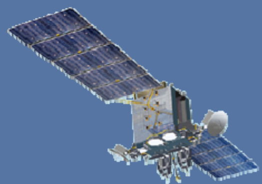

Characteristics and Signatures of Electrostatic Discharges (ESD) with Applications to Locating ESDs

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

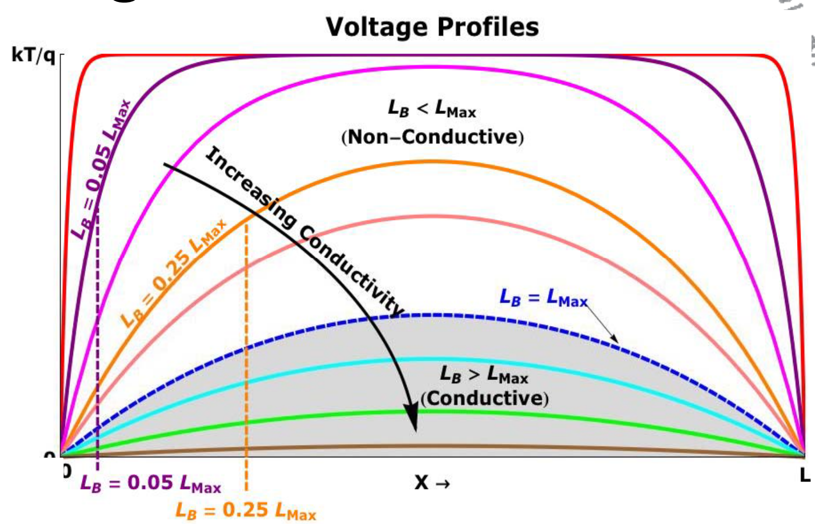
THEORY
Brush Fire Surface Discharge

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:

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

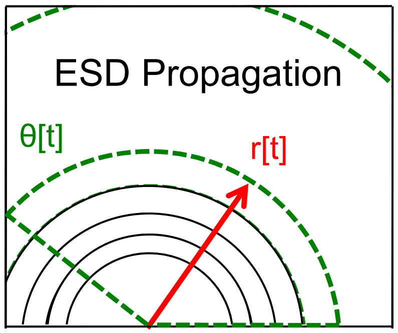
The constant, L_B is called the "Sweep Range*."



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:

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

where σ_q is the surface charge density and $\theta[t]$ is *origination point-dependent*.



Homogeneous Surface:

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

Solar Power Panel:

$$i(t) = \sigma_q \left(dr/dt\right) \sum_{All\ cells} \left(r[t]\ \theta[t]\right)_{cell}$$

Note that r[t] θ[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.

