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Passive RF Electronics for High Power Payloads

ESA Contract No. 4000124877/18/NL/CRS

FINAL PRESENTATION

LEADERS IN IDEAS AND SOLUTIONS

activeaerogels

UNIVERSITAT POLITÈCNICA DE VALÈNCIA

Programmatic overview

Milestone	Date planned	Actual date	Comments / Reasons for deviation
KO	08.04.19	08.04.19	
SRR	June 19	05.07.19	~1 month delay due to programmatic aspects
PDR	Nov. 19	13.11.19	On time from T0
CDR	May 20	30.06.21	- Covid lockdown stopped work in March 2020 - Availability of VSC lab for 1st test campaign (Feb. 21) - Validate the "desiccation" hypothesis (Go/No Go)
FR	Aug. 20	Oct. 23	- Sample refurbishment and delays with plating - Material laboratory tests (Aug. 2022) - Availability of VSC lab for 2nd test campaign (Dec. 2022) - Review results (March 2022) - Documentation preparation

Multipactor

- Multipactor - resonant RF vacuum breakdown phenomenon.
  - Electrons accelerated by an RF E-field gain sufficient momentum to release secondary electrons from surfaces
  - An avalanche effect can occur.
- Multipactor is affected by:
  - The strength of the RF electric field.
  - The frequency in conjunction with the geometry (f x d)
  - The surface properties of the boundary walls e.g. secondary electron emission coefficient, surface coating, shape etc.
- **Multipactor may limit the power handling of (resonant) passive RF components**

Multipactor Mitigation

- Pressurisation
- Control of the frequency-gap product
- Magnetic or DC bias
- Surface treatment: reduce SEY
- Dielectric filling

Aerogel

- Synthetic porous ultralight material derived from a gel
- The liquid component of the gel replaced with a gas
- Solid with extremely low density and excellent thermal insulation properties
- Investigations have so far indicated favourable electrical properties (loss tangent and breakdown voltage)

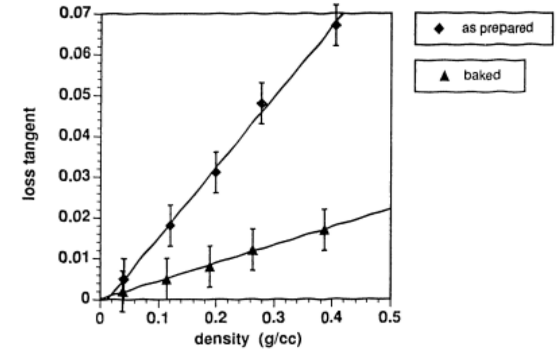

Figure 2. Plot of loss tangent for 'as prepared' and 'baked' silica aerogel versus density.

DIELECTRIC PROPERTIES AND ELECTRONIC APPLICATIONS OF AEROGELS

L. W. Hrubesn
R. W. Pekala

This paper was prepared for submittal to International Symposium on Advances in Sol-Gel Processing and Applications Chicago, Illinois August 24-28, 1993

July 1993

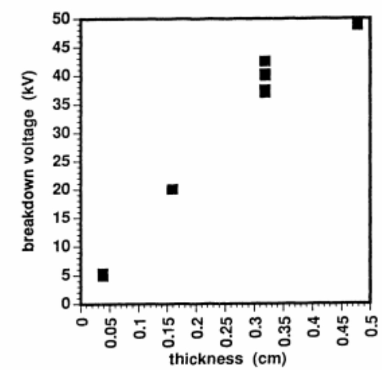

Figure 6. Breakdown voltage for various thicknesses of silica aerogel. The average dielectric strength for the silica aerogels is 128 kV/cm.

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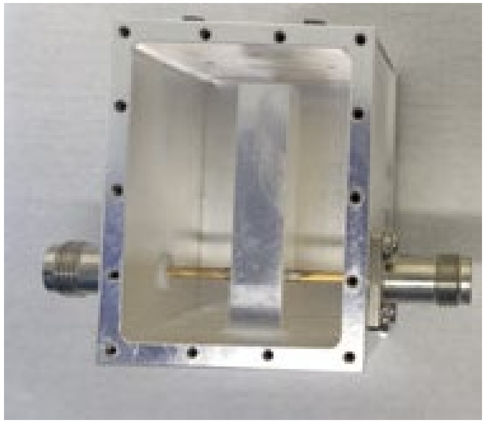
Research hypothesis

