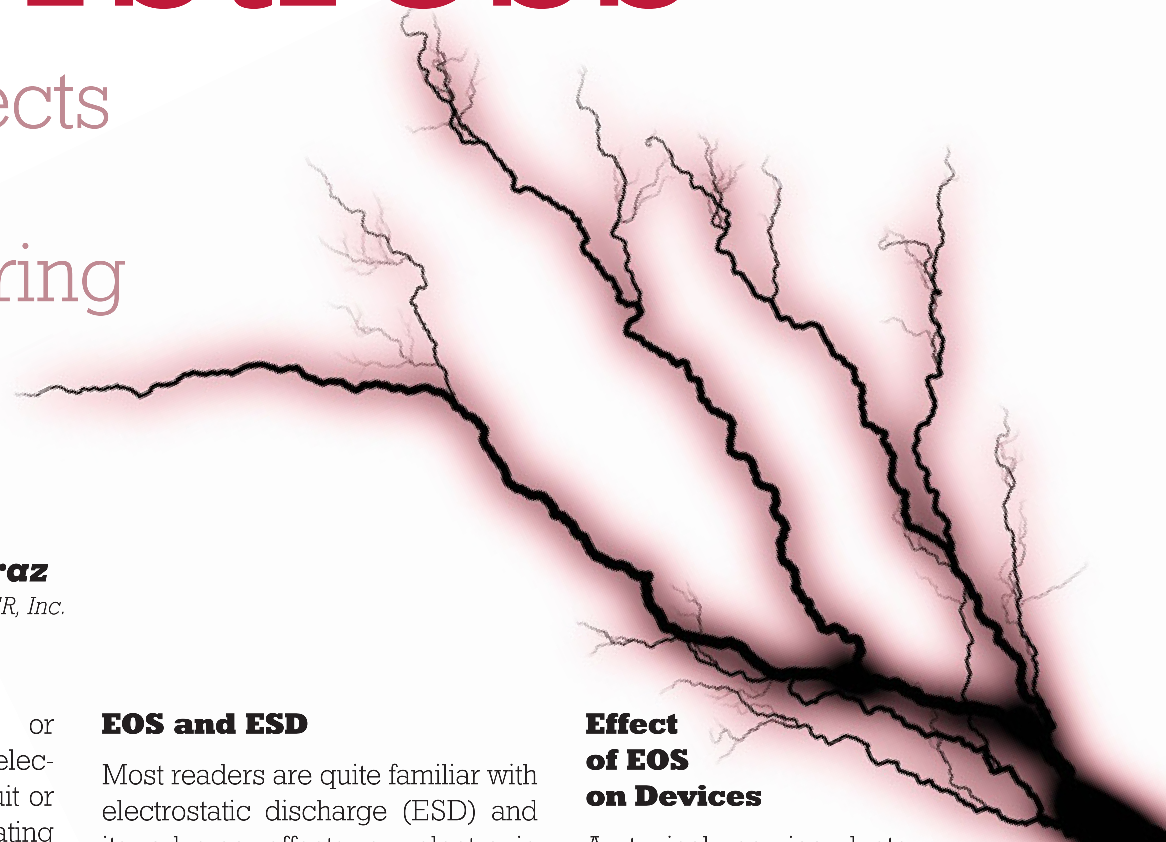
Electric Overstress

and Its Effects on Today's Manufacturing



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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. Here we will discuss the effects of electrical overstress on devices and equipment, the origins of EOS, its propagation, as well as mitigation of EOS in production environment.

