EOS Exposure of Components in Soldering Process

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Abstract

This paper examines the nature; the consequences and the mitigation of electrical overstress (EOS) caused by electromagnetic interference (EMI), or electrical noise, on power lines and ground in manufacturing environment.

Introduction

Soldering irons, solder extractors and other equipment that comes in direct electrical contact with sensitive components can inject significant energy into these devices. 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.

Where would a soldering iron tip get voltage? After all, it is supposed to be grounded, just like the PCB to which the components are being soldered, so theoretically there should be no difference in voltage and thus no harmful currents between the tip of the iron and the devices. This, however, may only be true for DC or for very low frequencies such as power mains (50/60Hz). For high frequency signals it may be very different.

Transient Signals as a Source of EOS

Assuming the tip of the iron is properly grounded, the voltage on it can arrive mainly via ground connection and to some degree via capacitive coupling between the heating element and the tip.

Ground by itself is not a generator of any signal. However, grounding wires connect the entire factory and once some stray electrical signal enters grounding network, this signal can reach quite far.

Main source of voltage on ground is transient signals leaked from power lines. Transient signals can come from a number of sources, such as switched power supplies, thyristor control, servo motors, equipment commutation and so on[1]. These signals can reach significant magnitude. Figure 1 shows transient signal on power line caused by turning on ubiquitous heat gun. As seen, the peak signal reaches 8.7V and this is not the highest magnitude found in manufacturing environment where plenty of high-current equipment is operating.

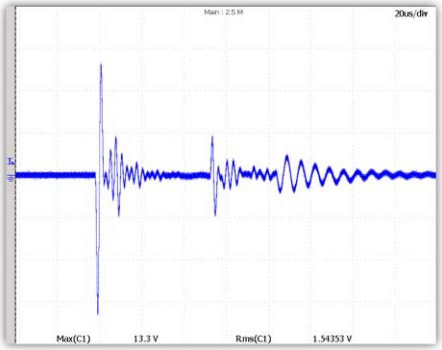


Figure 1. Transient Signal on Power Line Caused by Turning on Heat Gun

By virtue of neutral and ground being eventually connected together at some point and because of leakage currents (parasitic currents between power lines and ground) present in almost all equipment and, to a much higher degree, in manufacturing equipment, these transient signals are also present on ground. Current leakage at high frequencies is significantly higher than often-specified leakage at power line frequencies.

This is due to much-reduced impedance of parasitic capacitance coupling at higher frequencies. With the complexity of grounding network and increased leakage at high frequencies in the soldering iron itself, there is a strong possibility of current spikes between grounded iron tip and grounded PC board with components.

What is Acceptable and Safe?

There are a number of standards and recommendations limiting signal on the tip of a soldering iron. ESD Association' STM13.1-2000[2] sets current limit at 10mA and voltage limit at 20mV. While the test set-up in this document implies mains (50/60Hz) signal, there is no stated limit of properties of the signal. It should be noted that the current limit in this document is about 15 years old (it takes at least three years to finalize and to release a document within the standards organizations); the current limits now should be substantially lower to reflect higher sensitivity of today's components.

Now-obsolete MIL-STD-2000[3] and its associated military standards specify no more than 2mV RMS voltage on the tip. RMS values may be very misleading for transient signals. 2mV RMS may translate into quite high peak voltage of transient signal - the voltage spikes can be very narrow, i.e. have very short duty cycle - please refer to Figure 2 to see the difference between peak and RMS values of a transient signal, also from turning on the same heat gun on a workbench where the time base was spread to the degree where typical multimeter can measure it. 761mV peak translates into only 15.8mV RMS signal – a 48 times ratio in this case. For this type of waveform, a 2mV RMS signal would translate into 96mV peak signal. Obviously, RMS value is not the best way to specify signal on the tip of the iron. A common multimeter often used for this purpose provides measurements of either RMS value or close to average – good for 50/60Hz, but unusable for transient high frequency signals.

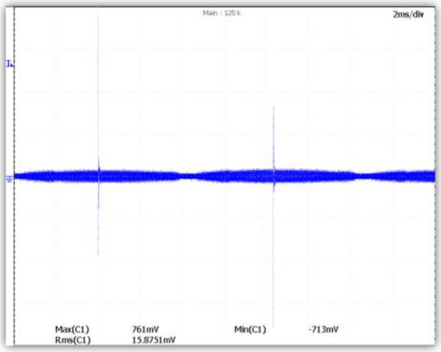


Figure 2. RMS and Peak Values of a Transient Signal Typical on Power Lines

IPC-TM-650 section 2.5.33.2 allows for 2V peak voltage on the tip of the soldering iron, which is extremely high; section 2.5.33.3 of the same document allows maximum of 1μA of current measurable with a multimeter, not a scope thus providing RMS or average value.

In dissent with the above IPC standards, IPC-A-610-E[4], the most fundamental document controlling quality of PCB assembly, provides the following instructions:

> **3.1.1 EOS/ESD Prevention – Electrical Overstress (EOS)**
>
> ...Before handling or processing sensitive components, tools and equipment need to be carefully tested to ensure that they do not generate damaging energy, including spike voltages. Current research indicates that voltages and spikes less than 0.5 volt are acceptable. However, an increasing number of extremely sensitive components require that soldering irons, solder extractors, test instruments and other equipment must never generate spikes greater than 0.3 volt.

IPC-77115 which provides directions for rework of the electronic circuits mimics IPC-A-610-E.

What Measurements are Important

Let’s examine the properties of the EOS signal caused by conducted EMI. As a rule, conducted emission signals are high-energy signals, i.e. having low output impedance and capable of delivering high currents. The reason for this is that creation of disturbances on low-impedance power line requires power and only truly low-impedance sources of noise can deliver. Even fairly low voltage transient signals on power lines can be quite dangerous because of their current capability.

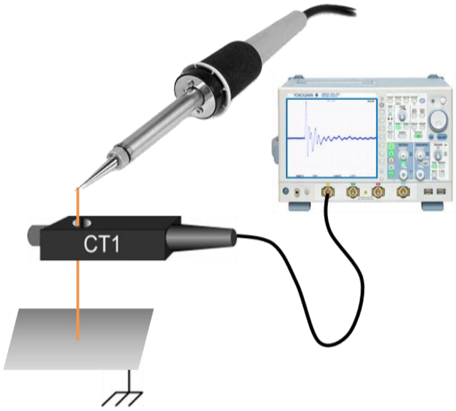


Figure 3. Test Setup for Measuring EOS Exposure

Current is a better measure of EOS safety of sensitive devices since it is the current that causes actual damage (with very few exceptions). In addition, due to complex impedances the current capability of some devices and boards may be limited at high frequencies; therefore voltage measurements alone may not be a definitive indication of current injection into the circuit.

Another factor in favor of current measurements vs. voltage is that strong transient signals on power lines and ground can easily inject corresponding signals into oscilloscope probe cables via radiated emission thus distorting voltage measurement results. Injection of radiated signal into current probe is significantly less than into a voltage probe due to a number of factors, including lower impedance of the current probe arrangement. We will focus on measurements of current.

A typical setup of a workbench is seen in Figure 3. A grounded metal plate is used in lieu of a PCB as the worst-case scenario. Current is measured using Tektronix’ CT1 current probe[6] with bandwidth of 1GHz. This probe has conversion factor of 5mV/ma, meaning that 1mA of current would be seen as 5mV on the oscilloscope.

