Characteristics and Signatures of Electrostatic Discharges (ESD) with Applications to Locating ESDs

Dr. Carl Christopher Reed, The Aerospace Corporation, RSSD
Mr. Thomas R. Newbauer, USAF SMC/EA
Dr. Richard Briët, The Aerospace Corporation, EPSD

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Introduction

• Without effective mitigation, surface or spacecraft charging can lead to electrostatic discharges (ESD). ESD is believed to be one of many on-orbit causes for mission degradation and/or mission failure.

• Motivations for being able to pinpoint ESD locations include developing
  – Improved operating procedures for existing satellites
  – More effective diagnostics for anomaly resolution
  – More robust satellites in the future.

• We present a novel technique to locate ESD on solar panels. The technique can be extended to locate surface discharges on other exposed surfaces.
Agenda

Theory
• *We present the Theory of Surface Discharges*

ESD Transient Characterization
• *We identify useful characteristics of surface discharges*

Determining ESD Location
• *We use characteristic signatures of surface discharges to detect the location of an ESD*

Technology Demonstrations: Verification & Validation
• *We apply our algorithm to published data on a test coupon to determine the location of an ESD*

Summary and Conclusions
THEORY
Brush Fire Surface Discharge
Brush Fire Surface Discharges

The theory of surface discharges is based on the brush fire discharge model of Dr. George T. Inouye[1]. For a rectangular surface of constant thickness, grounded at opposite ends along its entire width, the surface voltage profile is:

\[ V_B(x) = \left(\frac{kT}{q}\right) \left(1 - \frac{Cosh\left[(2x - L)/2L_B\right]}{Cosh\left[L/2L_B\right]}\right) \]

The constant, \(L_B\) is called the “Sweep Range*.”

According to his model, a plasma cloud forms at the initiation point of an ESD. This cloud sweeps in a radial direction across a charged dielectric surface. Neutralization of surface charge occurs at the edge of the traveling plasma cloud. This creates a transient return current given by:

\[ i(t) = \sigma_q (r[t] \theta[t])(dr/dt) \]

where \(\sigma_q\) is the surface charge density and \(\theta[t]\) is origination point-dependent.

*The sweep range is given by \(L_B = \sqrt{(kT/q)/(\rho J/t)}\)


Homogeneous Surface:
\[ i(t) = \sigma_q (dr/dt) r[t] \theta[t] \]

Solar Power Panel:
\[ i(t) = \sigma_q (dr/dt) \sum_{\text{All cells}}(r[t] \theta[t])_{\text{cell}} \]

Note that \(r[t] \theta[t]\) is the total circular arc length that lies within the boundaries of the rectangle at time \(t\):

It depends on, and therefore can be used to determine, the origination point.
Time Progression of a Discharge
ESD TRANSIENT CHARACTERIZATION
Conventional ESD Transient Current Characterization

Transient Current from an ESD on a Solar Panel

\[ i(t) = \sigma_q \frac{dr}{dt} \sum_{\text{All cells}} (r[t] \theta[t])_{\text{Cell}} \]

Rise Time
- **Governed by Plasma Cloud Expansion Rate**

Fall Time
- **Governed by Residual Charged Area at End of Pulse**

Pulse Width
- **Governed by ESD Initiation Point and Area Size**

Peak Current
- **Governed by ESD Initiation Point and Area Size**
Representative Signature of Measured Current Transient
(typically from Telemetry Data)

From the detailed shape of the signature of an ESD we can determine the point of origination of a discharge.
DETERMINING ESD LOCATION
The Signature of a Transient Current Depends on the Location of an ESD

Read from beginning to end:
The location of the initiating ESD event determines what the signature of the transient current will look like.

Read from end to beginning:
The signature of a transient current contains all the information about the location of the initiating ESD event.
Create a Distance Norm (or Metric) for the “Distance” between a Hypothesized Signature and a Measured Signature

- We need a way to measure how “close” a measured signature is to a hypothesized signature that was pre-calculated and stored in a look-up table.

- Use the area between the two curves as the basis for a Distance Norm or Metric. This area goes to zero when the hypothesized signature matches the measured signature.

![Diagram showing a hypothesized signature and a measured signature with total shaded area between the two curves highlighted.]
"Distance" (to measured current profile) vs. X and Y
Exhibits Four-Fold Symmetry
(for a Rectangular Region)

Four distinct points all minimize the distance
to the measured current profile
Possible/Candidate ESD Locations on a Surface with Inherent Four-Fold Symmetry

ESD location-ambiguities on panels with inherent symmetry can be resolved by measuring start-time differences between ESD current transients in separate wires.
VERIFICATION & VALIDATION
Steps to Extricate Location Information from the Signature of an ESD

1. Construct a catalogue of panel-specific, origination-point-dependent signatures
2. Reconstruct measured ESD signature
3. Compare signature with catalogue data
4. Determine/find minimum “Distance” to identify candidate ESD locations
5. Resolve inherent symmetry ambiguities

§ Patent applied for
Technology Demonstration:
Compare measured signature\(^{(2)}\) with cataloged signatures

- “Distance” metric shows approximate fourfold symmetry
- Most likely ESD location identified
  - One of four possible symmetry points

\(^{(2)}\) Measured signature data from discharges on test coupons representing typical solar panels was provided by Dr. J. Pollard of The Aerospace Corporation.
Summary and Conclusions

• After briefly mentioning the surface voltage profiles on dielectric surfaces, we discussed the propagation of a surface discharge across a dielectric surface. The theory is based on Dr. George T. Inouye’s Brush Fire discharge model [1].

• The brush fire discharge model predicts transient current signatures that are characterized by the electrical properties of the dielectric material, by its size, its shape, and by the location of the discharge.

• Based on the notion that the signature of a transient current from an ESD contains hidden information about the origination point of the ESD, we developed a technique to locate ESD on solar panels.

• The method requires no additional space hardware, and it can be extended to locate surface discharges on other exposed surfaces.

Thank you.

Questions N.E.1?