Electrostatic Characterization of Lunar Dust Simulants

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Abstract. Lunar dust can jeopardize exploration activities due to its ability to cling to most surfaces. In this paper, we report on our measurements of the electrostatic properties of the lunar soil simulants. Methods have been developed to measure the volume resistivity, dielectric constant, chargeability, and charge decay of lunar soil. While the first two parameters have been measured in the past [Olhoeft 1974], the last two have never been measured directly on the lunar regolith or on any of the Apollo samples.

Measurements of the electrical properties of the lunar samples are being performed in an attempt to answer important problems that must be solved for the development of an effective dust mitigation technology, namely, how much charge can accumulate on the dust and how long does the charge remain on surfaces. The measurements will help develop coatings that are compatible with the intrinsic electrostatic properties of the lunar regolith.

Olhoeft, G.R., A.L. Frisillo, and D.W. Strangway, "Electrical Properties of Lunar Soil Sample 15301,38," *Journal of Geophysical Research*, 79 (11): p. 1599-1604 (1974).

Kennedy Space Center

Electrostatics and Surface Physics Laboratory

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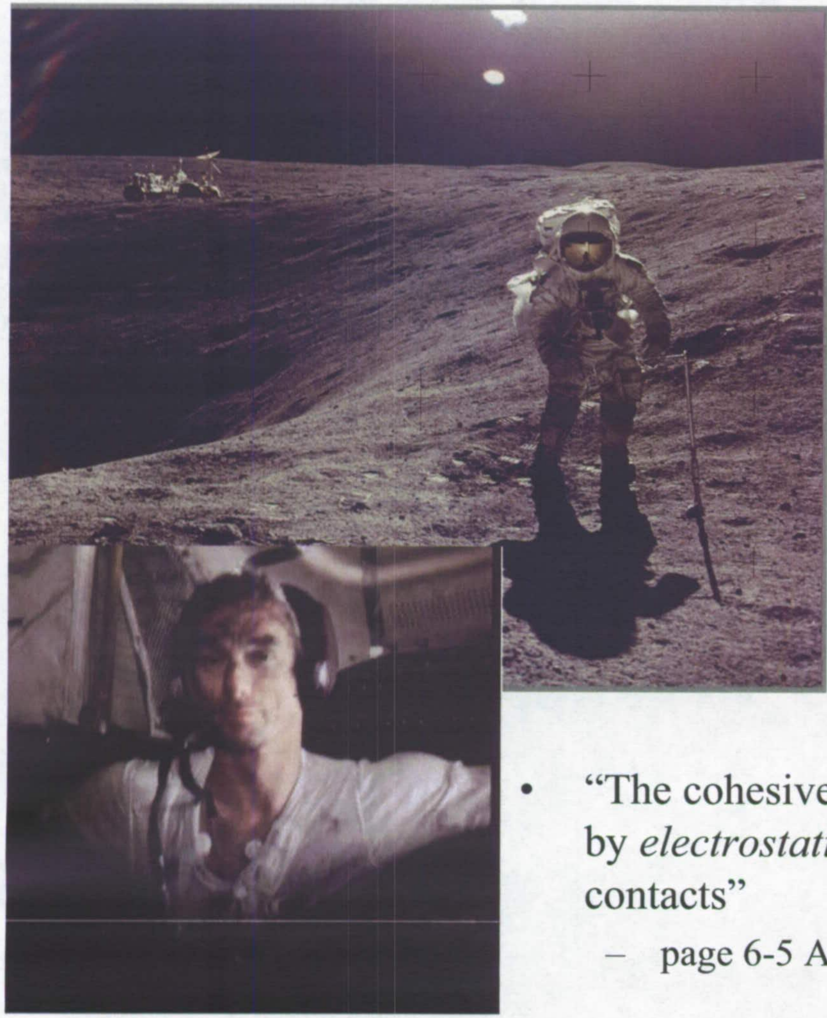
- “Dust is going to be *the* environmental problem for future missions, both inside and outside the habitats”
  - Harrison H. “Jack” Schmitt, geologist and Apollo 17 astronaut
- “Dust is going to be the number one concern in returning to the moon”
  - John Young, Apollo 16 astronaut



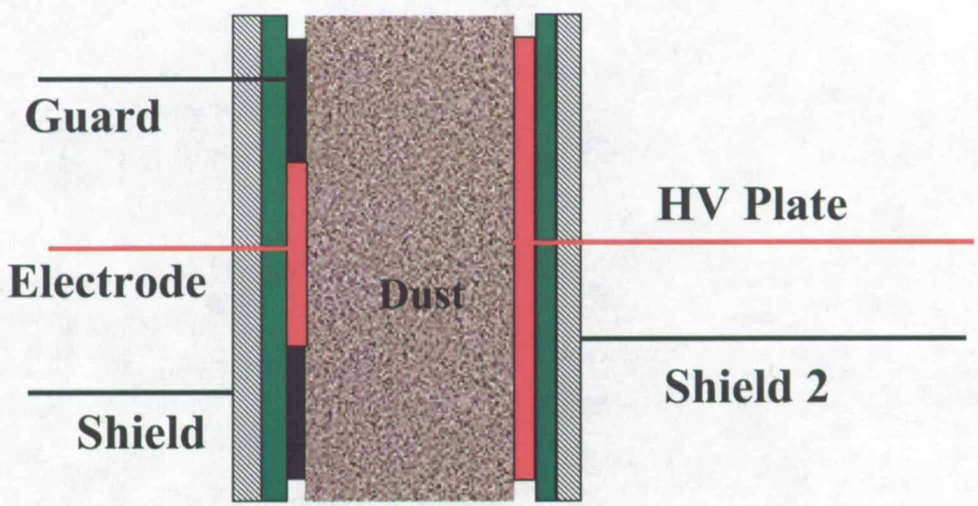
- NASA also stated that the two most important measurements before returning astronauts to the moon is the classification of the toxicity of the dust and its electrostatic properties
- Due to the dry surface of the Moon, the Electrostatic Force is probably the most dominating of all the four known forces of dust adhesion: Van der Waals, capillary forces, mechanical forces and electrostatic forces.
- “The cohesive properties of lunar dust in a vacuum, augmented by *electrostatic properties*, tend to make it adhere to anything it contacts”
  - page 6-5 Apollo 12 Mission Report