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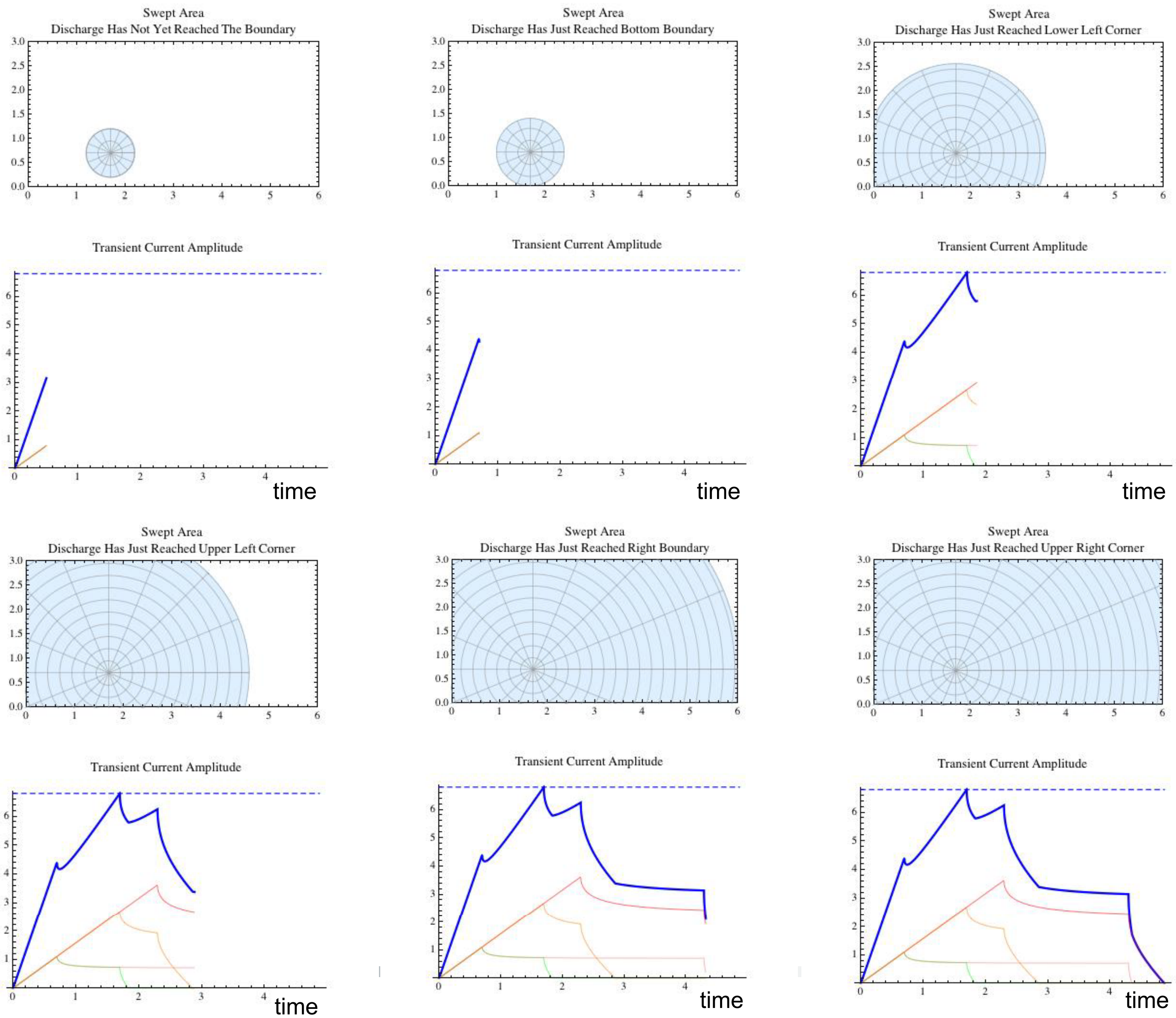
*The sweep range is given by $L_B = \sqrt{(kT/q)/(\rho J/t)}$

[1] G.T. Inouye, "Brushfire Arc Discharge Model," Spacecraft Charging Technology, 1980, NASA CP-2182, AFGL-TR-02770, 1981.

