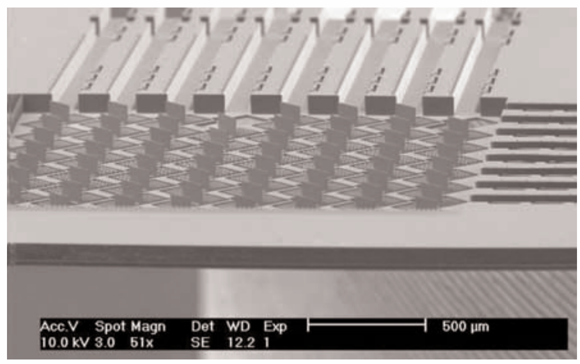
eurocomp

The newsletter of the Space Components Steering Board

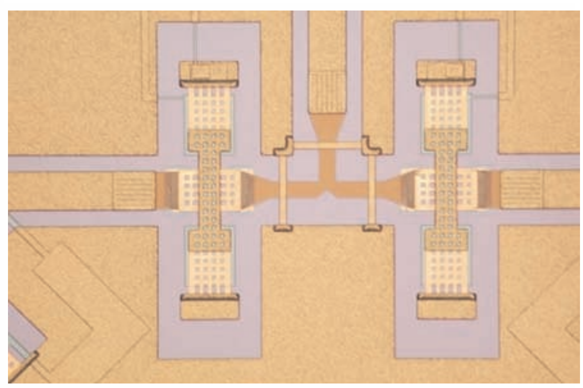
Introduction

Welcome to the ninth issue of *Eurocomp*, the newsletter of the Space Components Steering Board (SCSB). In this issue, we train the spotlight on Micro-Electro-Mechanical Systems devices, or MEMS.

MEMS are micrometre- and nanometre-sized systems that integrate mechanical elements with those of electronics – and at times, photonics – on a common platform, usually a silicon substrate. While the electronics are fabricated following integrated-circuit processes that are adapted for micrometre scales, the mechanical portions are fabricated using so-called micro-machining processes, resulting in minuscule devices that are used to sense, guide, or to generate a change in the compatible environment. The European Space Agency (ESA), a member of the SCSB, has supported the basic study of the technologies that will lead to the use of micro- and nano-technologies in space applications.



An 8 x 8 monolithic optical cross-connect



An RF-MEMS switch for antenna application

The space-application benefits of MEMS are many and have been well-documented [1, 2]. In particular, RF MEMS switches are one of the more prevalent topics of research in MEMS microwave systems. The reason is that they offer enticing characteristics in high-frequency applications with low insertion loss, high isolation, low signal distortion and wide-bandwidth operation. However, one of the prerequisites for use in a space system is that the technology being considered is robust and stable to meet the reliability demands of the space user [3]. ESA has been working with several companies to realise a micro switch suitable for use in space. This newsletter contains a detailed description of one such study with AAS and XLIM (formerly CNRS-IRCOM) concerning an electrostatically actuated switch that exhibits a promising performance and lifetime after radiation and environmental testing.

In a summary of the bi-annual ESA-sponsored round table directed at micro/nano-technologies for space applications, Nicolas Saillen and Laurent Marchand (ESA/ESTEC) recap the objectives and point to the key results reported during the 5th ESA Round Table on Micro/Nano-Technologies for Space.

The European Space Components Information Exchange System returns to provide a further insight into the rate of growth reported in the previous issue of Eurocomp. This time round, the ESCIES team expands on this growth in terms of the organisations, content and support used to manage the many tasks that come with heightened usage. The main message is that an organisation will benefit by becoming a member of ESCIES. The article provides the links to accreditation information and on-line registration.

In this issue...

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An Innovative RF MEMS Switch for Space Applications

MEMS (Micro-Electro-Mechanical Systems) technology plays a key role in the ongoing miniaturisation of electronic modules and systems for future telecommunications, observation and space exploration satellites and probes. While MEMS operating in the low-frequency region are currently being employed, e.g. as acceleration sensors in automotive applications, the field of RF (radio-frequency) MEMS is still in a state of research and early development. RF MEMS switches exhibit excellent RF properties, such as low insertion loss, low power consumption, and high isolation. In addition, MEMS can be integrated very straightforwardly into RF sub-modules to achieve a higher degree of functionality, for example in phase shifters or power-routing networks.

