Electric Field Control – EOS Mystery Solved

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Abstract
A new discovery of missing fundamental controls in electronic manufacturing is the cause for most Electric Overstress failures generated by PCB and cable discharge events. This discovery developed a new methodology, Electric Field Control, to reduce the energy in manufacturing and prevent the failures. The results are improved quality, reliability, and reduced failure rates of electronic systems. This fundamental control is needed for manufacturing advanced technologies, systems, and automation.

Electric Field Control - EOS Mystery Solved
The creation of the new concept of Electric Field Control comes from working in depth on electronic system failures since 2009 and investigating over 700 product failures. This experience resulted in a better understanding of why the patterns of failures happen and solutions that really resolve them. There are missing fundamentals which lead to increased failures and the inability to solve them. The understanding of the terms Electrical Overstress, EOS, and Electrostatic Discharge, ESD, failures have caused some misperceptions. These labels have misled the industry and hindered finding the "real" root cause.

EOS implies that an IC has experienced large thermal damage and suggests the root cause is that too much voltage, current, or power was applied in PCB or OEM manufacturing. The source energy is thought of as "DC power" coming from tester power supplies or batteries. The truth is this energy can easily be found in PCB and cable discharge events. This can cause immediate failures or latent failures (field failures) from small pre-damage event that fails later while under power. The extra power source provides the incremental energy to create large thermal events.

The ESD Industry Council published the "White Paper 4 – Understanding Electrical Overstress – EOS" [1] and Figure 1 represents the root causes of EOS. The chart shows known issues caused by ESD, EMI, or misapplication. The majority of the EOS failures are unknown. This paper will help provide an explanation and solution to the "unknown" category.

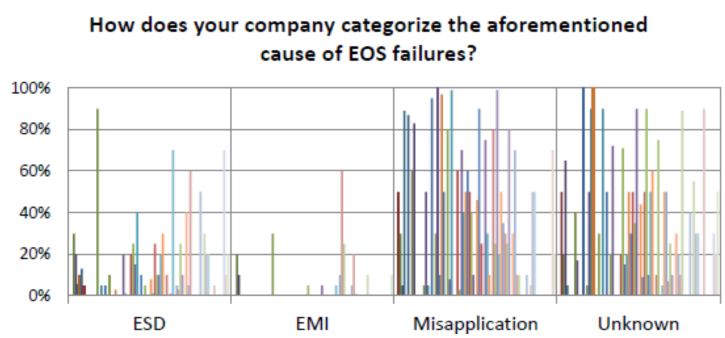

Figure 1 – Causes of EOS Failures

The IC failures categorized as ESD caused often have small thermal damage. The reason the failure analysis labs use ESD as a label is because it looks similar to IC level stress tests of ESD Charged Device Model, CDM. The ESD label suggests the cause is lack of equipment grounding or someone not wearing their wrist strap. Companies try to apply the ESD Standards to eliminate these types of failures. The ESD standards help but are not effective enough.

There is a new term, Electrically Induced Physical Damage, EIPD. This term is used to label an IC with large or small thermal damage and does not have a root caused assigned to it. The source of the damage is not known. It could later be labeled EOS or ESD based on the real root cause findings.

The above point of view has limited success in preventing the failures from reoccurring. The "mystery" of damage is from PCB and cable discharge events which may be labeled EOS, ESD, or EIPD and have unknown root cause. Electric Field Control is a new method to find and solve PCB and cable discharge events.

A successful failure investigation and solutions need the following fundamentals.

The missing fundamentals are itemized below:
1. Process of investigation with a systematic approach
2. Partnership of investigation, sharing info, and working together in parallel (IC, PCB, and OEM)
3. Electric Field Control to prevent PCB & cable discharge events
4. Effective use of ionizers
5. Understanding of field failures can be caused by manufacturing pre-damage

This scope of this discussion will be on Electric Field Control to prevent PCB and cable discharge events.

It is important to understand PCB and Cable discharge events, how it damages ICs, and where it happens in manufacturing, and how to implement Electric Field Control to prevent it.

Electric Field Control

Electric Field Control, EFC, is a method to evaluate each piece of equipment, each process step, and each PCB product and to proactively reduce the energy and avoid IC damage. Figure 2 is representative of the assessment process to measure the electric fields after each equipment process (yellow arrows) and to identify locations of metal to metal contact where PCB discharge events happen (red circles).

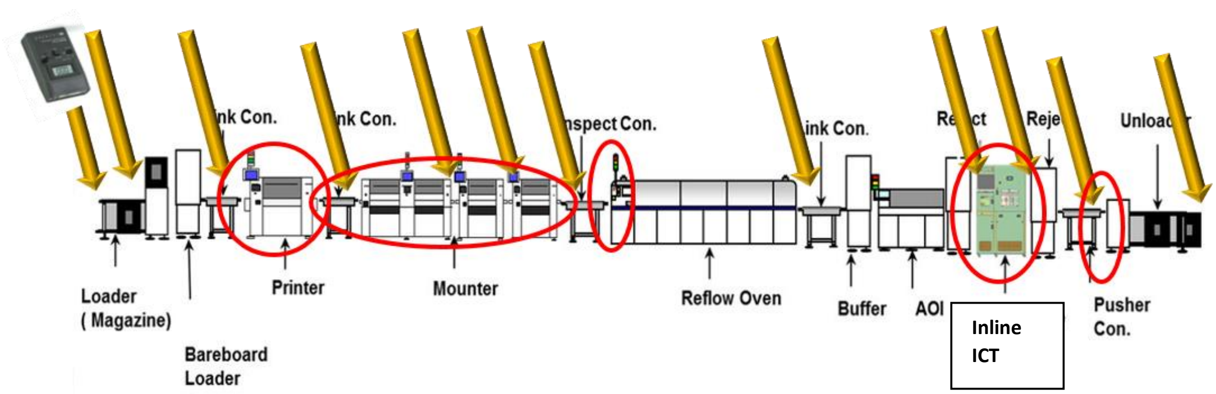

Figure 2 – EFC assessment of PCB manufacturing lines

EFC is a simple method to identify areas of risk in the manufacturing lines. The details below explain in more details about why PCB discharge events happen and how to apply Electric Field Control.

Voltages on PCBs

There are three main components on PCBs. Plastic insulators, Metal Conductors, and ICs (semiconductors). The plastics have surface charges and electric fields. The metal in a PCB is floating therefore it will take on the same voltages as the electric fields. The electric fields put force on the metal, polarizing it and creating voltage and stores energy just like a capacitor. The larger the piece of metal the more energy it can store. Figure 3 is a cross section of a PCB showing surface charges on insulators which generates electric fields causing voltage on the metals (stored energy). The voltage on the metal is an average of all the electric fields putting force on it. The voltage is roughly equal to the electric field strength. The PCB discharge happens when the PCB metal touches another conductive object. Metal to metal contact creates an ultrafast high energy transient that can damage ICs.

