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Pulsed Electro-Acoustic Measurements of Charging and Relaxation in Low Density Polyethylene

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4CS APS Fall 2017 Meeting
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Overview

- Pulsed Electro-Acoustic (PEA) method
- Importance of PEA
- Our PEA system
- Measurements of Low Density Polyethylene
- Conclusions
- Future work

What is PEA?

How it works:

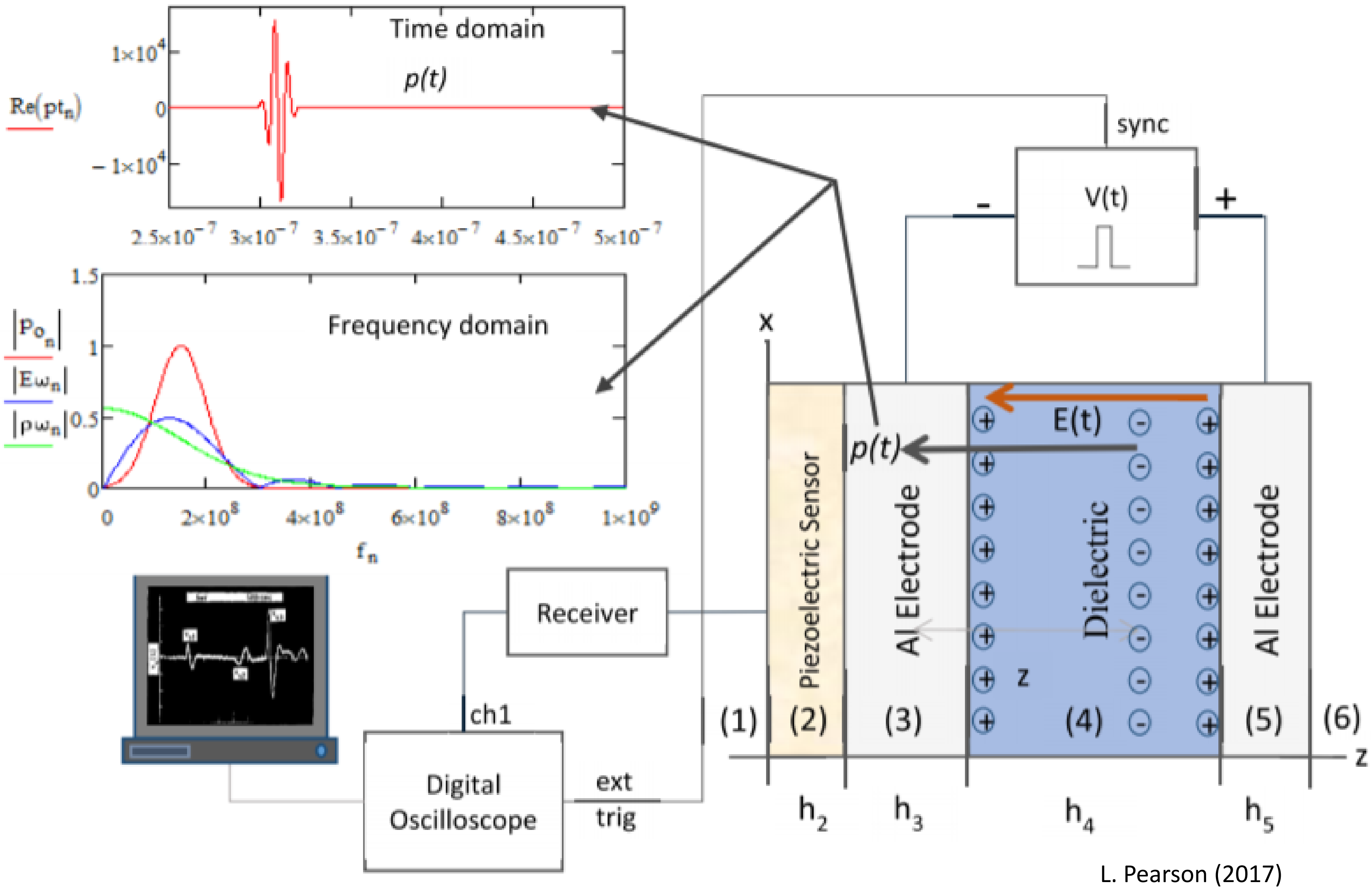
- Measures charge layers
- Charge is injected through electrodes or electron beam
- Pulsed voltage "bumps" charge in material
- Signal is processed to show charge in material

Benefits:

- Nondestructive measurement
- Low cost
- High resolution

Limitations:

- Instrumentation bandwidth
- Electronics for higher resolution are costly



L. Pearson (2017)

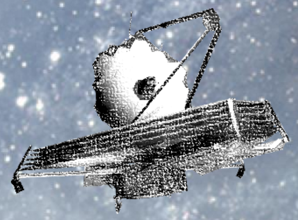
Importance

The majority of space environment-induced anamolies (failures) are attributed to spacecraft charging, therefore understanding the accumulation and mitigation of charge is critical.

