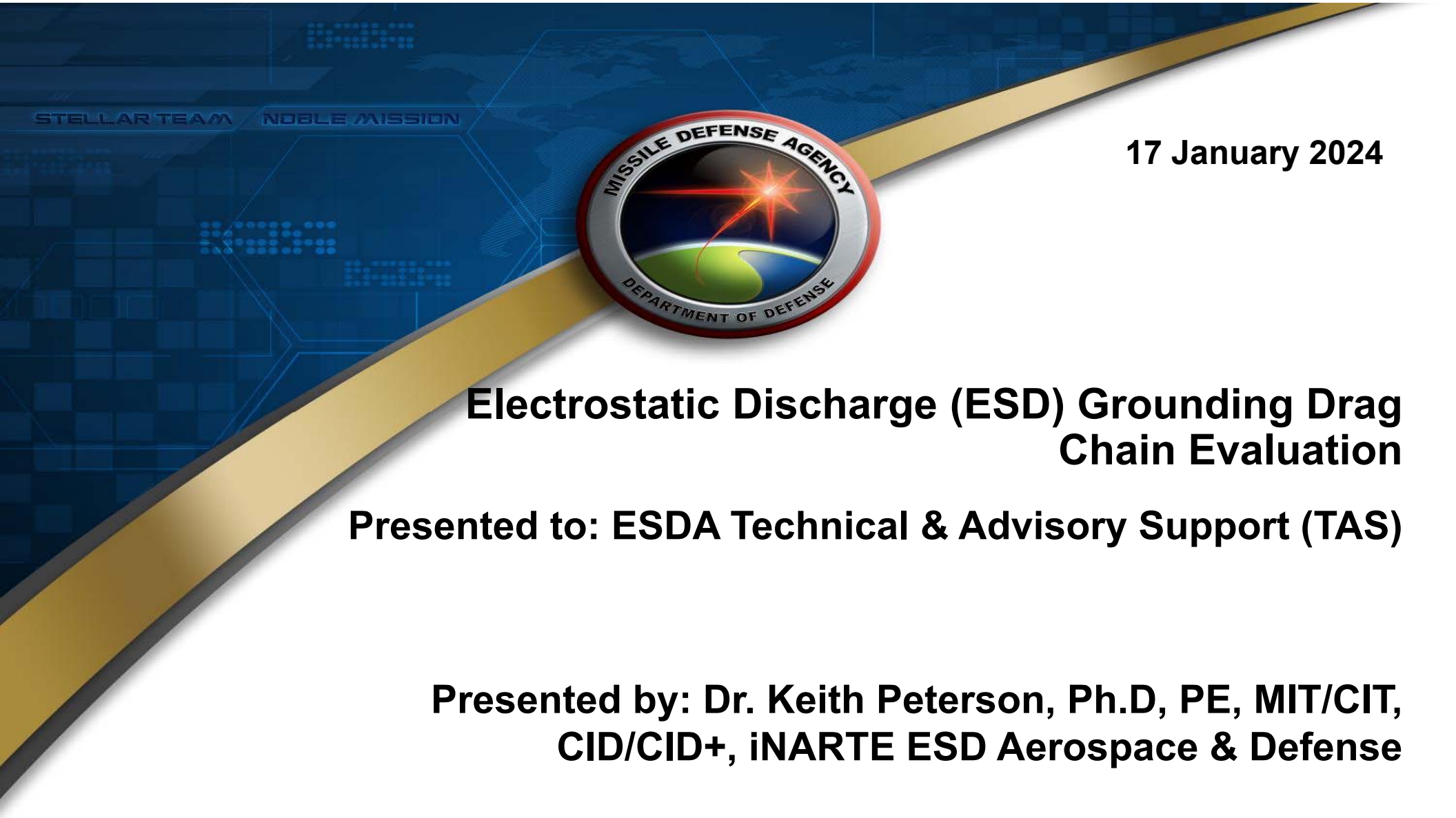

17 January 2024

Electrostatic Discharge (ESD) Grounding Drag Chain Evaluation

Presented to: ESDA Technical & Advisory Support (TAS)

Presented by: Dr. Keith Peterson, Ph.D, PE, MIT/CIT, CID/CID+, iNARTE ESD Aerospace & Defense

BLUF
Drag Chains used for Grounding ESD Elements

BLUF: Electrical measurements reveal drag chain poor performance is contributed to link to link contact resistance, which is influenced by chain weight and open link geometry.

