Electric Potential and Electric Field Imaging with Applications

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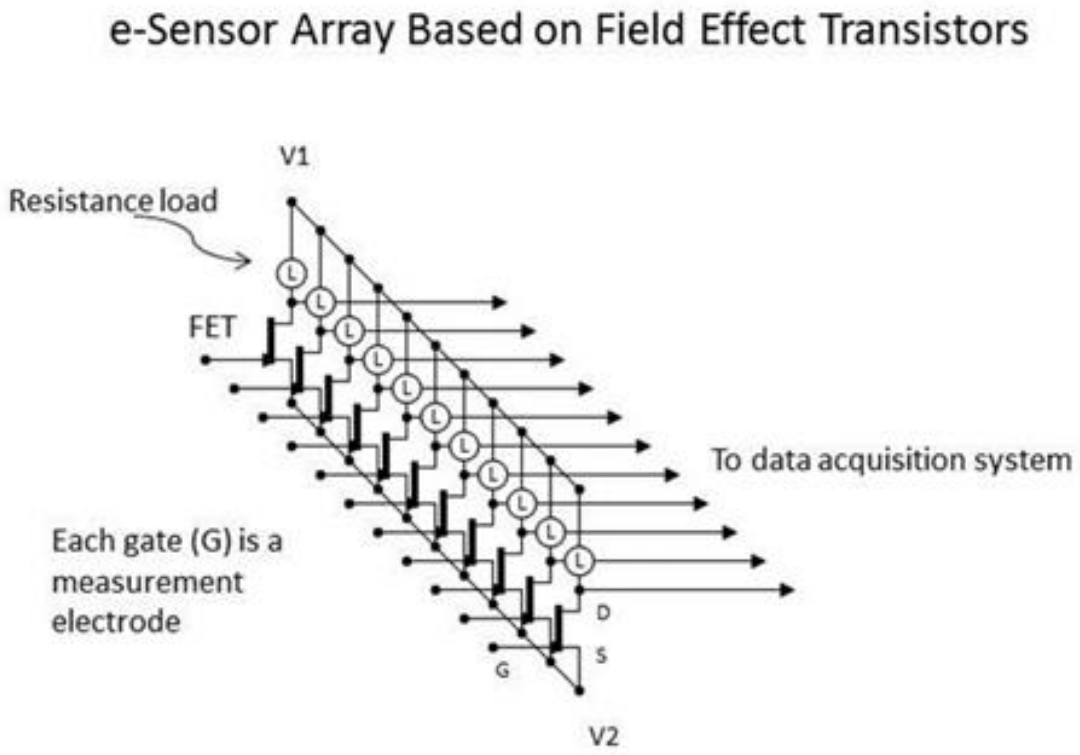
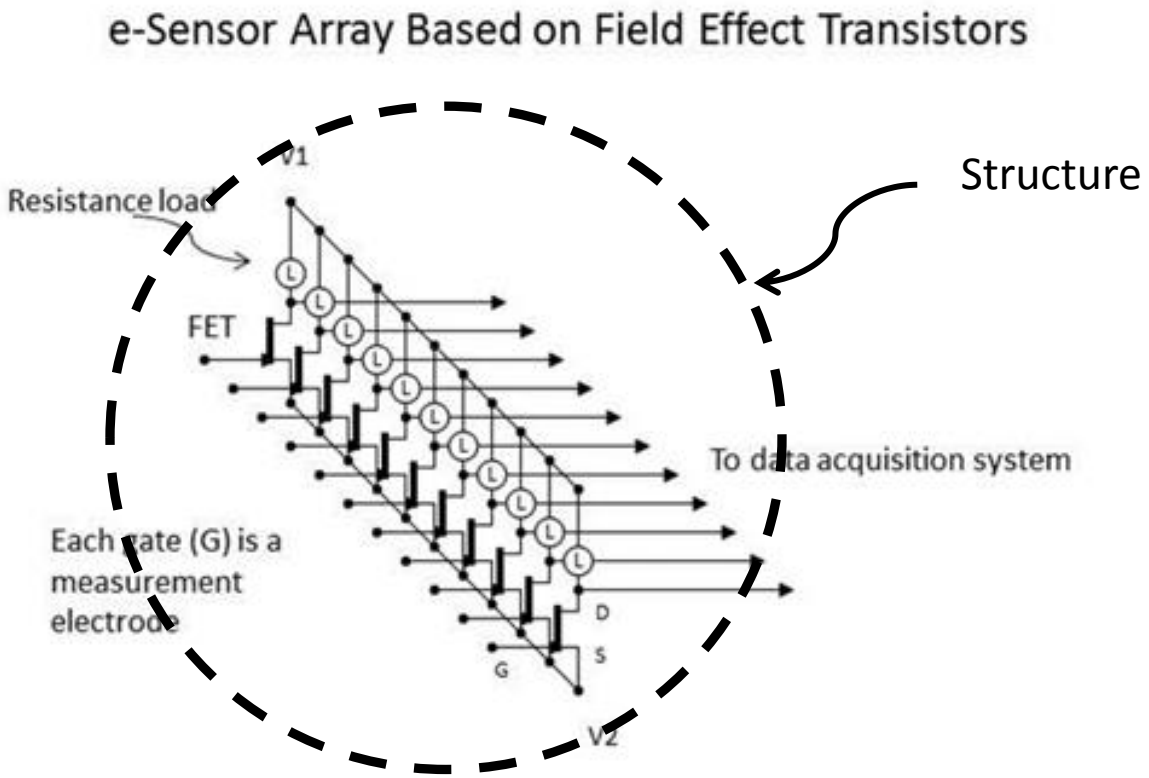
Overview

- Background
- Sensor development & design issues
- Electric field measurement systems
- Application examples

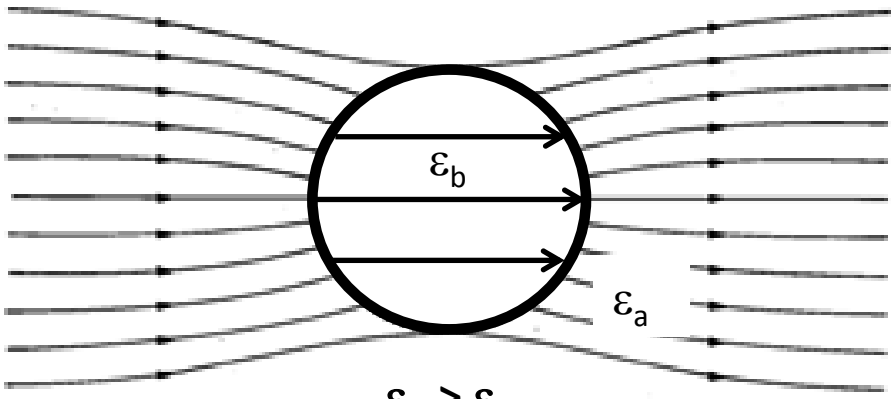
Background

- NDE historically has focused technology development in propagating wave phenomena:
  - X-ray, ultrasonic, microwave, thermal, terahertz, and eddy current
  - Little attention to the field of electrostatics and emanating electric fields.
- Interest in evaluating the integrity of wire insulation in aircraft and aerospace systems
- This work is based on the original electric field sensor (e-Sensor) work disclosed by Generazio (2002).

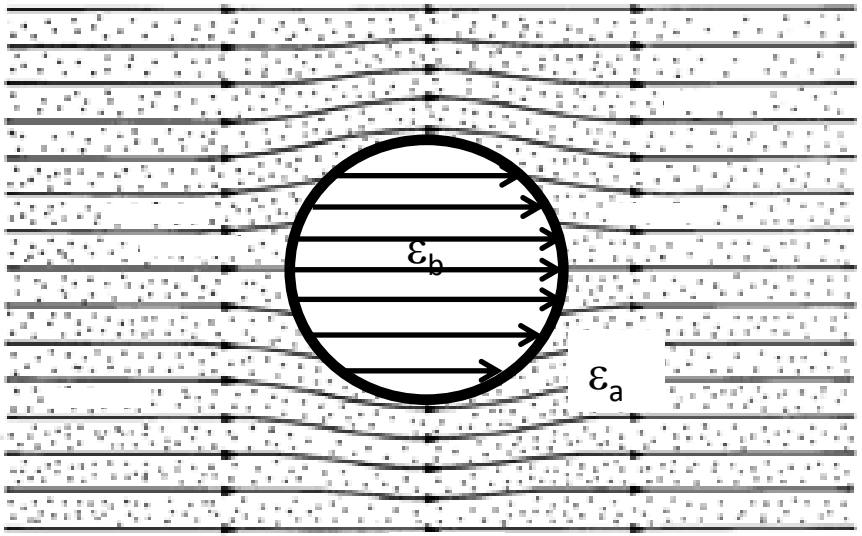

e-Sensor Array Based on Field Effect Transistors
V1
Resistance load
FET
To data acquisition system
Each gate (G) is a measurement electrode
D
S
G
V2



