Virtual Research Presentation Conference

High-power Breakdown Software Evaluation

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Program: Innovative Spontaneous Concept

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High-power Breakdown Software Evaluation

Abstract

High-power breakdown is phenomena where strong electromagnetic (EM) potential differences in space cause the surrounding medium to break down; such as creating swarms of free electrons, flow of charged particles, changing the visual appearance or pressure, temperature, etc.

Multipaction

Breakdown in vacuum

Electrons are accelerated by the EM field and impact the device wall.

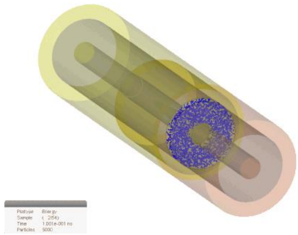
Secondary electrons are released and grow exponentially, and discharge develops.

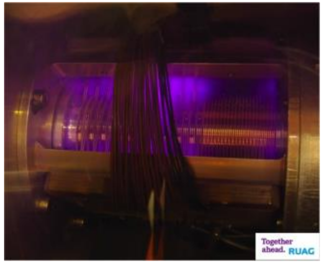
Corona

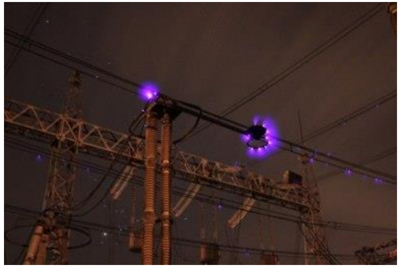
Breakdown in gas

Electrons are accelerated by the EM field and impact the gas molecules around the device

Molecules are ionized, electrons released and discharge develops, and furthermore recombines; **diffusion process** gets convolved.







Problem Description

Problem of High-power Breakdown :

The breakdown phenomena occur under certain conditions statistically.
So, the device will eventually experience breakdown in a long run which can result in the followings :

- **Loss of energy.**
- **Increase of signal reflection and noise.**
- **Generation of nonlinearities such as harmonics and intermodulation products.**
- **Progressive damage on electrical components : electrical wind pressure caused by particles impact on device wall and temperature change.**

Previous State of The Art : **Hatch & Williams & Woo's work**.

Thorough experiments showing upper & lower limit conditions on breakdown.
Simple but effective mathematical model that describes the phenomena fairly well.

Limits of Previous State of The Art :

Simple geometries such as parallel plates and coaxial cables

↪ **Conservative breakdown estimates**

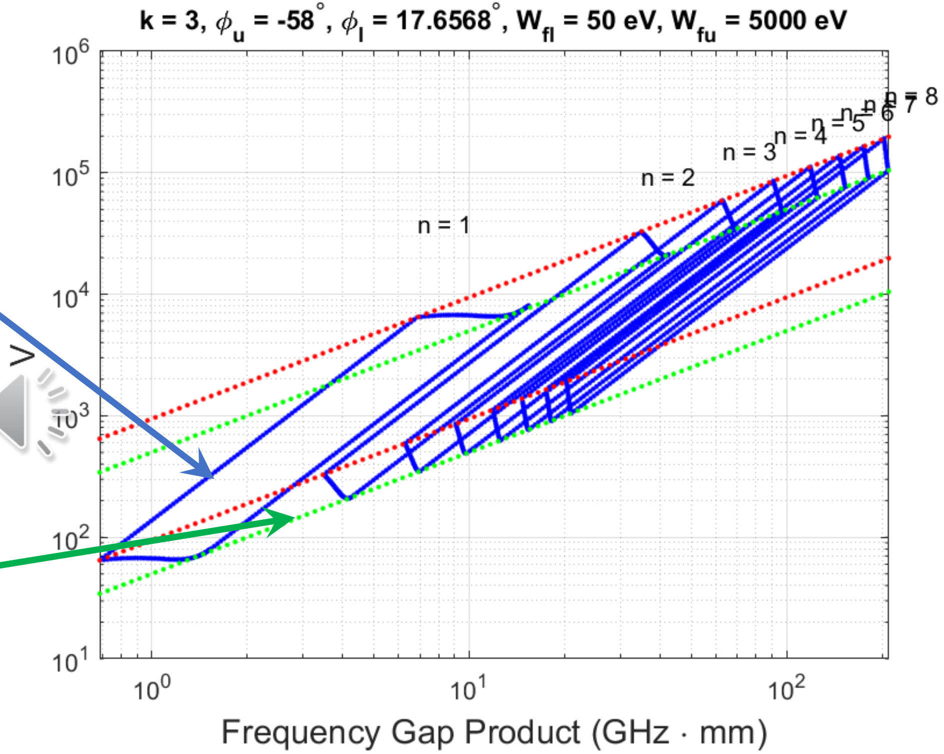
↪ **Increased cost by component oversizing or unnecessary performance evaluation tests**

