NSAU-CNES-INTAS Call 2006

TOPICS TECHNICAL DESCRIPTION

RF TOPICS

ATOMIC CLOCKS (Jérôme DELPORTE; jerome.delporte@cnes.fr)

Next generations of GNSS (Global Navigation Satellite Systems, like GALILEO or GLONASS) will require higher performance equipments and especially on-board frequency standards with improved stability.

The objective of this activity is to investigate new concepts of atomic clocks that would be able to reach a frequency stability below 5.10^{-13}/sqrt(tau) with a Flicker floor below 5.10-15. Being part of a space program, these new atomic clocks shall not exceed considerably the budget of mass/volume/power consumption of current on-board clocks. Reliability and lifetime shall also be considered as driving issues and shall be discussed in detail.

Different technologies may be envisaged: atomic beams, vapour cells using double radio-optical resonance or Coherence Population Trapping (CPT), cold atoms,…. This list is not exhaustive and any other clock schemes that might meet the above requirements are welcome.

In practice, this activity shall address both theoretical and technological issues, and demonstrate the stability performance at laboratory bread-board level.

ULTRA STABLE OSCILLATORS (Gilles CIBIEL; gilles.cibiel@cnes.fr)

Future space project of science, location and navigation need on-boar-clocks including ultra-stable oscillators (USO) with high performances and low MCV (mass, consumption, volume). The goal of this project is to investigated new concepts of USO at radio [5/10 MHz] and microwave [10-100 GHz] –frequencies that would be able to reach an ALLAN frequency stability below 7.10^{-14} at 1s (-65 dBrad²/Hz at 1 Hz offset frequency at 10 GHz carrier frequency).

Current USO based on quartz crystal present good performance/MCV trade-off but still present a non-negligible noise and radiation sensitivity. An other USO based on new piezoelectrical materials (LGT, LGS, LGN,…) is currently investigated. These piezoelectrical materials present very close characteristics of quartz crystal but there is no data about irradiation sensitivity of both material and oscillator.

More over, USO based on optical microresonator is investigated. These resonators present a high potential (high quality factor: $10^4<Q<10^6$ at 10 GHz to 100 GHz with a size around few to one hundred µm) to be a dangerous competitor of usual USO based on piezoelectrical material.

These USO are not the only ones and any other USO that might meet the above requirements are welcome. Therefore, USO based on **sapphire technologies and/or cryogenic solutions are excluded of the call**.

In practice, this activity shall address both theoretical and technological issues, and demonstrate the stability (phase noise) performance at laboratory bread-board level.

HIGH POWER RF MODELLING: Study of multipactor effect inside complex microwave devices (Jérôme PUECH; jerome.puech@cnes.fr)

New generation telecommunication satellites involves a constantly increasing number of users, all requiring higher and higher bit rates in the same frequency multiplex. Increasing power levels are thus needed in order to fulfil these requirements, leading to higher risks of microwave discharge phenomena inside high power space RF hardware. In a vacuum environment, this electrical breakdown is due to an avalanche –like increase of the electron density in the RF device, caused by secondary electron emission, when electrons, accelerated to high energies by the electric field, hit the walls of the device. The consequence is a change of the electro-dynamical properties of the device, leading to increased noise levels, link budget degradation and even damage of the equipment.

Several studies have been performed in that domain for many years. These activities were focused mainly on the 2 parallel plates model. Recent developments were carried in order to solve the problem of the fringing field effect inside waveguide components. In that case of geometry, some discrepancies were found between measurements and simulations. One aim of the proposed activity is to perform analytical and numerical studies in order to predict accurately the Multipactor effect. Simulations results will be compared with experimental data available in the literature.

In the domain of planar circuits with dielectric materials, some discrepancies have been found between simulations and measurements. Moreover, the localisation of the discharge experimentally has not been explained. The second part of the project will consist in explaining the physical phenomenon of the discharge in the case of microstrip circuits and in trying to find a way to predict accurately the initiation of the discharge.