Problem: Multiple & reoccurring noncompliance due to high resistance to ground measured on mobile workstations, carts, shelves, and chairs in multiple DoD and Industry electronic manufacturing facilities.

Causes: Multiple causes were reported:

- **Incorrect test method**
- **Excessive periodicities for compliance verification**
- **Dirty casters or drag chains**
- **Improper installation of mobile device, ground chains, or rope**
- **Trip hazards extending from underneath of carts and chairs**

Was the Root Cause Missed? Do we have an adequate solution to the problem?

Study: To gain deeper understanding the failure mechanism of drag chains, identify best test methods in evaluating ground chains, and provide some lessons learn on selection criteria and implementation of drag chains.

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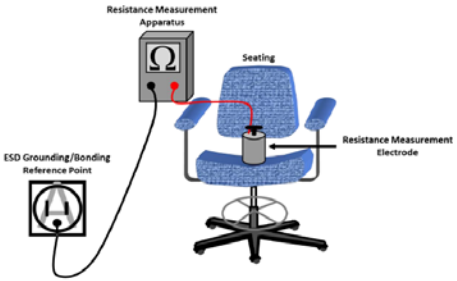
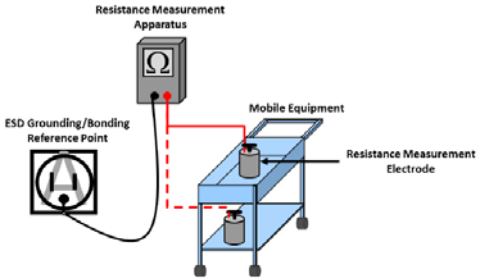
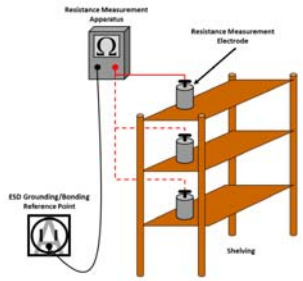
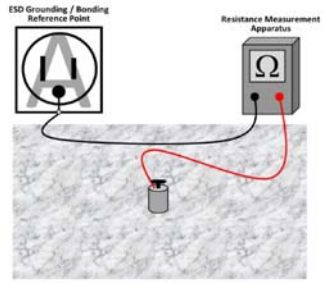
Industry Standard Test Methods for Mobile Technical Elements









Drag Chains are Evaluated during Total System Resistance Measurement
No Effective Standard Test Method to Evaluate Ground Chains

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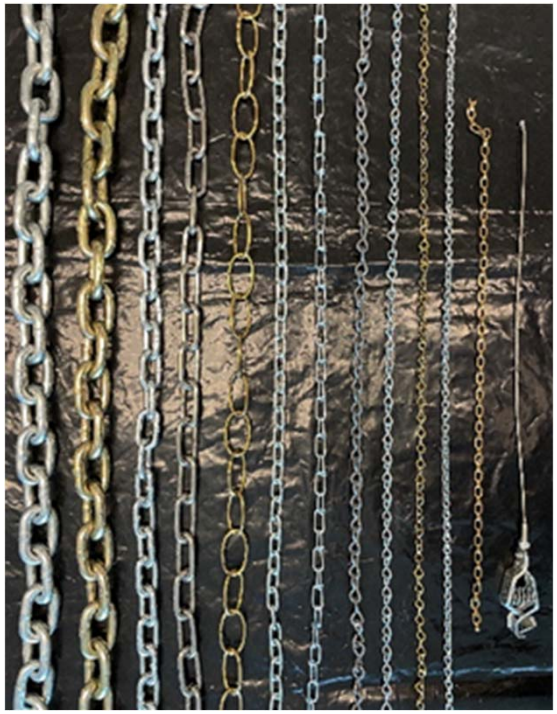
* ESD TR53 top row images

Summary of Electrostatic Measurements
Drag Chains

- Chain Geometric Measurements (evaluated 33 chains of various types)
  - Link size (thickness, length, width, shape, and color)
  - Link weight (grams/link)
- Resistance Measurements
  - Link surface resistance
    - Alligator clip
    - 2pt probe
  - Link Contact Resistance
    - Link to conductive & dissipative flooring
    - Link to Link
      - On conductive plate
      - On insulative surface
      - On dissipative floor
      - Suspended chain end to end
- Static Voltage Decay
  - Ground chain on conductive plate
  - Ground chain on dissipative flooring



What is the weakest link & Why do these Mobile Items Fail?