Time Progression of a Discharge



ESD TRANSIENT CHARACTERIZATION

Conventional ESD Transient Current Characterization

Transient Current from an ESD on a Solar Panel

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

Rise Time

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

Fall Time

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

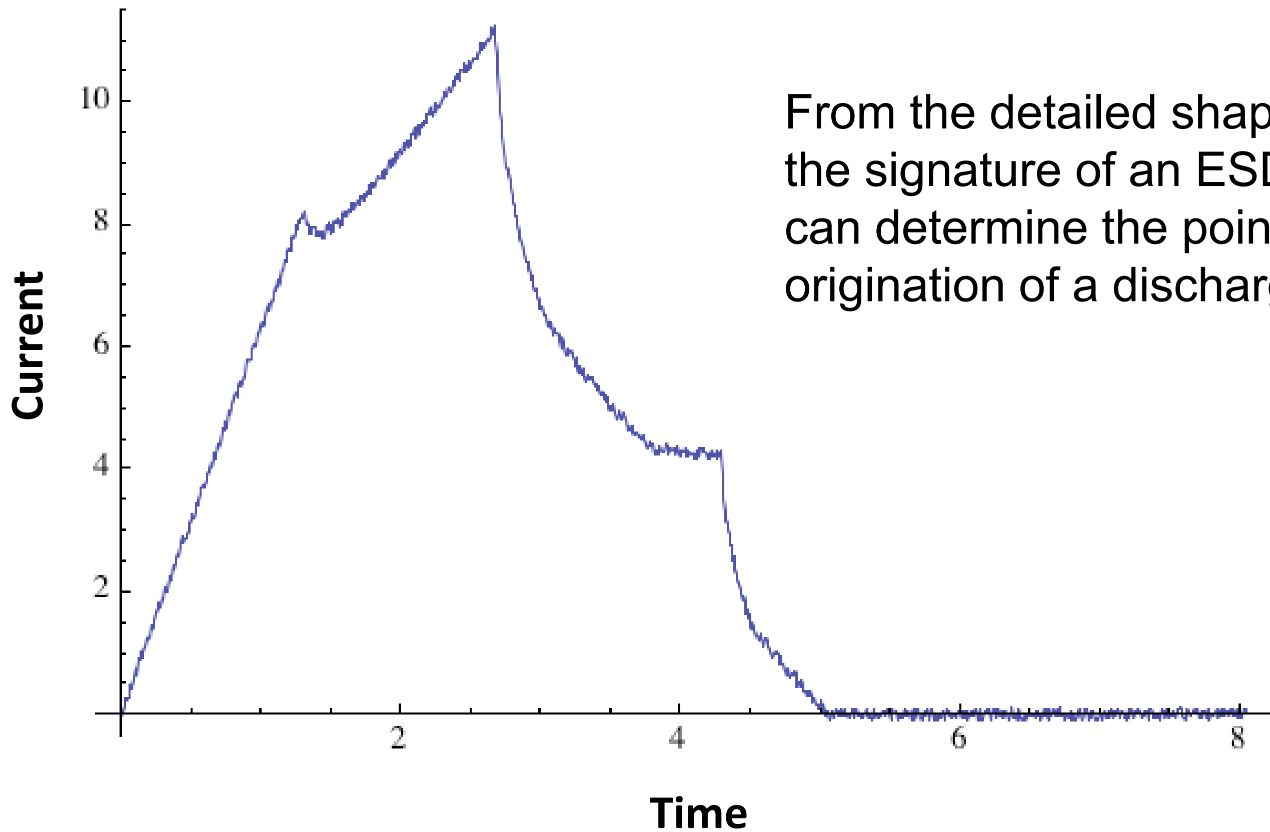
Pulse Width

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

Peak Current

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

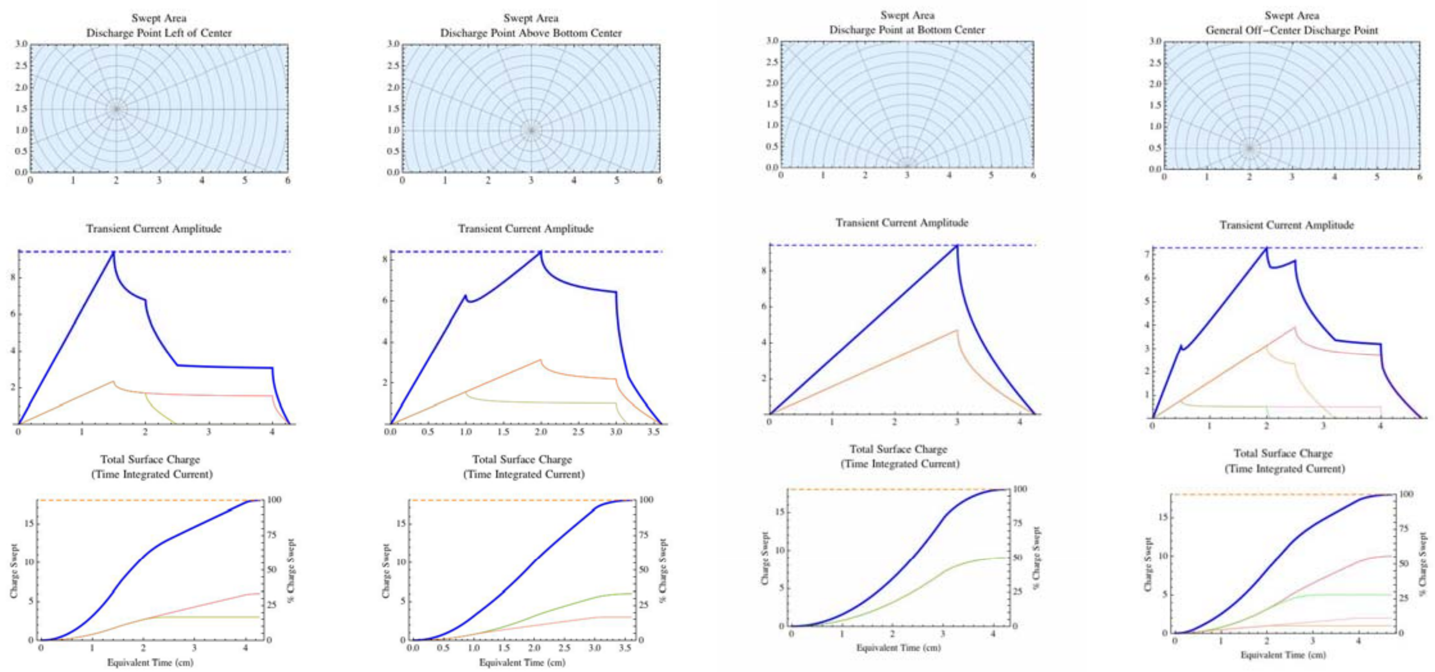
Representative Signature of Measured Current Transient (typically from Telemetry Data)



