Electrical Overstress – Many Sources; Any Solutions?

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ESD Association

Industry Council on ESD Targets

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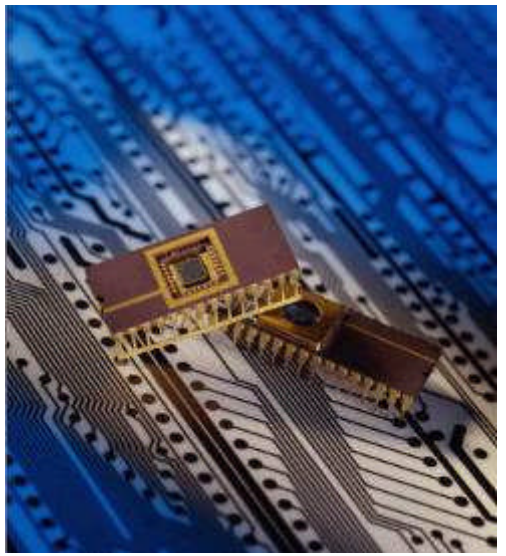
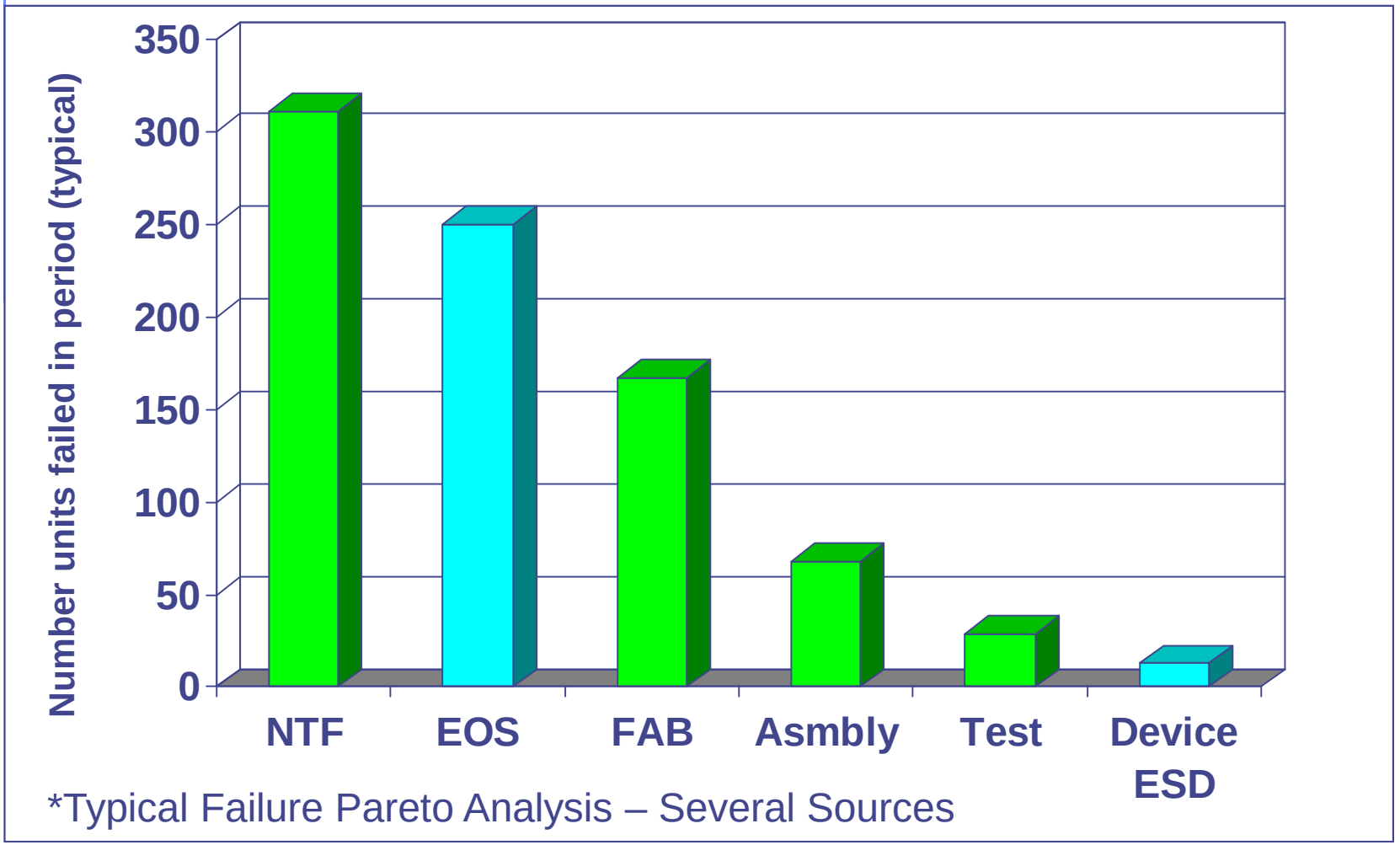
Outline

- Introduction
- EOS and ESD Background
- EOS Definitions and Terms
- EOS Categorization
  - EOS-like ESD (CBE and CDE)
  - Power-induced EOS
- Factory Mitigation
- Design Mitigation
- Industry Activities
- Conclusions – EOS Survey



EOS: Important Failure Category*



*Typical Failure Pareto Analysis – Several Sources

EOS: Important Failure Category*

*Typical Failure Pareto Analysis – Several Sources

Costs of EOS/ESD

- Many companies agree 25-35% of failures are EOS/ESD; some say more
- High burden for semiconductor and board assembly
- Failure fraction has remained about the same over many years
- Difficult to identify
  - Finger pointing about who is responsible
  - Often not systematic
  - Root cause hard to find

EOS Issues/Questions

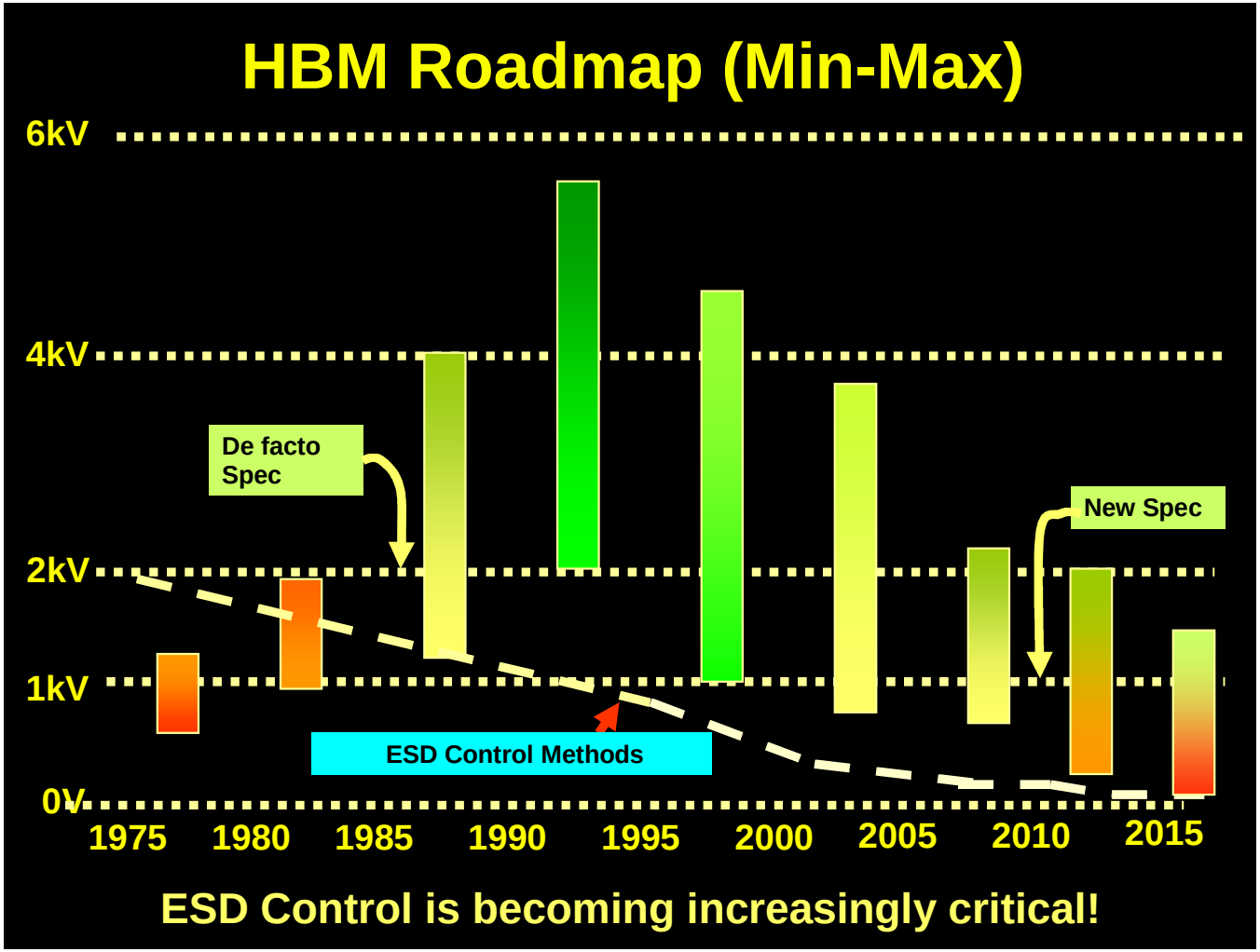
- EOS (by FA diagnoses) is main cause of electrical failure of device and systems
- Electrical failures sent to FA often return diagnosis of EOS or EOS/ESD without further information
- More information is needed to find root cause and implement corrective action
- Confusion about EOS definition
- Much progress has been made on ESD but not EOS. Why?

ESD Definitions

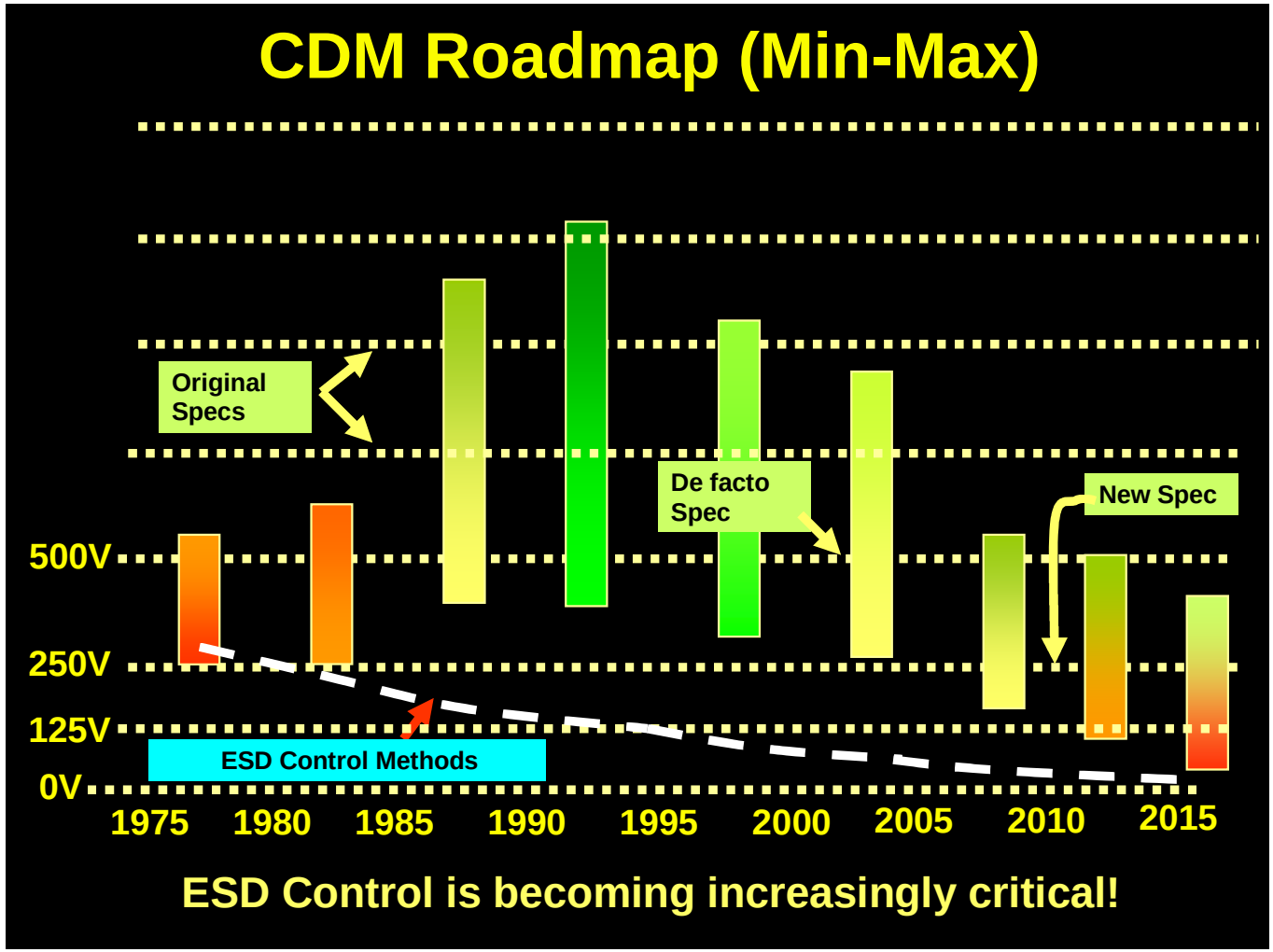
- **Withstand Threshold - Highest Known Voltage At Which A Device Can Pass A Given Model (E.G., HBM Or CDM)**
  - **Example: A Device That Passed HBM At 400 Volts And Failed At 500 Volts Would Have A 400 Volt HBM Withstand Threshold**
- **ESD Classification - Letter And/Or Number Designation Assigned To A Device According To Its Withstand Threshold**
  - **Example: The Device Above Would Be Class 1 HBM (Every device has two classifications (HBM and CDM)**

HBM Classification (JS-001-2012)	Voltage Range (V)
0A	< 125
0B	125 to < 250
1A	250 to < 500
1B	500 to < 1000
1C	1000 to < 2000
2	2000 to < 4000
3A	4000 to < 8000
3B	≥ 8000

ESDA Technology Roadmap



ESDA Technology Roadmap



Do Device ESD Classifications Apply at the Board Level? Yes and No

- YES – Handling of boards is usually defined by the lowest threshold device on the board
- NO – Devices can fail at levels below their expected voltage threshold levels when mounted on PWBs (see CBE discussion later)

Why more progress on ESD than other types of EOS?