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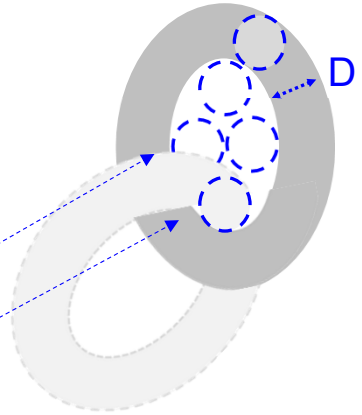
Physical & Dimensional Measurements

Drag Chains Mechanical Characteristics

- **Heavy, medium, light, & small link chains and rope with ball or cylinder drag chains.**
- **Link size variation used in measurements:**
  - **Material Type: Stainless steel, zinc plated, yellow zinc, galvanized, brass plated, black oxide, or coated (décor)**
  - **Link Termination: Open, twisted, pinched, or welded**
  - **Shape: Elongated, straight link, proof coil, jack, double loop, or handy link**
  - **Diameter: 1.1 - 8.4 mm**
  - **Length: 3.7 - 49.1 mm**
  - **Contact length: 3.7 – 28.3 mm**
  - **Width: 4.5 - 30.2 mm**
  - **Links/inch: 2.6 - 0.8 links/inch**
  - **Weight: 0.15 - 47.6 grams/link**
  - **Link Tolerance (W): 1.6D - 6.0D**
  - **Link Tolerance (L): 1.8D - 9.7D**



One Chain does not have ALL the Best Geometric Characteristics

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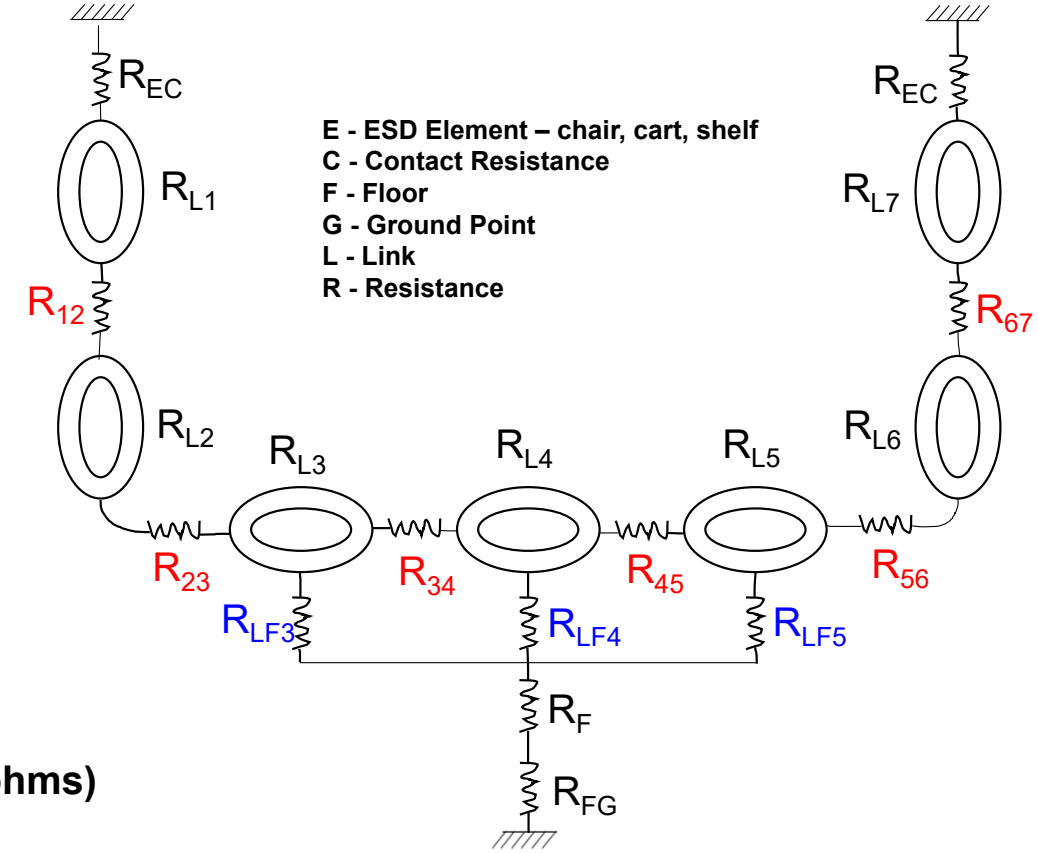
Electrical Measurements
Drag Chain Resistance Model

