SPACECRAFT CHARGING RELATED RISK OF FLOATING CONNECTOR PINS

Justin Likar(1), Kris Hartojo(2), George Ott(3), John Bird(4), Nigel Meredith(2)

(1)UTC Aerospace Systems, Danbury, CT, USA, Email: justin.likar@utas.utc.com
(2)Cobham RAD Solutions, Colorado Springs, CO, USA, Email: kris.hartojo@cobham.com
(3)Cobham RAD Solutions, Colorado Springs, CO, USA, Email: george.ott@cobham.com
(4)IRCOS, LLC, Colorado Springs, CO, USA, Email: jbird@ir-cos.com
(5)British Antarctic Survey, Cambridge, UK, Email: nmer@bas.ac.uk

ABSTRACT

Every national spacecraft charging related design guideline or design standard [1-3] includes prohibitions against floating, or ungrounded, connector pins. The rationale is obvious. A floating connector pin represents ungrounded metal with a propensity to accumulate charge from the space plasma environment and, upon breakdown, effectively couple the discharge energy directly into sensitive system electronics by virtue of adjacent pins and cables. Seemingly as common as the rationale is obvious are instances in violation of this clear guideline and impassioned arguments / rationale for permissions to do so. The present study represents a comprehensive effort is underway to quantitatively, theoretically, analytically, and empirically assess the risk associated with ungrounded connector pins in select orbits.

1. ESD THREAT ASSOCIATED WITH CONNECTORS

It is proposed that damaging breakdown in connectors (Fig. 1) may occur via:

1. "Peak charging" of pin where environment experiences moderate to significant increase in internal charging flux, and as result rise in stored charge, electric field, et cetera quickly. The "Peak Flux" is, of course, on top of any existing stored charge in the system that may have been acquired over long durations.
2. Long duration charging of dielectric where only a small to moderate charging event, on top of the existing steady state "background charging" is sufficient achieve breakdown of the dielectric.

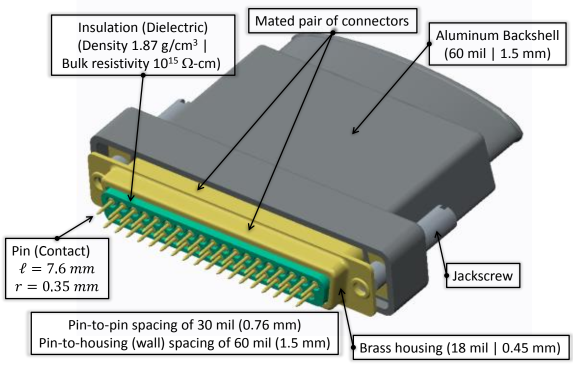

Figure 1. Summary of (typical) connector features.

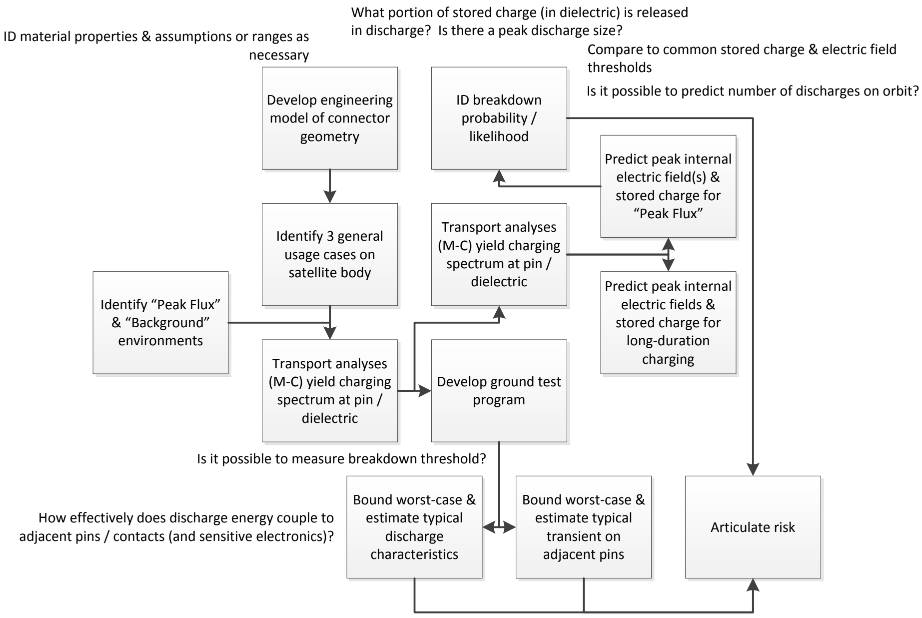

Figure 2. Summary of assessment steps.