EOS and ESD

Most readers are quite familiar with electrostatic discharge (ESD) and its adverse effects on electronic equipment and components. EOS, while technically encompassing ESD, is differentiated from ESD in a number of ways:

ESD Event	EOS Event
Caused by a rapid discharge of accumulated electrical charge. Once this accumulated charge is consumed, ESD Event can no longer manifest itself.	Caused by voltage and/or currents associated with operation of equipment or with power generating equipment. Lasts as long as the originating signal exists. There is no inherent limitation on it's duration.
Characterized by a specific waveform. While the waveforms of different models of ESD Events (CDM, HBM, MM and others) certainly differ in appearance, in general their properties include rapid rising edge (within few nanoseconds) and an asymptotic rear edge lasting typically less than 100nS.	Can technically have any physically possible waveform – the sources of EOS are often unpredictable. There are some major categories, however, which will described further in the text.
Non-periodic and non-repeatable – accumulation of charges cannot be guaranteed.	Mostly, but not always periodic and repeatable.

Figure 1

Effect of EOS on Devices

A typical semiconductor device can be damaged by an ESD Event with magnitude of anywhere from 100V to 250V CDM (of course, the overall damage range is much wider). EOS-induced damage, however, occurs at much lower levels. IPC-A-610[2] (§3.1.1) and IPC-7711[3] (§2.11), the standards used by PCB Assembly plants to control quality of electronic assemblies, recommend that the EOS levels should be kept below 0.5V and in case of sensitive assemblies – below 0.3V. Why there is such a discrepancy in damage voltage levels? This has to do with the waveforms of exposure, not just absolute voltage levels. Similar discrepancies exists between different ESD discharge models – the same device may be damaged by 2000V HBM model, while being sensitive to 100V CDM model discharge.

The effects on the device from an ESD Event and an EOS Event can be very different. At the risk of oversimplification, the following example can be helpful. An ESD Event could be compared with emptying a cup of water on a floor. There is a resulting small puddle, but once the content of a cup (i.e. charge) is gone, there is no more water coming and the damage from the spill is thus limited. An EOS event, however, could be compared with an open faucet. However little water it may drip in comparison with the sudden pour of water from the cup, with time this trickle may flood the entire floor and cause significant damage. The duration of typical EOS Events is several magnitudes longer than the duration of most ESD Events (microseconds or even milliseconds vs. nanoseconds) – thousand or even a million times longer; therefore this comparison "holds water."

According to Craig Hillman , one of the mechanisms of damage due to EOS is thermal runaway from Joule heating (excessive current). This is also systemic to ESD Events as well. While overheating due to ESD requires a significant current injection over a few nanoseconds, a much smaller EOS Event that would last thousands or even millions times longer – microseconds or milliseconds – may generate a similar amount of heat.

Figure 2: EOS Damage of Semiconductor Device. Source: Intel

EOS often causes massive damage of the device due to its high energy, as shown in Figure 2. Sometimes the signature of EOS-caused damage is similar to that of the Charged Board ESD model (CBM) due to the similarity in energy of the event.

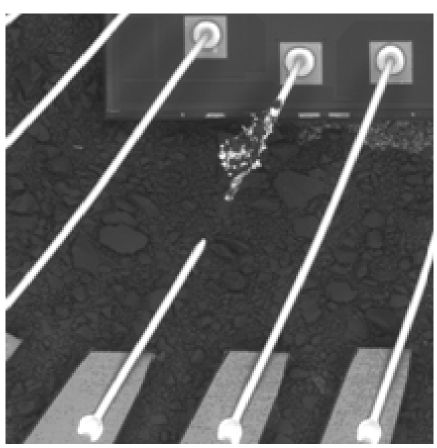


Figure 3: Damaged Wire Bond. Source: SEM Labs.

Figure 3 shows another example of damage due to EOS. High energy of EOS Event melted the bonding wire of the device.

To the author's knowledge, at the present there is no established correlation yet available between the levels of damage due to ESD and the ones due to EOS. This paper recommends that such relationship is examined by the experts in the industry and, if possible, a correlation is established for the benefits of the industry.

EOS Effect on Equipment

Device damage is not the only negative effect of unwanted electrical signals. Electronic equipment can be susceptible to noise on power lines and ground. Transient spikes all too common on power lines can add an "extra" pulse on digital lines (Figure 4) and cause numerous other problems – anywhere from sensor misreading to outright equipment lockup. Since most of production equipment today has significant electronic content, this problem cannot be ignored. Please see more on this subject here [4,5,6,7].

