RF Breakdown Analysis in Space Applications

Devices in the output section of a satellite payload, including filters and multiplexers are subject to high RF power. This could lead to RF breakdown, which may render the specific device useless and, in the end, degrades the reliability of the satellite. Therefore all space high power devices have to be analyzed with regards to their breakdown behavior. This application note shows how CST STUDIO SUITE® and SPARK3D® can be used to investigate these effects via simulation.

Breakdown Mechanisms

There are usually two different breakdown effects which are of relevance in space applications: Multipaction and Corona. Multipaction occurs if a resonance condition between free electrons and RF signal is met (Figure 1) under vacuum conditions. Free electrons could be in a satellite device due to field emission or solar storms. These free electrons will be accelerated toward the walls of the device and with enough energy, their impact could result in secondary electron emission. If resonance is present, this process can repeatedly occur leading to a self amplification of current and, finally, to a discharge. The amount of secondary electrons released per impact depends on the material of the wall and is characterized by the secondary electron emission yield (SEY).

While multipaction is important in vacuum, the corona effect is a breakdown which occurs due to the ionization of gases during the launching phase of a satellite. In this case, the process basically depends on the pressure, field amplitude, geometry and nature of the gas.
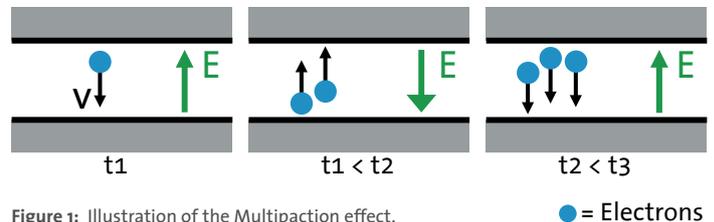

Figure 1: Illustration of the Multipaction effect.
● = Electrons

Full-Wave Simulation

As an example, this application note will use a 3 pole L-Band Filter, (Figure 2). This filter was designed, manufactured and tested in the framework of the ESA/ESTEC EVEREST Project[1], coordinated by CNES.
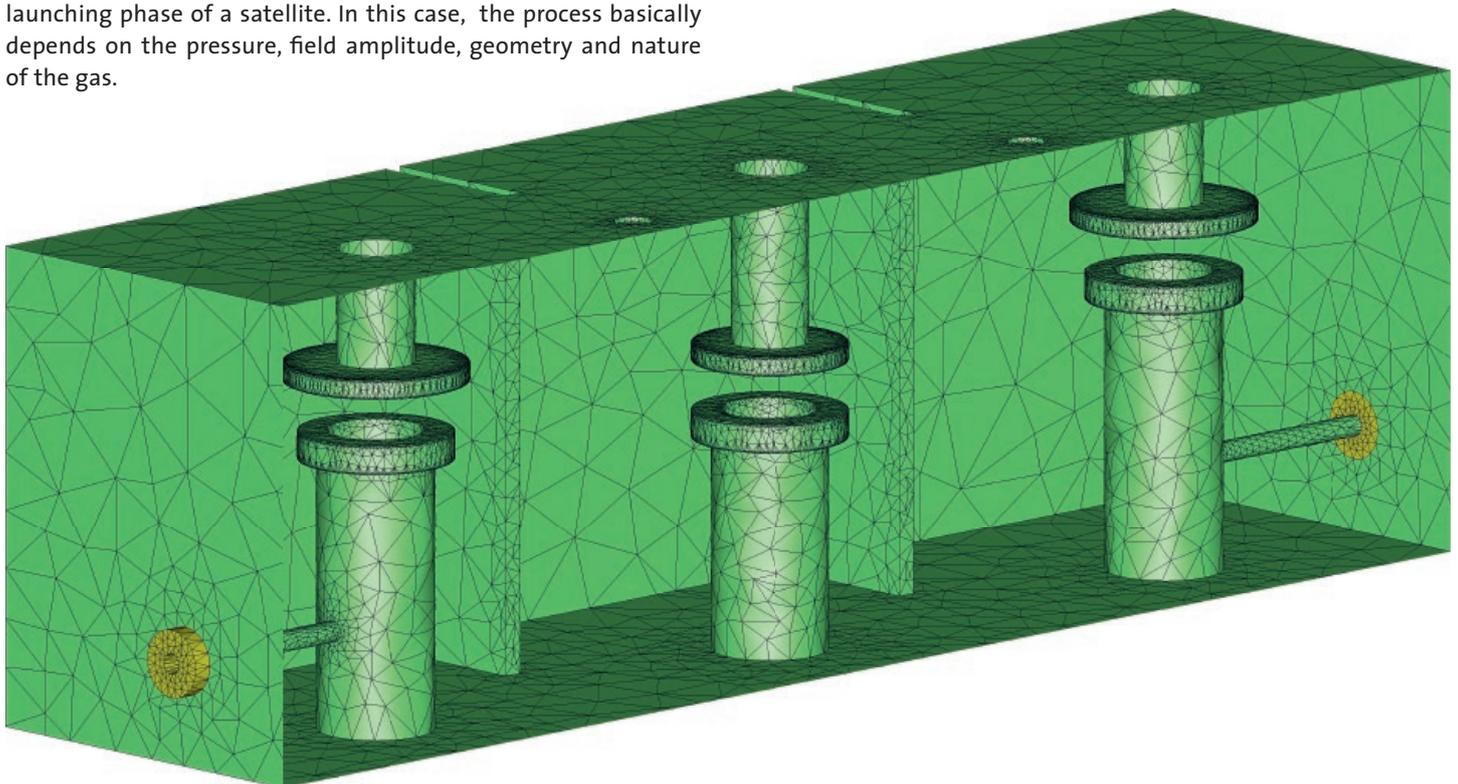

