HERIOT WATT UNIVERSITY	**Passive RF Electronics for High Power Payloads** **ESA Contract No. 4000124877/18/NL/CRS**	**Doc. No: D1** **Issue:** **Date: 06 October 2023**

Executive Summary

Prepared by: George Goussetis, Mark Kunes

1. INTRODUCTION

Multipactor has long been known as problematic in satellite equipment [1] and can lead to loss of channel performance or permanent equipment damage. The work reported here is a contribution to the mitigation of its effects. The authors would like to thank the European Space Research and Technology Centre (ESTEC), European Space Agency (ESA) for sponsoring this work, within the framework of the ITI project "Passive RF Electronics for High Power Payloads" (ref. ITI No. 8876).

2. MULTIPACTOR BACKGROUND

Multipactor is a resonant RF Vacuum breakdown phenomenon [2]. If electrons are accelerated by an electric field and gain sufficient momentum to release secondary electrons, an avalanche effect can occur, leading to increased RF noise or in extreme cases, to permanent damage of equipment.

Multipactor is affected by:

a. The initial energy and direction of the electrons.

b. The frequency and strength of the electric field.

c. The surface properties of the boundary walls e.g., secondary electron emission coefficient, surface coating, shape etc.

3. AEROGEL BACKGROUND

Aerogels are a class of synthetic porous ultralight materials derived from a gel, in which the liquid component for the gel has been replaced with a gas, without significant collapse of the gel structure. The result is a solid with extremely low density [3]. Fig. 1. demonstrates the strength yet tenuity of the substance. Image Courtesy NASA/JPL-Caltech, Public domain, via Wikimedia Commons

Fig. 1. Showing the strength of Aerogel

4. MOTIVATION

Multipactor effects can range from a slight channel noise degradation, to the complete destruction of an RF component. Many different methods have been used over the years in an attempt to reduce multipactor.

Anti-multipactor dielectric caps have long been used to interrupt the path of the electrons in coaxial filters, including those developed for ESTEC on the ECS/OTS [5] programme in the 1970s. In many cases these caps only work to a limited extent, and at very high powers can lead to a breakdown path around them.

Multipactor mitigation schemes such as the use of magnets, bias voltages, various coatings and surface shapes such as grooves, can lead to reduced performance through increased loss and mass.

In this work, we have attempted to overcome these problems by using aerogel to fill the cavity, and hence prevent alternative path multipactor and at the same time have a low impact on the mass and insertion loss.

Since multipactor relies on the electrons having a sufficient mean-free path to have time to be accelerated by the applied electric field and build up secondary electrons for an avalanche, anything which reduces this path length must help to reduce the effect.

Aerogel is one of the lowest density solid substances ever produced, and in the case of silicon dioxide (SiO2) holds the prospect of low RF loss as well as low mass. The fused quartz form of SiO_2 can have a tanδ of only 0.00006 at 1 GHz, such as in the commercial form vitreosil [4].

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.

5. TEST SAMPLE

The test piece is a single coaxial resonator operating at approx. 1.3 GHz in vacuum. It is manufactured from aluminium and silver plated.

The fig. 2. shows the unfilled cavity, and fig. 3. the cavity after filling with its lid alongside.

In the critical area near the end of the resonator, the wall is thinned to allow the Strontium β source to penetrate the cavity, and supply seed electrons to simulate the space environment (where electrons are generated by cosmic rays).

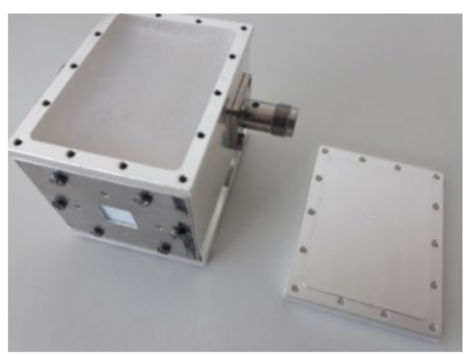

Fig. 2. Aerogel filled test cavity

6. AEROGEL FILLING

The aerogel used in the experiment is in powder form, which has the advantage that the cavity can be easily filled without machining of the 'solid' form or shrinkage and reaction with the metal surface, which can occur if the aerogel is produced in situ.

It was found that subsequent to filling, settling of the powder could occur, and so a procedure involving vibration and then refilling was devised to ensure that the cavity was tightly packed and contained no void areas.

It took only 4 grammes of aerogel to completely fill the cavity. A typical space qualified L-Band coaxial cavity resonator filter operating at this frequency would have a mass of the order of 100 grammes per resonator section, which includes the solid multipactor caps. These caps are of similar mass to the aerogel filling the whole cavity. Almost no overall mass penalty will result therefore from an aerogel filled filter.

