report from *MULCOPIM'08*

Frank Zimmermann

LCU Meeting, 1 October 2008

We acknowledge the support of the European Community-Research Infrastructure Activity under the FP6 "Structuring the European Research Area" programme (CARE, contract number RII3-CT-2003-506395)

organization & statistics

- ***multipactoring, corona and passive intermodulation*** in **high-power microwave systems for satellite applications**
- workshop series of ESA/ESTEC; every 2 or 3 years; 1st time outside Netherlands
- MULCOPIM'08 jointly organized by *ESA, Polytechnical University of Valencia, U. of Valencia & AURORASAT*
- **130-140 participants, 50 accepted abstracts**, only plenary talks: 35 on multipactoring; 7 & 8 on corona & PIM
- **sponsors:** Thales Alena Space, Rhode & Schwarz Espana, Agilent Technologies, INTA – Spanish Ministry of Defense, Alava Ingenieros, Generalitat Valenciana, Spanish Ministry of Education and Science

sessions

- *Opening*
- *Multipactor 1: Dielectrics*
- *Multipactor 2: Theory, Multipactor 3: Theory II*
- *CPI visit – Polytechnic City of Innovation, iTEAM Clean Room Facility for High-Power Measurements*

24.

- *PIM 1, PIM 2*
- *Multipactor 4: Accelerators*
- *Multipactor 5: SEY*

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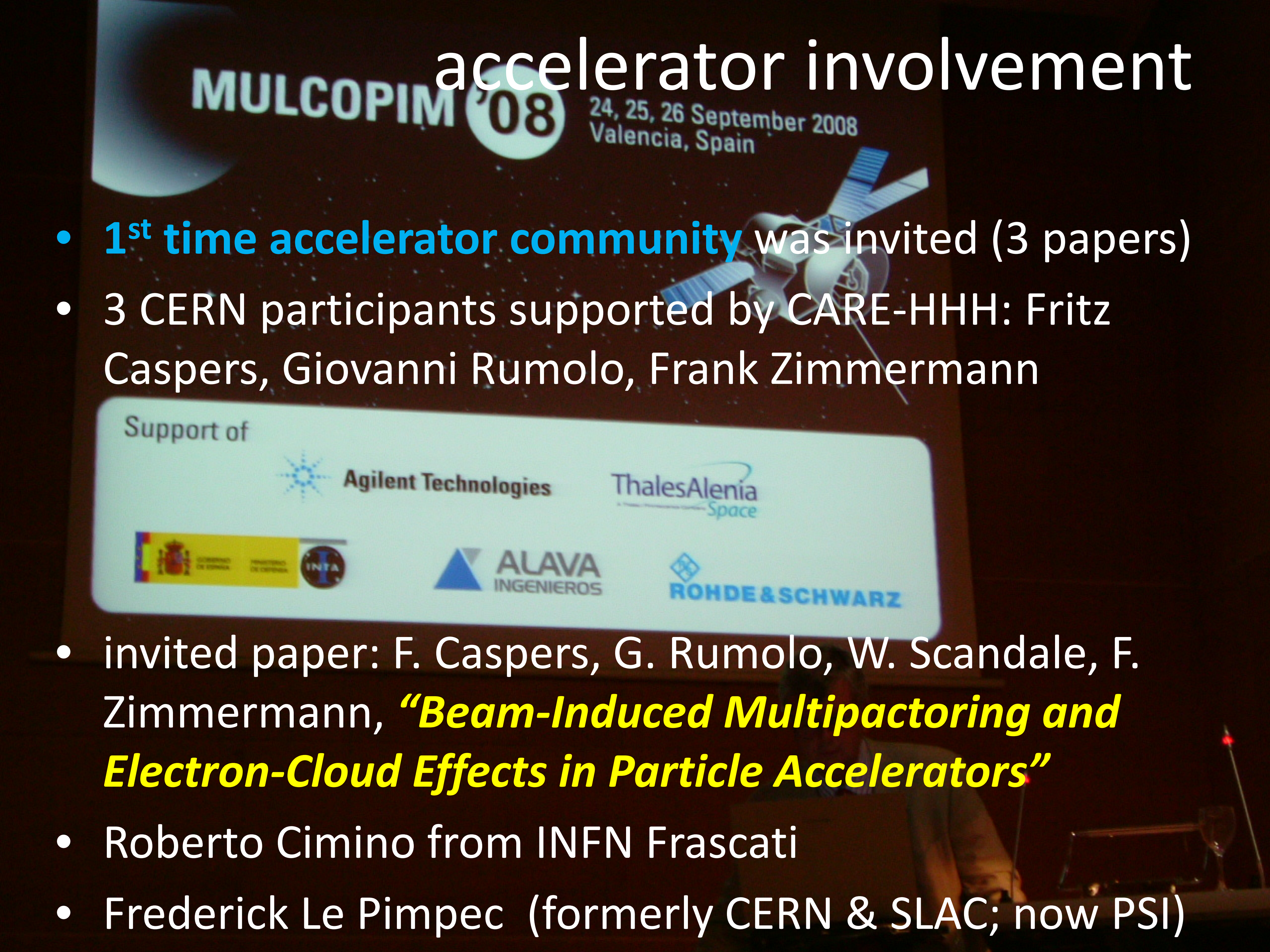
- *Corona 1, Corona 2*
- *Multipactor 6: Multicarrier*
- *Multipactor 7: Testing*

26.