Figure 2: Cut through view of the L-Band Filter together with the tetrahedal mesh including curved elements. Design courtesy of COM DEV Europe Ltd.
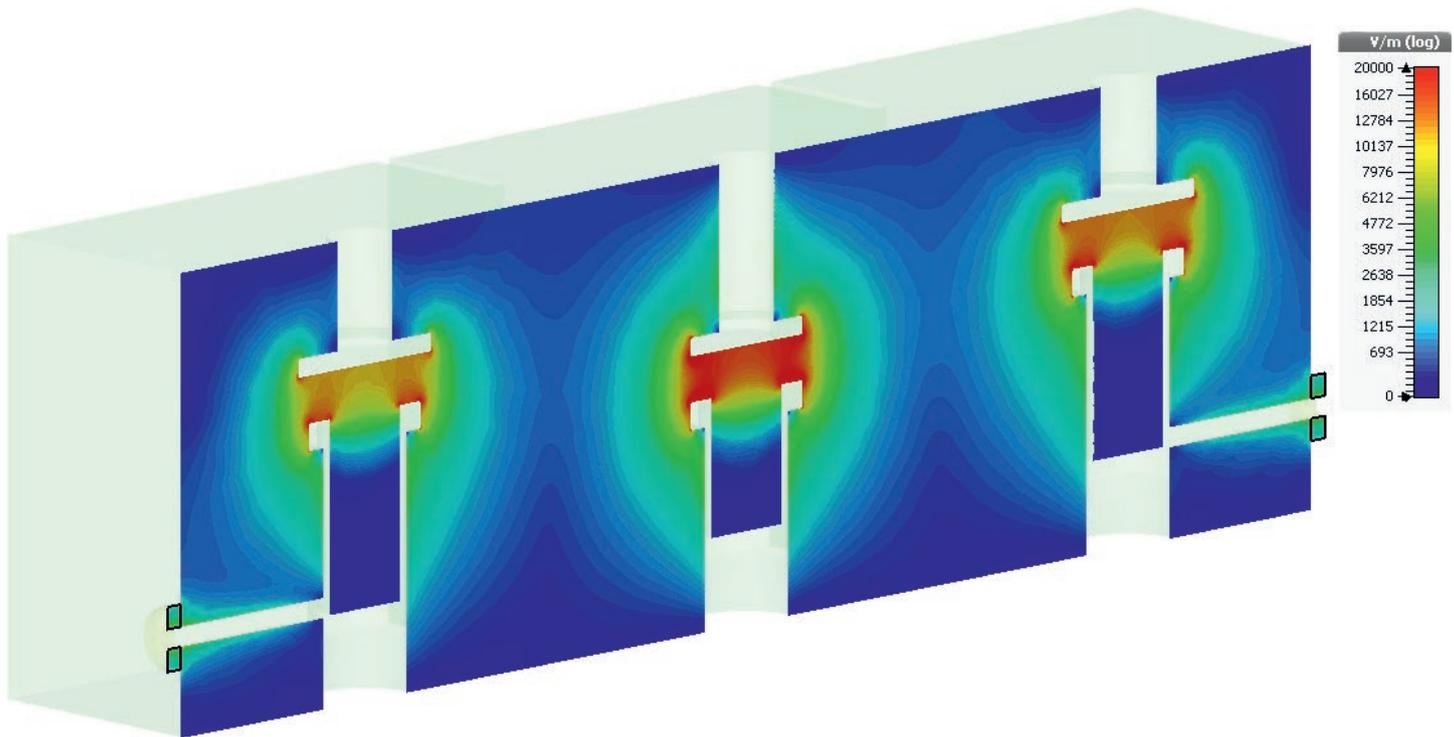
Figure 4: Electric field amplitude (phase independent) at 1.4 GHz.