A special PTFE particle mesh filter was procured [6], to ensure that no aerogel would escape through the vent holes and contaminate the test chamber, yet still allow adequate venting. The venting was verified by a helium leak test.

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.

7. TEST SET-UP

The thermal vacuum chamber setup includes high power TWTA source, high power loads, couplers and harmonic filters.

Multiple detection schemes were employed including:

a. Vector measurement of reflected and harmonic power
b. Electrometers
c. Thermo-couples
d. Pressure recorders

The complete system is under computer control and is shown in fig. 4.

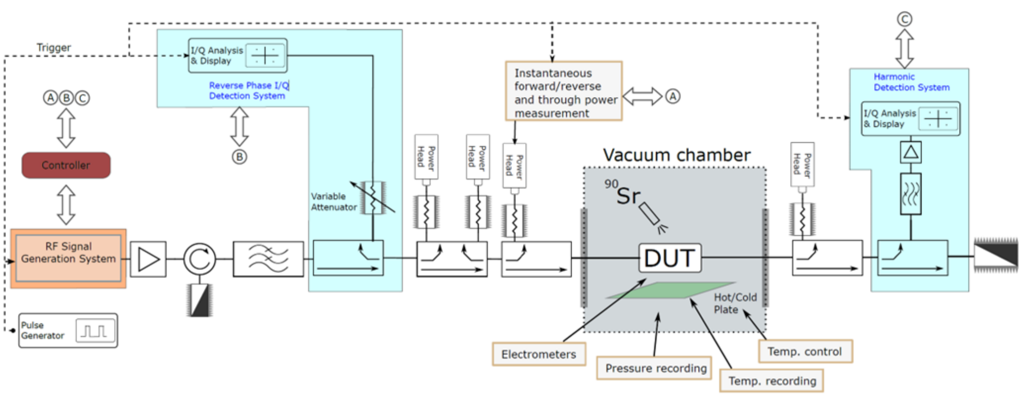

Fig 3 Test set-up

Fig.5. shows the test piece in the thermal vacuum chamber with connecting cables, thermo-couples and β radiations source pointing down towards the thinned end-cap of the device.

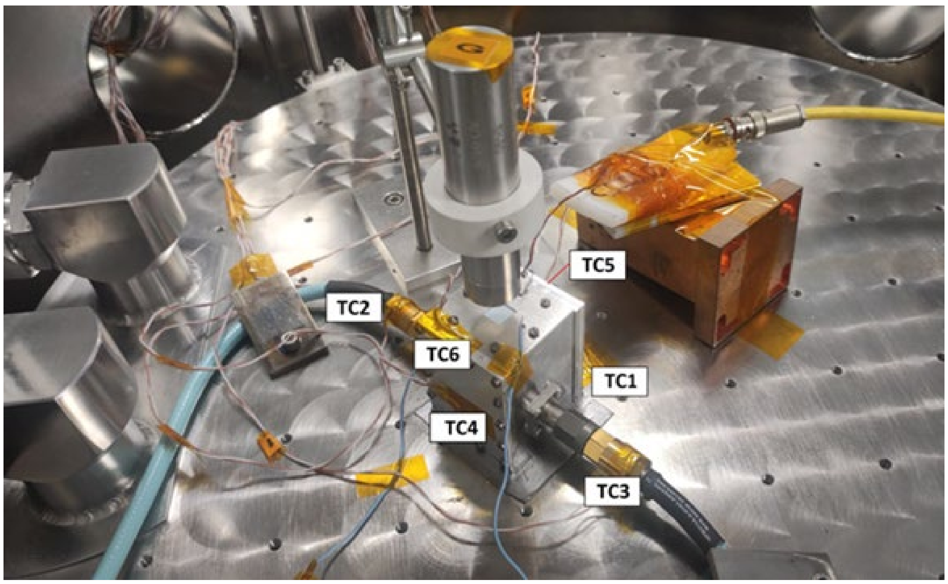

Fig 4 Photograph of device in vacuum chamber

Fig. 6 and Fig.7 show the temperature and pressure profiles during the test.

