly agreed fact that many times there is a lack of a systematic approach, engineering transparency and guidance of the FDIR engineering process. The objective was therefore to come out with a generic AOCS/GNC FDIR methodology and develop a software framework which would support the different steps of the process, allowing already in Phase A/B an early prototyping and dynamic verification of FDIR AOCS/GNC mechanisms.
The study logic was divided in three phases:

- Phase 1: Production of requirements and detailed design of generic FDIR methodology and framework
- Phase 2: Implementation and verification of the generic AOCS/GNC FDIR Engineering framework
- Phase 3: Validation of the approach on the basis of case studies

The presentation will show the proposed FDIR methodology and software framework developed in matlab/simulink to help in the implementation of the FDIR methodology.

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Space 3-axis CVG Gyro Unit, Arietis-1

Alberto Torasso
Innalabs Ltd

Over the past 50 years, many different gyro technologies have been developed and used in space, with Fiber Optical Gyros (FOG), Ring Laser Gyros (RLG) and Hemispherical Resonator Gyros (HRG) being predominantly used from the late ‘90s up to today. Each technology offers a wide range of advantages and disadvantages while most of the time offering a similar performance. More recently, new applications have emerged in the commercial industry for which accuracy and precision are no longer the driving factors. Instead, reliability, mass, power budgets, and meeting performance at reduced cost and size have become paramount.
In that context, Innalabs has developed a Coriolis Vibratory Gyroscope (CVG) sharing common features with HRG, and, with the support of the European Space Agency, a 3-axis Rad-Hard Rate Measurement Unit (RMU) named ARIETIS is now being developed by Innalabs with lifetime of more than 15 years.

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Optimal guidance and control for flexible and manoeuvring spacecraft

Alexandre Falcoz
Airbus Defence and Space

Agile satellites operate in LEO with weakly flexible structures using a specific AOCS control architecture. High accuracy pointing and maneuverable GEO satellites (e.g. GEO-HR) using the same agile AOCS architecture requires rigid S/C thus fixed and oversized Solar Arrays with important mass and cost impacts, and complex yaw steering maneuvers to optimize the sun power illumination.
In the future, to address these GEO missions using standard large flexible rotating Solar Arrays, it is necessary to revisit the agile AOCS control architecture to limit the overall attitude maneuver duration of a large flexible satellite.
A Kalman filter is used on-board to estimate the large structural modal parameters (oscillation frequency, amplitude, damping and phase). This information is used by a feed-forward controller (input shaping) which sends impulses in order to compensate for flexible structure oscillations occurring during an attitude maneuver. Several robust LTI controllers with different bandwidths are designed and scheduled using gain-scheduling technique to limit the total maneuver duration.

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RDV and Docking 3D camera technology trade-off and BB demonstration

Peter Davidsen
Terma A/S

In previous decades, the vision-based navigation problem based on 2D imaging has been largely studied and applied in space, for rendezvous and docking, as well as rover navigation, or Entry Descent and Landing. By providing measurement of the third dimension (range), 3D Time-Of-Flight technology camera technology looks a promising alternative for many applications. Illuminating a whole scene at a time providing a whole array image, there's no need for complex processing or a moving mechanism, which clearly appears as an advantage for space applications.
The presentation will provide an overview of the "RDV and Docking 3D Camera Technology Trade-off and Breadboard Demonstration" ESA study conducted by Thales Alenia Space, SINTEF and TERMA with focus on:

- Study objectives, requirements and trade-offs
- Preliminary camera design and breadboard camera
- Test results

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Session 4A / CD 2: Structures, Mechanisms, Materials, Thermal

High Density Interconnect Technology and Thermount replacement with assembled devices

Per-Erik Tegehall
Swerea IVF AB

The purpose of the study was to research and understand end-user needs for low-CTE HDI PCBs and investigate available alternatives on the market as replacement for Thermount 85 that was becoming obsolete due to stopped production of aramide fibres. A low-CTE material from Hitachi, Hitachi MCL 700, was identified as a possible replacement for Thermount 85NT. HDI boards were successfully produced with this material but it was found that it was necessary to prefill vias for god results. Test boards were also successfully mounted and soldered with different types of components including a CCGA 1152. Assembled boards have passed through environmental testing including vibration, chock and thermal cycling. In addition, specially designed bare boards were produced for testing the resistance against formation of conductive anodic filament (CAF). No large difference in performance was observed in the environmental tests whereas the Hitachi material performed better than Thermount 85NT in the CFA test.

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Characterisation of Demisable Materials

Jim Merrifield
Fluid Gravity Engineering

This initial characterization of demisable materials is performed to support destructive entry ground casualty risk assessments. Aerothermal testing was performed in two complementary Plasma Wind Tunnel (PWT) facilities and in one static test facility. The main purpose of testing in the PWT was to examine the effect of the plasma environment on the surface chemistry of the samples and to observe the phenomenology of demise. The main purpose of testing in the static facility was to allow the effect of applied mechanical loads to be observed. Tests were performed on basic and complex materials including a sample representative of actual flight hardware (CFRP over-wrapped tank).
The project demonstrated that the processes that lead to aerothermal destruction are still not well understood. For complex materials, like CFRP, the understanding of the demise process and mechanisms is extremely limited. The characterization of the physical properties of the materials is not sufficient in isolation. It is necessary to conduct experiments under realistic conditions.