Floating gate design



$\varepsilon_b > \varepsilon_a$

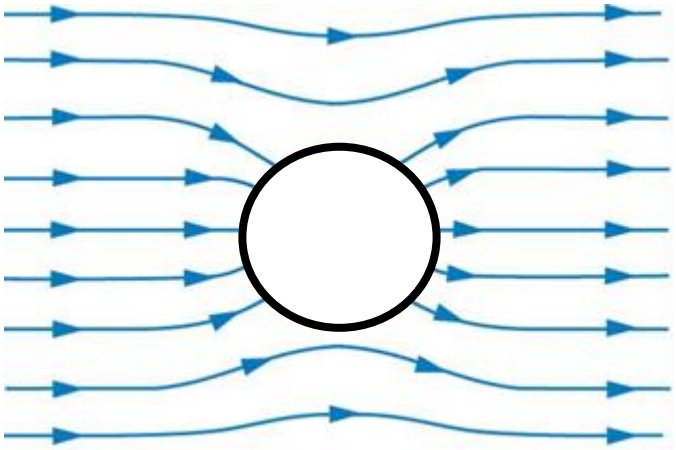


$\varepsilon_b \leq \varepsilon_a$

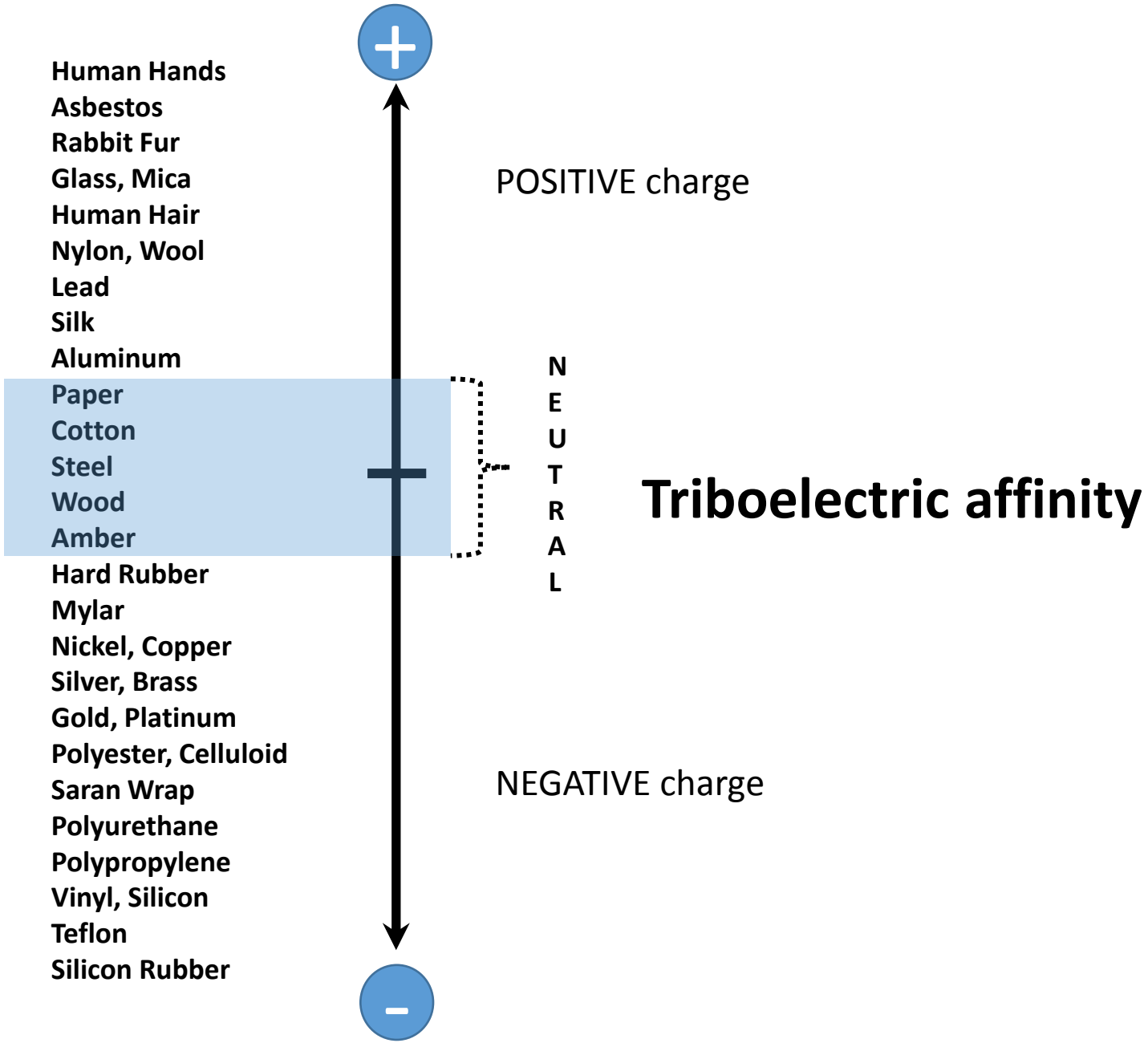
Dielectric constant, relative permittivity, ε

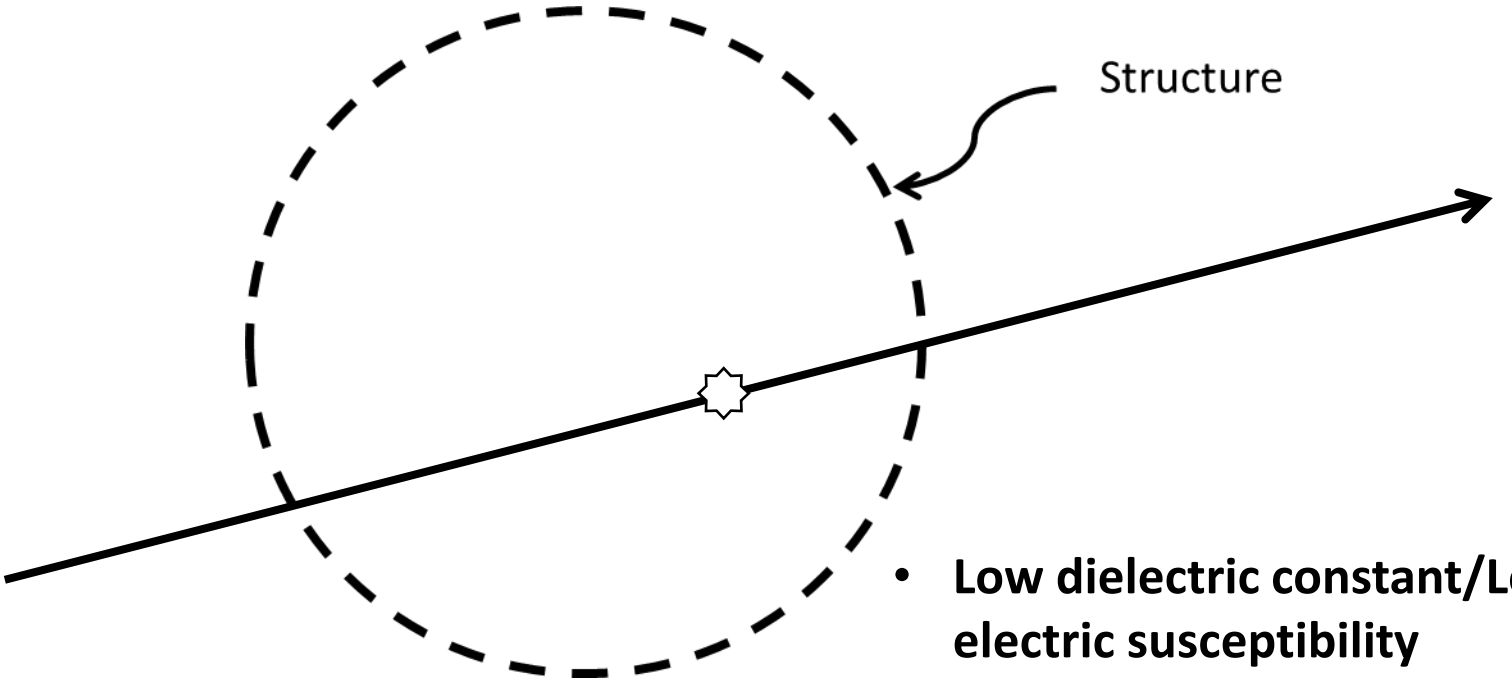
Electric susceptibility, $\chi = 1 - \varepsilon$

$\varepsilon = 1$ vacuum



Conductor


Human Hands
Asbestos
Rabbit Fur
Glass, Mica
Human Hair
Nylon, Wool
Lead
Silk
Aluminum
Paper
Cotton
Steel
Wood
Amber
Hard Rubber
Mylar
Nickel, Copper
Silver, Brass
Gold, Platinum
Polyester, Celluloid
Saran Wrap
Polyurethane
Polypropylene
Vinyl, Silicon
Teflon
Silicon Rubber
+
−
POSITIVE charge
NEUTRAL
NEGATIVE charge
Triboelectric affinity



- **Low dielectric constant/Low electric susceptibility**
- **Non-conductor**
- **Neutral triboelectric affinity**

Catch 22

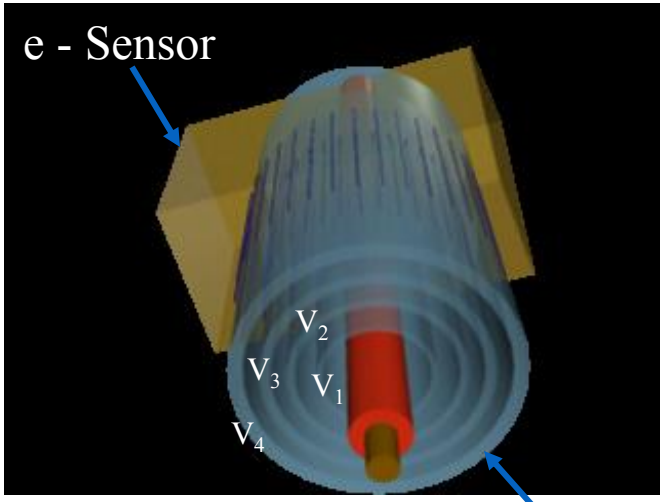
- **Want to select the best materials for constructing an electric field measurement system, however, the actual electrical properties vary or are unknown in configuration to be used.**

- **Insulation on wiring**
- **Wire diameters**
- **Circuit elements**
- **Support materials**

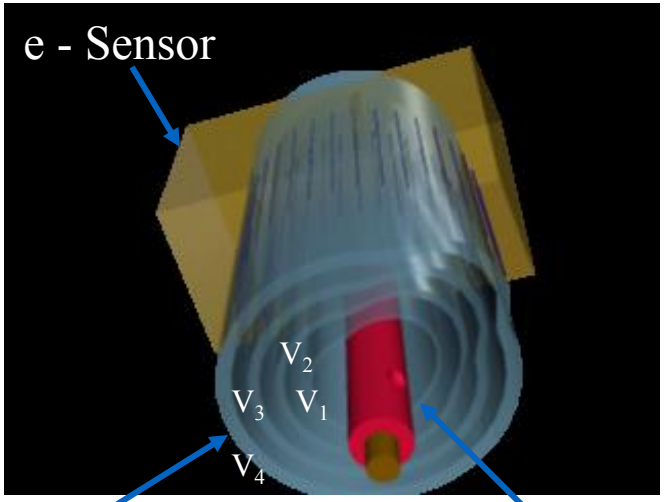
- **Don't know actual electrical properties until tested**

An Example, "e - Sensor" Antenna Configuration for Wiring Inspection

New Insulation



Damaged Insulation



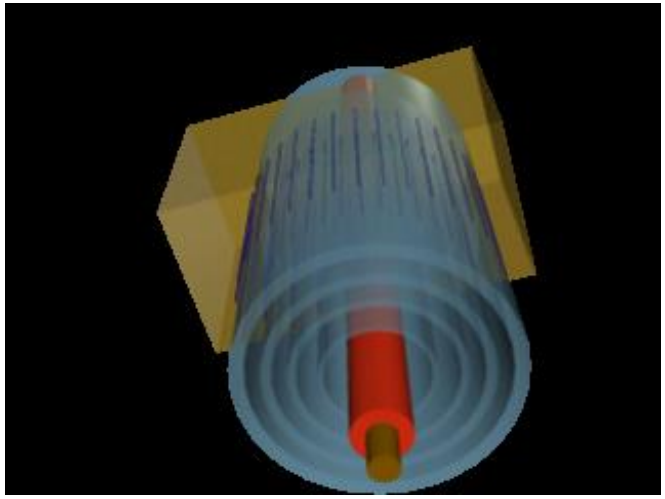
Equipotential surfaces

Damaged insulation

Electrical equipotential surfaces (V_1, V_2, V_3, V_4) are distorted due to damaged or aged insulation. Some antenna elements are no longer parallel to the electrical equipotential surfaces and now are exposed to an increase in potential.