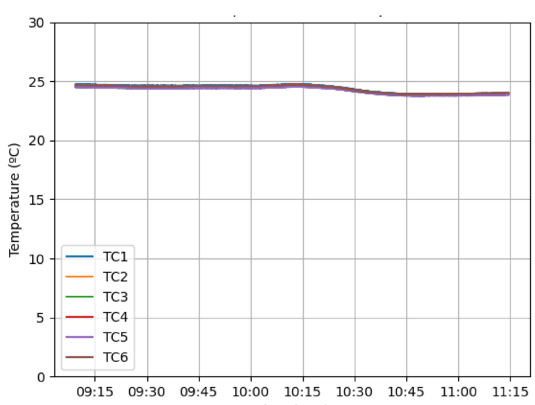

Fig 5 Temperature profile

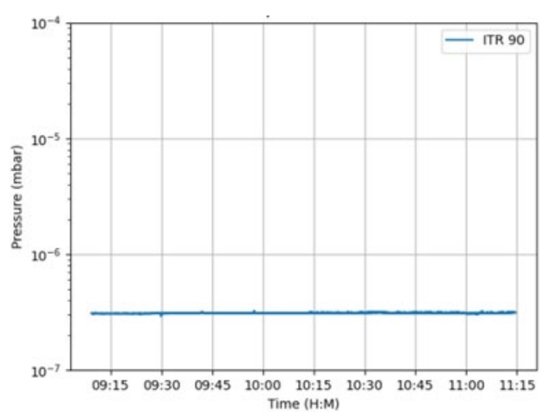

Fig 6 pressure profile

8. TEST RESULTS

The power, which operated under a 2% duty cycle, was gradually increased until the full power of the system was obtained [7]. The device under test withstood 700 Watts RF without breakdown as shown in Fig. 8.

After emptying of aerogel, the test was repeated and the device broke down at 80 Watts, as shown in Fig. 9. Note the change in the scale of the vertical axis.

The difference in level of the input power and output power is due to the connecting cables leading to the chamber, the port plate adaptors and the additional connecting cables between the input and output power measuring heads.

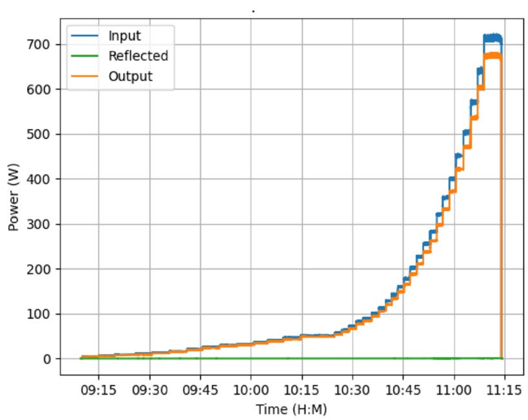

Fig 7 Power profile for filled cavity

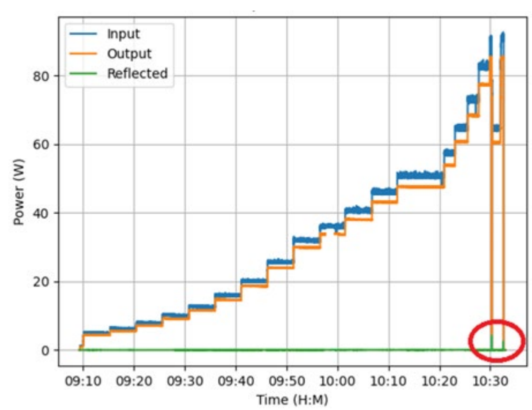

Fig 8 power profile for unfilled cavity

9. CONCLUSION

The experiment showed that filling a coaxial RF cavity with aerogel achieved a power handling of 700 watts, very well compared to only 80 watts for the empty cavity.

Further work will involve extending the design to a fully representative L-Band filter, and to the investigation of lower loss, mass and dielectric constant aerogel forms.

10. REFERENCES

[1] P. F. Clancy. Multipactor control in microwave space systems. Microwave Journal, 21:77-83, March 1978

[2] J. R. M. Vaughan, “Multipactor,” IEEE Trans. Electron Devices, vol. ED-35, no. 7, pp. 1172–1180, Jul. 1988.

[3] Definitions of terms relating to the structure and processing of sols, gels, networks, and inorganic-organic hybrid materials (IUPAC Recommendations 2007). Pure and Applied Chemistry. Vol. 79. 2007. pp. 1801–1829. doi:10.1351/goldbook.A00173. ISBN 978-0-9678550-9-7. Archived from the original on 30 November 2012.

[4] Saint-Gobain Vitreosil® 055 Optical Fused Quartz.

[5] https://web.archive.org/web/20161228010329/http://astronautix.com/e/ecsots.html

[6] Whatman filtration, Cytiva.

[7] Test report: Multipactor tests on two L-band Aerogel cavity samples for UPV (Spain). Prepared by J. Ossorio and M. Reglero (European High Power RF Laboratory). Reference ESA-TECEFE-LAB-TR-2022-003925, Issue 1, Revision 0. Date of issue 14/12/2022 Status Final Document type RP