accelerator involvement



- **1st time accelerator community** was invited (3 papers)
- 3 CERN participants supported by CARE-HHH: Fritz Caspers, Giovanni Rumolo, Frank Zimmermann
- invited paper: F. Caspers, G. Rumolo, W. Scandale, F. Zimmermann, ***"Beam-Induced Multipactoring and Electron-Cloud Effects in Particle Accelerators"***
- Roberto Cimino from INFN Frascati
- Frederick Le Pimpec (formerly CERN & SLAC; now PSI)

multipactoring - surfaces

- **waveguides, coaxial lines, and microstrip lines**
- main ESA mitigation strategy: modification of SEE properties
- preferred cure: coating that do not change over time: **POROUS COATINGS** ! (examples)
- do not rely on tabulated SEE properties!
- run prediction software only with related measured SEY data => **SEY DATABASE** (under construction)
- examples of treated surfaces, >9 db improvement in multipacting threshold, no sensitivity to time exposure.
- concerns: contamination and poor coating

multipactoring - tests

- ESA has enhanced R&D resources for this activity
- advanced testing techniques
- **e- seeding** by various means: beta emitter, UV flash lamp (120 Euro), regulated e- gun
- **ESA standard - ECSS-E-20-01 A "multipactor design and test"**
- **multicarrier operation** gives cloud evolution similar to e-cloud build up in accelerators (examples)
- multicarrier test facility is built up at ESA

multipactoring - simulations

- simulations codes: **FEST3D, MEST, Multipactor Calculator**
- **FEST3D: CAE tool for design of passive waveguide systems**; based on integral equations, BI-RME, method of moments, network theory; fast computation, arbitrary geometries
- **database for software** under construction
- harmonization and standardization – benchmarks for simulations and measurements
- **MEST & CEST** – simulating the **transition from multipactoring to corona regime** (increasing vacuum pressure); **friction and scattering forces**, algorithms

multipactoring - theory

- theoretical and analytical studies by teams in Russia, Sweden and Northern Ireland
- statistical theory of multipactor discharges between **two parallel plates** with different emission parameters
- non-resonant or **"poly-phase multipacting"** – similar to our case in accelerators
- **wedged wave guide** similar to rectangular wave guide, both have unstable stationary trajectory, little improvement in multipacting threshold
- **velocity spread of secondary e-** important
- **secondary emission yield description** often similar to ours; sometimes other historical formula from Vaughan

ideas & follow up

- contacts with ESA, PUV, EPFL etc.
- **Fritz "solved" satellite multipactoring** (magnetize the Ni layer used for Ag coating – **satellite becomes credit card**)
- proposed **modification of FEST3D** to include particle beam & static magnetic fields
  - simulate **microwave e-cloud diagnostics**
  - simulate **suppression or enhancement of e-cloud by microwave injection** near cyclotron resonance
  - simulate **"magnetron" effect**
  - **verify effect of ions**
  - benchmark CERN simulation codes

some highlights from talks

- *overview, databases for SEY & simulation codes (D. Raboso)*
- *novel porous coatings with low SEY (L. Galan)*
- *ESA multipactoring standard (Christoph Ernst)*
- *transition from multipacting to corona (L. Conde)*
- *multicarrier multipacting (S. Anza)*

MULCOPIM
(24th-September-2008)
Invited paper

"Multipactor breakdown: Present status and where are we heading"

David Raboso (ESA)

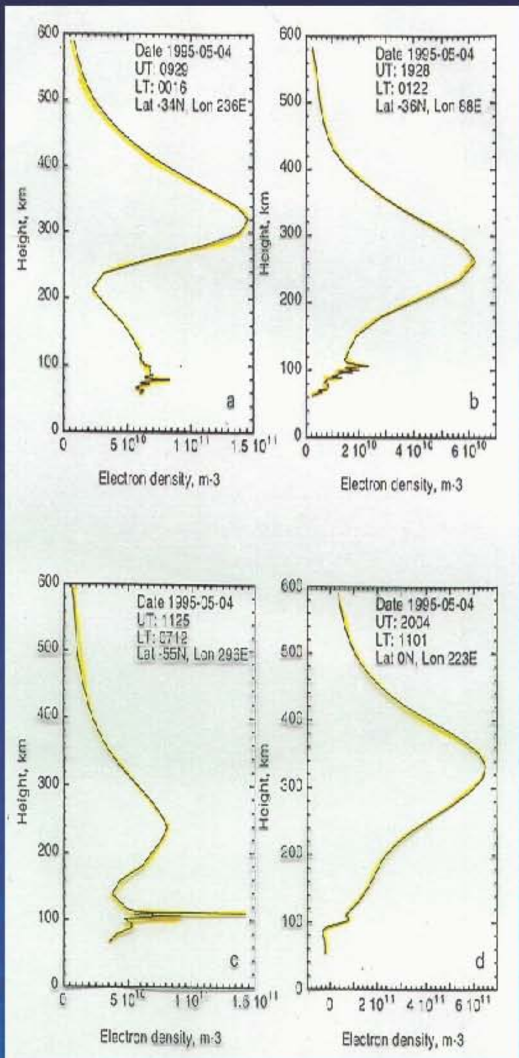
D. Raboso

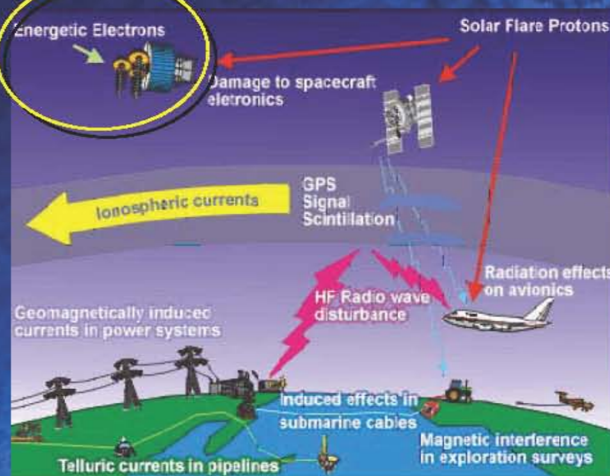
Ways to mitigate Multipactor

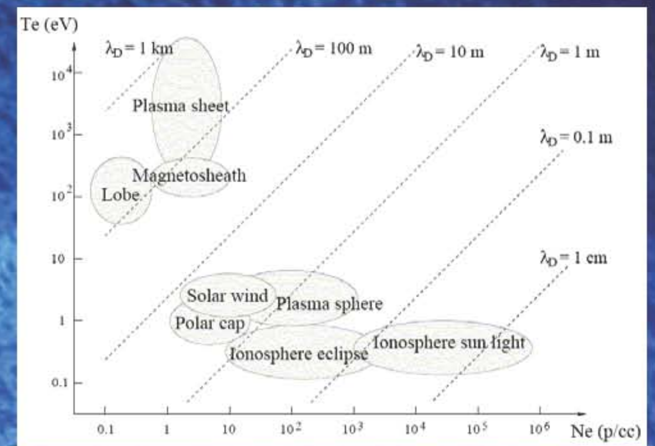
-By reducing RF power (NA)
-By increasing the gaps (Not always possible)
-Reducing the field strength (Not always possible)
-By increasing the frequency (NA)
-By working on the **SEE properties of the material**