The first step of the analysis is certainly an S-Parameter evaluation, which is performed with the frequency domain solver of CST STUDIO SUITE [2]. The simulation uses conformal tetrahedral meshes (Figure 2), which results in a high accuracy.

From the full wave simulation, the pass band (Figure 3) is obtained and can be optimized. The S-parameters and the 3D electromagnetic field are both obtained as well. For this application, it is interesting to find the electric field amplitude independent of the phase (Figure 4), to directly identify the most critical area. From the 3D electric field, the voltage along the gap could be evaluated. This is often used to predict multipaction with simple rules. The electromagnetic field values are normalized to 1 W peak input power. Since the power threshold of the breakdown has to be found, the voltage obtained by the simulation has to be scaled accordingly.

Although these simple rules are very valuable, they assume a parallel plate geometry, which is not valid in the given example. This can lead to very conservative breakdown power levels in this type of devices in which fringing fields dominate, as indicated by the electromagnetic field pattern. In these cases a rigorous Particle in cell simulation is necessary in order to obtain more reliable results.

Multipaction Analysis with SPARK3D

Once the design of the component is done in terms of S-parameter response, the high power analysis can be performed. To do so, the CST STUDIO SUITE macro "ExportFieldstoSpark3D" is used to transfer the field information from CST STUDIO SUITE to SPARK3D [3]. SPARK3D can directly import the file and visualize it. Moreover, in SPARK3D the user just needs to specify the material and number of electrons and gets the multipaction breakdown threshold by sweeping automatically in power. This can be done easily within the SPARK3D interface. (Figure 5). Breakdown is said to occur if electron population increases with time. Please, note that the multipactor breakdown power level tested was 32 W and the simulation provided a result of 27.5 W. And, finally, the breakdown power level computed using the parallel plate approach was 10 W, which clearly indicates the conservativeness of this simple approach and the advantages of using the full numerical analysis.
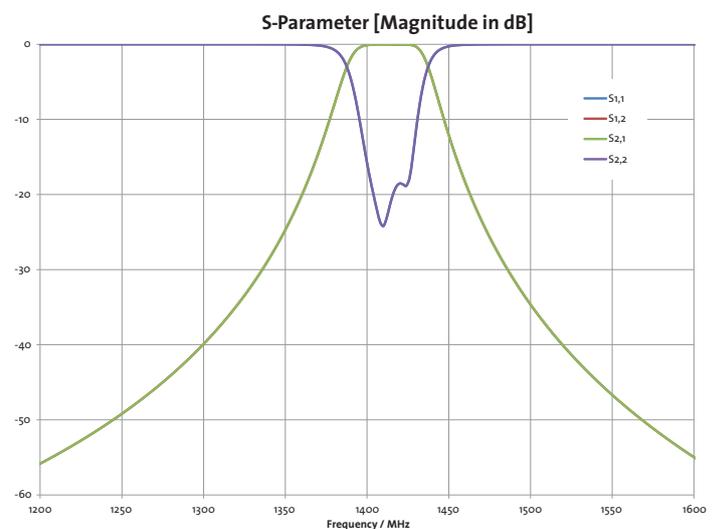

Figure 3: S-Parameter response of the L-Band Filter.