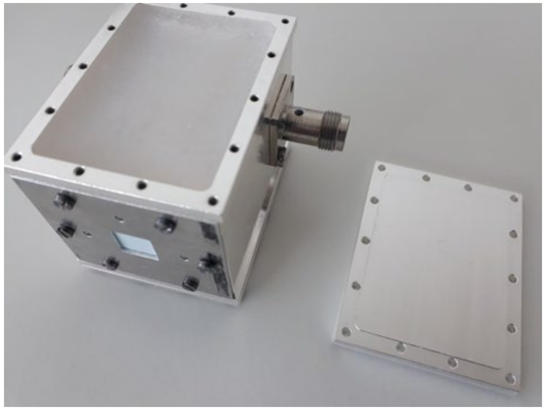
From aerogel properties

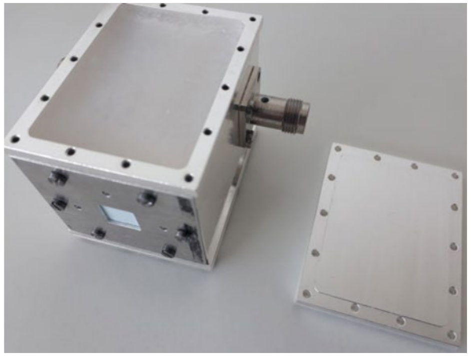
- Extra low density: expect high level of RF transparency
  - fused quartz form of SiO_2 can have a tanδ of 0.00006 at 1 GHz.
  - Since SiO_2 aerogel has a density hundreds of times less than its bulk form, it holds the prospect of having an even lower loss impact
- Extra high thermal insulation: expect high level of electrical insulation
- Could Aerogel provide a favourable solution for multipactor mitigation?

Experimental kit

- The test piece is a single coaxial resonator operating at approx. 1.3 GHz in vacuum.
- It can be used empty and filled to estimate ε_r, $\tan\delta$.
- Power handling test can then be performed





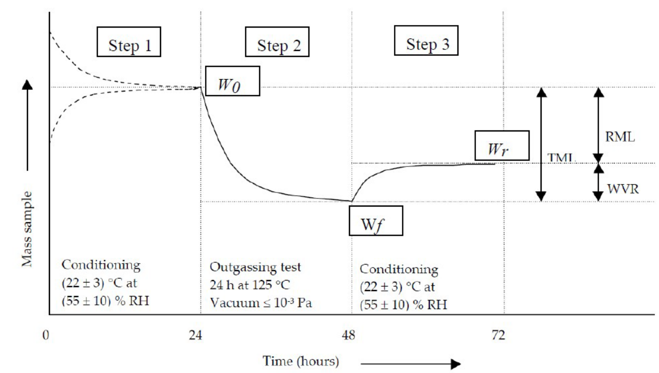


Filled cavity

- The aerogel used in the experiment is in bead form.
- A procedure involving vibration was devised to ensure that the cavity was tightly packed and contained no void areas.
- It took only 4 grams of aerogel to completely fill the cavity.
- Although the type of aerogel used is hydrophobic, it can still absorb some water and a bake-out regime was employed to remove as much as possible.

Outgassing

- Outgassing tests were performed
- Aerogel samples proved to be compliant
- Further testing received the green light



Samples (%)	1	2	3	Average
TML	0.0049	0.0072	0.0015	0.0046
WVR	0.0069	0.0117	0.0117	0.0101
RML	-0.0019	-0.0045	-0.0102	-0.0055

Empty

Samples (%)	1	2	3	Average
TML	0.6073	0.6613	0.6699	0.6462
WVR	0.4537	0.4362	0.4555	0.4485
RML	0.1535	0.2251	0.2144	0.1977