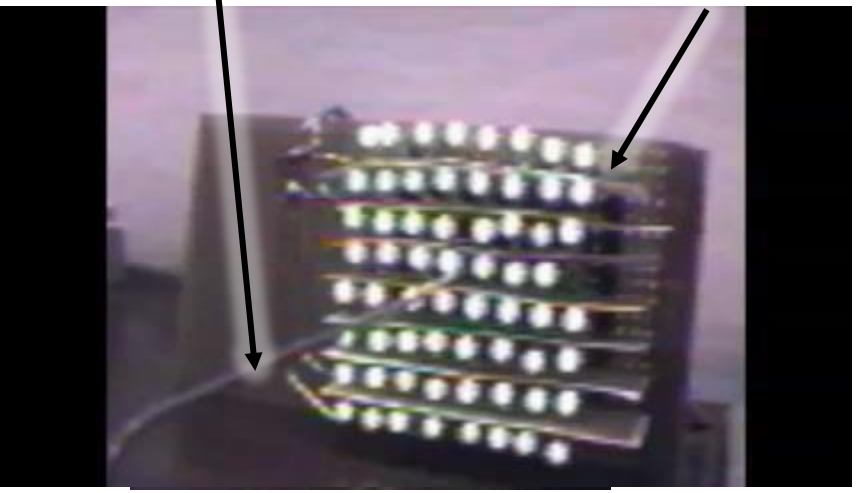
The electric field, **E,** at any point is given by $-\vec{\nabla}V = \vec{E}$, where V is the electrical potential

"e - Sensor" Data from Prototype

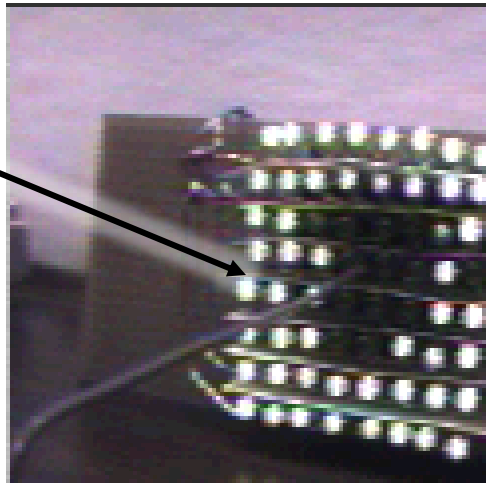


Wire passing through
e - Sensor prototype

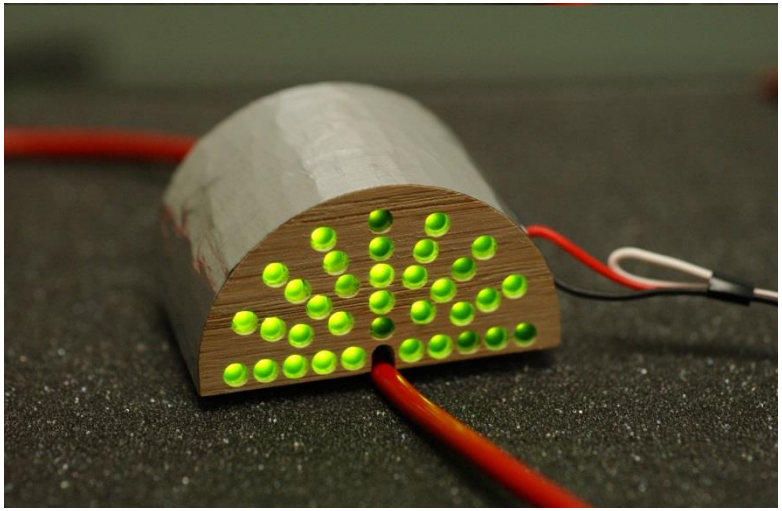
e - Sensor

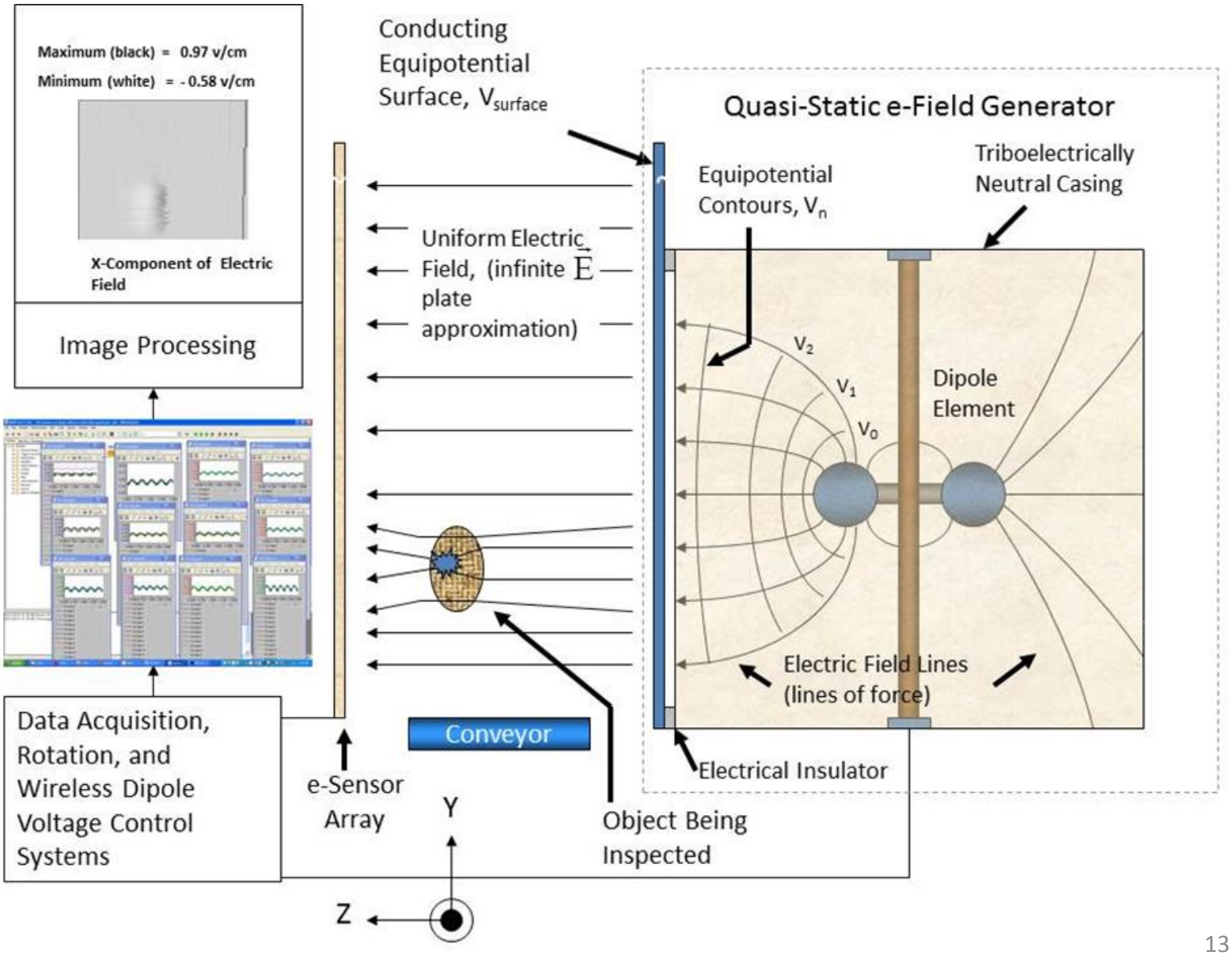


e - Sensor LEDs are dimmed proportionately by the presence of the spatially varying electric potential existing around statically charged insulated wire.

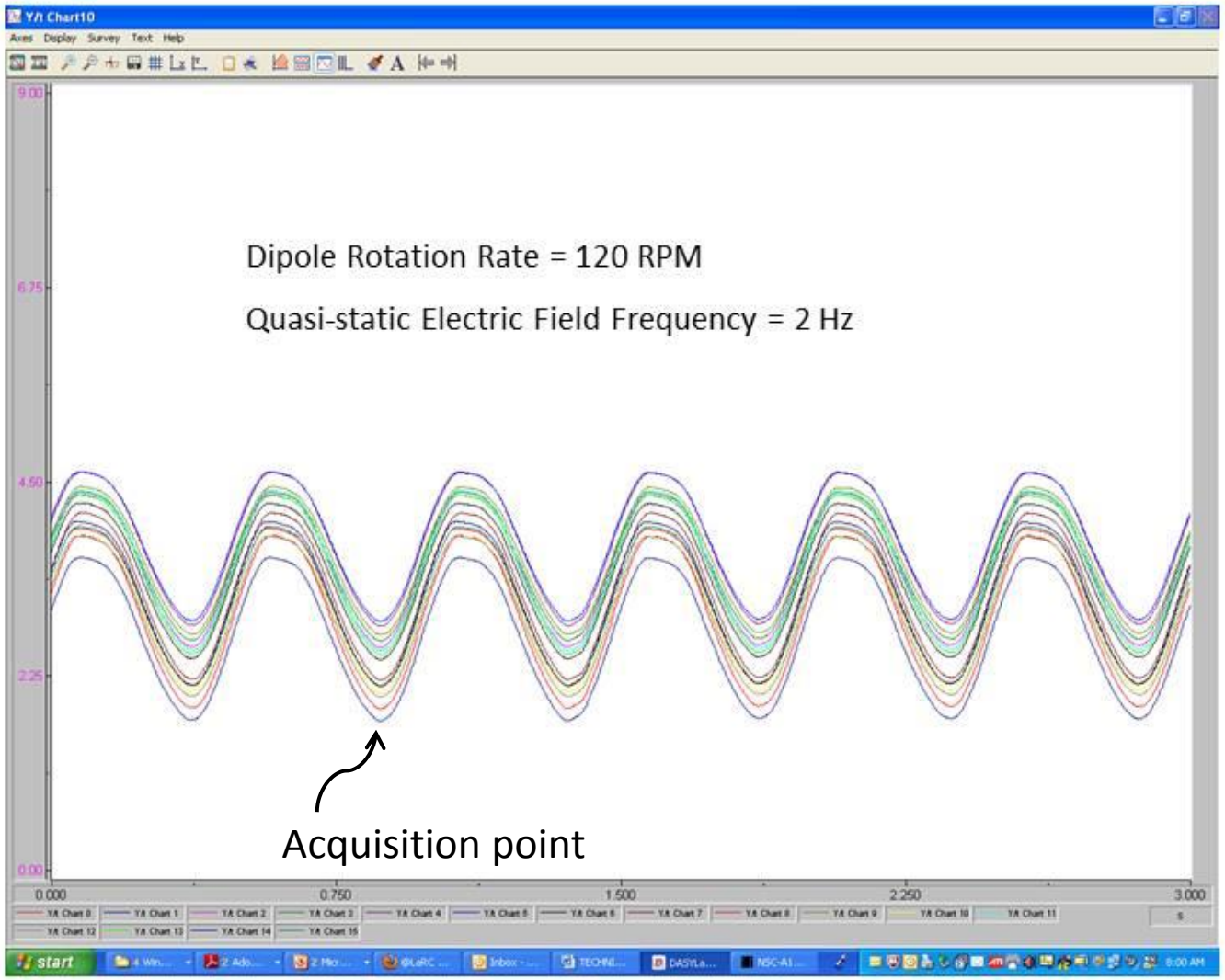


2nd Prototype




Maximum (black) = 0.97 v/cm
Minimum (white) = - 0.58 v/cm
X-Component of Electric Field
Image Processing
Conducting Equipotential Surface, $V_{surface}$
Uniform Electric Field, (infinite plate approximation) $\vec{E}$
Quasi-Static e-Field Generator
Equipotential Contours, V_n
Triboelectrically Neutral Casing
V_2
V_1
V_0
Dipole Element
Electric Field Lines (lines of force)
Electrical Insulator
Data Acquisition, Rotation, and Wireless Dipole Voltage Control Systems
e-Sensor Array
Conveyor
Object Being Inspected
Y
Z