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:

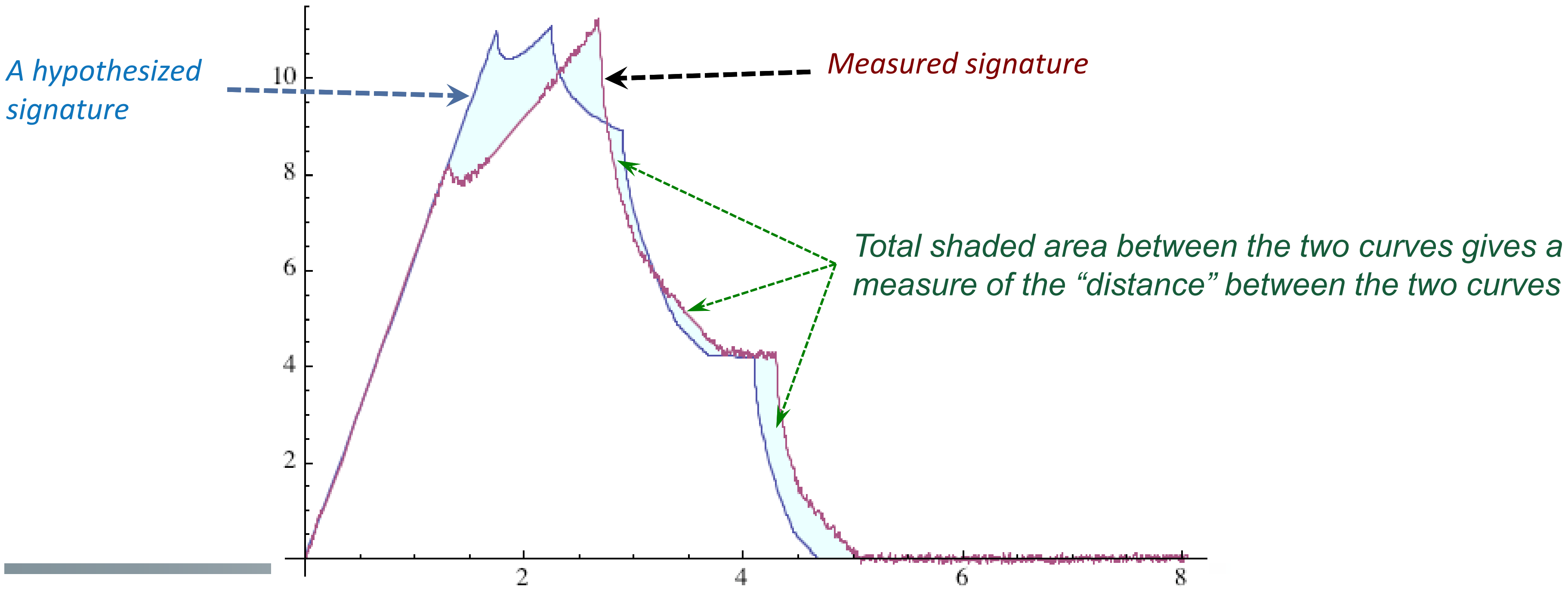
The location of the initiating ESD event determines what the signature of the transient current will look like.