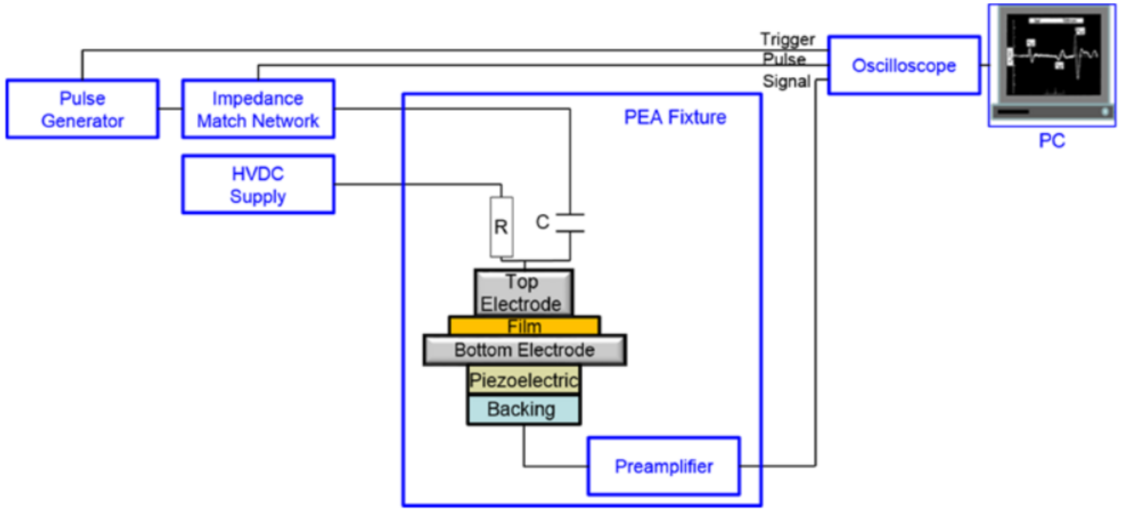
- Space plasma fluxes are typically ~10’s of keV, which means penetration depths of ~1-100 µm
- Spacecraft materials typically ~10’s – 100’s of µm thick
- Funding for our group and this project is for space craft charging

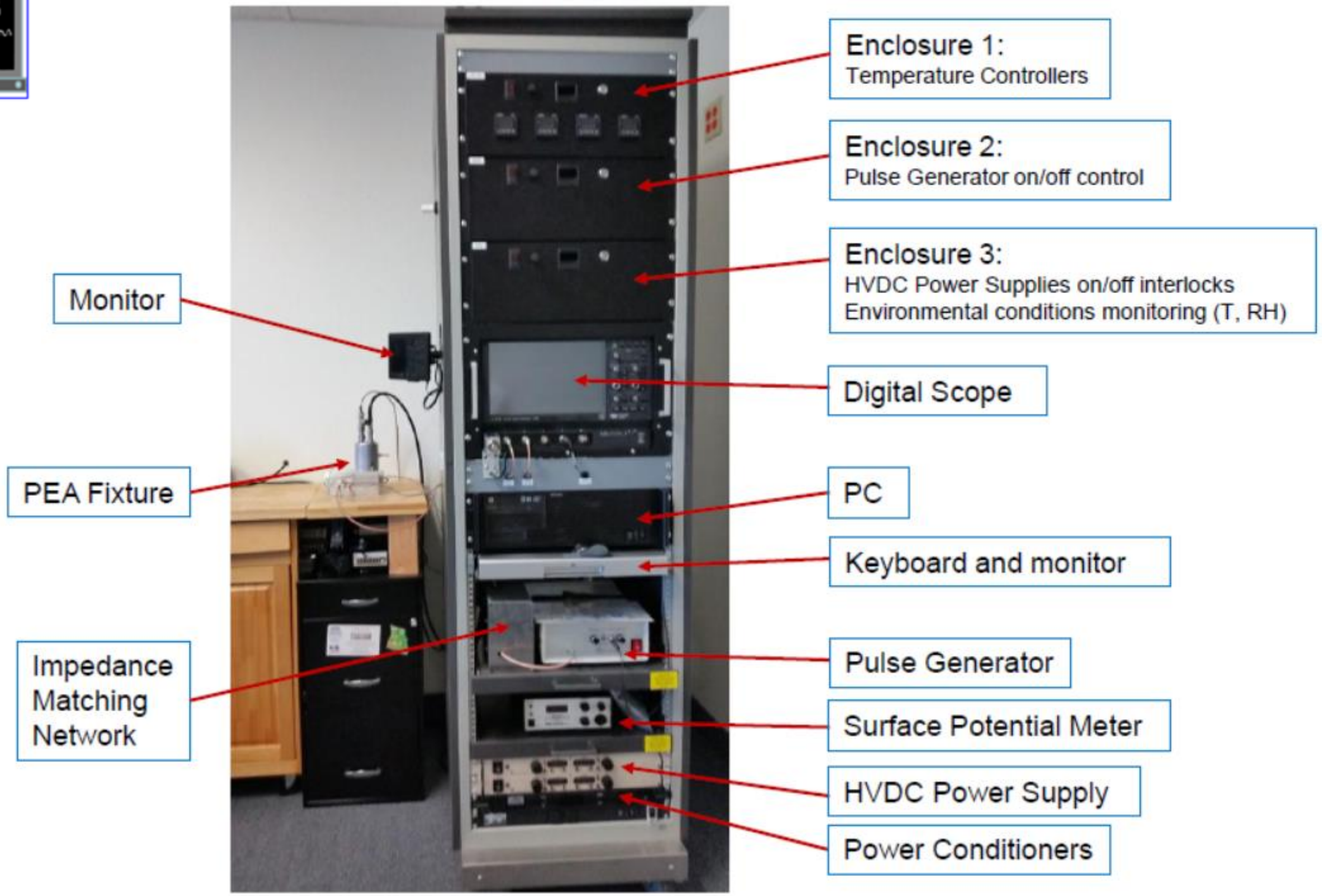
Also useful for many other applications:

- High voltage power cabling insulation
- High voltage devices and switches
- Electrostatic charging in accelerators and plasma chambers
- Plasma deposition
- Thin film dielectrics in semiconductors and sensors
- Electron microscopy and spectroscopy
- Photoconductive devices/sensors
- Inferring defect states in materials



Our PEA System





Specs:

- 0-10 kV DC voltage
- ~100 MHz
- 0-1000 V reference voltage
- ~2-5 µm resolution

Proposed PEA Measurements

The 19th International Symposium on High Voltage Engineering, Pilsen, Czech Republic, August, 23 – 28, 2015

THERMAL AGEING AND ITS IMPACT ON CHARGE TRAP DENSITY AND BREAKDOWN STRENGTH IN LDPE

Ziyun Li[1*], Ning Liu[1], George Chen[1], Mingli Fu[2] and Shuai Hou[2]
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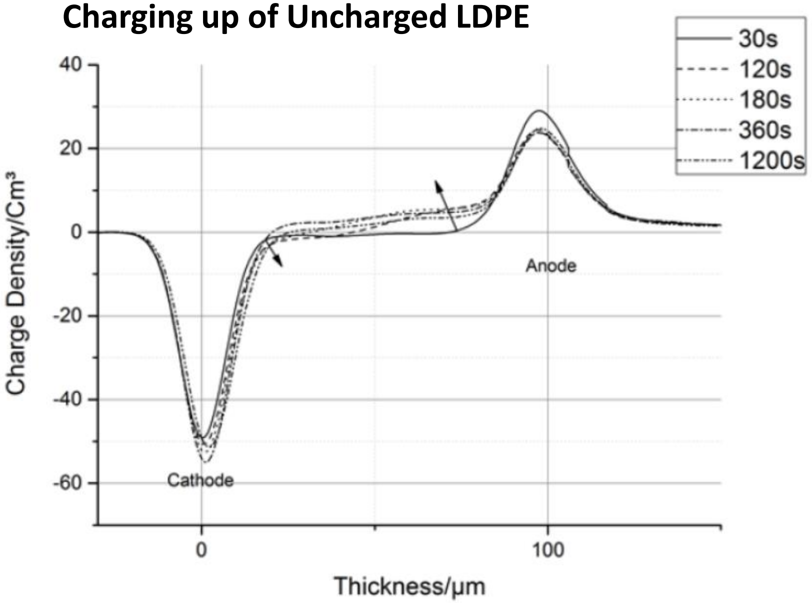
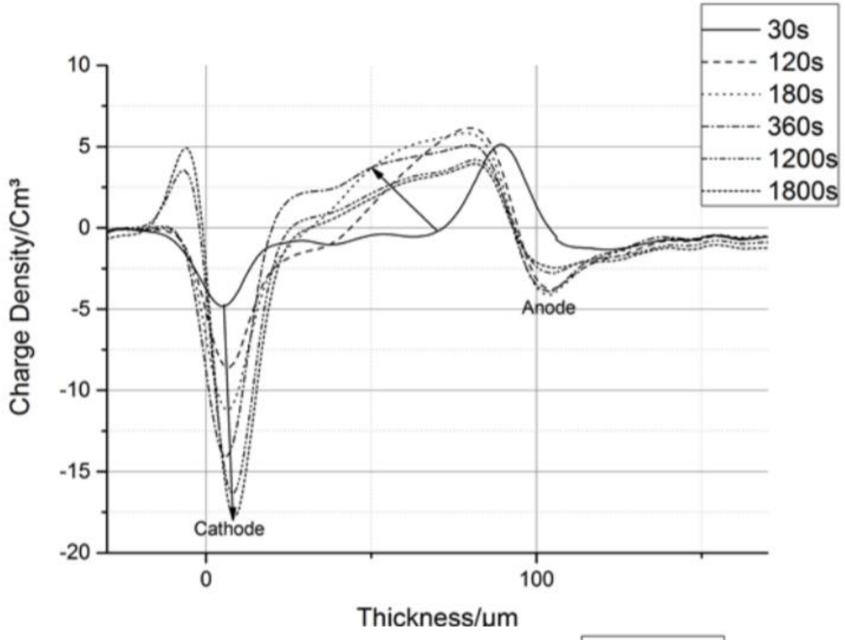
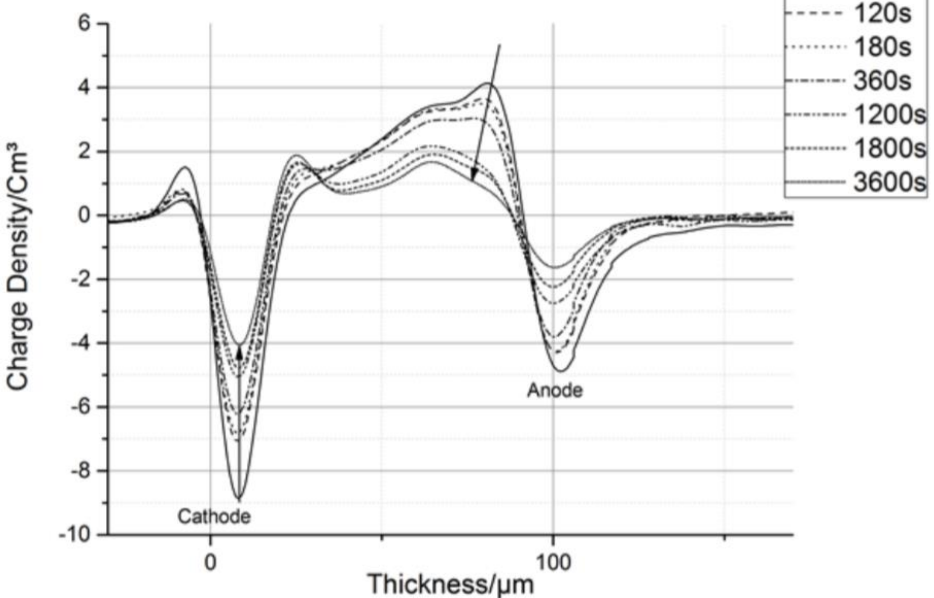
Space charge dynamics were measured using the pulsed electroacoustic (PEA) technique. The thickness of the sample was ~100μm. A drop of silicone oil was placed between LDPE film and both two electrode in order to make sure good acoustic propagation. The reference voltage was set at 1kV and all types of samples were stressed at an electric field of 40kV/mm. The PEA data were collected during volts-on for 1800s and volts-off for 1800s to explore both the injection and decay behaviours of space charge.