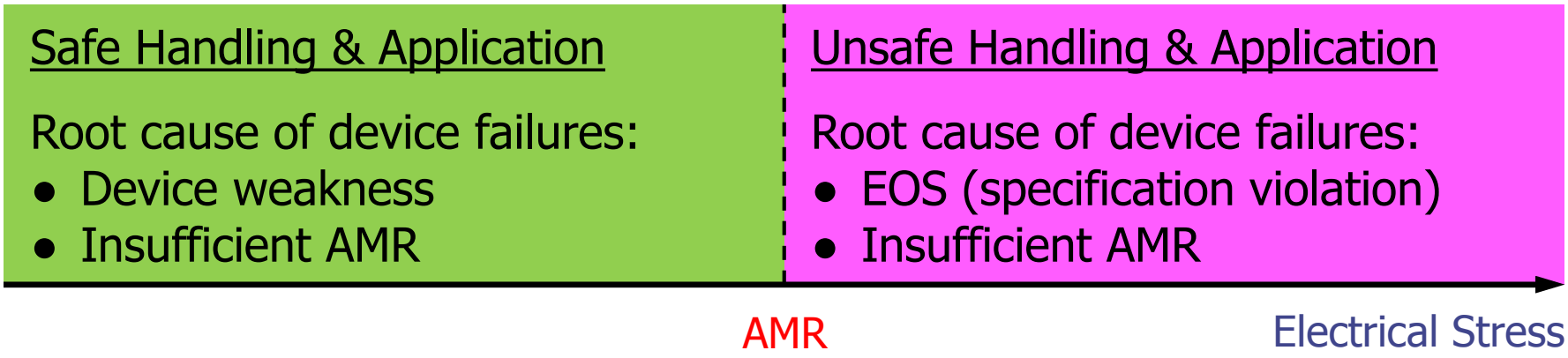
- Small number (~2) of ESD categories (HBM, CDM)
- At device level, well defined accepted models and test methods
- "Classification" has been an effective method for communicating ESD sensitivity
- Significant responsibility taken by IC manufacturers
- Resulted in dramatic continuous improvement in ESD threshold (1985-2000)

Early EOS Standard

- IEC60134 (January 1961) - Rating systems for electronic tubes and valves and analogous semiconductor devices
  - Scope: This recommendation applies to rating systems in use for electronic tubes and valves and semiconductor devices.
  - Definitions of rating, rating system, absolute maximum rating system, design maximum rating system, design centre rating system

Absolute Maximum Rating (AMR)

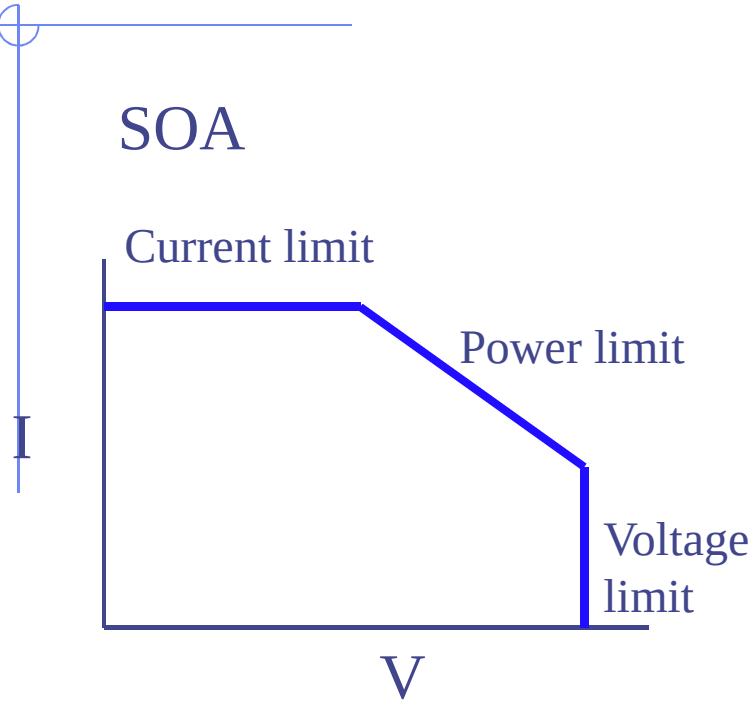
- Each user of an electronic device needs a criterion for safe handling and application of this device
- Each manufacturer of an electronic device needs a criterion to determine,
  if a device failure was caused by device weakness (caused by the manufacturer)
  or by specification violation (caused by the user)
- The Absolute Maximum Ratings (AMR) of the device represent this criterion

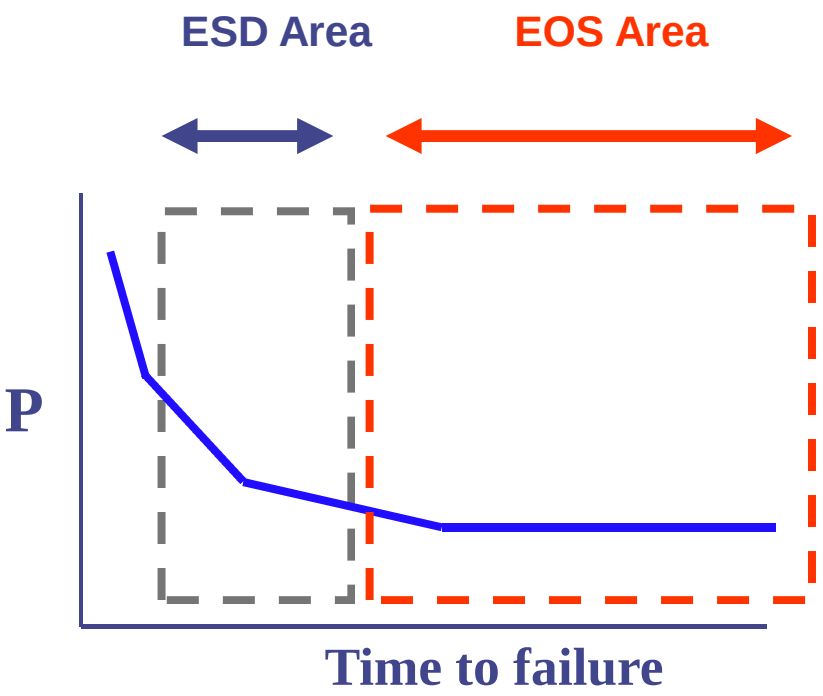


Safe Operating Area (SOA)

- **SOA** - A set of parametric conditions, often current and voltage, over which a device can be expected to operate without damage.
  - -Combines several AMR's
  - -Usually represented graphically
  - -Often found in datasheets as a design aid
  - -Maybe different SOAs for different pulse durations

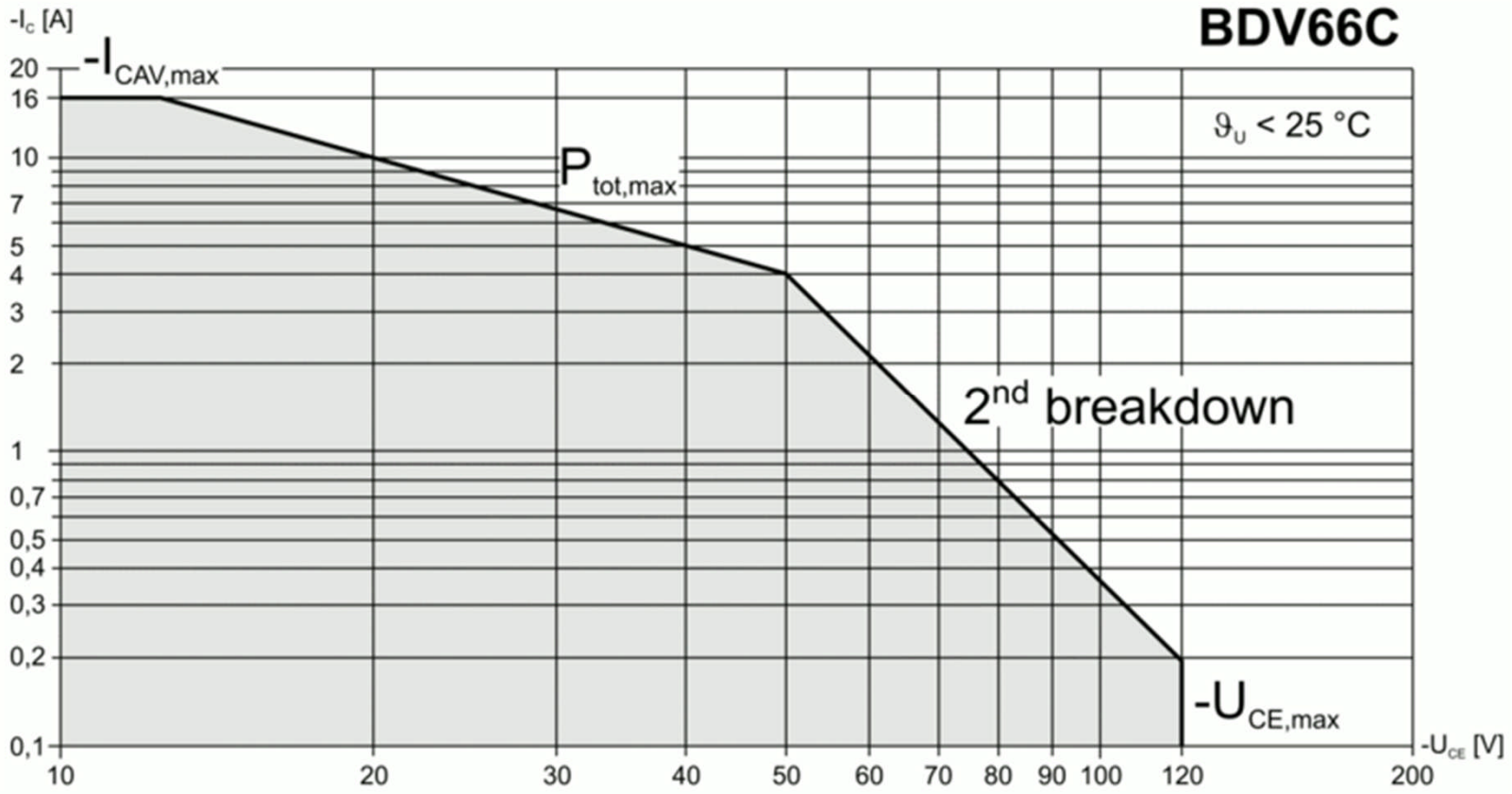
Safe Operating Area (SOA)





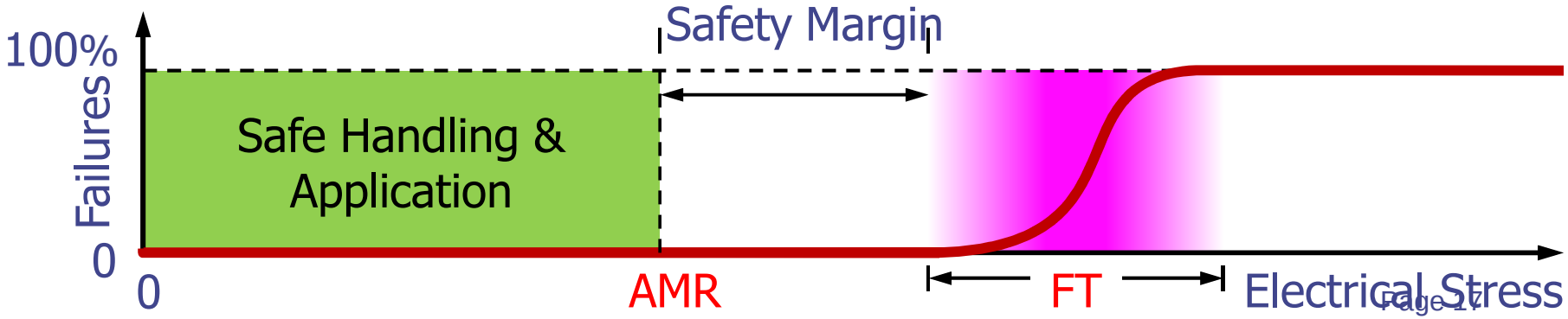
Over voltage tends to damage breakdown sites.
Over current tends to fuse interconnects.
Over power tends to melt larger areas.
EOS: Wide spreading of heat resulting in large areas of damage.
ESD: Heat does not disperse much causing localized failures.

Example Safe Operating Area (SOA)



AMR, Failure Thresholds and EOS

- Device robustness is represented by the typical failure thresholds failure thresholds (FT) of a device
- Failure thresholds are subject to the natural spread of the manufacturing process
- AMR *are set so as to provide the necessary safety margin* to the statistical spread of FTs and thus to avoid failures of healthy devices
- AMR are (or should be) published by device manufacturers
- FTs are NOT published by device manufacturers



Electrical Overstress (EOS)

(from ESDA EOS Technical Report to be published June 2013)

- Physically, EOS is any electrical stress (ES) that exceeds any of the failure thresholds of a device and causes it to fail.
- Practically, EOS is any electrical stress (ES) that exceeds any of the absolute maximum ratings (AMR) of a device and causes it to fail.
- Given these aspects of EOS, the definition of EOS being promoted by ESDA TR is: ***EOS is an electrical operation of device outside that device's AMR, leading to either damage, malfunction or accelerated aging.***
- ***Common alternate defintion:*** an electrical stimulus (event) outside the operational range of a component (includes ESD)

Electrical Overstress (EOS)

(Simple Working Definitions)

- ***Common alternate defintion:*** an electrical stimulus (event) outside the operational range of a component (includes ESD)
- ***Some improper but common uses of EOS terminology?***
  - ***FA –*** Large melted and/or burnt area on a chip
  - ***Pulse width –*** Any stress with longer time duration longer than ESD (Wunsch-Bell view)
  - ***EOS/ESD -*** means can't distinguish between:

    ESD

    overstress from excessive I, V, P

    Weak or defective device
  - ***Other?***
- ***We will revisit the EOS definition later***

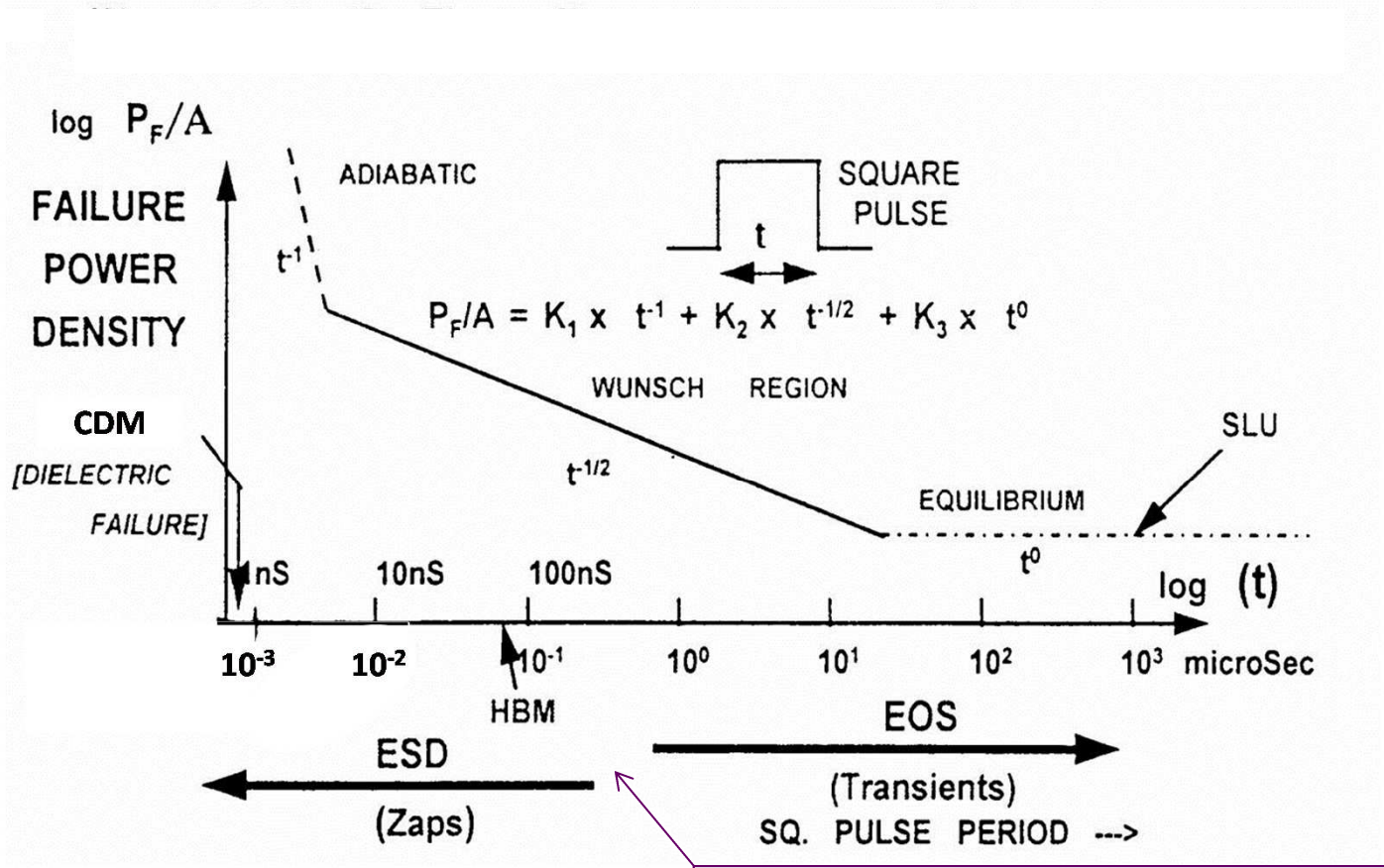
More About EOS

- An electrical stress produces an EOS *only* when it exceeds the device FT for that device (and therefore also exceeds the AMR)
- Any EOS of an „healthy“ device is a violation of the specification of the failing device
- A device is „weak“ if any of its failure thresholds falls below the expected tFT range of the device
- An EOS cannot occur without a device (compare ESD which is defined as a physical process on its own)

How do we categorize EOS?

- By Stress Type?
- By Failure Signature and Physical Damage?
- By Root Cause?
- By Failure Mechanism?
- By Pulse Waveform Characteristics?