Theory and Methodology

Intra-modular Trend : $V = \frac{4\pi^2 (fd)^2}{\left(\frac{e}{m_e}\right)\Phi_n} \propto (fd)^2$

Inter-modular Trend : $V = \left[\frac{(k-1)\pi}{k \cos\phi}\left(\frac{2W_f}{\frac{e}{m_e}}\right)^{\frac{1}{2}}\right](fd) \propto (fd)$

Conservative breakdown estimates



Modern tools actually simulate the particles' physical states using physics simulators solving the governing equations and Monte-Carlo simulation → **More accurate breakdown estimates.**

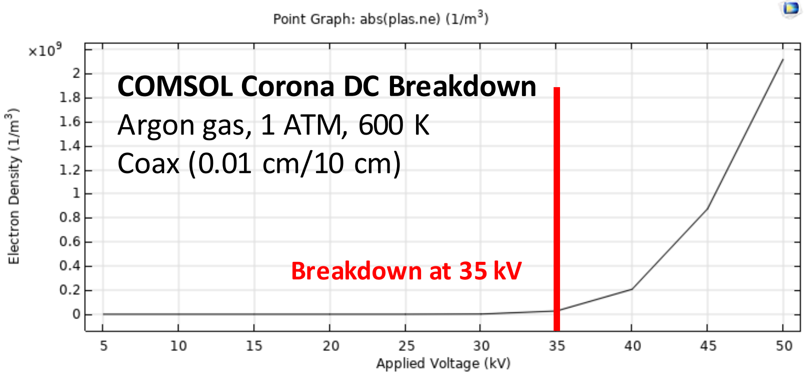
Total 6 tools that provide breakdown analysis have been identified :

Spark3D, VSIM, Comsol, Ansys HFSS, CST Particle and ESA's ECSS Multipactor tool

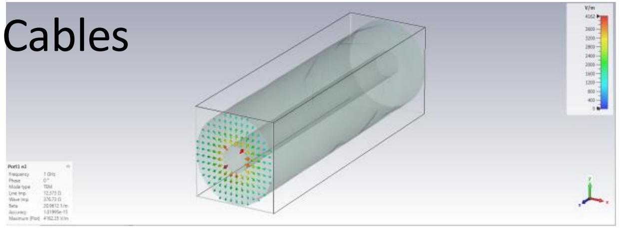
Results

Ease of Use	Accuracy / Flexibility
Easy	High
ESA	COMSOL
HFSS	**Spark3D**
Spark3D	VSIM
CST	CST
VSIM	HFSS
COMSOL	ESA
Difficult	Low