Read from end to beginning:

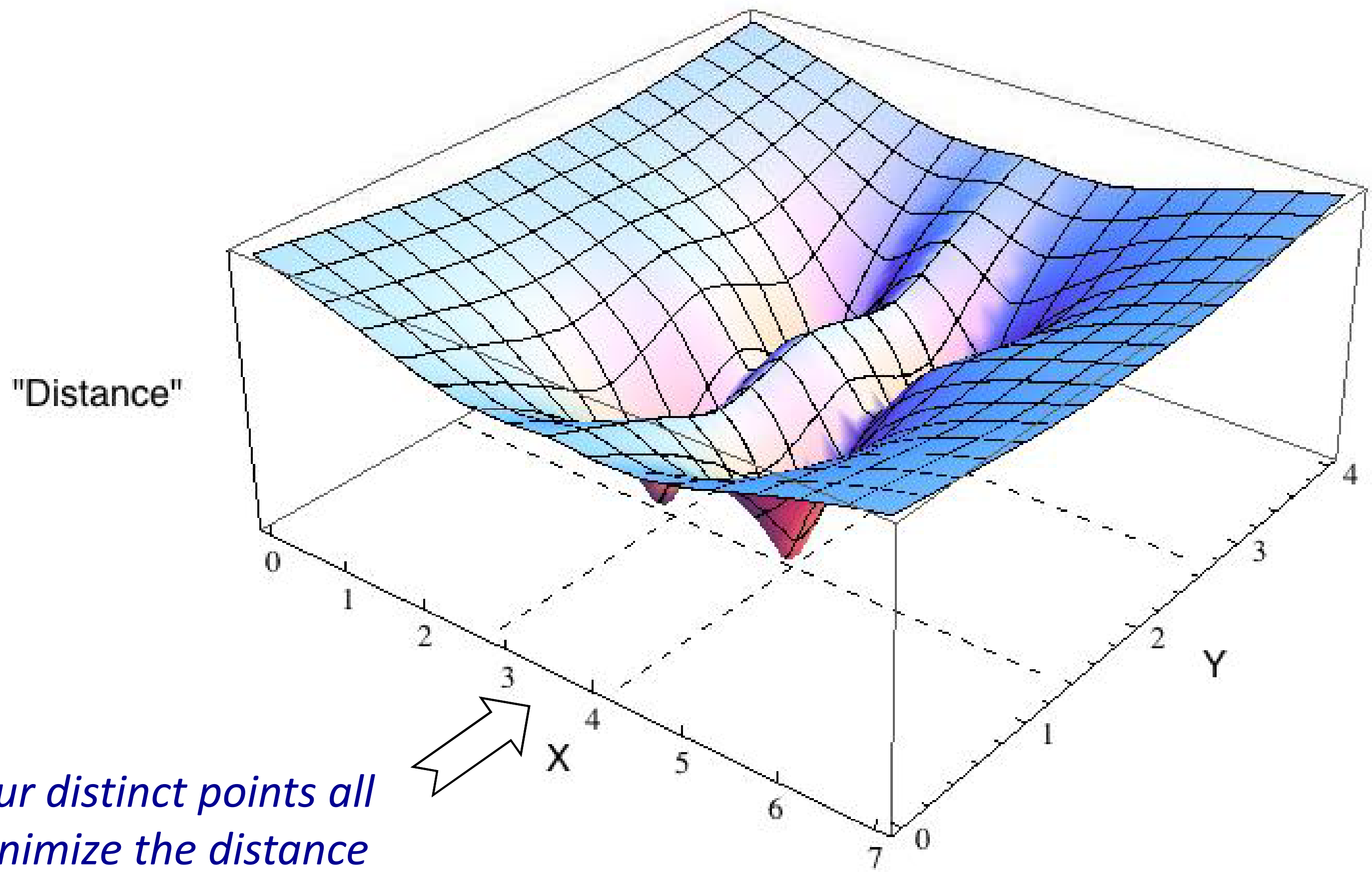
The signature of a transient current contains all the information about the location of the initiating ESD event.