Thermal Failure Models (Wunsch-Bell-Tasca)

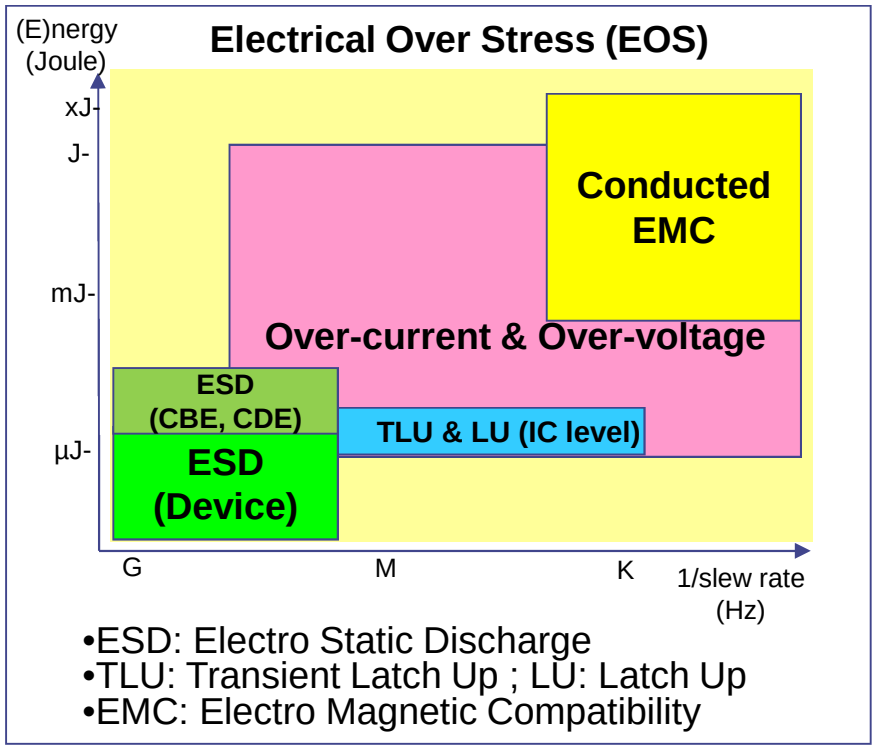


Artificial division between EOS & ESD

Industry Council White Paper 3 Part I & Alan Righter (2011)

Another Set of EOS Categories

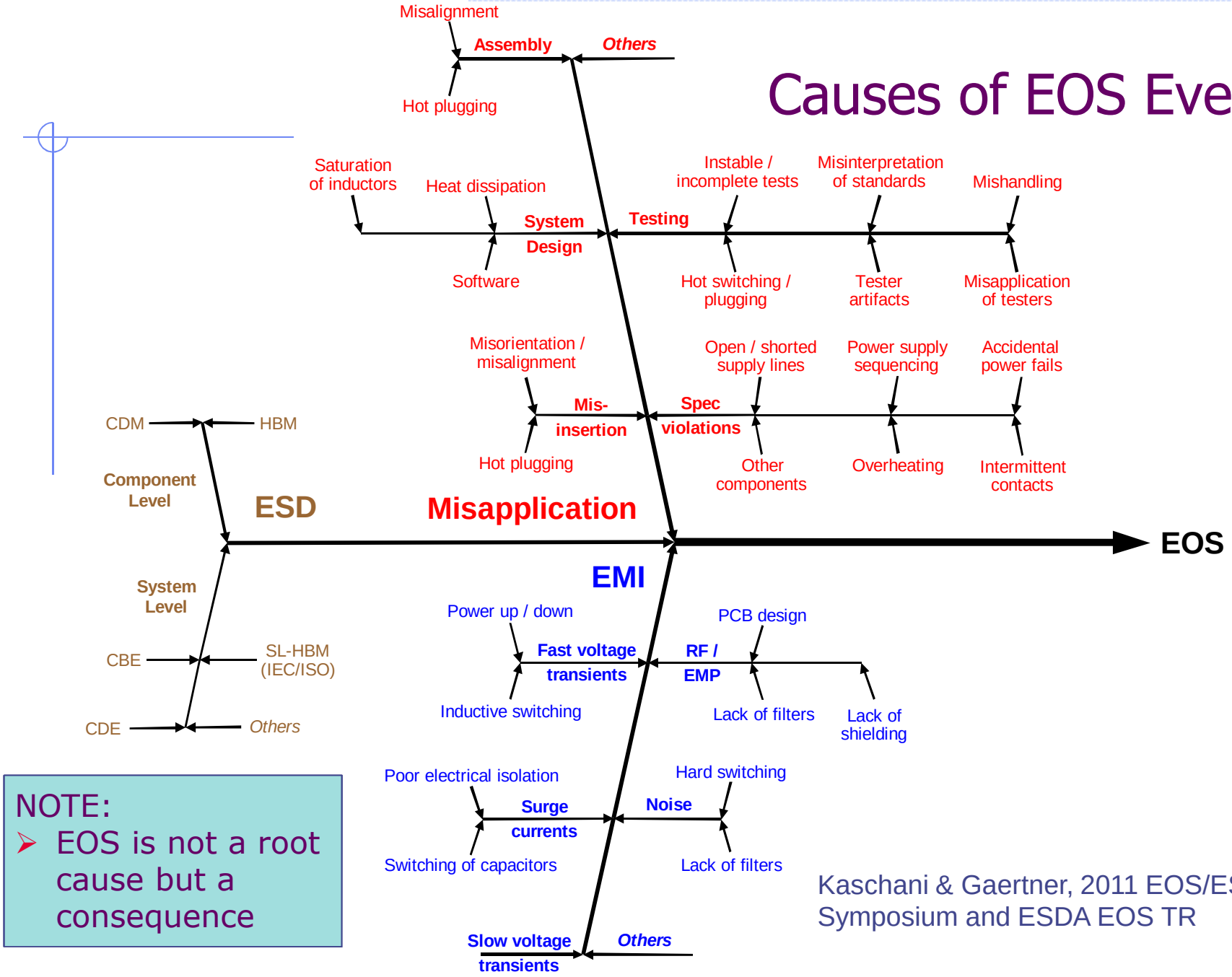
- ESD, TLU & LU, EMC, Over-current & Over-voltage => Frequency and Energy range



Main test standards at system level:
(Conducted EMC: 61000-4 series)
-IEC/ISO: ESD-HBM
-IEC: SURGE
-IEC: BURST
-IEC: Pulse field
-IEC: Damped oscillation
-IEC: voltage dips, short interruption & variation

Main Std & test methods at IC level:
-JEDEC/ESDA/JEITA: ESD-HBM
-JEDEC/ESDA/JEITA: ESD-CDM
-JEDEC/ESDA: Latch-up
-ESDA: ESD-HMM

Causes of EOS Events



NOTE:

- EOS is not a root cause but a consequence

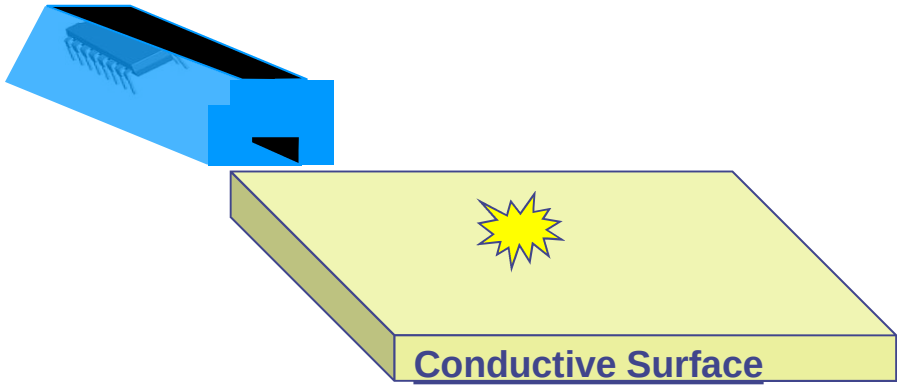
Kaschani & Gaertner, 2011 EOS/ESD Symposium and ESDA EOS TR

Charged-Board Event – ESD that "looks like" EOS

Charged Device Model

“99% of ESD Failures are CDM!”

Andrew Olney, Analog Devices, Quality Director

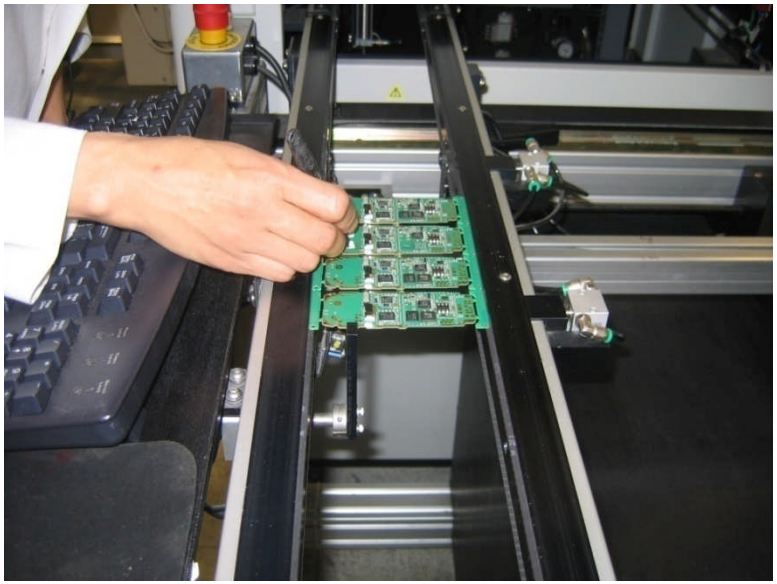


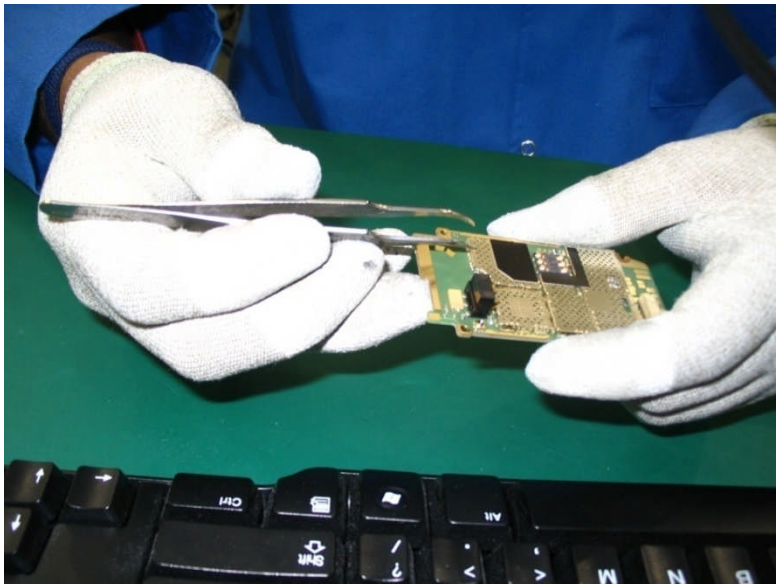
Capacitance of Device

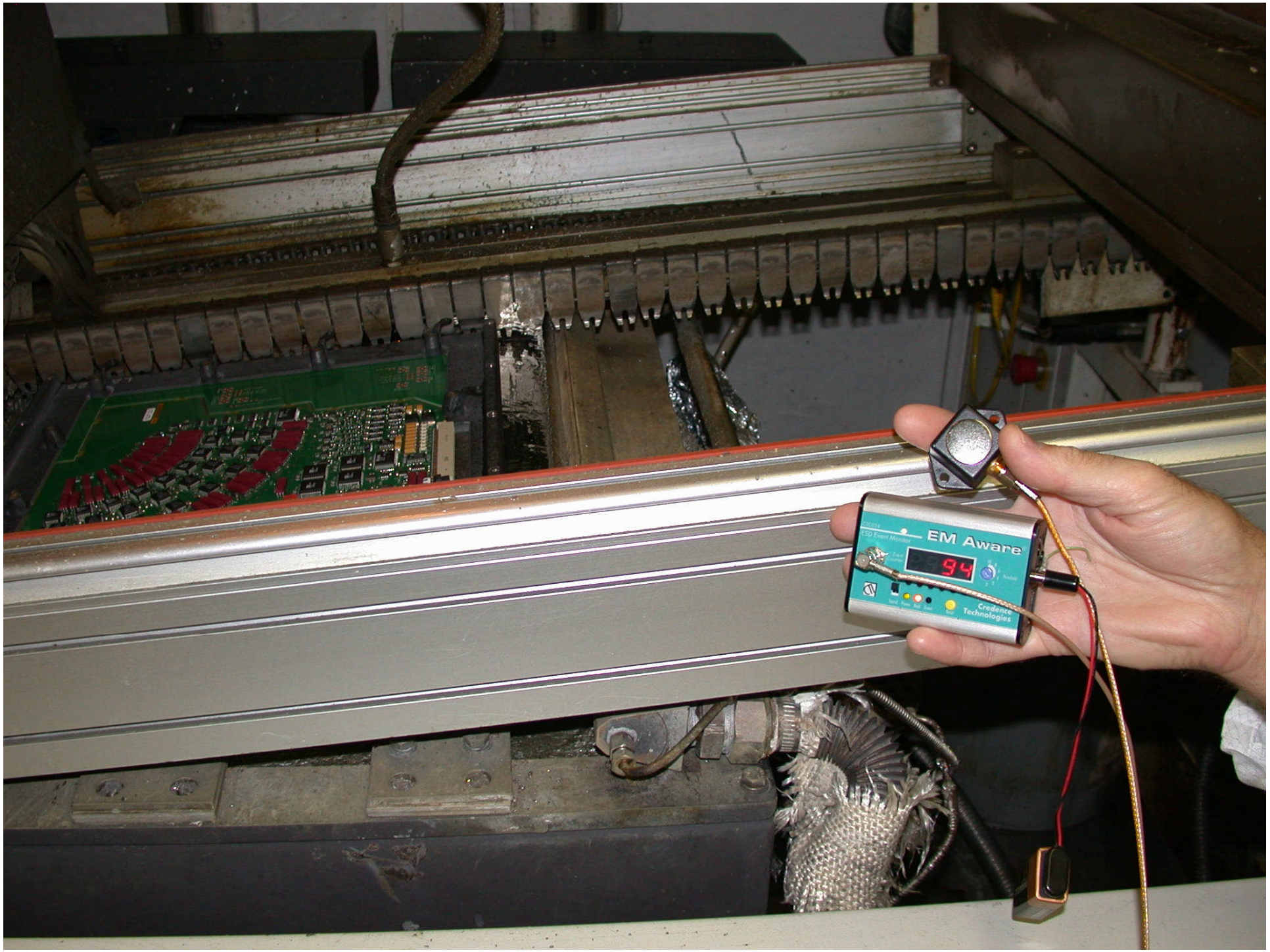
Contact Resistance

CBE Background

EOS/ESD failures of ICs that are mounted on Printed Circuit Boards (PCBs) have been published since 1981