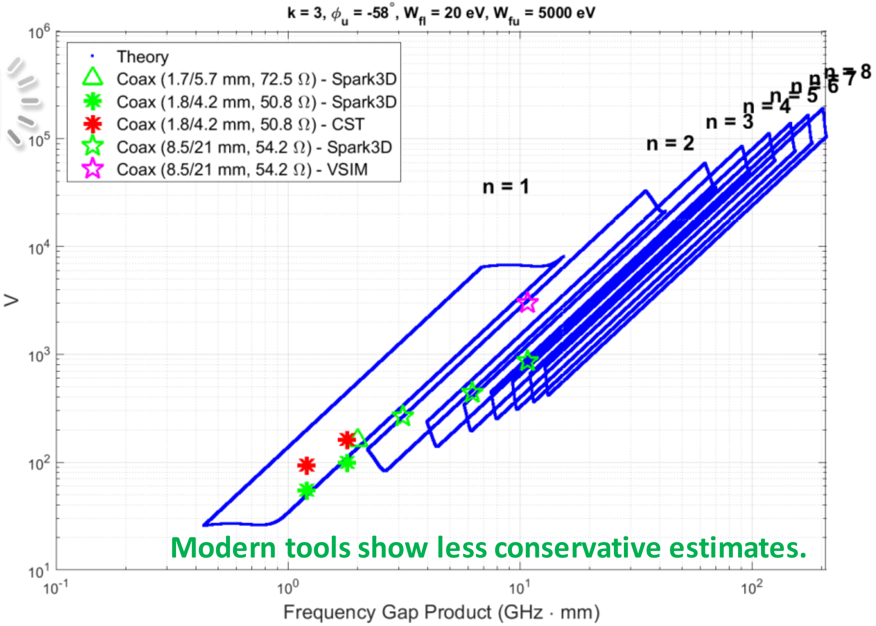
Optimal Tool : **Spark3D**



Geometry : Coax Cables



Multipaction Breakdown



Modern tools show less conservative estimates.

Future Work and References

Future Work :

Simulate more general and complex geometries, and establish systematic approach to link the modern results to the previous state of the art Hatch & Williams & Woo. Also, experiment/test to validate modern tools' result.

Find mathematical explanation on upper-limits of breakdown by generalizing the mathematical model with damping effect and linking the previous theory to quantum mechanics.

Extend the study to more general signal type such as modulated signals.

References :

A. Hatch, The Secondary Electron Resonance Mechanism of Low-Pressure High-Frequency Gas Breakdown.
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R. Woo, A Similarity Principle for Multipacting Discharges.
R. Woo, Multipacting Discharges between Coaxial Electrodes.
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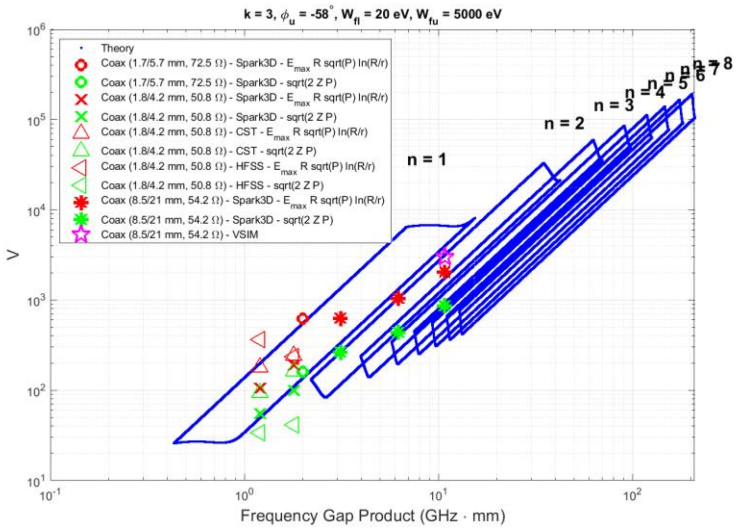
Standard Handbook for Multipactor Breakdown Prevention in Spacecraft Components.
D. Iglesias, Multipactor RF Breakdown Analysis in a Parallel-plate Waveguide Partially Filled with a Magnetized Ferrite Slab.

Update on Multipactor in Coaxial Waveguides using CST Particle Studio, Gennady Romanov, Fermilab, Batavia, IL 60510, USA, Proceedings of 2011 Particle Accelerator Conference, New York, NY, USA
https://www.epfl.ch/research/domains/swiss-plasma-center/research/plasma_applications/plasma_applications_research_areas/plasma_applications_research_areas_arc_mitigation/
https://www.tumblr.com/search/corona%20discharge
Dassault Systems, RF Breakdown demo for NASA

Backup Slides

SEY Parameters we used are from ESA/Spark3D/CST :

Surface Type	E1 (eV); W_l	E2 (eV); W_u	Em (eV)	α_max
Gold	150	4000	1000	1.79
Silver	20	5000	175	2.2
Aluminum	30	5000	805	2.98
Alodine	41	5000	180	1.83
Copper	25	5000	175	2.3



Backup Slides

Multipaction Summary Table :