Types of EOS in Production Environment

There is a large variety of types of EOS occurrences in a typical production environment. This paper outlines the most common types and provides brief description of their properties and their most likely origins.

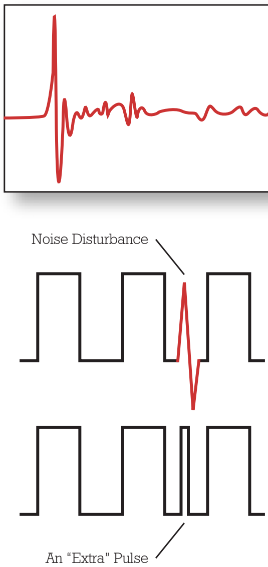


Figure 4: Noise on Power Line Affecting Equipment

Mains-Caused EOS (AC 50/60Hz)

Voltage Induction

Since most equipment operates on AC power from the mains, it is not surprising that the mains' artifacts can be present in some tools. Poor wiring schemes, lack of adequate grounding and ground loops are all contributors to this. There is a strong relationship between ground impedance and the AC voltage – the higher the ground impedance, the higher the resulting AC voltage[8,9].

Neutral/Ground Reversal

It is an unfortunate (and unsafe) occurrence when neutral and ground wires in the electrical outlet or inside the tool itself are reversed. In the author's experience this happens even in the best-run facilities in the world. To complicate the matters, conventional testers such as the ubiquitous three-light checker, which is obtainable from hardware stores, cannot test for this condition. In such a situation the return current flows not through neutral but through ground wire, creating voltage on ground, which is never good thing.

Current Induction

Whether in wires connected to motors or other current consumers in the tool or within the motors, heaters and other devices, strong currents generate magnetic fields, which can produce currents and voltages in largely accidental loops within the same tools. Spreading power cables away from data cables and wires and reducing loops mitigates this problem to some degree.

High-Frequency Noise on Power Lines and Ground

High-frequency signals, or electromagnetic interference (EMI), on power lines are usually parasitic in nature (an exception to this is outlined below) and are a result of transient signals generated by operation of equipment such as stepper and variable-frequency motors, solenoids, relays and the like. The higher the power consumption of such a device the stronger the EMI signal. Figure 5 shows a typical signal on power lines generated by EMI. As clearly seen, it is anything but a continuous waveform. When assessing EMI signals for the possibility of EOS, it is imperative that instruments with the ability to capture the peak signal are used. In the author's experience, it is not uncommon to encounter spikes of up to 20V on ground and in power lines. Figure 5 shows some typical waveforms on power lines in a production environment.

There are cases, however, when the predominant signal in cables and wires is a continuous waveform. Some examples are signals from servos and variable frequency motors. Their fundamental frequencies lie typically below 20kHz. Another source is RFID readers. Passive RFID tags require strong magnetic field to power them up which results in strong induced signals into anything resembling a conductive loop, which are not difficult to find in production tools. The resulting voltage, with a typical frequency of 13.56MHz, then propagates through wires throughout the facility. While these signals are intentional and are used for specific purposes, when they spread outside of the equipment involved they are liable to create EMI-related problems.