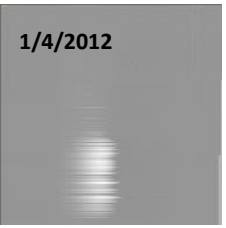
Voltage Response from 16 e-Sensors



Electric Potential and Electric Field Imaging with Applications

Electric Potential Image of Human

Using [Electric Field Imaging (2016) US 9279719 B2](#) & [Quasi-Static Electric Field Generator (2016) US20160049885A1](#)



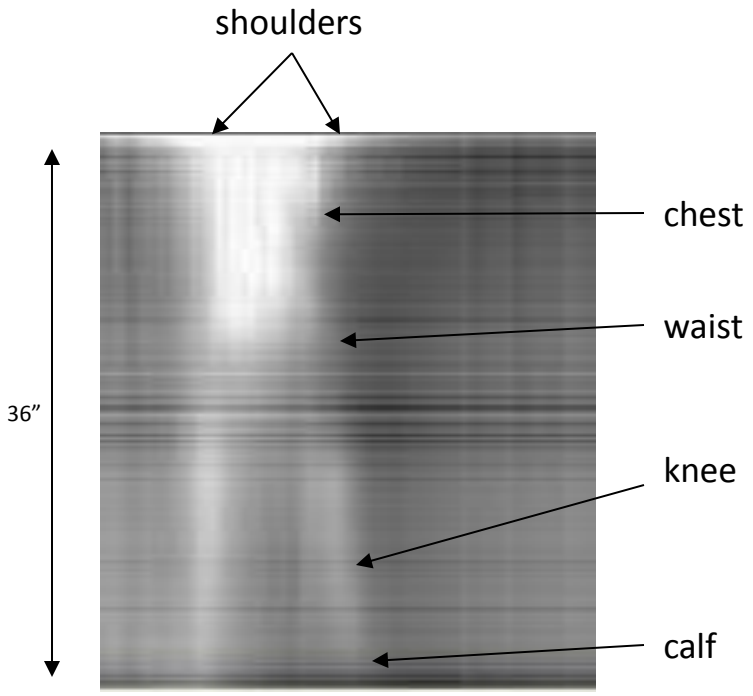


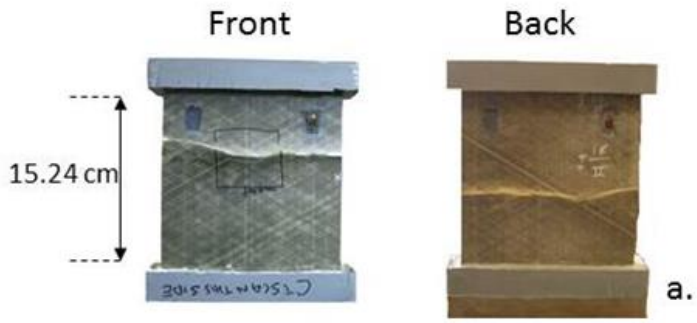
Image Processing

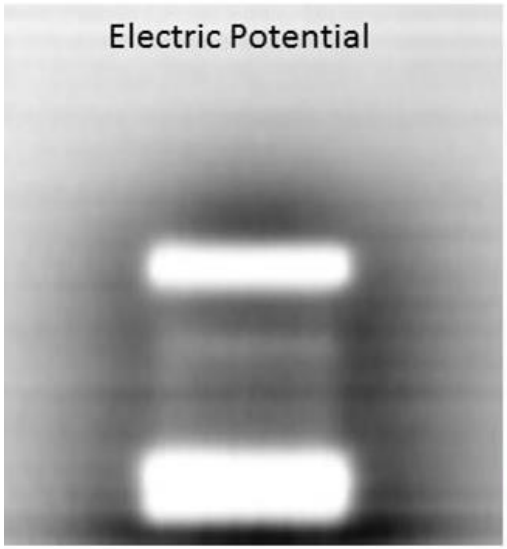
Ed Generazio’s

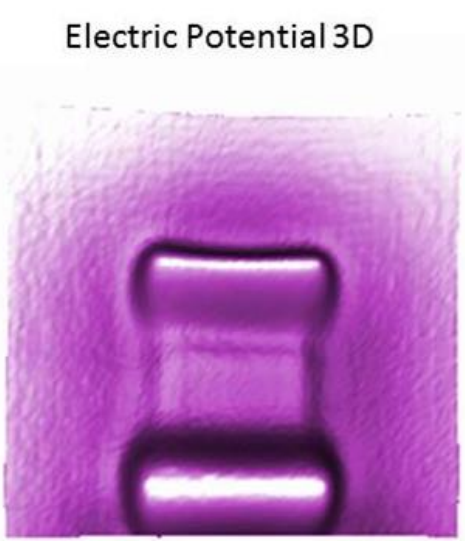
1st electric field image of a human, 10/23/2012

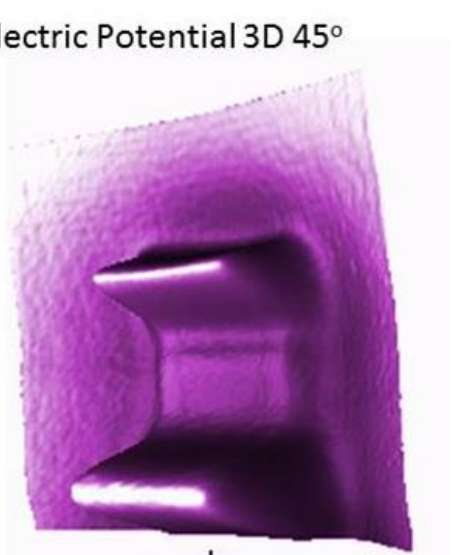
Electrical potential image of a human in a uniform electric field

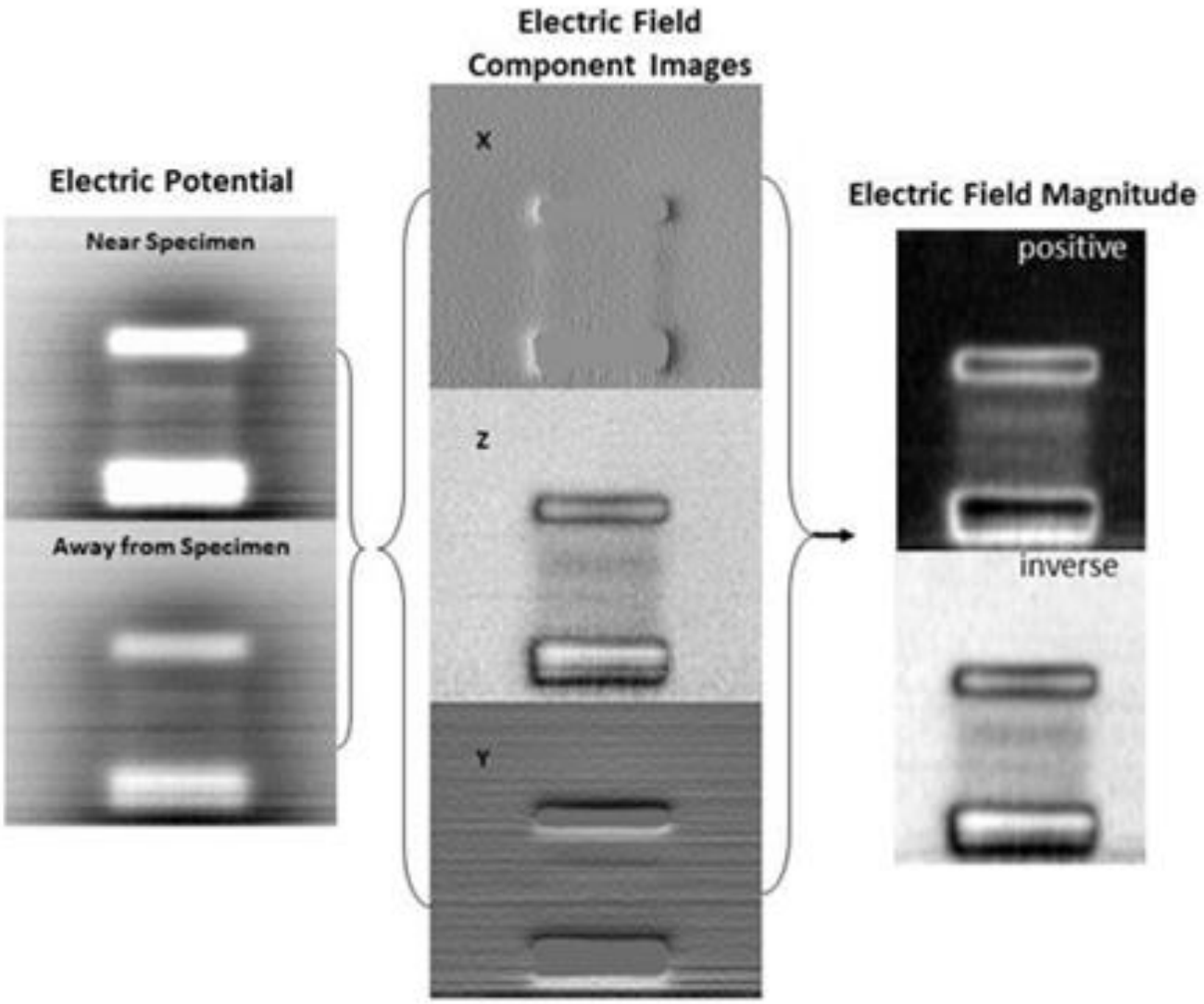
- First images identify rich areas of improvement.
- Imaging volumetric dielectric properties of structures


Front
Back
15.24 cm
a.