The space environment poses specific packaging challenges for RF MEMS components, which will directly affect the overall performance and lifetime of a device. Compliance with a large temperature range, mechanical vibrations and shock, etc. has to be achieved not only by the single MEMS device, but also by the packaged subsystems. Adaptations of present technology and the resultant reliability of the packaging are key issues for the application of MEMS in space. One of the devices described later in the article relies on dielectricless technology.

Electrical components with mechanical functionality can have many failure modes not present in purely electrical components. Although a lot is known about failure modes in electrical systems, and ways of investigating them, this is not the case for micro-mechanical components. This is due not only to the relative immaturity of the field of MEMS, but also to some inherent differences between electrical and mechanical failures. Most electrical failures are thermally activated, i.e. they will occur sooner at elevated temperatures, thus supporting meaningful accelerated testing. Also, the lifetime can be calculated rather easily. However, most of the dominant mechanical failure modes relevant to MEMS are not so temperature dependent. Accelerating the conditions in which a certain failure may occur may even decrease the failure rate of other types of failures. Some failures cannot be accelerated at all. This means that the field of mechanical reliability is, in a way, even more complex and demanding than that of electrical reliability.

A lot of failure modes may cause a MEMS device to cease operation. However, some failures are more common in certain types of device or structural part than others, and therefore a prediction of the important failure modes can certainly be made. But before that, it is necessary to separate 'process-related' and 'device- related' failure modes, noting though that these two separately driven types of failure mode may interfere with each other. This is one of the big challenges in assessing the reliability of quite new technologies. This fact somewhat justifies performing a first phase of technology assessment prior to going into a more formal reliability test plan.

A literature survey reveals that there are four major factors governing the initial reliability of a metal micro-machined product in use: *stiction* (static friction), *creep, dielectric charging, and electro migration*. Note that metal fatigue is not on the list: observations made by current manufacturers indicate that metal fatigue due to long-term mechanical stress cycling of micro-structures is not normally seen with the technologies presently assessed. What is observed is only short-cycle fatigue – the fracturing of metal parts under large mechanical stress within a relatively small number of cycles (usually less than a thousand). Other effects, inherent to the microscopic properties of MEMS devices like some of those listed above, are more severe than we would expect from macroscopically known behaviour.

Assuming the space use of a capacitive MEMS switch, stiction and dielectric charging are the main failure modes that are predicted for the components. In order to address these, ESA initiated a study contract with with AAS and XLIM[1] to consider these two failure modes and to address them through technological improvements such as:

- hydrophobic surface treatment (Teflon, Diamond-Like Carbon (DLC)…)
- improved intrinsic properties of dielectric materials (alumina (Al_2O_3), DLC), and
- development of a dielectricless capacitive switch.

With these three initiatives, it was considered that there would be an improvement in the robustness of the capacitive MEMS switch with regard to constraints related to stresses such as humidity, high voltage and radiation.

A Prototype RF MEMS Switch

The ESA-sponsored study report describes the context of RF MEMS application within satellite payloads, followed by the specifications and conceptual design of the micro-switches that were developed and fabricated using a capacitive switch design methodology based on two approaches:

- ***Capacitive shunt switches***
  The first approach relied on standard shunt capacitive switches on coplanar wave (CPW) transmission lines using stiff bridges and various dielectrics (Figs. 1 – 3). The dielectrics in this case were deposited using two deposition system processes: pulsed laser deposition (PLD) for Teflon, DLC and Al_2O_3; and plasma-enhanced, chemical-vapour deposition (PECVD) for Al_2O_3.

- ***Dielectricless capacitive switches***
  Another innovative approach is based on dielectricless capacitive switches, for which reliability concerns such as dielectric charging have been addressed by removing the actual dielectric layer.