- **Measurements indicated most drag chains may become have high resistance when measured end to end, several orders of increase resistance of base metal due to open link designs (for flexibility).**
- **Link to Link contact resistance drives drag chain performance and not floor contact resistance as traditional thought.**
  - **Link to Link resistance is the largest resistance in resistance model.**
  - **Link to Floor resistance is below floor resistance (clean drag chain).**

$$R_{LL} >> R_F > R_{LF} > R_L > R_{EC} > R_{FG}$$

R_{LL}	>>	R_F	>	R_{LF}	>	R_L	>	R_{EC}	>	R_{FG}
10^{12}-10^3		<10^9-10^5		10^4-10^2		0.4-40		1-10		<1 (ohms)



Link to Link Contact Resistance Dominates Drag Chain Performance

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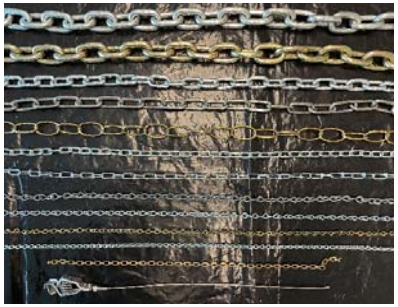
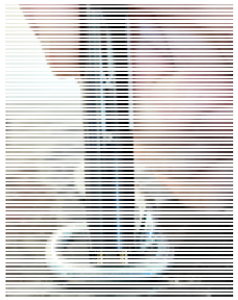
Electrical Resistance & Voltage Decay Tests

Drag Chain Electrical Characteristics



Grounded Chain Size, Color, Shape

Ground Chain Dimensions



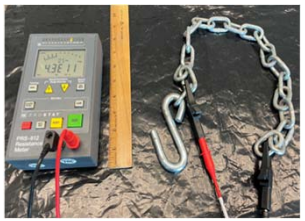
Link Surface Resistance 2 Pt

Link Surface Resistance Alligator

Link Contact Resistance to conductive plate

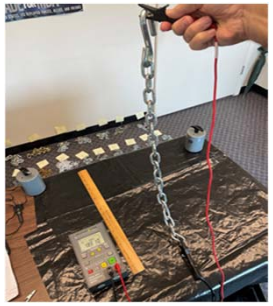
Chain to Dissipative Flooring

Link to Link on Conductive Plate



Link to Link on Insulative Surface

Link to Link on ESD Dissipative Flooring



Suspended chain End to End

Voltage Decay Chain on Conductive Plate

Voltage Decay Chain on Dissipative Flooring

Link to Link Resistance Governs the Electrostatic Performance of the Chain

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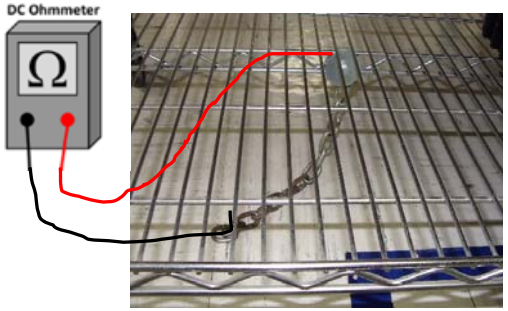
Resistance Measurements
Sources of Resistance

R_L
(0.4 - 40 ohms, 100+ measurements)

R_{LL}
(10^{12} - 10^3 ohms) , 600+ measurements)

R_{LF}
(10^4 - 10^2 ohms, 100+ measurements)

R_F
(<10^9 - 10^5 ohms, 20+ floor types)



R_{EC} (1-10 ohms)

R_{FG} (<1 ohms)