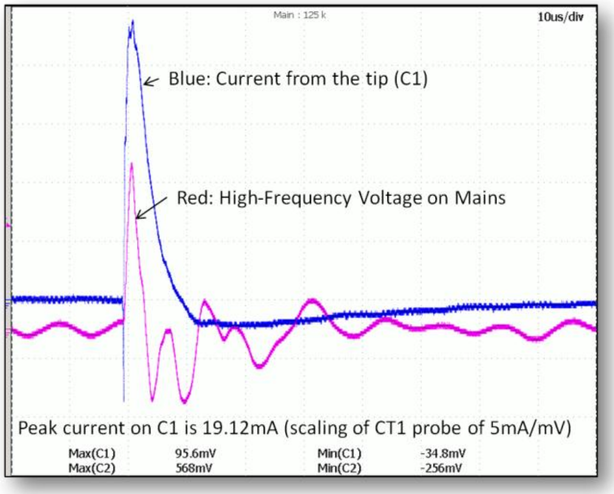


Figure 4. Transient on power line from periodic signal and resulting current from the tip

There are many sources of noise in manufacturing environment. Some of them are random, such as transients from turning on and off a typical heat gun or other piece of equipment. Others are periodic, synchronized with the waveform of voltage on the mains (50 or 60 Hz). Periodic transient signals are caused by a variety of equipment, including heaters, brightness control for vision systems and countless more. For the purposes of repeatability of the data we will focus on periodic signals. An easily-reproducible noise from a common light dimmer connected to a 60W light bulb was used in tests described below. Figure 4 depicts such transient signal on power lines and corresponding current between the tip of the soldering iron and the component in the setup of Fig. 3. As seen, the peak current from the tip (19.12mA) is significantly higher than allowed by ESDA STM13.1-2000. It should be noted that typical transient signals on power lines in the industrial settings are often significantly higher than the ones shown in Figure 4 – see earlier Figure 1.

Data from previously-published sources corroborate the above data. Raytheon in its paper[7] presented at the ESD Symposium in 2005 show transient currents at the tip of soldering iron reaching 1000mA.

How Does the Noise Get on the Tip of the Soldering Iron?

Although the tip of most professional-grade soldering irons is grounded quite sufficiently for DC and very low frequencies, at high frequencies the situation is quite different. Figure 5 shows how the soldering iron and a workbench look like at high frequencies.

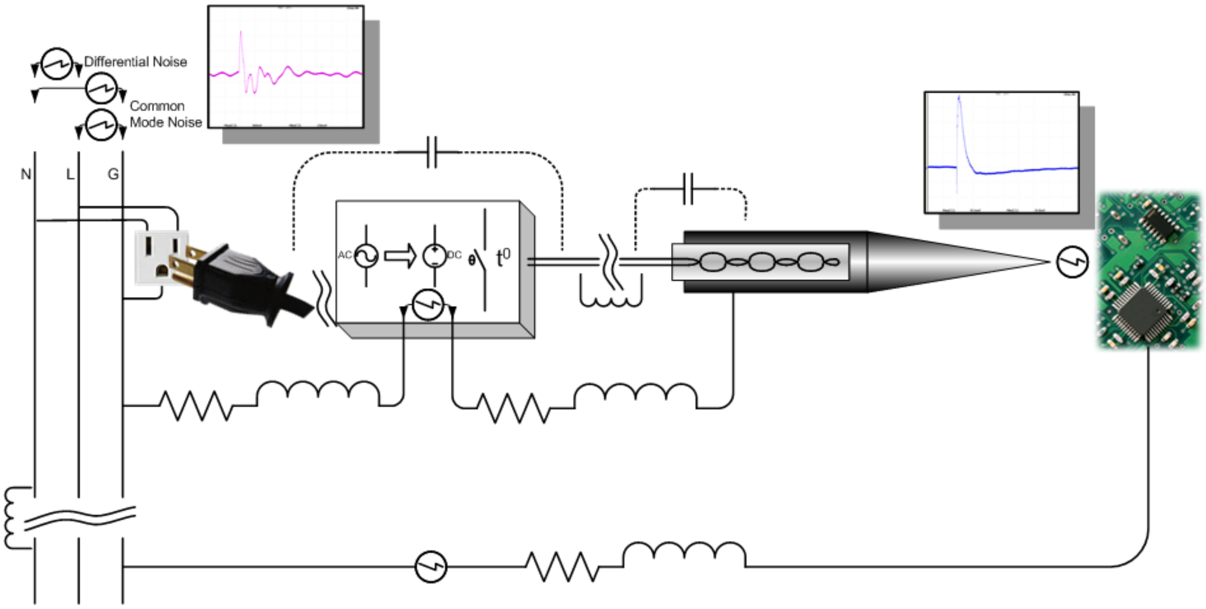


Figure 5. Noise Propagation in the Soldering Iron

Several factors are at play (in no particular order of significance):

- Noise on power lines induces corresponding noise on ground via capacitive and inductive coupling as well as via leakage currents.
- Switched power supplies (the ones that are used in soldering irons to convert 120/250V down to a typical 24V) can be transparent for high frequency signals due to a number of factors, parasitic capacitance being the dominant one. The noise from the mains thus can propagate to the low-voltage line of the iron’s heating element
- Switched power supply inside the soldering iron can be a source of noise by itself
- Iron’s heating element is capacitively coupled with the tip allowing propagation of high frequency signals
- Ground wires – from mains to the iron’s supply, from the iron’s supply to the iron itself and from the soldered object to the facility ground – have complex impedance, including resistance and inductance.

If the voltage on the tip is the same as the voltage on the PCB or on the soldered components, then there won't be any current. At DC and 50/60Hz the grounding scheme of professional soldering irons typically works well.

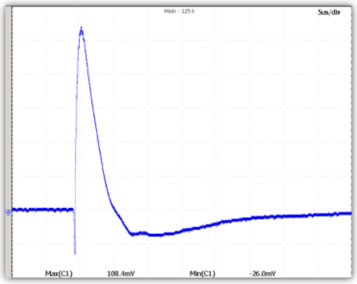


Figure 6a. PCB is grounded ~1.5m from the iron

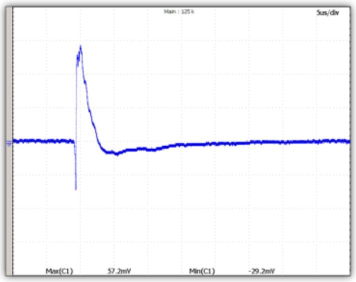


Figure 6b. PCB is grounded ~18" from the iron

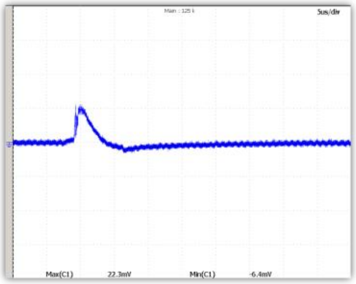


Figure 6c. PCB is grounded next to the iron

At high frequencies the voltage between the tip and the components is nearly impossible to equalize due the complex impedance of overall grounding wiring. This impedance causes, among other things, ground bounce[8] and phase shift, as well as resonance and ringing[9]. What sometimes aggravates the situation is that some factories opt for a separate "ESD Ground" – a different grounding network which is eventually connected to a facility ground. The long wires in these two grounding networks leading to the soldering iron and to the workbenches greatly contribute to a voltage differential at high frequencies. Figure 6 shows the current from the tip of the iron in several situations with different distances between where the soldering iron is plugged in and grounding of the workbench/PCB. As seen, the difference in current reaches ~80%.

Soldering Iron Properties

Are all soldering irons alike in generating and/or passing the noise down the tip? What about top-of-the line soldering irons? If there is a current from the tip of the soldering iron, does it mean that the iron itself is defective or unsuitable for work with sensitive components?

High-frequency currents from the tip of the professional-grade properly-installed iron are caused not by the iron itself, but by the reality of complex facility topology, wiring and operation of equipment. Soldering iron is just one component in soldering process and no matter how good it is it cannot fundamentally solve the issues of facility by itself. In short, if you have a quality soldering iron, it is doing its job. It is a user's task to provide safe EOS environment for the entire bench where the iron is only one of components.

Mitigating Effects of Transient Signals on Power Lines and Ground

If the sources of transient signals on power lines is known and can be removed without affecting production process, then the reduction of current from the tip of the soldering iron is relatively simple. However, too often the source is either unknown or cannot be removed. The only remaining options are grounding management and filtering out the transient signals on power lines and ground.

