SEEKING OUT ELECTRICAL ARCING REGIONS IN SATELLITE SYSTEMS

Electrical arcing discharge in orbiting satellites can cause system failure, but is hard to predict. Engineers at the Russian Institute of High Current Electronics have adopted multiphysics software to find the critical regions where failures originate and to protect onboard equipment.

by GEMMA CHURCH

In 1995, Boeing Satellite Systems introduced a new family of communication satellite buses, the bodies that contain power, control, and propulsion systems. They used a high-voltage bus connected to a 100 V stabilized power source, instead of the standard 27 V voltage. This introduced an increase in operating voltage that decreased operating currents and lowered the corresponding ohmic losses in the conductors. However, it also introduced a potentially catastrophic failure to the satellites' electronic systems: electrical arcing (Figure 1).

Vasily Kozhevnikov, researcher at the Institute of High Current Electronics in Tomsk, Russia, explains: "The transition to the new standard of operating voltages has led to the problem of an electric arc ignition between the elements of the electronic circuit boards. In order to keep the mass of the satellite as small as possible, the space inside the circuit housing is not filled with an insulator or built to hold a vacuum. But that allows electric arc discharge or discharge cascade that can potentially spread over a large volume of onboard equipment."

"The ignition of an electric arc inside the onboard satellite system always leads to partial or complete failure. In most cases, it causes the termination of satellite use," he added.

This research closely relates to the physics of a gas discharge under extreme conditions, where electrical equipment does not always perform as conventional physics would dictate. For example, electrical discharges sometimes occur below a threshold known as Paschen's minimal values, where the voltage should not normally be sufficient to start a discharge, or electric arc, between two electrodes.

"We think this research will also have potential use for the diagnostic of electronics operated under a wide range of external parameters such as pressure, ionization levels, and so on. It's widely applicable beyond the space industry and space science," said Kozhevnikov.

As electronic systems are used in increasingly extreme environments, electrical arcing is not just an issue faced by the civil space industry. It affects any electronic application designed for long autonomous work with improved fault tolerance requirements. A solution to

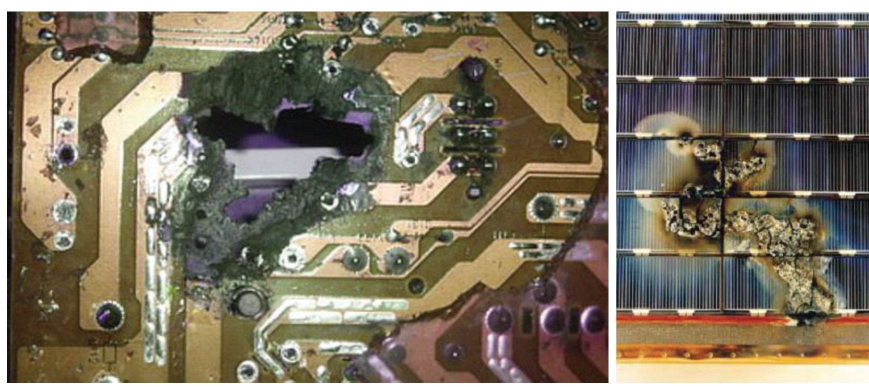

FIGURE 1. Typical damage from a primary arc in a power supply operating at 100 V.

