The Importance of Being Grounded

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The proper grounding of all conductive items in the production workplace is an essential element of ESD (electrostatic discharge) management. ESD damage to components and assemblies in manufacturing is getting more and more attention. Smaller geometry and faster speeds of semiconductors have resulted in devices with increasingly higher ESD sensitivity. A typical sensitivity of integrated circuits and other devices is now in a 100V CDM range and many of the devices are already in 30 to 50V CDM sensitivity range. CDM stands for charged device model, and is defined as when a small device suspended by either pick-and-place vacuum picker or tweezers is charged and then is placed on a printed circuit board (PCB) making electrical contacts to the traces on the board and generating rapid discharge that can be quite harmful. Even if the device itself is not charged, a PCB or any other metal surface on which the device is placed, such as the shuttle in the IC handler, can be.

Conductors (i.e. any metal part) in the manufacturing process present ESD danger to the devices even if the voltage on them is low. This is because metal parts of the tools have high electric capacity and can contain plenty of charge. In a simple example, imagine a large bucket filled with an inch of water. Even though the water level is fairly low, the total amount of water in this bucket can be substantial. Because of that, it is important to realize that the damage to semiconductor devices in a real life situation can occur at lower levels than specified for standard device models.

A typical manufacturing tool, such as pick-and-place SMT machine, has many metal parts, which are supposed to be electrically connected to each other and then to ground. In reality, there is little assurance that such connections are good and that every part of the tool is properly grounded at all times. There are several typical reasons for that:

Grounding via Ball Bearings. This is quite a common situation in many tools. Ball bearings are, unfortunately, several pieces of metal separated by insulating lubricant. Indeed, when the tool is not moving, the ball bearings offer reasonable conductivity because in this state, the lubricant is squeezed out and the balls offer electrical connection between the rings. However, when the tool is moving, i.e. when it handles the electronic parts, the electrical connection is far from being guaranteed due to the lubricant, which insulates balls from the rings as it should for reducing friction.

Assumed Connection. Quite often it is assumed that, when two pieces of metal are pressed against each other, there is good electrical connection. This assumption is very far from reality. Many parts of today's tools are made from anodized aluminum, which is, on its surface, an insulator. There is often no electrical connection between parts of the tool frame constructed from aluminum extrusion due to the nature of how the different parts are connected together. On occasion, one can find grounding wires trying to make connection to a painted surface which, of course, won't work, unless it is a conductive paint.

Broken Grounding Wires. In a brand-new tool, grounding connections may be good; but after some time, the wires bend, stretch and break as shown in Figure 1 (as presented by Jos van de Giesen of NXP (former Philips Semiconducor) at the 2006 ESD Forum in the Philippines.

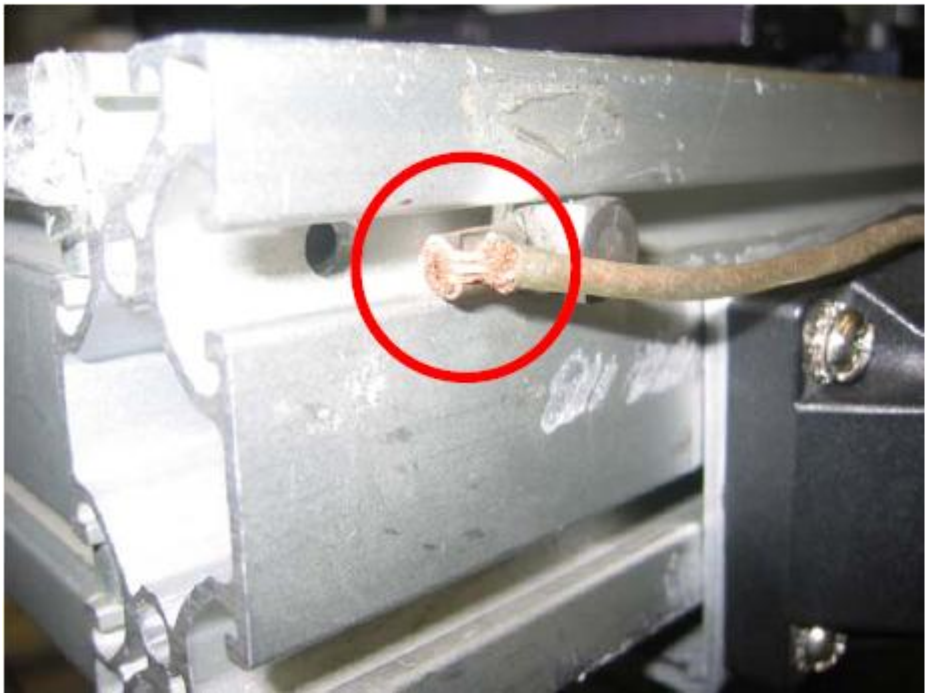

Figure 1. Broken Grounding Wire

This figure also illustrates an attempt to ground an anodized piece of metal which, of course, doesn't work.