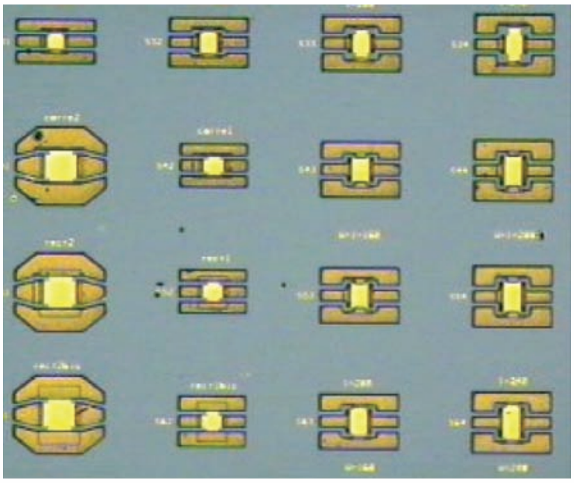

Figure 1. Optical microscopy picture of MEMS dielectric switches with different dimensions

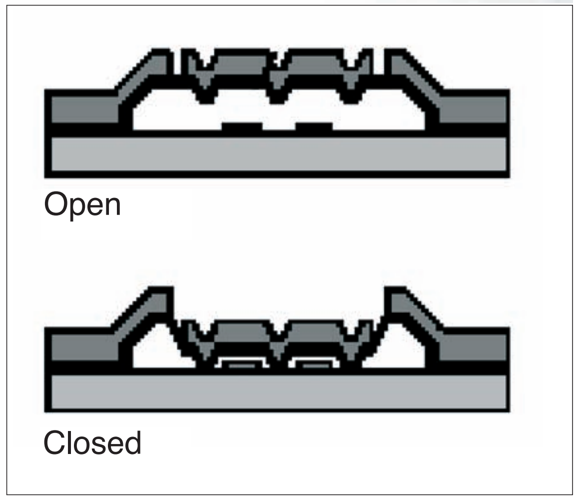

Figure 4. Principle of the capacitive dielectricless switch

A mechanical movement is used to achieve as high a contrast as possible between high-gap and low-gap positions of the designed switch, as shown in Figure 4. The advantage is that the device will be less sensitive to radiation and charging effects when used in a space environment. It also has no metal-to-metal contact susceptible to degradation. Moreover, with appropriate corrugation dimensions, switch contact surfaces will be reduced thereby improving the parasitic effects associated with the contacts. One current design drawback observed by the researchers was that the on/off ratio of this type of switch was too low because of the absence of dielectric in both positions. However, this ratio can be further improved by optimising the gap between the contacts in the down state.

The design is based on a computation of the spring constant in the up state and in the down state. In the up state, the switch is dominated by the spring constant of the non-electroplated areas that can be approximated as a switch of length $2L$ with a thickness of t (Fig. 5). Again, in order to maximise the number of functional structures, the dimensions of the fabricated switches were varied in the study:

L, l = the length and width of the non-electroplated area
wf = width of the corrugations
gd = height of the gap
W = pitch.

The electrode is made of six lines running in parallel. The spacers are in contact with the substrate in this Area, and they prevent the top electrode from being in contact with the bottom electrode, as shown in Figures 4 and 5.

Prior to a reliability study, the device selection was made based on process repeatability.

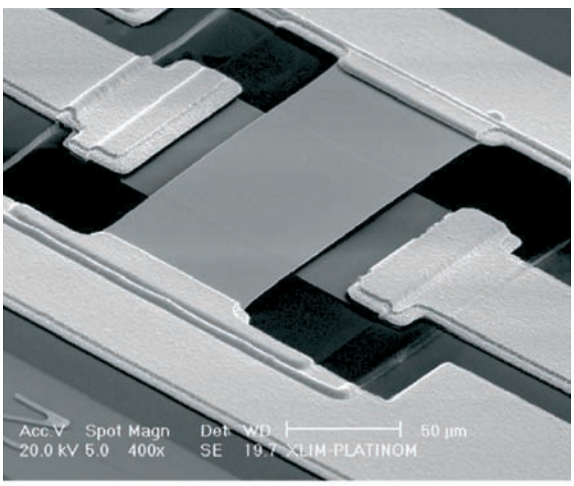

Figure 2. Scanning Electron Micrograph (SEM) of a typical metallic micro-membrane