Link to Link Resistance required More Evaluation

R_{LL}>>R_F>R_{LF}>R_L>R_{EC}>R_{FG}

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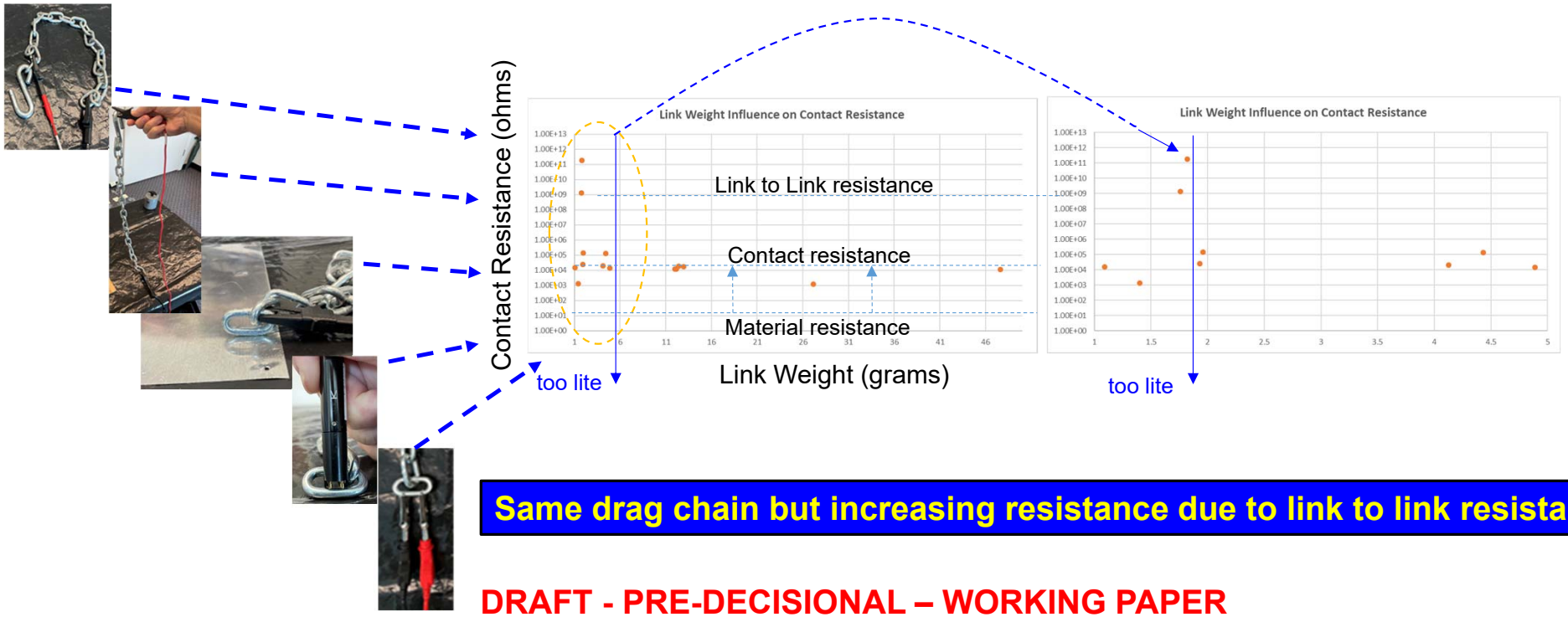
E - ESD Element – chair, cart, shelf
C - Contact Resistance
F - Floor
G - Ground Point
L - Link
R - Resistance

Drag Chain Contact Resistance

- **Base material surface resistance varies 2x – 40x between alligator clip vs 2pt probe (all <40 ohms). Alligator clip has sharp teeth & clamp force reducing contact resistance as compared to 2pt spring loaded probes.**
- **Contact resistance increases up to 1000 times the base material due to weight, size, geometric, surface, etc.**
- **Link to Link resistance increases up to 10^3 – 10^{11} times the base material, going from conductive to insulative range.**