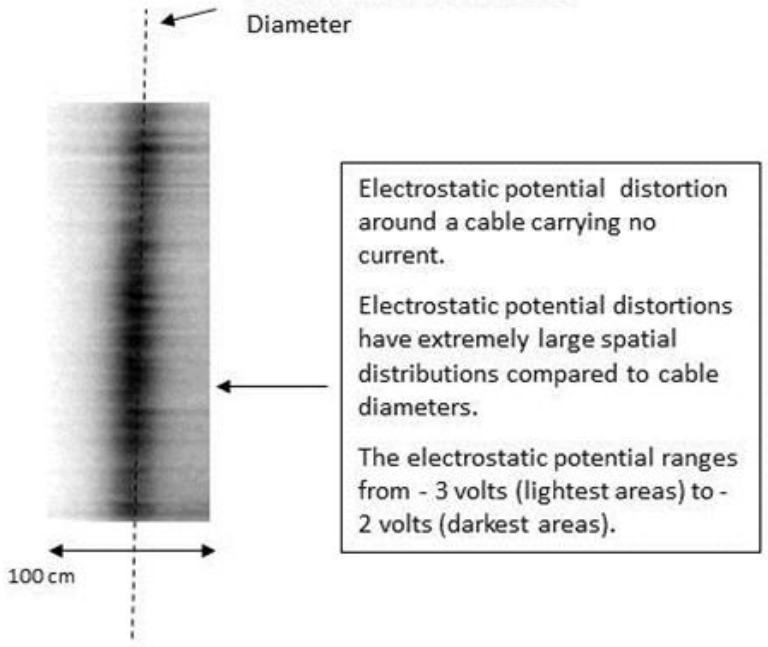

Electric Potential
b.


Electric Potential 3D
c.


Electric Potential 3D 45°
d.



Generazio, E. R., *Electric Potential and Electric Field Imaging with Applications*, Materials Evaluation, November 2015, pgs. 1479 - 1489



Electrostatic potential distortion around a cable carrying no current.

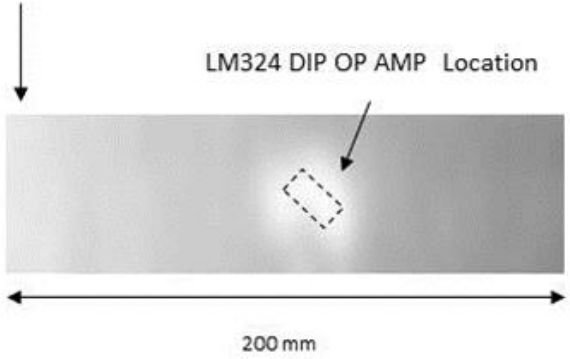
Electrostatic potential distortions have extremely large spatial distributions compared to cable diameters.

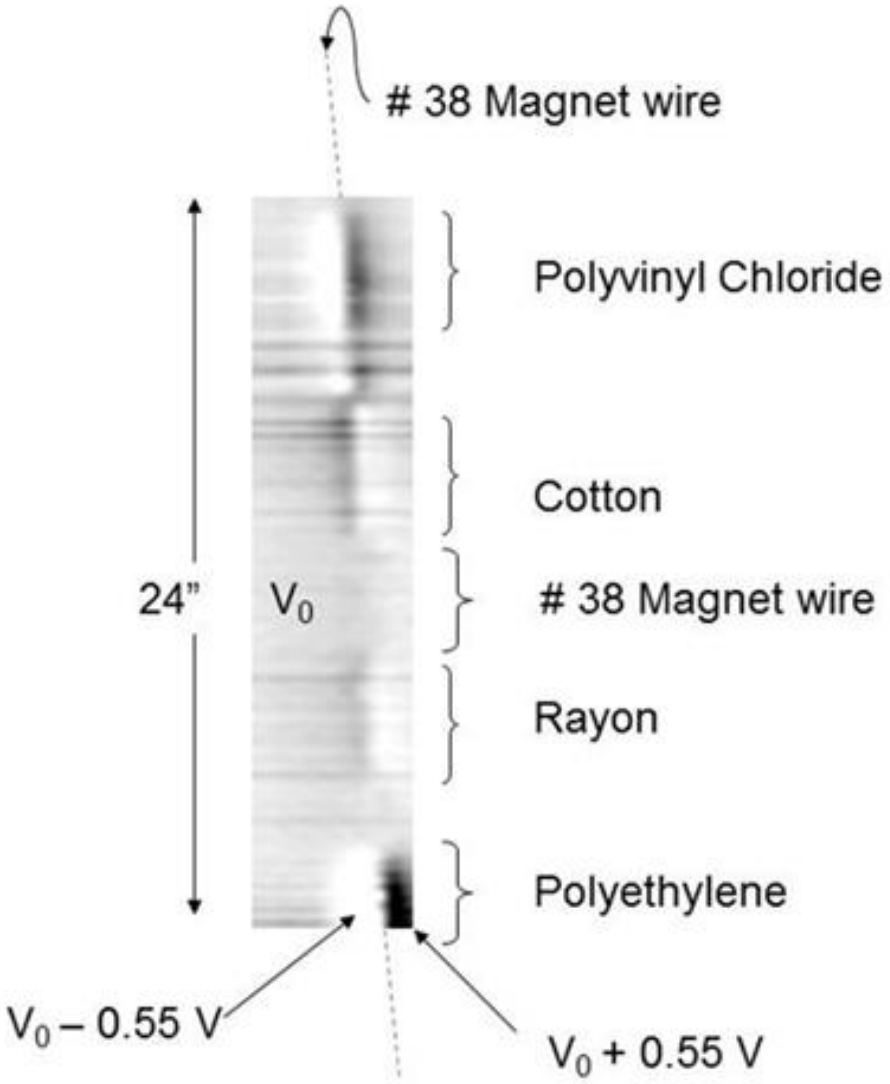
The electrostatic potential ranges from - 3 volts (lightest areas) to - 2 volts (darkest areas).

Image of actual electrostatic potential distortion around LM324 Operational Amplifier (LM324 DIP), 10 mm x 20 mm top surface is normal to reference electric field.

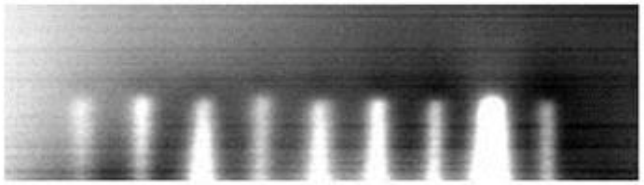
Electrostatic potential distortions have extremely large spatial distributions compared to amplifier dimensions.

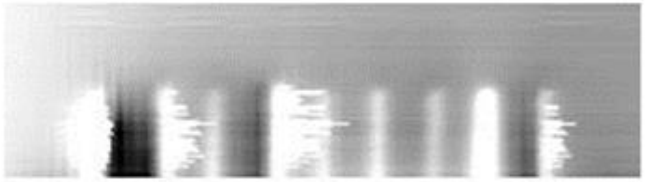
The electrostatic potential ranges from - 3 volts (darkest areas) to - 4 volts (lightest areas).




38 Magnet wire
Polyvinyl Chloride
Cotton
24"
V_0
38 Magnet wire
Rayon
Polyethylene
V_0 – 0.55 V
V_0 + 0.55 V

As received rods





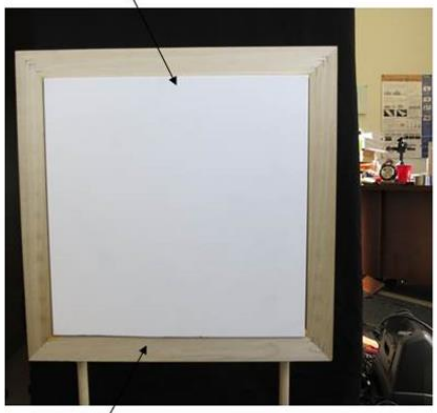
Silk cloth passed over surface

Dielectric Constant ε		Triboelectric Affinity
2.0 – 2.1	PTFE	-190
2.7	Acrylic	-10
1.2 – 2.1	Wood	+7
3	Nylon	+30
5 – 5	Garolite	+30
4 - 9	Mica ceramic	
3.8	Borosilicate Glass	+25
	Copper	~0
2.8 - 4.1	Polyester	-40

Samples are in order left to right

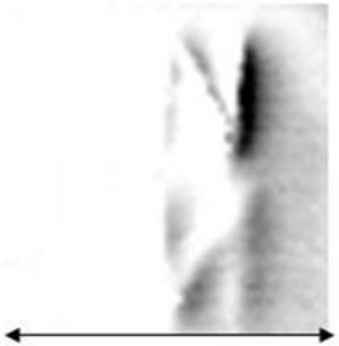
Electric Potential and Electric Field Imaging with Applications

EFI: New Electrostatic Eyes



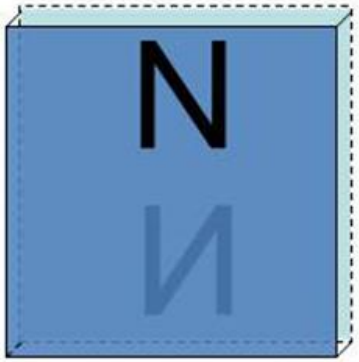
EFI Electrostatic Potential Image of latent charge distribution generated by triboelectrically drawing the letters "NASA" on PTFE. The EFI image is ovelaid onto the area scanned.

Electric Potential Image



PTFE, Teflon Panel

6.35 mm x 30.38 cm x 30.38 cm

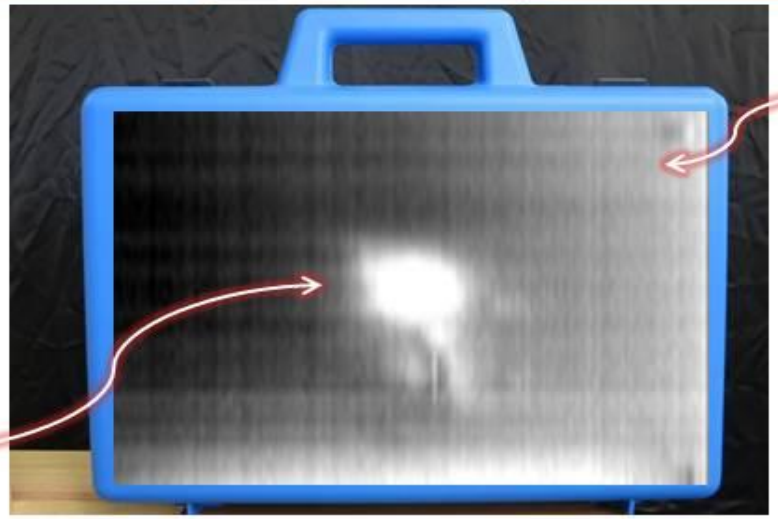


The letter "N" triboelectrically hand drawn on the front (upper) and back (lower) of a PTFE panel.