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Citric Acid as a Green Replacement for Steels Passivation

Anthony Kent
ESR Technology

The objective of this activity was to evaluate the suitability of the environmentally friendly citric acid process for replacing the health hazardous nitric acid systems, used for passivating stainless steels used in manufacturing spacecraft and ground support structures. Equivalent or better performance compared to nitric acid treatment was to be demonstrated through significant test evidence, on a representative selection of stainless steel grades. The identification of optimum citric acid process parameters for three representative stainless steel grades are presented. Characterization of welded and non-welded citric acid passivated specimens (in terms of chemical, corrosion and mechanical testing) is reported, and comparisons with the properties of specimens passivated with a reference nitric acid process are shown. The environmental benefits of passivation using the citric acid processes, compared to a baseline nitric acid process, were assessed by Life Cycle Assessment. Finally, considerations are given to the applicability of citric acid processes for passivation of stainless steels used in spacecraft and ground support equipment.

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Electron Beam Welding for Safety Critical Space Applications

Chris Allen
TWI

Mono-propellant thruster control valves are manufactured from a number of different steels using welding techniques such as Laser Beam Welding and Electron Beam Welding. In recent years there has been a number of weld quality issues which have affected a number of ESA led missions. In this activity a programme of work was performed to provide a comprehensive comparison of Laser and Electron Beam welds in dissimilar stainless steels and representative penetration depths to determine if one process was more suitable. Non-destructive and destructive evaluation was completed on flat plate coupons and then demonstrator components. Extensive pre-weld beam measurements were also made to understand the state-of-the-art quality assurance possibilities for both processes. The results indicated that with the correct equipment, quality assurance tools and procedures, it is possible to make welds of the appropriate integrity with either welding technique to meet flight acceptance requirements.

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Session 4B / CD 5: End-to-end RF and Optical systems and products for navigation, communications & remote sensing

Phaseless Near Field Measurements

Olav Breinbjerg
Technical University Denmark

Near Field (NF) Antenna measurements have many advantages. One of the disadvantages is the required phase information (coherent measurements). Especially with higher frequencies, the reliable measurement of phase information becomes increasingly difficult. Since the introduction of the “amplitude only” or “phaseless” technique, the higher mm- and sub-mm wave frequencies have been seen as THE application area.
The objective of this activity was a quantitative assessment of the Phaseless Near Field Antenna Measurement technique on several aspects impacting the accuracy. Both planar and spherical scan geometries had to be assessed. A literature study and trade-off has been performed to select the most promising phase retrieval approach. The selected algorithm has been implemented in Software code. Measurements have been performed at 12 GHz (DTU Spherical NF facility), 60 GHz (DTU Planar Near Field facility), and 600 GHz (ESA Planar Near Field Sub-Mm wave Scanner Facility (SMS).
Results have been critically assessed against coherent measurements (i.e. using phase information) and/or antenna models.

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Advanced low loss dual polarized slotted waveguide antenna

Maurice Paquay
ESA

Future SAR instruments will benefit from enhanced antenna polarisation control on both Transmit and Receive. In this project, an antenna called ADESA (ADvanced ESA Sub-Array) has been developed. ADESA is a centre-fed resonant-array configuration consisting of two identical parallel squarax transmission line channels. Slots are cut into them in order to excite microstrip patch radiators etched on a dielectric superstrate. Arbitrary polarisation (including linear and circular) can be synthesized when both channels are fed simultaneously with appropriate phase & amplitude offsets.
A breadboard has been designed, manufactured, tested and compared to a Sentinel-1 Direct Radiating Array (DRA) breadboard. (The Sentinel-1 DRA was used as a benchmark.)
The measured performance satisfied all the Sentienal-1 requirements except for the port isolation. This is a clear limitation of this concept. The radiative performance was considered to be excellent for these prototype Subarrays. The Subarray insertion loss (excluding mismatch loss) was found to be ~0.6dB on average, which falls well within the 1dB requirement.

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Session 4B / CD 4: Energy Storage (Electric Architecture/Power and energy/EMC)

Li-S Cells for Space Applications (LiSSA)

Céline Barchasz
Oxis Engery

Common energy storage devices based on Li-Ion technology used in space are reaching a plateau in performance. A step towards the novel Lithium Sulfur technology could improve this situation. In this project the state of the art Lithium Sulfur technology was assessed towards an application for geostationary satellites. A comprehensive research of all the patents in this field was conducted. The main challenges were identified and potential solution elaborated. Following a period of production development, the resulting cell chemistry was successfully scaled-up to high capacity cells, of which 20 were sent to Airbus for testing (characterisation testing, geostationary life cycling and calendar ageing tests). The final cell design demonstrated an energy density of 400 Wh/kg at relaxed discharge rates. At geostationary-like cycling conditions, an energy density of around 270 Wh/kg was obtained, with a maximum cycle life of 4 seasons. A further effort towards reducing the cycling capability could bring a large benefit for future space applications.