2. SUMMARY OF DISCUSSION AND OBSERVATIONS

Fig. 2 describes the analysis and test process which begot noteworthy and informative observations,

- Mated connectors (see Fig. 1), even in exterior spacecraft applications, provide appreciable shielding to interior dielectrics and contacts. Contacts are small (cross sectional area <0.5 cm^2) and typical connector dimensions yield low capacitance estimates (<0.5 pF).
- "Peak flux" (Fig. 3 and Fig. 4) studies down-selected from several common design environments but did not include extreme environments. 1-D Monte-Carlo [4, 5] considered >10^5 histories (Fig. 4).
- 4 kV on contact fails to exceed dielectric strength of insulator (estimated properties below); risk increases with pin density.
- Dielectric properties are rather poorly known and subject to estimation or simplification (dielectric constant of 2.2, bulk resistivity of 10^{15} W-cm to 10^{18} W-cm, and dielectric strength of 15 kV/mm (~380 V/mil) for example); yields estimated time constant (τ) of ~3 d. Only DICTAT analyses (Fig. 5), which treated the dielectric as Kapton) consider RIC.

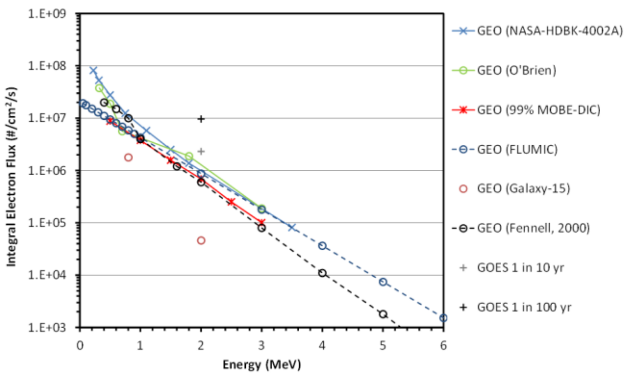

Figure 3. Comparison of common GEO "Peak Flux" design environments and >2 MeV extreme environments [1, 7-9, 11].

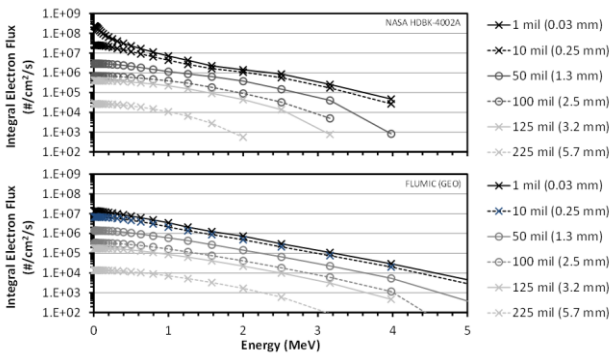

Figure 4. Transported (via 1-D NOVICE Adjoint Monte Carlo "Peak Flux" spectra [4].

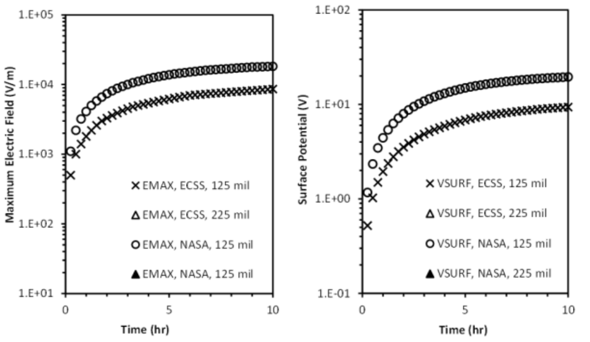

Figure 5. Calculated (via DICTAT) [6] internal electric field & surface potential for transported "Peak Flux" (10 hr).

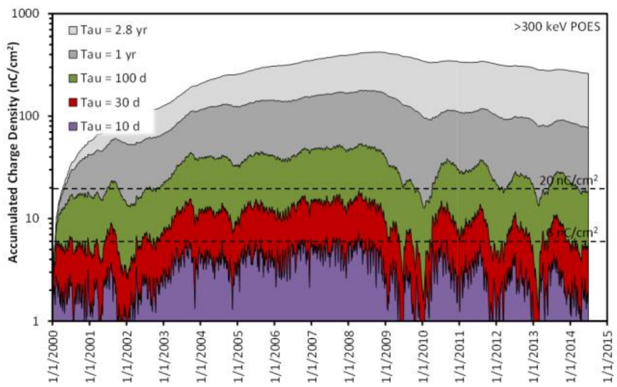

Figure 6. Cumulative charge density as calculated using >300 keV POES electrons [10, 13].