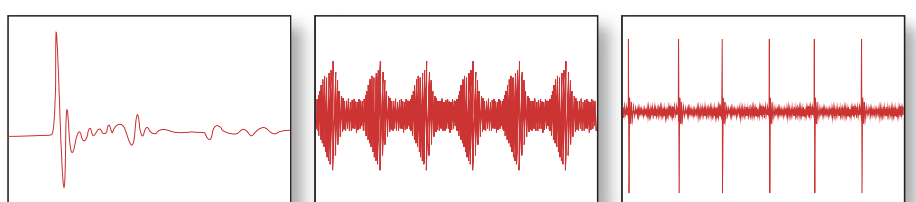


Figure 5: Typical Noise Waveforms on Power Lines

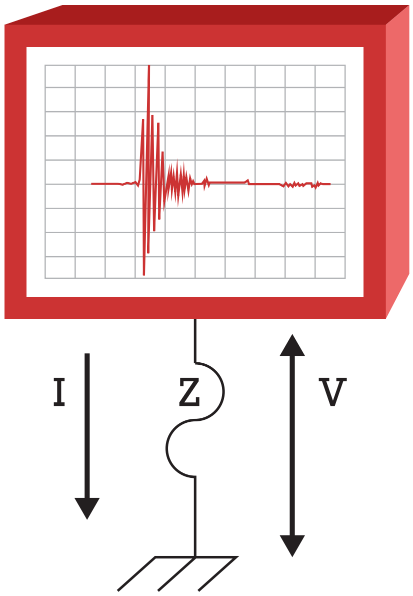


Figure 6: Ground Bounce

Ground Bounce

This phenomenon deserves special consideration for high frequency signals. Though mostly attributed to ICs and PCB layout issues, ground bounce is a significant factor for factory-scale signals. This paper[6] provides adequate background of the phenomenon of ground bounce. In short, when ground wire has substantial impedance at high frequencies, current passing through this wire from noise-generating equipment to ground produces voltage across this wire thus floating what was supposed to be the ground of the tool – see Figure 6. According to calculations in this paper[7] this voltage may reach several volts at just a few milliamperes of current. This should trigger considerations for a proper grounding scheme.

Cases of EOS in Production

Now that we discussed what phenomenon can cause EOS exposure, let's examine some of the cases of EOS in real-life production environment and match them to the physical phenomenon which is manifested in each case. Only very few of such sources are outlined in this paper due to limitation of the scope.

Soldering Irons

The tips of soldering irons touch the most sensitive electric components, therefore it is under the most scrutiny for EOS exposure. Some standards (MIL-STD-2000) require the tip of soldering iron to produce no more than 2mV of signal, which is quite unrealistic in most environments, especially given that the document does not limit the signal to only low frequencies. Papers such as this one[8] were written on the subject. A voltage on a tip of a soldering iron can inject EOS signal into a sensitive component during soldering and damage it. Let's take a look at why a soldering iron tip have voltage to begin with.

Bad Grounding

Loss of Ground

If a soldering iron loses ground, the tip of the iron can have any voltage up to ½ of the supply voltage to the iron. The voltage due to ground loss is usually AC 50/60 Hz. DC voltage on the tip would be contributed to other phenomenae, usually caused by a defective power supply in the iron itself. In the very best case the voltage at the tip of the iron due to loss of ground would be equal to voltage on neutral which, as discussed before, is not zero and is typically several volts of AC. Loss of ground can occur within soldering irons themselves or in power outlets. Raytheon[9] reported an occasion of massive failure of ground in power outlets which led to EOS and resulting damage in sensitive circuit. Reversal of ground and neutral also leads to excessive voltage at the tip.

Noise on Ground

Whatever signal is present on ground, it will be present on the tip of the iron. Noise on ground can be quite high as discussed before. When the voltage on the tip is measured with a multimeter or an off-the-shelf iron checker, it will easily miss high-frequency signals and especially spikes that are typical in the production environment. It is imperative to be able to measure voltage with instruments that are capable of measuring high-frequency spikes. A high-speed digital oscilloscope or a dedicated meter with high-frequency capabilities should be used.

