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EMI-Caused EOS Exposure of Components and Its Mitigation

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***Abstract* - Increasing sensitivity of today's components brings issue of electrical overstress (EOS) to the front lines of efficient high-yield manufacturing. One of the main causes of EOS is electrical noise (EMI). This paper investigates the sources of EMI in electronic manufacturing and methods of mitigation of EOS exposure.**

1. EOS PHENOMENON

Electrical overstress, or EOS, is a phenomenon where electrical signals applied to a circuit or a device exceed normal operating parameters. These excessive electrical signals are abnormal by definition and are not a part of normal operation of the devices. According to Intel [(1)], EOS is the number one cause of damage to IC components. In the broadest terms, EOS also includes electrostatic discharge (ESD), however, commonly EOS is used for excessive signals other than ESD and this is how it will be used in this paper.

2. EOS EFFECT ON THE DEVICES

The impact of electrical overstress on the devices is quite different from those from ESD, however the end results have a lot of similarity. Signals that cause electrical overstress typically last significantly longer than the ones from electrostatic discharge. Typical duration of EOS-causing signals ranges from several hundreds of nanoseconds to tens of microseconds or even longer – hundreds or thousands of times longer than electrostatic discharge. The amplitude of the EOS-causing signals is relatively small in comparison to ESD – just a few volts or even millivolt-range. Even with such small amplitude, the energy supplied by the EOS-causing signals can be significantly higher than that from the electrostatic discharge due to event duration. Such documents as IPC-A-610 [(2)] recommend levels of EOS of no higher than 0.5V, and for sensitive circuits - below 0.3V. Another property of EOS-caused signals is that they are periodic, often repeating with the frequency of the mains or of pulses from servo motors (see below in the text). This causes a problem with the devices' ESD-protective structures. According to [(3)] "…on-chip IEC-ESD protection can absorb the energy of single ESD and EFT pulses, but it's helpless against the high-energy battering from EFT pulse trains and surge transients, no matter how small the transient voltage is."

Due to high levels of energy, the typical EOS-cause defect on close examination looks like a "meltdown" – see Figure 1.

3. HIGH-FREQUENCY NOISE ON POWER LINES AND GROUND

In a perfect situation there should be no voltage on grounded surfaces. At high frequencies, however, this is not the case. Distributed inductance of wires and metal structures adds to impedance to ground. Parasitic capacitance between non-connected metal parts acts as a pathway for high-frequency signals. This results in voltage differential between seemingly grounded parts which, in turn, causes significant high-frequency current ending in electrical overstress[3].

Figure 1. Typical EOS Damage
Source: Intel

The source of significant energy high-frequency signals is usually the power lines, both AC and DC. The high-frequency noise on power lines, otherwise known as EMI (electromagnetic interference), is caused by operation of electrical equipment. Non-zero impedance of power lines and strong currents of actuators (motors, relays, solenoids) generate substantial transient signals on power lines, which, in turn, induce corresponding signals on grounded conductors. Difference in voltages between different grounded parts creates currents between these parts and potentially damaging EOS situation. A particularly damaging factor is that this EMI signal has very low output impedance thus having high current capacity. In order to

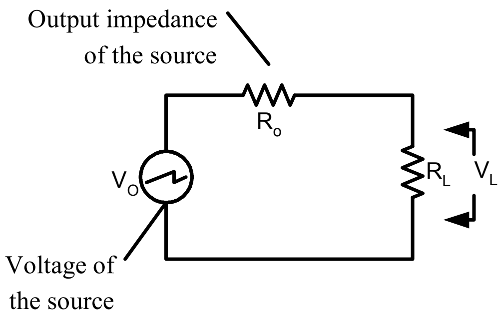


Figure 2. Equivalent Schematic of EMI Source

V_O – Source of EMI signal
V_L – Resulting voltage on the load
R_O – Output impedance of the source
R_L – Impedance of the load

calculate output impedance of EMI source in a tool, the following setup is used (Figure 2). By using two different resistor values as R_L, it is possible to calculate output impedance R_0 using the following equation (1):

