



EMI-CAUSED EOS SOURCES IN AUTOMATED EQUIPMENT

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Abstract

Electrical overstress causes damage to sensitive components, including latent damage. A significant source of EOS is high-frequency noise in automated manufacturing equipment. This paper analyses sources of such noise, how it affects components and how to mitigate this problem.

Introduction

"Electrical Overstress (EOS) is the number one cause of damage to IC components" states Intel in its Manufacturing Enabling Guide¹. While most manufacturers are concerned with electrostatic discharge (ESD), not enough attention is paid to the much more damaging EOS phenomenon.

Significant source of EOS in manufacturing environment is high-frequency noise (often called EMI - Electromagnetic Interference). High-frequency noise is present in most manufacturing tools such as pick-and-place machines, lead trimmers, wire bonders and many others. This noise is caused by operation of various electric and electronic equipment, both inside the tool and by the tools nearby or even far away. Understanding the sources of EMI and how to mitigate EMI-caused EOS exposure is important for safe handling of sensitive components.

Sources of EMI in Tools

Every electrical and electronic equipment generates some sort of artifacts on power line and ground during its operation. Different types of equipment generate different types of noise.

Commutation of Power

Commutation of power, such as turning equipment on and off causes strong transient signals. Figure 1 shows typical voltage spike caused by turning on a regular heat gun. The more powerful the load, the stronger the spike. This type of transient noise does not easily follow an observable pattern and often is difficult to diagnose, in part because the spike can originate quite far away from the source and propagate via power lines and ground.



Figure 1. Power line transient from turning on heat gun.

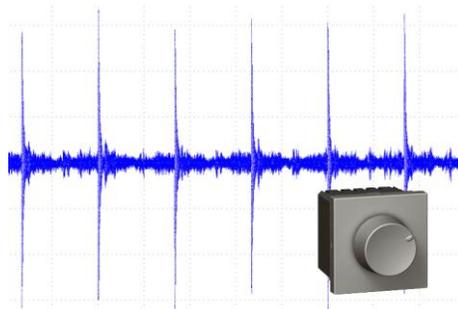


Figure 2. Noise from the dimmer



It doesn't take an entire tool to be turned on or off in order to produce a significant transient signal - all it takes is to have heating element, solenoid or other load within the tool to be turned on or off. The resulting transient signal propagates throughout the tool via common power and ground.

Dimmers/Gradual Heat Control

Common power line dimmers that control light brightness, such as in microscope light, or temperature of certain heating elements produce periodic spikes synchronized with the power line frequency. Typical waveform of noise from dimmer is shown in Figure 2.

Switched Mode Power Supplies (SMPS)

While many power supplies provide small manageable level of noise, there are enough SMPS in use that skip on noise suppression and serve as a major source of electromagnetic interference. Switch mode power supplies generate DC voltage from AC mains using high-frequency pulses (typically between 40 and 200kHz). These pulses have sharp edges which are the main culprits in generating undesirable noise. This noise may have rather complex waveform as illustrated in Figure 3. It is important to know that SMPS generate noise both on DC output and on AC mains.

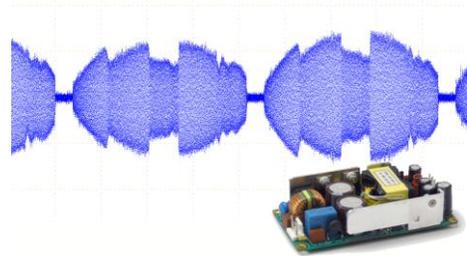


Figure 3. Noise on AC mains generated by several switched mode power supplies

Uninterruptable Power Supplies (UPS)

UPS provide AC power to your equipment when main AC power either fails completely or when its key parameters fall below acceptable levels. In such cases UPS reconstructs AC mains power from its internal battery. The output power in case of mains failure, however, is far removed from the expected sine wave. It is most likely a square wave with sharp edges that cause significant high frequency noise at the output. Figure 4 shows AC output of a typical UPS (blue trace) and resulting high-frequency pulses on power line (red trace). Power conditioning in absolute majority of UPS does not include noise filtering and, in those that do, it is mostly sub-standard.