Charging up of Uncharged LDPE





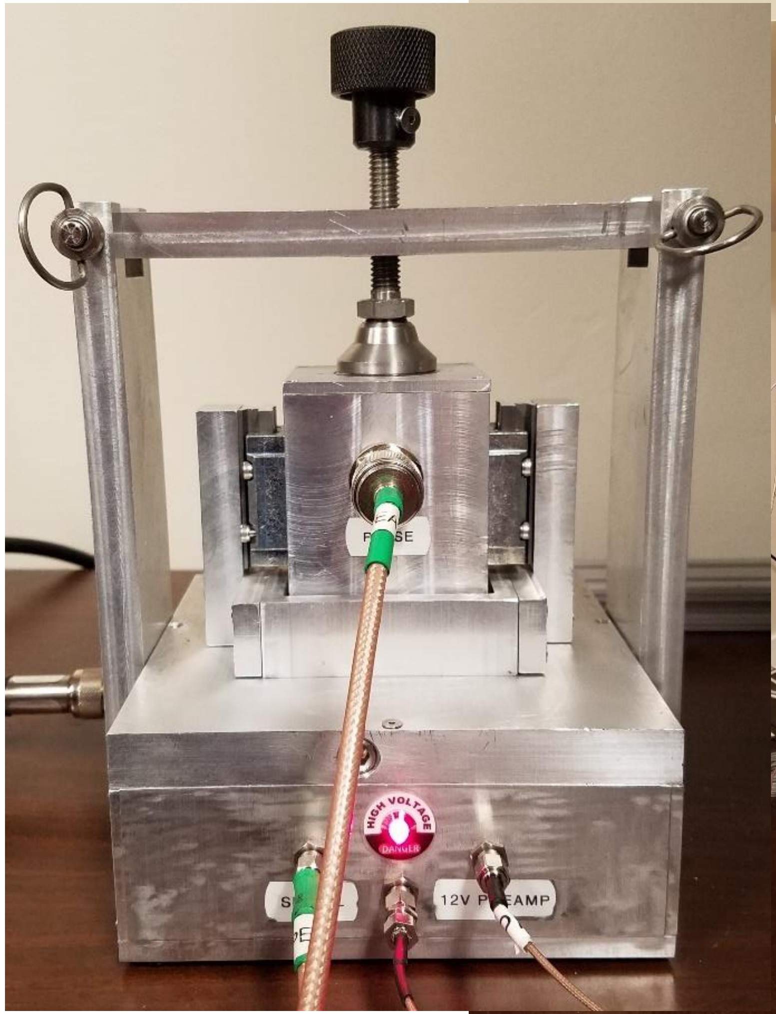
Charge Dissipation of Charged LDPE

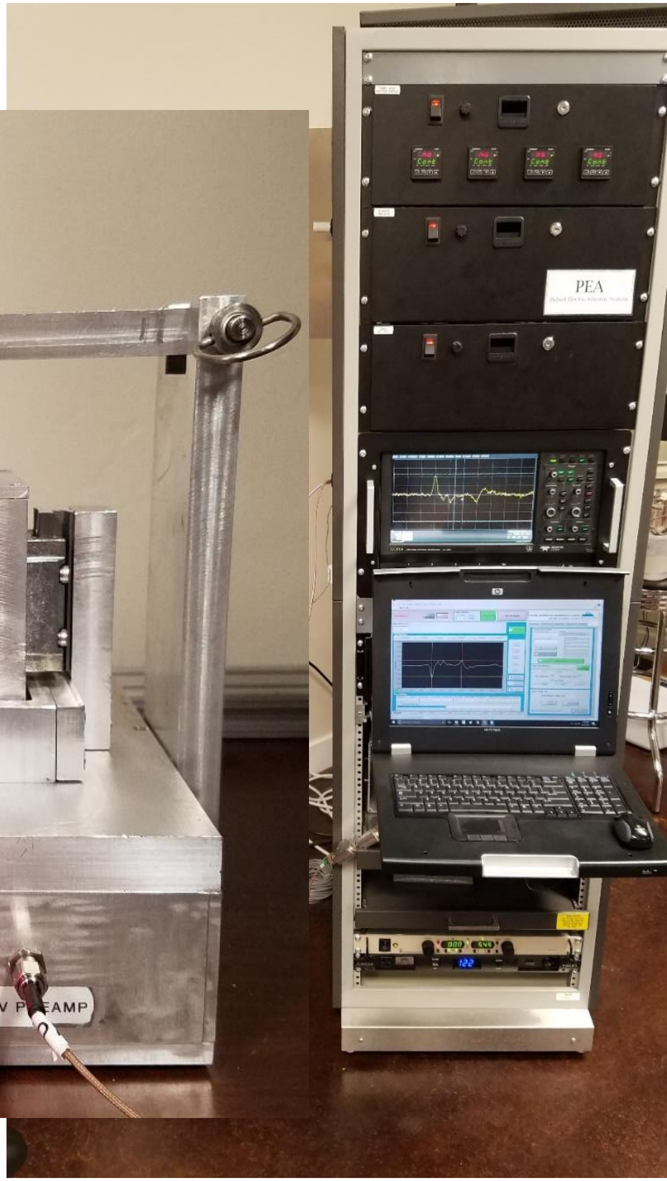


Resistivity and Decay Time of Common Spacecraft Materials			
Material	Resistivity (Ω·cm)	Thickness (μm)	Decay Times (s)
LDPE (ambient)	10^{15}	125	~200 (minutes)
LDPE (baked out)	10^{18}	125	~2x10^{5} (days)
Kapton	10^{19}	125	~5x10^{6} (month)
Teflon	10^{20}	125	~5x10^{7} (year)