The purpose of this research is to generate a simple method to characterize the bulk electrostatic properties of lunar dust *in-situ* since the seals of all of the sample return containers were compromised.

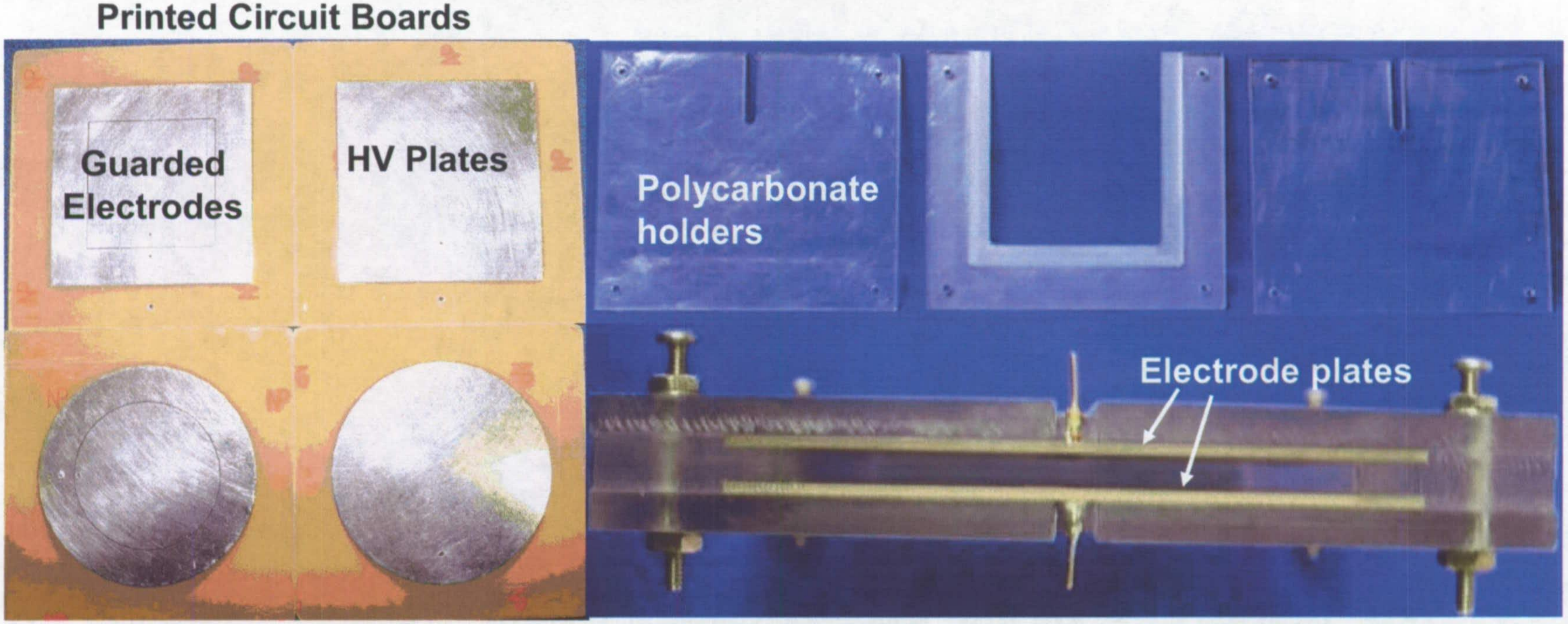
The electrostatic properties of interest include:

- Chargeability – charge-to-mass ratio of the dust (has not been tested)
- Volume Resistivity – Has been tested extensively: $>10^{12}\ \Omega m$
- Charge Decay – Has not been tested
- Dielectric Constant / Permittivity – Tested extensively
- Triboelectric Properties – Not been tested

- A prototype test cell was built and tested which has the following advantageous features:
  - Capable of measuring <u>all</u> of the bulk electrostatic properties.
  - Complies with national (ASTM Standard D 150) and international (BS 5958) test standards.