Grounding Management

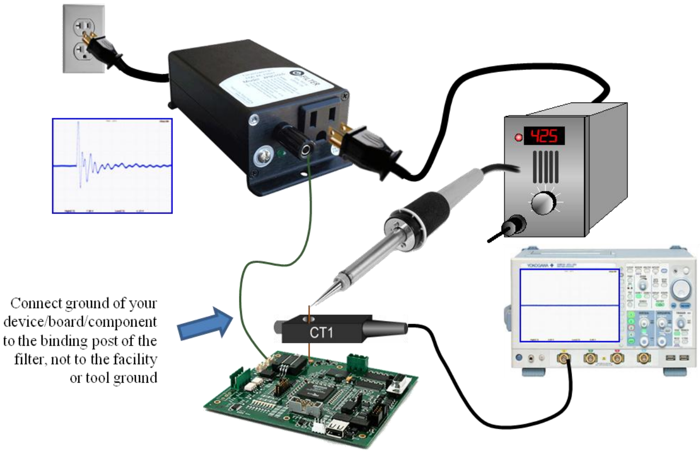
Re-routing of ground connection and separation of "noisy" ground from a clean one can help to reduce harmful currents. Techniques recommended and explained in this paper[4] help to alleviate some of the noise issues. Specifically, low impedance to facility ground and separation between "noisy" and "quiet" grounds and connecting soldering iron and the workbench to the "quiet" ground often result in lower level of transient signals.

As shown in Figure 6, grounding of the workbench and of the soldering iron as close as possible to each other can significantly reduce current exposure during soldering.

Grounding management alone, however, cannot satisfactory resolve noise issues since the source of EMI is not removed and the problematic signal still present in the soldering iron.

Filtering Out the Noise

Unless noise on power lines and ground is greatly reduces, there always will be a possibility of EOS exposure during soldering. Intel recommends10 power line filters as the first line of defense against EOS.



Connect ground of your device/board/component to the binding post of the filter, not to the facility or tool ground

Figure 7. Soldering Iron with Power Line EMI Filter (OnFILTER model APN515LG)

These filters suppress noise on power lines and provide soldering iron with relatively clean power. Some EMI filters also suppress noise in ground line.

Figure 7 shows recommended application of power line EMI filter with the soldering iron. It is important to connect ground of your workbench or tool to the ground terminal of the filter, not to the facility ground – the filter creates quiet "EMI ecosystem" at its output. Figure 8 shows the current from the tip of the iron used with OnFILTER' APN515LG filter under the same noise on power lines as in Figure 4. As seen, the current from the tip becomes negligibly low.

This requires specially-designed filter optimized for soldering process properties. Some soldering irons that include a "generic" type of filter can actually add noise as described in[7]. This paper[9] provides explanation of this phenomenon.

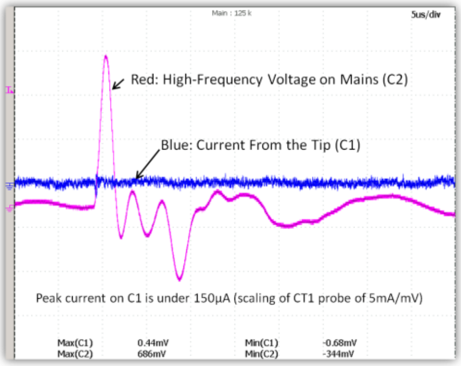


Figure 8. Soldering Tip Current after Power Line EMI Filter (OnFILTER model APN515LG)

Conclusion

High-frequency signals on power lines and ground can cause high currents into sensitive devices during soldering resulting in electrical overstress and device damage. Proper analysis of the soldering environment, as well as any environment where conductive objects come in contact with the sensitive devices and implementation of preventive and corrective measures improves yield and reduces EOS-caused failures.

References:

1 Electrical Overstress (EOS) and Its Effects on Today's Manufacturing, V. Kraz, Pulse Magazine, April 17, 2012

2 ESDA STM13.1-2000 www.esda.org

3 MIL-STD-2000 Military Standard: Standard Requirements for Soldered Electrical and Electronic Assemblies

4 IPC-A-610-E-2010, Acceptability of Electronic Assemblies, IPC

5 IPC-7711B Rework, Modification and Repair of Electronic Assemblies, IPC

6 AC Current Probes, Tektronix

7 EOS from Soldering Irons Connected to Faulty 120VAC Receptacles, Raytheon, W. Farrel et.al. ESD Symposium Proceeds, 2005

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

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

10 Intel Manufacturing Enabling Guide, May 2010, Ch. 3

EOS Exposure of Components in Soldering Process

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OnFILTER

Objectives

- Electrical Overstress (EOS) is a substantial threat for components in production environment
- As sensitivity of components grows, EOS gains more prominence while it lags in terms of attention from manufacturing and in technical details of exposure
- Understanding the exposure to EOS and EOS-caused damage to components will significantly benefit those dealing with sensitive components
- This paper describes the nature of EMI-caused EOS in soldering and shows ways of its mitigation

What is EOS?

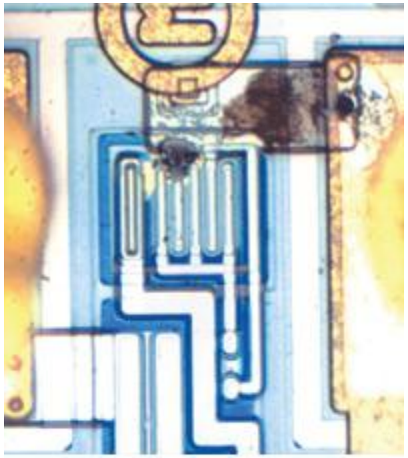
- EOS is a signal applied to the device in excess of the device’ absolute maximum ratings
- ESD is a partial case of EOS
- EOS, as we define it, is any overstress that is not caused by static charge

EOS Properties

- Though EOS can have any properties, the ones below are the most typical in a manufacturing environment:
  - Duration of individual EOS Events is longer than an ESD Event (i.e. 1µS or longer)
  - Peak signal levels are typically much lower than from ESD Events
  - EOS signals can be of any type: AC, DC, EMI, transients
  - EOS signals are often periodic and/or continuous unlike ESD

ESD vs. EOS

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 its 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 be described further in the text
Non-periodic and non-repeatable – accumulation of charges cannot be guaranteed	Mostly, but not always, periodic and repeatable



EFFECTS OF EOS ON COMPONENTS

EOS and Component Damage

- EOS causes two basic types of failures
  - Fatal failure due to overstress
    - high levels of induced signals
  - Latch-Up
    - induced voltages outside of supply rails
    - causes overheating leading to failure
    - sometimes recoverable after power-cycling

EOS and Component Damage

- EOS signals deliver significant amounts of energy to the devices
  - Virtually no limit on current
  - Relatively long duration
- Damage to the devices is often manifested as massive meltdown

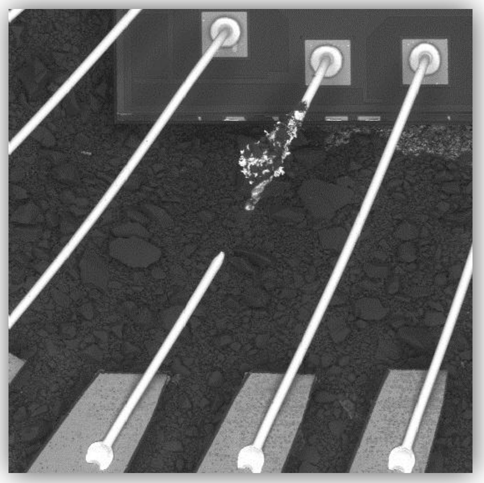
- EOS Damage of IC

Source: Intel

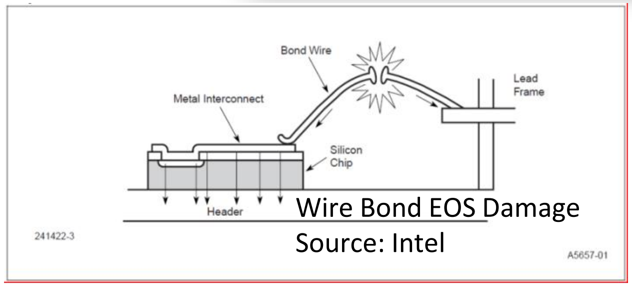
EOS and Component Damage

- Massive energy delivered by EOS can melt wires inside the packaged device
- Most problematic is latent failure when the wire is weakened but the damage is not detected during the device test
- Such weakened device can fail in product' use