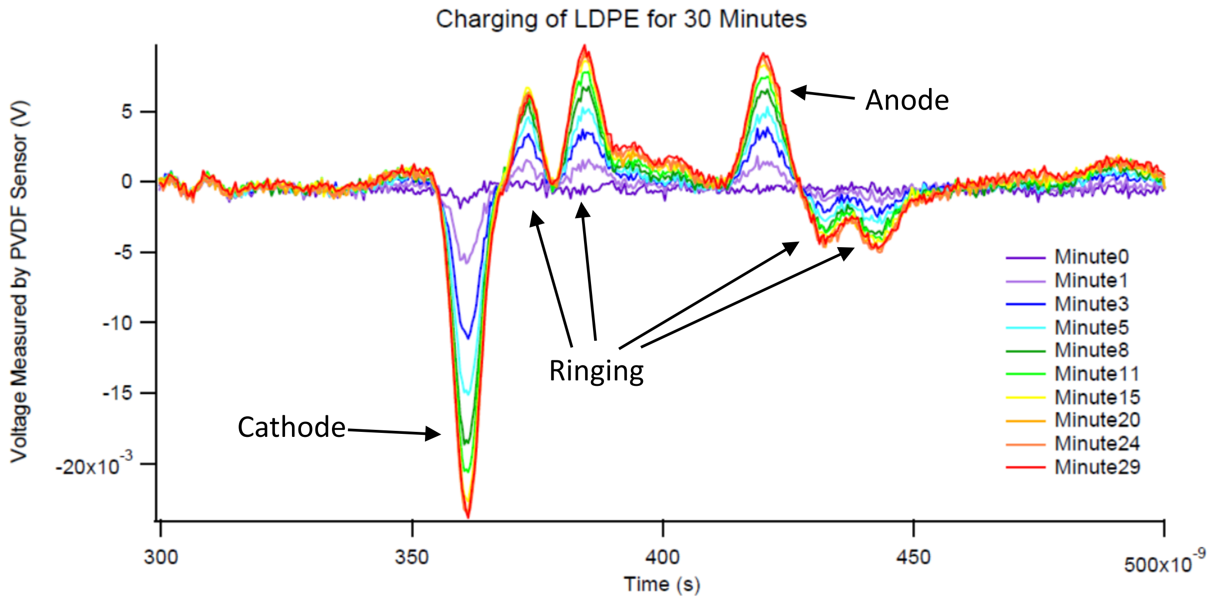
Measurements: Set-Up

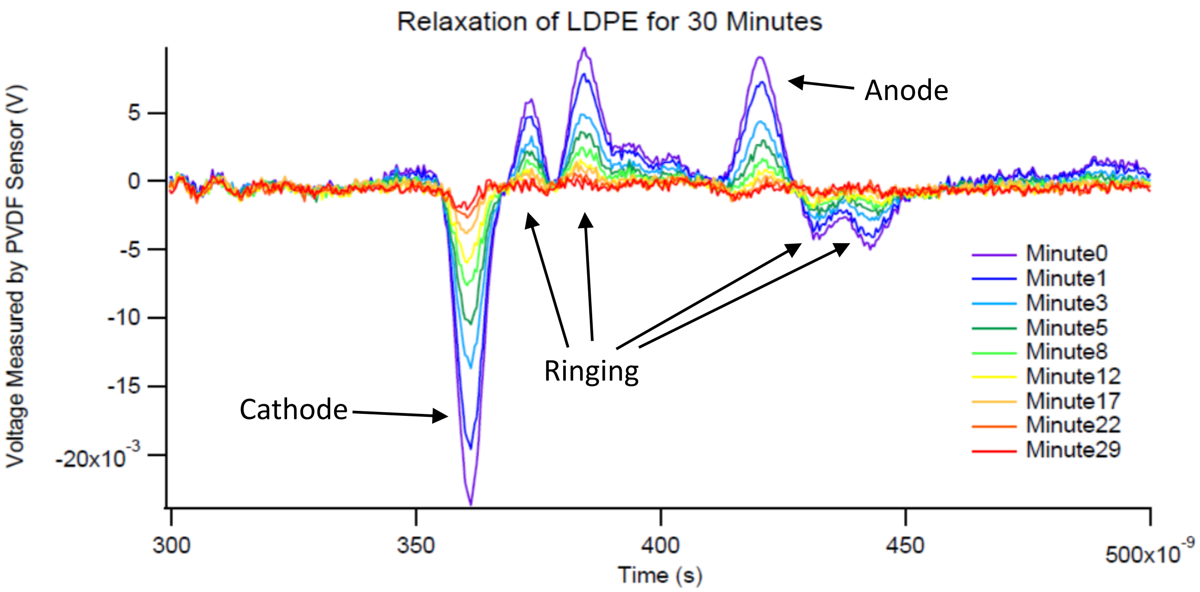
- Sample is 4 mil (100 µm) thick LDPE
- Measured charging at ~40 kV/mm with an applied DC voltage of 4.4 kV for 30 minutes
- Measured discharging/relaxation for 30 minutes at 0 V applied voltage
- Reference voltage for pulsed electro acoustic measurement was ~800 V
- 100 MHz
- Silicone Oil used for acoustic coupling for sensor-electrode, and electrode-sample interfaces