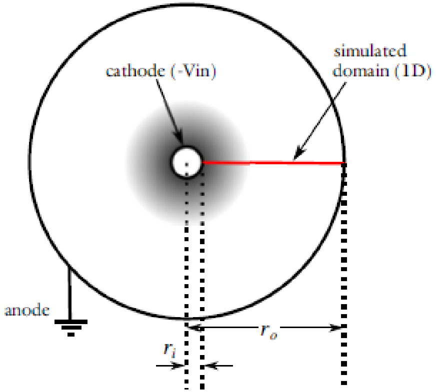
Tool Type	Freq.	Type (r / R)	fd (GHz x mm)	Emax	Breakdown Wattage (P)	Breakdown Voltage (V) $E_{max} R \sqrt{P}\ ln(R/r)$	Breakdown Voltage (V) $\sqrt{2ZP}$	HW-Low (V)	HW-Up (V)
Spark3D	500 MHz	Coax (1.7/5.7mm)	2	6804	177	624.24	157.42	136.16	549.65
Spark3D	250 MHz	Coax (1.8/4.2mm)	0.6	5727.81	*No Breakdown*	*No Breakdown*	*No Breakdown*	26.9	49.6
Spark3D	500 MHz	Coax (1.8/4.2mm)	1.2	5413	30	105.5076754	55.1983	48.9	198.2
Spark3D	750 MHz	Coax (1.8/4.2mm)	1.8	5412	97	189.6832819	99.2546	110.1	445.8
CST	250 MHz	Coax (1.8/4.2mm)	0.6	-	*No Breakdown*	*No Breakdown*	*No Breakdown*	26.9	49.6
CST	500 MHz	Coax (1.8/4.2mm)	1.2	5412	86	178.6045069	93.4575	48.9	198.2
CST	750 MHz	Coax (1.8/4.2mm)	1.8	4270	260	245.019105	162.4993	110.1	445.8
HFSS	250 MHz	Coax (1.8/4.2mm)	0.6	30496	*No Breakdown*	*No Breakdown*	*No Breakdown*	26.9	49.6
HFSS	500 MHz	Coax (1.8/4.2mm)	1.2	30355	11.4	364.7271	34.0265	48.9	198.2
HFSS	750 MHz	Coax (1.8/4.2mm)	1.8	16181	16.9	236.7195	41.4293	110.1	445.8
Spark3D	250 MHz	Coax (8.5/21 mm)	3.125	1306	650	632.4216455	265.4588	115.4	1343.8
Spark3D	500 MHz	Coax (8.5/21 mm)	6.25	1306	1788	1048.899322	440.2752	198.9	5374.6
Spark3D	865 MHz	Coax (8.5/21 mm)	10.8	1306	6835	2050.781103	860.8148	379	6628.8
VSIM	865 MHz	Coax (8.5/21 mm)	10.8	-	-	3000 (Tool report)	-	379	6628.8

Backup Slides

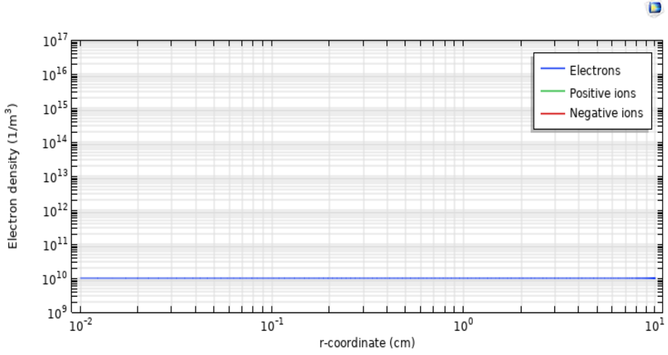
COMSOL Corona DC Breakdown :

Airline Coaxial Cable: (center conductor, Argon gas, shield/ground)

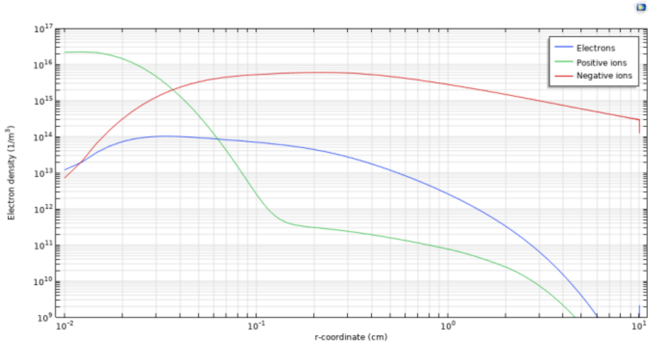
r = 0.01 cm
R = 10 cm
Gap = 9.99 cm



Electron & Ion Density Number



Initial Time Step (0 s)



Last Time Step (1 sec)