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Navigation on a chip

Sabine Ludwig and Uwe Schmidt
Jena-Optronik

The objective of the Navigation on a Chip project was the preliminary design and de-risking of a low cost, re-useable Navigation Camera that could be easily re-configurable from one mission scenario to another, with scenarios comprising Planetary Approach, Small Body Navigation, Rendezvous and Entry-Descent and Landing (EDL) in Low and High Dynamics. A trade-off has been performed between the two new image sensors under development in parallel by ESA (HAS3 and Faint Star, both intended to work in the visible range). The needs in terms of configurability, HW/SW architecture (FPGA, CPU, memories, buses) were also identified. The preliminary design for the Navigation Camera provides a versatile system that can be used in a variety of scenarios and phases within a mission, taking advantage from the synergies of previous developments in ESA.

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GNSS receiver for LEO/GEO/HEO applications (GAMIR-2) - EQM

Franz Zangerl
RUAG Austria

The objective of the overall GAMIR activity was the design, development and testing of a generic GPS/Galileo Miniaturised Multi-frequency Space Receiver (GAMIR), in Engineering Qualification Model (EQM) form, for supporting absolute and relative GNSS navigation in LEO/GEO orbits. While the design of the key elements of the receiver are suited for a wide range of missions, the actual receiver configuration and the mechanical concept of the EQM targeted on high-end scientific LEO missions. This multiple-frequency receiver had to be designed to satisfy the on-board navigation requirements of near term and future space missions using the civilian/OS signals of the GPS and Galileo systems. The target was a self-consistent, compact and highly integrated receiver. The objective to optimally support near term missions was the motivation to maintain the capability to process GPS P(Y)-signals, which initially had been excluded from the GAMIR development. The EQM had to be manufactured, tested and qualified in compliance with ECSS standards.

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HEOP: GNSS HEO Navigation Preparation

Pedro Freire da Silva
Deimos Space

Development of acquisition, tracking and navigation engines for the demonstration and performance assessment of GNSS-based navigation in high elliptic orbits, taking the Proba-3 mission as reference. Development of a space service volume analysis tool.
Different techniques suitable to be used in high elliptic orbits have been implemented and evaluated. An extensive simulation campaign has been carried out, taking the Proba-3 mission as reference. Results in the perigee and GNSS altitudes show successful acquisition and tracking down to 20 dB-Hz, and position errors of 2.5 m (RMS) and positioning solution convergence in 10 seconds. For apogee no positioning solutions are available with the solutions proposed. The receiver is able to acquire and track, losing lock after several seconds. The problem has been extensively studied but no solution has been found by the consortium for low C/N0 conditions (below 20 dB-Hz).

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MosaicNG Single-Frequency Multi Constellation GNSS Receiver Development

Michael Marx
Airbus Defence and Space

The space-borne GNNS receiver market ranges from high-end market products, that are designed for maximum performance with resulting high price, to a high volume market segment, that currently requests GNSS receivers with a performance of 10 - 15 mrms for position, 30 mm/s for velocity and 1 µs for time at a moderate price per unit.
The MosaicNG (commercial name LIONneo) has been developed for this high volume market, based on the LION1300 state-of-the-art product; it provides high-end receiver technology (AGGA-4 ASIC for GNSS signal processing, new RF Front-End design based on discrete components and internal LNA) for multi-constellation and modular single- or multi-frequency features at an attractive price/performance relation.
The activity enveloped the development and qualification of a multi-frequency, multi-constellation GNSS receiver EQM (TRL 7). The development of the MosaicNG receiver enables continuous support of upcoming ESA missions with a cost-optimized and highly reliable GNSS solution, with same HW and SW interfaces as all other LION GNSS receivers.

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Nano-enabled Fibre Reinforced Plastics for Space Applications

Athanasios Baltopoulos
HTS

This work demonstrates the use of nano-enabled Carbon Fibre Reinforced Plastics (CFRP) in a series of space application demonstrators. NEPTUNE activity developed specific nano-enabled CFRPs for three space applications; (a) stiffened composite structures, (b) spacecraft sandwich structural panels, and (c) electronics enclosures. The identification and definition of all demonstrators was done in collaboration with end-users: (a) was investigated with ATG Europe, (b) and (c) in collaboration with HTS GmbH. Following the Made-to-Measure Materials Design process different functionalities are targeted for each application; interlaminar toughness and thermal conductivity. The technology investigated is based on prepregs and autoclave manufacturing, enabling near-term utilization of the achieved performances. The achieved materials have then been scaled-up in terms of industrial processing to produce representative spacecraft elements. Manufacturing took place following conventional autoclave processing as used in production of spacecraft element demonstrators. Benefit assessment was performed via simulation and testing.

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Development of Space Fibre Metal Laminates (FML)

Jochem Frudiger
GTM Advanced Structures

The objective of this activity is to design, model, manufacture and test at least three new FMLs, based on the experience of GLARE1, which have better HVI protection than materials already in use.
In this study a protection system based on the Whipple shield will be developed for MMOD objects with a size of 1.0 cm and a velocity of 7km/s. With a smart choice of fibre metal laminates (FML) it is possible to decrease thickness, weight and cost compared to current shields, while remaining the resistance characteristics against High Velocity Impact (HVI).
This shield consists of two parts, a bumper and a rear wall. The main task of the bumper is to fragment the projectile such that the impact of the projectile on the rear wall is distributed over a large area.