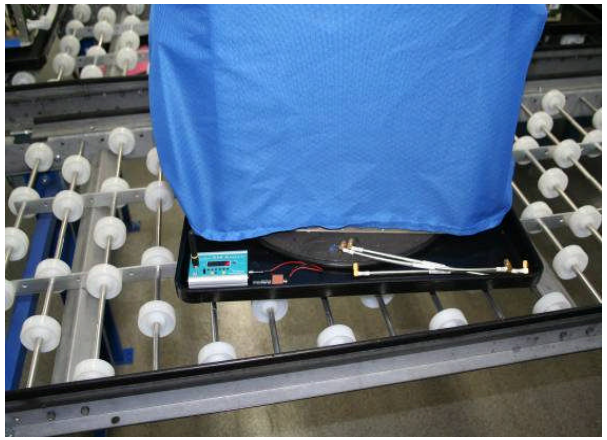





EM Aware
94
Credence Technologies

Charged Rollers in Conveyors

Events and charging detected as boards on and between conveyors



Root cause is static generating rollers

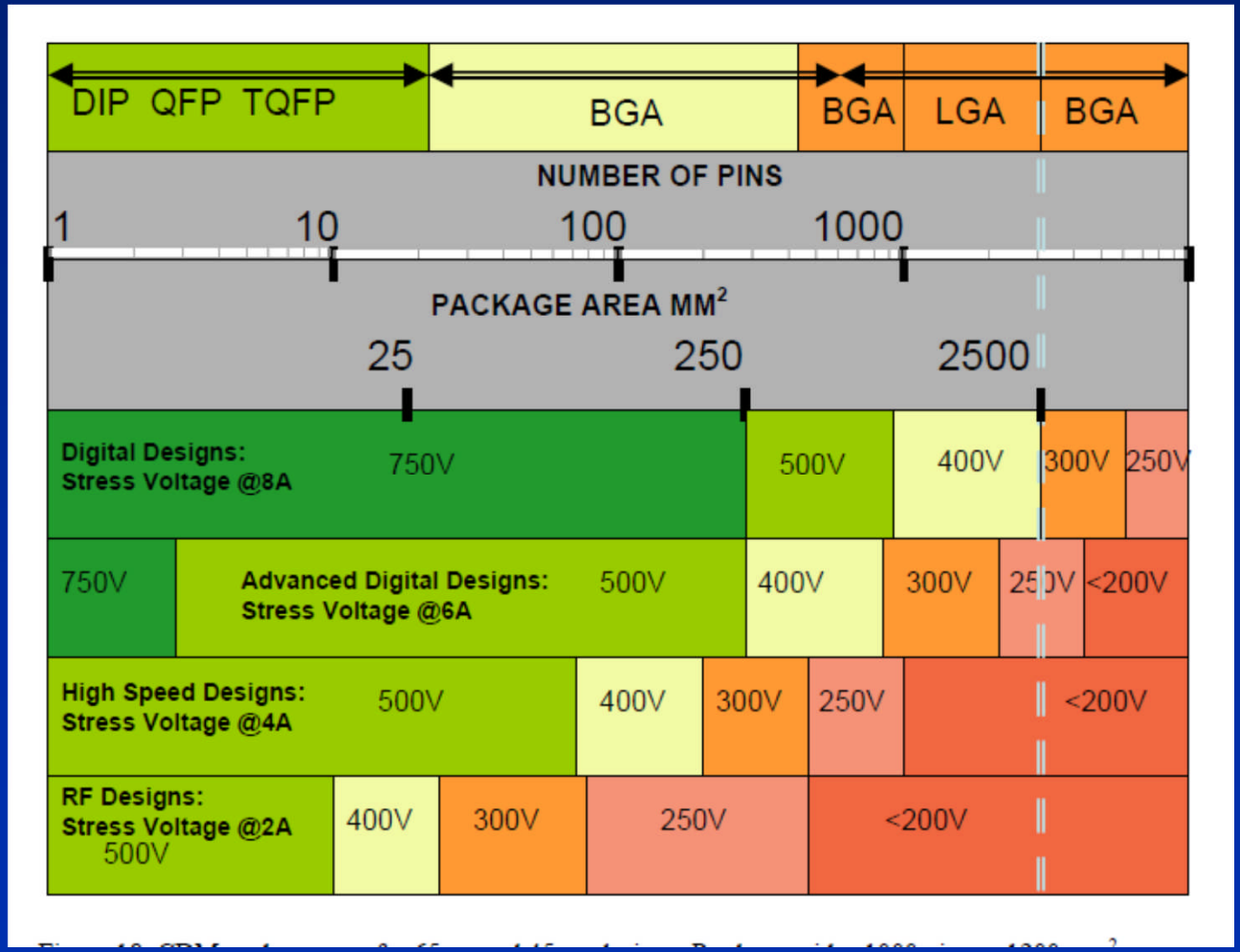
Induction

3000 volts on Plexiglas cover can cause CBE when board is touched

CDM Threshold Dependencies

Larger Device Package Size

Higher Operating Speeds



Ref: Industry Council WPII 2009

CDM Threshold Dependencies

Larger Device Package Size

CBE

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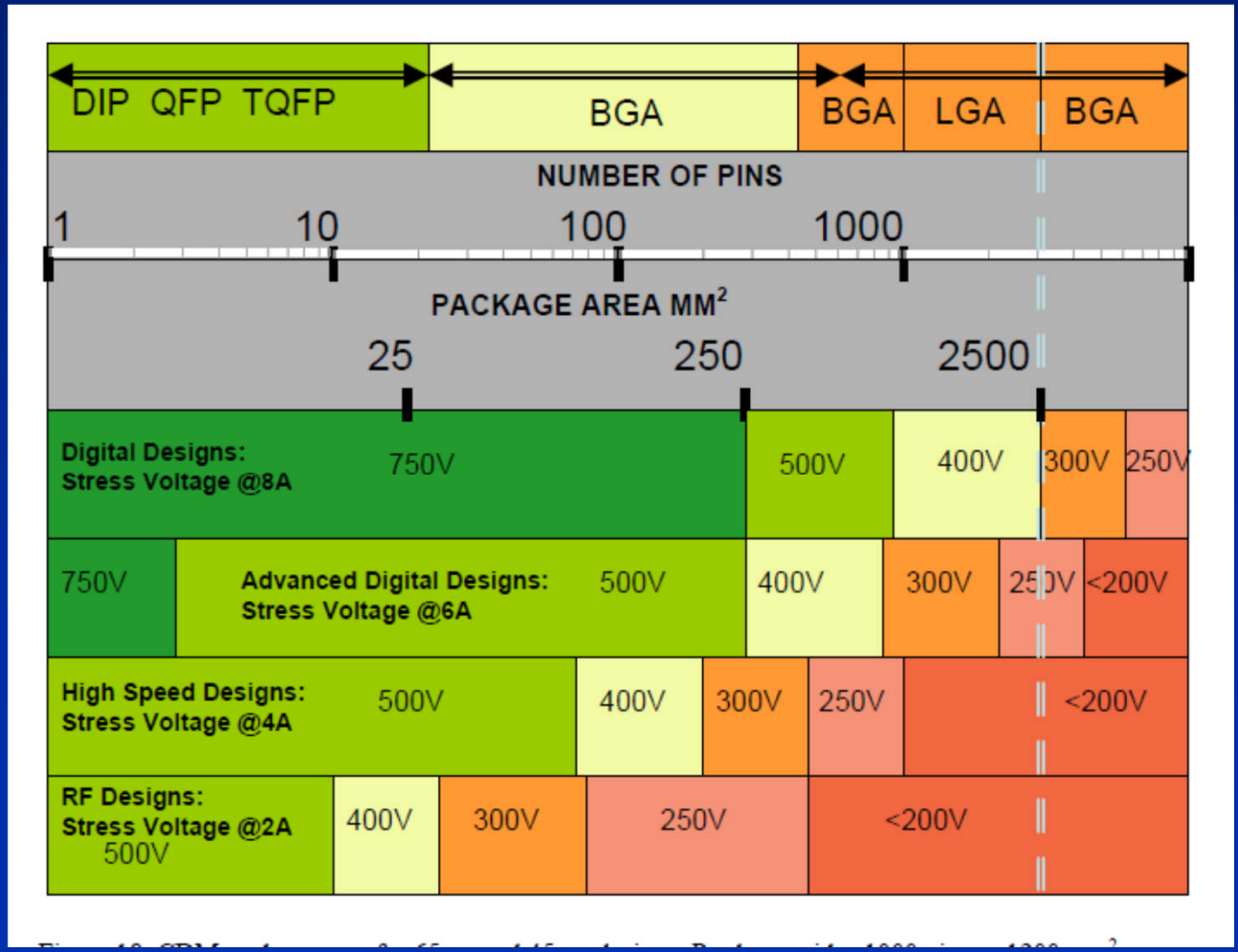


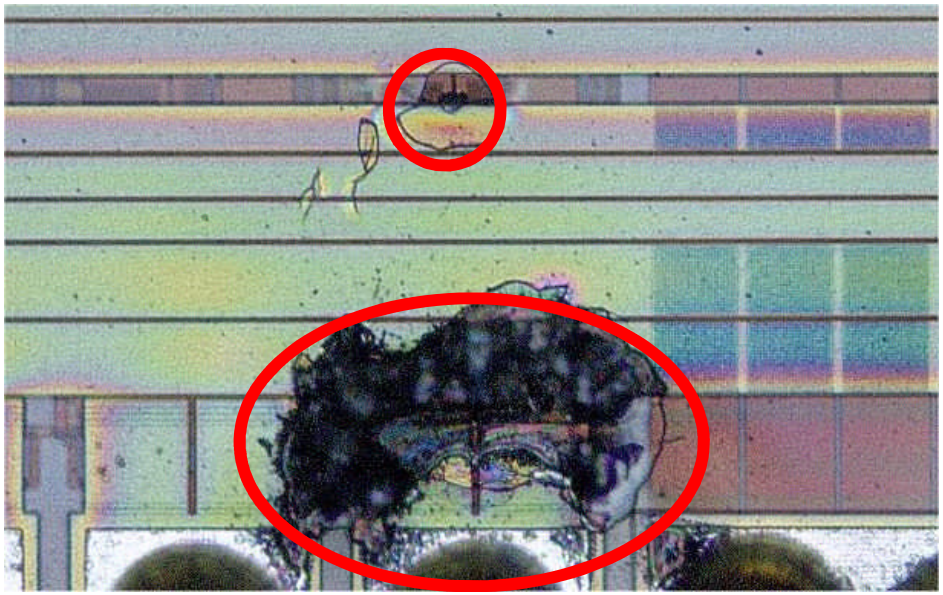
Ref: Industry Council WPII 2009

Charged Board Event (CBE) — Overview

- CBE is analogous to CDM — PCB is the "device" which stores the charge.
- PCBs have higher capacitance than an IC, so peak discharge current for a CBE event is typically but not always >> than for a CDM
- Rise time can be similar or longer depending on series impedance
- CBE discharge damage easily mistaken for power-induced electrical overstress (EOS) damage.
- Some report as high as 50% misdiagnosis.

CBE Damage — An under-reported event!

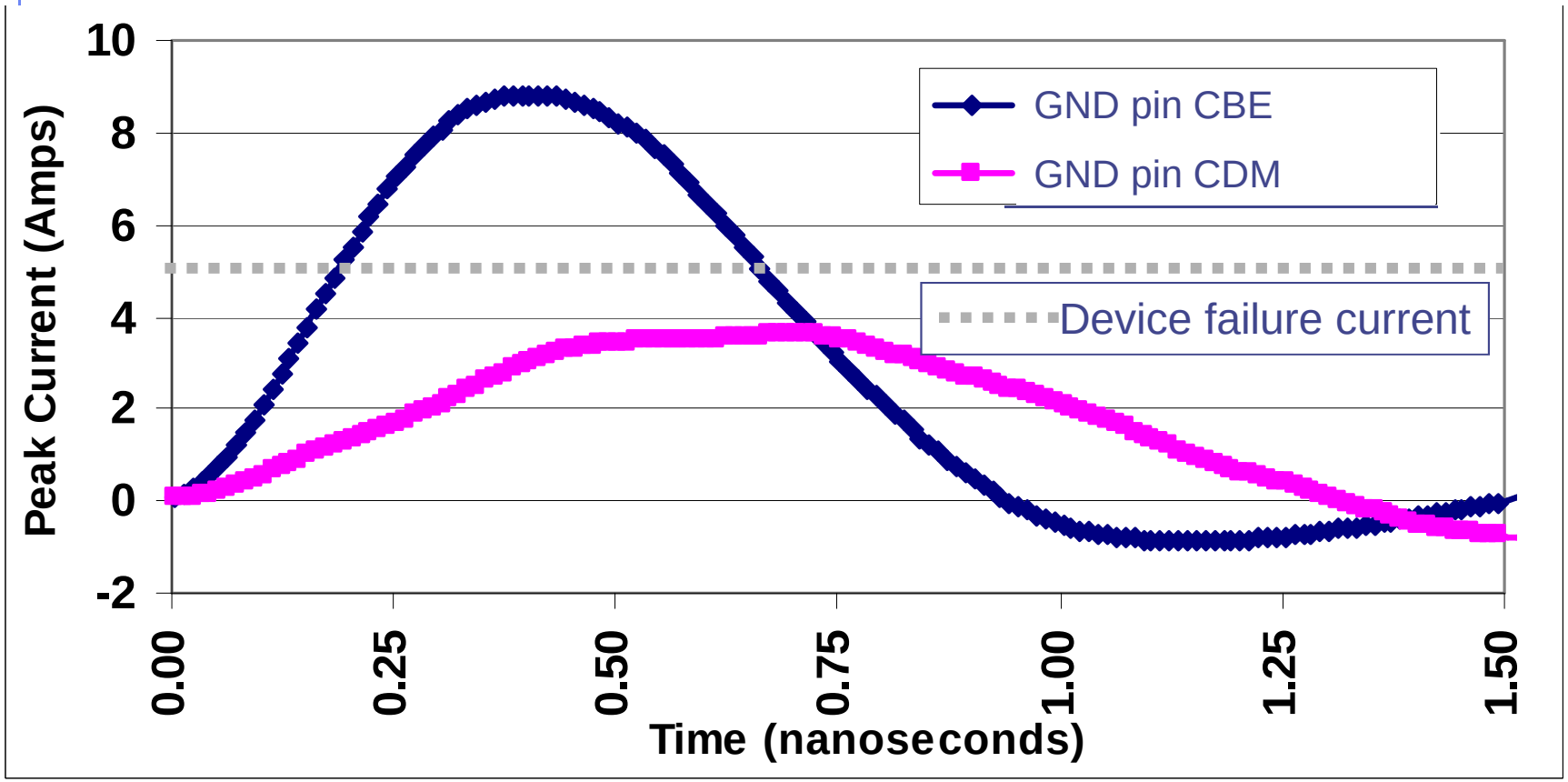
Up to 50% of "EOS Failures" are CBE but many are misdiagnosed (and thus root cause is not found and eliminated)! (2008)



CBE Device Damage on Circuit Board

Courtesy: Andrew Olney, Quality Director, Analog Devices

CBE vs. CDM Discharge* Waveform Comparison (250 V)



*In both cases the ground probe contacts the same device pin directy

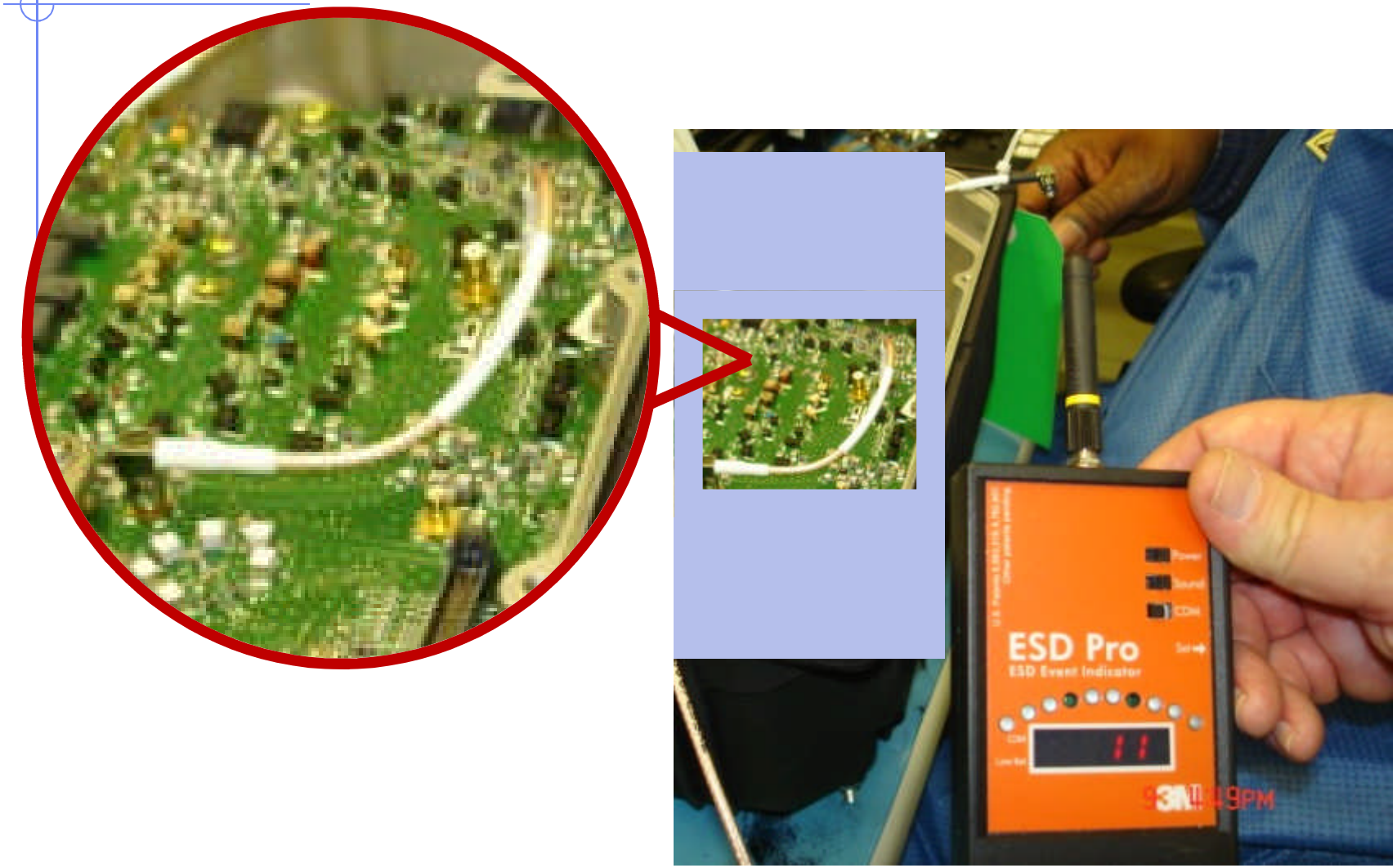
Cable Discharge Event (CDE)

- Occurs when Plugging Charged Cable Into Equipment (Ethernet, USB, Etc.) or in assembly manufacturing
- High Cable Capacitance can produce "EOS-like" damage
- Charge on cables can induce a discharge to equipment causing damage or malfunctions