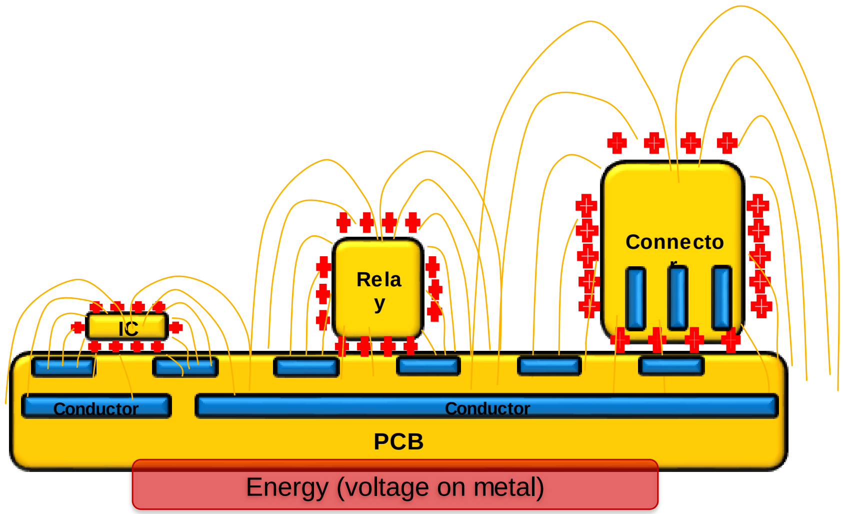

Figure 3 – Electric fields create voltage on PCB metals

The solution is to remove the electric fields by removing the surface charges from the plastics with an ionizer. Plastics can not be grounded. The only way to remove it is with an effective use of an air ionizer, Figure 4. The ionizer creates positive and negative charges that neutralize the surface charges on the plastics. Ideally, the electric fields will be 0V and thus the voltage on the PCB metals will also be 0V.

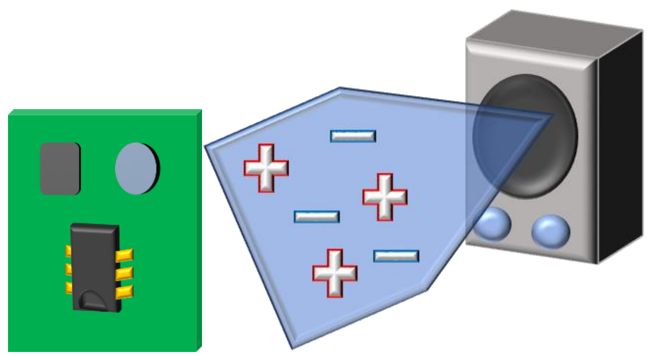

Figure 4 – Ionizer for plastic components

Voltages on Equipment

The PCB manufacturing line has many locations where metal directly contacts the PCB metal. The equipment needs all metal and ESD material parts grounded to equipment ground. This keeps the equipment metal at 0V as in Figure 5. It is best practice to remove any unnecessary metal equipment parts to avoid a discharge event with the PCB and to remove or replace plastic parts that generate high electric fields with lower charging or ESD materials.

Test fixtures may also have high electric fields that will cause voltage on the PCBs. An example is the In-Circuit Test fixture having insulative push down pins. These pins build up electric fields every time it opens and closes. The electric fields have been measured from 0V from grounded ESD push pins to thousands of volts on large insulative push pins.

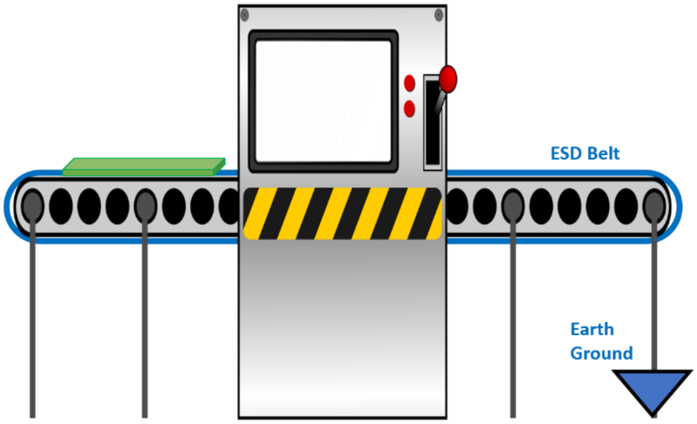

Figure 5 – Grounding equipment metal

PCB discharge event on In-Circuit Tester

An example of a PCB discharge event happens when a PCB contacts the In-Circuit Tester, ICT, metal pogo pins. The ICT is high risk because the pogo pins touch PCB test points near the IC pins such as for decoupling capacitors. The discharge event occurs because of a voltage difference between the PCB metals and the test fixture pogo pins.. The voltage on the PCB is caused by the electric fields on the PCB and test fixture. The voltage on the pogo pins are usually 0V because the tester ran the discharge routine. The discharge current can easily damage an IC (See Figure 6).

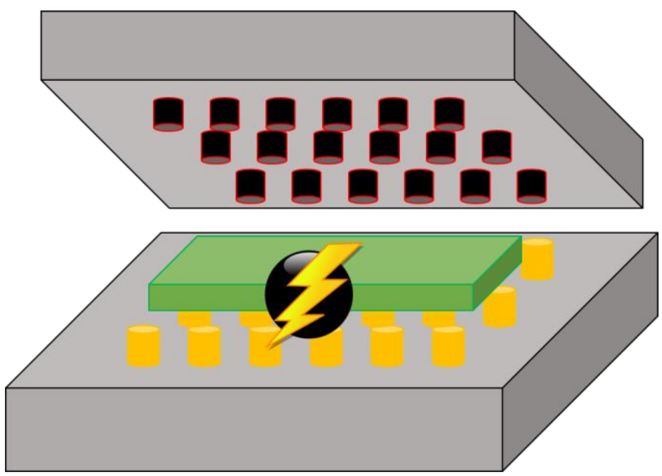

Figure 6 – PCB discharge event on In-Circuit Tester

The PCB discharge has a very fast rise time because of the metal to metal contact. This type of discharge event has been measured as fast as 30psec rise time. The peak current can vary from a range of mAs to 10As. The damage occurring at ICT has been high enough to fuse open IC bond wires and low enough to cause small thermal damage that fails in the field.

The IC can be damaged if the voltage difference (PCB versus Pogo pin) is high enough to activate IC circuits and often enough stored energy (charge stored on PCB metals) to cause thermal damage. For example, microprocessors often have VDD shorts due to PCB discharge events at ICT. The VDD pin has a max rating of 1.1V. Exceeding this value can activate the ESD protection circuit which is typically one diode voltage drop about VDD (or below ground). An estimate of 1.1V + 0.7V = 1.8V. If there is a 1.8V difference this can activate the ESD circuit. If the PCB metal can hold enough charge the current flow will be high enough to cause thermal damage. The ESD circuits are typically rated at 50uJ of energy. ESD protection circuits can also be activated by fast rise times with dV/dt trigger designs.

Figure 7 is a simulation of a PCB discharge event on an ICT fixture. For the initial conditions the PCB metals had 500V and the pogo pins are 0V. The test fixture was disconnected from the tester. The current waveform was measured by a high speed current probe around the test fixture wiring harness. The moment the PCB contacted the pogo pins the current peak measured is 8 Amps with a rise time faster than 100 psec. The oscilloscope bandwidth limited the rise time. This PCB discharge event can easily damage ICs.