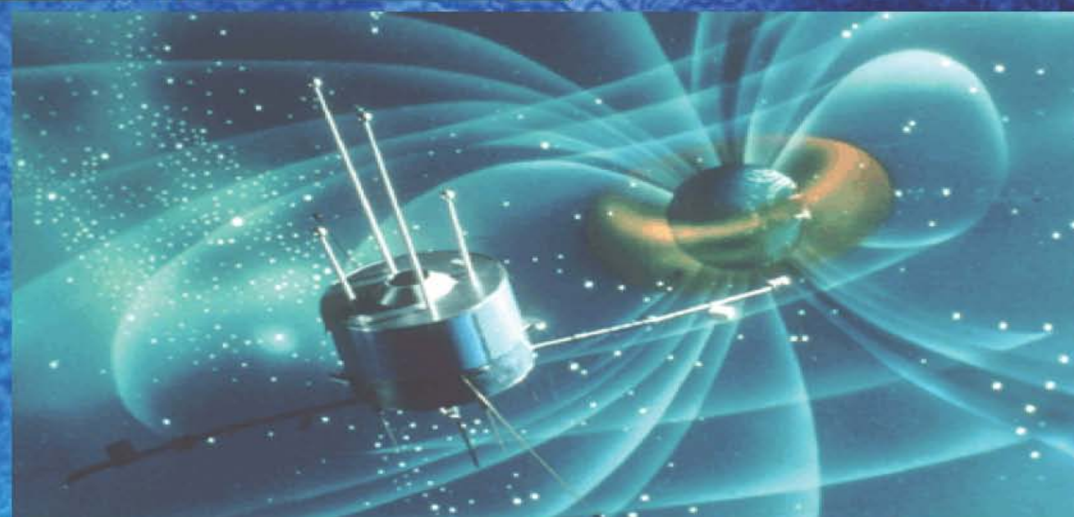
D. Raboso

Space weather









D. Raboso

Secondary emission: Lines of Investigation

- Create low loss surface coatings with stable SEY over time (POROUS COATINGS)
- Always measure the SEY of the component with a separate sample
    - -Same batch metal and same coating bath as component
- Run prediction software only with the related measured SEY data (DATA BASE)
- Concentrate more in the surface profile rather than the material properties

D. Raboso

Surface coatings: Porous coatings

The advantages in this type of surfaces are:

- Time exposure has little or none effect in the SEY curve
- Multipactor breakdown threshold is increased above 9 dB respect to standard coatings
- Low cost implementation
- Low loss influence

esa

D. Raboso

Surface coatings: Data base

ESA is running a small activity with ASAT, UAM and CSIC to create a SEY data base of typical coatings used by industry for high power RF applications.

The data base shall also include microscopic photos and roughness analysis together with "Hatch and Williams" charts.

Users will be able to extract these data for their simulations.

Industry will be contacted in October in order to include them or not in this survey.

Coating information and industrial process will be kept confidential.

Results will be made available in the new ECSS standard in 2009.

D. Raboso

ESA resources for R&D

In 2008 ESA (ESTEC) enhanced the internal resources (both human and equipment) dedicated to R&D in the field of Multipactor effect (Also Corona and PIM).

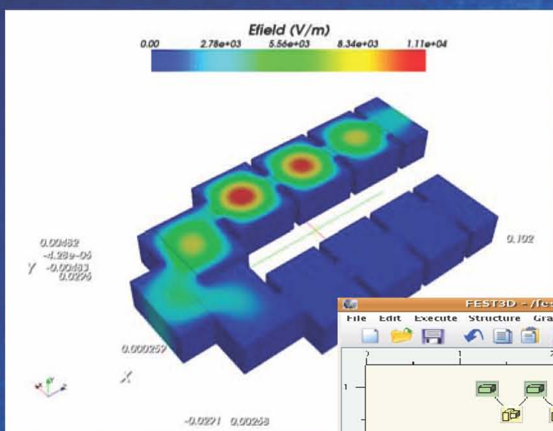
- Facilities dedicated to R&D
- Trainees 100% dedicated to R&D
- Support from Universities and industry

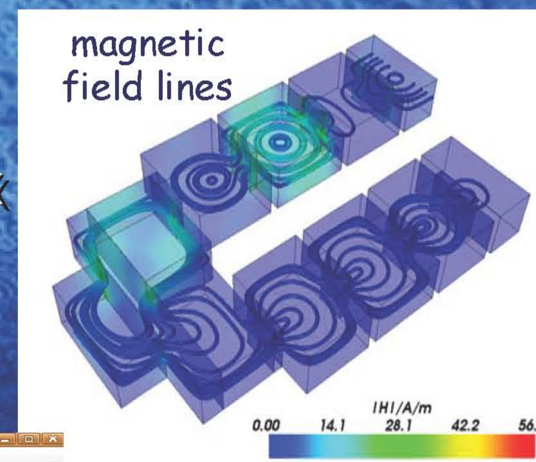
D. Raboso

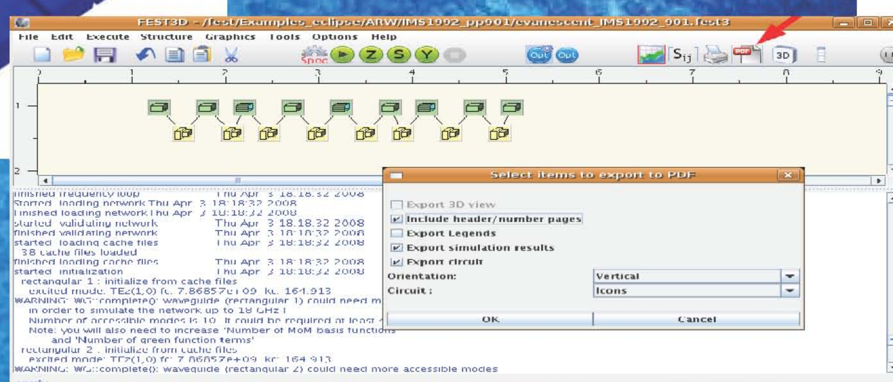
Simulation and prediction software: FEST3D

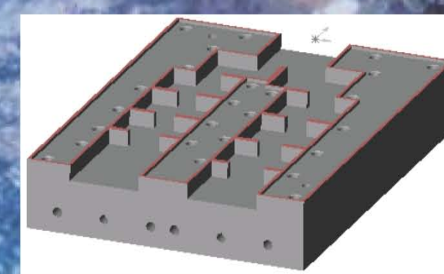
ESA funded several simulation/prediction software packages along many years. However, main efforts were concentrated in the development of FEST3D.