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Surface Engineering for Parts Made by Additive Manufacturing

Antti Vaajoki
VTT Technical Research Centre

The effect of surface engineering techniques to improve the surface roughness of AM materials is not well characterised. Material surface roughness affects properties relevant to space applications.
Four AM materials; SLM Al-Si10-Mg, SLM SS-316L, SLM Ti-6Al-4V and EBM Ti-6Al-4V; were manufactured in three surface roughness conditions, employing specifically-developed methodologies, were subject to space industry standard tests to evaluate the effect of each methodology. Treated materials generally performed similarly to that of the parent material for static and dynamic mechanical properties, and compatibility with paints and coatings. Corrosion resistance was increased, generation of particulate contamination was decreased.
The surface improvement methodology scenarios developed are considered to be viable methods of improving surface roughness in AM materials and suitable for further development and qualification. The ESA TRP was led by VTT Technical Research Centre (Finland), supported by The Manufacturing Technology Centre (UK) and Magna Parva (UK).

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Session 5B / CD 4: Nuclear Power (Electric Architecture/Power and energy/EMC)

Radioisotope Heater Unit Prototype Development

Richard Ambrosi
University of Leicester

Radioisotope Heater Units (RHUs) are fundamental to keep the internal spacecraft temperatures within the required operational and survival limits, especially in regions where the availability of solar power is limited. RHUs are being developed in Europe as part of a European Space Agency (ESA) funded program. Aimed at enabling or significantly enhancing space science missions, these systems rely on the cost-effective production of americium-241 for the fuel. System architectures and laboratory prototype systems have been designed built and tested. The RHU designed to deliver 3 W of thermal power output. The design implements a multi-layer containment approach which includes representative materials including platinum-rhodium alloy cladding and carbon-carbon composite aeroshell. Re-entry performance studies have confirmed the compliance with safety requirements, while thermal and structural modelling and testing have proved the feasibility of the design.

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Thermoelectric Converter for Small Scale RTG

Richard Ambrosi
University of Leicester

Radioisotope thermoelectric generators (RTG) are being developed in Europe as part of a European Space Agency (ESA) funded program. Aimed at enabling or significantly enhancing space science missions, these systems rely on the cost-effective production of americium-241 for the fuel. The use of an iterative approach and the application of lean methodologies for the development has been the approach of this technology program. System architectures, laboratory prototype systems and bismuth telluride based thermoelectric generators have been developed. The RTG heat source configuration is designed to deliver 200 W of thermal power output while minimizing the volume occupied by the fuel. A 5% total system conversion efficiency and a modular scalable design imply that electrical power output can range between 10 W and 50 W. Each RTG system could house up to 5 heat sources. An electrically-heated RTG system based on the 200 W heat source architecture has been designed, analyzed and tested.

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Delay-Tolerant Networks for Earth Observation Satellites

Jeremy Pierce Mayer
GMV Insyen

The Delay-Tolerant Networks for Earth Observation (DTN-EO) project set out to enhance European knowledge with regards to the applicability of Delay Tolerant Networks (DTN) in existing and future Earth observation missions. In order to accomplish this task, a software-based emulator was developed, which allowed DTN to be tested for behavior and performance, utilizing realistic data profiles. Three high-level scenarios were provided by ESA, which were refined by the DTN-EO team. Once the emulation was completed, a low-level analysis was performed, which proved the feasibility of DTN utilization. In parallel, a high-level rollout and Return on Investment strategy was devised, which has shown DTN to be a valuable addition to future missions.
Further analysis is ongoing, focusing on the low-level implementation recommendations for various mission classes; by incorporating the emulation results, the recommendations are intended to provide future mission designers with a valuable toolkit for DTN within their respective systems and use-cases.

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Complex Constellation Management

Enrico Stoll
TU Braunschweig

Recently, several announcements were published to deploy satellite constellations into LEO containing several hundred to thousand satellites. This trend towards larger constellations is related to the benefits of distributed systems such as higher redundancy, higher reliability, and better coverage. The price for these benefits is a greatly increased complexity of control and coordination, as conventional manual commanding cannot be scaled to mega constellations.
Many indications point to a further increase in the size and number of constellations due to the evolution in the space sector, often referred to as “Space 4.0” or “New Space”. This necessitates a rethinking of the way satellites and satellite constellations are planned, designed, and operated. The aim of ASIMOV is to identify and address fundamental challenges that arise when large constellations have to be efficiently operated. This includes assessing today’s approaches on automated constellations operation, developing a service-oriented automation strategy, and designing and implementing a proof of concept for the derived solution.