RF DESIGN SOFTWARE: Microwave design simulator enhancement (Christophe LAPORTE; christophe.laporte@cnes.fr)

RF and Microwave simulations and design of Monolithic Microwaves Integrated Circuits (MMIC), even at very high frequency, are now achievable with a good precision (thanks to model validity) with dedicated CAD tools. However, the part of the design process including matching network impedance choice and topology determination stills very difficult and needs to be enhanced. The proposed action is mainly focused on the enhancement of a specific software tool to help the designer in the precedent step description of the design. Power and Low Noise Amplifiers will be specifically concerned by this activity focused on the development of an oriented tool design software:

- to accelerate the overall design process,
- to give an easy to use methodology to rigorously choose best matching impedance value and network topology needed,
- potentially compatible with European MMIC foundry (UMS and OMMIC) models to facilitate true MMIC passives models use.

A Low Noise Amplifier with very constraints specifications at Ka Band will be designed and fabricated with an European MMIC technology in order to evaluate the new design process with the new software tool kit.

THERMAL, POWER, PROPULSION AND PYROTECHNICS TOPICS

HEAT PIPES: Technological experiment of Arterial and high performance Grooved Heat Pipes (Amaury LARUE; amaury.laruedetournemine@cnes.fr)

Even if lots of grooved heat pipes are commonly used for the thermal control of spacecrafts (especially telecommunication satellites), the thermal performance of this technology is nowadays not precisely known in microgravity conditions. The aim of this activity is to define, manufacture and test an on-ground and in-orbit technological experiment of one or several heat pipes.

This activity could be split in two phases; the first one being covered by the INTAS founding and the second one being managed in the frame of another European or industrial program.

The phase one is the definition, manufacturing and on ground test of the heat pipe experiment. In this task, a detailed specific instrumentation will be defined as well as a specific detailed thermohydraulic model of the heat pipe. This model will be correlated to the on ground results. Finally, the in-orbit results will be predicted.

The phase two (not included in INTAS project) is dedicated to the in-orbit experimentation and lessons learned. The parameters to be measured during the tests are the following:

- dependence of the maximum heat power transported vs the temperature,
- dependence of heat pipe thermal resistance vs the heat power value,
- values of the heat transfer coefficients (evaporation and condensation),
- dynamic characteristics of the heat pipe start-up.

The thermohydraulic model could be correlated to the in-orbit results. Some new modellisations could be proposed in order to fit both the on-ground and in-orbit results.
Two or three type of high performances HP (NIS & west European space used technologies) could be proposed for inter-comparison purpose in microgravity conditions.

RHU / RTG: RTG for planetary landers or rovers (Jean-Pierre CATANI; jean-pierre.catani@cnes.fr)

Photovoltaic arrays with batteries are generally the preferred power source for most space missions. However there are missions where the solar flux is too low due to large distances from the sun. Beyond some missions on Mars require operation in shadows, operations where long-term power throughout the diurnal cycle is essential or where settling of dust on photovoltaic arrays would be deleterious. Radioisotope Thermoelectric Generator (RTG) technology can then be used.

The projected power level for lander or rover missions could be typically 5 to 10 W (electrical). An objective of mission duration shall be 10 years, covering various planetary missions. Meanwhile the generator would be used for probe heating.

The radioelement shall be plutonium oxide with a thermoelectric converter. Increase the power is the motivation for developing a new RTG. A first INTAS contract ended in the definition of a 1 W RTG, the NRG project, achieving 1 W/kg of specific power. The main requirement of a new definition should be a 5 W (end of life electric) RTG with optimization of the hot source temperature for achieving the best compromise between electrical power generation and mass. Temperature of cold source shall be assumed to be 25°C. The end-of-life power requirement comprises natural decay of radionuclide activity and degradation of thermo-insulators and thermoelectric elements.

The design philosophy shall support the following objective: to prohibit the release of nuclear fuel in the form of biologically significant breathing particles. If existing, a vent hole provided to permit helium gas release from the radioisotope shall prevent a release of particulates. The case shall be design to minimize biosphere contamination and maximize long term immobilization following potential heat source accidents.