Distributed by ASAT and ItLink









L. Galan et al , Madrid

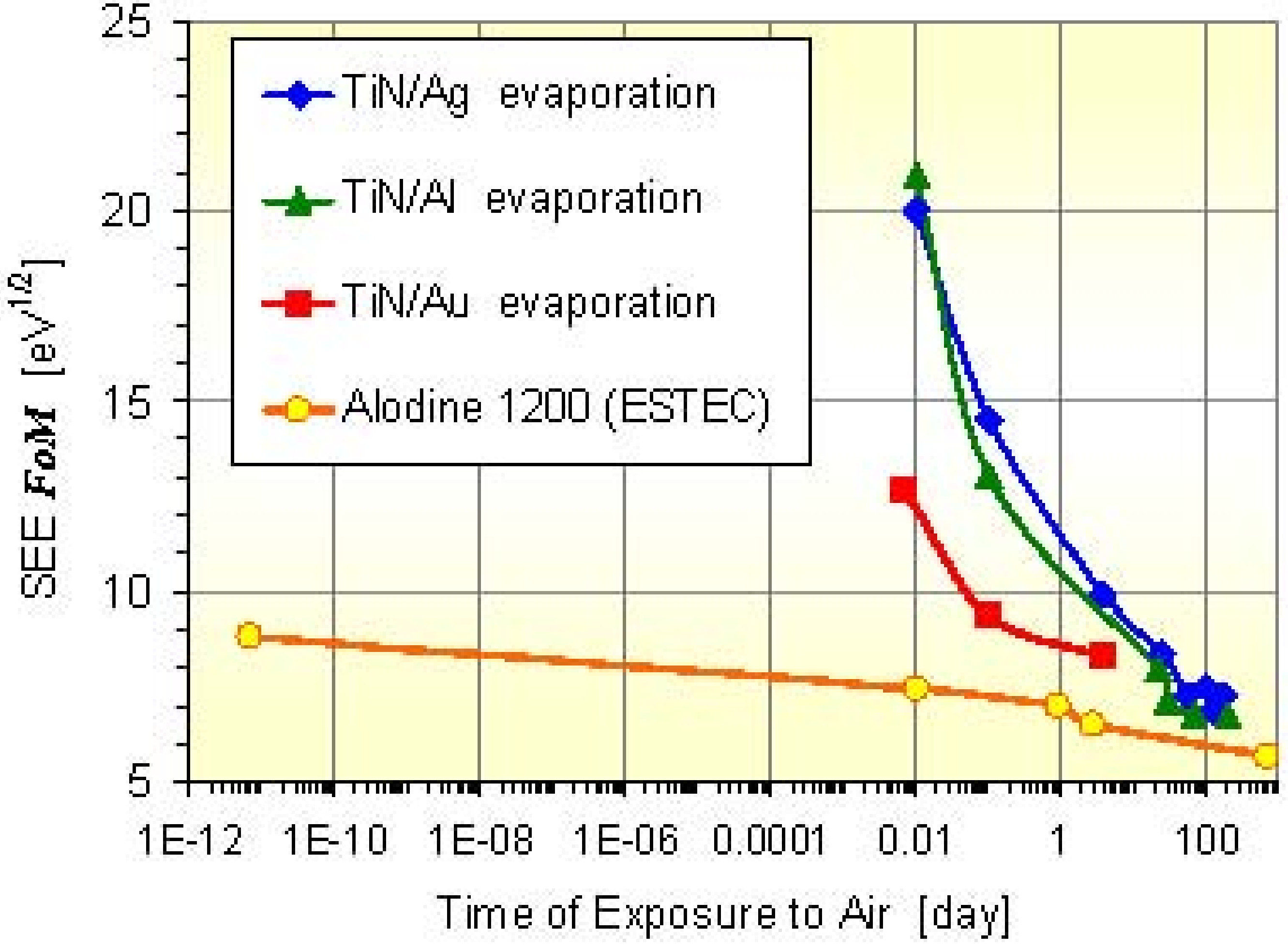


Fig. 1. Influence of air on SEY of Alodine and Ti nitride coatings.

The figure of merit $FoM = (E_1/\sigma_m)^{1/2}$ for secondary electron emission of anti-multipactor coatings is represented. [9]

Alodine: reference anti-multipactor coating for ESA since several decades; goal of R&D: to develop even better coating