With Aerogel

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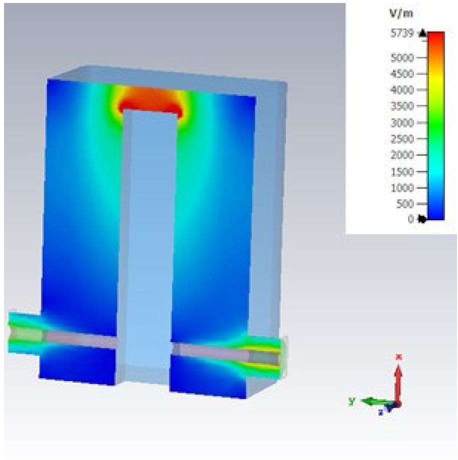
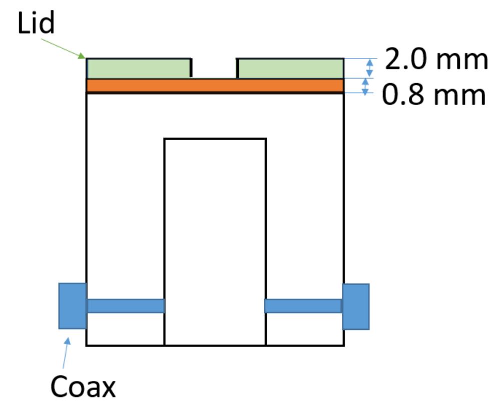
SPARK3D analysis

- Power handling estimated at 47W

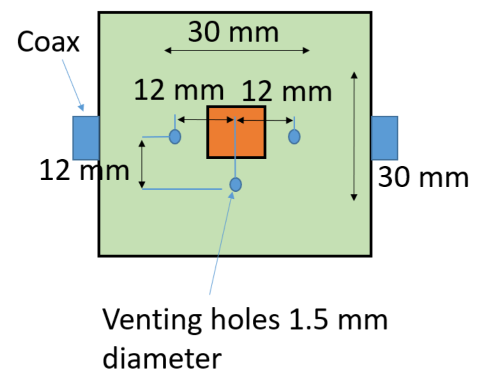
Material	E_{max}(eV)	E_1(eV)	δ0	δmax
Aluminium	315	19.86	0.5	2.34



Venting



- Simulations confirm that with three holes an empty cavity will vent to pressure level below $2x10^{-5}$ mbar in less than 7 hours.
- Additional electromagnetic simulations confirm that the perturbation to the resonant characteristics of the cavity are negligible.
- A particle filter is used to ensure no aerogel particles can lead from the venting holes



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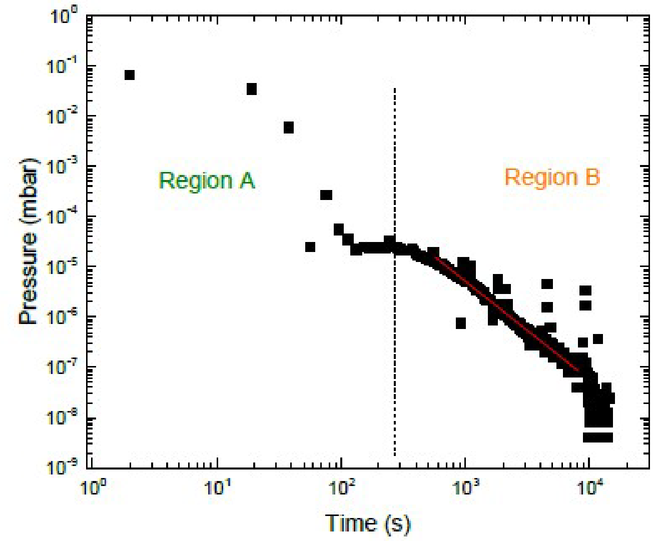
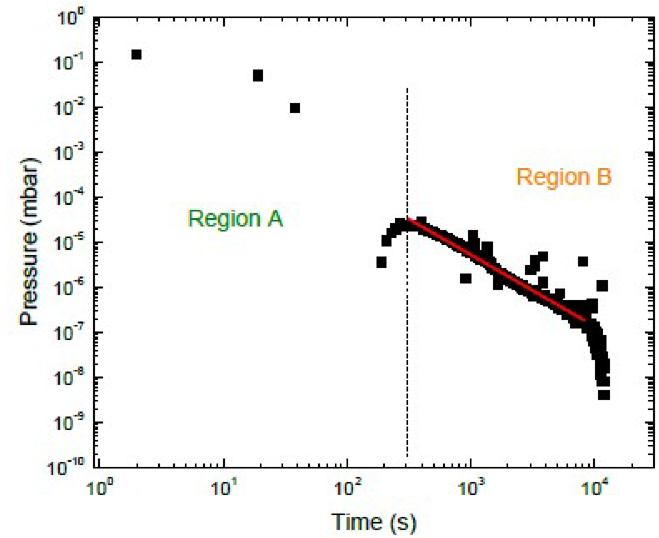
Venting tests

Time (s)	$1 \cdot 10^{-5}$mBar	$1 \cdot 10^{-6}$mBar
No aerogel	469	1733
With aerogel	595	2898

Summary of the time to reach the pressure indicated for the DUT (estimated error: 5 %).