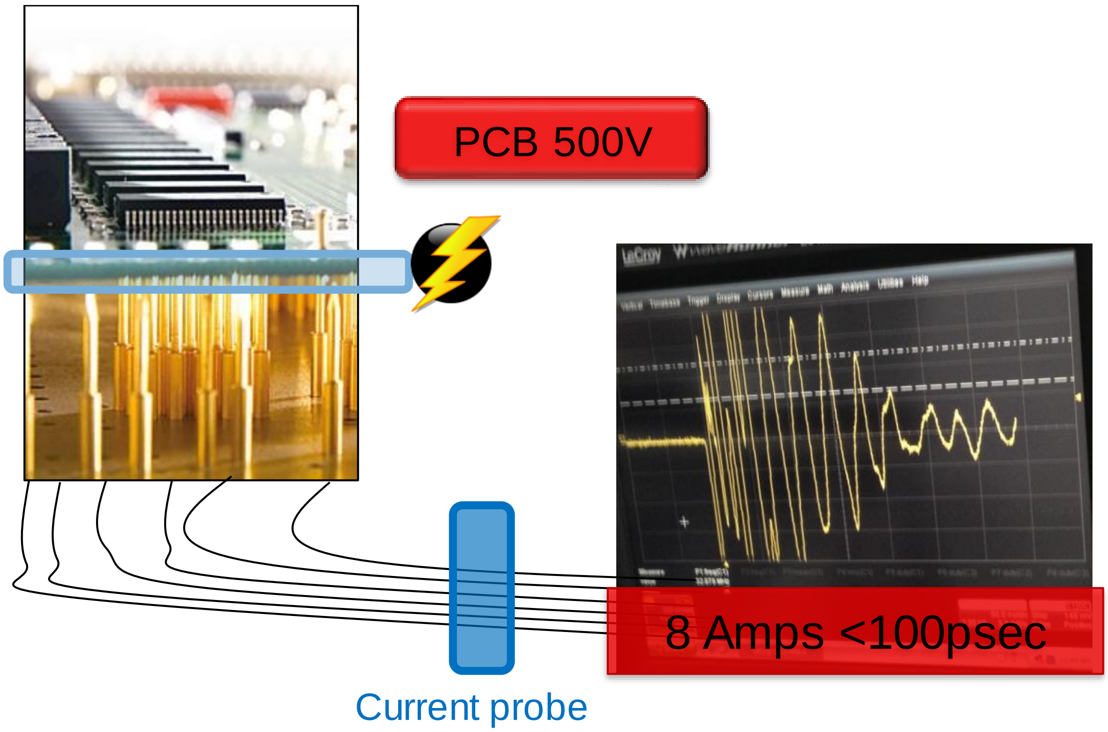

Figure 7 – Current waveform from a PCB discharge event on an In-Circuit Tester

Electric Field Control applied to In-Circuit Tester

How does one prevent the IC damage during PCB manufacturing? It is relatively easy by implementing Electric Field Control, EFC. This is a method that finds the sources of electric fields and removes it. It changes the metal to metal contact sequence to contact PCB ground first. Removing the electric fields significantly lowers the energy. For example, a plastic housing on the PCB may be at 30,000V which significantly increases the risk of damaging ICs. The EFC method would be to have an ionizer near the plastic housing to remove the electric fields to a low level, like 50V, thus making it much safer and prevent high energy discharge events.

Electric Field Control on the In-Circuit Tester is critical during PCB manufacturing because the metal to metal contact happens directly on the IC pin and the energy stored in the PCB can damage it. The EFC method used at ICT also entails implementing the use of an ionizer near the PCB before testing. This removes the electric fields on the plastic (insulative) components on the PCB. An ionizer near the test fixture specifically for the push down pins is also helpful. The push down pins are often plastic and charge up every time it makes contact and separation to the PCB. The fixture can easily reach 2,000V without proper controls. EFC also controls the contact sequence to the PCB by raising the height of the GND pogo pin to contact first. The raised GND pogo pin reduces the energy in the PCB further before the pogo pins touch the IC. See Figure 8.

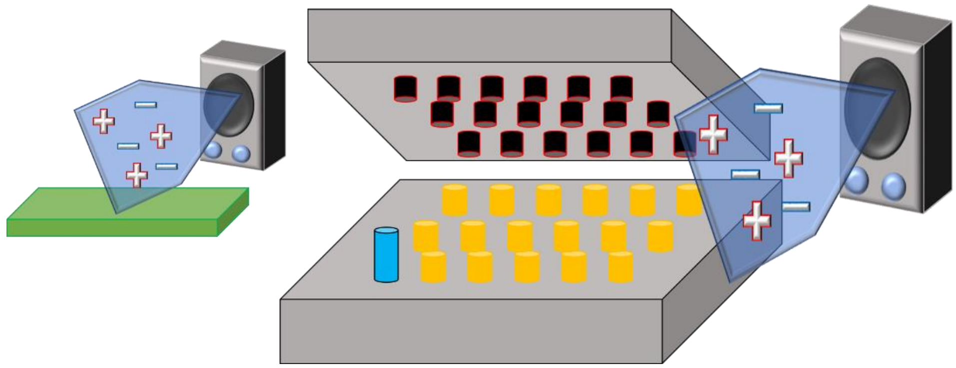

Figure 8 – Electric Field Control on In-Circuit Tester

Electric Field Control measurements in the PCB assembly lines

There are many locations in PCB manufacturing that have metal to metal contact. At these locations, it is important to know if there are electric fields and an effective way to remove it.

The sources of high electric fields can be test fixtures, large capacitors, plastic connectors, plastics on relays, IC packages, displays, plastic housings, equipment fixtures, etc.

The locations of metal to metal contact can be testers, metal fixtures, connector pins, large capacitor pins, cables, pogo pins, solder pastes, and/or pick –and place.

Figure 9 is an actual assessment performed at three PCB manufacturing locations running similar product with similar equipment and processes. The vertical axis is measurement is electric field voltage. The horizontal axis is the process steps from beginning of SMT through Back End and finally outgoing shipping. Highlighted are the places of metal to metal contact identified that caused IC damage and the Electric Field Control solutions of where the ionizers were added. The electric field voltages were much lower after the ionizers were installed. That coupled with raising the ground pins significantly reduced the failures.