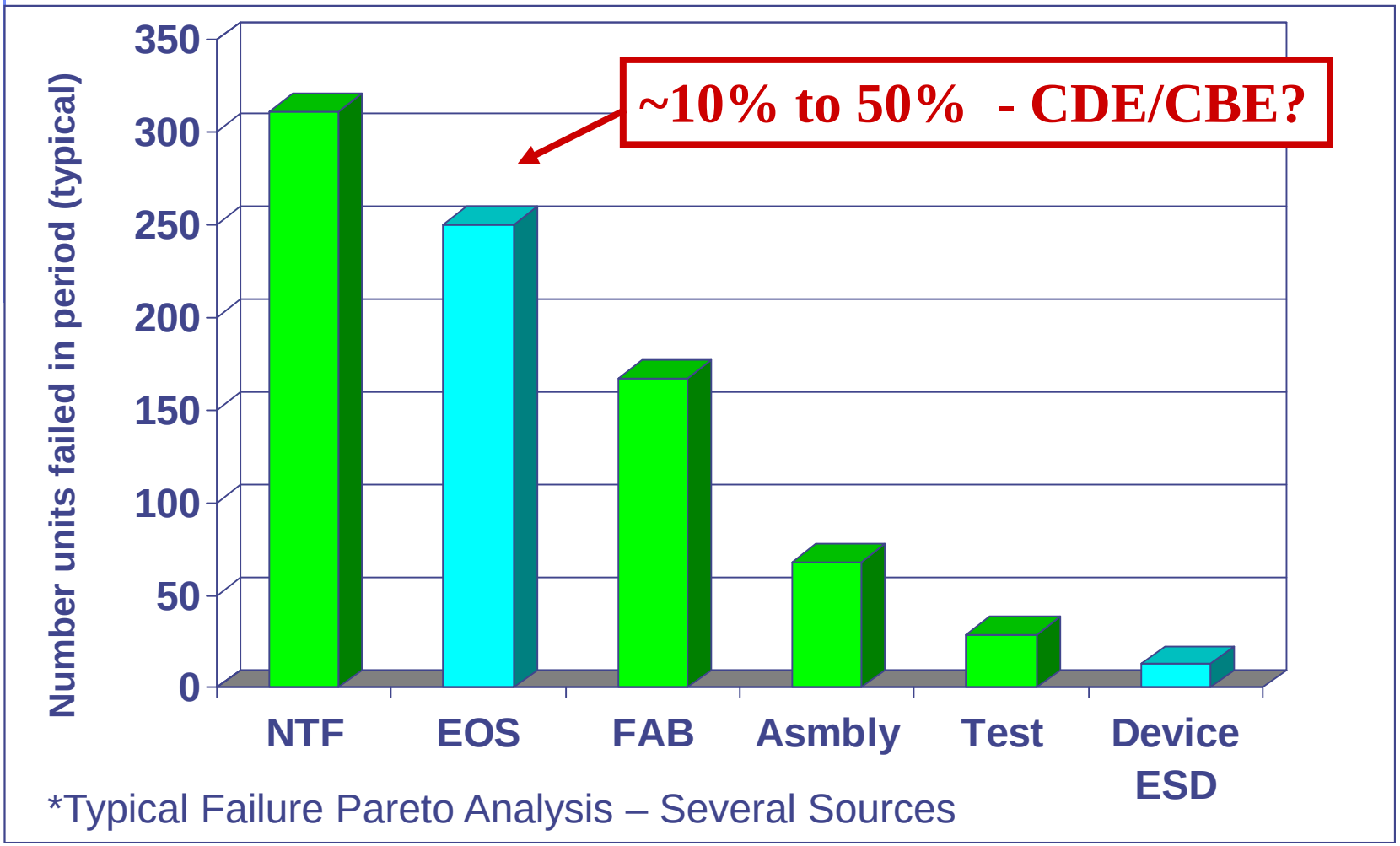
CDE in Assembly

Plastic bags triboelectrically charge cable as they are removed

Cable Discharges in Assembly



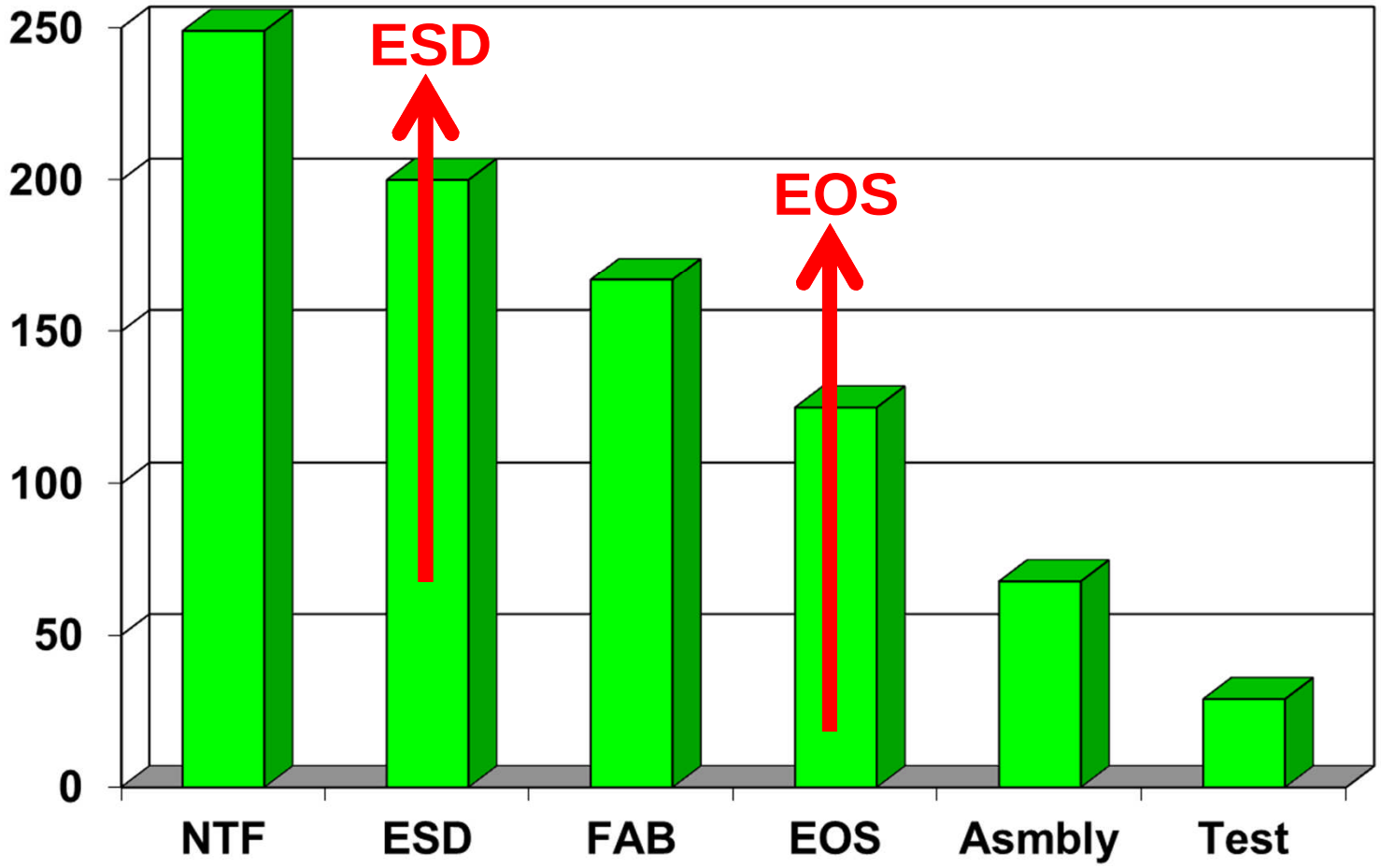
EOS: Important Failure Category*



*Typical Failure Pareto Analysis – Several Sources

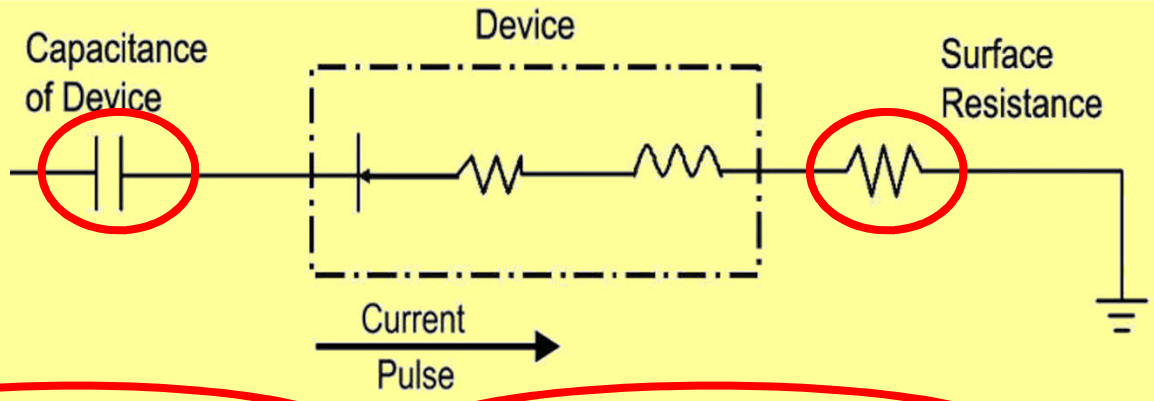
ESD & EOS Failures Likely to Worsen

Without Advanced Mitigation



*Typical Failure Pareto Analysis – Several Sources

CBE Mitigation
Two Strategies



Lower board voltage or higher surface resistance in the discharge path can *reduce discharge current*.

CDE Mitigation

- Avoid charging cables by motion
- Ground cable and connector (or maintain at same potential)
- Do not plug cable in presence of charged insulators
- Use ionization if necessary
- Monitor critical steps using event detection

Sources of EOS from "Power" – P-EOS?

- High ground impedance (inductive coupling)
- Ground loops
- Improper power wiring
- DC voltage from tools in automated equipment
- DC voltage from ungrounded floating metal
- Faulty soldering irons and power tools
- Faulty power adaptors
- Hot plug-in and faulty power sequencing
- Wirebonding

Categories of EOS by signal type

- AC continuous
- DC continuous
- Conducted transients
- Induced transients
- Fast transients

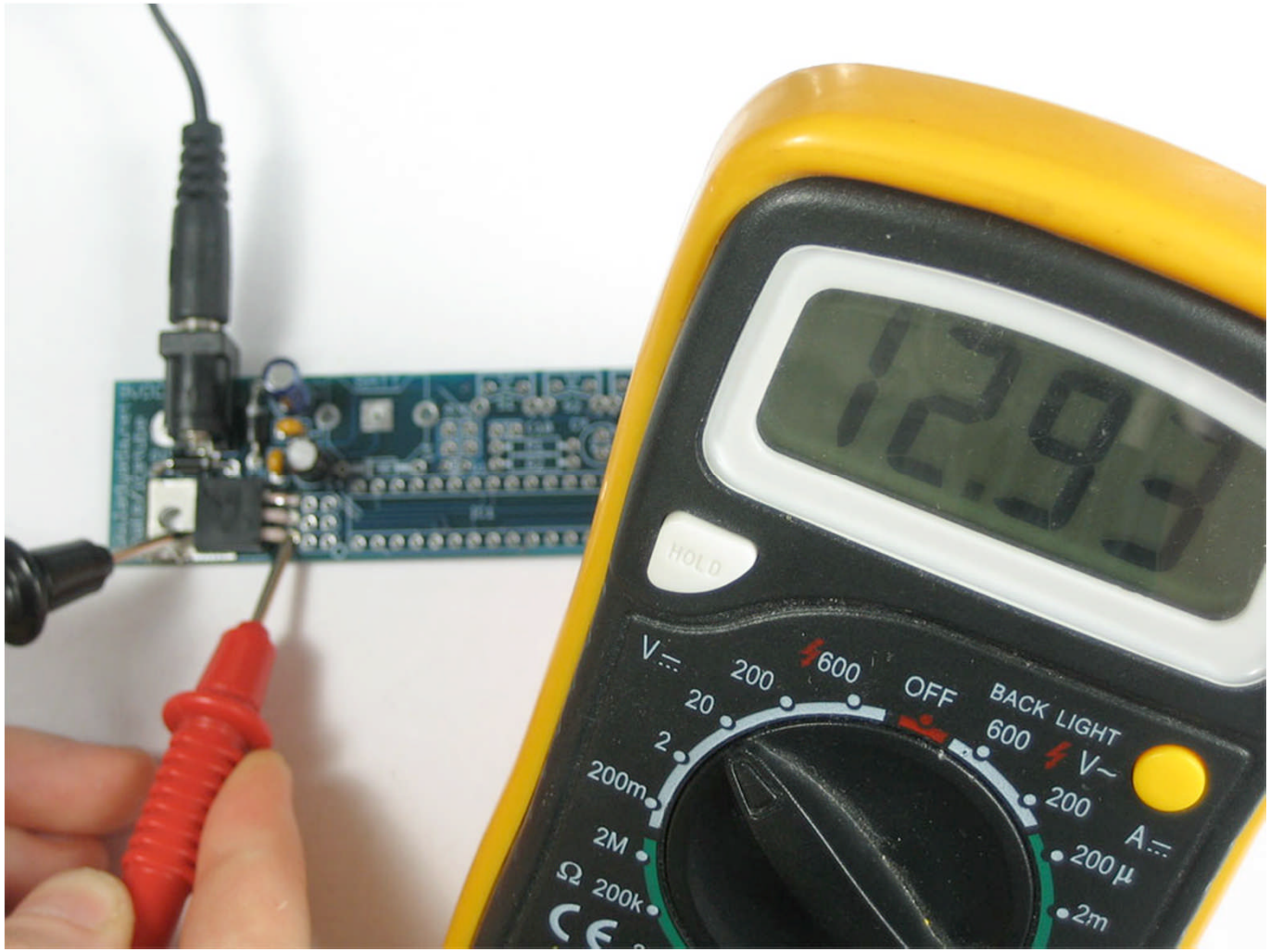
Sources of EOS in Manufacturing and Test

IPC-610 – EOS "Requirements"

Before handling or processing sensitive components, tools and equipment need to be carefully tested to ensure that they do not generate damaging energy, including spike voltages. Current research indicates that voltages and spikes less than 0.5 volt are acceptable. However, an increasing number of extremely sensitive components require that soldering irons, solder extractors, test instruments and other equipment must never generate spikes greater than 0.3 volt.

As required by most ESD specifications, periodic testing may be warranted to preclude damage as equipment performance may degrade with use over time. Maintenance programs are also necessary for process equipment to ensure the continued ability to not cause EOS damage.

DC Voltage From Tools



Production Sources

- Soldering Irons
  - Bad Grounding (Loss of Ground, Noise on Ground)
  - Noise on Power Line
  - Switching spikes
  - Tip oxidation
- Power Tools
- Power Supply Commutation

ESD Association STM13.1-2000
Electrical Soldering/Desoldering Hand Tools

Provides electric soldering/desoldering hand tool test methods for measuring electrical leakage and tip to ground reference point resistance

Tests:

- Resistance
- Voltage
- Current

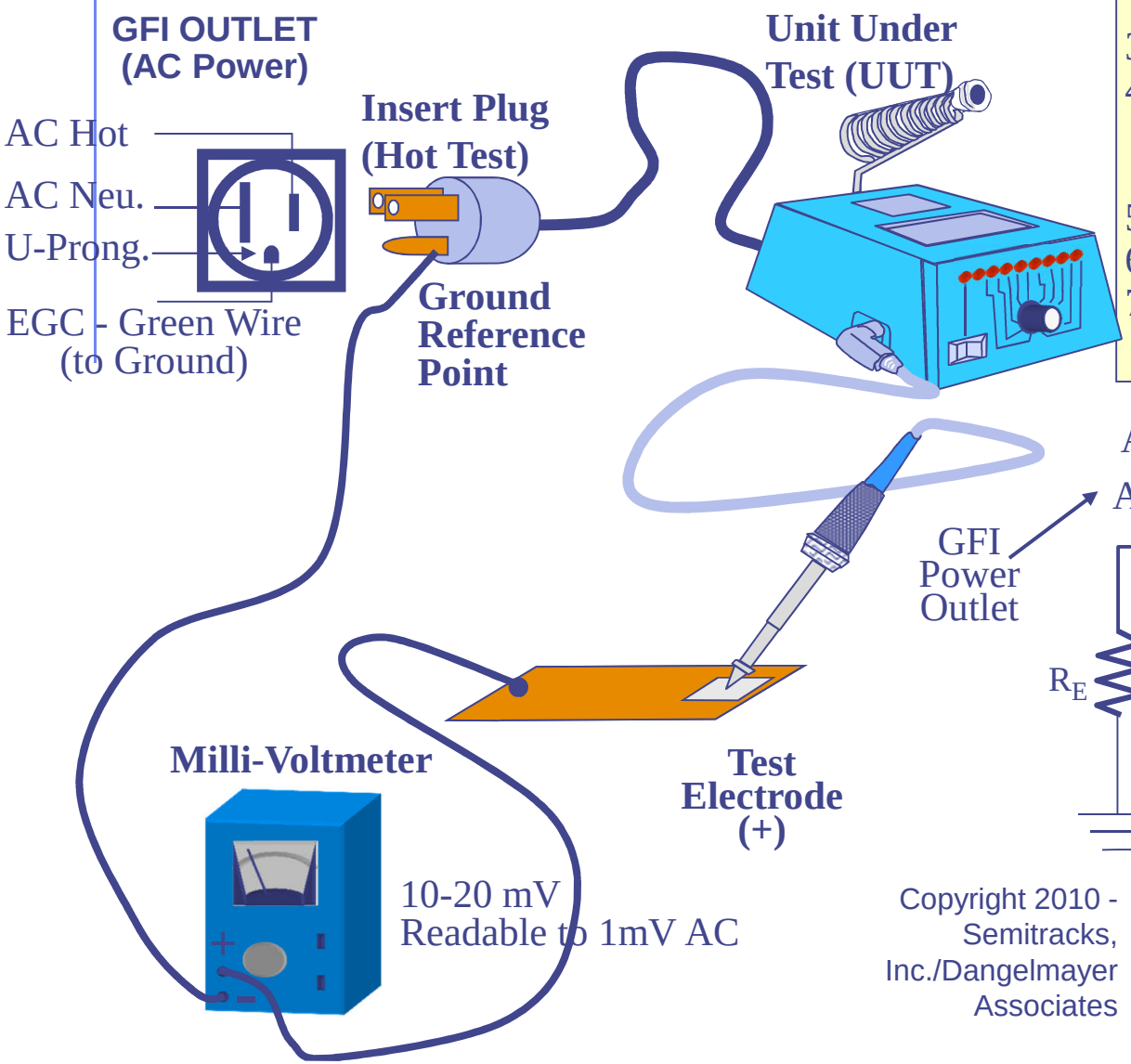
Soldering Iron Tip Voltage Measurement

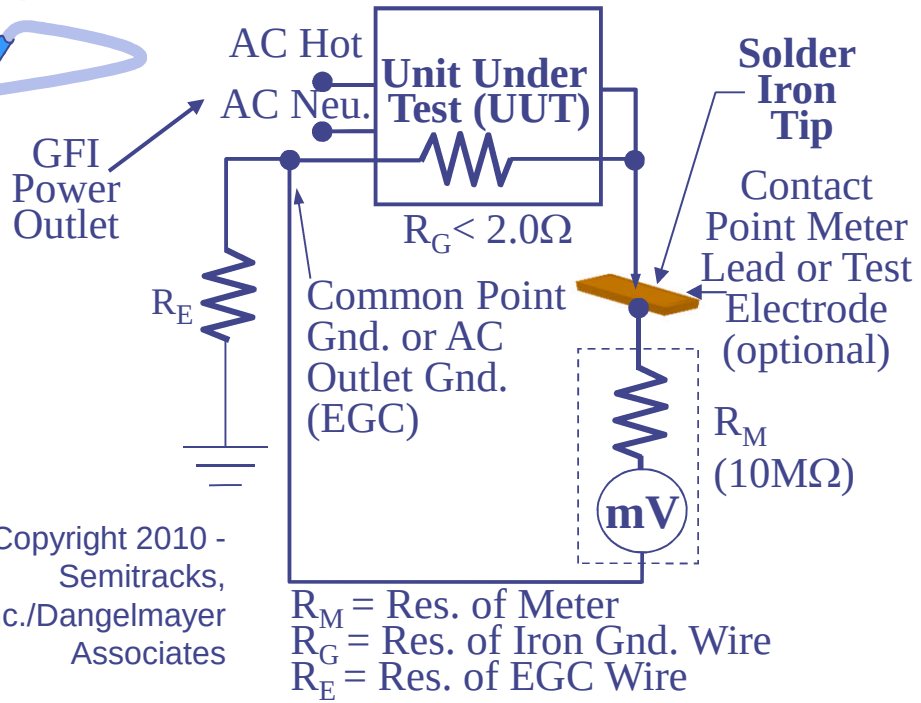
ESDA STM13.1-2000

Procedures

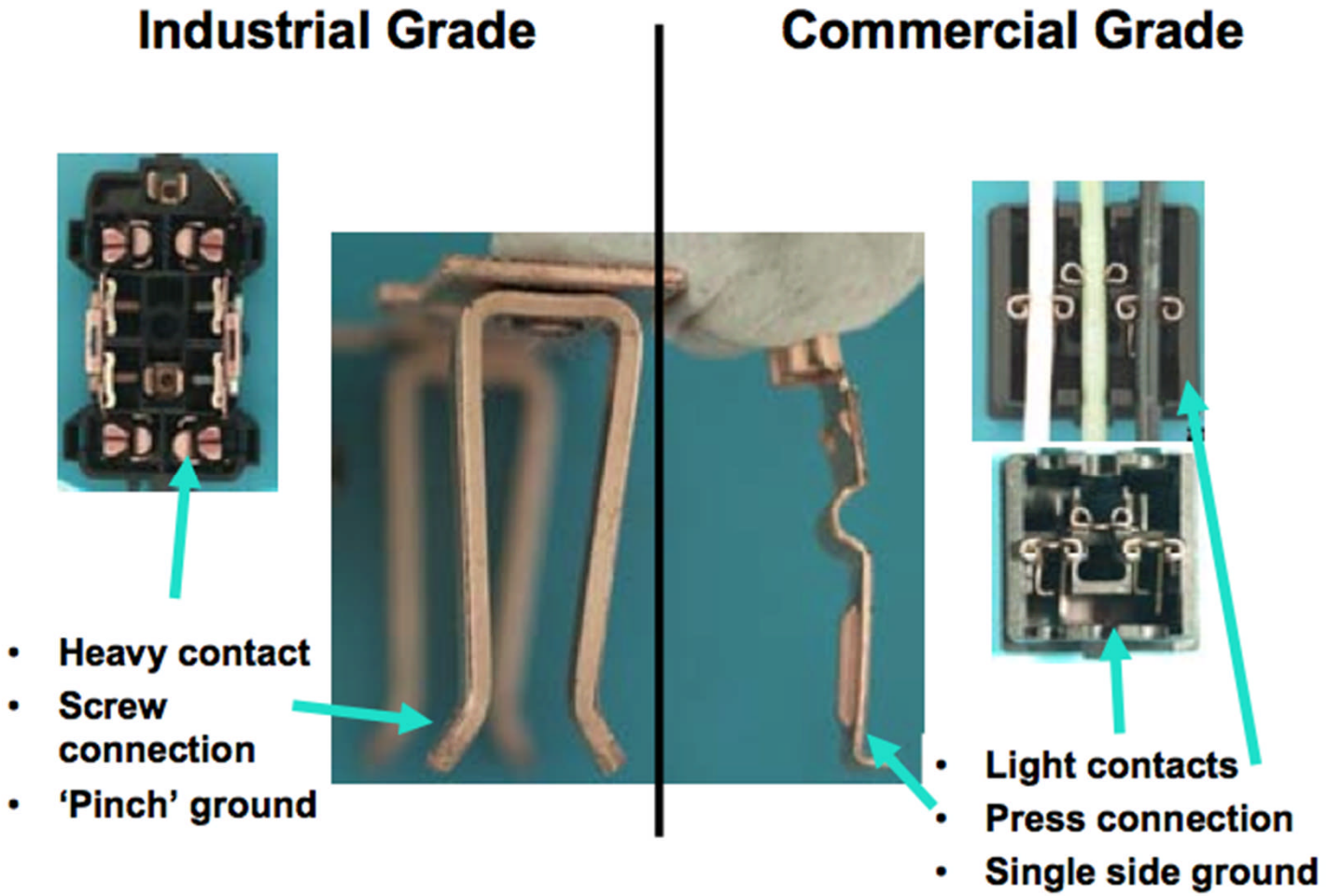
1. Connect negative meter lead to GRP.
2. Plug in UUT - Obtain operating temp.
3. Set meter to AC mv range.
4. Clean Tip

   Note: run various functions if present & allow to stabilize.
5. Record AC Measurement
6. Repeat for mv DC if desired.
7. Values shall be < 20 mv AC. (DC if DC is measured.

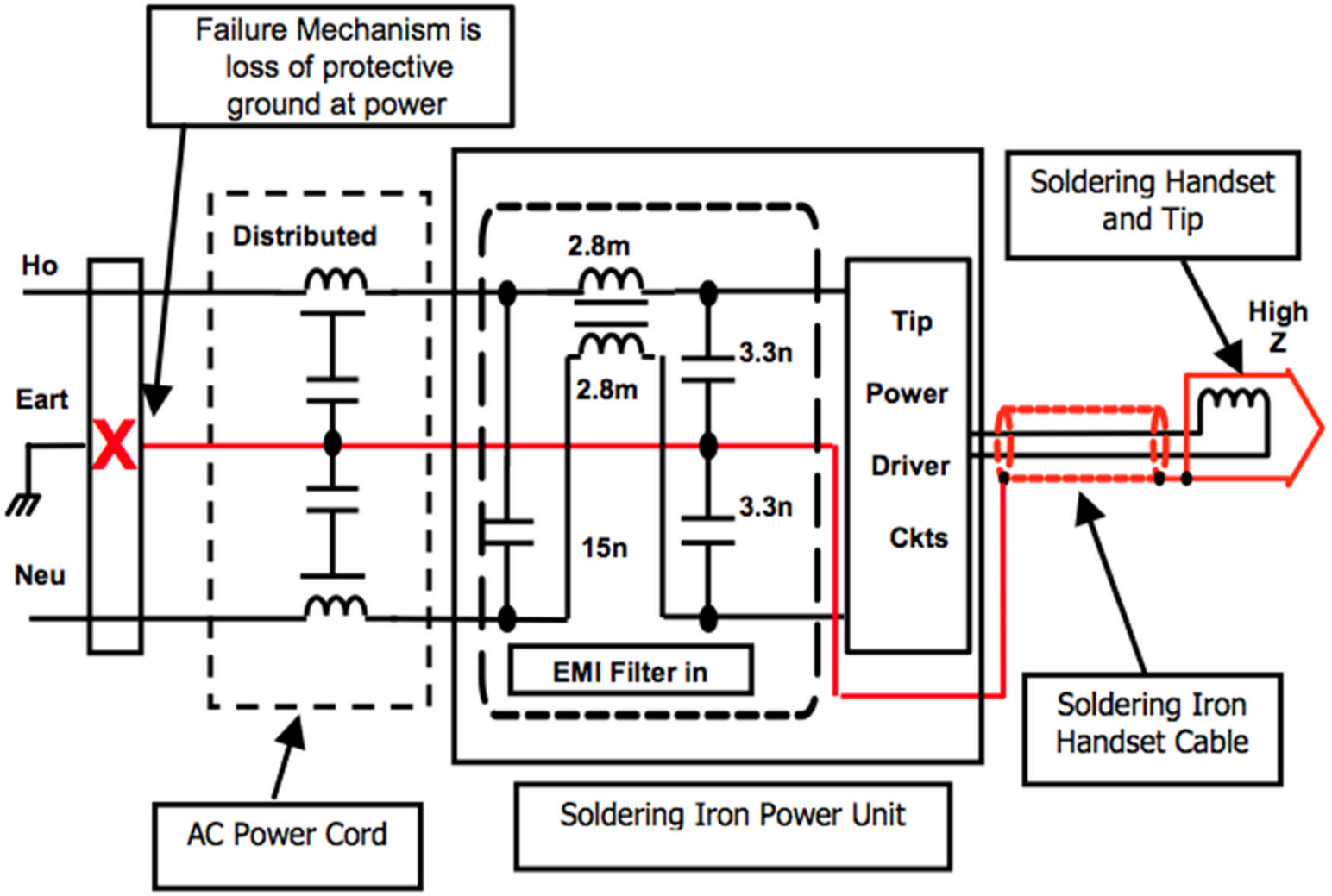




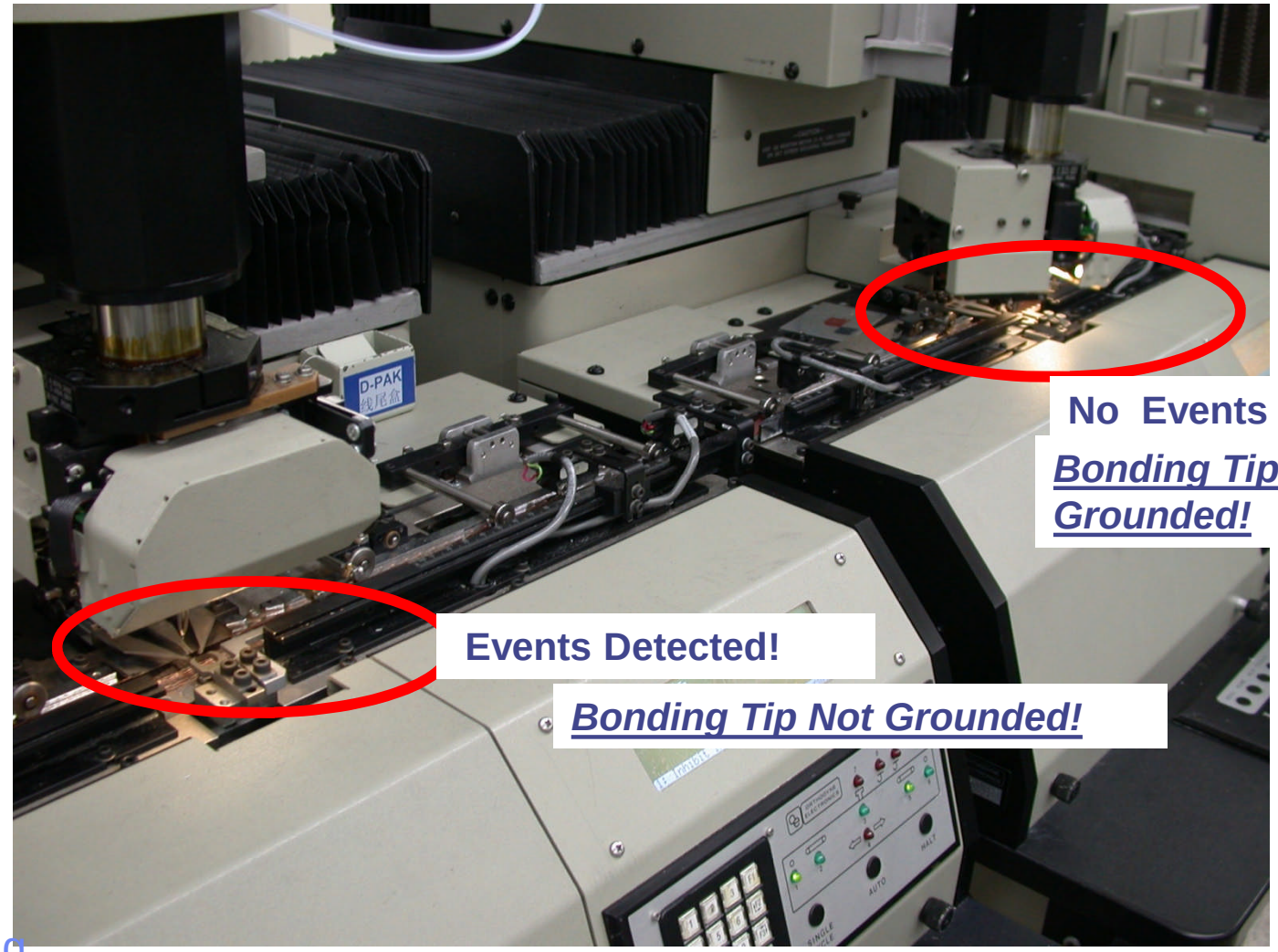
Faulty Power Receptacles



Faulty Power Receptacles (cont'd)