- EOS and Wire Bond



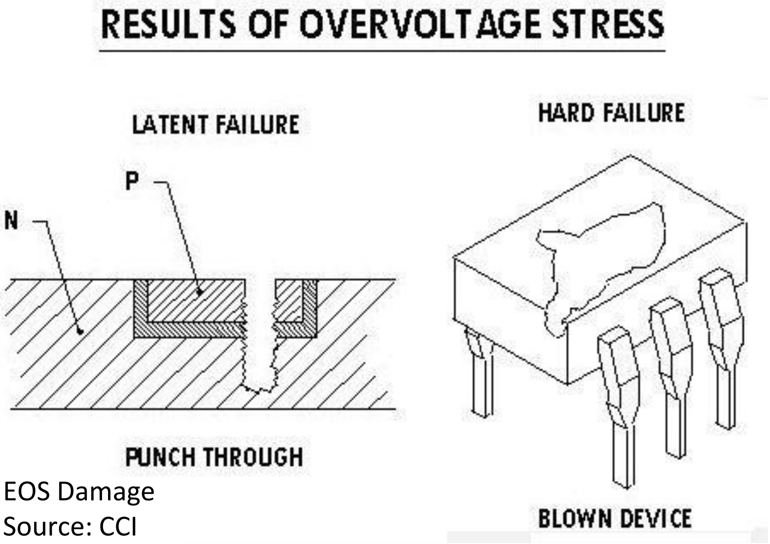
EOS Damage
Source: SEM Labs



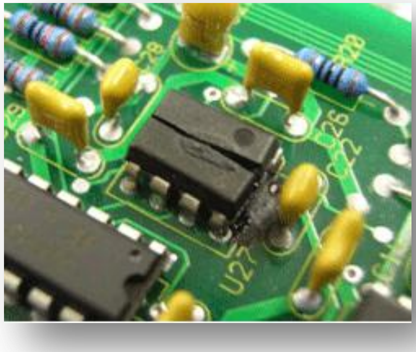
Wire Bond EOS Damage
Source: Intel

EOS and Latent Damage

- EOS can be more prone to cause latent damage than ESD
- Large energy delivered by EOS weakens the structure, the features and the geometry
- Weakened elements may still perform adequately during final test but fail in use when even the slightest normally acceptable stress is applied



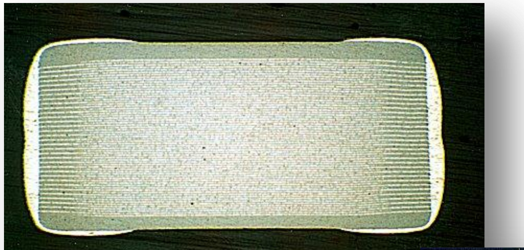
EOS Damage
Source: CCI



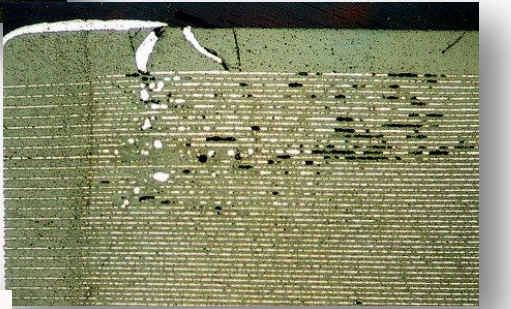
Source: EDN Magazine

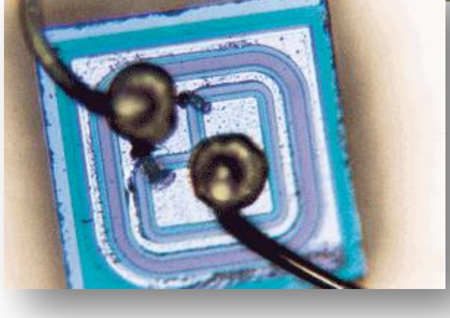
Does EOS Induce Damage only in Complex Devices, such as ICs?

- EOS is just as harmful for simple devices as for complex ones
- Capacitors and transistors can be affected by EOS as shown
- Latent damage is also a concern for simpler devices



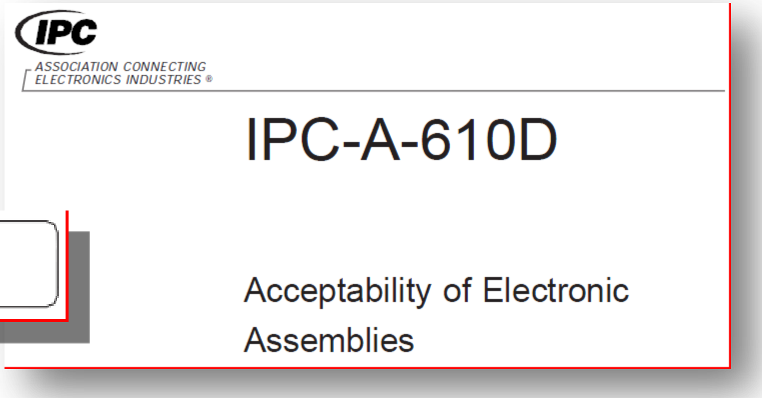
EOS Damage of Capacitor
Source: Assurance Technology





EOS Damage of Transistor
Source: Test and Measurement World Magazine

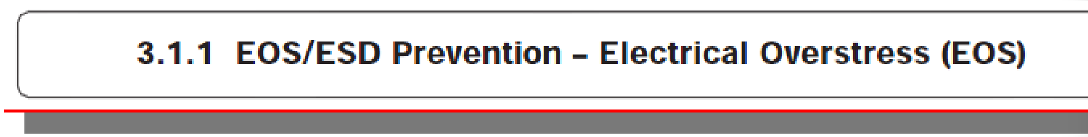
How Much EOS is Too Much?



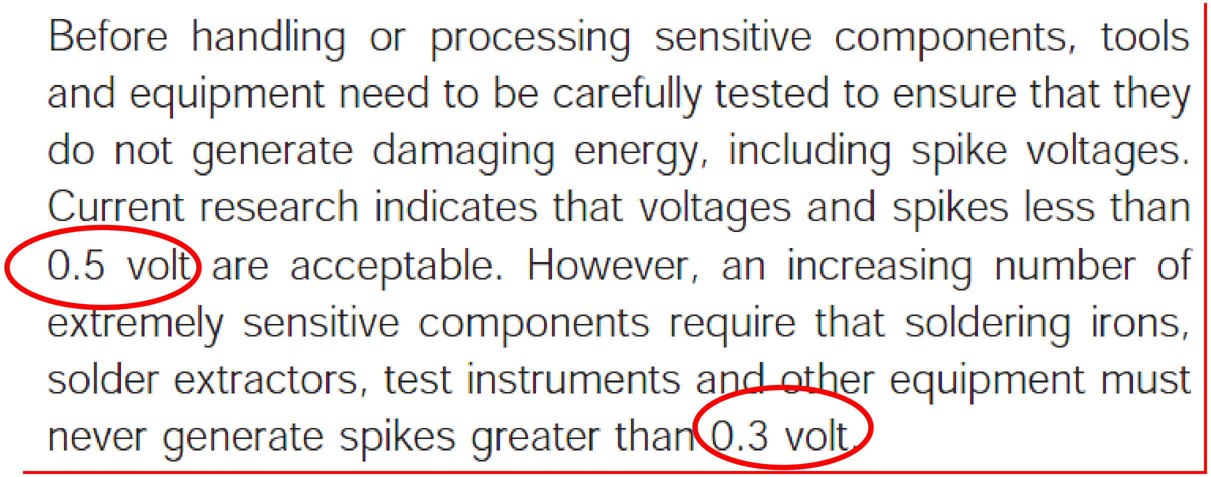
IPC ASSOCIATION CONNECTING ELECTRONICS INDUSTRIES ®

IPC-A-610D

Acceptability of Electronic Assemblies



3.1.1 EOS/ESD Prevention – Electrical Overstress (EOS)



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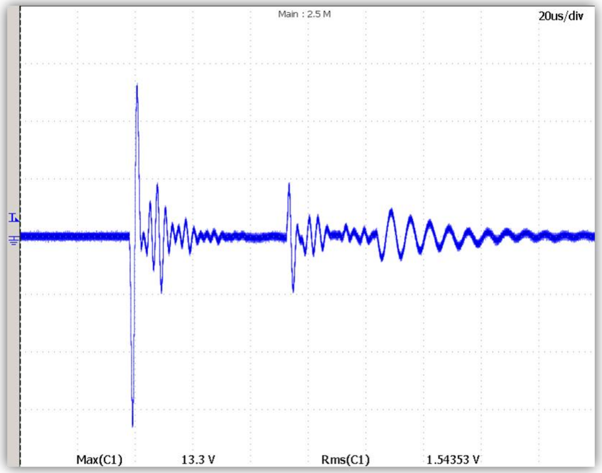
Why Such Huge Discrepancy in Damage Levels?