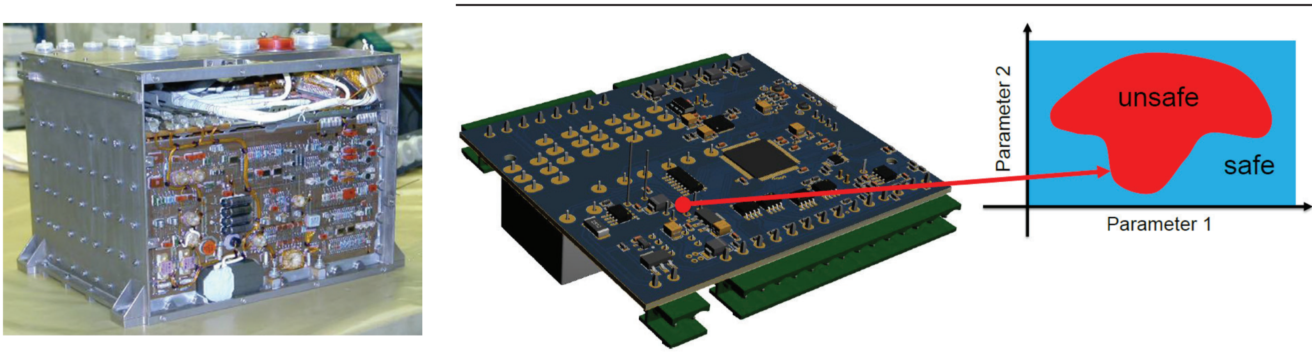

FIGURE 2. Example of a circuit board for satellite equipment. Critical regions are smaller than 5-mm wide. Engineers at IHCE must determine the range of unsafe operating conditions and properties in order to design a system that can travel aboard satellites without being destroyed.

this problem, therefore, extends beyond satellites and to terrestrial systems and underwater equipment as well.

⇨ FINDING THE CRITICAL REGION

To prevent the destruction of an onboard electronic device by a spontaneous electric arc, a so-called "critical region" must be identified, which is the area where self-sustained discharge ignition occurs. Once this potentially problematic area has been found, engineers need to conduct further investigations into what may trigger an electrical arc discharge.

Experimental studies fail to stand up to the challenge of identifying these electronic hotspots because they cannot reproduce the full range of operating parameters that exist in space orbit.

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>
> — VASILY YU. KOZHEVNIKOV, RESEARCH ASSOCIATE, IHCE

The only remaining investigative option, simulation, also faces monumental challenges. For one, a typical onboard electronic device consists of multiple printed circuit boards distributed over a large area, placed inside a metal casing (Figure 2). Kozhevnikov explained:

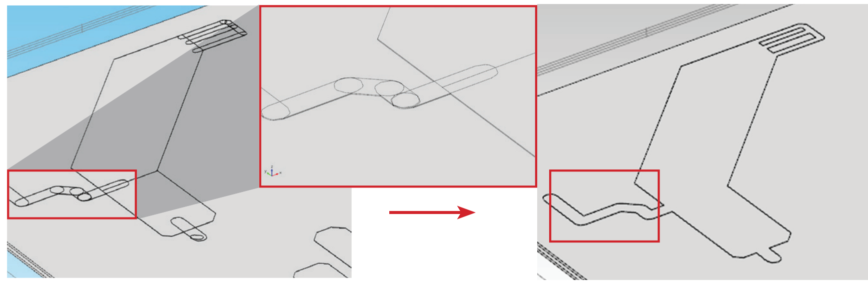

FIGURE 3. Geometry correction in COMSOL.

"The only way to identify possible self-sustained discharge regions is the numerical simulation of the discharge, but this is practically impossible for such large-scale problems due to the associated computational costs. The discharge problem is both multiphysics and multiscale."

⇨ CATCHING GEOMETRIC INACCURACIES

The Tomsk-based research team worked hard on finding a computational approach that would prove both accurate and practical. The researchers proposed a "decomposition" methodology implemented with computational tools to tackle this problem. Instead of performing a complete direct current discharge simulation for the entire electronic device, they created a custom simulation app that would autonomously partition and analyze the device to find the most probable critical regions. To this aim they used the COMSOL Multiphysics® software and its Application Builder tool to create a multiphysics model supporting the entire simulation process.

An important modeling step was preprocessing, which was carried out to apply the proper boundary conditions and import the detailed geometry of the real on-board electronic system.