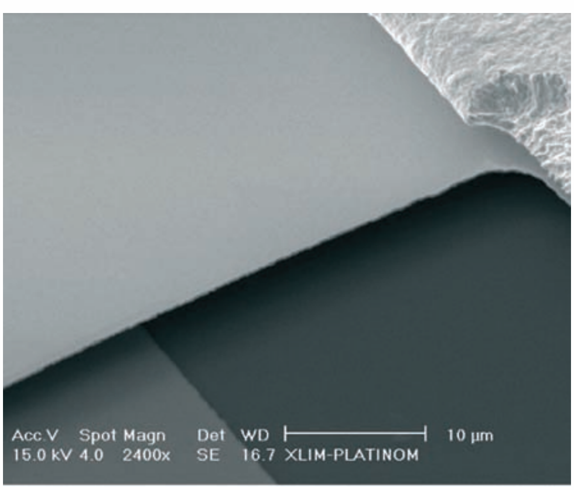

Figure 3. A closer view of the suspended bridge over the actuation electrode

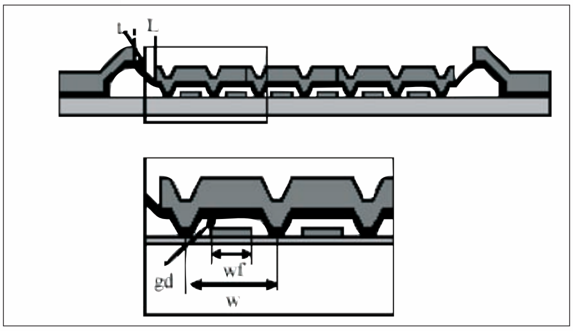

Figure 5. Cross-section of the structure in the down state

- ***Testing***
  A test campaign was conducted on the switches, which consisted of PLD and PECVD Al_2O_3 dielectrics with two dielectric thicknesses (200 and 400 nm), as well as on two dielectricless switches. The testing included thermal storage, thermal cycling, accelerated ageing, and radiation total-dose testing. Based on S-parameter measurements, and the fast S21 (V) charging curve, we were able to precisely study the impact of the various stresses applied on the intrinsic properties of the switches. These were the electrical (RF transmission) properties and mechanical properties ($V_{pull-in}$ and $V_{pull-out}$).

Test Results

- Thermal storage (260 h @ 125°C) on 200 nm Al_2O_3 PECVD switches clearly showed a minor impact on the switch: on similar devices, the S parameter remained unchanged, while the pull-in voltage was decreased due to stress relaxation within the membrane.
- During thermal cycling (-55°C, +125°C; 10°C/min, 500 cycles) on 200 nm Al_2O_3 PECVD, the device remained functional but the pull-in voltage increased from 40 V to 70 V DC.

In both of the above cases, the switches remained functional.

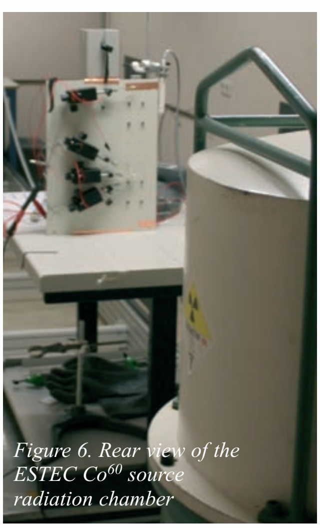

Figure 6. Rear view of the ESTEC Co^{60} source radiation chamber

- ***Endurance Testing***
  Endurance testing was also performed on what the study considered the most suitable devices based on stable manufacturing processes. The devices identified were the 400 nm thick Al_2O_3 PECVD and the dielectricless. The conclusions drawn from this testing are:

- For Al_2O_3 dielectric switches, lifetime is short and is limited by charging.
- For dielectricless switches, no failure due to charging was observed and the anticipated higher order failure modes due to mechanical fracture or strain that were expected to appear at a very high number of cycles were not observed within this study. One issue not addressed in the study was the potential thermally accelerated mechanical failure due to creep of the membrane.