FUEL CELLS: Adaptation of existing fuel cell systems to space requirements using new electrolyte materials (Gérard GAVE; gerard.gave@cnes.fr)

Recent developments in solid state ionic conductors lead to two types of products which are:

- Cationic membranes, presenting a good protonic conductivity (the material needs nevertheless to be humid) at relatively low temperature,
- Ionic oxygen conducting ceramic (Zircone), operating at relatively high temperature (800°C)

and both present a great interest in the field of fuel cell applications.

Cationic membrane technology has recently been subjected to a vast development programme in fuel cells (using H2/O2 couple) in the frame of terrestrial applications (power plant stations and electric vehicle), the main advantage of this solution being:

- direct use of air instead of pure oxygen without carbonation risk of the electrolyte,
- low temperature working (70°C to 100°C) permitting to start relatively rapidly.

Due to its principle and state of development, this design can be adapted to space applications by the mean of reasonable efforts. The necessary investigations axis concern: reliability, operation in a large range of gravity (from some g down to zero g, mainly for produced water elimination) and robustness to mechanical constraints. In this case, the same quality of oxygen and hydrogen than those devoted to propulsion can be used for applications with large autonomy such as launchers and manned spacecrafts. Secondary fuel cell application can also be studied (by the association of the fuel cell stack and a water electrolyser which can use a neighbouring technology), which could open the way to GEO and lunar applications when high powers are required. In the present case, the **requested works would lead to propose solutions both for space adaptations of the existing fuel cell and give the first basis of a secondary fuel cell design.**

Ionic oxygen conducting ceramics (whose technology is actually less advanced than the previous one) presents also good possibilities in fuel cell applications and oxygen compressors. With this type of fuel cells, not only H2/O2 couple can be used, but also CO/CO2 couple (this last possibility being particularly attractive for power conversion on the Martian ground). Investigations on a **universal cell using CO/CO2 couple having both the functions of fuel cell and electrolyser would be performed, with an adapted experimentation permitting to accurately identify the technological problems** (choice of catalysts, thermal cycling on the used ceramic, lifetime, degradation modes…).

ELECTRIC PROPULSION: HET (Franck DARNON; franck.darnon@cnes.fr)

The subjects, which are proposed to focus on for the field of HET propulsion are:

- Investigation on classical Hall Effect Thrusters operating at high voltage (typically 1000V), using improved characterisation diagnostics or methods,
- Evaluation of improved Hall thrusters, e.g. using an external RF power source for enhancing the ionisation efficiency or any other innovative concept,

- Determination of facility effects, using cross comparison of thruster performances/behaviour in different facilities and compared with flight data,
- Fundamental assessment on electron transport across magnetic field lines, e.g. due to turbulent phenomena,
- Thruster plume expansion characteristics, evolution function of thruster characteristics and operating point and impact on thruster/spacecraft interactions.

ELECTRIC PROPULSION: PPT (Enrico CHESTA; enrico.chesta@cnes.fr)

In the field of PPT technology, the following objectives will allow to enlarge the potential missions applications:

- Improvement of the PPT ionisation and acceleration efficiency, through optimisation of the geometry, of the electrical coupling, enhanced propellant characteristics,....
- Extended PPT operating range, down to the sub-mN one.
- Characterisation of the PPT plume (components, divergence, velocities,...).

CHEMICAL PROPULSION (N_2O and cold gas): (Nicolas PILLET; nicolas.pillet@cnes.fr)

A current INTAS contract (INTAS-03-53- 5301) deals with the research of a suitable catalyst for the decomposition of nitrous Oxide (N_2O), which can be stored as a liquefied gas under ambient temperature and reasonable pressure. The potential application is small thrusters for satellite orbit control and / or attitude control. N_2O is a non toxic alternative to hydrazine propulsion system.

More generally, potential subjects of interest in the field of green propellant for small satellites could be proposed, including cold gas propulsion system (with liquefied storage to increase the compacity of the system) and any other “green” propellant witch allows cost reduction in comparison of classical toxic propellant.

Both catalytic and thermal decomposition of the propellant could be proposed. In case of cold gas without decomposition, small resistojet could be proposed. The simplicity of the propulsion system should be the driver of the proposal. The compatibility with the material of the propulsion system should be addressed and in case of a 2 phases storage, the problem of correct feeding of the thrusters shall be taken into account.

