GAS DISCHARGE PHENOMENA IN SPACECRAFT DISCHARGE PULSES

A. R. Frederickson and C. E. Benson
California Institute of Technology Jet Propulsion Laboratory
Pasadena, CA 91109, USA

Various experiments are performed to determine that the typical pulsed discharge current is controlled by a low-pressure gas discharge. Although not broadly accepted, this has been mentioned often by previous investigators. The phenomenon has important technical implications which are now being investigated. We find that both the spatial arrangement of the vacuum chamber grounds and the divergence of the space-charge electric fields strongly modify the pulsed-current waveform. The results are consistent with the interpretation that the pulse current is carried by a Townsend gas discharge, and not by electrons emitted from the insulator. The amplitude, duration, slew-rate, polarity and total charge in the pulse can be dramatically changed by changing the spatial arrangement of grounded surfaces in the vacuum chamber. As a result, the pulsed energy delivered to a threatened circuit element is varied by an order of magnitude or more by seemingly unimportant parameters such as the "geometry" of the discharge space. Useful quantitative distinctions can now be made.

Multi-keV electron beams are used to charge the front surface of FR4 epoxy fiberglass planar circuit board material and other materials to high voltage, typically of order 20 kV. The back surface is metalized with copper, and grounded through 50-ohms. Pulsed currents are measured flowing from the copper to ground through the 50-ohm circuit in this standard charging/discharging experiment configuration. Beam energies from 5- to 35-keV are employed at 0.5 nA/cm2. In one instance a thin strip of copper on the front surface is also monitored.

Various grounded wire grids are placed 2.5 cm above the front surface so that the keV electron beams must pass through the grid in order to bombard the front surface of the sample. The charged sample surface (typically 20 kV) produces a strong electric field between the surface and the grid. Negligible electric field penetrates beyond the grid into the remainder of the vacuum chamber. The high-voltage on the sample produces a strong electric field in the sample and occasionally generates a spontaneous discharge tree in/on the sample. The discharge tree issues a burst of gas into the evacuated space above the sample.

The results are briefly outlined as follows. A very transparent grid (90% open) allows the neutral gas molecules and atoms to escape the region of electric field and thus not contribute to the Townsend avalanche. This produces "weak" discharge pulses with small peak currents that discharge a small fraction of the surface potential because the quantity of gas is not sufficient to maintain a strong discharge. A very dense grid (30% open) confines the much of the gas to remain within the electric field region and thereby contribute to a strong Townsend avalanche. This produces pulsed currents of large peak amplitude and short duration that more fully discharge the sample surface. With the dense grid, the energy deposited in the 50-ohm resistor, or in a sensitive spacecraft circuit

element, is up to ten times larger than that with the transparent grid. Yet the electric fields and voltages are the same in both cases.

Real cases of interest rarely have grids. But real cases have divergent electric fields. Divergent electric fields can also constrain neutral gas molecules within the high electric field region in a vacuum. Further tests with divergent electric fields controlled by grids find that the strong pulses are also developed in this case.

One can also constrain gas molecules with thin films such as thermal blankets that allow passage of the high-energy electrons to charge insulators. Tests with this configuration also develop strong current flows by causing the more complete avalanching of the gas discharge. Additionally, constraining the gas in this manner allows all of the gas current to become concentrated on a small conductor which would not happen in traditional test procedures.

These findings have strong implications for real spacecraft experiencing internal or external charging threats. They provide guidelines for improved spacecraft design standards, and for design and interpretation of ground tests.

Keywords: Gas discharge, solid dielectric, dielectric discharge, vacuum breakdown, spacecraft charging, radiation-induced breakdown, electrical breakdown, high-voltage