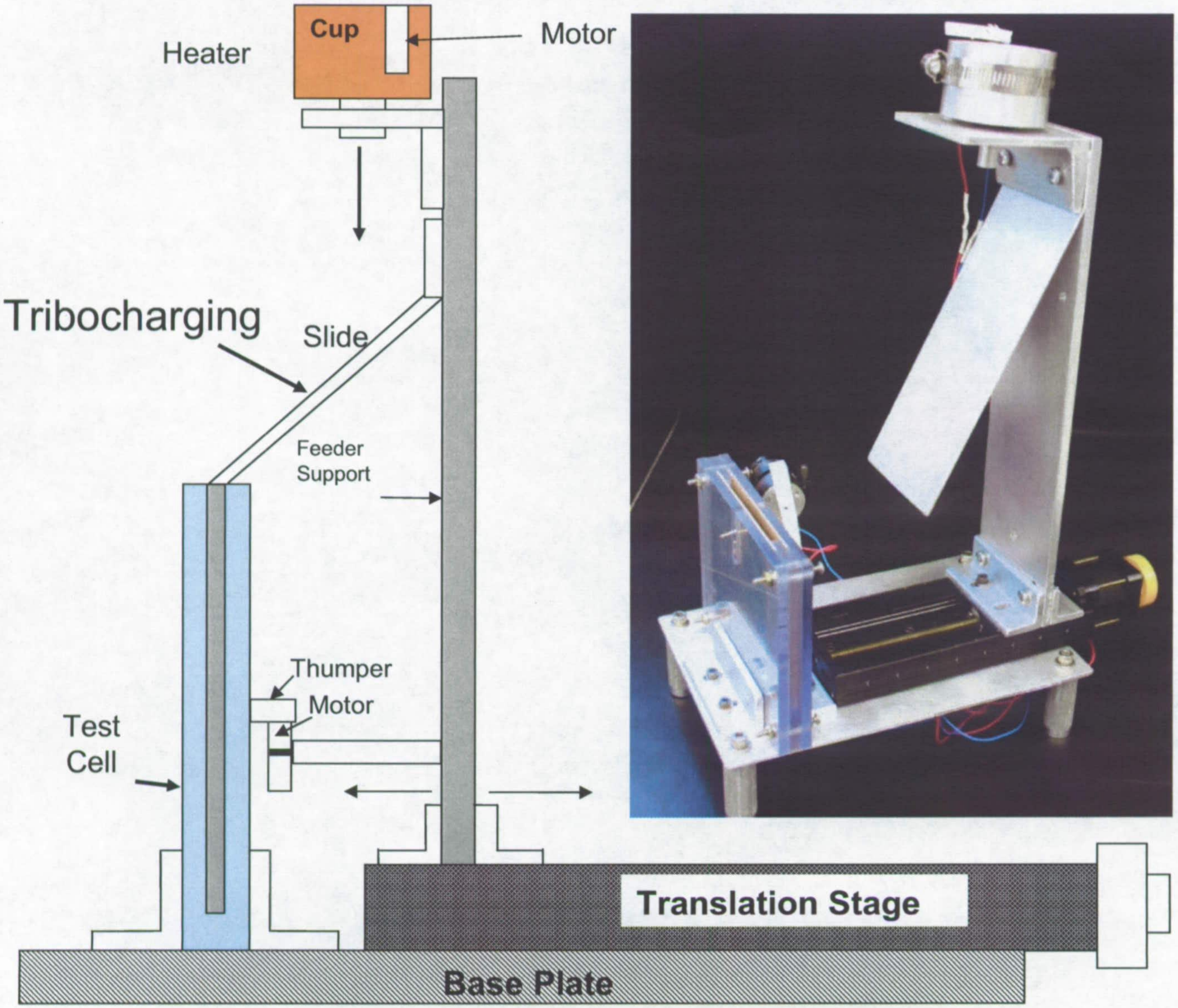


Prototype Test Cells



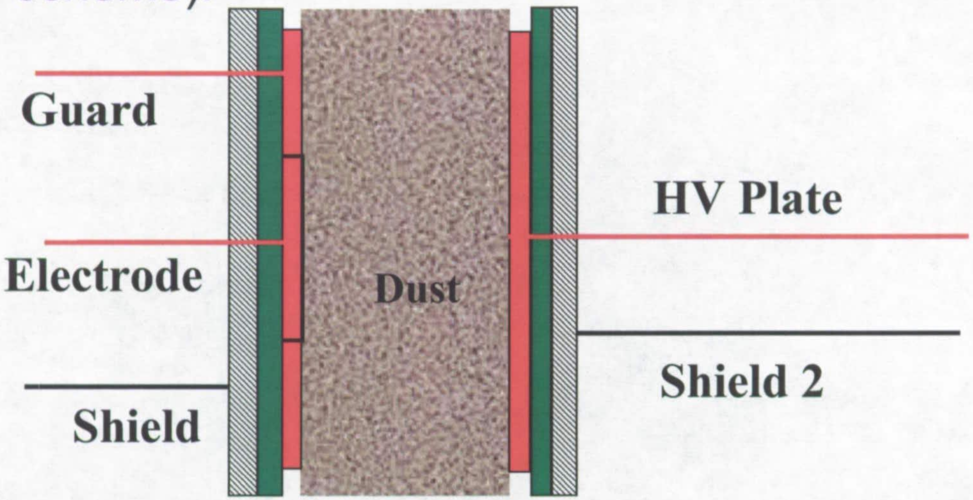
- Test cell dimensions :
  - Spacing between electrodes 5 mm (BS 5958)
  - Area of electrodes = 19.635 cm^2 (BS 5958)
  - Test specimen and guard extend to at least twice the distance of the gap so edge effects are minimal (ASTM D150)
  - Test cell possess dielectric strength > 5000V (polycarbonate housing)

Loaded the cell with 50-75 micron MLS-1



Chargeability and Triboelectric Measurements

As MLS-1 lunar simulant enters the test cell, measurements of the total charge can be performed by connecting the guard with the electrode and HV plate which are monitored with a nanocoulomb meter (feedback electrometer scheme).