Same drag chain but increasing resistance due to link to link resistance

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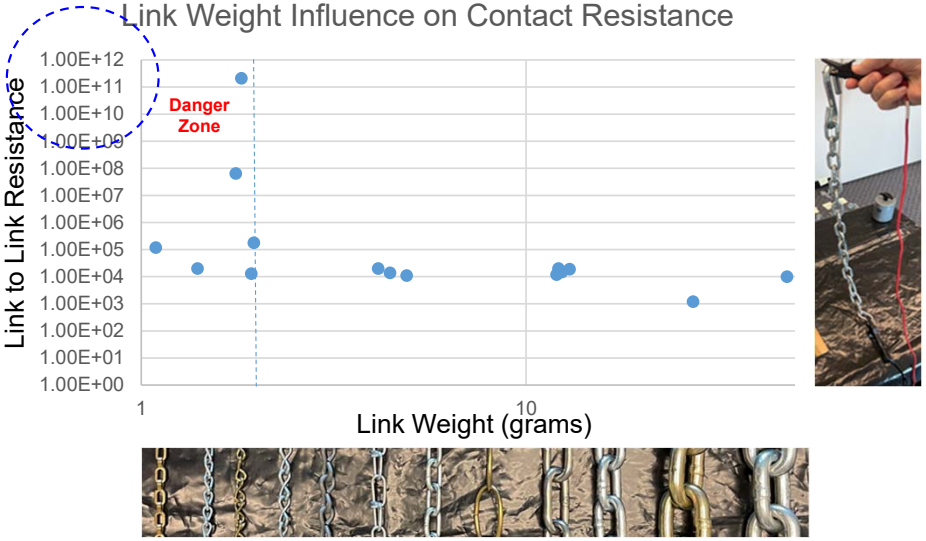
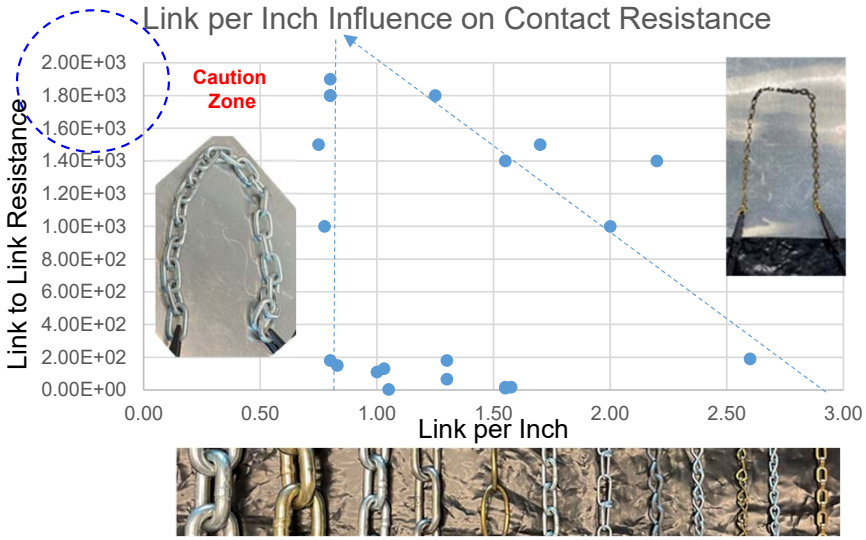
Link to Link Contact Resistance

- **As link weight increases, link to link contact resistance decreases.**
- **Link length (link/inch) can perturbate contact resistance, but insignificant to overall system resistance.**
- **Decrease in opportunity for links to contact the floor, (low # links per inch) increases contact resistance.**
- **Some chain geometries are impervious to changes in resistance, i.e. flat double lap link geometry.**
- **Contact resistance "link to link" is more important that "link to floor".**





Link to Link Contact Resistance Dominates Total Resistance of Drag Chain

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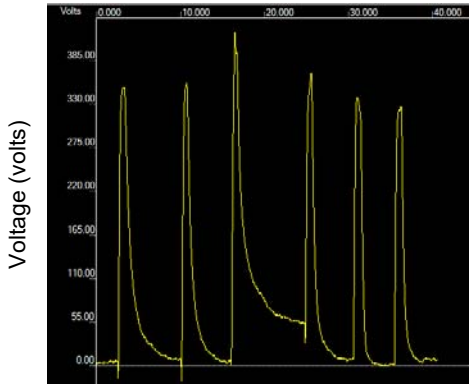
Electrostatic Decay Measurements
Drag Chain

Peak Voltage & Decay Measurements

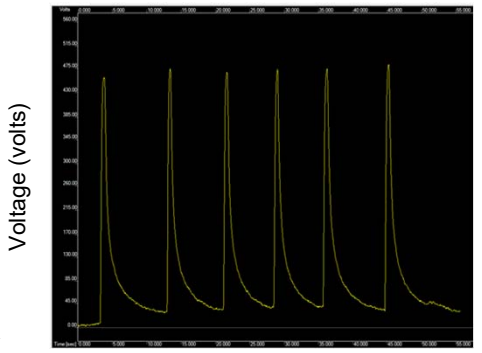
- Conductive floor (10^6 ohm) attached to ground (<1 ohm)
- Conductive plate attached to electrostatic field (ESF) meter's charge plate
- Drag chain laid over conductive floor and conductive plate
- Charged (+/- 1000 volts) applied to ESF charge plate
- Observe peak voltage & voltage decay to 10% of original value, 100 volts
- Repeat for taught and loose drag chains