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Feasibility Study of Active Debris Mitigation for Mega Constellations

Carole Billot
TAS-I

The objective of this activity was to perform a cost assessment and subsequent feasibility study resulting in conceptual designs of active debris mitigation concepts for mega constellations, and trade re-entry, re/de-orbiting and active orbit cleaning.
On average, two satellite failures per year in LEO result in a total loss due to a power, propulsion or electronics bus failure (plus one satellite total loss due to other reasons). For mega constellations containing hundreds of satellites this could imply a loss of several satellites, i.e. the creation of several debris objects, each year within the constellation. The uncontrolled debris objects will result in a collision risk to the active satellites within the constellation and/or a decreased service. Furthermore it will also violate the space debris mitigation rules if the debris is left in protected zones.
The study investigated Active Debris Removal for mega constellations, and traded possibilities such as re-entry, de/re-orbiting and servicing/replacing satellites or cleaning the orbit.

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USACDF – Upper Stage Attitude Control Development Framework

Hans Strauch
Ariane Group

The increased demand for greater functionality and for extending the domain of applicability of future launchers leads to higher complexity of the GNC algorithms. Furthermore, there is also a need for a responsive design methodology, which can quickly adapt to changes in the requirements during the development process. These demands are stretching the current, largely manual, development process, which is fragmented in the different disciplines and activities concerning modelling, algorithm design, software coding, implementation on the avionics platform and the associated testing.
The model-based-design (MBD) philosophy presents an attractive solution in addressing the multi-disciplinary nature of the task. The suite uses Mathwork's toolchain and dSpace.
Although the focus of the work is on a proper establishment of a framework and not a particular design, the versatility of the suite has been tested by applying it do two particular problems, namely the development for a vertical take-off and landing demonstrator and the active damping of sloshing in one and zero g.

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On-board Real-time Trajectory Generation

Carlo Alberto Pascucci
Embotech

The objective of this activity was to analyze, design, develop, prototype, test and evaluate a concept for on-board trajectory optimization able to perform in real-time on a flight representative processor. In addition to the core real-time software, a development environment has also been designed. The software infrastructure comprises: novel mathematical formulations of optimal real-time guidance concepts; auto code generation engine for real-time optimization software code; code analysis and inspection tools to assess and verify intended correct code behavior; tools to deploy and embed the optimization software packages on target processors. Initial tests on flight representative processor in the loop hardware show that the optimal trajectory generation code is fast enough for real-time implementation. Full reliability of the trajectory generation procedure has been achieved on the considered set of test cases. The technology as developed, applies in general to any space transportation system. Such capabilities also enlarge the operational mission perimeter while reducing the mission preparation costs through automation.

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Analytic Stochastic / Time Varying Mu Analysis for the VEGA GNC

Andres Marcos
University of Bristol

Previous ESA TRPs established to introduce advanced analytical modelling, analysis and design tools in the industrial Space Verification and Validation (V&V) process clearly showed the gaps between classical linear (i.e. gain/phase margins) and nonlinear (i.e. Monte Carlo) tools. They also show the potential complementariness of these robust techniques with the current industrial state-of-practice, represented by Monte Carlo campaign, to reduce (in terms of time and cost) the control design and V&V cycles.
This project was established to: [i]consolidate and demonstrate the robust modelling and analysis techniques known respectively as linear fractional transformation (LFT) and structured singular value (or mu-analysis) as applied to launchers; [ii] Study the relation between worst-case mu deterministic and probabilistic analysis tools; and [iii] demonstrate the need of robust control design tools such as H-infinity and linear parameter varying (LPV) to address the identified gaps resulting from time/parameter varying system aspects.
The selected system was ELV VEGA launcher, and the focus was on the robust stability and robust performance assessment of the VEGA TVC control system under uncertainties and external perturbations (using for example the VV05 flight wind data).
The achievements of the project were:

1. Development and validation of a robust modeling methodology using closed-loop simulated and real data.
2. Consolidation and validation of robust stability and performance analysis tools in their application to VEGA.
3. Comprehensive study of the status of probabilistic tools for worst-case analysis. The current TRL of these techniques is very low due to computational limitations but its potential for impact very high (as demonstrated by recent, and increasingly more numerous, studies by the space industry on these techniques).
4. Establishment of the preliminary work towards application of LPV and adaptive control design techniques for VEGA.

In conclusion, it was shown that the complementariness of the consolidated robust modeling and analysis techniques with the current industrial state-of-practice (represented by Monte Carlo campaigns) has the potential benefit of reducing the control design and the V&V cycles –both in terms of time and cost.

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Simulation Tool for Rendezvous and Docking in High Elliptical Orbits with 3rd Body Perturbation

Mario Innocenti
University of Pisa

The aim of the activity was the study and characterisation of the relative motion dynamics in the restricted three-body problem, with reference to the local-vertical local-horizon coordinate system, for the preliminary design of rendezvous and docking missions.
The study produced four equation sets for relative motion description, with different level of accuracy. These sets were used for the systematic computation of rendezvous manoeuvres for a chaser spacecraft approaching a target in the restricted three-body scenario. Both impulsive and continuous thrust manoeuvres were considered, and an innovative formulation to handle multiple firings during a transfer arc was also developed, which improves the overall performance. In the frame of the study a simulation tool was developed for rendezvous missions' preliminary design (ROSSONERO, Rendezvous Operations Simulation Software on Near Rectilinear Orbit). In particular, the tool allows the definition of a set of control points that the chaser must reach performing the type of manoeuvre chosen for the transfer arc.