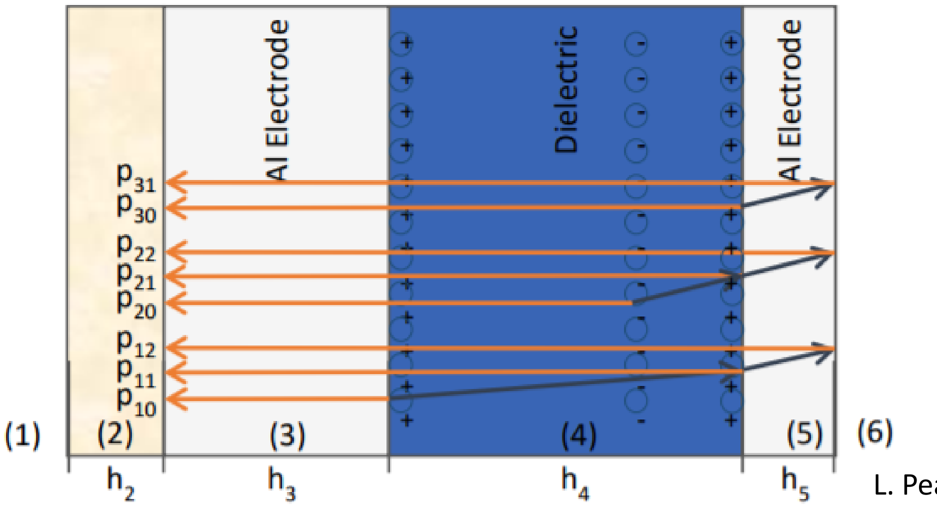


Measurements: Raw Data





- At first pass it looks to be charging up
- Ringing is due to multiple reflections within the materials as shown to the right



L. Pearson (2016)

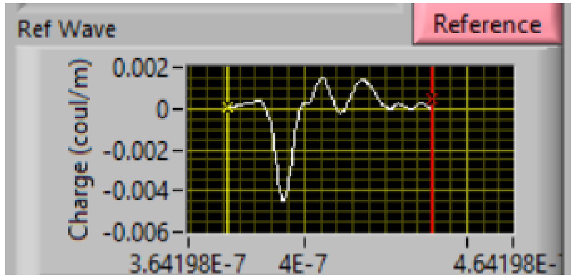
Measurements: Signal Processing

Still in progress

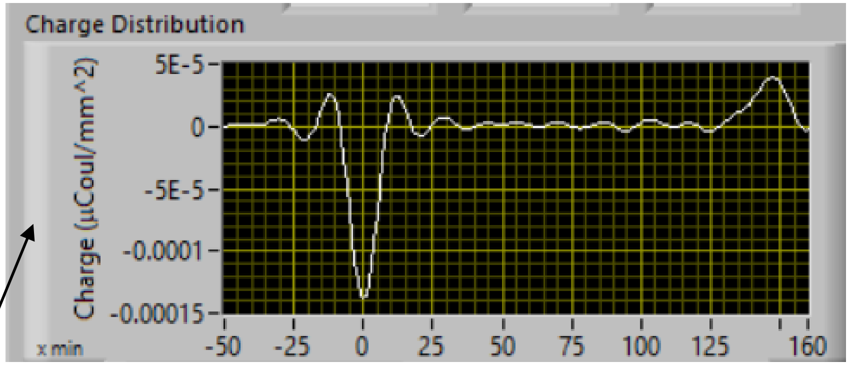
Example of Signal Processing:

- Remove DC offset
- Apply bandpass filter
- Deconvolve waveform using response of charge on front electrode to remove “ringing”

