As originally published in the IPC APEX EXPO Conference Proceedings.

EMI-Caused EOS Sources in Automated Equipment

Vladimir Kraz
OnFILTER, Inc.
Santa Cruz, CA
vkraz@onfilter.com

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) has been reported to be the number one cause of damage to IC components[1]. 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.

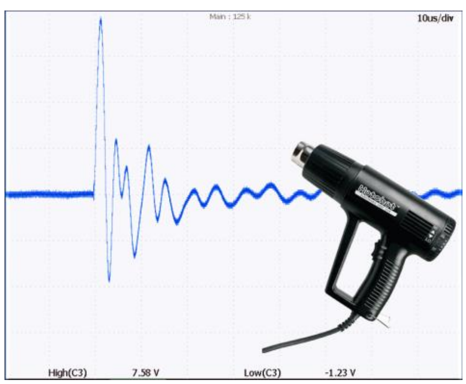

Figure 1. Power line transient from turning on heat gun.

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.

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.

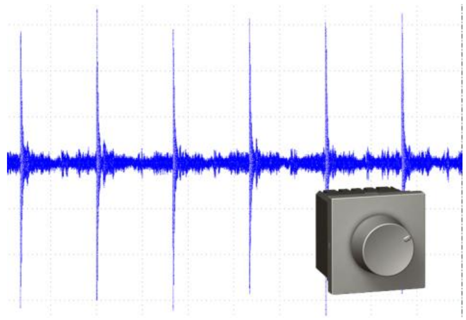

Figure 2. Noise from the dimmer

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.

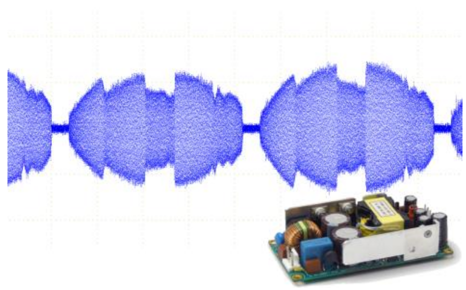

Figure 3. Noise on AC mains generated by several switched mode power supplies

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 sinewave. 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.

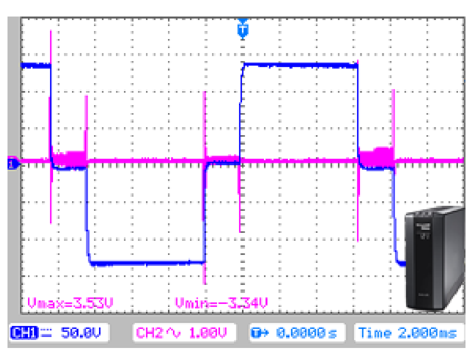

Figure 4. Noise from UPS

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 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 a production 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.

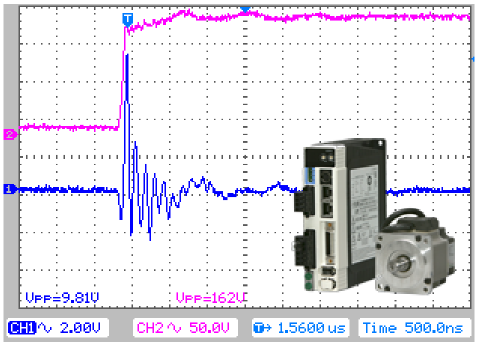

Figure 5. Effect of Servo Motor Pulse on Ground Noise

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.

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.

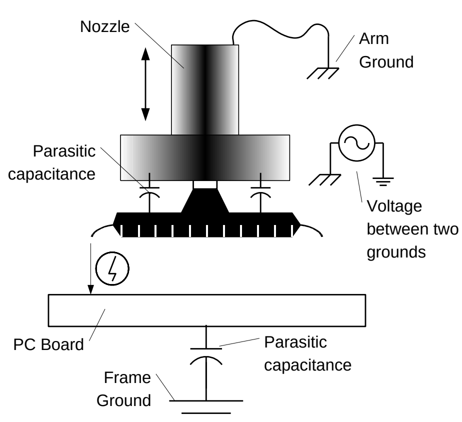

Figure 6. High-frequency current path through the device in pick-and-place

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

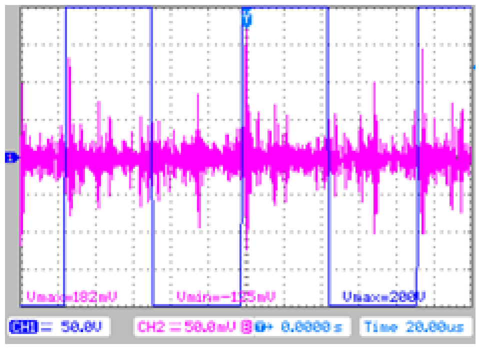

Figure 7. Current through the device in an IC handler

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 exposure[4].