- 0.5V vs. 100V?
- The difference is in delivered energy
- ESD Event lasts few nanoseconds
- EOS Event may last microseconds or milliseconds – thousand or million times longer

vs.

What Does This Mean?

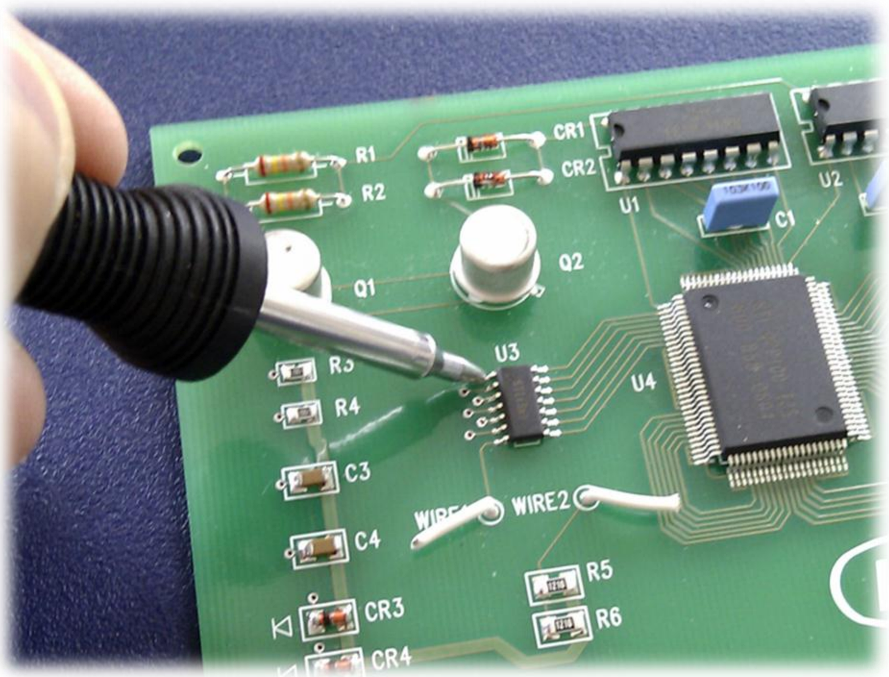
- Conventional methods of measuring voltages in production environment, while being perfectly good for ESD, are not sufficient for EOS
- EOS is measured with high-frequency tools, not regular static instrumentation
- ESD and EOS measurements are NOT interchangeable
- EOS control is not a subset of ESD control – it is a separate entity



EMI-CAUSED EOS

EMI-Caused EOS in Soldering Process

- Soldering irons come in direct electrical contact with sensitive components
- Any voltage residing on soldering irons causes unwanted current into sensitive devices
- This current causes electrical overstress (EOS) that damages sensitive devices



What EOS Exposure is Safe?

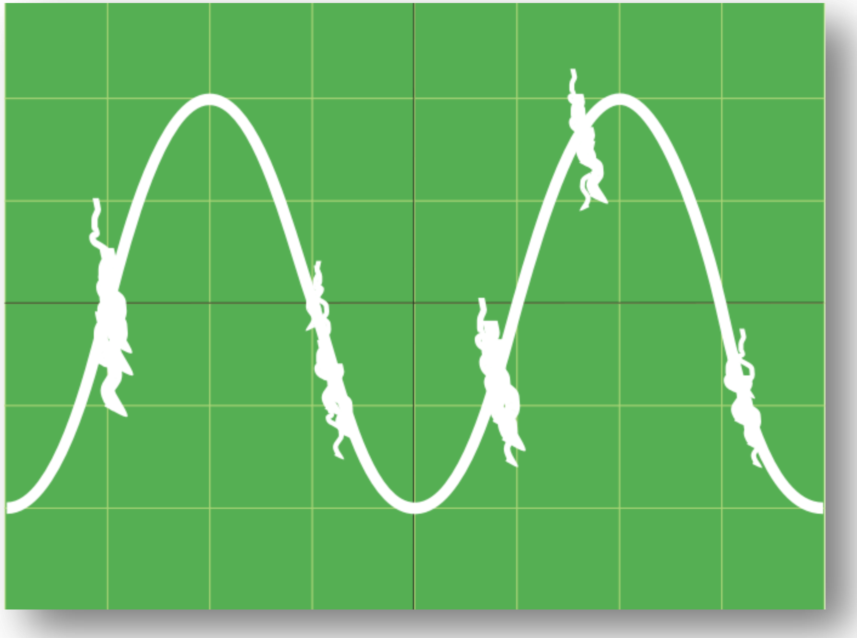
- Various industry standards and recommendations do not always agree as seen below

Standard / Organization	Voltage	Current	Comment
ESDA STM13.1-2000	20mV	10mA	
MIL-STD-2000	2mV		RMS
IPC-TM-650 Sec.2.5.33.2	2V		Peak
IPC-TM-650 Sec.2.5.33.2		1µA	RMS
IPC-A-610	0.5V / 0.3V		Peak

- Ultimately, it is the users who has to set EOS requirements for their devices
- No component got damaged from reduced levels of EOS

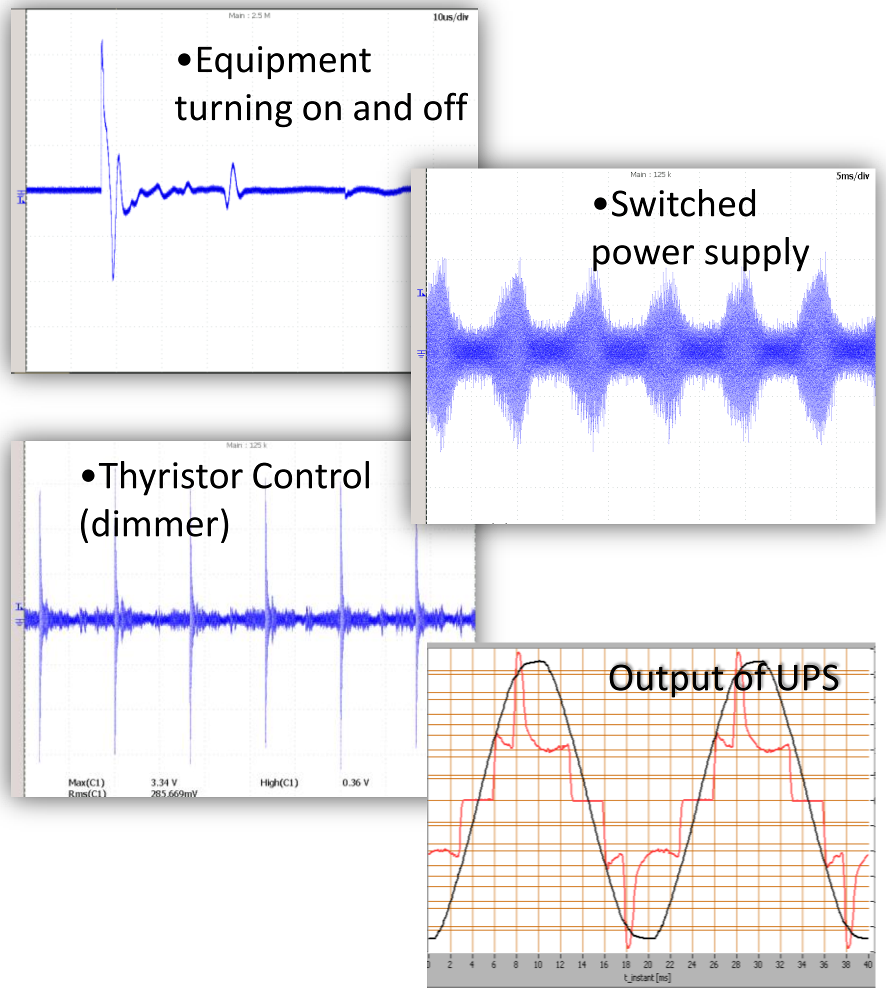
EMI-Caused EOS

- Significant proportion of electric overstress in manufacturing is caused by high-frequency transient signals
- This phenomenon is called conducted emission, or EMI – electromagnetic interference
- EOS-generating EMI in production environment comes from power lines and from equipment within tools