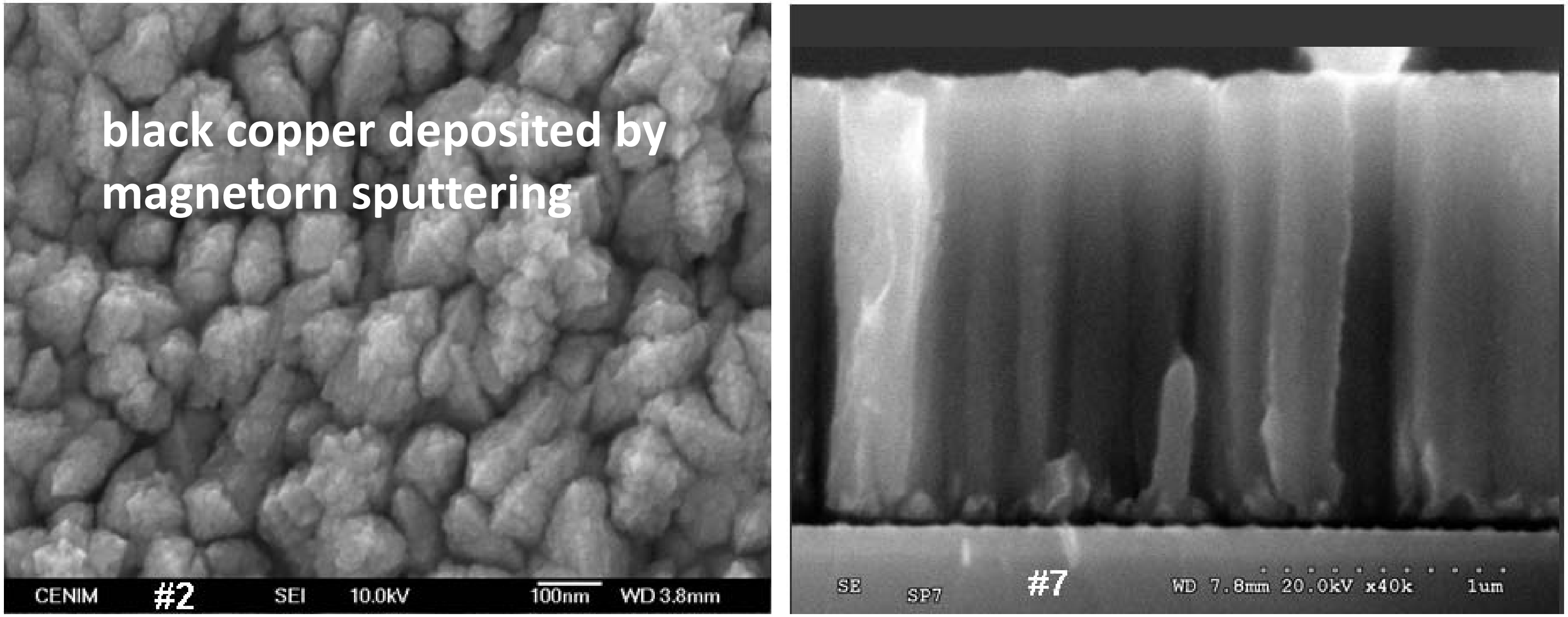


Fig. 3. SEM images of rough "black" copper deposited by magnetron sputtering. Samples #2 and #7, deposited at relatively high pressure and rate for separate columnar growth. Sample #7, deposited over single crystal Si wafer, was cleaved and its profile examined.

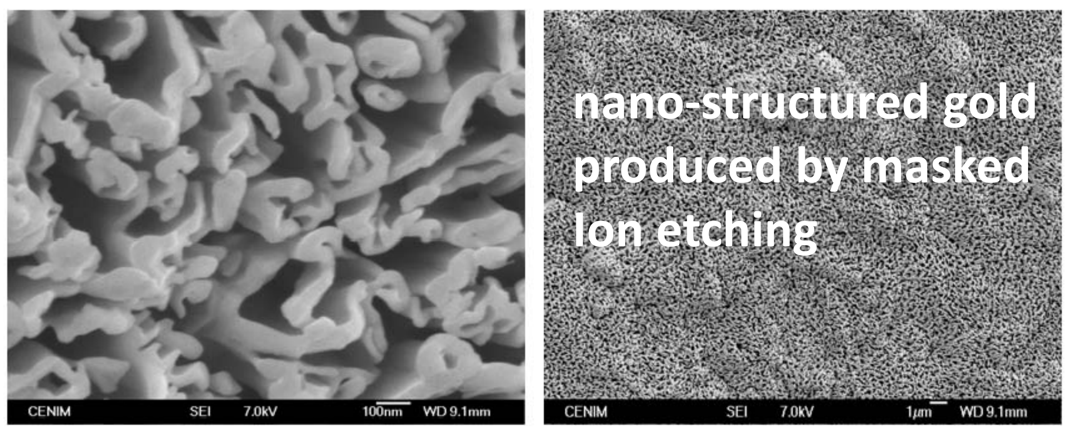


Fig. 8. SEM images of gold nanostructured by masked ion etching by sputtering Showing a nano-structured surface with very high aspect ratio, very uniform, with only one scale (about 500 nm), formed by walls of about 80 nm thick. This type of surface morphology has never been observed before.