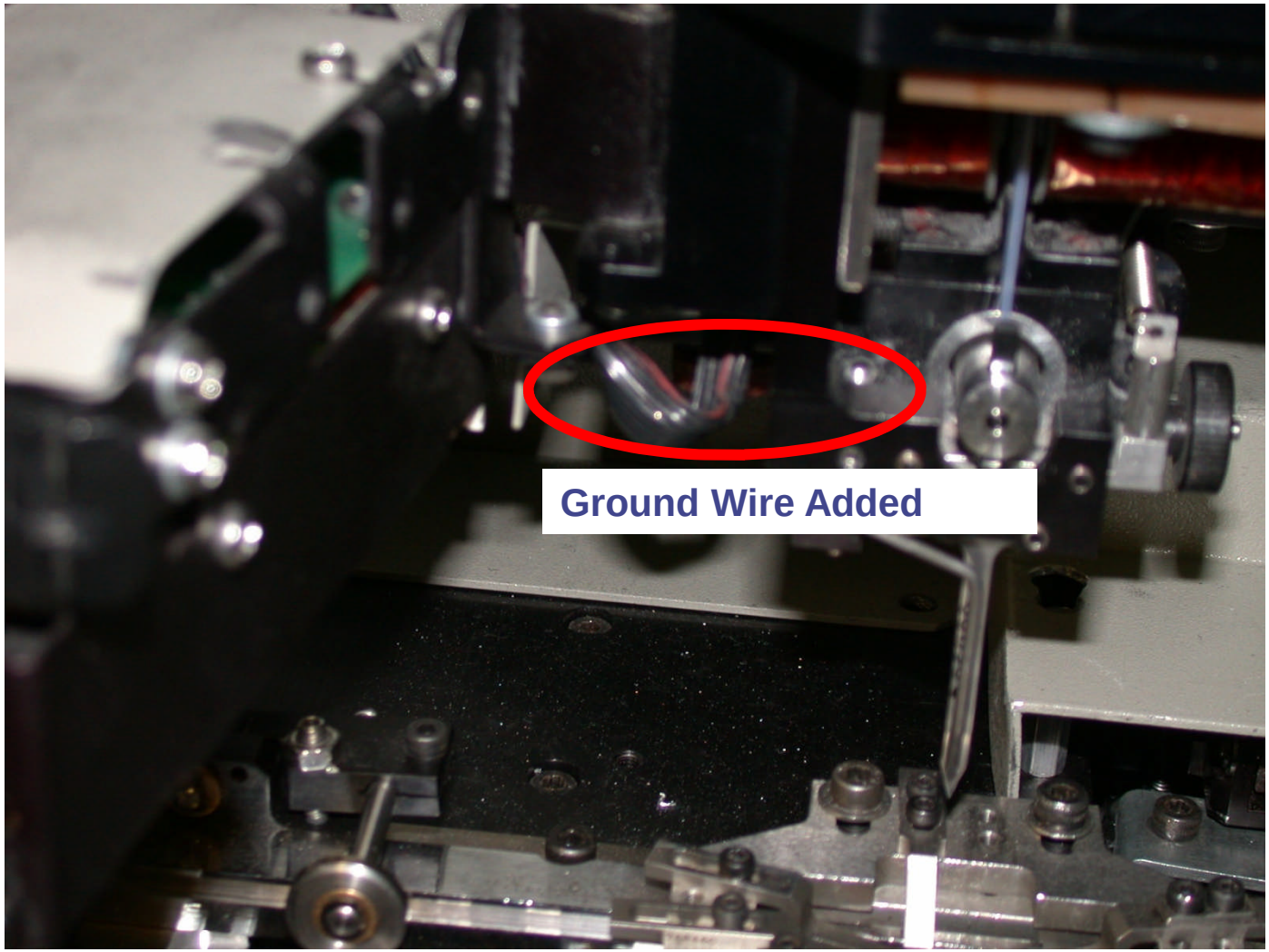


EMI Detection Exposes Faulty Grounding

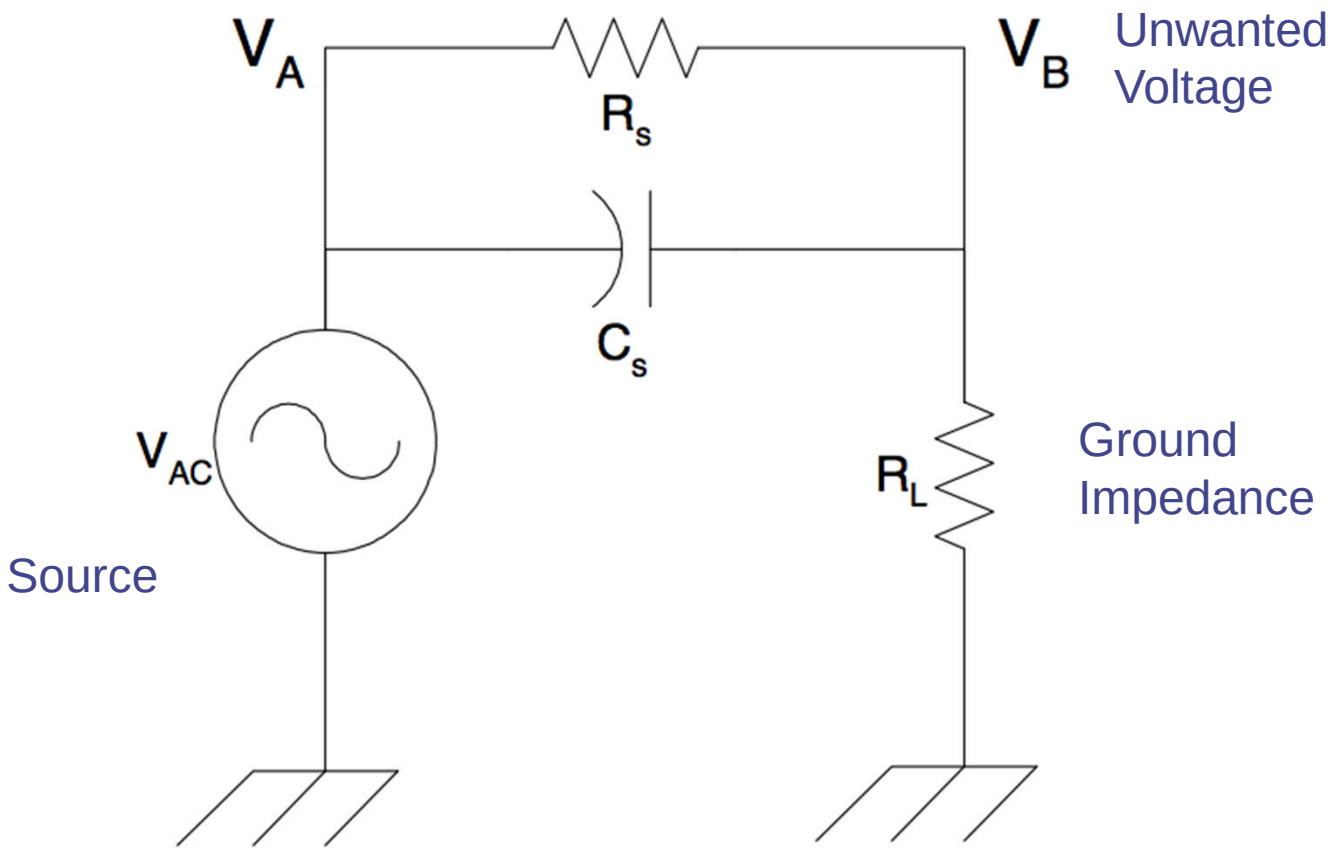


Video: Bonding EMI

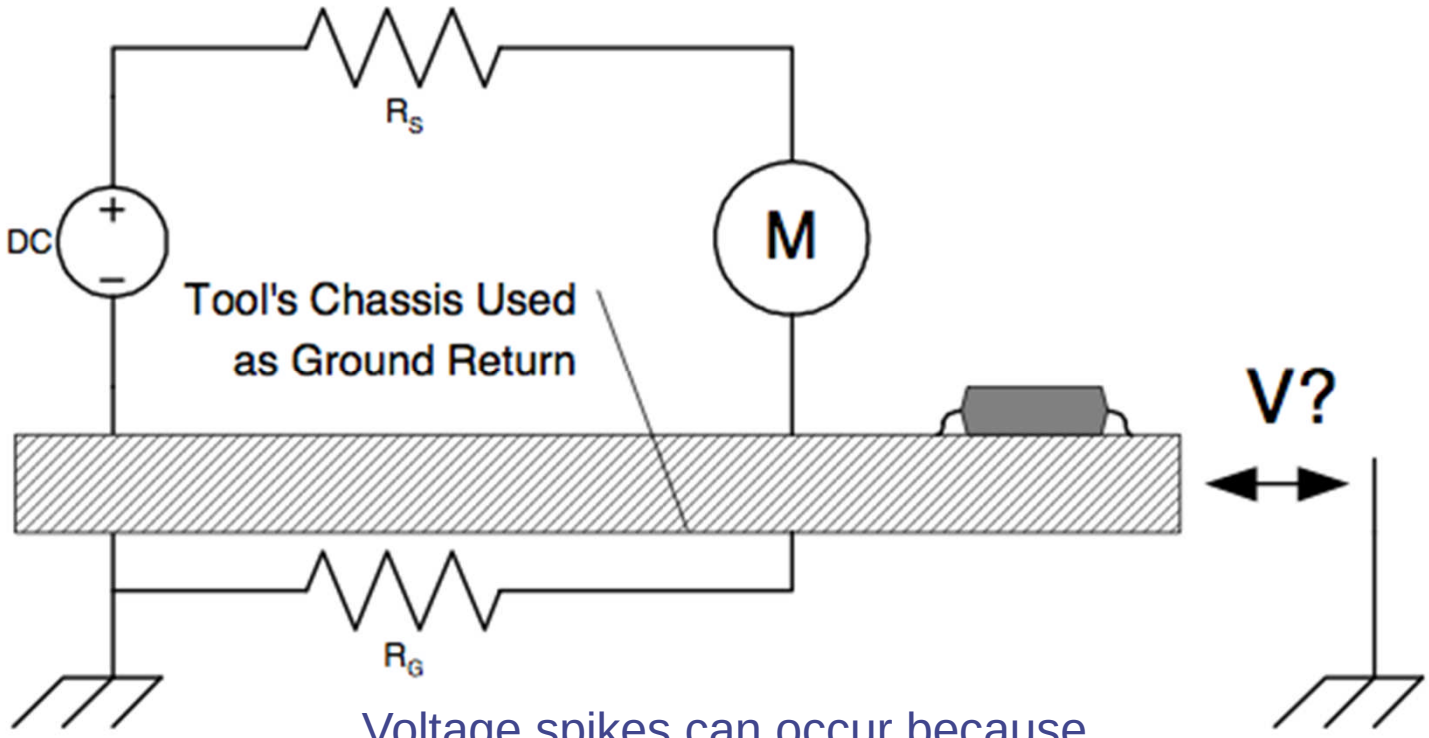
Corrective Action — Improved Grounding



Induction of an AC voltage

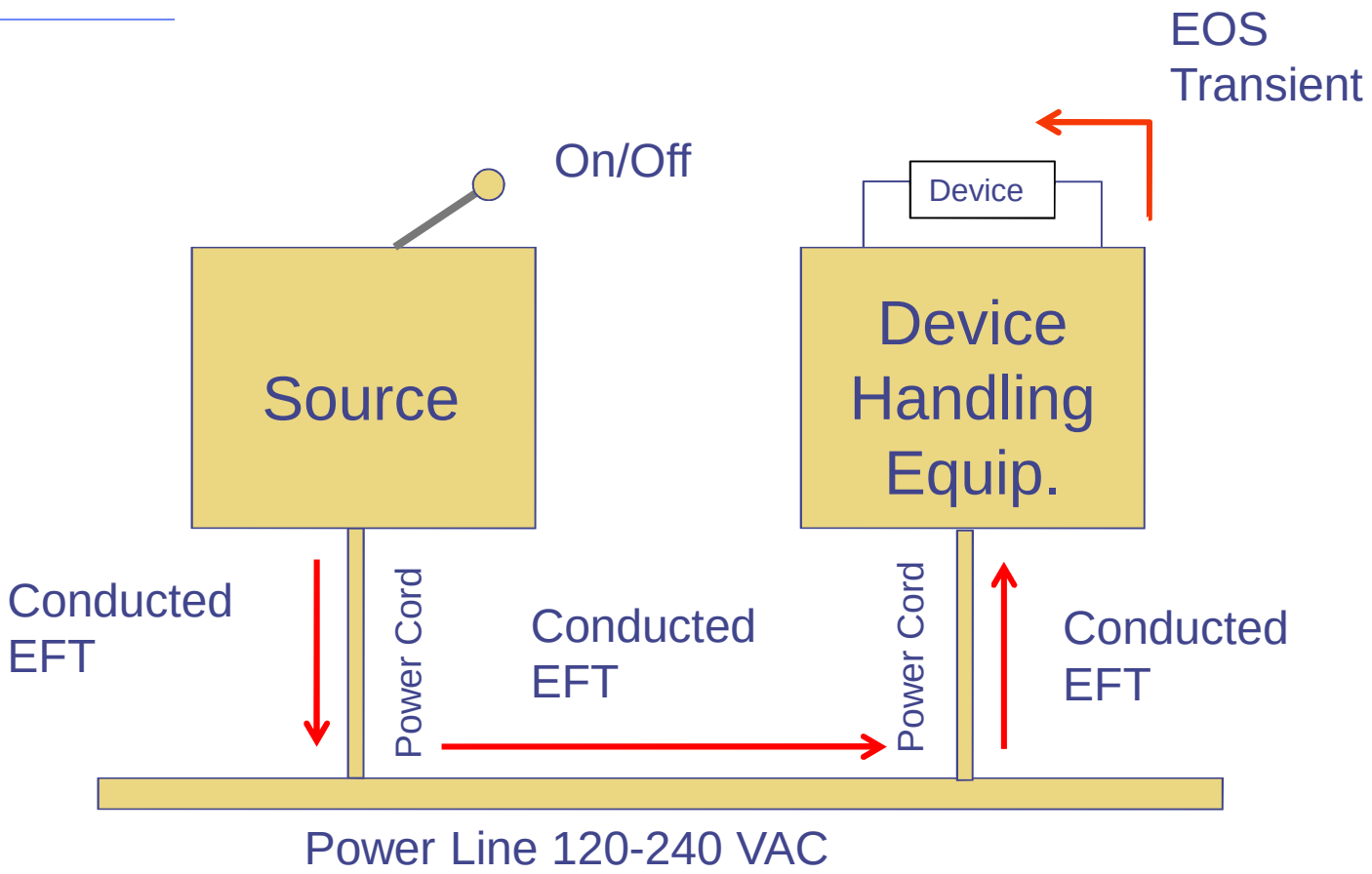


DC-Caused EOS



Voltage spikes can occur because tool chassis resistance is not zero

Fast Transients (EFT) on AC Power

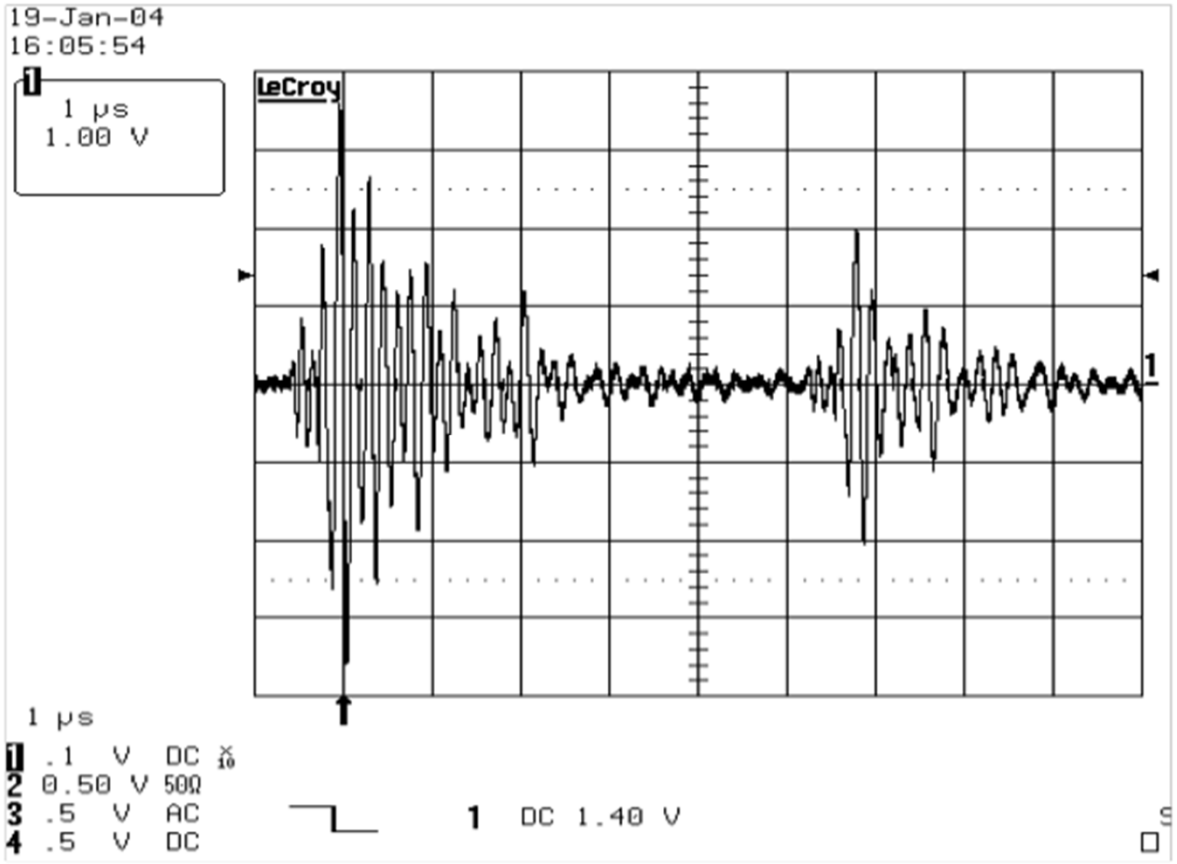


Sources:

- Plugging power cord
- Switching source equipment on/off
- Relays open/close

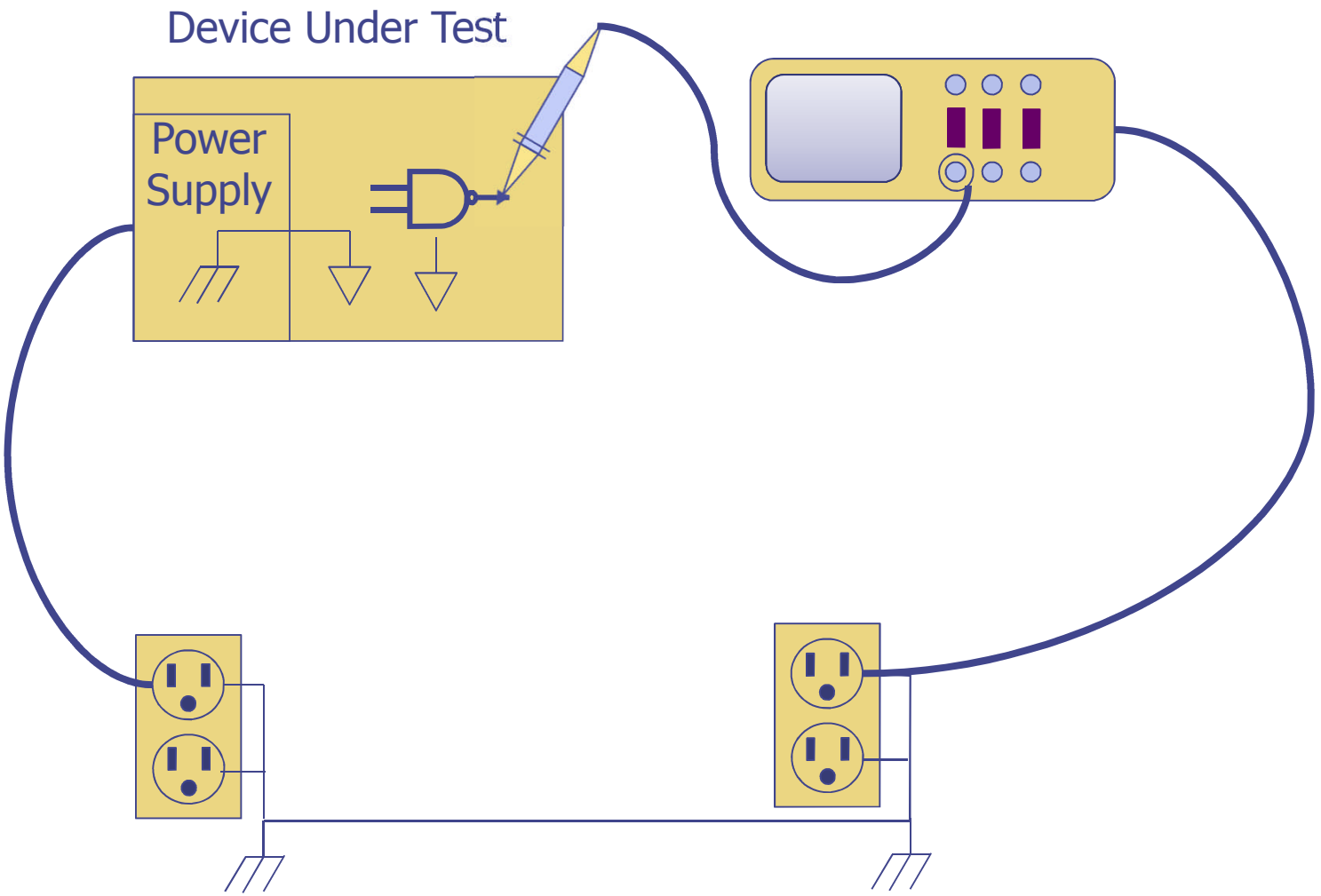
Kraz, Wallash EOS/ESD 2010

EMI Waveform on Ground Line

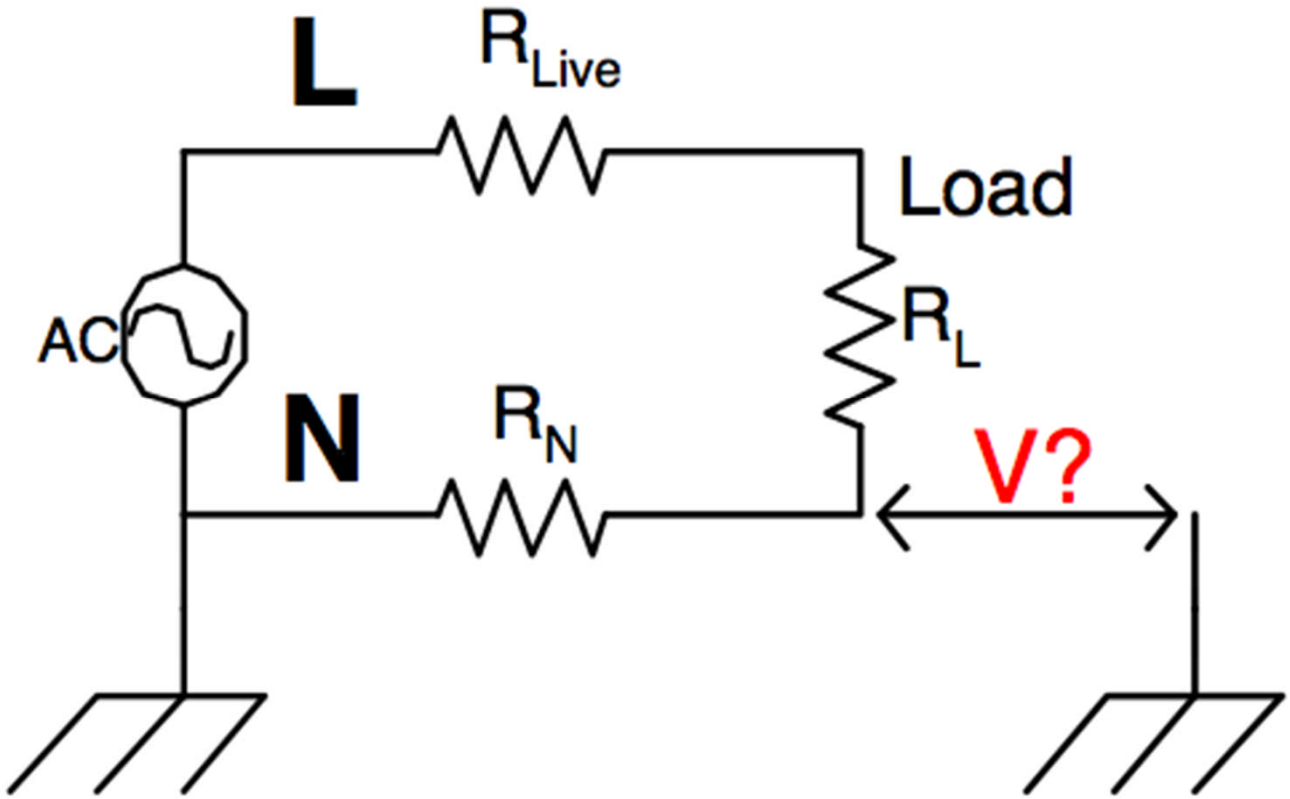


Can be caused by low voltage DC motors, or other circuits that draw large currents on startup. Issue in RFID locations?

Ground Loops

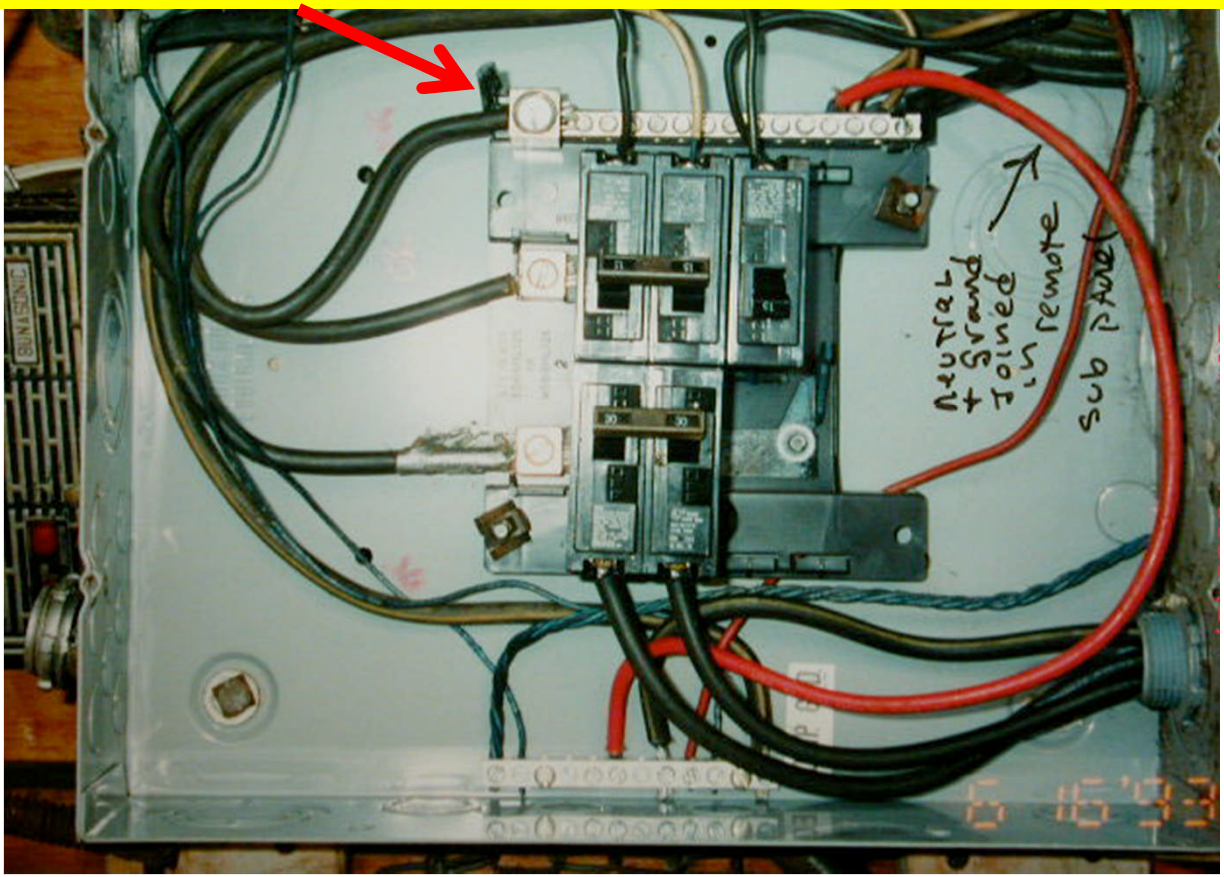


Neutral and Ground Lines Switched



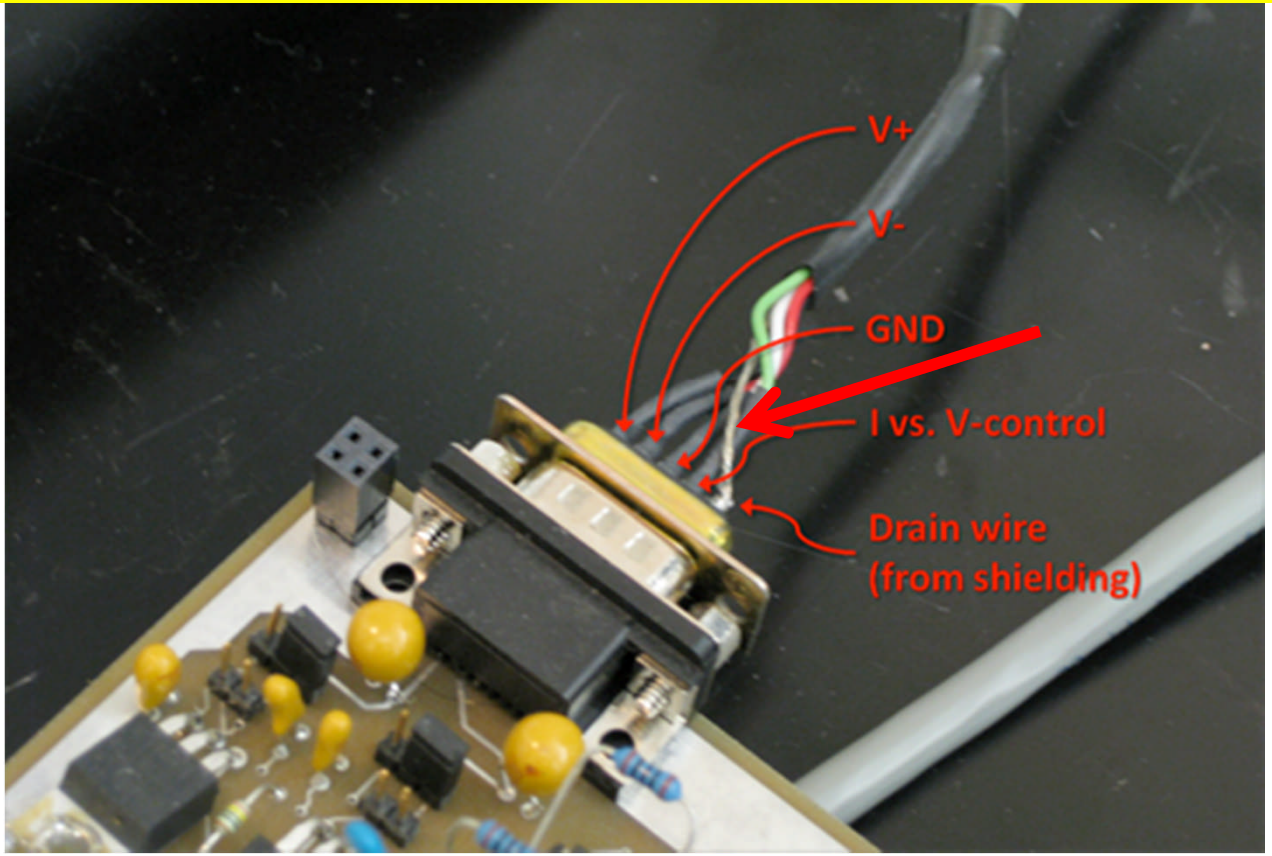
Improper Power Wiring

Incoming Neutral line was not connected to the panel – Even though it looked connected



Improper Wiring (cont.)

The drain wire should be shielded with heat shrink tubing as well to prevent a short to other pins



EOS and ATE – Device Level Testing

- most issues are due to severe voltage over/under shoots:
  - hot switching of relays (e.g. connecting power to a pin, through a relay, when the power supply is on and programmed to the desired voltage)
  - Improper power sequencing
  - Improper force/sense connections (e.g. sense line connected in such a way that handler alignment or a bent pin can allow the force connection to contact, without the sense connection).
  - Poor board design for high dI/dt applications (e.g. DC/DC convertors)
  - Poorly chosen bias levels for continuity testing (e.g. mAs of current forced)
  - Reversed part

EOS and ATE – System Level Test

- Similar issues in system level testing: these can include the above, but more specifically:
  - hot-plug test cable (plugging cable in while 'hot')
  - Reverse cable (plugging test cable in backwards)

In most cases, a simple monitoring of the voltage on the damaged pin with an oscilloscope reveals a voltage over/under shoot, and then it is a simple process for working backwards to find out what generated the excursion.

EOS Mitigation in Manufacturing

- Unlike ESD, formal EOS prevention, monitoring and auditing systems are not common in manufacturing
- Like ESD, EOS failures are often the result of lack of awareness of the problem
- Like ESD, many stakeholders
  - Product design
  - Test and Production equipment design
  - Facility design and maintenance
  - Quality/process control

EOS Mitigation in Manufacturing

- The organization should have an EOS control program similar to the ESD program (often can be combined in same responsibility)
  - Defined and documented requirements
  - Compliance verification
  - Feedback FA information to EOS control program
- MFG floor EOS weakness detection
- Incorporate/enhance EOS control, monitor

Example of EOS Audit Checklist

Typical Audit Item	Measurement
AC Power Cables	Basic Cable Socket Tester
AC Power Quality	Power disturbance analyzer (e.g., Fluke 435)
AC/DC power up/down timing	Visual observation
Board removal after power off	Visual observation and timing
Correct Power Supply or AC Adapter	Check model requirements compatibility with application
Hot swapping	Visual observation/Event Detection

EOS Mitigation

EOS Concern	Mitigation
Hot Swapping of Components	Define and audit test & debug procedures – can be product dependent
Functional test power sequencing	Define and audit manual test procedures; insure that software meets power sequence requirements
AC power adapter or AC/DC power supply used at test/debug stations	Be sure that power supplies meet manufacturer specification and are being used correctly
AC power quality and grounding	IEC 61000-4-30 Class A is a good guide

Do not assume these things are being done!

Additional EOS Mitigation Activities

- Failure Analysis
- Root Cause Analysis
- Corrective Action
- Feedback to Design and Manufacturing Engineering
- Training

Design EOS Mitigation Activities

- Design to AMR constraints
- Closed Loop FA/RCA/CA
- Customer Education/Communication
- Product Documentation
- EOS Check Points in Design Process

Current Industry Activities – ESD Association

- EOS Status Technical Report – mid 2013
- EOS Best Practices for Manufacturing and Test – need participants
- Increased Emphasis on EOS at EOS/ESD Symposium – need EOS papers and case studies
- CBE Technical Report – mid 2013
- Transient Latch-Up (TLU) Technical Report – published 2012
- TLU Standard Practice – Test Methods – 2015
- 2013 ESD Roadmap

Current Industry Activities – Industry Council

- White Paper 4 – EOS – 2014
- EOS Survey - CN version
- Data collection
- International ESD Workshop
  - May 20-23
  - Airlie Conference Center, Warrenton, VA
  - Early Registration ends April 5

Summary

- EOS is a major cause of electrical fail both in factory and in the field
- ESD is a type of EOS
- Some ESD (CBE, CDE) look like power-induced EOS
- Power-induced EOS comes from many sources and root cause often goes unidentified
- Control of power-induced EOS in the factory could be managed like ESD
- Reducing EOS occurrence requires adherence to AMR constraints

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