Reliability under gamma-ray radiation was extensively studied (Fig. 6). All switch types (i.e. PLD and PECVD 400 nm Al_2O_3 switches and dielectricless switches) were stressed both with and without biasing conditions. The observations from this testing were:

- For unbiased switches, Al_2O_3 (400 nm PECVD) initially seemed the most promising option as they remained functional up to 88 krad, with slight variation of the $V_{pull-in}$ and $V_{pull-out}$ that could be due to charge building up during irradiation (Fig. 7). It was found that this deviation is reduced after a certain period of annealing time, nominally 168 h at 25ºC (Fig. 8).

  When biasing was applied during radiation, the switches rapidly failed after a few on/off cycles, demonstrating that stiction was primarily driven by the charging effect of the biasing applied rather than by the radiation itself. This also confirmed the results of the endurance testing.

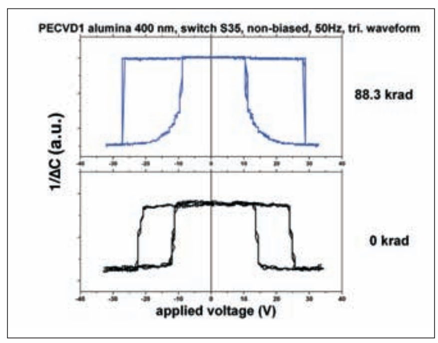

Figure 7. 1/C(V) curves before and after several total dose irradiation steps, for 400 nm thick Al_2O_3 PECVD based switches

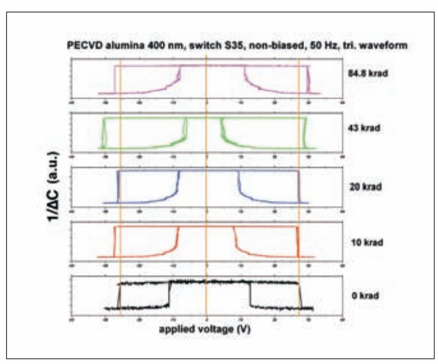

Figure 8. Evolution of the 1/C(V) curves during the total dose irradiation test campaign. The last test was made after 1 week of annealing at 25°C (ref. PECVD2 Al_2O_3 400 nm)

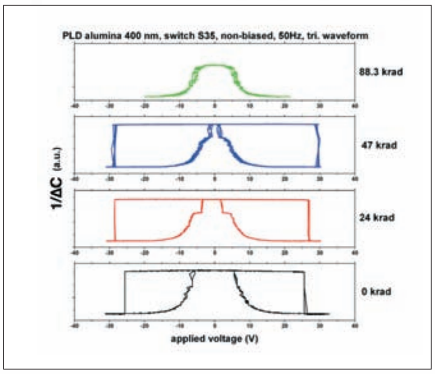

Figure 9. 1/C(V) curves before and after several total dose irradiation steps, for 400 nm thick Al_2O_3 PLD based switches

– The dielectric with the worst charging signature (400 nm PLD Al_2O_3) showed failure related to stiction at a total dose of between 58 krad and 88 krad, as shown in Figure 9. This result was obtained with unbiased conditions.

– After gamma-ray irradiation of dielectricless switches, no failure was observed in the devices tested with or without uni-polar stress conditions. These devices are very robust and are promising for space use because they have been demonstrated not to be sensitive to total dose radiation tests up to 75 krad while operating with on/off uni-polar biasing. Under these conditions, up to 3 x 10^6 cycles at a frequency rate of 5 Hz have been demonstrated. Several devices have been tested with the same conclusion.

– For total dose sensitive devices (PLD 400 nm), some failure recovery is observed in some switches after one week of annealing at 25°C. This opens some new paths for investigation of the effect of gamma rays on RF MEMS devices, such as trying to understand what exactly happens within the dielectric.

In conclusion, all switches tested during the study remained functional after thermal stress (high temperature storage 260h@125ºC and thermal cycling -55ºC, +125ºC, 10ºC/min, 500 cycles). For dielectric capacitive switches, Al_2O_3 (400 nm PECVD and PLD), the switches exhibited a very short lifetime limited by charging (less than 1 hour in cumulated time in down state). This behaviour was also evidenced during radiation testing under biased conditions.