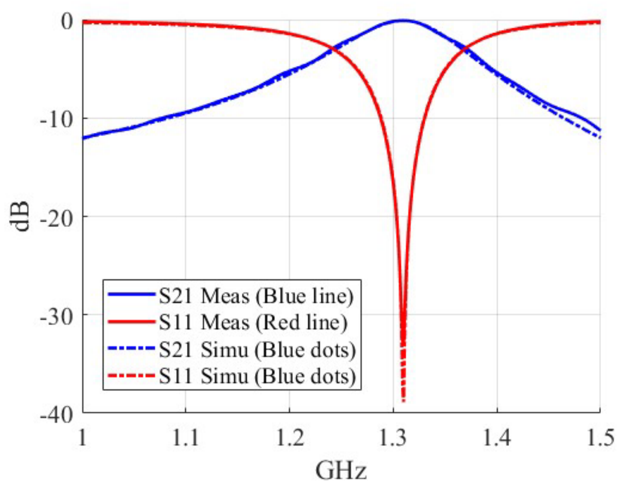


Pressure as a function of time for (top) DUT without aerogel and (bottom) DUT filled with aerogel.

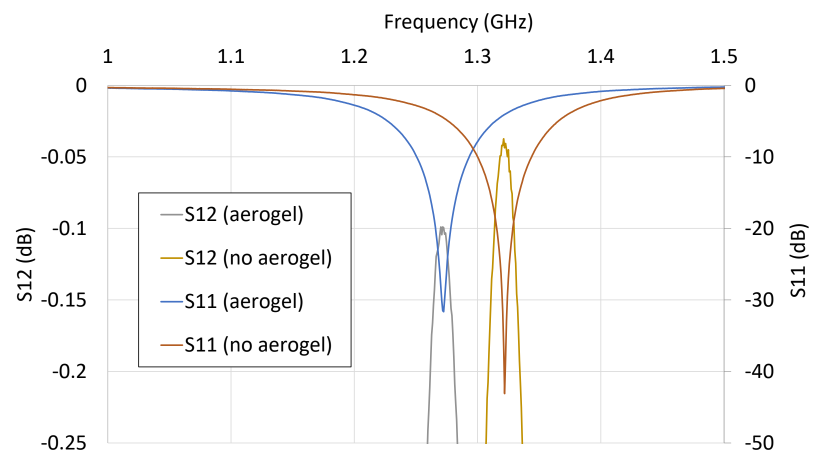
Experimental procedure

- DUTs
  - Cavities with aerogel (DUT1, DUT2)
  - DUT2 is then emptied and tested for reference
- Process
  - S-parameters are measured before the test
  - Sample was under high vacuum for at least 65 hours and bake-out (18 hours)
  - S-parameters are measured
  - Multipactor test is conducted
  - S-parameters are measured

Low-power characterisation



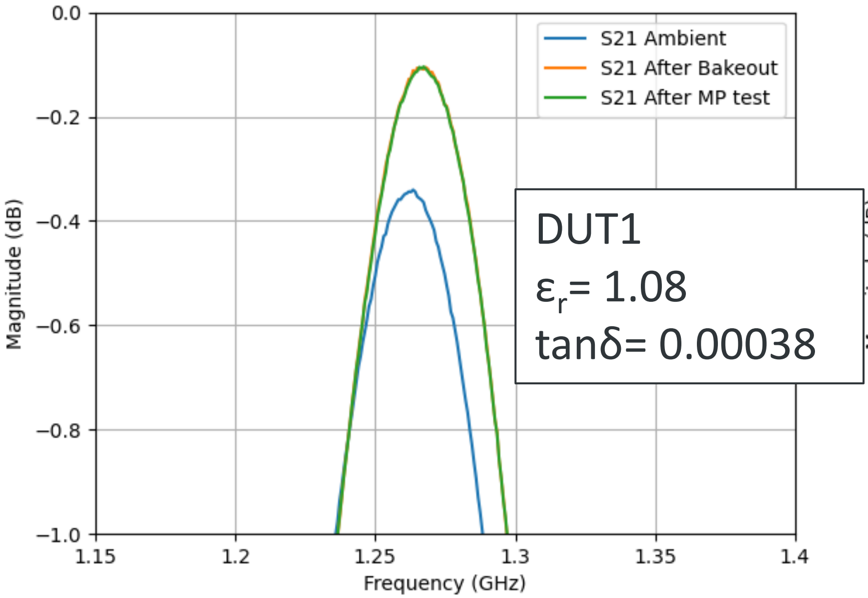
simulated (Simu) and measured (Meas) responses of the high-power reference sample without aerogel