With the Application Builder, the team performed preprocessing using a custom 3D macromodel method. They also implemented their own import engine with automatic correction of object boundaries. The method consisted of both import and automatic correction of object boundaries functionalities, Kozhevnikov explained (Figure 3). Without correction, these errors could have become serious obstacles in the simulation.

⇨ BREAKING DOWN THE PLASMA PHYSICS PROBLEM

After preprocessing, the modeling methodology consisted of three stages: preliminary electrostatic analysis of potential critical regions in a 3D model; extraction of field-enhancement areas and the definition of critical regions, with associated 2D models; and DC-discharge simulation of critical regions to further investigate parameters of interest.

The team initially used COMSOL Multiphysics because of its unique ability to implement all the features

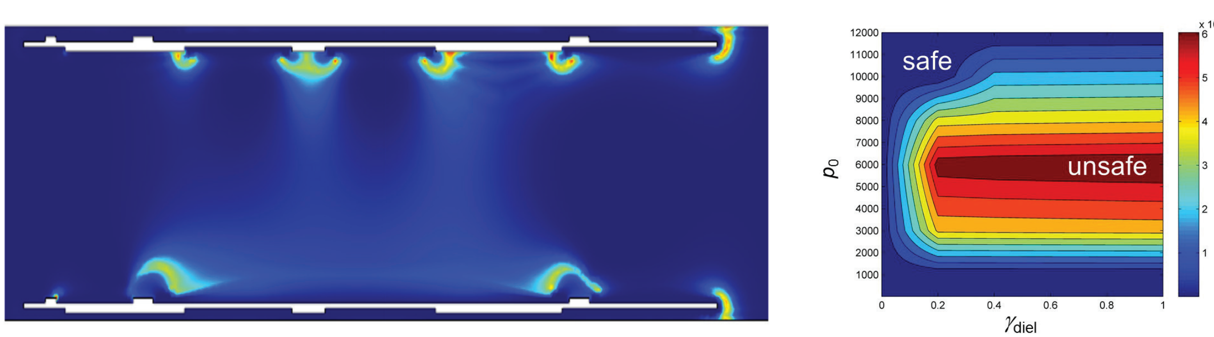

FIGURE 4. Left: Electron density distribution for the self-sustained discharge phase. This 2D model is derived from critical regions defined from the 3D model of the satellite's power supply. Right: Example of a critical parameter diagram where pressure vs. emission is shown for a critical region. The color map represents the level of discharge current density.