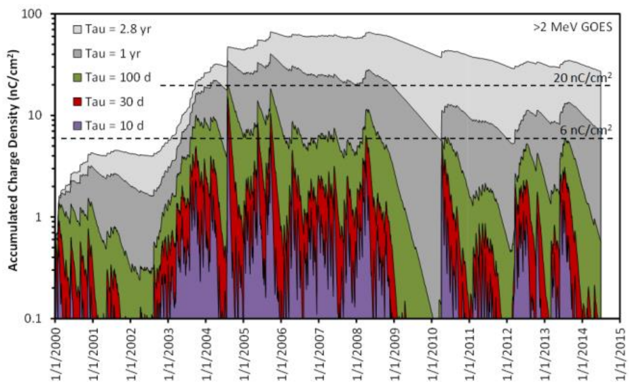

Figure 7. Cumulative charge density as calculated using >2 MeV GOES electrons [11, 13].

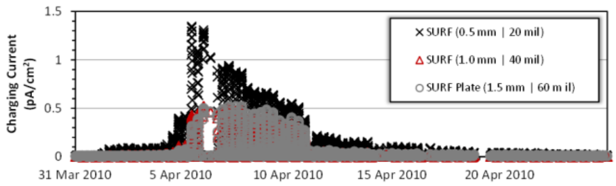

Figure 8. Charging currents as measured by SURF detector (Giove-A) for April 2010 [12]. SURF data used with permission of Ryden, K. and Hands, A. (now with University of Surrey).

Energy (MeV)	Range (mil)	Range (mm)
0.30	15	0.4
0.60	40	1.0
2.0	175	4.5

Figure 9. Electron penetration ranges in aluminium.

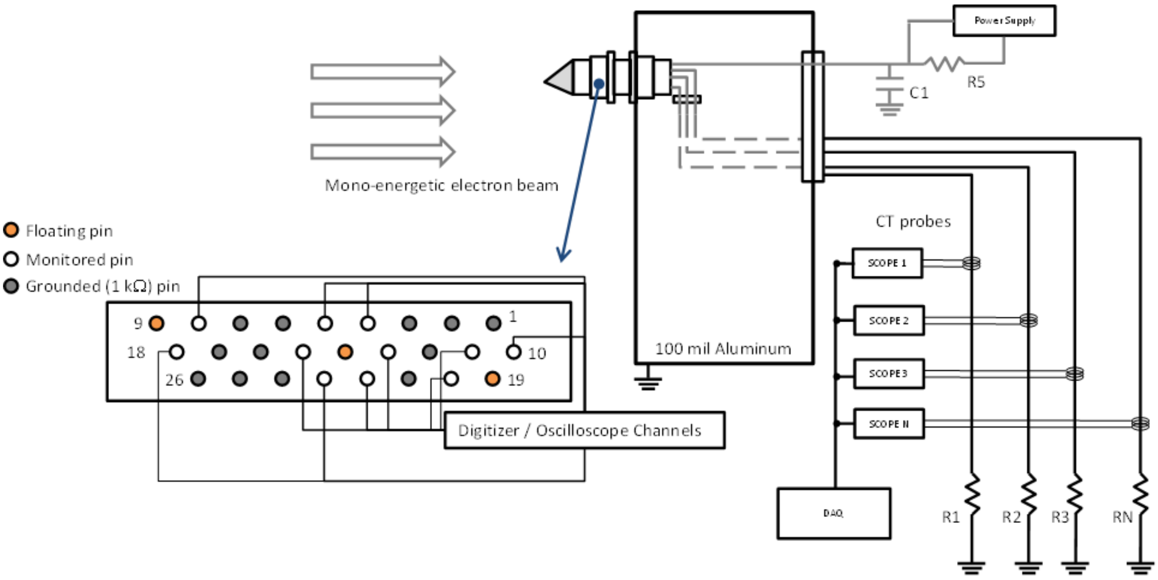

Figure 10. Test conditions for mono-energetic electron exposure in Pelletron; C1 varied between 1 μF and 10 μF.