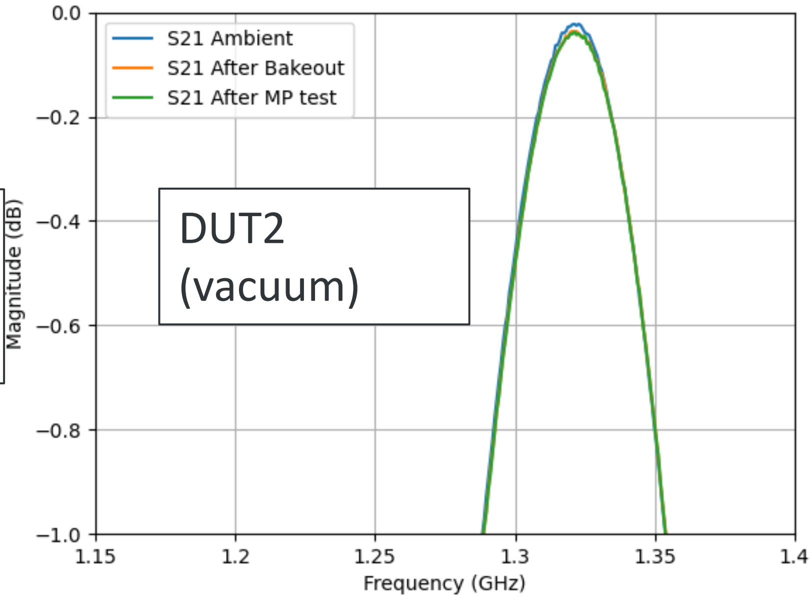


Comparison of the S_{21} frequency response of the manufactured Test structures with and without aerogel.

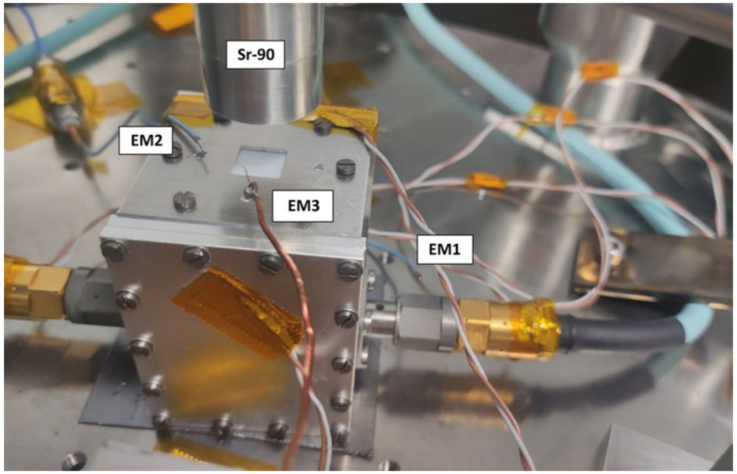
dielectric constant εr ≈ 1.09 tanδ ≈ 0.0004.