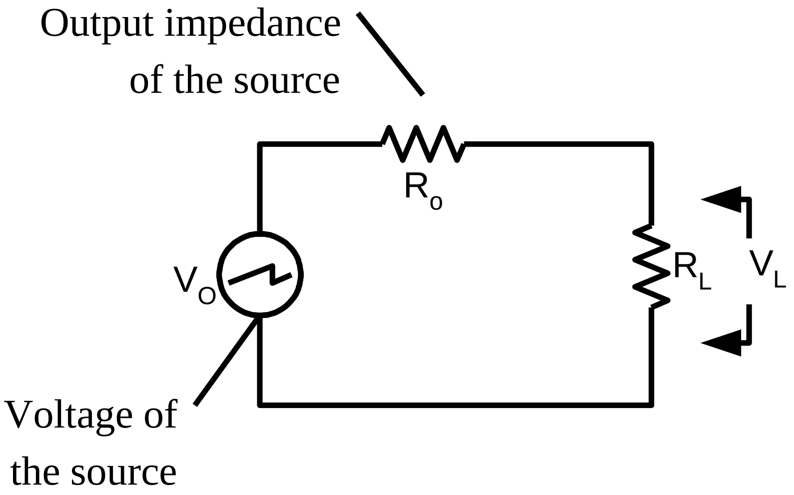
Noise From Power Lines

- Ideal power line (mains) provides sinusoidal voltage
- Every device consuming electricity loads power line and alters its voltage
- Most of noise is spikes and transient signals
- This noise travels from one tool to another and enters facility ground, propagating far
- These spikes enter other tools and may cause EOS in devices



How Much Current Can EMI Source Provide?

- Ability of EMI source to provide current is determined by its output impedance
- The lower the output impedance, the higher the current capabilities of the source
- Since EMI is caused by power elements, it appears that output impedance is low



Equivalent Schematic of EMI Source

V_O – Source of EMI signal

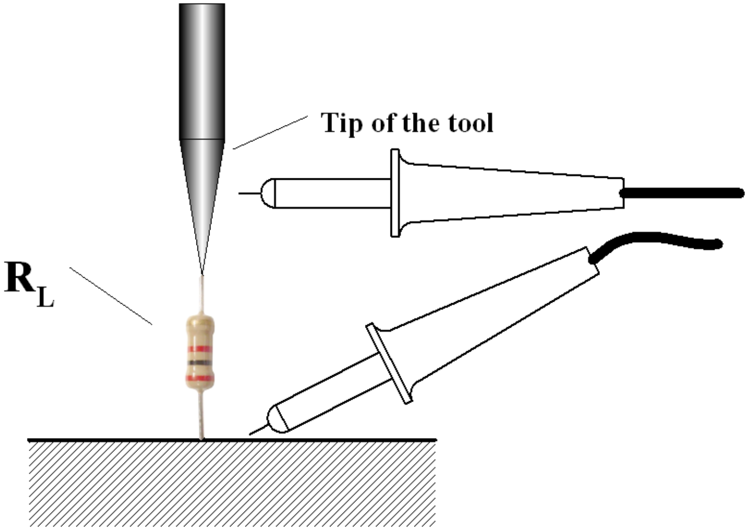
V_L – Resulting voltage on the load

R_O – Output impedance of the source

R_L – Impedance of the load

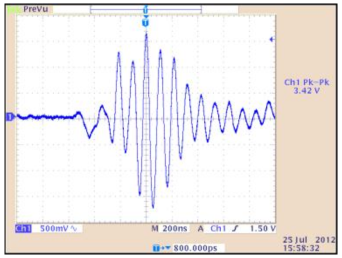
Calculating Output Impedance

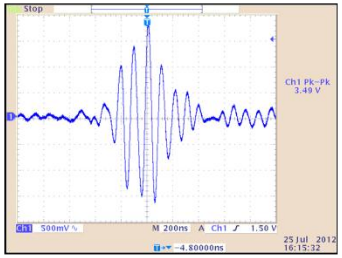
- EMI source is loaded with two different resistors
- Voltage across load resistors is measured
- Output impedance is calculated with the formula shown
- Two resistors – 50Ω and 100Ω - were used
- Voltage values were very close: 3.49V and 3.42V
- Output impedance of the source in this case is 2.09Ω
- Such low impedance is capable of supplying significant current



$$R_O = R_{L1} \times R_{L2} \frac{V_{L2} - V_{L1}}{V_{L1} \times R_{L2} - V_{L2} \times R_{L1}}$$

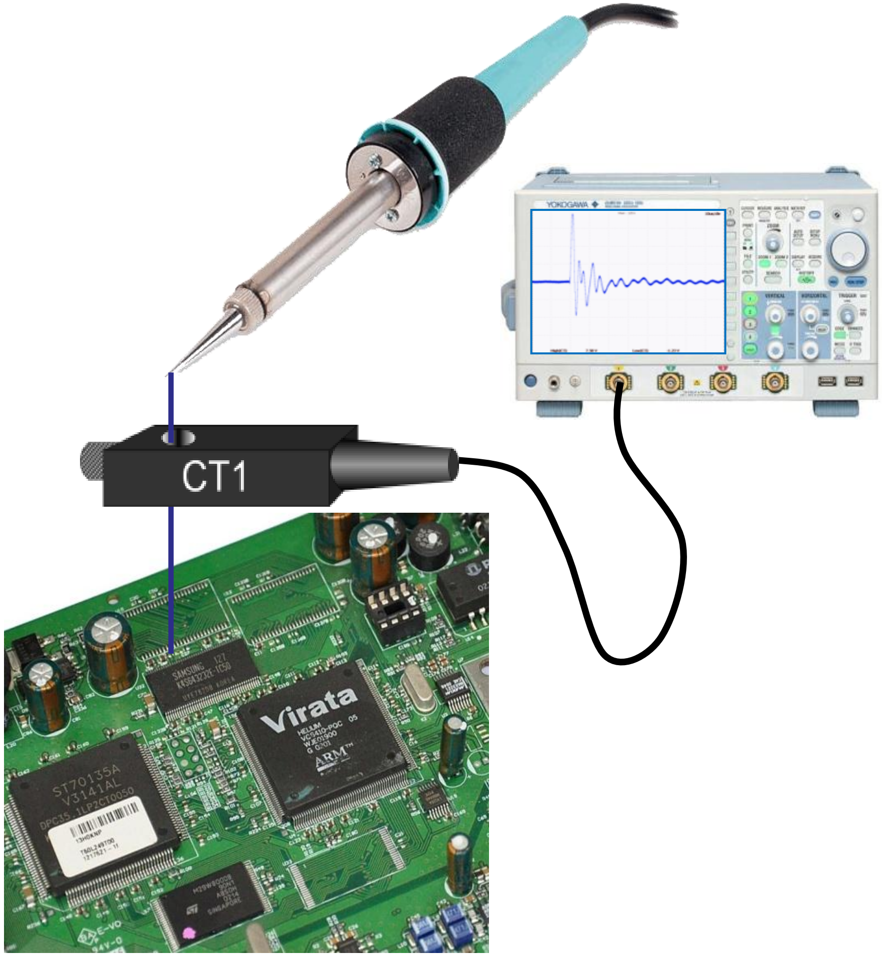
$$R_O = 50 \times 100 \frac{3.49 - 3.42}{3.42 * 100 - 3.42 * 50} = 2.09\Omega$$