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

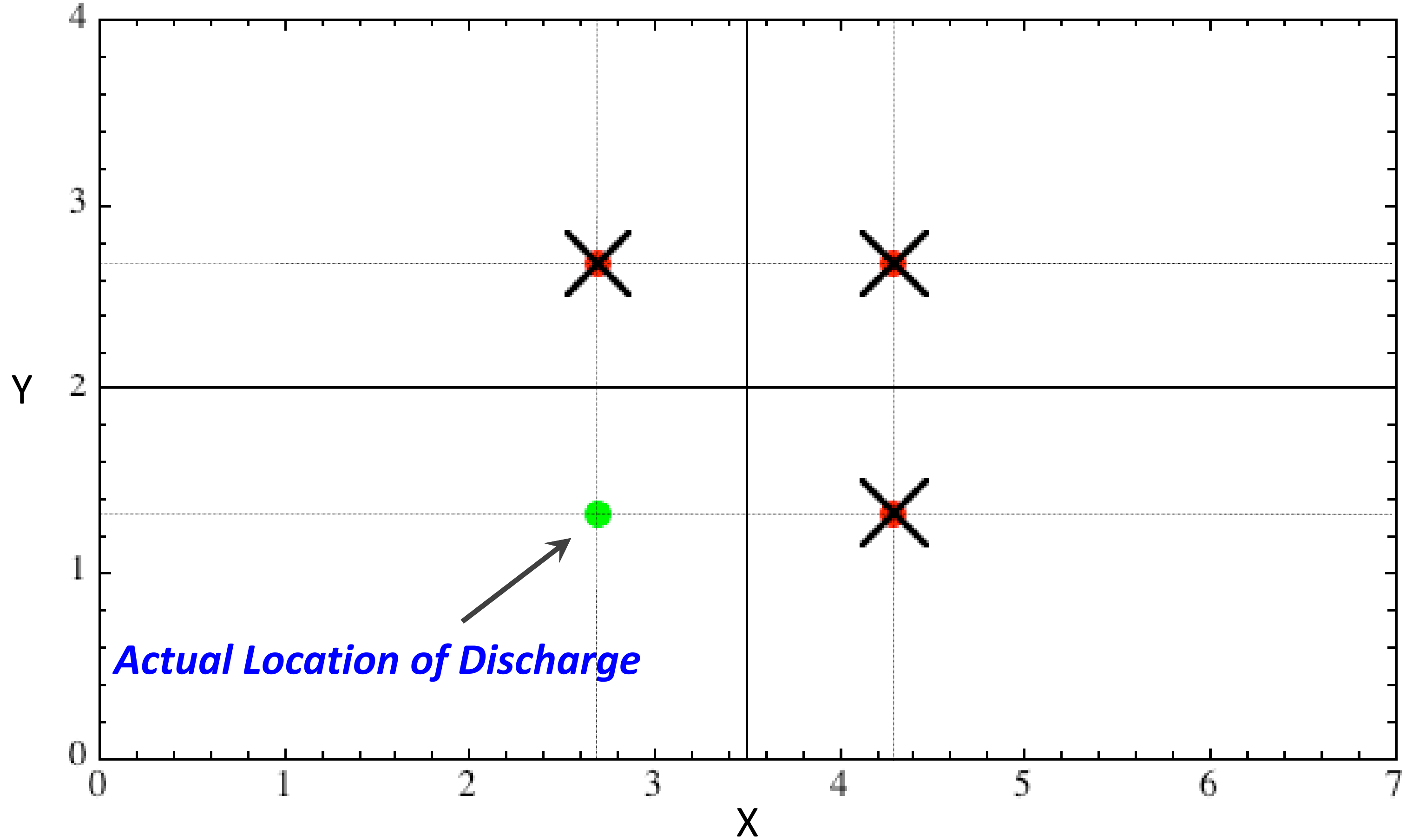


"Distance" (to measured current profile) vs. X and Y Exhibits Four–Fold Symmetry (for a Rectangular Region)



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.