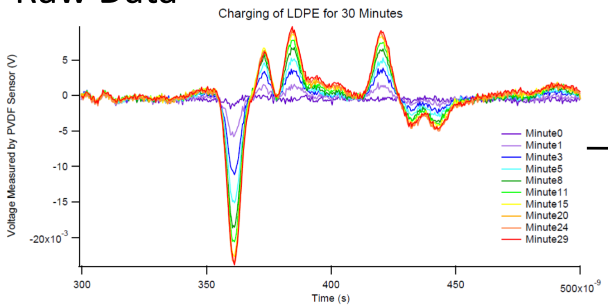
Reference for deconvolution



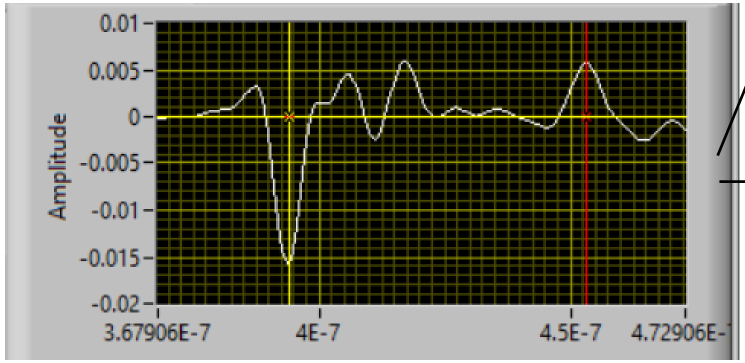
Deconvolution: Beginning of charging



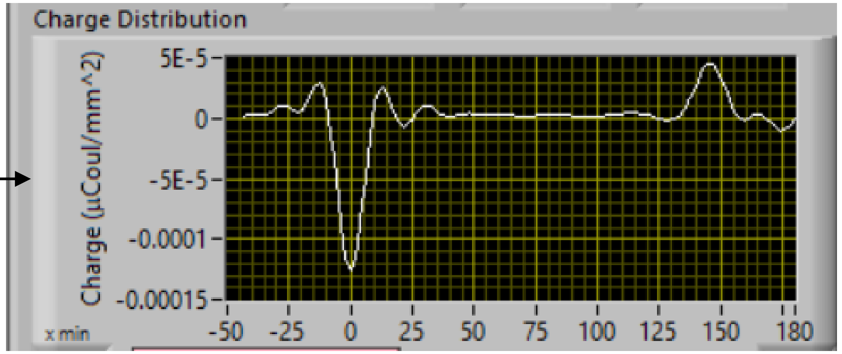
Raw Data



Remove DC +Bandpass filter



Deconvolution: End of charging



Conclusions

- Our system works ... perhaps
- Raw data *seem* to corroborate previous studies
- Signal processed data seems to imply little to no charging in the bulk of the material
- More work is needed

Future Work

- Better measurements
- Improve data-analysis
- Improve spatial resolution of ambient system to limit
- Develop in-situ system with resolution of ~1 µm