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P-channel and N-channel CCD performance comparison

Ross Burgon
Open University

CCDs continue to be the detector of choice for high resolution and high-performance space applications. One perceived drawback is their susceptibility to radiation damage, manifesting in poor charge transfer efficiency. To that end, ESA started a programme to investigate a new generation of devices based upon p-channel technology. The main objective of the study was to evaluate the intrinsic performances and degradation under proton irradiation of the p-channel CCD204, to allow direct comparison with the existing characterised n-channel version. This included in-depth modelling and analysis of p-channel CCD performances, the complete electro-optical characterisation of the p-channel CCD204 and device parameter optimisation, irradiation tests (both at room temperature and at cryogenic temperatures) and post-irradiation device characterisation and a direct comparison of p-type and n-type CCD technologies in flight representative conditions. The results showed that, when appropriately optimised, CCDs based upon P-Channel technology can offer comparable or superior performance than the N-Channel equivalent for operating conditions consistent with large scale space missions.

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Evaluation of micro-Lenses for Space Imagers

Xavier Rottenberg
IMEC

This activity evaluated the European microlens array integration on imagers for space applications. We designed various sizes and types of Fresnel phase plates lenses (FPPLs), i.e. 5/30µm on FSI and 5µm on BSI pixels. Simulated 3-level FPPLs perform like classical organic lenses on FSI and BSI imagers with the advantage of being planar CMOS compatible. We developed the process modules to produce 2-level metamaterial and 3-level classical FPPLs on commercial CMV12000 imagers. Possible failure mechanisms and their prevention techniques have been analyzed. A test campaign has been performed on manufactured/packaged FPPLs to evaluate these, their CIS enhancement and reliability impact. Stressed (T-shock, T-cycling, high-T storage, high-T/humidity (85/85), nano-indentation, irradiation) and non-stressed devices were characterized at wafer- and die-levels. Fresnel lenses were not sensitive to the environmental stress and provided reduced sensitivity against radiation.
They showed similar light collection efficiencies to the organic lenses with better potential for local pixel-level optimization, combination with hyper-spectral capabilities and further use in space.

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Large Aperature 2D MEMS Scanning Mirror for LISAR based miniaturized Rendezvous and Docking Sensor Unit

Vincent Kuenlin
Sercalo

Sercalo Microtechnology is a leader in fiber optic Micro-Electromechanical Systems (MEMS) technology and recently proves that their expertise could be applied to other product like MEMS scanner. Development was undertaken to create an alternative to scanning galvanometer. This led to various single-axis products with large diameter (up to 14mm). After discussion with potential customers, it appears that a small dual-axes device with large aperture is something that was missing on the market. With ESA support, Sercalo wishes to fill that gap.
The final product consists of a two axes scanning mirror which is etched from a silicon wafer. The polished silicon membrane can be coated with a metal coating, yielding a very flat and highly reflectivity mirror surface (10.0x14.2mm). Using magnetic actuation, the device is linearly tilted with the current and could reach up to ±7.5° of mechanical angle on two axes.

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MagUltra - Novel Magnesium Composites for Ultralight Structural Components

František Simančík
Institute of Materials and Machine Mechanics, Slovak Academy of Sciences (IMSAS)

The weight of load-bearing components is limiting factor in almost all space structures. The aim of the activity was to develop novel structural material with increased property to density ratio. The primary choice was magnesium based composite reinforced with high modulus carbon fibers that has a chance to be one of the lightest structural materials in the world. To solve known interfacial problems suitable elements (Zr, Cr, Ti, Y), which form stable carbides at the interfaces, were added to Mg matrix. The composites were prepared by gas pressure infiltration of molten matrix into the array of carbon fibres. The technology was develop to improve quality of fibre/matrix interface, whereas alloying elements were entirely spent for carbide forming reaction without any impact on Mg matrix properties. The most promising composites achieved bending strength over 600 MPa and Young's modulus over 300 GPa at the density of Mg. The complex shape component (strut joint) has been manufactured to demonstrate attained TRL.

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BIRD - Bismides for infrared photodetector applications

Arunas Krotkus
Centre for Physical Sciences and Technology (CPST)

The goal of the BIRD project was to incorporate bismuth into active regions of photodetecting devices sensitive in the near- and mid-infrared spectral regions, to improve their performance.
One possible application of bismide layers is to improve efficiency of multi-junction solar cells. Growth technology of GaAsBi layers with compositions corresponding to 1 eV bandgap has been developed. More than 1 micrometer thick layers of this compound with carrier lifetimes of several hundreds of picoseconds and other material parameters appropriate for their use in solar cell applications were grown on GaAs substrates. GaAsBi layers with up to 6% Bi were for the first time grown also on Ge substrates.
Much narrower energy bandgaps that those obtained for GaAsBi/GaAs and larger shift of the absorption edge towards longer wavelengths were obtained when growing Bi-containing compounds on InP or GaSb substrates. GaInAsB/InP layers were used in photodiodes photosensitive up to 2100 nm. Ternary InAsBi/GaSb sensitive up to 4400 nm wavelength were also demonstrated.