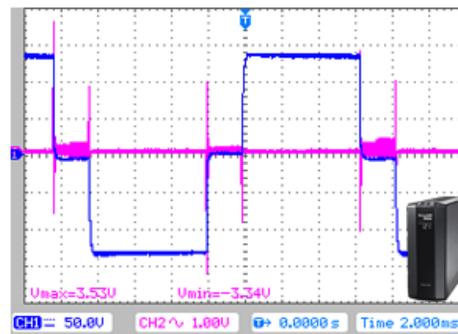


Figure 4. Noise from UPS

Servo and Variable Frequency Motors

Almost every equipment with moving parts utilizes either servo or variable frequency motors. They are a workhorse of today's automation. Unfortunately, they are also the strongest source of EMI in the tools. These motors are driven by the pulses ranging typically between 8kHz and 20kHz with sharp edges only a few nanoseconds long. This pollutes the entire tool, especially its ground, with strong sharp transients with repetition rate of that of drive pulses.

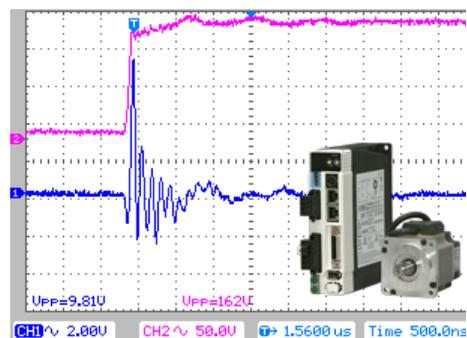


Figure 5. Effect of Servo Motor Pulse on Ground Noise



Figure 5 shows how rising edge of servo motor drive pulse (red trace) is synchronized with ground current inside the tool (blue trace). This current was measured using Tektronix' CT1 current probe and with its 5mV/mA ratio the ground current peak-to-peak measure is almost 2A with width of pulses of under 100nS.

A typical production tool has several servo/variable frequency motors, sometimes more than 10. Combined electrical noise from all motors can significantly pollute the ground of the entire tool.

How does EMI Turn Into EOS?

EMI-caused electrical overstress occurs when a device, such as an IC, is in a contact with grounded parts of a different potential which causes current through the device. While it is fairly easy to establish equipotential environment inside the tool at DC and at 50/60Hz, at high frequencies it becomes very difficult. One of the reasons for that is that at high frequencies conductors behave differently. Even a straight wire becomes an inductor with noticeable impedance and a phase shift.^{2,3} Metal parts that are not in physical contact can still conduct current because of parasitic capacitance between them. This creates unanticipated current paths and further phase shift. Actuators of robotic arms with associated wiring have substantial inductance and high capacitance to the tool's frame. The result is that high-frequency voltage on the robotic arms is not the same as on the tool's frame. This leads to a possibility of current through the devices.

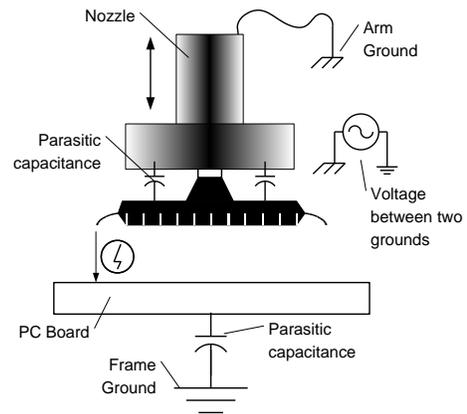


Figure 6. High-frequency current path through the device in pick-and-place

While for DC and 50/60Hz metal-to-metal contact is required for current passage, at high frequencies parasitic capacitance offers low impedance to current even without physical contact. Consider as an example an IC suspended on a nozzle of a pick-and-place machine (or, similarly, an IC handler) as shown in Figure 6.

The silicon die of the IC and its leadframe form one plate of a capacitor and the nozzle forms another. Close proximity of these plates provides big enough capacitance and resulting low impedance between the IC and ground of the robotic arm.