3. CONCLUSIONS

We draw several conclusions from present work:

- "Peak Flux", in absence, of steady-state accumulated charge, appears insufficient to cause obvious risk of breakdown.
- Over typical mission lifetimes moderate charging events coupled with long-duration / steady charge accumulations yield exceedances of common risk thresholds (nC/cm^2 or V/m)
  - GOES >2 MeV (Fig. 5), POES >300 keV (Fig. 6), & MEO (Fig. 7).
- Small discharge energies (0.2 mJ to 2.0 mJ) & relatively small coupling (~nH) to adjacent lines place sensitive devices at risk.
- Note that Class 1B sensitive to HBM ESD <1000 V (ANSI / ESDA / JEDEC JS-001-2010).
- Conclusion of ground testing will provide valuable insights into contributions of charged dielectric to breakdown properties.
- Flat connectors (dielectric) [14], such as those common in some solar panel designs shall be studied separately as these are also of great interest to designers and spacecraft charging experts / engineers.
- Obvious solution remains best – prevent all ESD – ground pins through <10^8 W & ensure dielectric is well shielded (>120 mil)
- One must consider mission specifics in assessing risks

4. REFERENCES

1. "Mitigating In-Space Charging Effects – A Guideline." NASA Technical Handbook NASA-HDBK-4002A, 3 March 2011.
2. "European Cooperation for Space Standardization, Space Engineering, Spacecraft Charging. ECSS-E-ST-20-06C, 31 July 2008.
3. "Japan Aerospace Exploration Agency Design Standard Spacecraft Charging and Discharging." JERG-2-211A, Rev. A, 10 May 2012.
4. Jordan, T. "The Accuracy of NOVICE Electron Shielding Calculations." *Proceedings of the First European Conference Radiation and its Effects on Devices and Systems (RADECS)*, 1991.
5. Lei, F., Truscott, P.R., Dyer, C.S., Quaghebeur, B., Heynderickx, D., Nieminen, P., Evans, H., and Daly, E. "MULASSIS: a Geant4-based multilayered shielding simulation tool." *IEEE TNS* Vol. 49, No. 6, December 2002, pp. 2788-2793.
6. Rodgers, D., Ryden, K., Wrenn, G., Latham, P., Sorensen, J., and Levy, L. "An Engineering Tool for the Prediction of Internal Dielectric Charging." *Proceedings of the 6th Spacecraft Charging Technology Conference*, 2-6 November 1998, Hanscom AFB, MA.

7. Loto'anlu, T.M., Singer, H.J., Rodriguez, J.V., Green, J., Denig, W., Biesecker, D., and Angelopoulos, V. "Space weather conditions during the Galaxy 15 spacecraft anomaly." *Space Weather*, Vol. 13, No. 6, August 2015, pp.484-502.
8. Skov, T.M., Fennell, J.F., Roeder, J.L., Blake, J.B., and Claudepierre, S.G. "Internal Charging Hazards in Near-Earth Space During Solar Cycle 24 Maximum: Van Allen Probes Measurements." IEEE TPS, Vol. 43, No. 9, September 2015, pp. 3070-3074.
9. Sarrailh, P. and Paulmier, T. "3-D Time-Dependent Modelling of Internal Charging in MEO and Model Validation Through Experiment." *Presented at Space Environments and Effects (TEC-EES) Final Presentation Days*, 15-16 December 2015.
10. Meredith, N.P., Horne, R.B., Isles, J.D., and Green, J.C. "Extreme energetic electron fluxes in low Earth orbit: Analysis of POES E > 30, E > 100, and E > 300 keV electrons." *Space Weather* Vol. 14, No. 2, February 2016, pp. 136-150.
11. Meredith, N.P., Horne, R.B., Isles, J.D., Rodriguez, J.V. "Extreme relativistic electron fluxes at geosynchronous orbit: Analysis of GOES E > 2 MeV electrons." *Space Weather* Vol. 13, No. 3, March 2015, pp. 170-184.
12. Ryden, K.A., Hands, A.D.P., Underwood, C.I., and Rodgers, D.J. "Internal Charging Measurements in Medium Earth Orbit using the SURF Sensor: 2005-2014." *IEEE TPS*, Vol. 43, No. 9, September 2015, pp. 3014-3020.
13. Bodeau, M. "High Energy Electron Climatology that Supports Deep Charging Risk Assessment in GEO." Paper AIAA 2010-1608, *Proceedings of the 48th AIAA Aerospace Sciences Meeting Including the New Horizons Forum and Aerospace Exposition*, 4-7 January 2010, Orlando, Florida.
14. Bodeau, M. "Observation of Sustained Arc Circuit Failure on Solar Array Backside in Low Earth Orbit." *IEEE TPS*, Vol. 43, No. 9, September 2015, pp. 2961-2974.