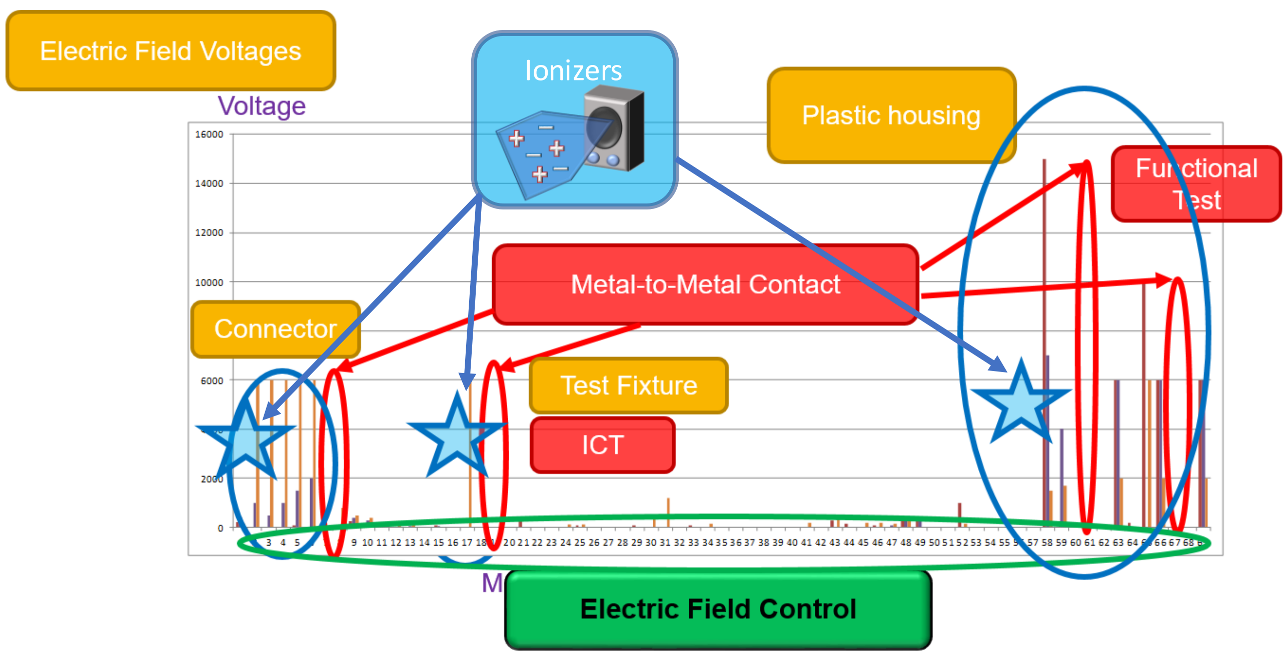

Figure 9 – EFC assessment of three PCB manufacturing lines

Electric Field Control can be used as a troubleshooting technique to identify fail locations and implement solutions to correct it. It can also be used as best practices to always implement at high risk locations like the In-Circuit Tester.

The understanding of how to use an ionizer effectively is not explained clearly. The purpose of an ionizer is to remove the electric fields which is accomplished by neutralizing the surface charges on plastics. The ionizer must be functional. The ionizer airflow must cover all surfaces of the product. And the ionizer output must match the processing speed. It takes time to remove the surface charges depending on the size and charge level of the plastics. It is better to set up the ionizer output to match the process than to slow the process down.

The future requires the development of equipment, robots, and manufacturing processes with Electric Field Control built in instead of adding it on later after a failure. Robotic equipment has a trend of handling PCBs more like "nuts and bolts" than like sensitive electronics. There have recently been seen PCB conveyors with metal chains that scrap the PCBs and robot arms that have high electric fields and no grounding for the PCB leading to damage when the board contacts the tester.

Case studies

EFC has some very good success stories with customers. One company in China had seven locations that manufactured the PCB and final product. They implemented EFC controls in all 7 locations and after 1 year reported a 70% reduction of line failures and 10X reduction of field failures.

An electronics manufacturing customer recently had EOS failures on a microprocessor used in an automotive application. They were provided EFC training and assessments in five of their PCB manufacturing locations. They implemented the changes and are now performing their own EFC self-assessments. This effort resulted in a significant reduction of failures between 50% to 70%.

Conclusions

Semiconductors are advancing rapidly with technology. This advancement is making them more sensitive to ultrafast transients created by PCB and cable discharge events. The future of electronic system manufacturing must include better design to compensate for these discharge events. Manufacturing must use Electric Field Control to reduce the energy and prevent damage. The damage can happen immediately, or worse, in the field.

The Electric Field Control method is effective to use for all electronic systems from IC to PCB and OEM manufacturing.

References

[1] Industry Council White Paper 4 – Understanding Electrical Overstress – EOS
www.esdindustrycouncil.org/ic/en/documents/40-white-paper-4-elecrical-overstress

Electric Field Control
EOS Mystery Solved

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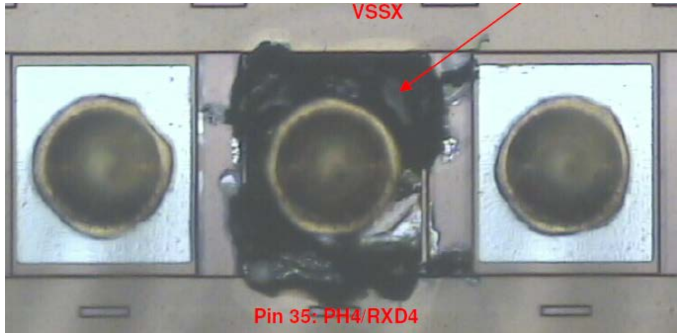
Overview

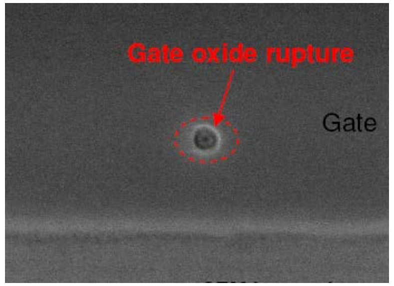
1. Terminology
2. Background of electronic system failures
3. Missing fundamentals
4. Electric Field Control
5. Case Studies
6. Conclusions

Failure Terminology Clarified

- A large portion of failures are categorized as: EIPD, EOS, ESD
  - *Electrically Induced Physical Damage, Electrical OverStress, Electrostatic Discharge*
- The terms have different meanings to different groups
- IC Suppliers failure analysis uses the terms based on the amount of thermal damage
  - *Large thermal damage = EOS. Small thermal damage = ESD.*
- PCB and OEM manufacturing use the terms based on root cause
  - *EOS is too much voltage or current from a tester. ESD is from not using a wrist strap.*
- New term EIPD is now used for thermal damage without a root cause identified.



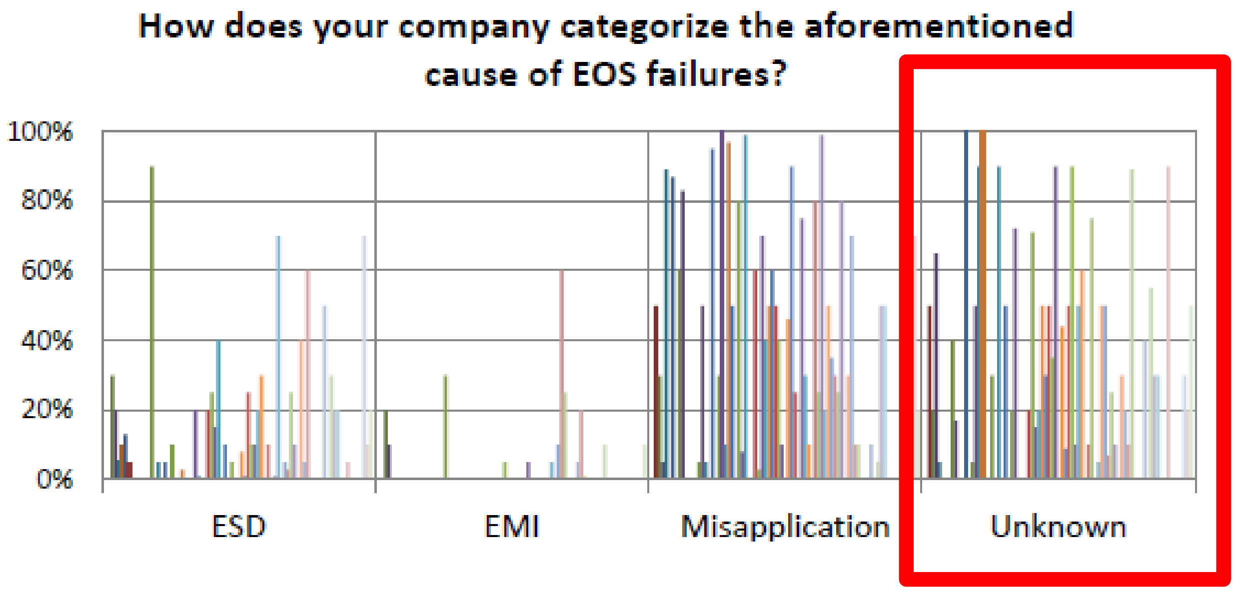
Large thermal damage



Small thermal damage

Background of Electronic System Failures

- 50% of failures are categorized as: EIPD, EOS, ESD
- Known failure root cause identified as ESD, EMI, and Misapplication
- More than half and not solved “unknown”
- PCB and Cable discharge events are the cause of the “unknown”
  - *Immediate or latent failures*