The innovative dielectricless switch appears to be a very promising technology. The switches survived thermal stress and were not affected during radiation testing both in biased and unbiased conditions up to 75 krad. Up to 3 x 10^6 cycles at a frequency rate of 5 Hz have been demonstrated in the frame of the ESA study. This approach may also allow the packaging condition of the switch to be relaxed, opening the door to quasi-hermetic wafer-level packaging solutions.

The dielectricless switch is therefore worth optimising in terms of RF performance (C_{on}/C_{off} ratio) and the French MOD (DGA) has decided to spin-off the technology for military applications by placing a follow-on development contract with XLIM.

References

[1] This study was performed under ESA Innovative TRP Contract No. 17161/03/NL/PA.

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ESCIES Update

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Member organisations

In the previous edition of Eurocomp, growth in the use of ESCIES was reported in terms of the number of accesses or 'hits'. While most of the activity is with the publicly accessible content, there has also been a steady increase in the number of organisations joining ESCIES and in the corresponding number of registered users with access to the privately shared data. It is perhaps useful to recall that ESCIES is an information exchange system and that once accredited to ESCIES, by the SCSB, a company or organisation is responsible for administering its own users and data contributions.

The on-line registration system identifies both the registrant and the organisation they claim to belong to. The ESCIES Secretariat processes an application by obtaining confirma-tion from the coordinator of the relevant organisation that the registrant is indeed a member and is to be accorded a user ID and password. All accredited organisations and users are listed in ESCIES, so that there is visibility to each user of their fellow participants. Presently, there are 42 accredited organisations and more than 350 registered users. A facility of ESCIES is that all users are listed in a manner that permits one user to send a message to another.

Another aspect of ESCIES growth is the increase in facilities and content. Recent examples of this include:

- The addition of radiation data within the EPPL (as of Issue 8).
- E-mail notification (for registered users only) when new or updated ESCC specifications are posted or new ESA laboratory reports are added.
- Under the Technologies and Conference Papers sections, there has been considerable content addition, particularly in the fields of optoelectronics and micro/nano technologies, both in the public and ESCIES private arenas.

It is also interesting to note that a lot of items requiring attention by the small ESCIES development/maintenance team remain very much invisible to the user. The team's work covers the spectrum from enabling aspects, such as hardware, underlying software, data security, etc., to the development of applications and the deployment of data. The latter two are what are generally visible to the user. Only when something breaks, and this is rare, are the underlying aspects apparent.

The team uses an on-line 'issue tracking' system to control the description and resolution of each task, be this adding data, developing a new application or merely a bug fix. Typically there are around 200 open issues, prioritised based on their criticality and varying from the trivial to projects taking man-months to complete. An internal development server provides for testing before completed items are released on the production ESCIES server.

It is hoped that this further insight into ESCIES will encourage additional European organisations to join, and for those already involved, to contribute additional data, thus adding to these aspects of ESCIES growth in 2006.

For ESCIES accreditation information, please see: *https://escies.org/public/unaccredited.html*.

For general questions about ESCIES, please refer to the FAQ at:
https://escies.org/helpfiles/faq.html,

or send your feedback to the Webmaster using the online form.

2006 IEEE Nuclear and Space Radiation Effects Conference

The 2006 IEEE International Conference on Nuclear and Space Radiation Effects will be held on 17-21 July in Ponte Vedra Beach, Florida, at the Sawgrass Marriott Resort and Spa. This meeting of engineers, scientists, and managers features: a technical programme consisting of eight to ten sessions of contributed papers describing the latest observations in radiation effects; an up-to-date Short Course on radiation effects offered on July 17; a Radiation Effects Data Workshop; and an Industrial Exhibit. The technical programme includes both oral and poster sessions.

Papers will be presented describing nuclear and space radiation effects on electronic and photonic materials, devices, circuits, sensors, and systems, as well as semiconductor processing technology and techniques for producing radiation-tolerant (hardened) devices and integrated circuits. International participation is strongly encouraged.

www.nsrec.com

NSREC 2006
Ponte Vedra Beach

The 2006 Radiation Effects on Components and Systems Workshop

The 2006 Radiation Effects on Components and Systems Workshop (RADECS 2006) will be held in Athens, Greece, at the Training and Conference Centre of the National Bank of Greece, on 27-29 September 2006. This meeting of engineers and scientists presents the latest results regarding testing, characterisation, risk assessment, mitigation, safety, and performance of microelectronic devices and circuits that are used in radiation environments for civilian, military or commercial applications.