L. Galan et al , Madrid

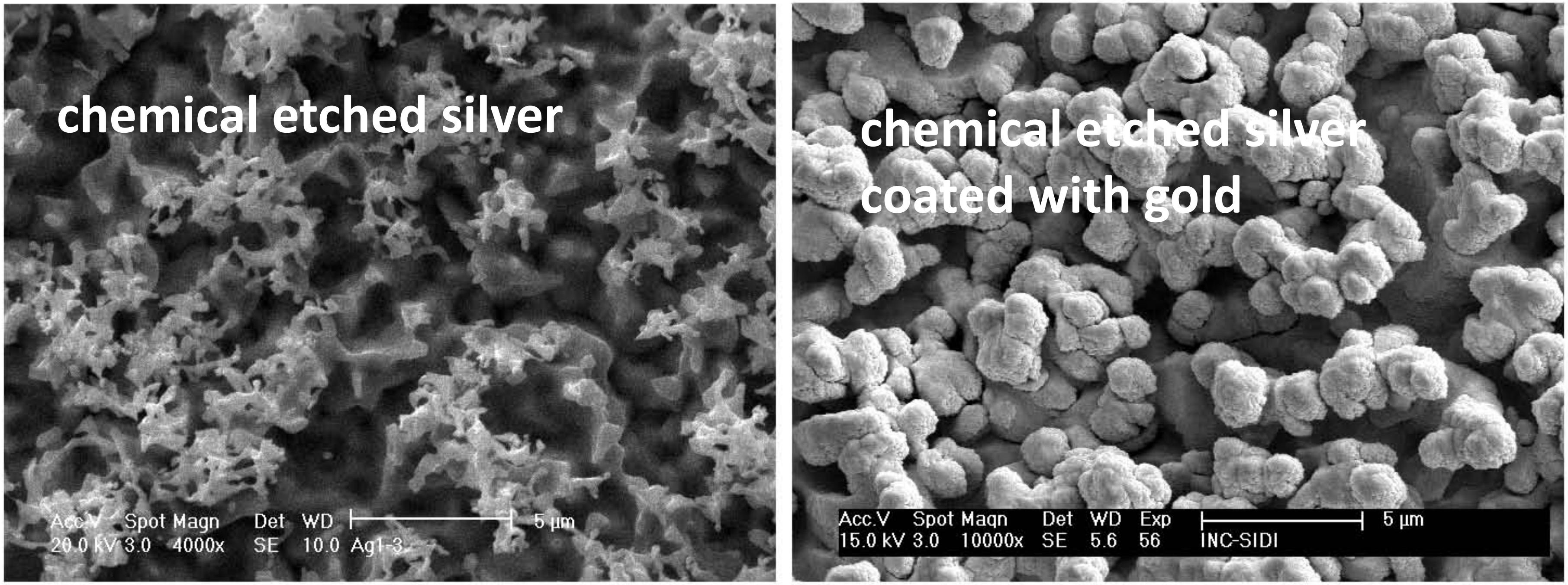


Fig. 13. SEM images of the effect of gold coating a chemical-etched silver sample. Effect of coating with 2 µm Au. Left, MP etched Ag sample; right, same after Au coating. The type of roughness has significantly changed. Samples MP were represantative (witness) of multipactor sample waveguide halves, see Fig. 14 . The substrates were of 20µm-Ag-plated aluminium from Tesat.

L. Galan et al , Madrid

D. Raboso, C. Ernst

ECSS-E-20-01A
5 May 2003

EUROPEAN COOPERATION
ECSS
FOR SPACE STANDARDIZATION

Space engineering

Multipaction design and test

ECSS Secretariat
ESA-ESTEC
Requirements & Standards Division
Noordwijk, The Netherlands

"ESA multipactoring standard"

1 Scope

This standard defines the requirements and recommendations for the design and test of RF components and equipment to achieve acceptable performance with respect to multipaction-free operation in service in space. The standard includes:

- verification planning requirements,
- definition of a route to conform to the requirements,
- design and test margin requirements,
- design and test requirements, and
- informative annexes that provide guidelines on the design and test processes.

This standard is intended to result in the effective design and verification of the multipaction performance of the equipment and consequently in a high confidence in achieving successful product operation.

This standard covers multipaction events occurring in all classes of RF satellite components and equipment at all frequency bands of interest. Operation in single carrier CW and pulse modulated mode are included, as well as multi-carrier operations. This standard does not include breakdown processes caused by collisional processes, such as plasma formation.

This standard is applicable to all space missions.

When viewed in a specific project context, the requirements defined in this standard should be tailored to match the genuine requirements of a particular profile and circumstances of a project.

NOTE Tailoring is a process by which individual requirements of specifications, standards and related documents are evaluated and made applicable to a specific project, by selection and in some exceptional cases, modification of existing or addition of new requirements.
[ECSS-M-00-02A, clause 3]

RF Breakdown

L. Conde

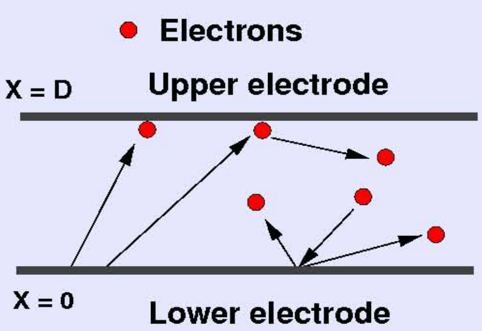
10^{-8} - 10^{-4} mbar

Electron multipactor

Secondary emission at the walls dominates

$$\lambda_{ea} \gg D$$

The electron motion is collisionless



The electric breakdown is controlled by the material at the walls and hence is *material dependent*

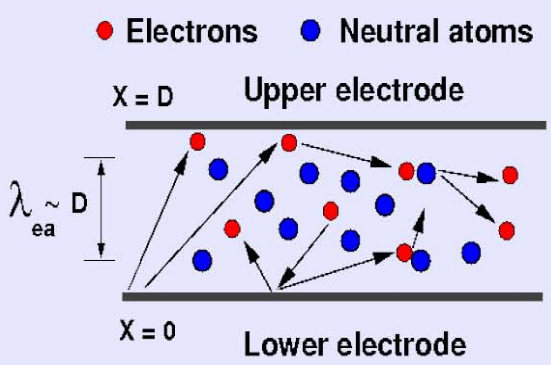
10^{-4} - 10^{-2} mbar

Multipactor plasma

Electron impact ionization and secondary emission at the walls.

$$\lambda_{ea} \sim D \qquad \nu_{ea} \sim f$$

Electron motion is weakly collisional



The breakdown *rely on the neutral gas AND on the properties of the material of electrodes.*

RANDOM EVENTS!

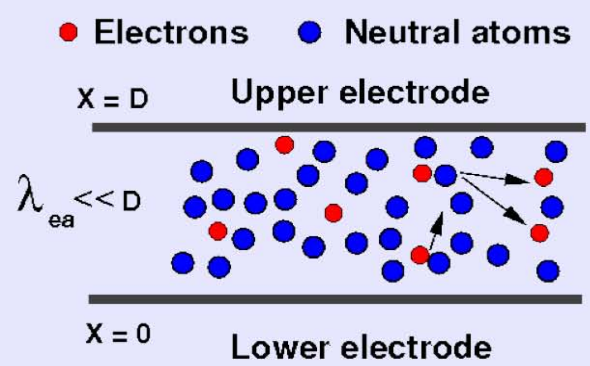
10^{-2} – 10^{2} mbar

Classical gas discharge

Electron impact ionization. dominates (Paschen)