Optical image of container

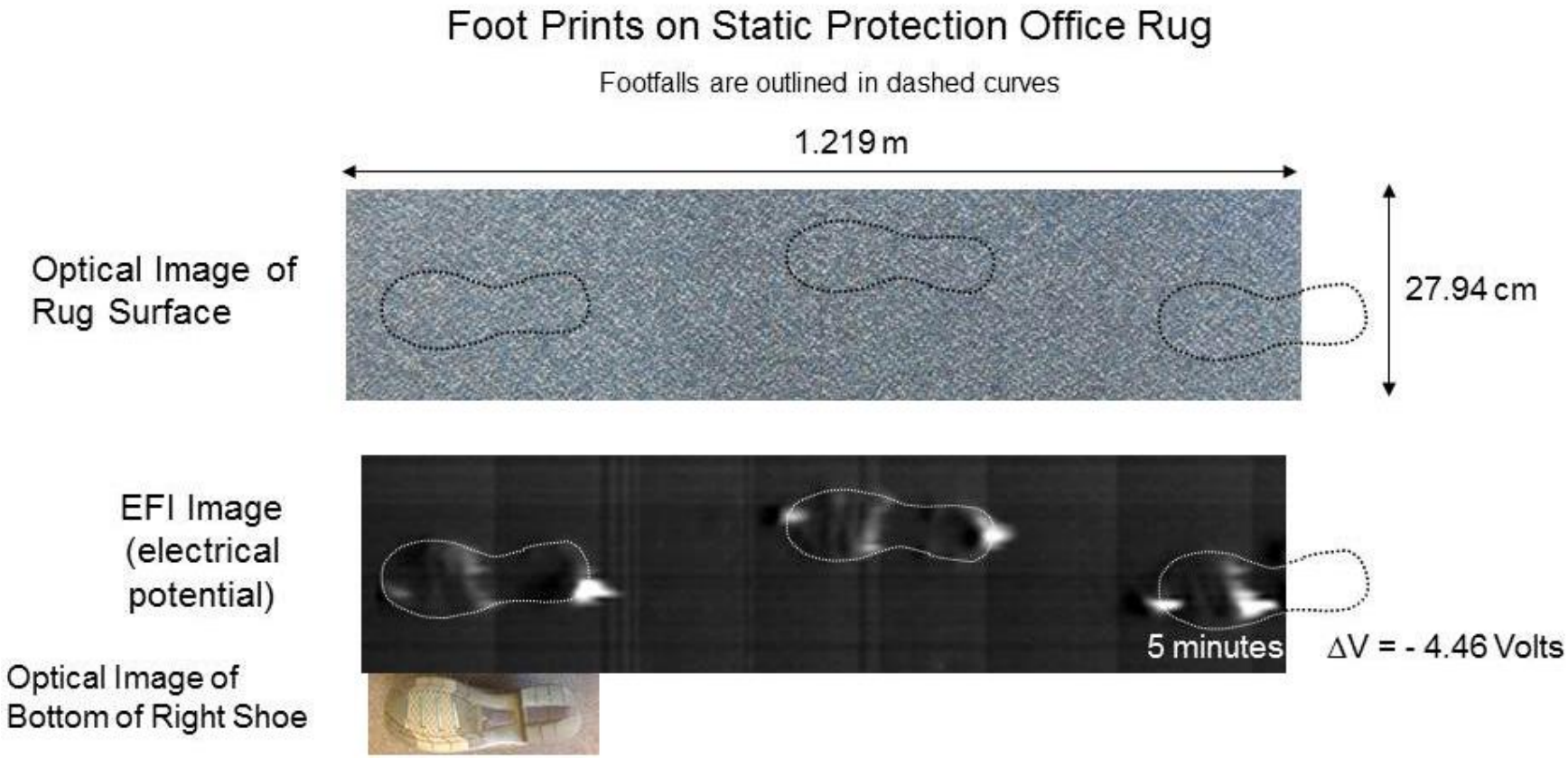
container

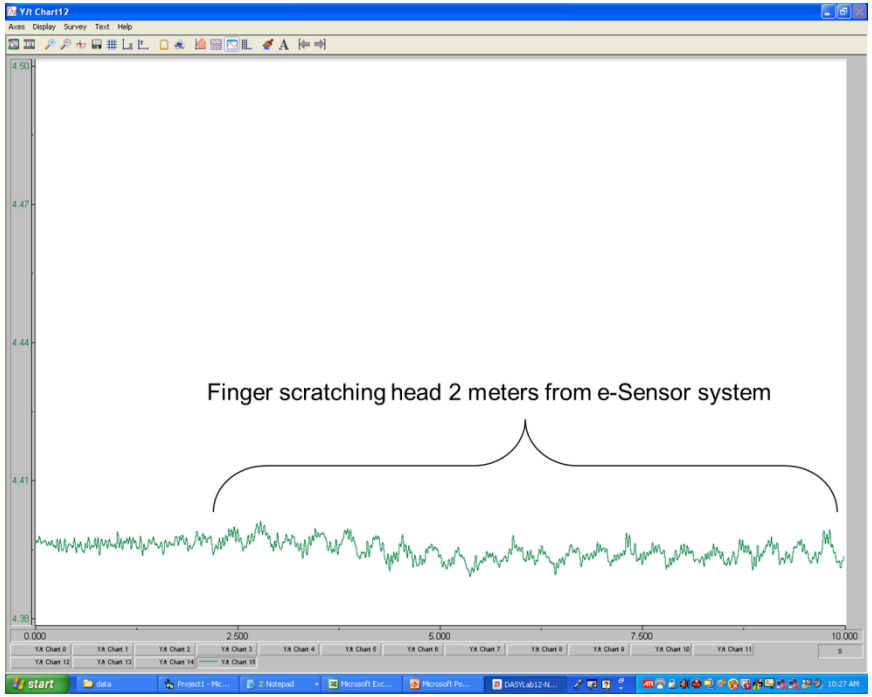
Optical image of ABS gun in container

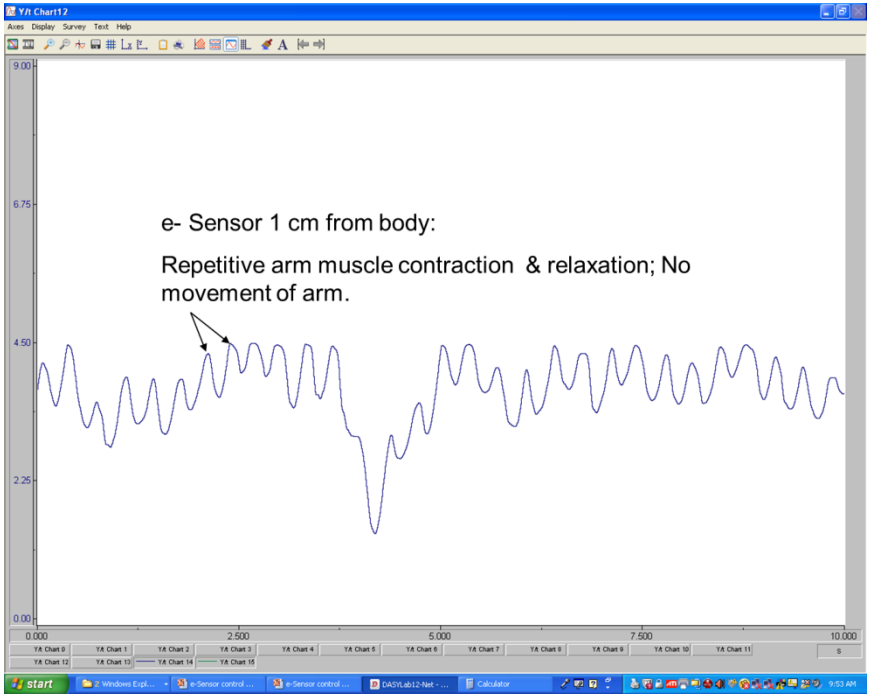


Electric potential image of container

Electric potential of gun

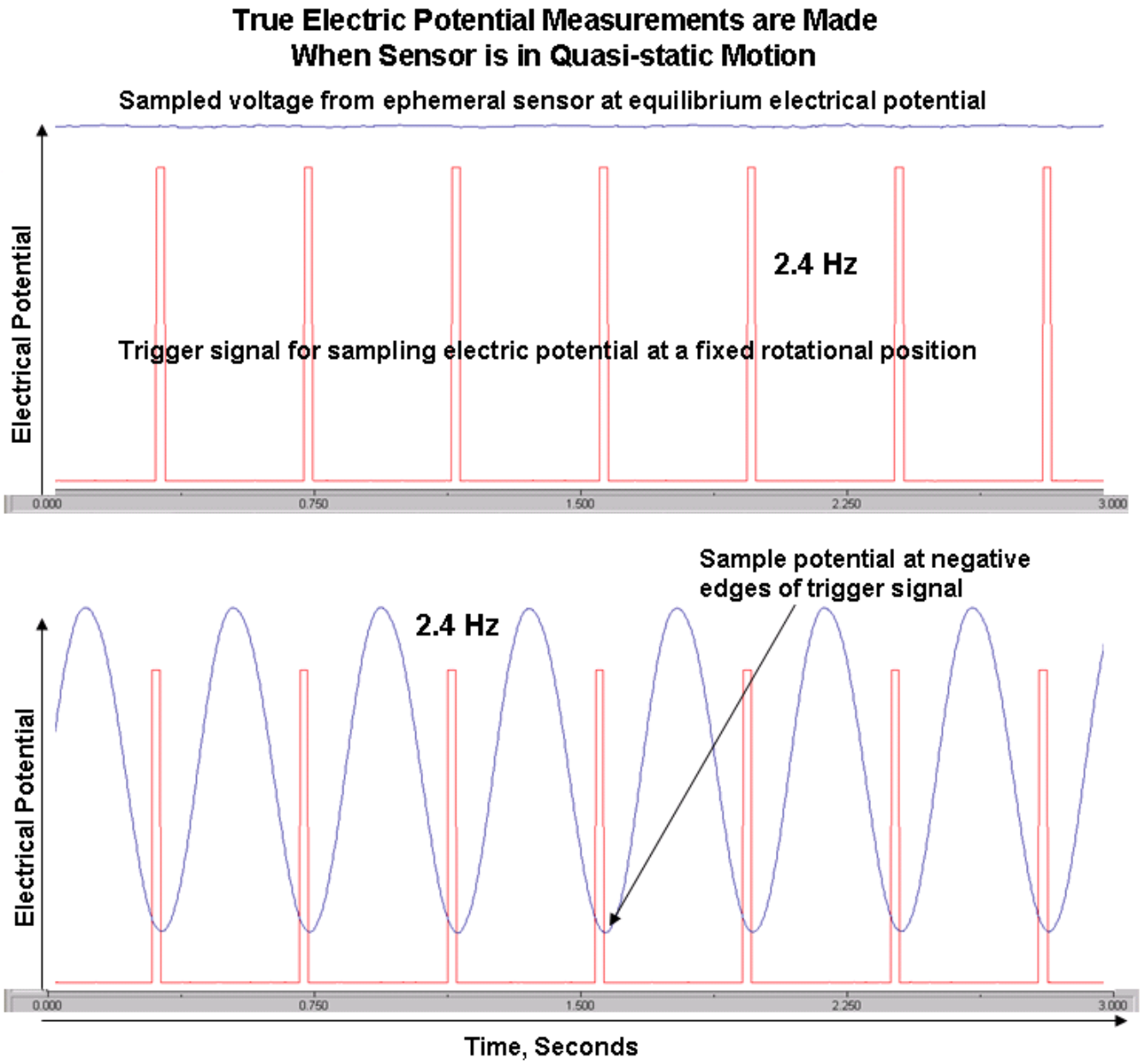

Foot Prints on Static Protection Office Rug
Footfalls are outlined in dashed curves
1.219 m
27.94 cm
Optical Image of Rug Surface
EFI Image (electrical potential)
5 minutes
ΔV = - 4.46 Volts
Optical Image of Bottom of Right Shoe