Research papers presented at the 2006 RADECS Workshop may be submitted for possible publication in the IEEE Transactions on Nuclear Science.

http://radecs2006.teipir.gr

RADECS 2006

ESCCON 2007

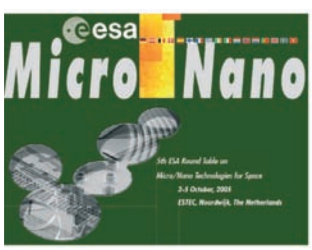
The third European Space Components Conference (ESCCON) will be held at ESA/ESTEC in Noordwijk, The Netherlands on 19-23 March 2007. The purpose of the Conference will be twofold:

- To report on the progress made in Europe with the availability of space parts, reflecting on the initiatives of the ESCC (through their strategic five-year plans and annual qualification programmes (AQP)), and of the space agencies (through the European Components Initiative (ECI)).
- To assess the technology areas of concern today that are still to be addressed by continuing initiatives, and the policies to be developed and reflected by cooperative agreements at European (EC and ESCC) level and at international level with the other space nations.

ESCCON 2007 is intended to be a working conference aimed at those in the European and global industry charged with making strategic decisions in implementing space systems and determining the component technologies to be used.

Further information regarding the practical arrangements and programme will appear on the ESCC web site in due course: https://spacecomponents.org/public/events

5th ESA Round Table on Micro/Nano Technologies for Space



ESA has been interested in micro and nano systems for more than 10 years, and organised the first Round Table on Micro/Nano Technologies (MNT) for space in 1995. The aim of the Round Table is to facilitate discussion between the research centres, companies and final industrial users to improve technology transfer to the industry and increase the flight opportunities for MEMS/NEMS components.

The 5th Round Table on MNT for Space was held from 3 – 5 October 2005. It comprised 12 sessions, one of which was entirely dedicated to nano technologies. The sessions tackled the following subjects:

- European Initiatives and Flight Opportunities
- MEMS Evaluation, Qualification and Reliability
- Micro-machining and Fabrication
- Scientific Payloads and Instruments
- RF-MEMS and Sub-Systems
- Attitude and Orbit Control Systems
- MOEMS and Bolometers
- Assembly, Packaging and Integration
- Micro and Nano Satellites
- Propulsion
- Interfaces, Thermal Management and Fluidics
- Nano Technologies.

These 12 sessions grouped together 64 presentations from 18 countries, and attracted more than 190 participants.

The first objective of this Round Table was to summarise achievements since the 4th Round Table. Significant advances were reported in the following domains:

- Improvement of RF-MEMS technology [1].
- RF-MEMS switches are now being integrated at sub-system level (antenna) [2].
- Various MOEMS are commercially available and can be used for space qualification testing [3].
- Micro-propulsion systems are now being considered [4] for flight opportunities.
- The number of flight opportunities is increasing significantly [5,6].

Another objective was to present the activities (approximately 17) that were started between 2003 and 2005 at ESA in the micro/nano technology domain. Moreover, the Round Table aimed to encourage and trigger effective cooperation between industries (final users) and universities/research centres (prototyping and development), and to facilitate technology transfer.

The Round Table was also a good opportunity for new Member States to present their micro- and nano-technology activities, e.g. Greece presented an interesting paper on an innovative nanomaterial [7].

One very important objective of the Round Table was to present initial data gathered by ESA and national space agencies on MST failure mechanisms, reliability and lifetimes. Approximately 10 papers reported on reliability and MEMS space-qualification activities. However, the standardisation and documentation (specification) issues still require additional effort and cooperation to provide standards dedicated to MEMS qualification for space.

Overall, the Round Table was well received and provoked many discussions. The Proceedings of this Round Table can be found in the ESCIES conferences section at: *https://escies.org/*.

Finally, ESA is pleased to announce that the 6th ESA Round Table on Micro/Nano Technologies for Space will be held at ESA/ESTEC in November 2007.

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Published by: ESA Publications Division

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