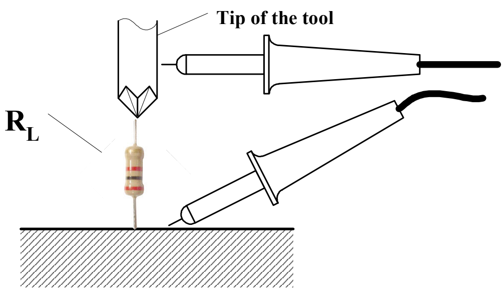
$$R_O = R_{L1} \times R_{L2} \frac{V_{L2} - V_{L1}}{V_{L1} \times R_{L2} - V_{L2} \times R_{L1}} \qquad (1)$$

Figure 3 shows results of the measurements performed in a wire bond tool. Two resistor values were employed – 50 Ohms and 100 Ohms. As seen the peak-to-peak voltage values varied only slightly (3.42V and 3.49V). While peak-to-peak voltage really doesn't exist – the peaks occur at different points in time – it is quite adequate measure for symmetrical signal shown in Figure 3.

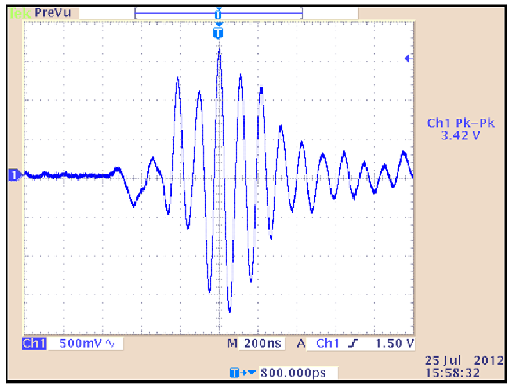
Utilizing equation (1), the output impedance is calculated as:

$$R_O = 50 \times 100 \frac{3.49 - 3.42}{3.42*100 - 3.42*50} = 2.09\Omega \qquad (2)$$

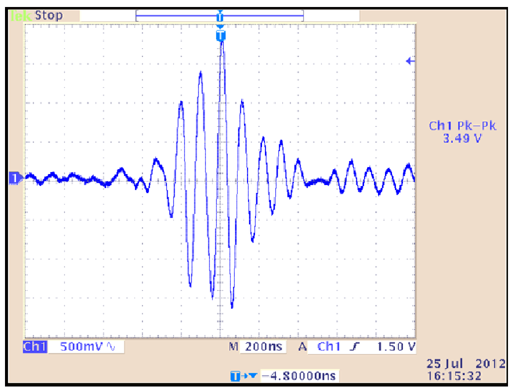
Such small output impedance allows for high current levels even when the voltage is low which may cause excessive currents and device damage even when the voltage doesn't appear to be threatening.



a) Measurement Setup



b) Signal at 50 Ohms



c) Signal at 100 Ohms

Figure 3. Measurement of EMI Signal in Wire Bonder with Different Load Impedances

4. SOURCES OF EMI IN A TYPICAL MANUFACTURING ENVIRONMENT

This paper deals with two examples of EMI-caused EOS in manufacturing process and with recommendations on mitigating EOS: automated equipment with servo motors and manual soldering process. For other sources, such as noise on the mains please refer to [4]

4.1 Servo Motors and EOS

Majority of automated manufacturing equipment uses servo or variable-frequency motors. Most typically, these motors use three-phase pulsed signal with frequency in the range typically up to 20kHz. The rise and fall time of these pulses is often too short – often under a microsecond, which creates energy with significant high-frequency content. Because the cables between the servo controller and the motor, as well as input and output impedances of the above are not optimized for high frequencies, the pulsed signal exhibits high level of typical artifacts as seen in Figures 5 and 6 taken in different tools