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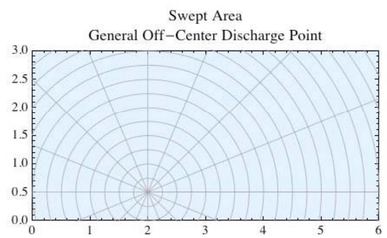
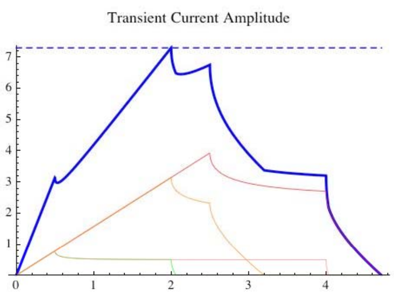
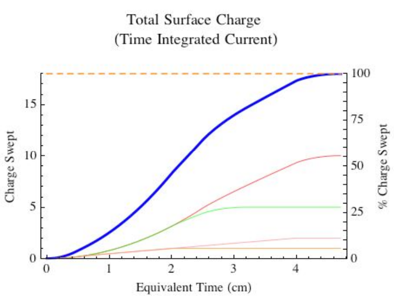
Steps to Extricate Location Information from the Signature of an ESD§







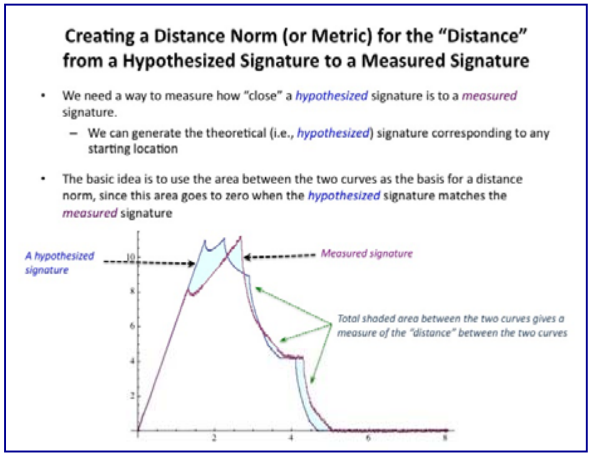
Construct a catalogue of panel-specific, origination-point-dependent signatures

