Electric Potential and Electric Field Imaging with Applications

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QNDE—July 17-22, 2016
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).
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e-Sensor Array Based on Field Effect Transistors

Resistance load

FET

Each gate (G) is a measurement electrode

To data acquisition system

V1

V2
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Floating gate design

e-Sensor Array Based on Field Effect Transistors

Resistance load

Each gate (G) is a measurement electrode

To data acquisition system

Structure
Dielectric constant, relative permittivity, $\varepsilon$

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

$\varepsilon = 1$ vacuum

Conductor

where $\varepsilon_b > \varepsilon_a$ for the left side and $\varepsilon_b \leq \varepsilon_a$ for the right side.
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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

Triboelectric affinity

POSITIVE charge
NEGATIVE charge
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- Low dielectric constant/Low electric susceptibility
- Non-conductor
- Neutral triboelectric affinity
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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

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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, \(\mathbf{E}\), at any point is given by \(-\nabla V = \mathbf{E}\), where \(V\) is the electrical potential.
“e - Sensor” Data from Prototype

Wire passing through e - Sensor prototype

e - Sensor LEDs are dimmed proportionately by the presence of the spatially varying electric potential existing around statically charged insulated wire.
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2\textsuperscript{nd} Prototype
Voltage Response from 16 e-Sensors

Dipole Rotation Rate = 120 RPM
Quasi-static Electric Field Frequency = 2 Hz

Volts

Acquisition point

Time (sec)
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
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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).

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).

Representation of Cable Showing Cable Orientation RG-174/U 50 OHM Cable 0.256 cm Outer Jacket Diameter
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As received rods

60.96 cm

Silk cloth passed over surface

<table>
<thead>
<tr>
<th>Dielectric Constant</th>
<th>Triboelectric Affinity</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.0 – 2.1</td>
<td>PTFE</td>
</tr>
<tr>
<td>2.7</td>
<td>Acrylic</td>
</tr>
<tr>
<td>1.2 – 2.1</td>
<td>Wood</td>
</tr>
<tr>
<td>3</td>
<td>Nylon</td>
</tr>
<tr>
<td>5 – 5</td>
<td>Garolite</td>
</tr>
<tr>
<td>4 – 9</td>
<td>Mica ceramic</td>
</tr>
<tr>
<td>3.8</td>
<td>Borosilicate Glass</td>
</tr>
<tr>
<td></td>
<td>Copper</td>
</tr>
<tr>
<td>2.8 - 4.1</td>
<td>Polyester</td>
</tr>
</tbody>
</table>

Samples are in order left to right
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EFI: New Electrostatic Eyes

PTFE Panel

Wood Frame

EFI Electrostatic Potential Image of latent charge distribution generated by triboelectrically drawing the letters "NASA" on PTFE. The EFI image is overlaid 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.
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Optical image of container

Optical image of ABS gun in container

Packing material

ABS gun simulator inside

container

Electric potential image of container

Electric potential of gun
Foot Prints on Static Protection Office Rug

Footfalls are outlined in dashed curves

Optical Image of Rug Surface

EFI Image (electrical potential)

Optical Image of Bottom of Right Shoe

1.219 m
27.94 cm

5 minutes
$\Delta V = -4.46$ Volts
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Very conservative sensitivity at 1.55mV/cm

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

Finger scratching head 2 meters from e-Sensor system

e- Sensor 1 cm from body:
Repetitive arm muscle contraction & relaxation; No movement of arm.
True Electric Potential Measurements are Made When Sensor is in Quasi-static Motion

Sampled voltage from ephemeral sensor at equilibrium electrical potential

Trigger signal for sampling electric potential at a fixed rotational position

Sample potential at negative edges of trigger signal

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

Non-rotating sensor

Equilibrium electrical potential

Rotating sensor

Equilibrium electrical potential

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2D EFI
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Individual element sensor responses due to changes in strobe circuit electrical potentials

Measured voltage, $V$

Strobe electrical components are activated (charged)

Strobe starts discharging (flashes)

Sensor A

Sensor B

Strobe components charging

Strobe components discharged

$0 \quad \tau_0 \quad \tau_0 + \Delta \tau \quad \text{Time (seconds)} \quad 0.88$
Electric potential of stobe light circuit charging and discharging 6 times at 10Hz
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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
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Q & A

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

For EFI technology listing and licensing opportunities:

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

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