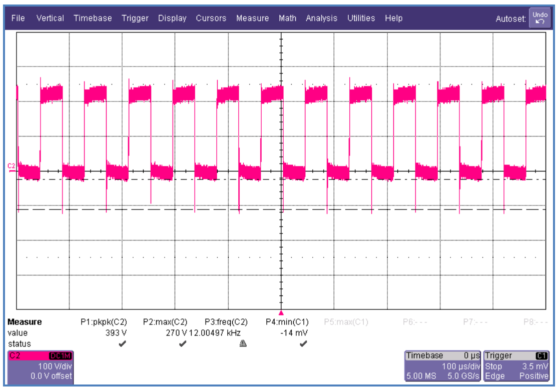


Figure 4a. Drive Signal on Servo Motor

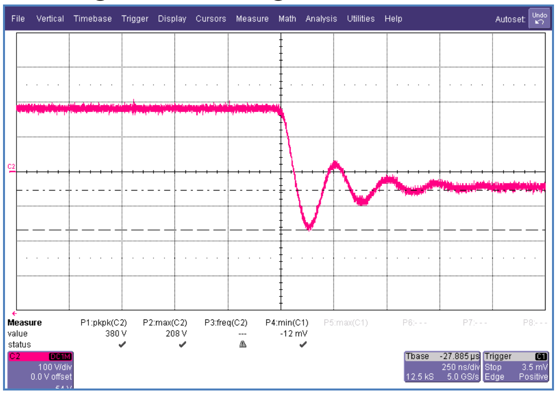


Figure 4b. Zoomed-in Signal Artifacts

with different motors.

As seen in Figure 4a, the drive signal is 270V peak, 12kHz pulse. Sharp rise and fall times create ringing (Figure 4b) of amplitude over 100V above and below the drive signal with the duration in a range of 250 nS.

Figure 5 shows screenshot of drive signal from a different motor in a different tool. The signal artifacts are plenty and abound.

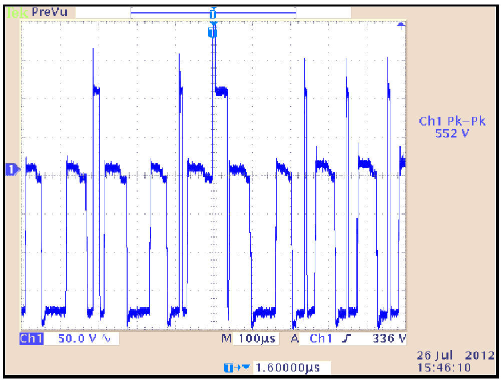


Figure 5. Drive Signal of Servo Motor

Such high frequency spikes can easily pass through capacitive coupling between the windings of the motor and the rotor as shown in Figure 6. In addition, these spikes feed back to the AC mains, causing pollution of the factory' power lines and possible EOS in other tools.

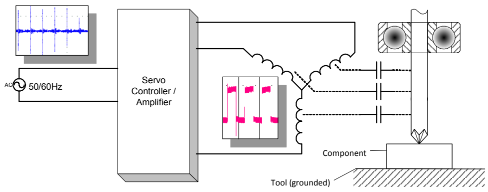


Figure 6. EMI Caused by Servo Motor

Ball bearings of the actuator offer little connectivity to ground during motion due to the lubricant. The result is high-frequency voltage difference between the actuator and the grounded surface on which the components are placed. Previous studies [(5)] show that current can be quite high – up to 200mA or even higher.

5. MITIGATION OF EOS IN SERVO ENVIRONMENT

Details of mitigating efforts will be described in details in the final paper due to space requirement limitations in this summary. The mitigating efforts include, but not limited to:

- Improvements in wiring
- Improvements in grounding scheme
- Use of EMI filters

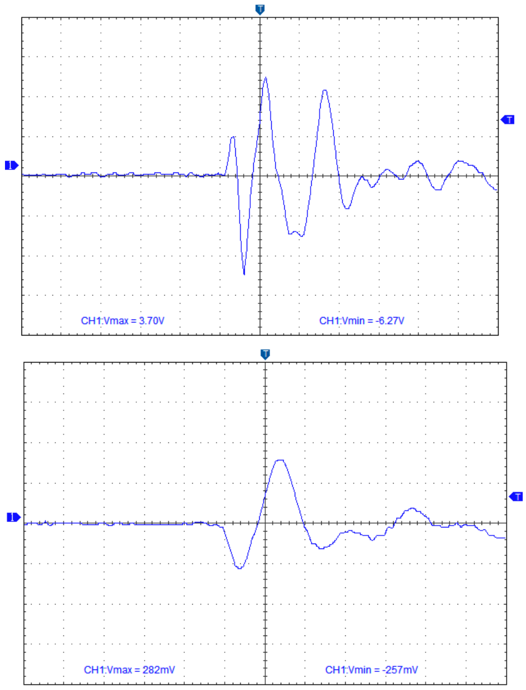


Figure 7 Voltage at the tip of an actuator before and after mitigating efforts. Note the values for each screenshot.