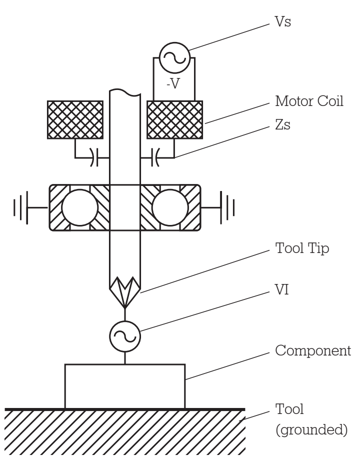
Noise on Power Line

Noise is propagated not only via ground but via power lines as well. Transformers and power supplies converting mains voltage to 24V, for example, are often transparent to high-frequency spikes which end up on the soldering iron tip. Spikes caused by commutation of equipment (e.g. heat gun, etc.) can also propagate through the power supply. The effect is similar to that which is caused by noise on ground and the signal should be measured in a similar fashion to what is mentioned above. Power line filters can help to reduce this noise.

Power Tools

Power tools such as electric screwdrivers commonly used in electronic assembly may not always have good grounding of the tips during rotation. Grounding via ball-bearings during rotation does not work since the lubricant in the bearing is insulative. In addition, some mains-powered screwdrivers may not have dedicated grounding since they may be using double insulation to satisfy safety requirements. Resulting voltage on the tip of the screwdriver may be quite high. The author observed 107V AC on the tip of a screwdriver used in the assembly of mobile phones in a 220V region.

Even the screwdrivers used in equipment for such a sensitive process as assembly of disk drives can generate significant voltage. As described in[10] voltage induced into a screwdriver's ground wire



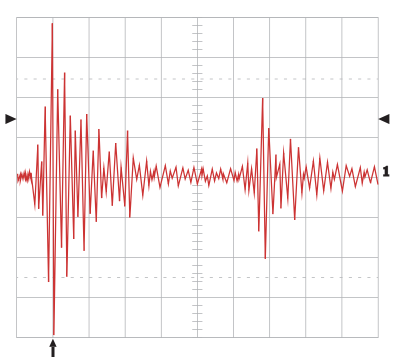


Figure 7: High-Frequency Noise at the Tip of Power Screwdriver. Current at contact reached 180mA

by simply being routed in the same bundle as the wires to the stepper motor generated significant spikes (Figure 7)

Mitigation of EOS in Production Environment

Good grounding with less than 1 Ohm impedance usually resolves most of 50/60Hz issues. High-frequency noise, however, is quite a bit more challenging. The most effective way to deal with noise on power lines is EMI filtering which is included with recommendations by Intel[1] in the abovementioned document. EMI filters allow mains signals (50/60Hz 120/250V) to pass through, but greatly reduce extraneous noise. In addition to the power lines, it is also highly desirable to filter noise from ground as well, as it may carry a significant amount of noise throughout the factory.

Some equipment at your factory may already have some sort of EMI filter built in – equipment manufacturers do it in order to comply with emission regulations, such as FCC and CE. While such built-in filters help to reduce noise on power lines in the laboratory environment, they are much less effective in managing noise on a factory level, where the length of power lines and their complex network are very different from a sterile and predictable laboratory environment. Sometimes, built-in EMI filters can amplify the noise signal in a factory environment rather than suppress it. Figure 8 shows noise on power line amplified by a regular built-in EMI filter. This paper[11] presents more details on this phenomenon