Source: ESD Industry Council - “”White Paper 4 – Understanding Electric Overstress - EOS

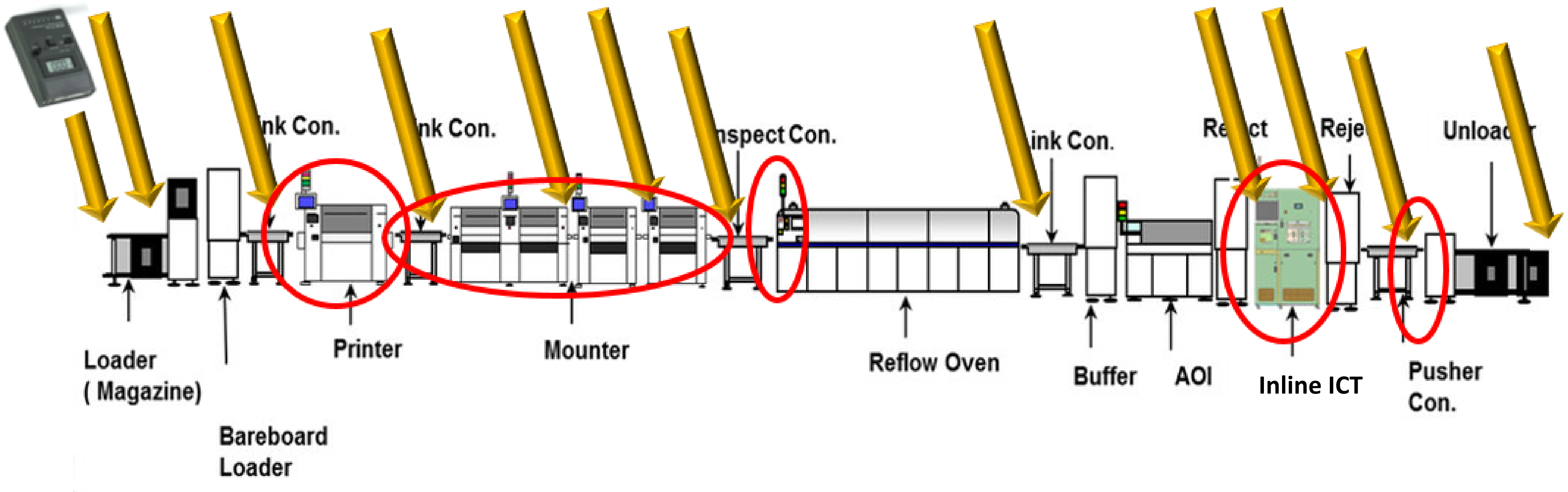
Missing Fundamentals to Solve the Failures

1. Process of investigation with a systematic approach
2. Partnership of investigation, working together, and sharing information (IC, PCB, OEM)
3. Electric Field Control to prevent PCB and Cable discharge events
4. Effective use of ionizers
5. Understanding that field failures can be caused by manufacturing pre-damage

- The main focus of this presentation will be Electric Field Control as applied to PCB manufacturing.

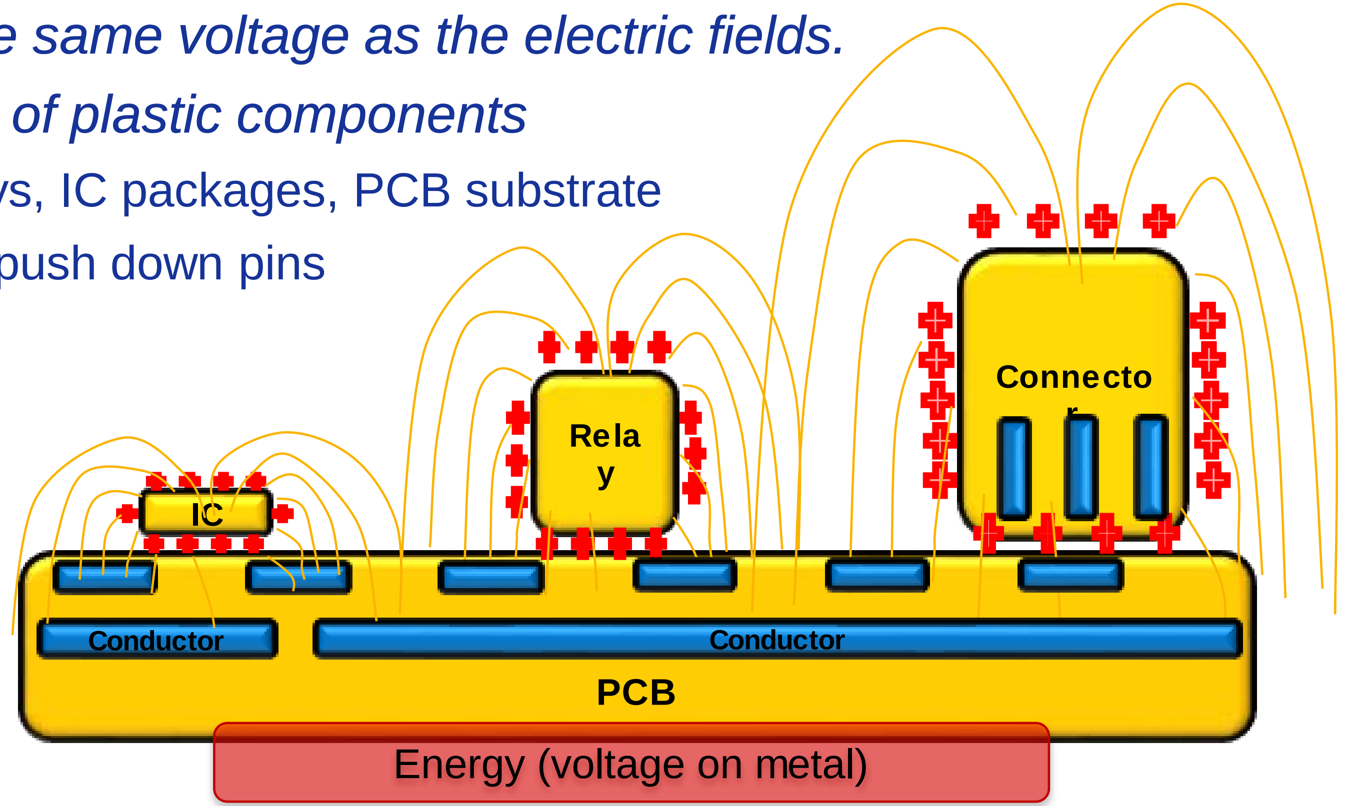
Electric Field Control

- Electric Field Control, EFC, is a method to evaluate equipment, processes, and products to reduce the energy and avoid IC damage from PCB and Cable discharge events.
- EFC assessment of PCB production line is measuring electric fields on PCB and fixtures after each step (yellow arrows). Identifying locations of metal-to-metal contact where PCB discharge events happen (red circles).
- And implementing appropriate solutions like ionizers and controlling connection sequences.