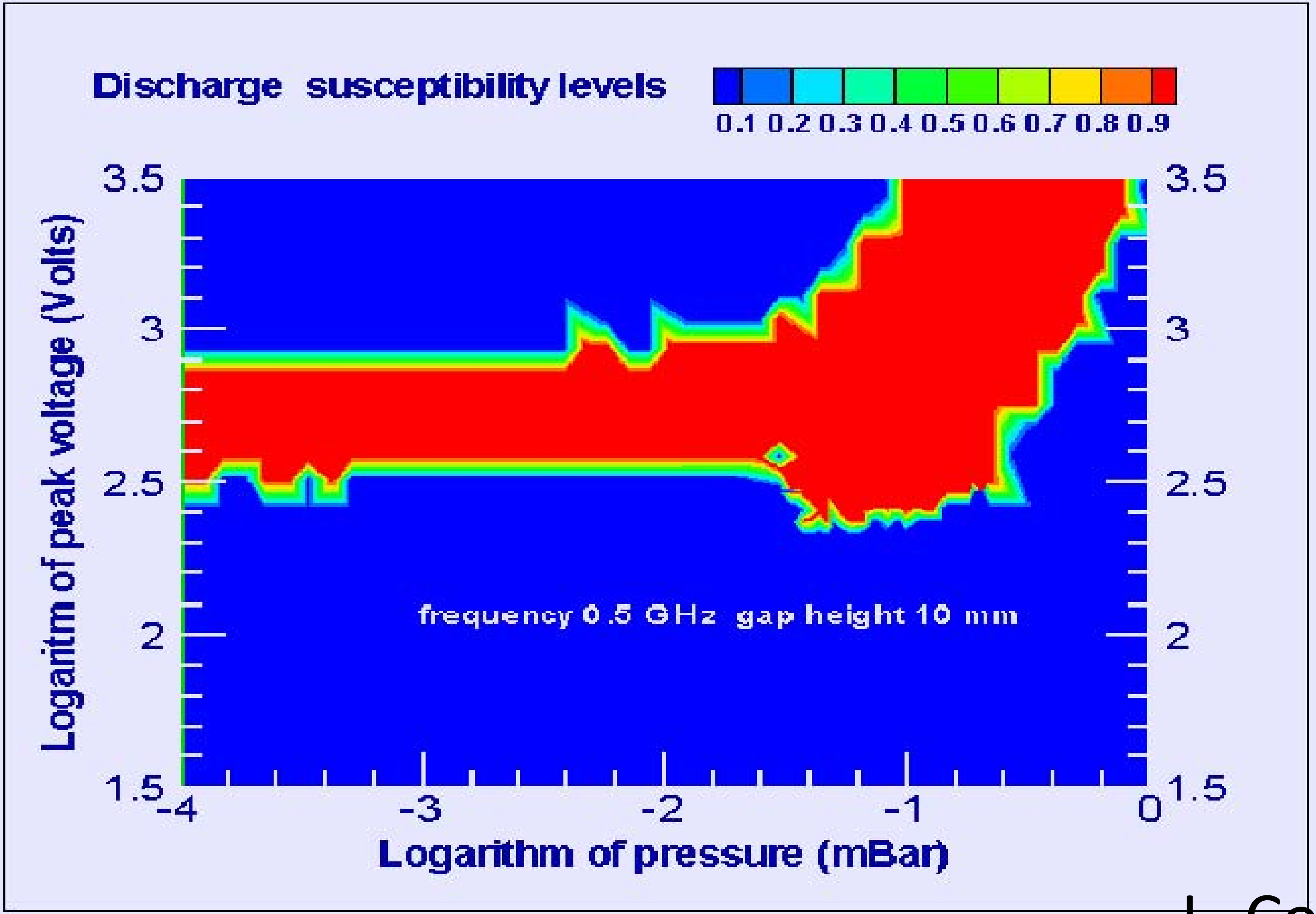
$$\lambda_{ea} \ll D \qquad \nu_{ea} \gg f$$

Collisions are dominant



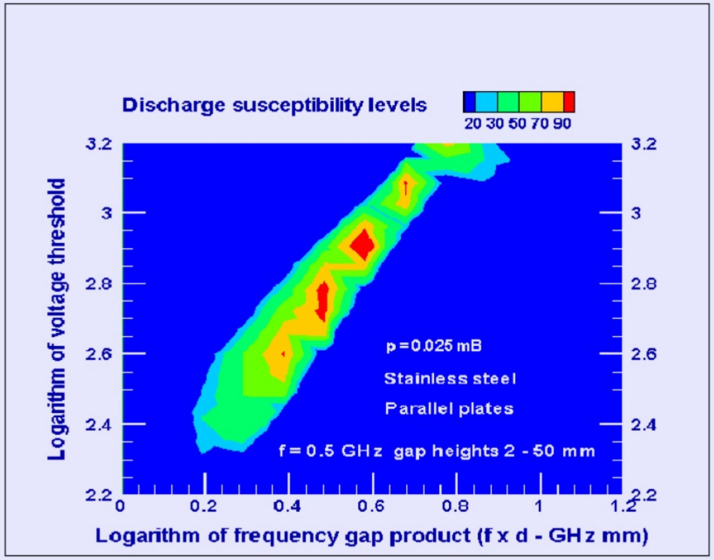
The breakdown *rely on neutral gas* and *is essentially independent of the material of electrodes.*