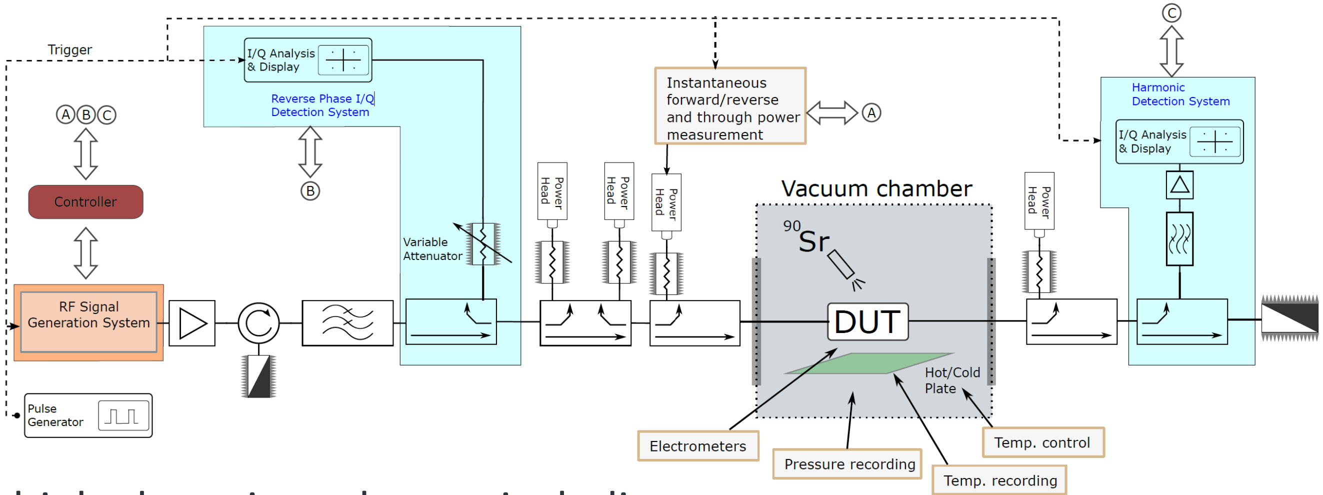
Low power tests before & after MP





MP Test set-up





Multiple detection schemes including:

- ✓ vector measurement of reflected and harmonic power
- ✓ Electrometers
- ✓ Thermocouples
- ✓ Pressure recorders

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MP Results

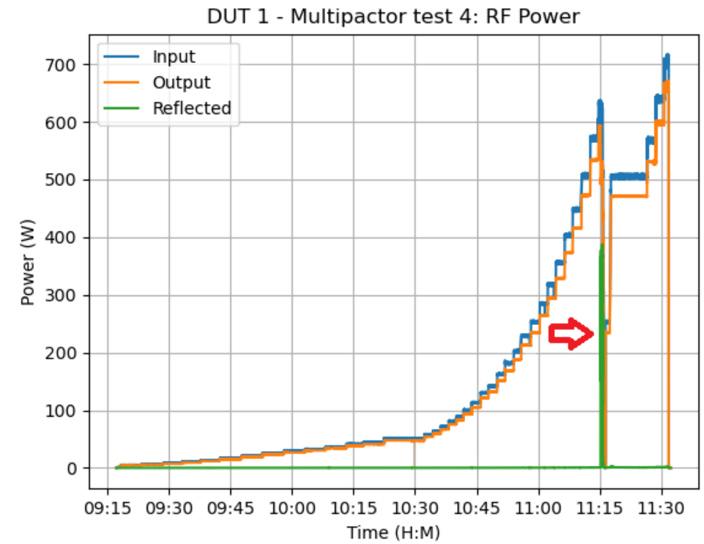
DUT1 (aerogel)

- Discharges were detected **around 600 W_{pk}** in the reverse IQ, 3H and RF power sensors
- Then, the RF power was reduced to extinguishing the discharges. After 1 minutes, the RF was increased again.
- Discharges were detected again at 700 *Wpk* in the IQ and 3H systems

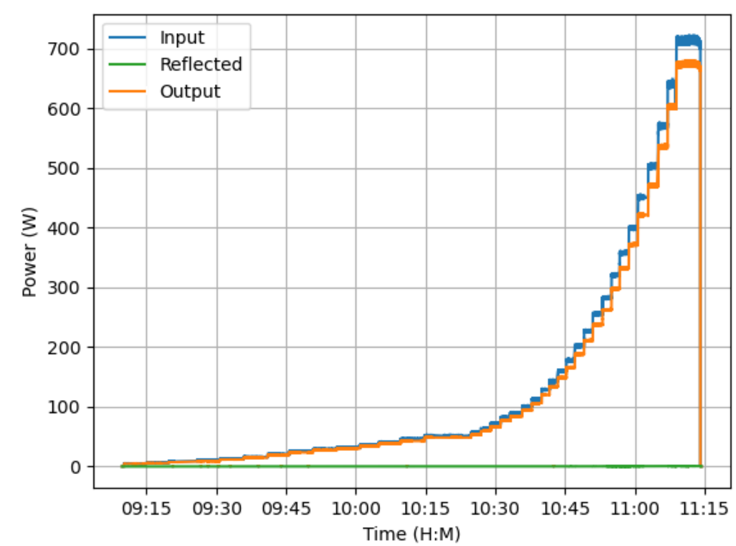
DUT2 (aerogel)