BS 5958

Operation	Mass charge density (charge-to-mass ratio) μC/kg
Sieving	10^{-3} to 10^{-5}
Pouring	10^{-1} to 10^{-3}
Scroll feed transfer	1 to 10^{-2}
Grinding	1 to 10^{-1}
Micronizing (3 μC/kg with MLS-1)	10^{2} to 10^{-1}
Pneumatic conveying	10^{3} to 10^{-1}

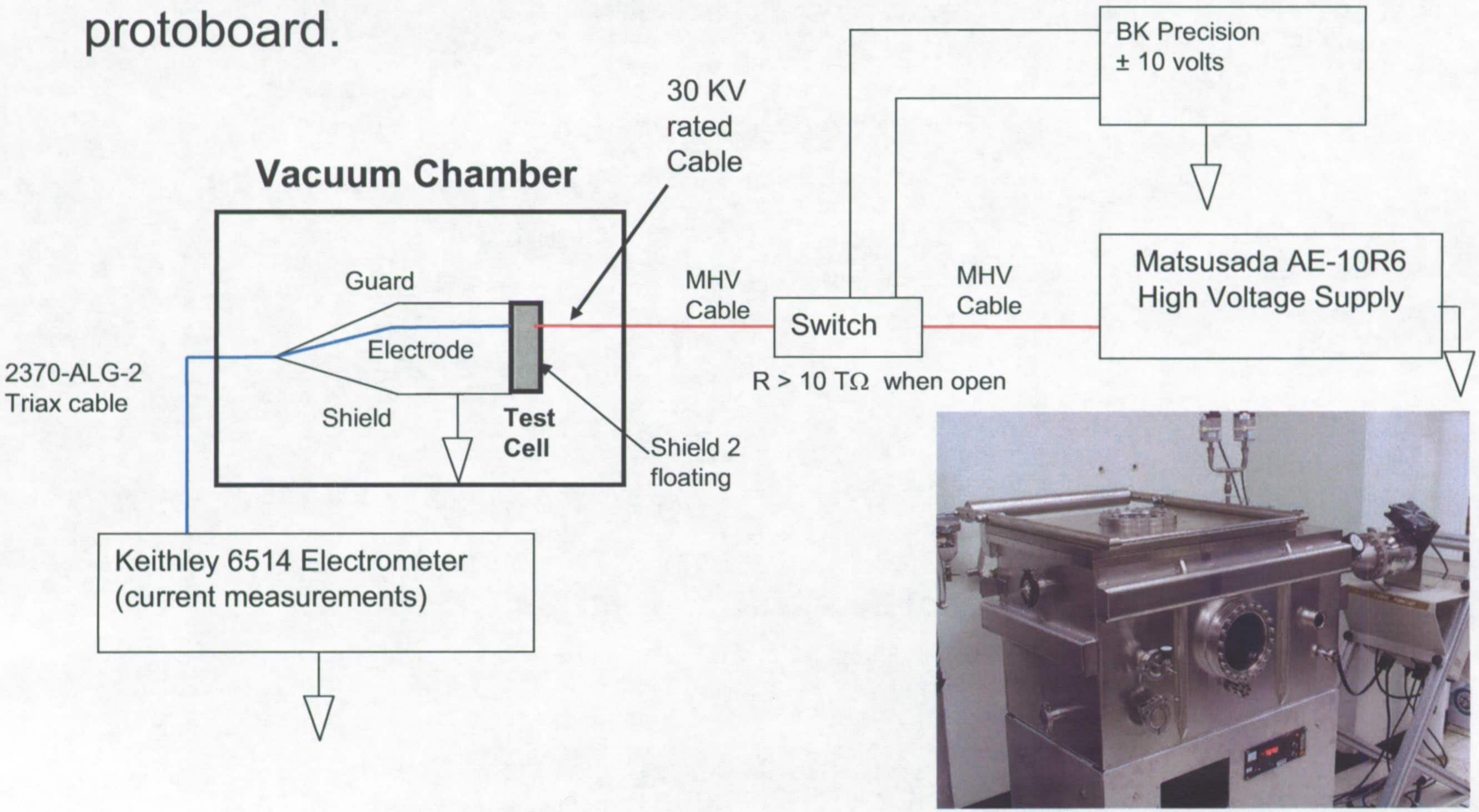
Permittivity Measurements

After MLS-1 lunar simulant filled the test cell, measurements of the frequency dependent permittivity and the dissipation factor were taken using a QuadTech LCR Digibridge Model 1730. (Guard rings and shield were grounded per ASTM D 150).