The copper of PC Fab which may not be galvanically connected to the tool's grounded frame nevertheless forms even bigger capacitance with the tool's frame and other metal parts of the tool.

Once the IC is placed on the copper pads of the PC Fab, the metal-to-metal final contact closes the circuit and the current now can flow. Strong current with high repetition rate is a viable cause of EOS.

Figure 7 depicts actual measurements made in an IC handler. The blue trace shows drive pulses of a servo motor; red trace - current through the device. As seen, current pulses are synchronized with the

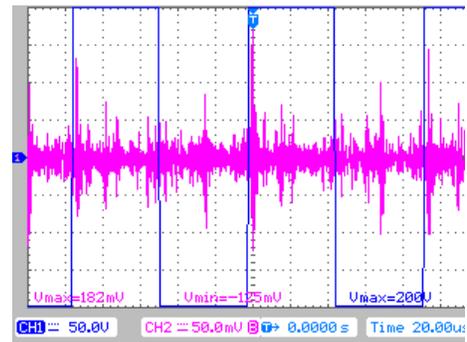


Figure 7. Current through the device in an IC handler



drive pulses. Other (non-synchronized) pulses are associated with other servo motors in the tool (there were total of 6).

It is important to note that these current pulses are continuous -they "hit" the device up to 20,000 times a second every second. This weakens the device structure and can cause latent damage which is more pronounced due to EOS than to ESD exposure⁴.

Not surprisingly, such current pulses weaken not only the device structure but the tool itself - just like dripping water often causes more damage than an occasional pour. The most wide-spread phenomenon is damage to ball-bearings of servo and variable frequency motors⁵. Figure 8 shows typical damage to the bearings from ground transient pulses caused by EMI. If such damage occurs to hardened steel, what would it do to small silicon structures of the devices?

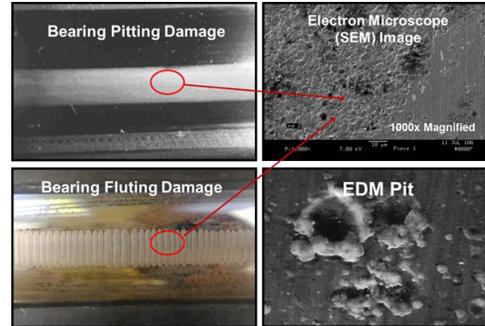


Figure 8. Damage to bearings due to high-frequency currents⁶

Places of Likely EMI-Caused EOS Exposure

Every place in automated equipment where there is a metal-to-metal contact is a possible source of EMI-caused EOS. Among the tools liable to produce such exposure are:

PCB Assembly	Device/IC Manufacturing
<ul style="list-style-type: none"> • Pick-and-place tools • Lead formers • Lead trimmers • Wave soldering • Testers 	<ul style="list-style-type: none"> • IC handlers • Wire bonders • Singulators • Lead formers • Testers

Acceptable EOS Limits

How would a responsible specialist assess current EMI levels in the tool and how would he specify the "safe" limits? The only document today that specifies maximum acceptable EOS levels in PCB assembly is IPC-A-610-E⁷. In its section 3.1.1 it states that " equipment must never generate spikes greater than 0.3 volt." For semiconductor device manufacturing ITRS (International Technology Roadmap for Semiconductors - www.ITRS.net) in its Factory Integration Tables⁸ recommends essentially the same levels today and even lower levels for the near future.

Once your factory has conducted an EMI audit of its tools it would become clear where EMI needs to be mitigated and to what levels.

Other Effects of EMI in Manufacturing

Besides causing electrical overstress noise on power lines (AC and DC) and ground infiltrates data lines. The most frequent result is errors in test. It is not uncommon to test the same board or the device several times until it passes. While such problems are not fatal, they reduce productivity and may lead to a bad board erroneously passing the test and be shipped to a customer.



Mitigation of EMI-Caused EOS

While it is appealing to have inherently low EMI levels generating by electrical equipment, in practice factory specialists have to deal with noise-generating equipment all the time. Sometimes improvement in wire routing can help a bit in some circumstances. However, the most practical way to effectively suppress EMI in the tools is implementation of properly-designed EMI filters¹. The difference between commonly-found generic EMI filters and specialized filters for factory level EMI suppression is outlined here⁹

Specialized AC power line filters help to stop noise on power lines from reaching the tool as shown in Figure 9. This filter which is "plug-and-play" and requires no special installation effectively blocks noise on power line and ground in both directions.