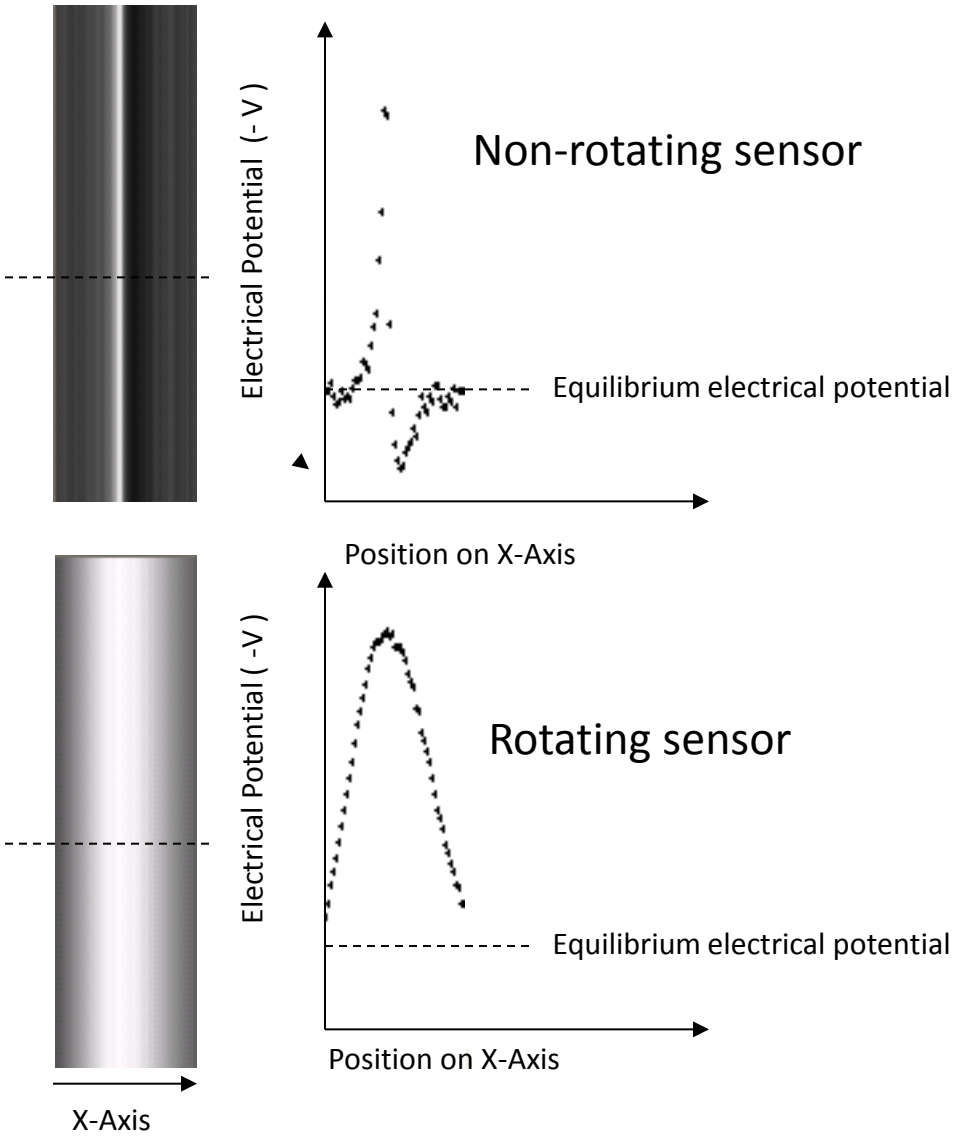


Very conservative sensitivity at 1.55mV/cm

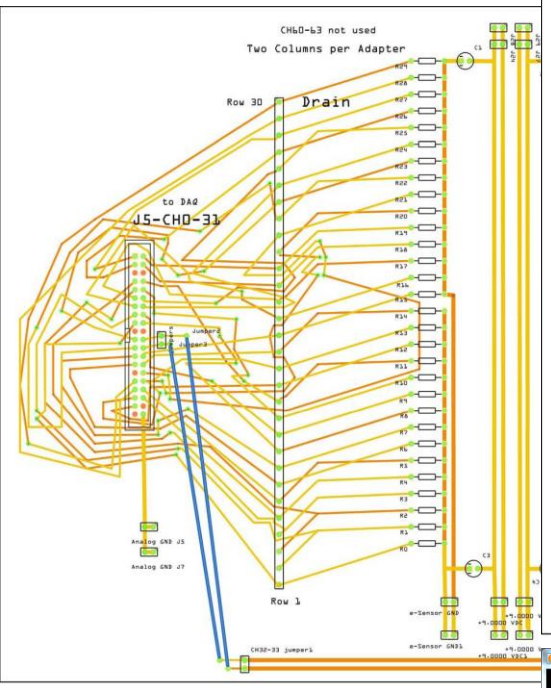
Several orders of magnitude by FET selection, components, filtering, structural design, etc.

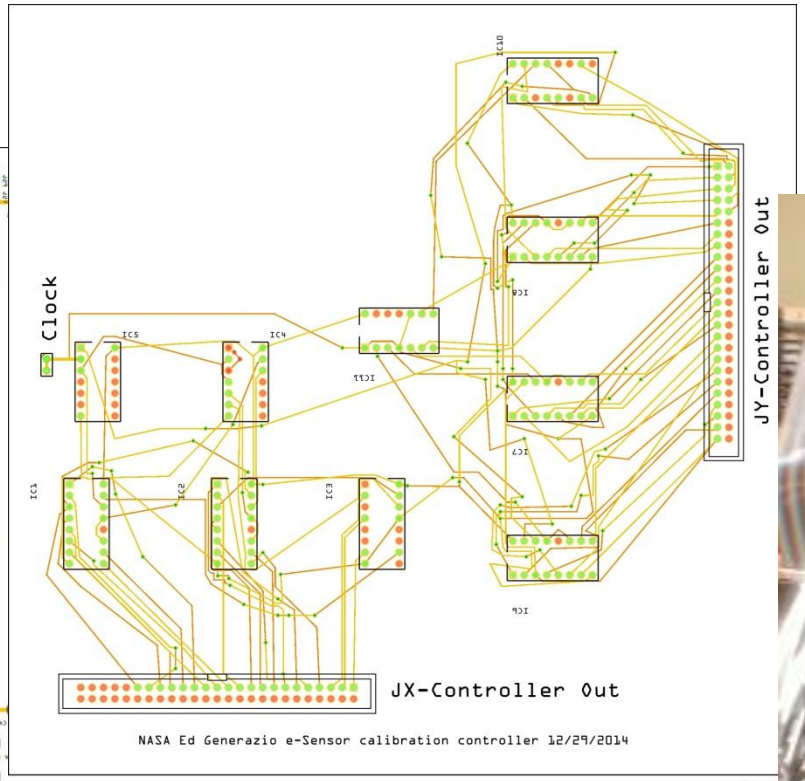

True Electric Potential Measurements are Made
When Sensor is in Quasi-static Motion
Sampled voltage from ephemeral sensor at equilibrium electrical potential
Electrical Potential
2.4 Hz
Trigger signal for sampling electric potential at a fixed rotational position
0.000
0.750
1.500
2.250
3.000
Sample potential at negative
edges of trigger signal
2.4 Hz
Electrical Potential
0.000
0.750
1.500
2.250
3.000
Time, Seconds

Typical Measured Ephemeral Sensor Response in the Presence of a Charged Axially Symmetric Object