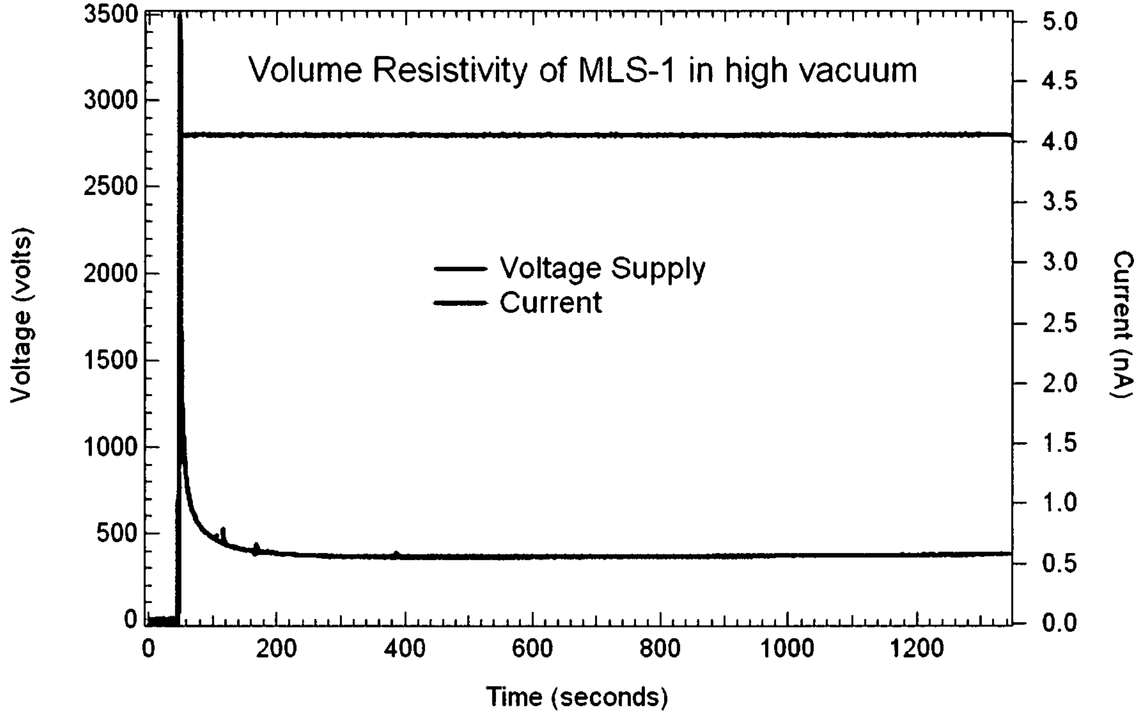
	Empty Cell Square Electrodes		MLS-1 Square Electrodes		
Frequency (Hz)	**Capacitance (pF)**	**Tan δ**	**Capacitance (pF)**	**Tan δ**	**Dielectric Constant**
50	3.9	0	17.8	0.045	4.56
60	3.9	0	17.8	0.045	4.56
100	3.8	0	17.6	0.045	4.63
120	3.9	0	17.6	0.045	4.51
1000	3.92	0	17.02	0.0213	4.34
10,000	3.93	0	16.66	0.0141	4.24
20,000	3.97	0	16.73	0.0145	4.21
40,000	3.94	0	16.51	0.013	4.19
50,000	3.96	0	16.55	0.0127	4.18
100,000	4.074	0.0041	16.94	0.016	4.16
AVERAGE	**3.9294**	**0.00041**	**17.121**	**0.02716**	**4.36**

Volume Resistivity Measurements

- Tests were performed up until breakdown across the soil occurs ~3700 volts.
- Shield 2 was left floating to prevent breakdown across the protoboard.