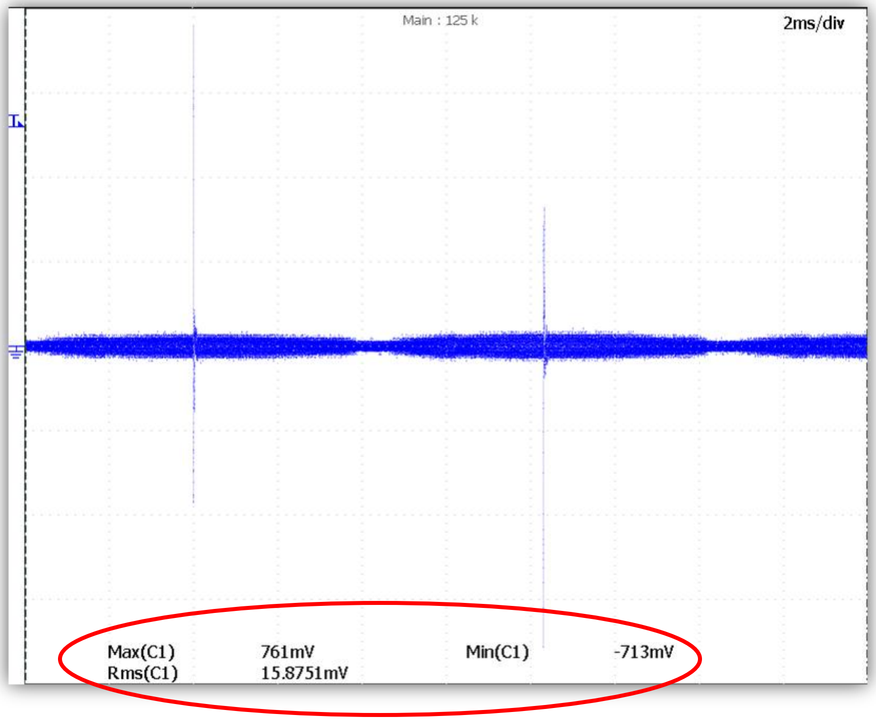
What to Measure?

- Typical specification for signal on soldering irons is in voltage
- Transient voltage measurements may be subject to radiated EMI distorting the data
- More accurate are current measurements
- It is current that damages the devices, not voltage



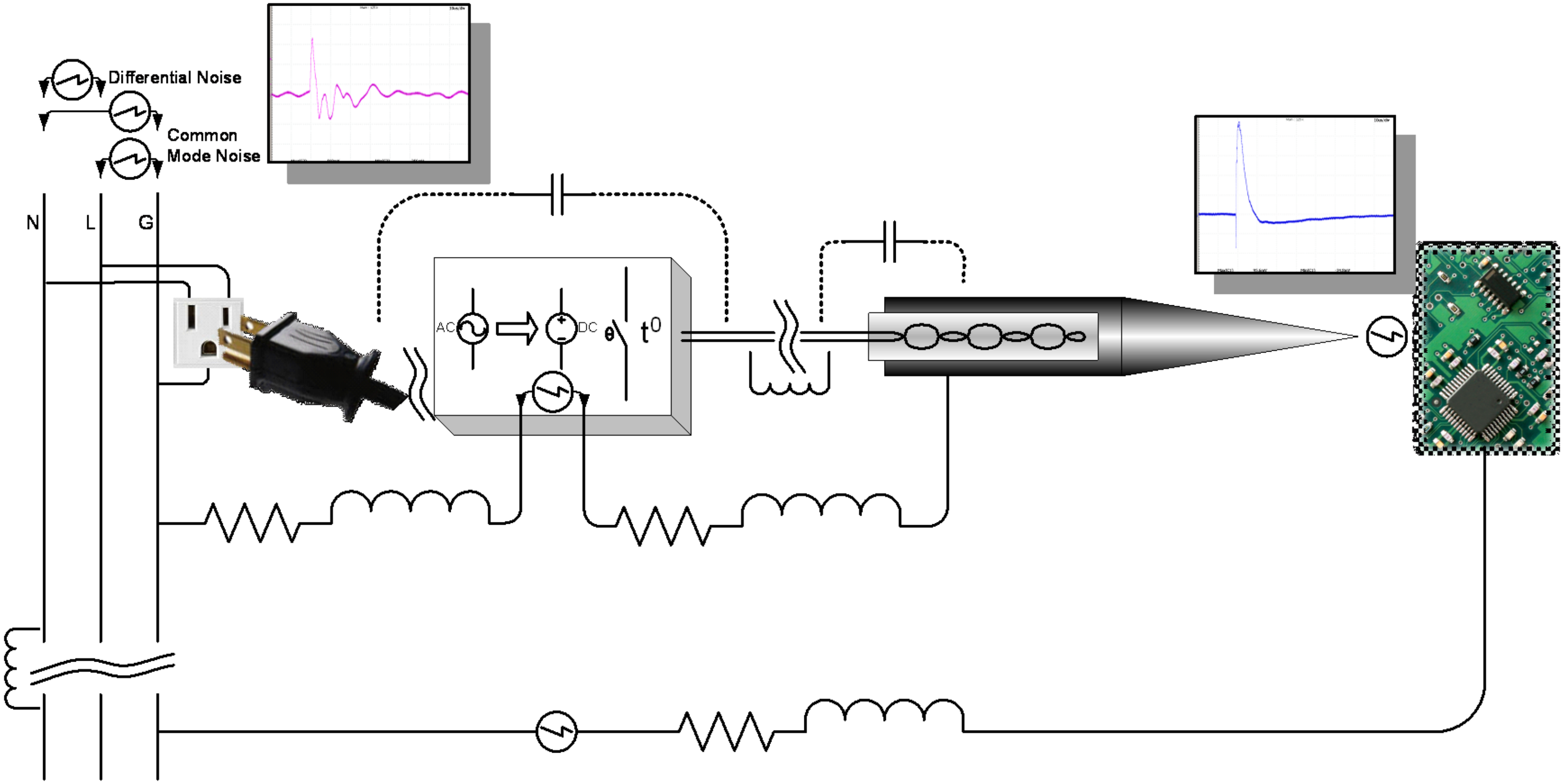
RMS or Peak?

- Most of EMI-caused EOS are transient in nature
- Measurement of such signals using RMS or average data is meaningless
- Figure to the right shows transient signals with peak values of over 700mV but RMS values of only 15.8mV
- Use only peak values obtained with appropriate instruments



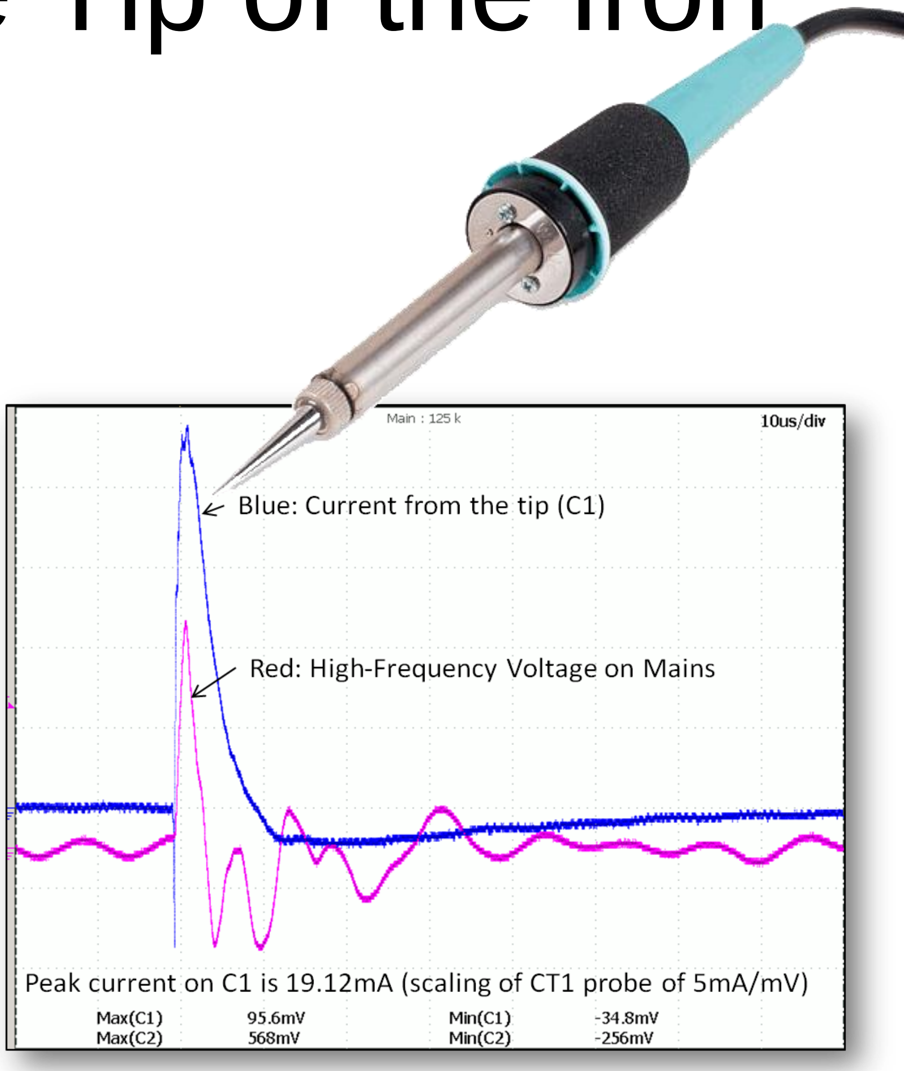
Max (C1)	761mV
Min (C1)	-713mV
RMS (C1)	15.8751mV