The RF discharge thresholds for different gas pressures

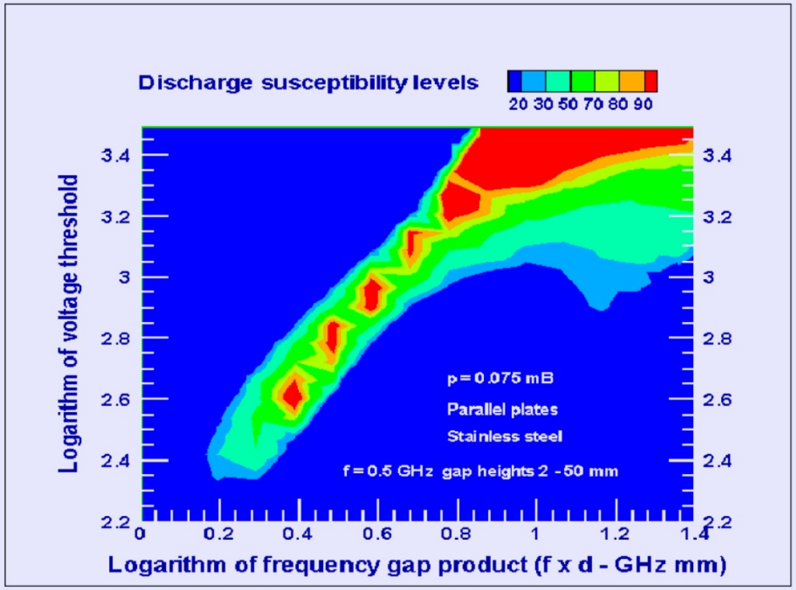


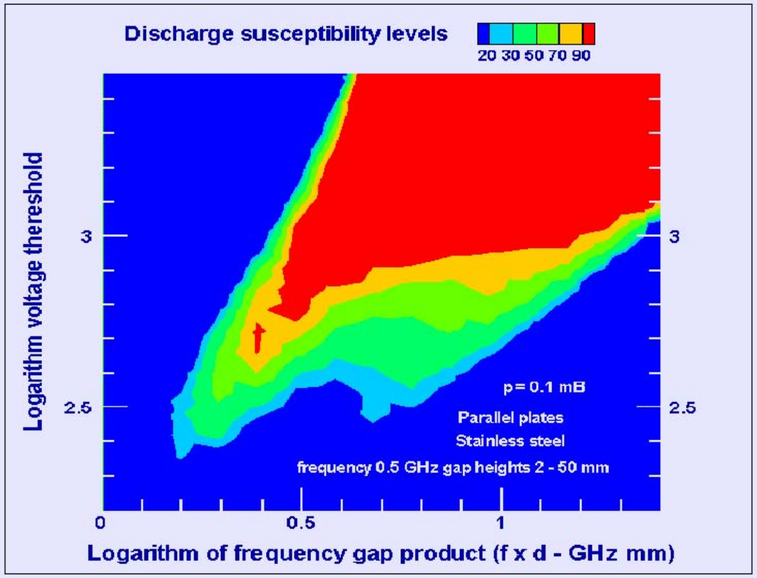
L. Conde

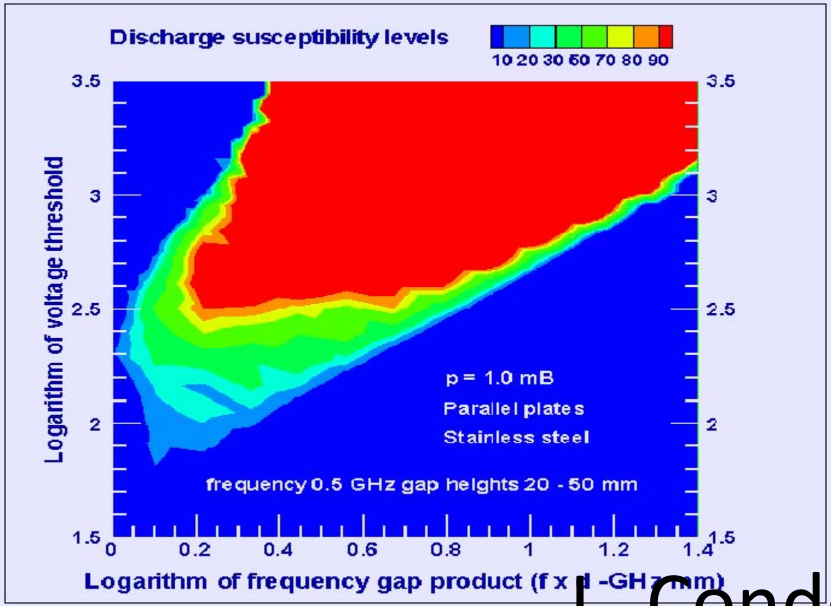
- The experimental results and the simulations using MEST for low pressure electron multipactor are recovered with CEST.



- The higher neutral pressures lead to the expansion of the discharge regions.







L. Conde

multicarrier multipacting resembling beam-induced multipacting

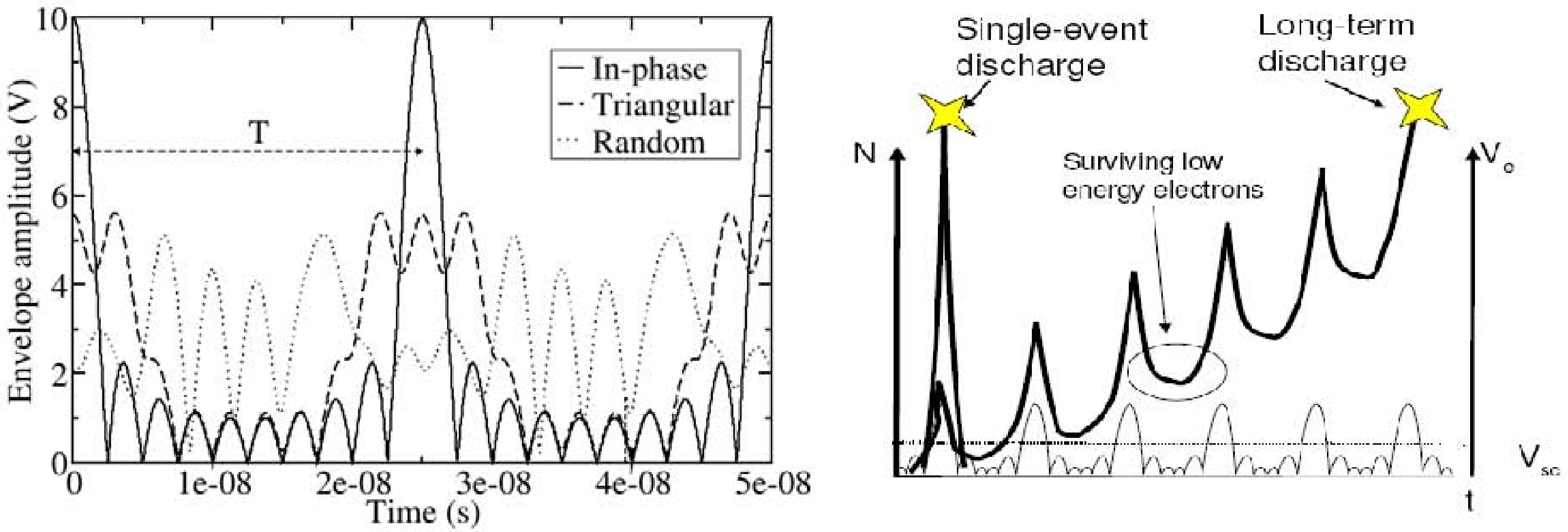


Fig. 1 (left) Envelope of a 10-carrier signal with Δf=40 MHz and different phasing schemes (right). Different kind of multipactor discharges under multi-carrier operation.

S. Anza

the end

we will try to invite some satellite e-cloud colleagues to CARE-HHH mini-workshop on e-cloud mitigation, CERN 20-21 November 2008