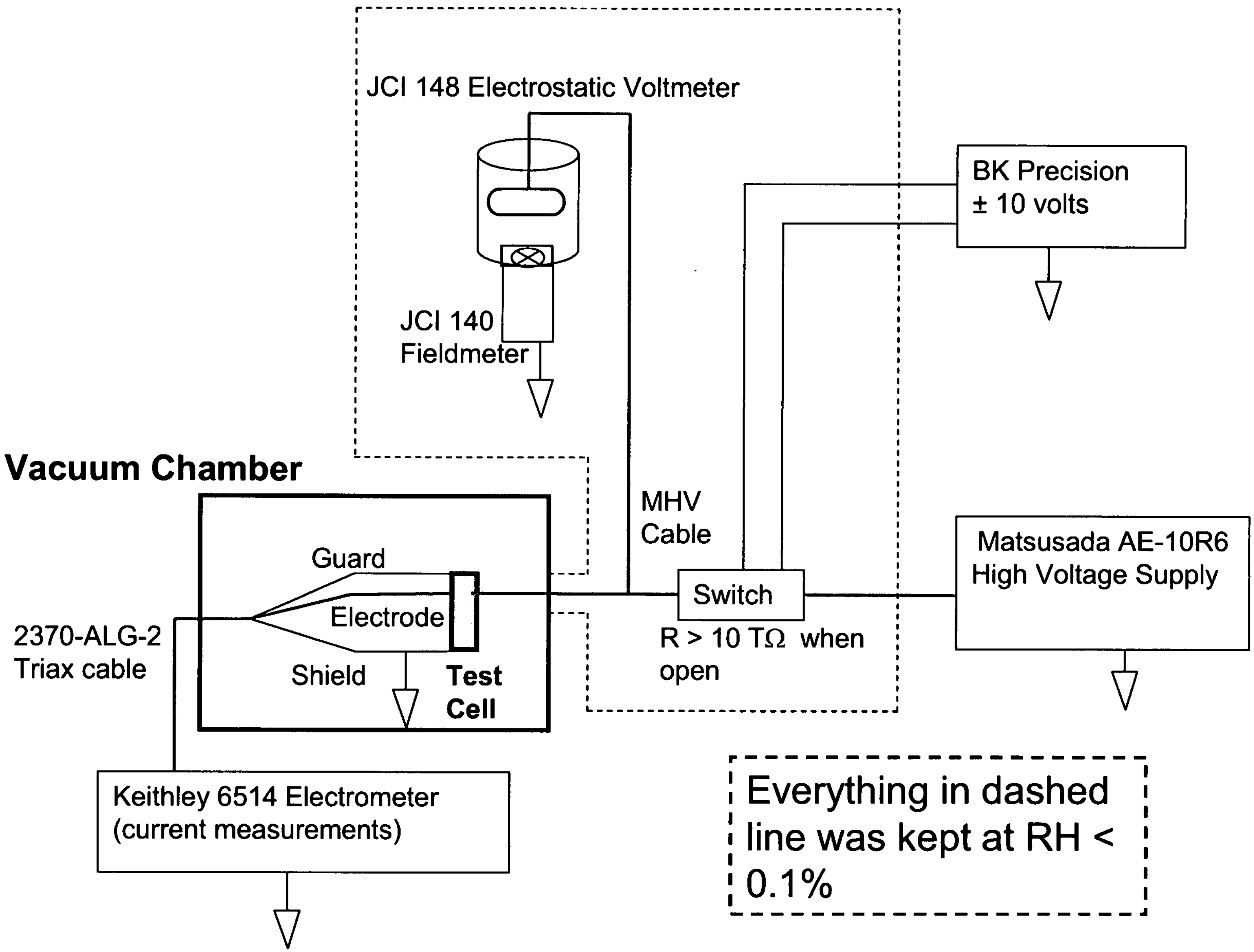


Volume Resistivity Measurements

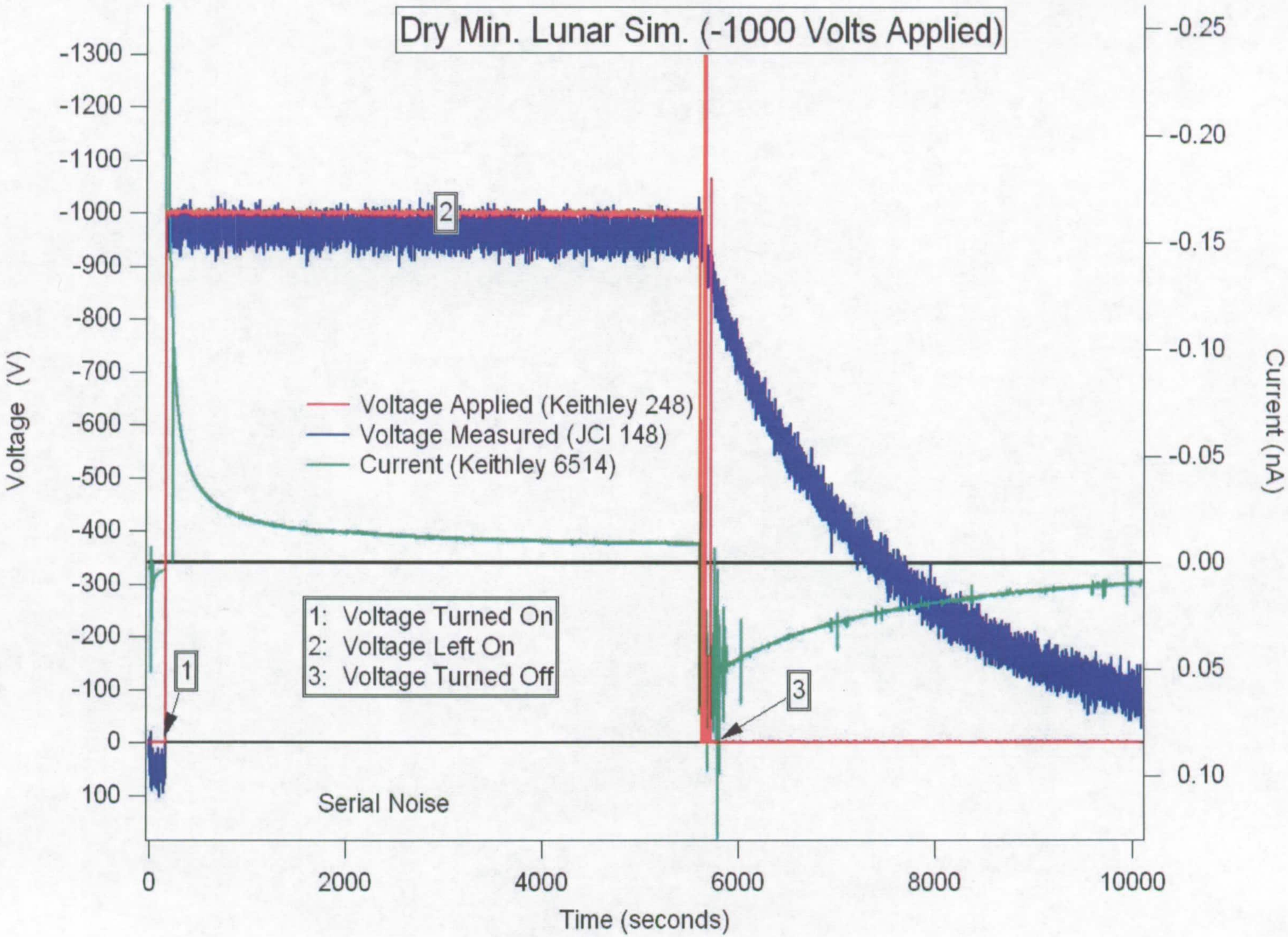


Voltage (v)	Current (A)	Resistance (Ω)	Resistivity (Ωm)
1690	2.10E-10	8.04762E+12	3.15867E+12
2170	4.10E-10	5.29268E+12	2.07737E+12
2810	5.70E-10	4.40351E+12	1.72837E+12
2940	1.10E-09	2.67273E+12	1.04904E+12
3330	1.70E-09	1.95882E+12	7.68834E+11
Average		**4.47507E+12**	**1.75646E+12**

