Spacecraft Charging Facts

- “The largest cause of mission failures related to the space environment is surface ESD.” [Koons, et al., 1999.]

- 200 annoying to serious and 10 critical operational anomalies due to electrostatic surface discharge are expected over the lifetime of a S/C in GEO. [Wrenn, et al., 1993.]
Why should we monitor S/C charging?

- Mission Safety - placing S/C in safe mode
- Post-Failure Analysis
- Evaluate charging mitigation techniques
- Study the S/C charging phenomenon
Monitoring Spacecraft Charge

- Few S/C are equipped with charge monitors
- Why don’t we have more?
  - Uncertainty?
  - Denial?
  - Ignorance?
- What is the cost/benefit analysis of placing monitors on S/C?
<table>
<thead>
<tr>
<th>Instrument</th>
<th>Method</th>
<th>Major Limitations</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Double Probe</td>
<td>Spacecraft Electric field measured by potential difference between two probes mounted on booms</td>
<td>Biases due to changes in probe work function, probe photoemission, etc. Booms needed [Maynard, 1998]</td>
<td>100 Meter Boom</td>
</tr>
<tr>
<td>Langmuir Probe</td>
<td>Volt-Ampere characteristic of probe immersed in space plasma is measured</td>
<td>Biases due to changes in probe work function, magnetically induced probe potentials and so on [Brace, 1998]</td>
<td>Will not work in GEO</td>
</tr>
<tr>
<td>Retarding Potential Analyzer (RPA)</td>
<td>A current voltage curve from instrument is analyzed to determine ion drift velocity</td>
<td>Biases due to uncertainty in expected ion drift for spacecraft at zero potential. [Anderson, 1994]</td>
<td>Will not work in GEO</td>
</tr>
<tr>
<td>Ion Energy Analyzers</td>
<td>Ion Spectra of space plasma are analyzed for ‘low energy cutoff’</td>
<td>Biases due to uncertainty in the ‘low energy cutoff’ from such measurements [Moore, 1996]</td>
<td>Crude and slow as done today</td>
</tr>
</tbody>
</table>
Today…

- ‘Commercial off-the-shelf’ devices for monitoring charge do not exist
- Spacecraft charge has only been measured with unwieldy, one-of-a-kind, multi-million dollar, mission specific instruments
- Existing charge monitors return data of questionable accuracy and reliability
Spacecraft Charge Monitor (SCM)

- 14-year development effort...
- Far superior to anything that has flown before...
Pre-History of the SCM

- The Photoelectron Spectrometer (PES) Experiment on the Atmosphere Explorer satellites (1970’s)
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PES (1970’s)
PES Charge Sensing

‘Electron-spectroscopic Method’

S/C charge = + 2.5 V
PES Charge Sensing
‘Electron-spectroscopic Method’

S/C charge = 0.0 V
PES Charge Sensing
‘Electron-spectroscopic Method’

S/C charge = - 3.5 V
Goals for Goembel Instruments

- PES gathered data slowly
- A major goal for Goembel Instruments was to monitor charge more rapidly and accurately
- A fundamental design change to PES was needed
First Attempt at SCM (1996)

- Started at APL
- 3 times better than PES
Second Attempt at SCM (1997)

- Addition of another aperture
- 6 times better than PES
Third Attempt – A Breakthrough!

- If two apertures worked - why not more?

Arc-shaped Aperture
Traditional Aperture
New design is 60 times better than PES!
Applied for Patent in 2001
AFRL proposed using SCM on NPOESS in 2001
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Lab Prototype SCM 2001-2
SCM Delivered 2006

- 650 grams
- 2 watts
- FPGA on board
- RS422 S/C interface
- Ready to fly today!
SCM-2

- 2007-2009

- Goembel Instruments was asked to design a charge monitor for GEO

- SCM-1 is for minor charging (+/- ~100V)

- Charging up to -10,000V expected in GEO

- SCM-2 is a modified SCM-1 for GEO
SCM-2

- Two charge monitoring methods
  - Electron-Spectroscopic
  - Low Energy Ion Cutoff
SCM-2

- Chosen by both prime contractors for their proposals to build DoD’s TSAT in early 2009
- TSAT program cancelled in Spring 2009
- Development of SCM-2 continued into Fall 2009
SCM-2 Performance

- Accurate, No Calibration Drift, No Booms Needed
- Compact: ~1kg, 2W
- Determine charge +500 to -10,000 volts
- Two methods used to validate measurements within 5% under all conditions
- Determine charge ~ once a minute
SCM-3

- 2010
- Not for monitoring charge
- Spin-off of previous SCM technologies
- Designed to monitor solar wind
  - Speed
  - Direction
  - Temperature
  - Density
SCM-3 is 600 times better than the instruments used today to monitor the solar wind!
Conclusions

- Over the last 14 years, Goembel Instruments has developed innovative spacecraft charge monitoring technology
  - Outperforms Current Spacecraft Charge Monitoring Options
  - Costs are significantly less due to the minimal overhead and focused development of Goembel Instruments
Next Steps Ahead…

- SCM-2, for high level charging in GEO, is awaiting funds to be built.

- SCM, for accurately monitoring low level charge, is ready to fly today!
Thank You

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