In IC handlers and pick-and-place machines high-frequency transient signals find their coupling via parasitic capacitance between the substrate of the devices and nearby metal objects which results in unacceptable current levels.

Figure 8 shows the typical setup in an IC handler and alike. The arm of the handler is connected to ground in a different part of the tool than a test socket or a shuttle. There is high-frequency voltage differential between the two. Capacitive coupling between the device and the arm provides conductive path for high-frequency signals. Figure 9a shows current between the pins of the device and grounded part of the tool. With CT-6 probe' sensitivity of 5mA/mV the peak current is 28mA. Figure 9b shows the same current after mitigation which peaks at 0.624mA.

5.1 Mitigation of EMI-Caused EOS in Automated Tools

Several basic approaches can be applied: reduction of noise at the source, optimization of wiring and reduction of noise at the target.

Special EMI filters can reduce high-frequency artifacts generated by servo motors and other actuators. Such filters need to be carefully constructed – use of "generic" types can be ineffective at best [6] [7] and damage the motors and servo amplifiers at worst.

Optimization of wiring, while not a complete solution, may add to reduction of coupling between noisy cables and other parts of the tool. However, in all practicality, this is the most challenging approach since when a user receives a tool, such as IC handler, all wiring is already done and is extremely difficult to change.

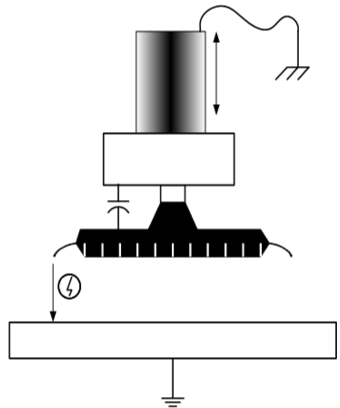
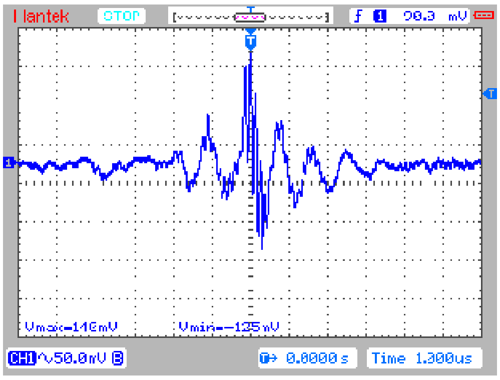
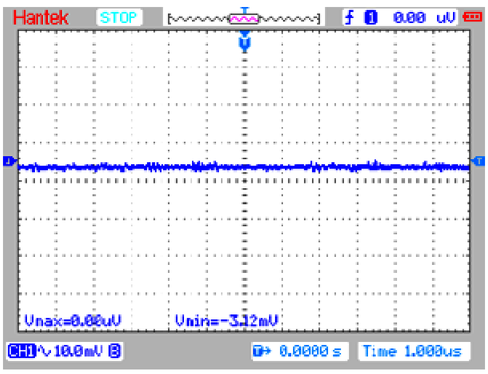


Figure 8. EMI-caused EOS current through the device



a)Unmitigated



b) With the filters

Figure 9. Current through the device in IC handler

Filtering of noise at the "target," i.e. close to the device may be the most rewarding since it has a potential of blocking noise from all sources, but it may also be a challenging one due to construction of the tool and need of modification of ground path.

Often, a combined approach is the most effective as different methods compensate for "misses" of others. Figures 7 and 9 show improvements in the EMI-caused EOS using the above methods.

6. MANUAL SOLDERING PROCESS AND EOS

Soldering irons, solder extractors and other equipment that comes in direct electrical contact with sensitive components can inject significant energy into these devices [7]. Specifically, metal-to-metal contact between the tip of the soldering iron and pins of the components is a gateway for high current that can cause significant device damage [8]. While most of industrial-grade soldering irons today provide good ground path to the tip, facility power line and ground disturbances can "seep through" to the tip. Figure 10a shows basic test setup. Figure 10b shows measurement results. Top (blue) trace is current between the tip of the iron and the board measured with CT1 current probe, bottom (purple) trace is the noise on power lines. As seen, in this example the current spike reached 19mA which may be harmful for many sensitive components [6] especially that such signals are repeated every 10 milliseconds for 50Hz power.