How the EMI Voltage Gets to the Tip of the Soldering Iron



Current from the Tip of the Iron

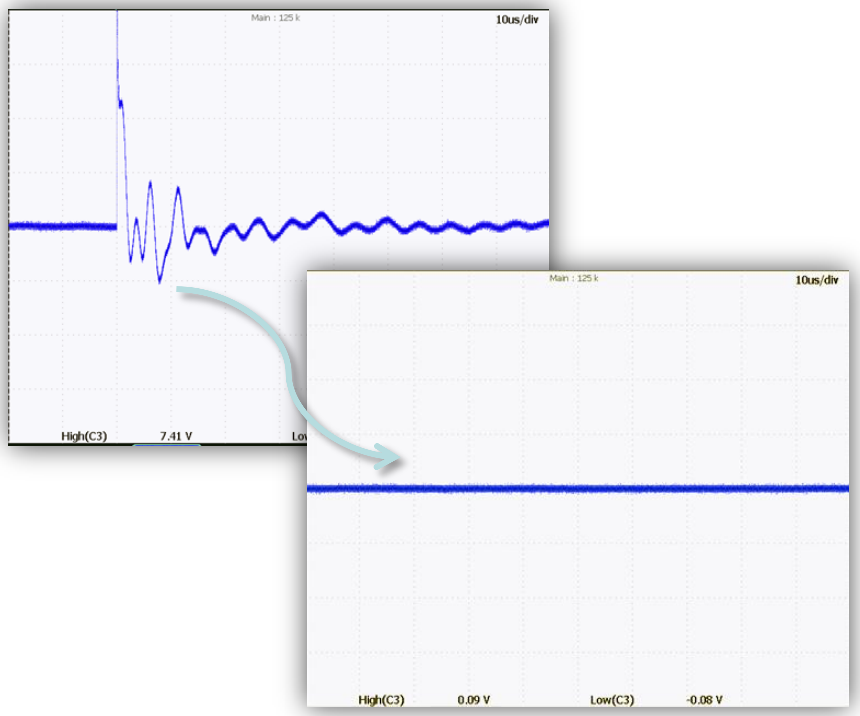
- EMI-caused EOS here comes largely from noise on power lines and ground
- Even though both the tip of the iron and the board are grounded, from high frequency point of view they are different circuits
- The high-frequency voltage differential between the tip and the board creates EOS current



Peak current on C1 is 19.12mA (scaling of CT1 probe of 5mA/mV)

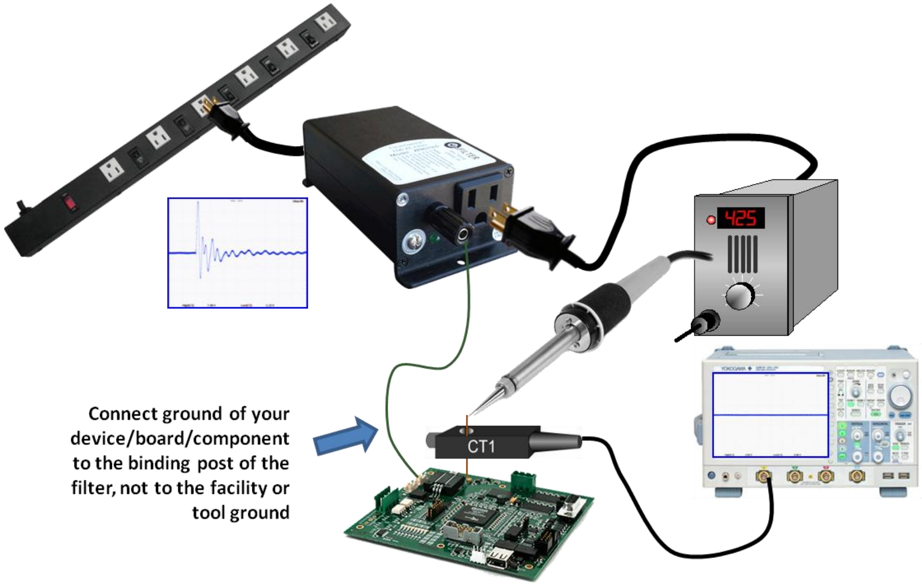
Mitigation of EOS in Soldering

- The way to prevent EMI-caused EOS current from soldering iron is to put the circuit in the EMI-protective environment using special EMI filters
- Intel: "…install EOS line control equipment such as incoming line filtering …"
- Regular EMI filters do not provide noticeable advantage and may add to the noise (Raytheon, 2005)

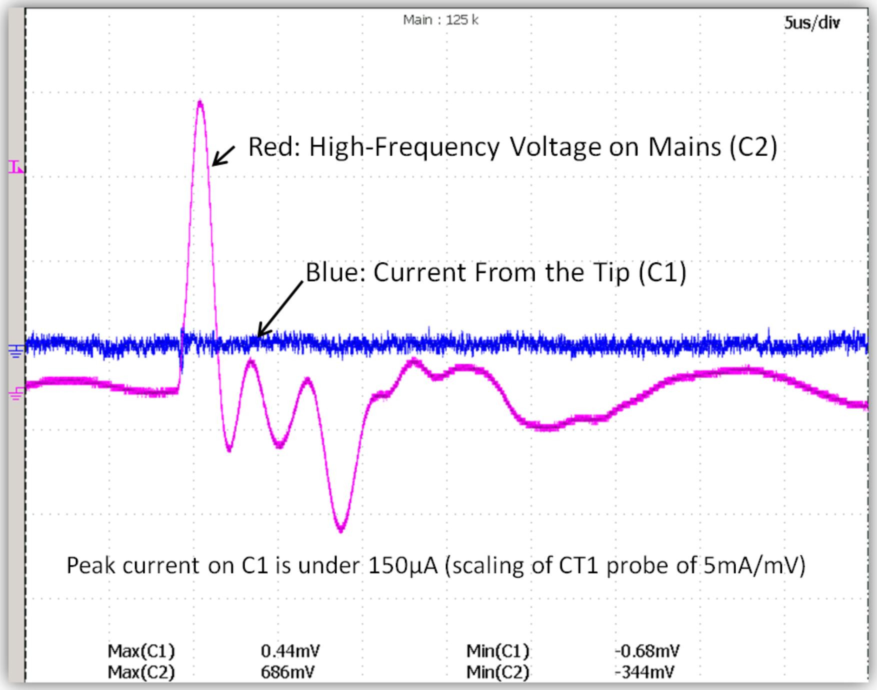


Mitigation of EOS in Soldering

Specially-designed EMI filters create EMI-protective environment for the soldering process



Connect ground of your device/board/component to the binding post of the filter, not to the facility or tool ground



Red: High-Frequency Voltage on Mains (C2)

Blue: Current From the Tip (C1)

Peak current on C1 is under 150μA (scaling of CT1 probe of 5mA/mV)

Conclusion

- Electrical overstress is a serious problem for sensitive devices
- High-frequency noise on power lines and ground is the biggest source of EOS in soldering
- Proper measurements of high-frequency EOS current is critical in assessment of safety of soldering process
- Use of EMI-suppressing filters in soldering substantially lowers the risk of EOS

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