Figure 5: SPARK3D interface showing the multipactor breakdown results for this particular component with electron evolution over time for different power levels.
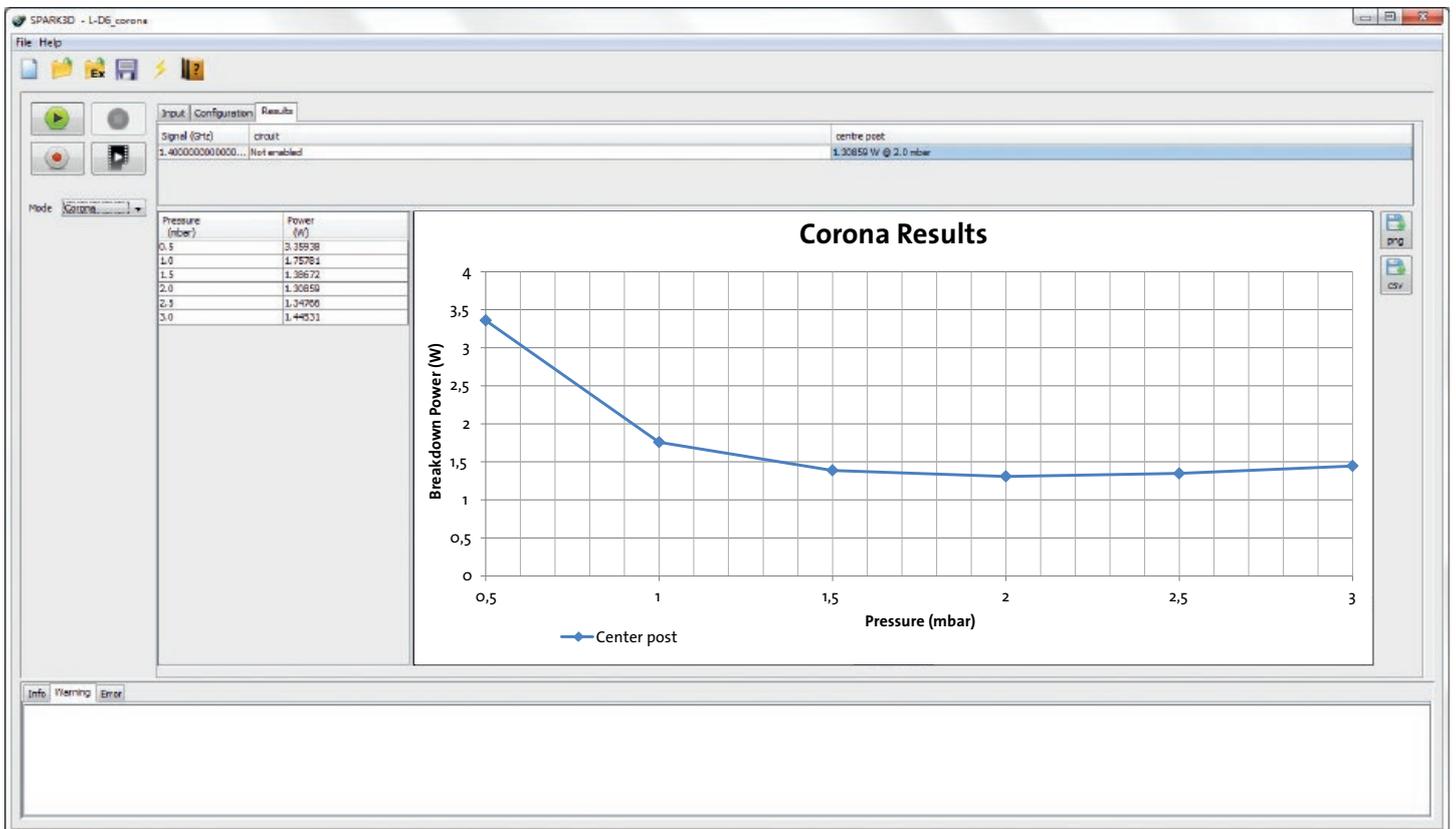

Figure 6: SPARK3D interface showing the corona breakdown results as a function of pressure for this particular component.

Corona Analysis with SPARK3D

Analogously to the case of multipaction, EM fields from CST STUDIO SUITE can be exported to SPARK3D in order to perform a corona discharge analysis. In this case, one can obtain automatically the breakdown power level as a function of the pressure for a particular gas (Figure 6). Please note that this device was tested at the critical pressure (4 mBar in this case) with a breakdown power level of 1.9 W whereas the numerical breakdown level at the same pressure is 1.6 W showing an excellent agreement.

Conclusion

In this application note we have shown how to combine CST STUDIO SUITE capabilities to solve complex microwave structures with SPARK3D features for the determination of breakdown power levels relevant in space applications. The importance of using numerical approaches has been also highlighted when comparing the numerical breakdown power level to test results and when using other techniques based on analytical approaches.

References

[1] ESA/ESTEC project, EVEREST, coordinated by CNES: "Evaluation and Validation of Electromagnetic Software, Test Facilities and Test Standard in Europe to Predict and Test RF Breakdown and Passive Intermodulation."

[2] www.cst.com

[3] www.fest3d.com/spark3d.php

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