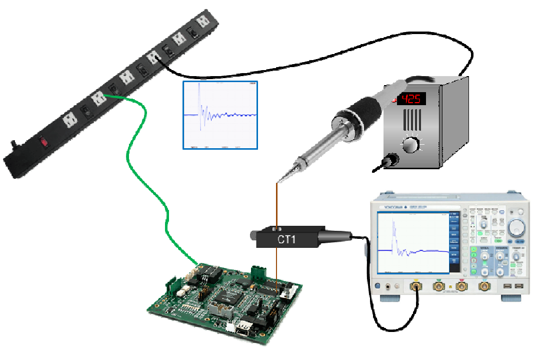


Figure 10a. Soldering Iron Test Setup

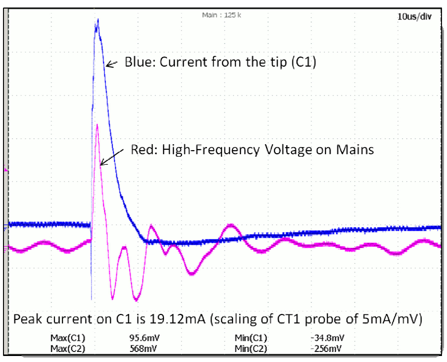


Figure 10b. Resulting current at the tip of the iron

6.1. Mitigation of EOS in Soldering Process

The way to reduce EOS threat in soldering due to EMI is to employ specially-designed filters. Such EMI filter would reduce noise from power line entering soldering iron and will create and EOS-protective "bubble" for the circuit and components.

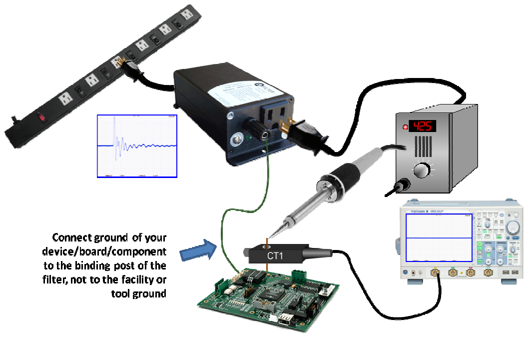


Figure 11a. Soldering Iron Setup with APN515LG filter

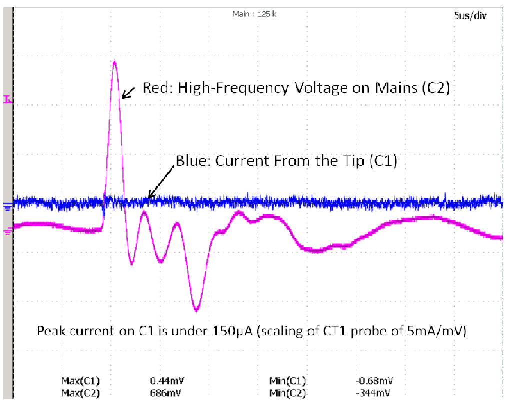


Figure 11b. Resulting current at the tip of the iron

Figure 11a shows the setup for soldering iron with EMI filter APN515LG which was specifically designed for soldering applications. Current from the tip of the soldering iron was measured in the same way as before. The resulting current as seen in Figure 11b is under 0.15mA – significantly lower than the current without the filter under the same conditions, i.e. with the same EMI signal on power lines. To the authors' knowledge, such current is quite safe for known sensitive components.

7. CONCLUSION

EOS is prevalent in the factory environment. Most of EOS exposure comes from either EMI on power lines and ground or from actuators within automated tools. Recognizing the EOS threat and mitigating it reduces EOS-related yield losses. Proper EMI-mitigating measures on the facility level and in the tools can significantly reduce EOS exposure with no downside. Intel in its Packaging Databook [(9)] and in its Manufacturing Enabling Guide [(1)] names "lack of AC line filters" one of the key causes of EOS. In the same document it issues recommendation to "…install EOS line control equipment such as incoming line filtering…" as the first practical measure to prevent EOS. Specially-designed EMI filters [(6)] offer the best EMI reduction in these applications with the highest benefit/cost ratio.

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