Observations

- Taught drag chains, decay times range 1- 4 seconds at 74°F/50% RH
  - Tight chains (hang method) shows when resistance <10^9 ohms, peak voltage is <200 volts
- Loose drag chain, shows little to no forced voltage decay due to poor ground chain (peak voltage 75-1000 volts), increasing CDM risks
  - Most loose drag chains peak voltage exceeds 200 volts
  - Ball and rope drag chains show similar performance, i.e. 480 volts peak



Heavy Drag Chain



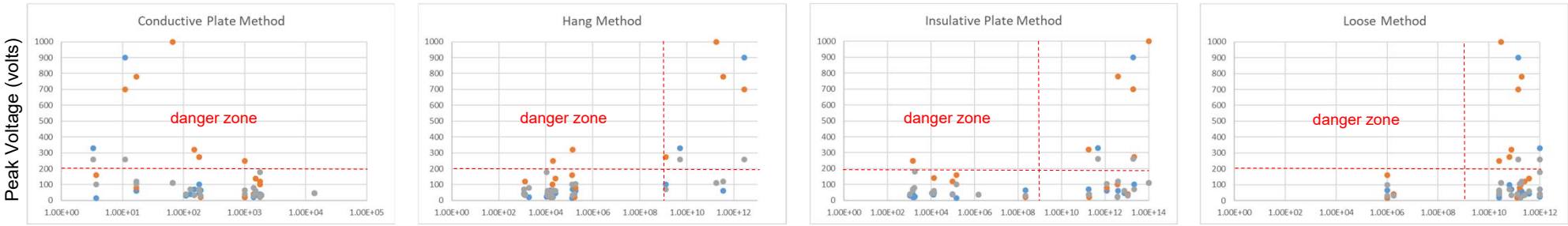
Ball & Rope Drag Chai

Need to keep chain in tension and multiple heavy links on the floor

Link to Link Contact Resistance vs Voltage Decay

Each method provides quantitative and qualitative assessment on drag chain performance

- **Conductive Plate Method – demonstrates link to floor resistance is insignificant if chain has multiple links on floor**
- **Hang Method – keeps chain in tension when hanging from ESD element to the floor**
- **Insulative Plate Method – demonstrates link to link contact resistance is the most important to keep low**
- **Loose Method – demonstrates tremendously increase in link to link contact resistance, if chain is bunched up**
  - **Loose method demonstrates why ESD elements (chair, carts, etc) fail after being certified for use.**



increasing screenability of poor performing drag chains but less inclusive

Hang Drag Chain Test Method is Effective for Screening Good Ground Chains

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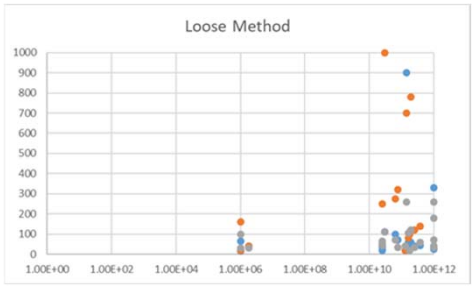
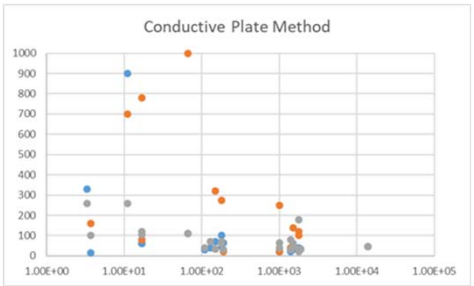
Double Hang Test Method
Effective Drag Chain Solution