Some factories use separate facility grounding throughout the facility. This separate ground serves as a pipeline for noise delivering it to every tool in the facility. Figure 10 shows installation of ground line filter with ground bars. Installation with ground wire under the floor is very similar. Connecting ground filters every 2...3 meters in dense tool environment effectively stops propagation of noise while maintaining required ground quality

Servo and variable frequency motors require specialized servo filters such as one shown in Figure 11. The specific filter shown (OnFILTER' model SF20031) is installed between servo controller (also called "servo pack") and the motor. By processing drive pulses while preserving their driving ability this servo filter reduces ground noise by more than 20dB in this particular example. The resulting current through the device as was shown in Figure 6 is now reduced even more - 45 times as shown in Figure 12. As a positive "side effect" servo filter also improves reliability of motor's ball bearings by reducing erosion-causing ground current.

Conclusion

Electrical overstress is a serious and increasing threat to sensitive devices. Reduction of EOS exposure in assembly is an important way to improving yield and to reduce latent damage to the devices. High-frequency noise (EMI) in automated equipment is a significant source of electrical overstress.

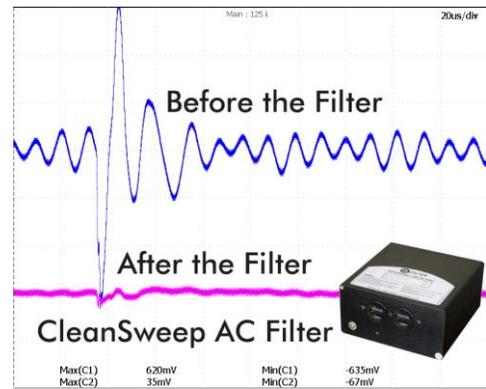


Figure 9. Reduction of noise on AC power line using stand-alone CleanSweep® AC Filter

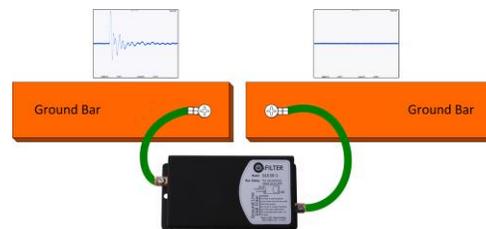


Figure 10. Ground Line Filter GLE30-01 prevents propagation of noise via facility ground

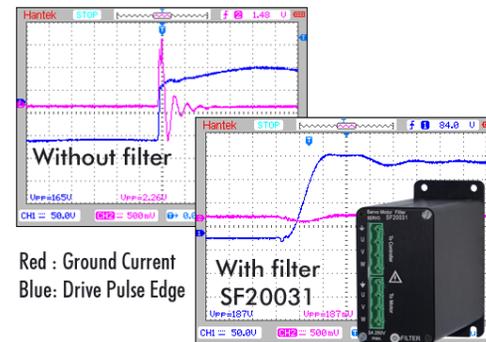


Figure 11. Ground current (red trace) with and without servo filter

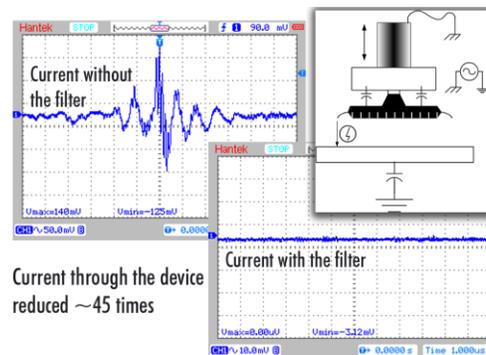


Figure 12. Current through the device with and without servo filter



Proper analysis of EMI environment in the facility and inside the tools, setting EOS limits for your process and proactive mitigation of EOS exposure improves yield and reduces EOS-caused failures.

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