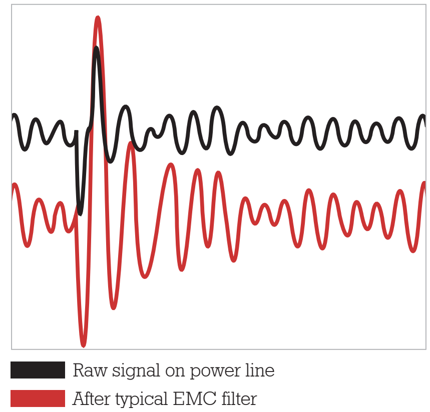


Figure 8: Noise Amplification from Regular EMI Filter

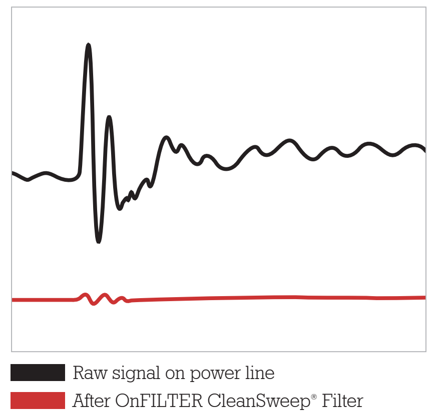


Figure 9: Reduction of Noise after specially-designed power line EMI filter

Suppression of noise on power lines in a factory environment requires special considerations which are very different from those required for regulatory compliance. shows suppression of noise by a specially designed filter for such applications – OnFILTER's CleanSweep power line filter AF series. As shown in Figure 9, the transient signals on power line are reduced to the point of insignificance.

Connecting an EMI filter is quite simple, as shown in Figure 10 – plug a filter into an electrical outlet and plug your equipment into the outlet on the filter. Now your equipment is protected against noise on power lines.

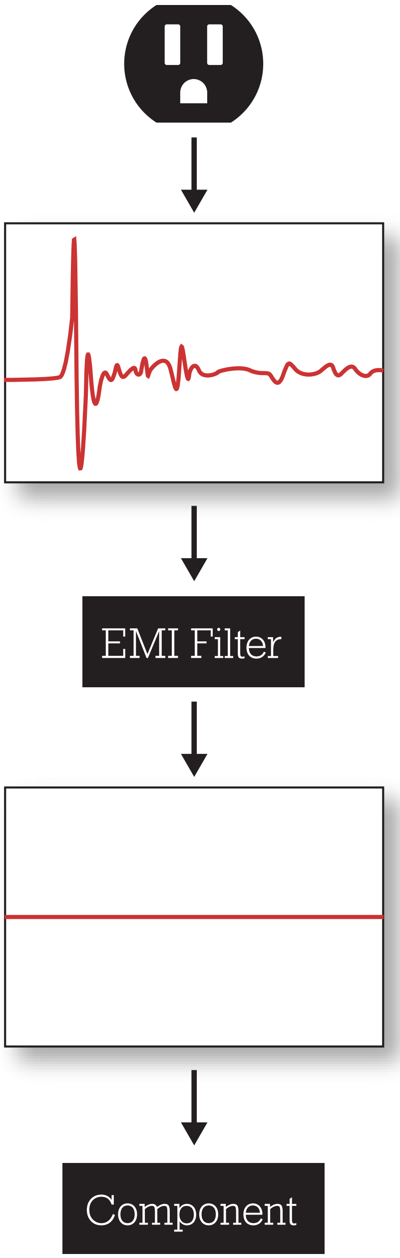


Figure 10: Connection of CleanSweep(R) Power Line EMI Filter

There are two fundamental methodologies to consider: one is to reduce a generation of EOS-causing signals; another one – to prevent EOS signals reaching sensitive equipment and components. If you know the "culprits" that cause most of the noise in your environment, then the first approach may help. However, because there can be so many pieces of equipment in a single production environment and the difficulty in identifying noise sources, it is a much more practical approach is to use EMI filters for noise-sensitive equipment as they will suppress noise regardless of its source. OnFILTER's CleanSweep® EMI filters suppress noise in both direction, assuring that noise generated by filter-protected equipment itself won't pollute the power network as well.

To conclude, the use of power line EMI filters is the most cost-efficient and the most effective way of improving uptime by reducing EOS in production environment, reducing downtime and improving reliability of sensitive components.

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About The Author

Vladimir Kraz is a founder and a president of OnFILTER, Inc. Prior to founding OnFILTER he started and was a president of Credence Technologies, Inc., a manufacturer of ESD and EMI instrumentation, which was acquired by 3M. Mr. Kraz holds 22 U.S. Patents and is active in ESD Association' and SEMI Standards activities. He has written a number of papers on the subject of ESD and EMI physics and management, many of which can be found at www.onfilter.com/library.html ■

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