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Methodology for assessment of damage resistance properties of sandwich structures for European space sector

Kaspars Kalnins
Technical University of Riga

A proof of concept for assessment of damage resistance properties of sandwich structures for European space sector has been developed and both analytically and experimentally validated. A family of software tools has been delivered including: an application for analytical estimation of indentation residual depth required in simple verification study of low-velocity drop weight impact and quasi-static indentation. A toolbox for detection, analysis, and reporting of the extent of damage caused by low-velocity drop weight impact or quasi-static indentation from physical and numerical experiments. Moreover integrating test videos and library of measurements of Compression After Impact tests and results of the tests for panels with various layups and indentation or impact damage. Finally, a software pre-processing tool for Finite Element Model ANSYS has been programmed in APDL user configurable log file language. This enables user to generate an input analysis file for assessment of damage resistance properties of CFRP/AL-honeycomb sandwich structures applicable in satellite structures.

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Session 7A / CD 7: Propulsion, space transportation and re-entry vehicles

Revlansys: Terminal Entry and Landing Mission System and Gnc Requirements for Re-Entry Vehicles

Gabriele De Zaiacomo
Deimos Space

Europe has been very active in the last decades in the field of investigation and development of re-entry technologies. The most relevant programs included different vehicles, from capsules, to biconic, to the more advanced lifting body IXV, that allowed in-flight testing of high speed re-entry critical technologies, like TPS, structure, aerodynamics, and GNC with a combined flap and RCS control. Upcoming European programs, as the SPACE RIDER, will however focus on the TAEM and landing flight phases, for which current technological solutions have not reached a high maturity. In this context, the ESA REVLANSYS study aimed at developing key technologies in the field of terminal entry and landing Mission Engineering and GNC, and to derive coherent mission, system and GNC requirements. REVLANSYS resulted in the design of a Mission and GNC solution for the terminal entry and landing phases of a re-entry mission. The results provide support to European activities towards an autonomous end-to-end mission for a reusable re-entry system.

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Miniaturised Gridded Ion Engine breadboarding and testing for future Earth Observation missions

Maria Smirnova
TransMIT

Transmit GmbH started the development of a thruster specially designed to fulfill the propulsion requirements of the NGGM. For this development ESA granted a contract within the basic Technology Research Programme (TRP) for Miniaturised Gridded Ion Engine Breadboarding And Testing For Future Earth Observation Missions. TransMIT developed a plasma, EM and performance model which resulted in a first thruster design.
This activity was supported by Apcon for the production and Radio Frequency Generator (RFG); and Thales Alenia Space in Turin overtook the activities related to mechanical and thermal modelling according to NGGM enviromental condition. The activity was completed by building and extensive testing of a breadboard model of the miniRIT thruster which demonstrated thrust range from 50 uN - 2.5 mN, stepping under 0.2 uN, Isp between 300s and 3800s depending on the thrust level and a power to thrust ration below 40 W/mN at bus level. Overall, results showed a very good correlation between the model and the experimental results and full compliance with NGGM requirements.

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Coupling mechanisms of combustion and acoustics in rocket combustors

Justin Hardi
DLR

Thermoacoustic instabilities remain a major concern during the development of liquid rocket engines. The focus of this project was to test the performance of numerical tools for predicting coupling between acoustic modes of the combustion chamber and the injectors for cryogenic propellants like LOX/H2 or LOX/LNG. Two sub-scale LOX/H2 thrust chambers operated at the P8 test bench at DLR Lampoldshausen were used as test cases for numerical modelling. The computationally economical methods employed allowed the large number of conditions to be computed within a timeframe relevant for industry. The systematic study showed the influence of injection conditions on thrust chamber acoustic eigenmodes and the conditions under which injector coupling can occur. In parallel, the ability of the DLR TAU code to model dynamic acoustic phenomena in thrust chambers was investigated. Aspects of the models which require improvement and detailed validation were identified. Finally, the conceptual design of a new experimental combustor capable of validating the numerical tools was proposed.

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Aerothermodynamic Tools for Hypersonic Inflatable Decelerators TRP Achievements

Samuel Overend
Vorticity Ltd

Large Inflatable Entry Decelerators (LIEDs) are an enabling technology for high mass missions to planets with low density atmospheres such as Mars. The purpose of this programme was to examine the capabilities within ESA member states to develop LIEDs.
Mars reference missions for LIEDs were defined and used to determine the key characteristics and aerothermodynamic requirements of LIEDs. Measurement techniques for the key performance parameters were evaluated and the capability of facilities in ESA member states to perform the necessary tests was assessed. Any deficiencies were identified and necessary improvements defined. A roadmap to improve European capabilities in the field of LIEDs to the point that mission design and implementation could commence was proposed.
Flexible Thermal Protection Systems manufactured using European materials were successfully tested and characterised at DLR's L2K facility at heat fluxes typical of Mars missions. The objectives of the TRP were fully met.

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RF MEMS switch technology for space application. Phase 1: Benchmarking and selection.