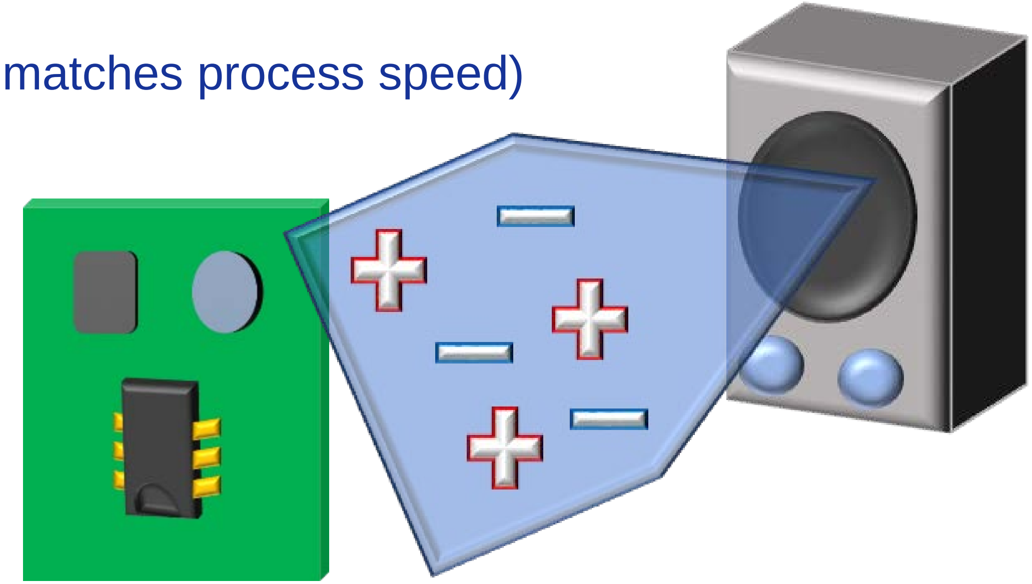
PCB Discharge Events

- PCB discharge events occur because of a voltage difference between the PCB and equipment (testers, fixtures, cables, pogo pins, etc). The moment they make contact ultrafast energy transients can damage the ICs.
- Voltages on PCBs
  - *PCB metals are floating and take on the same voltage as the electric fields.*
  - *Electric fields are from surface charges of plastic components*
    - PCB components like connectors, relays, IC packages, PCB substrate
    - Test fixtures with connectors or plastic push down pins



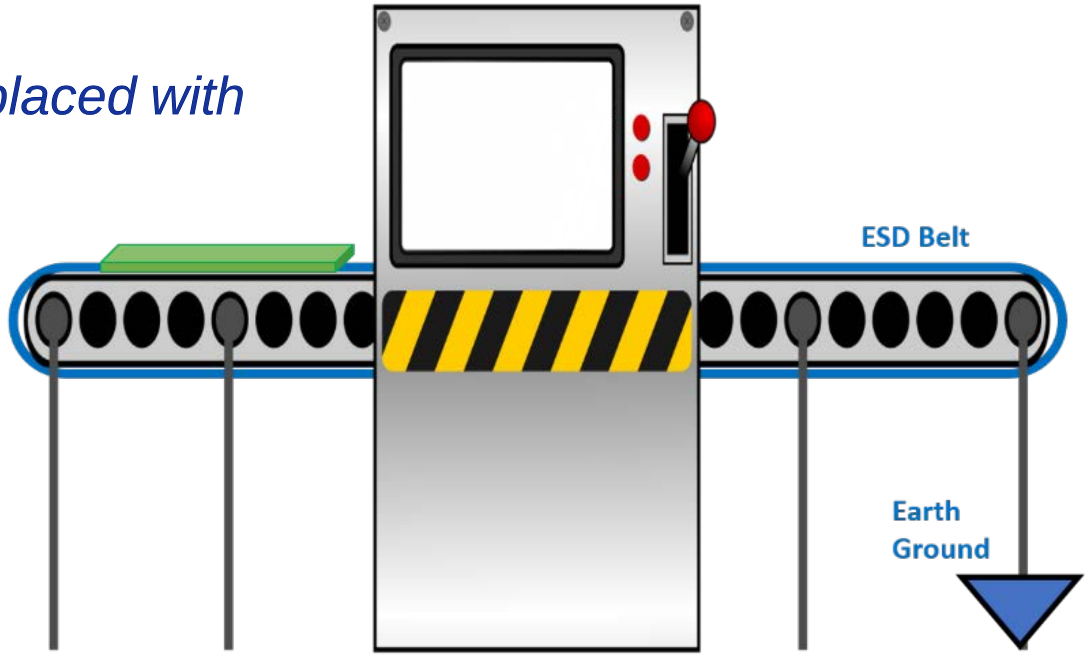
PCB Discharge Events

- Plastics can not be grounded
  - *An ionizer is the only effective tool to remove the electric fields*
- Effective use of ionizers
  - *Ionizer must be functional (balance & decay times) – ESD standards*
  - *EFC requirements for effective ionizers*
    - Airflow must cover all surfaces of PCB
    - Enough time to remove the electric fields (ionizer matches process speed)
    - Verify PCB is 0V after ionizer



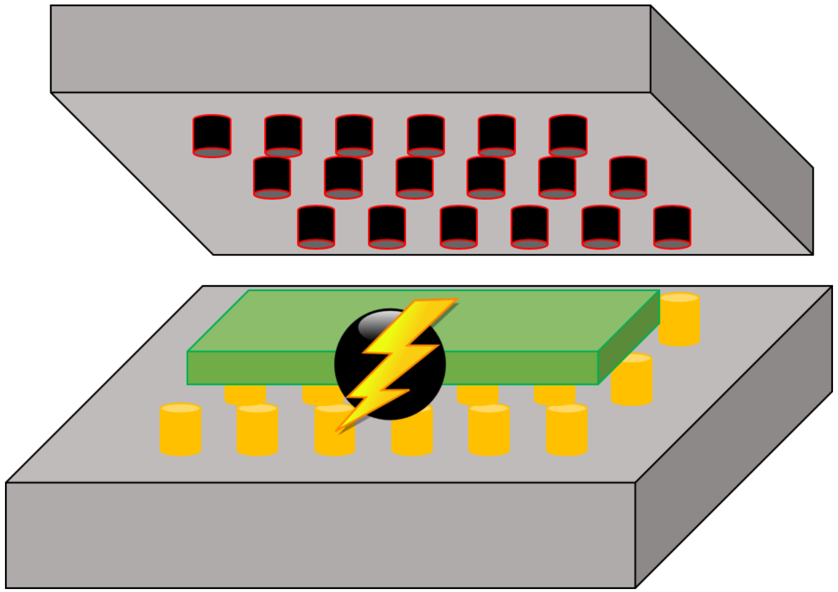
PCB Discharge Events

- Voltages on Equipment
  - *Equipment components must be grounded, thus 0V*
  - *Metal parts, fixtures, ESD belts or tracks, motors, pick up tools*
- Avoid unnecessary metal contact
  - *There is a risk of PCB discharge event when contacting metal*
  - *If metal can be avoided it is better*
  - *Example metal PCB holding fixtures should be replaced with ESD material*