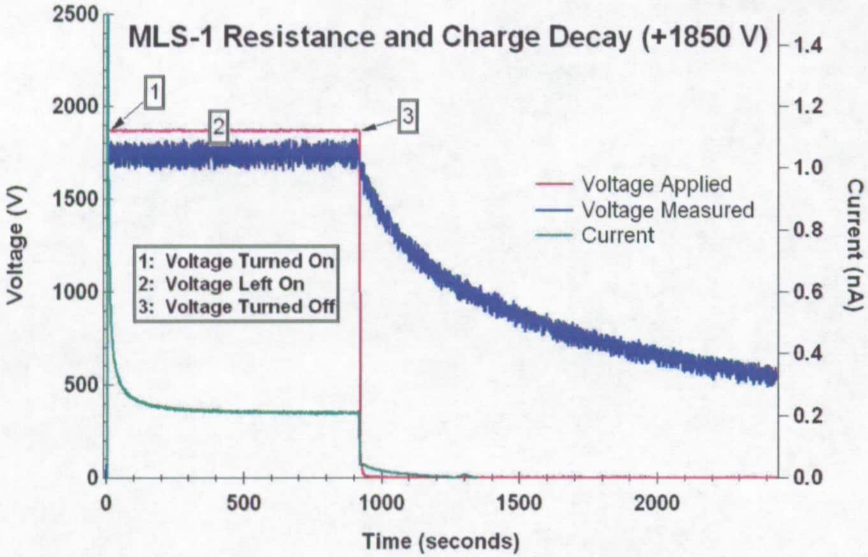
Charge Decay Measurements

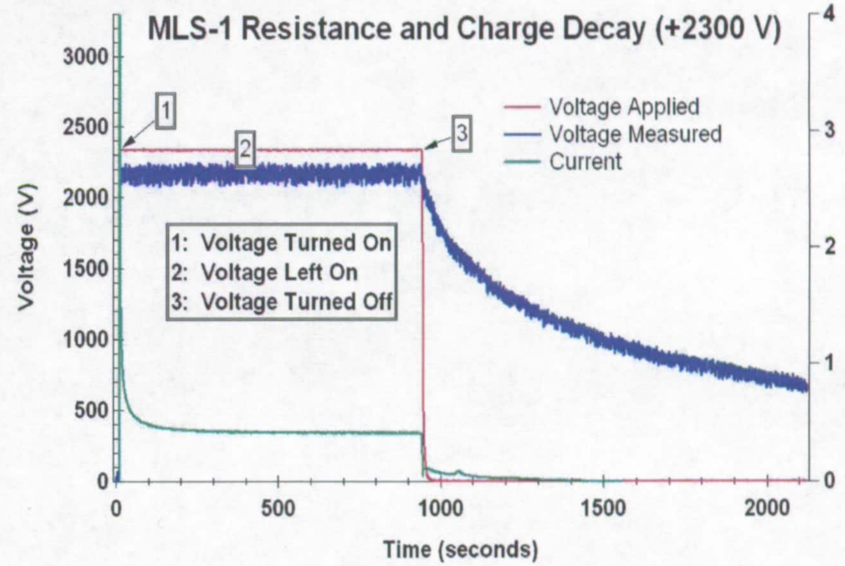


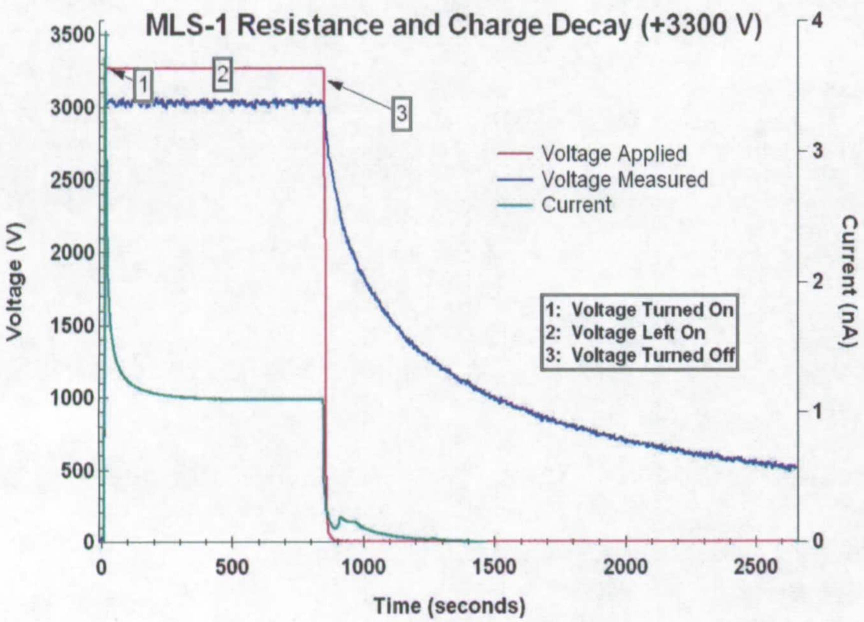
Charge Decay Measurements

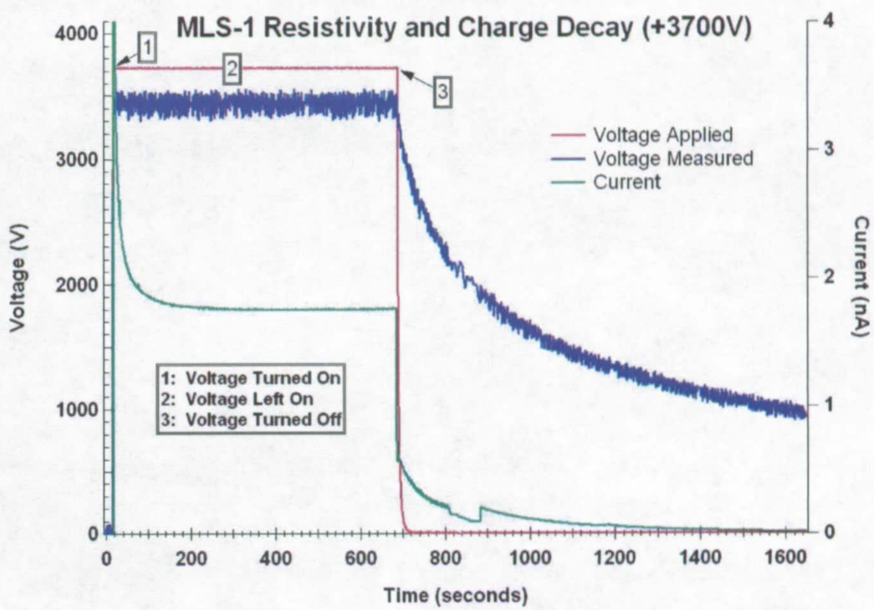


Charge Decay Measurements









Charge Decay Analysis

Exponential Decay: providing information on the conductivity and resistivity.

$$\rho_{Exp}(t) = \rho_{p0} \exp(-t/\tau_m) \qquad \tau_m = \frac{\varepsilon}{\sigma_m} = R_v \varepsilon$$

Hyperbolic Decay: providing information on the charge mobility.

$$\rho_{Hyp}(t) = \frac{\rho_{p0}}{\left(1 + \frac{t}{\tau_p}\right)} \qquad \tau_p = \frac{\varepsilon}{b_p \rho_{p0}}$$

Seaver Analysis: providing information on the conductivity, resistivity and the mobility.

$$\rho_{Seavor}(t) = \frac{\rho_{p0}}{\left(1 + \frac{\tau_m}{\tau_p}\right) \exp\left(t/\tau_m \right) - \frac{\tau_m}{\tau_p}} \qquad \tau_p = \frac{\varepsilon}{b_p \rho_{p0}} \qquad \tau_m = \frac{\varepsilon}{\sigma_m} = R_v \varepsilon$$

Seaver, A.E. *An Equation for Charge Decay Valid in Both Conductors and Insulators*. in *Proceedings of the ESA-IEJ Joint Meeting of Electrostatics*. 2002. University of Arkansas at Little Rock.

Charge Decay Results

	Seaver Analysis					
Voltage (V)	τ_m (sec)	τ_p (sec)	ρ_0 (C/m^3)	Resistivity (Ωm)	Conductivity (S/m)	Mobility (m^2/Vs)