Jérémie Dhennin
ELEMCA

Over the last two decades several MEMS technologies have been explored in the attempt to provide cost effective and reliable solution for RF switching functions. In spite of this only few organizations have hold the promises and been able to deliver K-band space specification compliant components. In the benchmarking campaign presented here four different RF-MEMS switches of SPST type, from as many European MEMS providers, have been tested. The results have been showing a great evolutionary path in terms of design and but also a quite severe performance limitation, essentially due to lack of technology maturity (below TRL 5) and underlying reliability shortcoming. As matter of fact, the most critical failure mechanisms identified during these tests (e.g current leakage, fatigue, contact sticking), are triggered either by manufacturing process instability, or by environmental condition (e.g. high temperature). In spite of this the activity has allowed us to define the challenges left open and to identify the most promising candidate.

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Evaluation of MCT APD detectors for future space applications

Mark Herrington
Leonardo MW

Leonardo's SAPHIRA devices were exposed to gamma and proton irradiation. Pre, during and post exposure measurements were taken to monitor device performance such as APD gain, excess noise, quantum efficiency, dark noise and dark current. Two devices were exposed to total ionising doses of ~30 and 50 krads. No significant degradation of the performance was observed during or after the exposure. A curious phenomenon was observed, where after the initial exposure an increase in the number defects was seen for both devices. This reduced with TID and by the end of the testing the number of defects returned to the initial values, suggesting that this is not related to long term exposure.
Four devices were exposed to proton irradiation, two at 100 K and two at ambient temperature. No variation in the avalanche process was observed in the intermediate measurements, and additionally there was no long term degradation of the dark current (measured after a few weeks at room temperature).

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Space evaluation of UMS GaAs PPH15X-20 MMIC Process

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UMS

PPH15x-20 technology has been developed by UMS to design high power and linear amplifiers for Ka-band. PPH15x-20 technology is based on a 0.15µm pseudomorphic AlGaAs/InGaAs/GaAs double recess PHEMT structure. In comparison to the first generation technology called PPH15X-10, the gate passivation is made of a low dielectric material in order to reduce feedback capacitances. PPH15x-20 offers a linear gain increased by about 1.5 to 2dB and a C/I3 ratio improved by 10dB compared to PPH15x-10.
A complete space evaluation of this technology has been successfully conducted in the frame of the R&T CNES program which includes the following outcome: end of life characterization, environmental test, RF robustness evaluation, radiation hardness on active and passive elements. The main novelties validated during the activities are; the BCB coating as final protection to enable non hermetic assembly product, the definition of a Dynamic Safe Operating Area based on RF load-pull measurement offering more confidence on reliable design.

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Session 7C / PECS

ICPE achievements in the field of steppers for space applications

Ioana Ionica
ICPE

Through a first project “Electric Motor Technology Spin Into Space”, ICPE was awarded a contract with ESA for evaluating the suitability of its electric motors for the space sector. The main focus was developing a product for operations in space, with applications directed towards LEO or GEO orbits. In the EMSIS project, a hybrid stepper motor in a frameless configuration was chosen to be developed. All activities foreseen for Test Campaign were completed. The test results will be presented largely in a paper.
Through the second project “Stepper Motor”, ICPE was awarded with a contract with ESA for study and develop a new version of a stepper motor for ESA space applications. Currently, we are at second breadboarding stage. Numerical modeling based on FEM was largely used and results will be presented in an extended paper.

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CRYOFOAMS - Rigid Polyurethane Foams for Internal Tank Insulation for Launcher Upper Stages

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In the framework of the present project CRYOFOAMS, work was carried out on the development of rigid polyurethane (PUR) foam material for external cryogenic insulation of a LH2 tank for the next generation launcher with a cryogenic upper stage. The main advantage of PUR foams, in comparison with other thermal insulation materials, is the possibility to cover this material on the complicated shape metal surfaces by spraying method. The spraying of PUR foams on metal constructions is chemical – technological process. The properties of PUR foams and their adhesion to substrate materials depend not only on the chemical structure and macromolecule architecture of the polymeric matrix, but also on the technological factors of PUR foam production. The tasks of this project were to investigate some technological effects on the physical and mechanical characteristics of the selected foams and their modifications as well as development of necessary polyol component for production of spraying cryogenic insulation with optimal technological parameters.

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Session 7C / Concurrent Engineering

Added value of early adoption of CE approach throughout the project life cycle

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As a lessons learned exercise, the CDF carries out systematically assessments of the differences in design between the pre-phase A CDF models and the later mission phases. These studies include the evolution of the design, the analysis of the added value of the CDF activity and the usage of multi-disciplinary concurrent engineering tools available at the facility (IDM/OCDT).
The latest comparison analysis completed at the CDF has been on the Sentinel-5 precursor mission. During the nine years between the CDF activity and the launch, the mission design went through several iterations.
This mission will be assessed as well as previous comparison studies. The aim is to investigate the traceability of information and requirement consolidation, as well as, the evolution of mission objectives, technology derivation and road mapping from concept to launch. The presentation will focus on the added value of early adoption of CE approach throughout the project life cycle, along with the identification of limitations, and ideas for improvement.

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