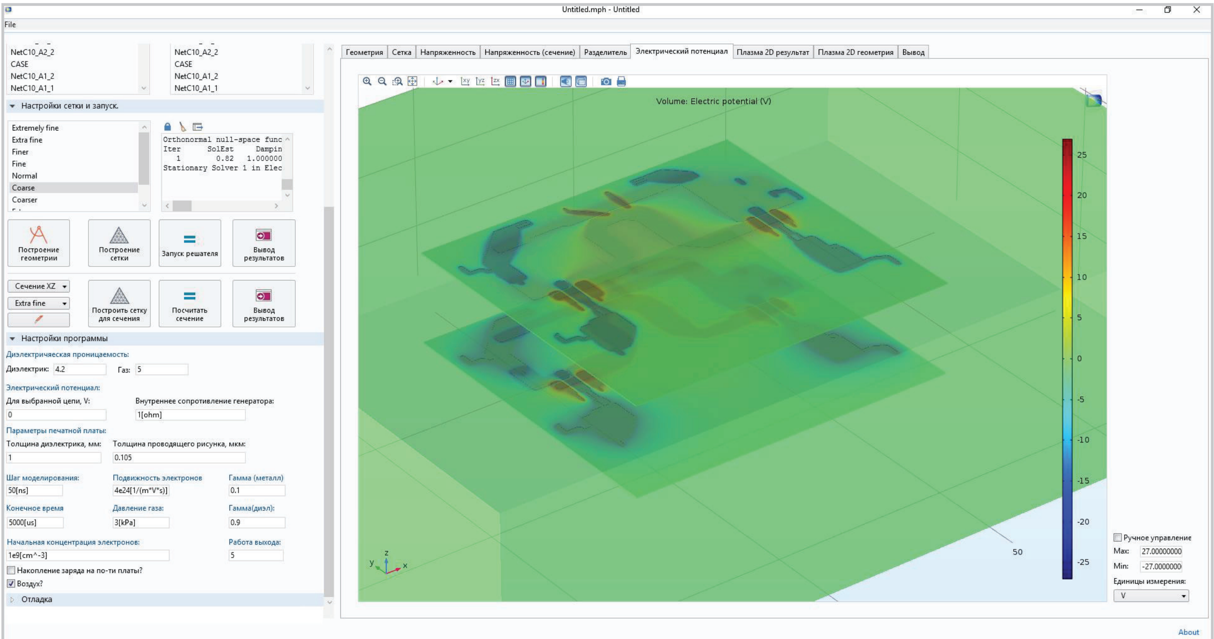

FIGURE 5. The multiphysics app Kozhevnikov developed makes it possible to vary parameters such as pressure and electron emission to search for regions where a self-sustained discharge is most probable. The app combines arc positioning with the investigation of certain regimes of discharge ignition without full-scale DC-discharge simulation and gives results such as the electric potential throughout the circuit system.

of the two-moment direct current discharge theoretical model and alter the necessary parameters. The simulation analyzed the electron density distribution and identified the critical region (Figure 4). Kozhevnikov explained: "COMSOL Multiphysics finely meets the requirements of our project, namely, an analysis of the operating pressure range. This is much faster and more convenient than a particle-in-cell (PIC) simulation for medium and high pressures."

"PIC simulations are simply unfeasible for such problems due to extensive computational costs. The simulation of simplified configurations (e.g., gas diodes) is possible, but depending on the problem, can take 5–20 times longer for medium pressures than a COMSOL simulation. The average computation time in COMSOL for this configuration is less than 2 hours."

The custom app that the team built, shown in Figure 5, hides the complexity of the physics involved in the model setup. This exposes the app user only to parameters relevant to the analysis at hand and allows for the inclusion of custom commands and algorithms.

Kozhevnikov said: "Strictly speaking, COMSOL made it possible to perform our research without the creation of our own computational code, which would be extremely complicated in light of this problem. We expect the software to be most promising for our future investigations concerned with gas discharges." Other arguments in favor of choosing COMSOL were its wide choice of pre- and post-processing tools, including CAD import features and the Application Builder.

⇨ ORBITAL AND INTERDISCIPLINARY IMPLICATIONS

There is scope to integrate such simulations with real-world investigations, Kozhevnikov explained. "If it is possible to perform fully nondestructive testing in the future, a COMSOL simulation will narrow the region of interest for experimental testing by excluding nonessential parts. Some work toward nondestructive testing development was performed by our colleagues from the Laboratory of Vacuum Electronics at the Institute of High Current Electronics, in the framework of the project we collaborate on."

"Within the spacecraft industry, the automated software system's adaptability should guarantee its continued use," he continued. "Standards in spacecraft industry change from time to time, so it is difficult to account for all the consequences of such changes. We have solved the problem of arcing diagnostics; nevertheless we expect that the voltage increase will also require serious redesign of certain on-board electronics to fit new operating conditions. Simply speaking, if the operation conditions of some device significantly differs from 'normal conditions', then you need to rebuild its architecture in the certain way. Our app provides recommendations for the redesign of printed circuit boards in order to make them more arc-resistant, but it could also be useful in designing fault-tolerant electronic systems." ❖

Vasily Yu. Kozhevnikov received his PhD in theoretical physics from Tomsk State University, Tomsk, Russia, in 2008. Since 2008, he has been a research associate with the Laboratory of Theoretical Physics of the Institute of High Current Electronics SB RAS (Tomsk). He has been using COMSOL intensively since 2012.