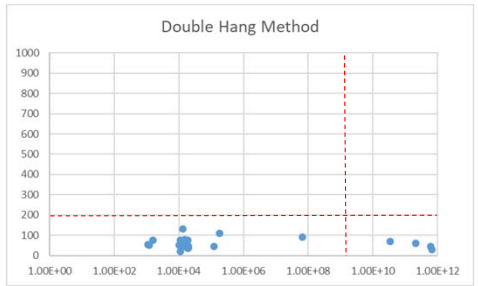
nothing passes





everything passes

- **Keeps chains in tension**
- **Provides two ground paths**
- **Allows more links on floor**
- **Avoids trip hazards**
- **Independent of chain characteristics**



no escapes, inclusive

Double Hang Drag Chain Method is Effective

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Other Drag Chain Proposed Solutions

Drag Chain Attributes for Superior Ground Chain Performance

- **Attachment of ground scheme is < 10 ohms**
- **Conductive chain and ground rope without insulative coating**
- **Corrosion resistance material to ensure resistance is maintained over time**
- **Keep drag chain tight between link to link thru hanging and/or geometry**
- **Multiple links on floor to increase probability of ground point**
- **Low maintenance and cleaning required**
- **Drag chain does not cause FOD or damage to the floor**
- **Avoids trip hazards**

- **Conductive casters with frequent cleaning**

okay

Double Hang Drag Chain Method is Effective

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Take Aways & Lessons Learned
Drag Chains

Take Aways

- **Chain link opening allows link to separate and significantly increase (10^{12}x) resistance to ground.**
- **Coated chains typically are insulative and should not be used.**
- **Dirty & corroded chains increase surface resistance, corrosion resistance materials are needed.**
- **Number of links on floor & shape of link increase the link contact surface area to the floor.**
- **Heavier link weight reduces contact resistance and increase some self-cleaning thru abrasion.**
- **Available chains and configurations may not be optimal, casters may solve some issues.**
- **Contact resistance increases is 1000x more than base material.**

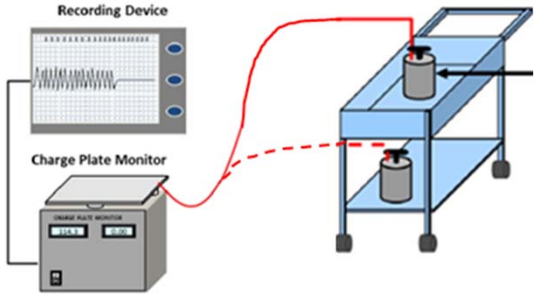
Common Audit Issues

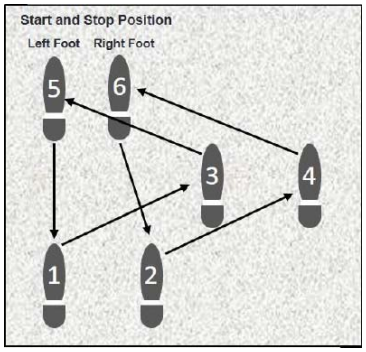
- **No grounding deployed for mobile devices, chairs, shelves, or carts.**
- **Chairs, carts, & shelves have insulative materials in the ground path between multiple tier sections.**
- **Lack of testing or improper testing of chairs, carts, or shelves.**
- **Light, short, or rope/ball drag chains show elevated resistance.**
- **Elevated workstations used drag chains to connect to lower conductive bench.**

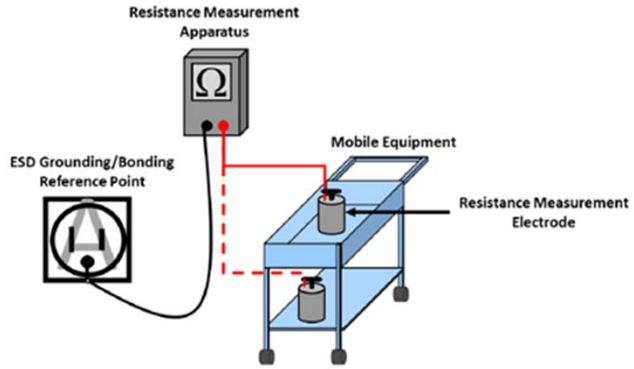
Drag chain resistance can change by 1,000,000,000,000x

Follow on Experiments

- Ground mobile element with ground chain on conductive or dissipative floor
- Use STM 97.2 walking test with operator (isolated from mobile element) moving the mobile element
- Capture dynamic peak resistance measurements during walking test
- Capture dynamic peak voltage generation during walking test
- Observe charge/discharge events due to making/breaking ground between floor & ground chain using ESD event detector







Dynamic Measurements may provide more insight to drag chain risks

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