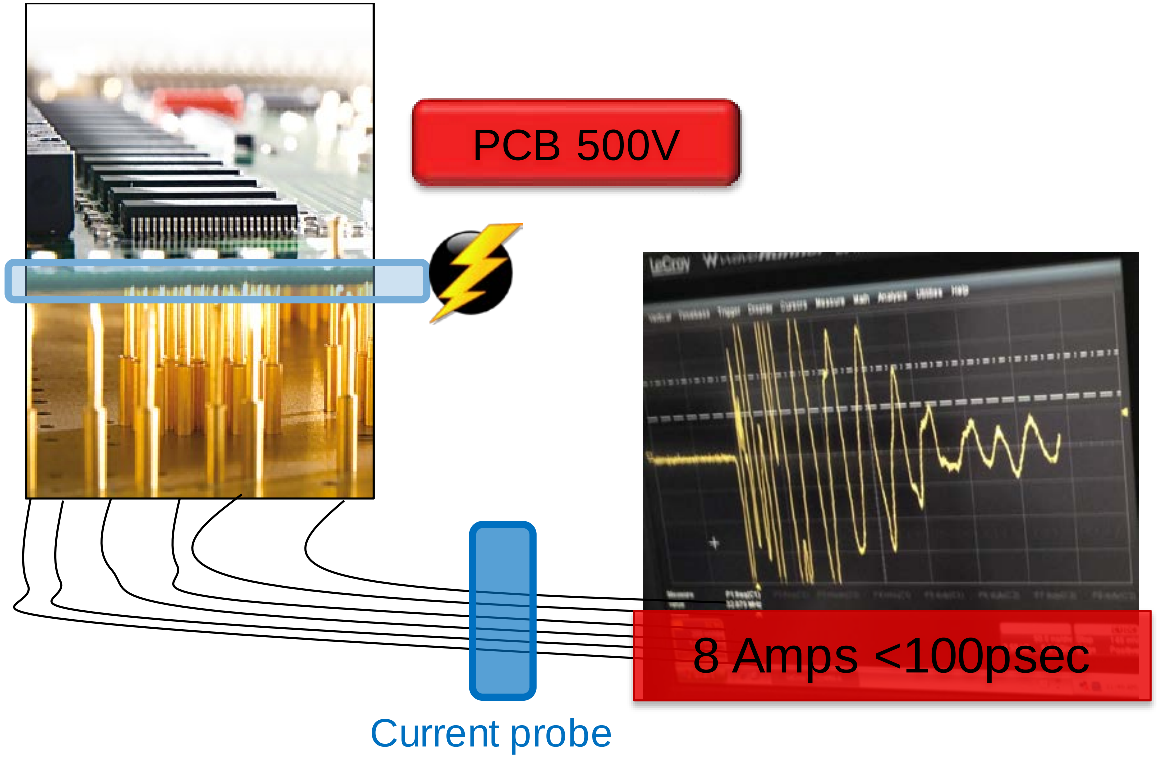


In-Circuit Tester

- High risk of damaging the IC on the In-Circuit Tester, ICT, because the metal pogo pins touch PCB test points near the IC pins, like for decoupling capacitors.
- Electric fields can be on the PCB and the Test fixture
- Simulation of PCB at 500V contacting the fixture resulted in fast transient with peak of 8 Amps



ICT Fixture: push pins top, pogo pins bottom

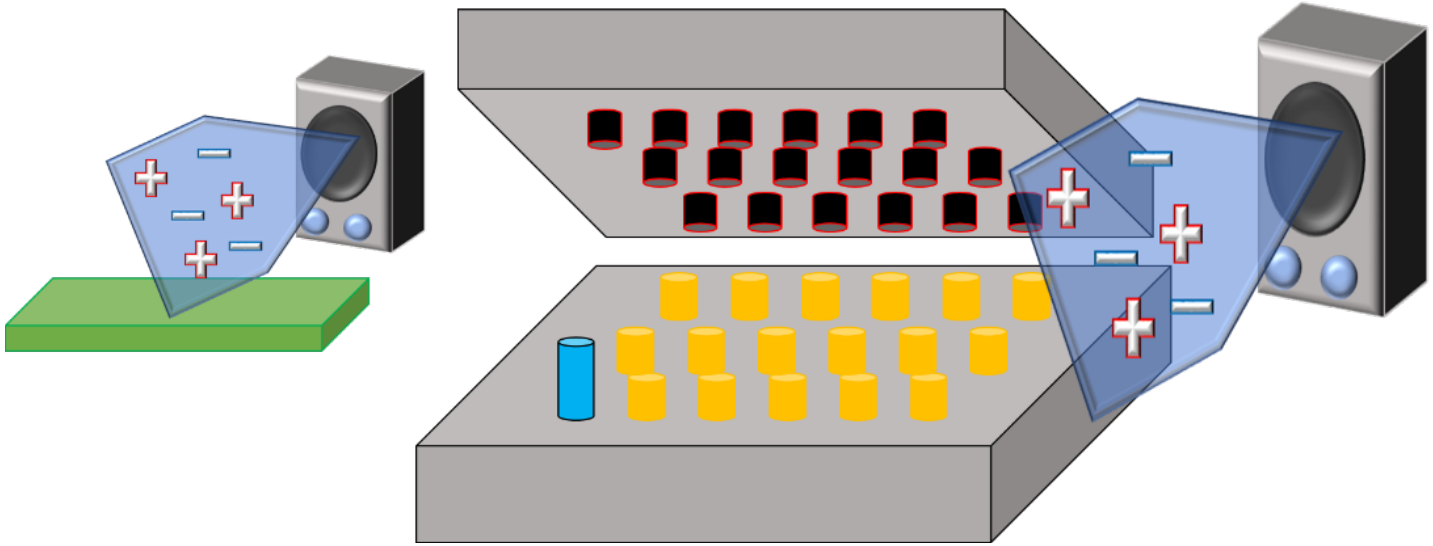


Electric Field Control for In-Circuit Tester

- Remove electric fields with ionizers from PCB and Test fixture
- Consider improved fixture design to reduce electric fields
- Control contact sequence by raising GND pogo pins (GND first reduces energy further)