- Measure charging, transit, decay times and rates for many dielectrics and highly disordered materials in different environments by varying temperature, irradiation, applied voltage, etc.

Questions?

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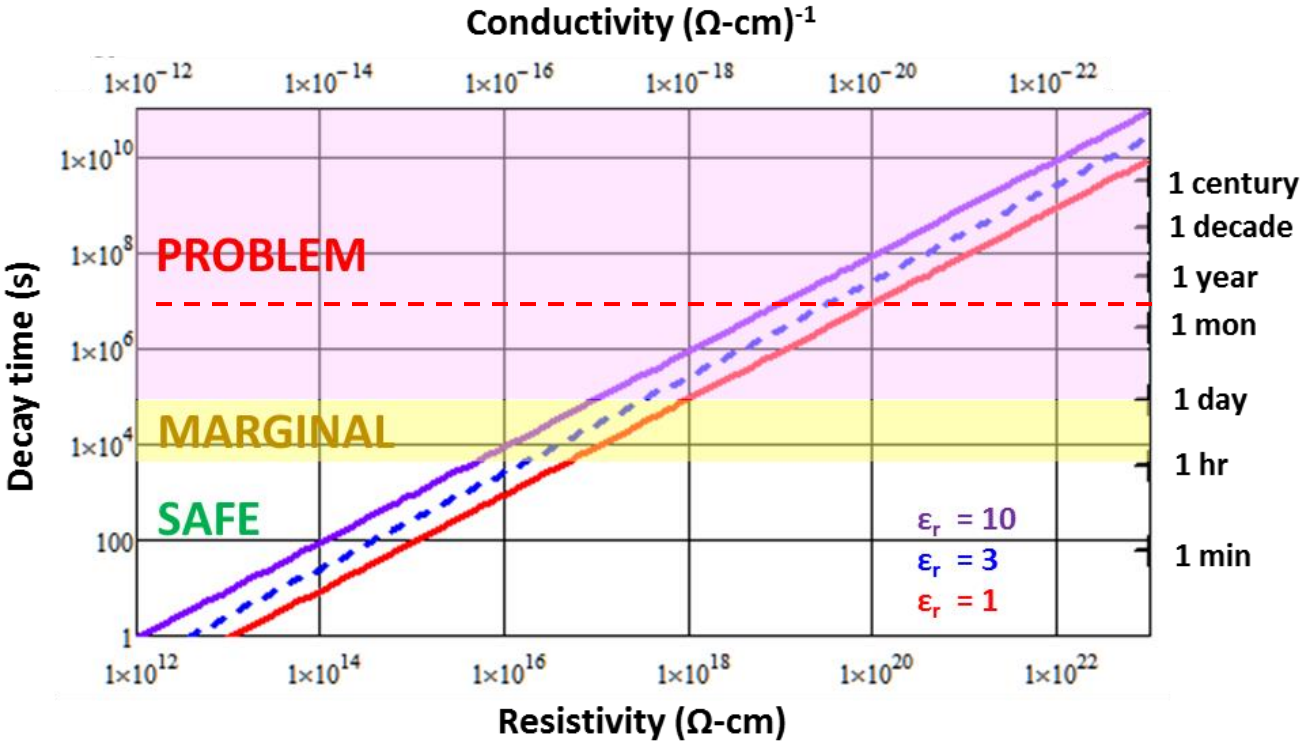
Decay Time Based on Resistivity



Corresponding Decay Times (ε=1)

ρ ~1•10^{23} Ω-cm → 500 yr

ρ ~5•10^{21} Ω-cm → 15 yr

ρ ~4•10^{20} Ω-cm → 1 yr

ρ ~1•10^{18} Ω-cm → 1 day

ρ ~4•10^{16} Ω-cm → 1 hr

ρ ~1•10^{15} Ω-cm → 1 min

Decay time vs. resistivity base on simple capacitor model.

$$\tau = \rho \, \varepsilon_r \, \varepsilon_o$$