AEROTHERMODYNAMICS: (Pierre OMALY; pierre.omaly@cnes.fr)

In the field of Aerothermodynamics, the call is focused on the 3 following topics:

a. Dynamic stability of planetary entry capsule :

During the entry of a space vehicle into planetary atmospheres, when the low supersonic regime is reached, most of the capsules exhibit lack of dynamic stability that generates large oscillations of the capsule eventually leading to a failure of the parachute deployment. So far very few theoretical and experimental evidences of the mechanisms leading to these instabilities have been identified. The purpose of this activity is to examine the state of the art on the subject, the existing tools able to predict these phenomena, and to present a set of concomitant numerical and experimental developments that could allow to characterize the dynamic stability of planetary entry capsule.

b. Thermal Protection System (TPS):

In the context of Earth re-entry and Mars mission, many aspects still need to be investigated to support the ground based testing in the field of TPS design. Several developed tools should be assessed for further aerothermodynamics applications as:

- Physico-chemical modelling of CO2 flows (thermal & chemical non-equilibrium),
- Free stream diagnostic of CO2 plasma flows,
- Efficient catalycity model development and implementation (Model development of Gas-Surface interaction and experimental comparison),
- Experimental and numerical treatment of ablation phenomena in CO2 flows.

c. CFD of high temperature gas :

The main objective is to improve the physical modelling and understanding of flow phenomena associated to high temperature gas mixtures typical for Mars atmosphere entry. The project will combine theoretical, experimental, and numerical research. It will address the modelling of the fluid dynamics of hypersonic reacting gas mixture relevant to Mars atmosphere composition with the development of physical models, their implementation in Computational Fluid Dynamics codes (CFD) and the validation of those CFD codes in ground testing facilities. Comparison will be produce with standard CFD codes. In addition to the flow simulation, the heat radiation resulting from the high temperature gas mixtures will be investigated. Furthermore, issues associated to non equilibrium flows during these Mars entry phases and their consequences on the flow and radiation simulations will be addressed. This work is in the continuation of running project INTAS 5204.

PYROTECHNIICS: (Denis DILHAN; denis.dilhan@cnes.fr)

Pyrotechnics are widely used on space vehicles. Their reliability has been demonstrated for many years. Technology improvements and cost reduction are now the main research fields for future applications.

a. Pyrotechnic compositions and propellant powders

Standardized tests are applicable to determine the safety characteristics of pyrotechnic compositions (MIL STD 1751).

The properties are established by tests such as Vacuum stability - Electrostatic sensitivity - Friction sensitivity - Compatibilities with other materials - Aging characteristics - Impact sensitivity - Thermal stability (autoignition temperatures and rates),...

The first objective to fulfil is to determine formulations of new igniting pyrotechnic compositions useable in electro explosive devices (EED) and laser ignited devices (LID).
Up to now compositions such as Zr/KCLO4 or equivalent are commonly used in EED and LID, despite the sensitivity of this mixture.

Alternative compositions are looked for with a reduced sensitivity mainly to ESD, impact and friction. Additive requirements such as heat of reaction output (>950 cal/g), particles size of the chemicals compatible with the bridgewire diameter (60 µm) or laser spot diameter on the explosive (62,5µm) shall be taken into account. The tasks required are to determine the formulations of these

“low sensitive” igniting pyrotechnic compositions with the determination of the igniting energies required.

For pyrotechnics space applications, double base powders (nitrocellulose /nitro-glycerine) are used in European pyrotechnic devices for gas generation purposes. The drawbacks of these powders are the sensitivities to high temperature (>+100°c) exposure and also the influence of thermal environment storage on lifetime. The objective of this study proposal is to determine equivalent explosive materials **thermally stables** and able to withstand after a long time storage (> 10 years) **high temperature exposure** (up to +120°C or more) without any performances decrease.

b. Technologies for initiators

This research field covers the of EED and LID technologies. After harsh environments (thermal shocks +/-150°C; pyrotechnics shocks; etc.), these explosive devices shall withstand dynamic high pressure (>5000 bars) and /or static lower pressures 200 bars at high temperature (300 °c) for some minutes (up to 30 mn) (thrusters/ gas generators).