500	1.92E+04	2.98E+03	1.06E-03	8.30E+14	1.20E-15	7.28E-12
600	3.56E+03	2.37E+03	1.28E-03	1.55E+14	6.47E-15	7.64E-12
750	3.43E+04	2.56E+03	1.59E-03	1.49E+15	6.73E-16	5.64E-12
850	7.55E+03	2.84E+03	1.81E-03	3.27E+14	3.06E-15	4.49E-12
1000	1.25E+04	2.16E+03	2.13E-03	5.40E+14	1.85E-15	5.01E-12
1100	3.79E+03	2.76E+03	2.34E-03	1.64E+14	6.08E-15	3.58E-12
1200	1.38E+04	2.29E+03	2.55E-03	5.98E+14	1.67E-15	3.94E-12
1300	6.99E+03	2.18E+03	2.76E-03	3.03E+14	3.30E-15	3.83E-12
1850	6.22E+02	1.67E+01	3.05E-03	1.70E+13	5.89E-14	7.18E-10
2300	4.01E+02	1.88E+02	3.79E-03	1.09E+13	9.14E-14	5.15E-11
3300	4.82E+02	4.73E+01	5.44E-03	1.32E+13	7.59E-14	1.42E-10
3700	2.62E+02	1.02E+02	6.10E-03	7.15E+12	1.40E-13	5.89E-11

Conclusions

- We developed a prototype device that can classify the electrostatic properties of bulk lunar soil *in situ*.
- This device can successfully measure the chargeability, permittivity, volume resistivity, and charge decay characteristics of soils under high vacuum conditions.
- Charge decay measurements can provide additional information including charge mobility, resistivity, conductivity, permittivity and charge density characteristics of soils.
- We will soon begin to test <u>real lunar soil</u> under similar environmental conditions.