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 motors[5]. 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?

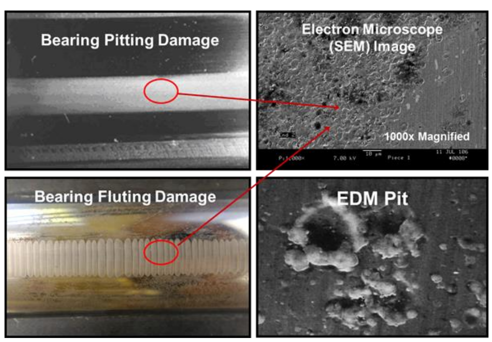

Figure 8. Damage to bearings due to high-frequency currents[6]

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
• Pick-and-place tools • Lead formers • Lead trimmers • Wave soldering • Testers	• 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 they specify the "safe" limits? The only document today that specifies maximum acceptable EOS levels in PCB assembly is IPC-A-610[7]. 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 Tables[8] 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 filters[1]. The difference between commonly-found generic EMI filters and specialized filters for factory level EMI suppression is outlined here[9]

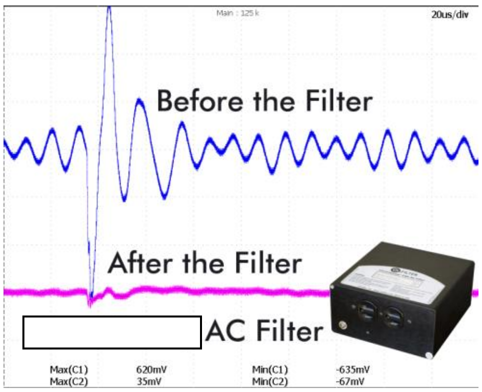

Figure 9. Reduction of noise on AC power line using stand-alone AC Filter

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.

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

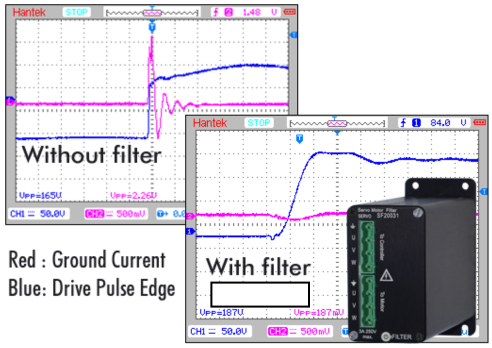

Figure 11. Ground current (red trace) with and without servo filter

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 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.

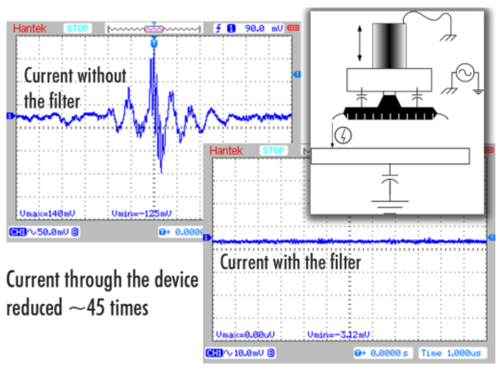

Figure 12. Current through the device with and without servo filter

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.

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.

References

1. Intel Manufacturing Enabling Guide, Section 3.2, May 2010

2. How Good is Your Ground? V. Kraz and P. Gagnon, Evaluation Engineering, 2001

3. Introduction to Electromagnetic and Microwave Engineering, By Paul R. Karmel, Gabriel D. Colef, Raymond L. Camisa, 1998 John Wiley and Sons).

4. Electrical Overstress (EOS) : Devices, Circuits and Systems, First Edition. Steven H. Voldman. 2014 John Wiley & Sons,

5. William R. Finley and Robert R. Burke, Siemens Energy and Automation Inc., Motion System Design May 2000

6. Bearing Currents, VFD.com 3/20/2014

7. IPC-A-610-E-2010, Acceptability of Electronic Assemblies, IPC

8. ITRS Factory Integration, 2013 http://www.itrs.net/Links/2013ITRS/2013Tables/Factory_2013Tables.xlsx

9 EOS Damage by Electrical Fast Transients on AC Power, A. Wallash, V. Kraz, Proceeds of ESD Symposium, 2010