The sealing technologies for the pins of the EEDs or the optical window of LIDs are the design and manufacture key elements for the reliability of initiators.

Glass seals are generally used but are sensitive to manufacturing process. An assessment of the **alternative industrial technologies and improvement of the existing technology** are looked for, in reference to past experience.

For LIDs, the needs are more specific due to the fact that optical focusing properties and dichroic coatings are also required. **Low cost dichroic deposit** technologies would be also addressed in this topic.

MISCELLANEOUS TOPICS

RADIATIONS (Robert ECOFFET; robert.ecoffet@cnes.fr)

The aim of this action is to collect in orbit data and improve radiations environment models. The final objective is to develop new radiation belts international models to replace present AE8/AP8.

A COSPAR initiative is on going and this project will help to go faster on this subject.

Main activities:

- Identification and exchange of reliable in orbit data,
- Data validation and calibration,
- Identification, evaluation and comparison of radiation belt dynamic models (eg : Salammbô),
- Improvement of engineering models of radiation belts especially on GEO and MEO orbits,
- ....

ADVANCED SYSTEMS, UNITS AND EQUIPMENT FOR PERSPECTIVE SATELLITES (Anatoly KAMELIN; kamelin@nkau.gov.ua)

Next generations of space platforms needs equipment and instrumentations of advanced performance. The following techniques are envisaged:

On-board energy sources: solar cells stable to the action of radiation and temperature, fuel cells with optimized electrolyte composition, etc.

Nowadays solar sells on the base of Si, elements on the base of GaAs, Li and Cd-Li batteries are used in space missions. The action's aim is technology improvement and cost reduction. Development of new principles for autonomous power supply (solar panels and inner long-term battery) is welcome.

Advanced sensors for multifunctional application (gravimeters, magnetometers and electronics for measuring devises).

Direct measurements of gravity are needed for development of geophysical models. The research field covers the development of a new methodology and an experimental optical-cryogenic device for ground gravimetry using magnetic levitation. Technologies such as laser measurements, applied cryogenic, nonlinear signal processing and optimization methods are welcome for applications.

The proposed action is included the enhancement of devices for ionospheric research, studies of space weather effects:

Flux-gate magnetometer (Frequency range: DC…20 Hz, Noise $5 \cdot 10^{-12}$ T);

Search-coil magnetometer (Frequency range: 10 Hz...600 kHz, Noise $5 \cdot 10^{-15}$ T/Hz$^{1/2}$);

Development of high temperature superconducting (HTS) microwave filters (2-20 GHz) with steeper pass band skirt (>100 dB/MHz) needed for much higher sensitivity of receivers, essentially better selectivity;

FUNCTIONAL MATERIALS (Marina YEVLASHINA; yevl@nkau.gov.ua)

Modern spacecrafts will require improved materials with a wide range of mechanical, thermophysical and thermochemical properties. The aim of this activity is to define, produce and test new kind of materials for increasing of satellites active lifetime and widening horizons.

The following techniques are envisaged:

New monitoring methods of exposed samples (crystal or amorphous structure changing, mechanical parameters changing, temperature dependence, impedance);

Development and creation of antifrictional and wear-proof materials for units of the space vehicles working in outer space; (materials with friction coefficient 0.12-0.15 at change of load in range 2-10 H, etc.)

Advanced nanocomposite materials, shape memory materials, Al and Ti-based alloys with unique properties for utilization in outer space (T = 4 ÷ 400 K)

IMAGE PROCESSING (Yaroslav STEPHANISHIN; stephanishin@nkau.gov.ua)

Several high resolution panchromatic optical sensors have been launched in the past years. In the other hand, several multispectral and hyperspectral systems have also been launched but with coarse resolutions. A lot of data are now available and the project could be to merge such different data to obtain high resolution multispectral images, by defining new physical fusion methods for data images characteristics optimization, image processing and interpretation.

The data processing of all channels the hyperspectral sensor requires large amounts of computing resources, though this information is redundant for a specific problem (practically the information of 10-20 channels is used). The subject is directed to solving the problem of selection the optimization criteria for channels quantity.