PCB voltages:
0V to 1,000s V

Connector 3,000V
Relays 800V
ICs 500V
PCB 200V



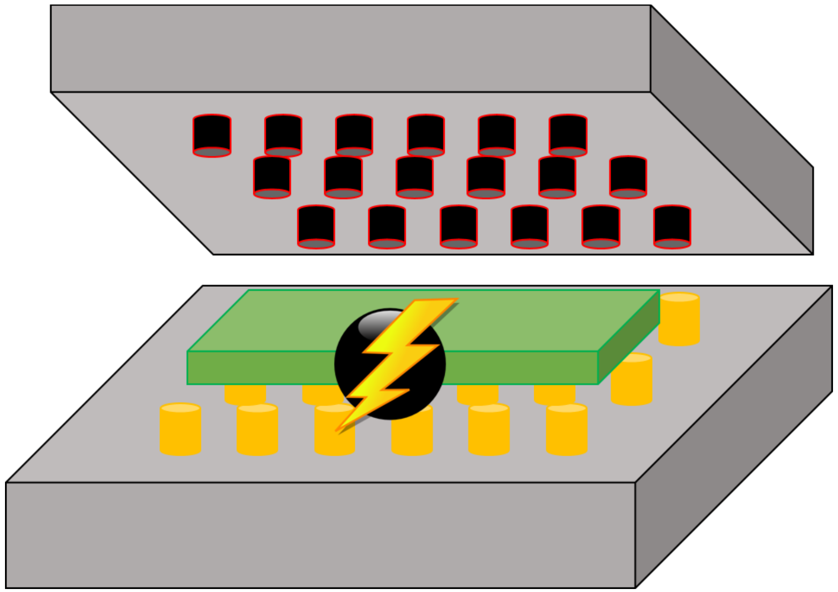
Fixture voltages:
0V to 30,000V

Grey foam 30,000V
Plastic push pins 2,000V
Capacitive plates 800V
Alignment blocks 600V
ESD foam 50V
Grounded ESD pins 0V

ICT Fixture: push pins top, pogo pins bottom (raised GND pin in blue)

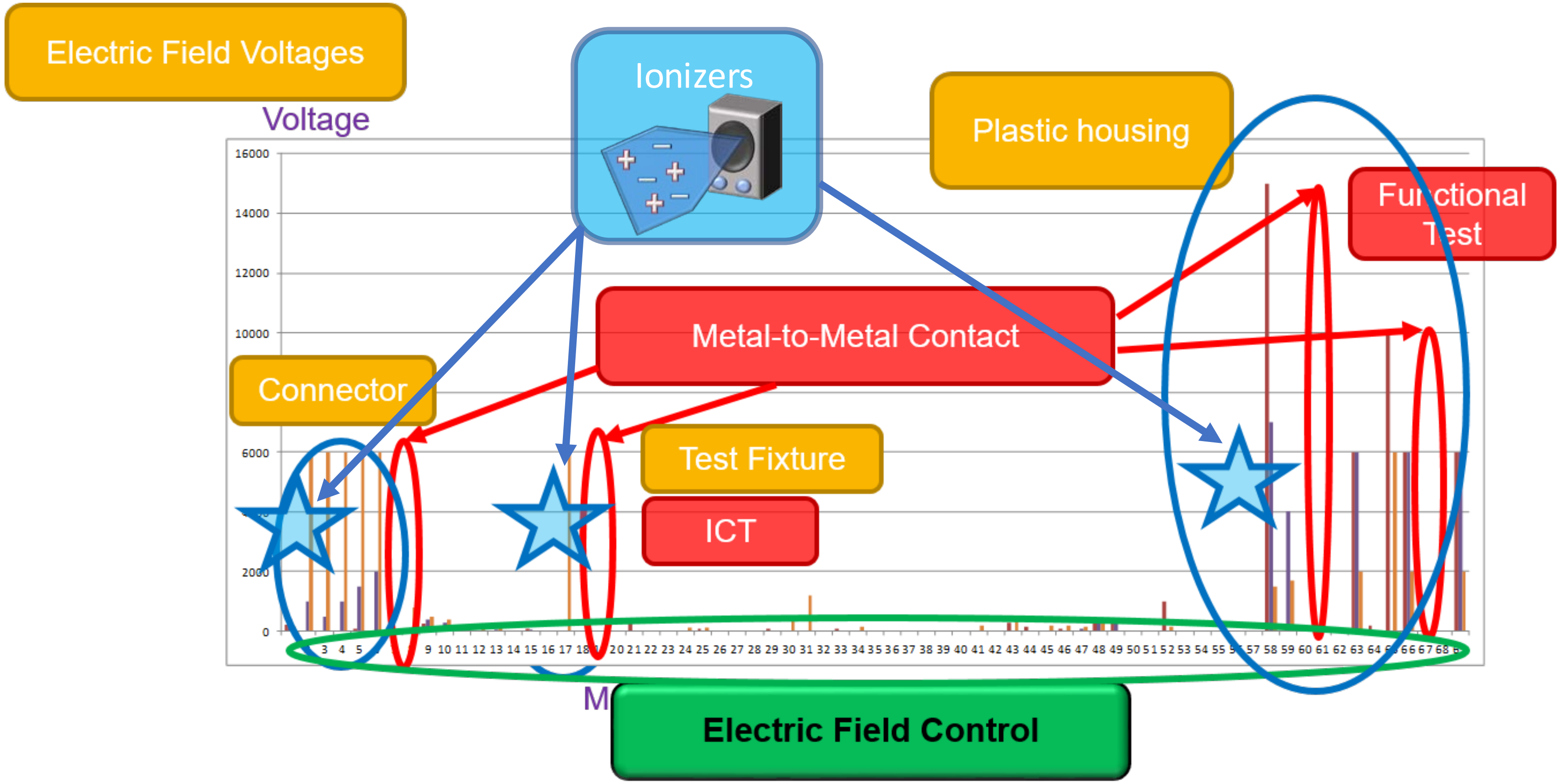
In-Circuit Tester Failure Example

- Failure mode of 0.5% PCB in-line failure for “open bond wires” and 500ppm field failures for thermal damage on ESD circuit (same IC pins).
- PCB 800V with plastic housing of 3,000V
- Solution was to add several ionizers for the PCB, plastic housing, and ICT fixture
- Conclusions:
  - *Negative voltage caused open wires*
  - *Positive voltage pre-damaged ESD circuits*
- Results:
  - *0% PCB in-line failures*
  - *50% reduction of field failures*
  - *Other contributors: IC and PCB design*



Electric Field Control for PCB Manufacturing Lines

- Assessment of three manufacturing lines running the same product (Voltage vs Process steps)
  - *Ionizers for connectors, test fixtures and plastic housings*
  - *Control connection sequence of In-Circuit Tester and End-of-line Tester*



EFC Case Studies

- Company in China used EFC across 7 manufacturing locations
  - *After 1 year reported: 70% reduction of in-line failures and 10X reduction of field failures*
- Many other company locations reported 50% to 70% improvements
- High failures rates like 30% fail on ICT causing damage to Micro VDD 1.1V pin. 0% after EFC.
- Medium failure rates are often a combination of design, defects, stresses. The implementation of EFC reduces significant stresses of PCB and Cable discharge events. This results in 50% to 70% reduction of failures.
- Low ppm failures have the similar results but require implementation of EFC best known practices. And takes time to see results.

- EFC method is effective to use for all electronic systems manufacturing from IC to PCB and OEM.

Conclusions

- Semiconductor technology is advancing rapidly. This makes ICs more sensitive to ultrafast transients created by PCB and cable discharge events.
- Future improvements must include:
  - *Better design to compensate for PCB and cable discharge events.*
  - *Manufacturing must use Electric Field Control.*
  - *Improved EOS Test coverage.*
- Electric Field Control is effective for IC, PCB, and OEM manufacturing.
- USCAR, United States Council for Automotive Research, and ESDA organization are including Electric Field Control into their work on reducing EOS.
  - *USCAR "Automotive strategies for EOS problem resolution"*
  - *ESDA WG27.1 "Recommended Information Flow For Potential EOS Issues Between Automotive OEM, Tier 1 and Semiconductor Manufacturers"*