Automated Software System for the Simulation Of Arcing In Spacecraft On-Board Power Electronics Equipment

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Today, in civil spacecraft the electric arcing is one the main factors leading to partial or complete failure of electronic equipment. This problem escalates with the increase of operating voltages from 27 Volts up to 100 Volts since 2000.
Experimental example of primary arc below Paschen’s minimum (in Ar)

$V_0 = 100 \text{ V, }$

$\rho_0 = 20 \text{ Pa}$

$V_{\text{breakdown}} = 169 \text{ V (!) }$
What is diagnostics?

- Search for the region where the self-sustained discharge is most probable;
- Investigate multiple conditions of arcing with respect to variation of main parameters (pressure, electrons emission, etc.)
Multiscale problem
(Full-scale DC-discharge simulation)

Device size ~ 500 mm,
Critical region ~ 1-5 mm
Debye length ~ 0.01-0.1 mm

Satellite secondary power supply
in 231x174x30 mm case:

“Fast”
DC-discharge simulation
~50Gb RAM & 240 cores
Our approach

1) Electric field-enhancement regions extraction

2) DC-discharge simulation + Parametric sweep option

Debye length scale

Parameter 1

Device scales

Parameter 2

Plasma module of COMSOL Multiphysics

Full-scale SPICE + Electrostatics simulation (AC/DC module of COMSOL Multiphysics)
Software interface
Preprocessing module

✓ COMSOL Application Builder

• Complete PCB (ASCII) file format import
  At the industrial partner “JSC Reshetnev Information Satellite Systems” request the PCB (ASCII) import was implemented in order to use Altium Designer files.

• Geometry improvements
  We have designed native three-dimensional kernel to correct inaccuracies obtained during import.
Preprocessing module: Example

• Automatic removing of inaccuracies in geometrical details.
Live PCB import procedure
Processing module

✓ COMSOL Application Builder
✓ AC/DC Electrostatics + Plasma modules.

• Solve complete electrostatics problem
Find electrostatic potential and electric field absolute value distribution for defined geometry. Border conditions (potentials at conductors) are implied using SPICE simulation results.

• Critical regions location (by estimating of |E| local maxima).

• Compile 2D models of critical regions from 3D using three coordinate sections

• DC-discharge simulation in 2D models with Parametric Sweep (in order to obtain critical parameters diagrams)
Electric field distribution

Full-scale SPICE + Electrostatics simulation (with AC/DC module of COMSOL Multiphysics)

$|E(x,y,z)|$

Satellite secondary power supply PCB
Location of critical regions

3D

Conductor

PCB #1

PCB #2

2D

Gas

Ground

Assembly

Electric Potential

Ground

Electric Potential in Electrostatic
Metal contact in DC Discharge

2D
DC-discharge simulation

Computation of critical parameters diagrams using DC-discharge simulation (Plasma module of COMSOL Multiphysics) for each simplified model.

Electron density distribution

Critical parameters diagram
The previously proposed innovative computational approach has been successfully implemented in pilot software system completely built with COMSOL Multiphysics. COMSOL Application builder was used along with COMSOL AC/DC Electrostatics and Plasma modules in order to create a complete simulation cycle.

The developed software enables to combine possible arc positioning with the further investigation of certain regimes of the discharge ignition without full-scale DC-discharge simulation. The software allows upgrading the development technology of arc-resistant electronics intended for operation in the wide range of temperature, pressure and other environment or/and technical parameters.
Set of models ("zoo")

Drawing up of a set of simple two- and three-dimensional geometrical configurations of discharge gaps using preliminary diagnostics results
Circular defect in laquer insulating coating (2D-axisymmetric model)
Sample 2D critical parameters diagram ($\gamma_{\text{diel}} - \rho_0$ plot)

**PRESSURE**

$\rho_0 = 10$ Pa – 10 kPa

**EMISSION FROM INSULATION**

$\gamma_{\text{diel}} = 0.01 - 1.0$

**Other parameters:**

- Interelectrode distance – 3 mm
- Insulation thickness – 0.05 mm
- Initial plasma density – $10^3$ cm$^{-3}$
Applied voltage: two cases

- Reference case $V_0 = 200$ V (above Paschen’s min.)
- Operating case $V_0 = 100$ V (below minimal breakdown voltage)
Reference case ($V_0 > V_{\text{min}}$): Self-sustained discharge @ 1 ms

$V_0 = 200$ V, $p_0 = 3$ kPa

Electrons density

$N_e(r,z)$
Operating mode
($\gamma_{\text{diel}}$ variation at $p_0 = 3 \text{kPa}, V_0 = 100 \text{ V}$)
Operating mode
(pressure variation @ $\gamma_{\text{dielectric}} = 0.9$, $V_0 = 100$ V

![Graph showing current vs. time with different pressure values: p0=10, p0=100, p0=1000, p0=3000, p0=6000, p0=8000, p0=10000]
Critical parameters diagram \((\gamma_{\text{die}}, p_0)\)

\[ R = 0.5 \text{ mm} \]

- Safe region
- Unsafe region