- Nominal and stable behaviour was observed **up to at least 700 W_{pk}**. No discharges were detected during all the test

DUT1 (aerogel) – Multipactor Test

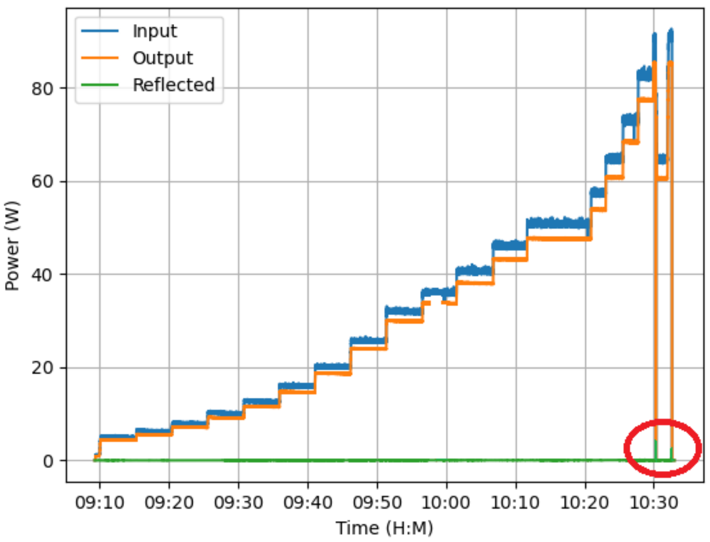


DUT2 (aerogel) – Multipactor Test



MP Results

DUT2 (empty) – Multipactor Test



DUT2 (empty, reference)

- Discharges were detected **around 80 W_{pk}** in the reverse IQ, 3H and RF power sensors
- Then, the RF power was reduced to extinguishing the discharges. After 2 minutes, the RF was increased again. Discharges were detected again around 80 W_{pk} in the reverse IQ, 3H and RF power sensor systems.

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Lessons learned

- The particle filter seems to be efficient in containing aerogel particles.
- Beads require a careful process for filling the cavity and avoid settlement.
- Of particular importance for the performance at both low power (tanδ) and high power (multipactor) is the desiccation. It calls for several hours of bakeout and vacuum.
- Although venting is estimated in the absence of aerogel, the desiccation conditions seem to deliver an effective venting
- The temperature exposure of the particle filters should be taken into consideration in bakeout
- There is a consistent validation of improved power handling thanks to aerogel

Future activity

- Develop techniques (perhaps pre-processing of aerogel) that reduce the required time in TVAC. Even if all other parameters are favourable, requiring several days in TVAC for a whole satellite is not viable
- Improve the loss tangent. Literature suggests that there is margin to improve the loss tangent by one to two orders of magnitude. This is critical for the Q-factor of the resonant components. This could be explored by different compositions of aerogel
- Aerogel monoblocks. In the study we used beads as these more easily conform to an irregular geometry. Monoblocks can be more robust but the following two challenges should be addressed; a) chemical interaction occurs between the solution and metallic cavities during curing, so settling the aerogel in the final component is not an option, and; b) aerogel shrink during curing and this needs to be calibrated
- Develop a functional RF device (e.g. an L-band GNSS filter) complying with specifications to demonstrate the value of the technology.

Conclusions

- A coaxial resonator was used for low and high power vacuum tests of aerogel
- Aerogel filling has shown to increase the power handling by an order of at least 9 dB
- The loss tangent is estimated at 0.00038 but literature indicates this could be reduced by one or two orders of magnitude
- Future works to focus on
  - ✓ Improving the loss tangent
  - ✓ Reduce sample preparation time in TVAC
  - ✓ Using aerogel monoblocks and consider partial filling
  - ✓ Demonstrate the performance in a functional component
  - ✓ Reduce the desiccation time by pre-treating the aerogel