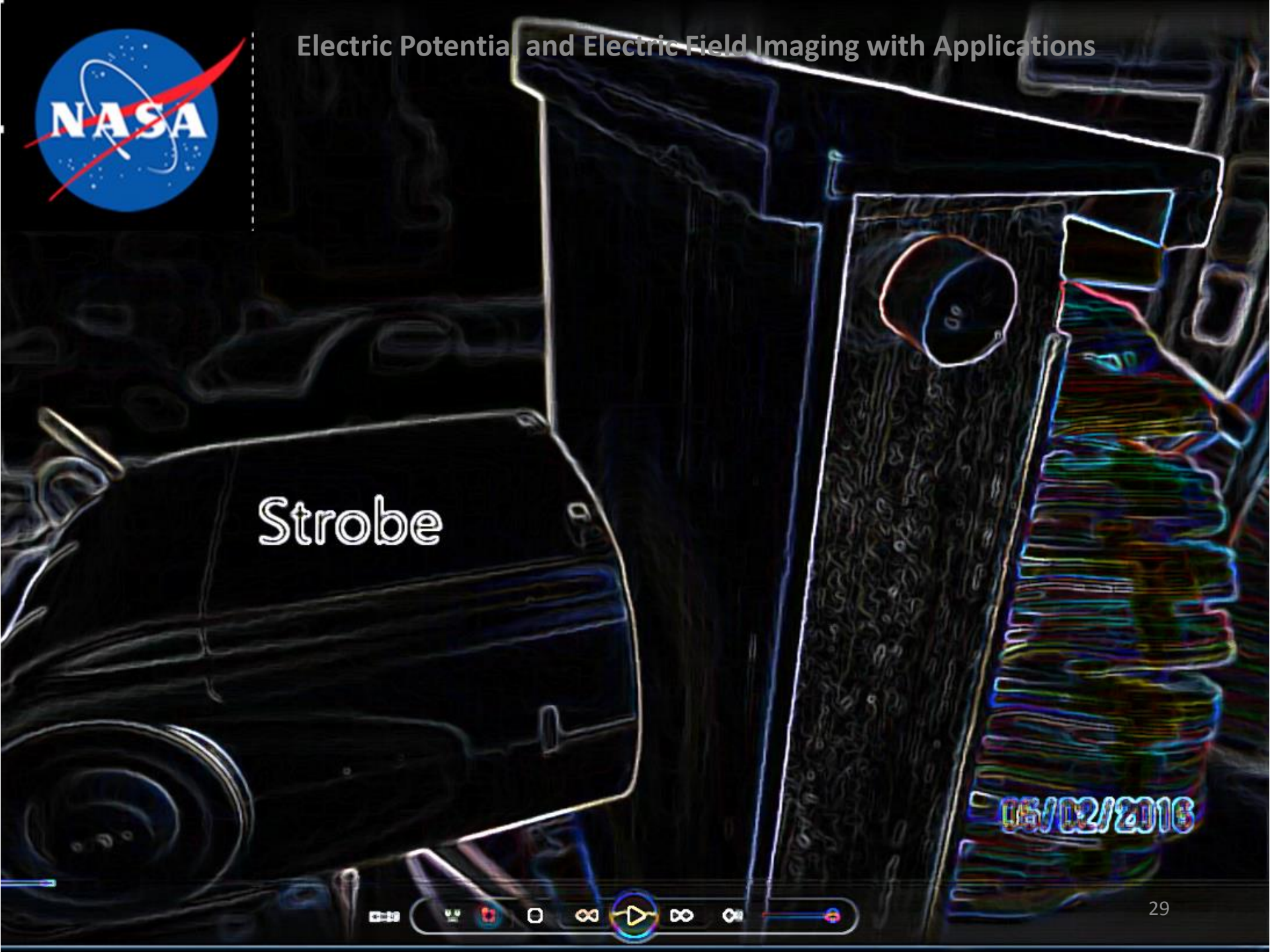


2D EFI

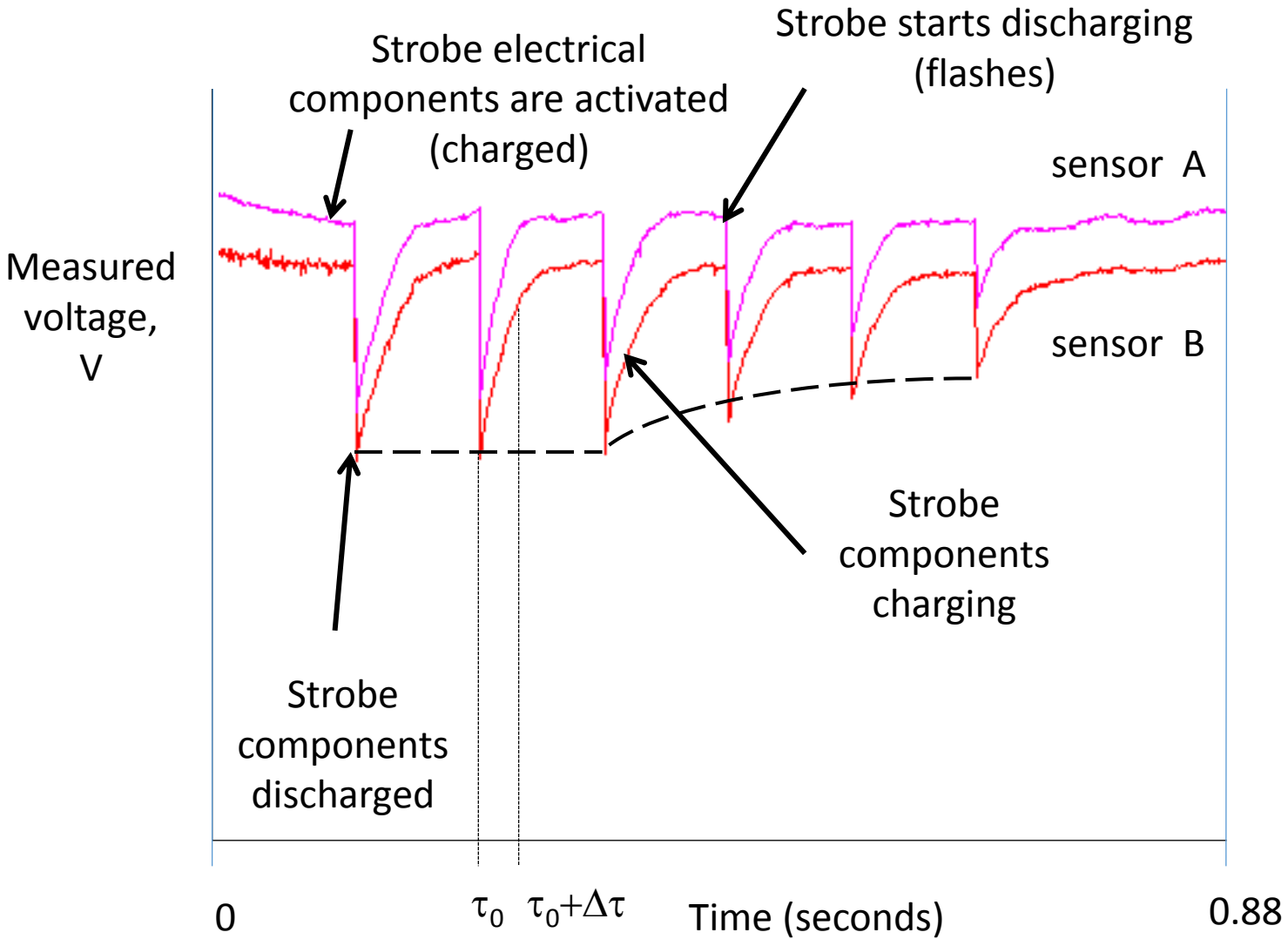

CH60-63 not used
Two Columns per Adapter
Row 30
Drain
to DAQ
J5-CH0-31
Row 1

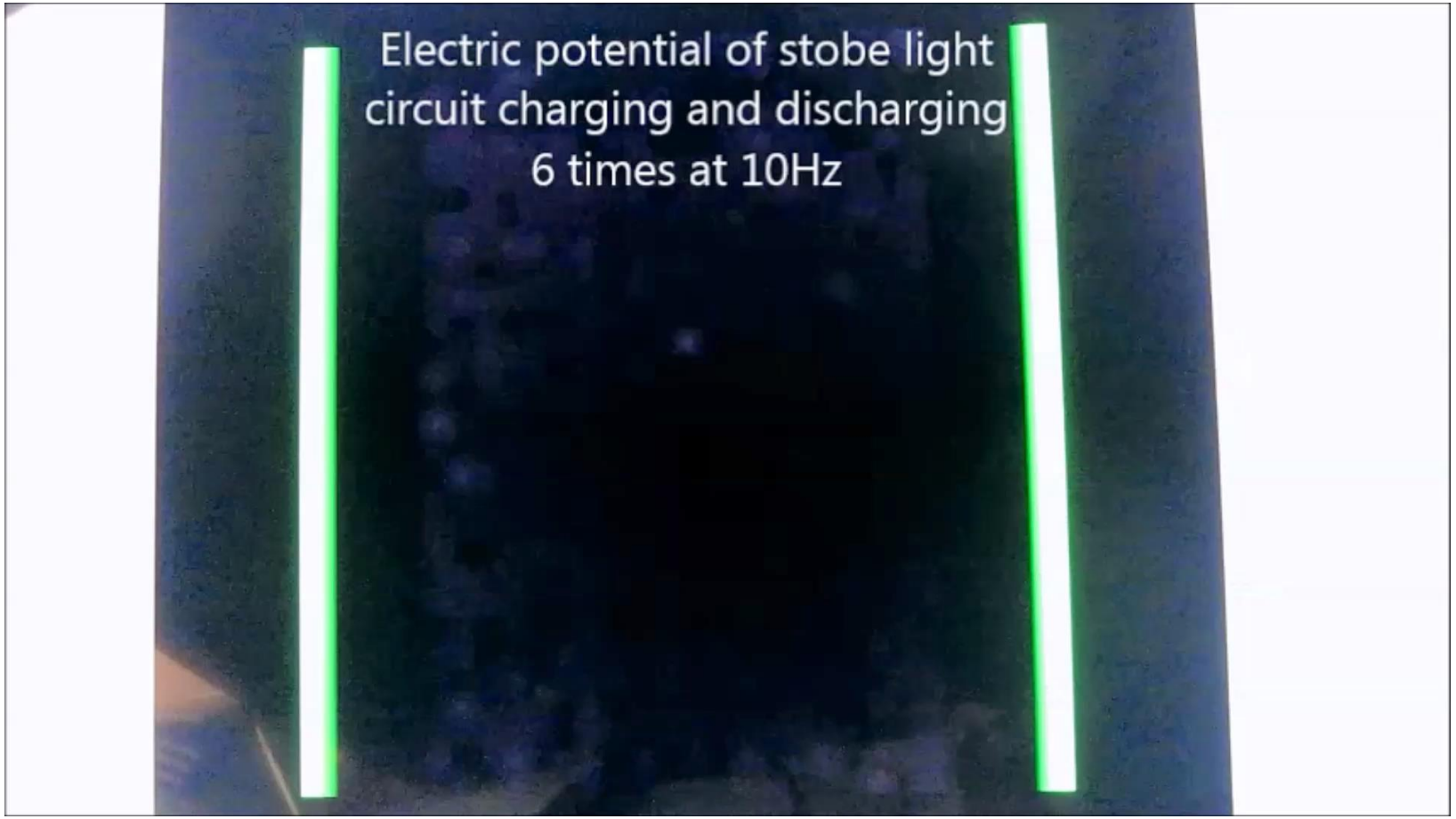

Clock
JY-Controller Out
JX-Controller Out
NASA Ed Generazio e-Sensor calibration controller 12/29/2014


MVI_0004
e-Sensor Unleashed
the movie
2016


Strobe

Individual element sensor responses due to changes in strobe circuit electrical potentials




Electric potential of stobe light
circuit charging and discharging
6 times at 10Hz

Strobe lamp flash

$$\Delta\tau = 0.060 \text{ sec}$$

Anticipated Benefits

- **NASA Programs and Commercial space industry**
  - Electrostatic discharge (ESD) control requirements
  - Damaged materials characterization requirements
  - Component operations and integrity
  - Tether quality control
  - Lightening Prediction
  - Vehicle and component charging requirements
  - Design and construction of unique electronic sensors
  - Systems and human health monitoring in space.
  - Atmospheric Imaging
- **The Nation**
  - Medical – non-contact EKG and EMG (electromyography)
  - Intrusion detection
  - US perimeter security
  - Transportation security- personnel and baggage inspection
  - Personnel identification and access
  - Electronic signature requirements

Q & A

- **Electric Field Imaging (2016) US 9279719 B2**
- **Quasi-Static Electric Field Generator (2016) US20160049885A1**
- **Ephemeral Electric Potential and Electric Field Sensor (2015) US20150137825**
- **Solid State Ephemeral Electric Potential and Electric Filed Sensor, Serial Number: 15/177,798 (2016)**

For EFI technology listing and licensing opportunities:

Jesse Midgett, Technology Transfer Specialist

J.midgett@nasa.gov

757-342-5569

https://technology.nasa.gov/patent/LAR-TOPS-116

LARC-DL-technologygateway@mail.nasa.gov