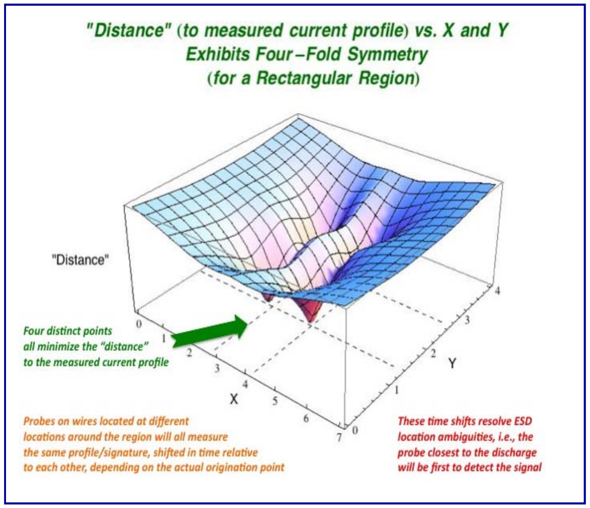
Reconstruct measured ESD signature

Compare signature with catalogue data

Determine/find minimum "Distance" to identify candidate ESD locations

Resolve inherent symmetry ambiguities

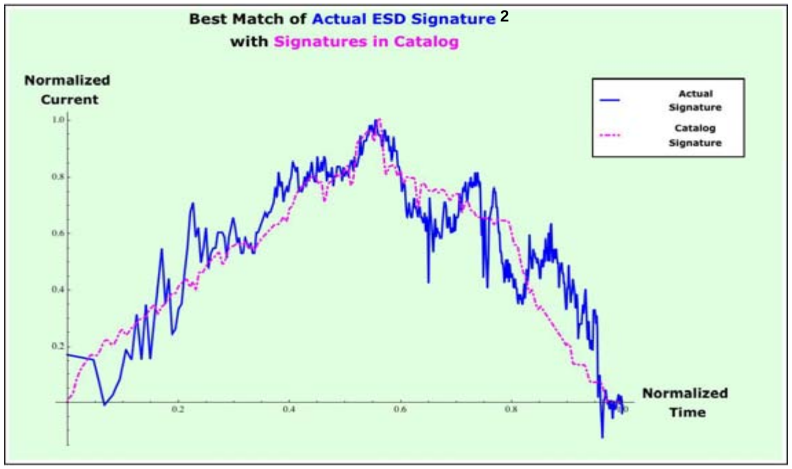




§ Patent applied for

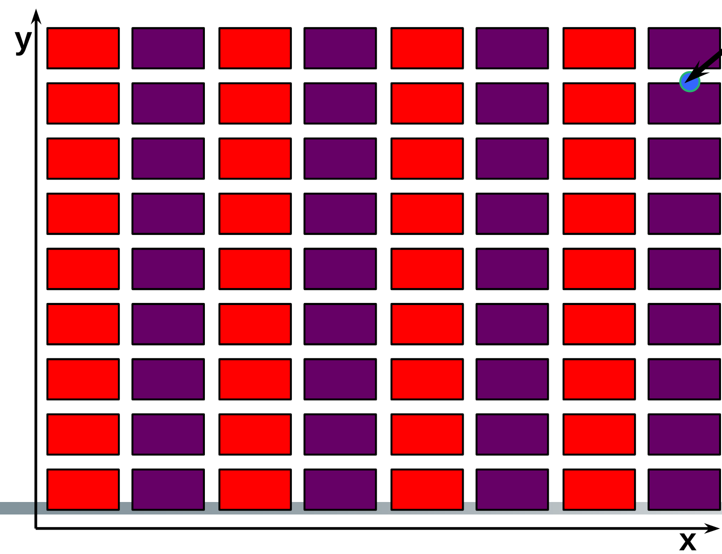
Technology Demonstration:

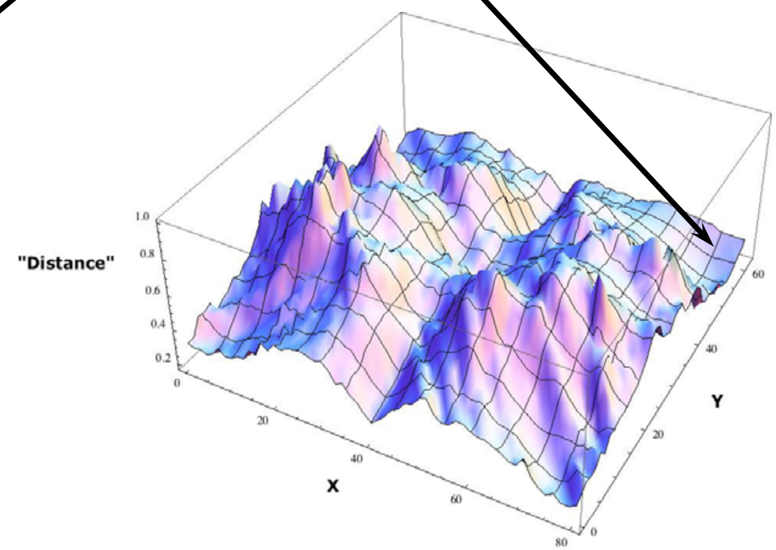
Compare measured signature(2) with cataloged signatures



- "Distance" metric shows *approximate* four-fold 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 & CONCLUSIONS

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.

[1] G.T. Inouye, "*Brushfire Arc Discharge Model,*" Spacecraft Charging Technology-1980, NASA CP-2182, AFGL-TR-02770, 1981.

Thank you.

Questions N.E.1?