A common assumption is that if there is a wire, it must be a conductor and that the part is grounded. This is far from reality. Table 1 below shows the data taken by the author in one of the best semiconductor fabs in the U.S. It was assumed that a particular tool that exhibited ESD-related problems was grounded. Upon close examination, the following was found:

Table 1. Connection to Ground in a Tool

Location	Resistance to Ground
Side cover to ground	1 kOhm
Frame aligner mount to ground	20 MOhms
Buffer to ground	520 kOhms
Top cover ionizer to ground	2.2 Ohms
Robot base to ground	6.6 Ohms
Upper robot to ground	9 Ohms
Equipment case and indexer	200 Ohms
Aligner to ground	400 kOhms
Tool frame to ground	1.8 Ohms

The factory standard for grounding was 2 ohms. As seen, the only acceptable grounding measurement was observed between the frame of the tool and facility ground – this is where periodic ground check was performed. Needless to say, this is insufficient as shown.

Readers are invited to conduct their own tests in their facilities on grounding connections within their own tools, paying special attention on interconnection between different internal parts of the tool when the tool is operating.

The only way to help assure proper grounding at all times is by continuous ground monitoring using tools such as 3M™ Ground Man Continuous Monitor and 3M™ Ground Man Plus Continuous Monitor as shown in Figure 2.

Figure 2. 3M™ Continuous Ground Monitors

Such monitors measure continuity of grounding via a closed-loop test according to such standards as ANSI 6.1 and ANSI/ESDA S.20.20. If any of the monitored grounds fails (that means not only a completely open circuit but also exceeding the set limit ground impedance), an alarm is issued alerting personnel to the problem. As an added feature, both these monitors offer a logic level signal to the host tool in case of ground failure. Connected to the PLC (programmable logic controller) of the tool, such a failure can turn on the tower light alarm, stop the tool or inform the service personnel in some other way.

These monitors also add monitoring of an operator via the wrist strap – this assures proper grounding of operator when he or she loads and unloads parts or does any other work with the sensitive components.

Continuous ground monitoring not only provides evidence of grounding at all times, it also saves money and time on maintenance personnel's' manual checking of grounding on every tool. In high volume production, downtime is expensive and continuous monitoring helps to reduce this downtime.

Those who test grounding on working tools perhaps notice that sometimes the readings of resistance are not quite right – such as negative resistance, abnormal resistance values, etc. This is caused by ground noise, which is present on virtually any working tool. Regular multimeters do not handle such noise well. Special monitors such as those described here use a patented method of rejecting such ground noise in their measurements, promoting accurate measurements at all times.

A question may arise – which parts in a tool should be monitored. There are too many to identify. The recommendation is to monitor those parts that either come into contact with the sensitive components or come close to them, since ground failure on such parts can cause the most problems. Moving robotic arms are always suspect due to the higher probability of failure in their grounding wires. In many tools, there are spare wires in a wire harness leading to those moving arms and these wires can be used for ground monitoring.

To conclude, grounding is the most fundamental element of ESD management in manufacturing and in service. A broken ground connection may result in personnel exposure to dangerous voltage, equipment lock-up or malfunction and damage to sensitive components. Only continuous ground monitoring can assure proper grounding at all times.

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Importance of Being Grounded

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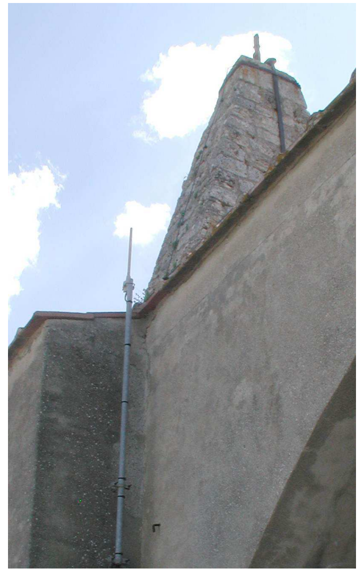
Grounding Through the Ages

Inside Power Station



Tower in
St. Giminiano, Italy

Buddhist Temple in Thailand

Florence, Italy

Old Scottish Castle

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Main Purpose of Grounding

- Safety
- Establish point of common zero potential
- Infinite “sink” for dissipating charges
- Infinite “sink” for absorbing EMI
- **Safety**

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Grounding Basics

- All electrically conductive objects not intentionally energized shall be adequately grounded.
- The equipment shall carry a prominent permanently installed warning regarding the necessity for grounding.

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Why Grounding?

- Grounding provides protection against electric shock by creating an *equipotential* environment.
- An *equipotential* environment is an environment where there is no potential difference between any two conductors. If there is no potential difference, then there can be no current between those conductors.
- All accessible by humans conductive surfaces of devices with electrical voltage shall be grounded

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How Important is Grounding for You?

- Good grounding is a foundation of proper operation of equipment
- Good grounding is assurance of low EOS exposure to components

>> Improper grounding accounts for up to 40 percent of costly power-related problems, including damage and downtime — whether it's lightning voltages induced between equipment cabinets, multi-grounding on the site or poor operation of computerized electronics.

- *From Allen-Bradley Journal, Sept. 2003 issue*

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Special Dangers in ESD-Protective Environment

- Many metal tools and surfaces in environment
- Grounding is done by many people, not only by licensed electricians
- Often, conductive objects are not at ground potential. High voltage may be present on "grounded" objects
- People can get hurt

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Importance of Metal Ground

- Quite often metal parts are assumed to be grounded if they
  - *Connected to ground via 1M resistor*
  - *Standing on dissipative floor*
- Without low-impedance connection to ground these metal parts may be
  - *Sources of high voltage*
  - *Sources of re-radiated EMI*
  - *Sources of ESD damage*
  - *Safety hazard*
- All exposed metal parts must have low-impedance connection to ground

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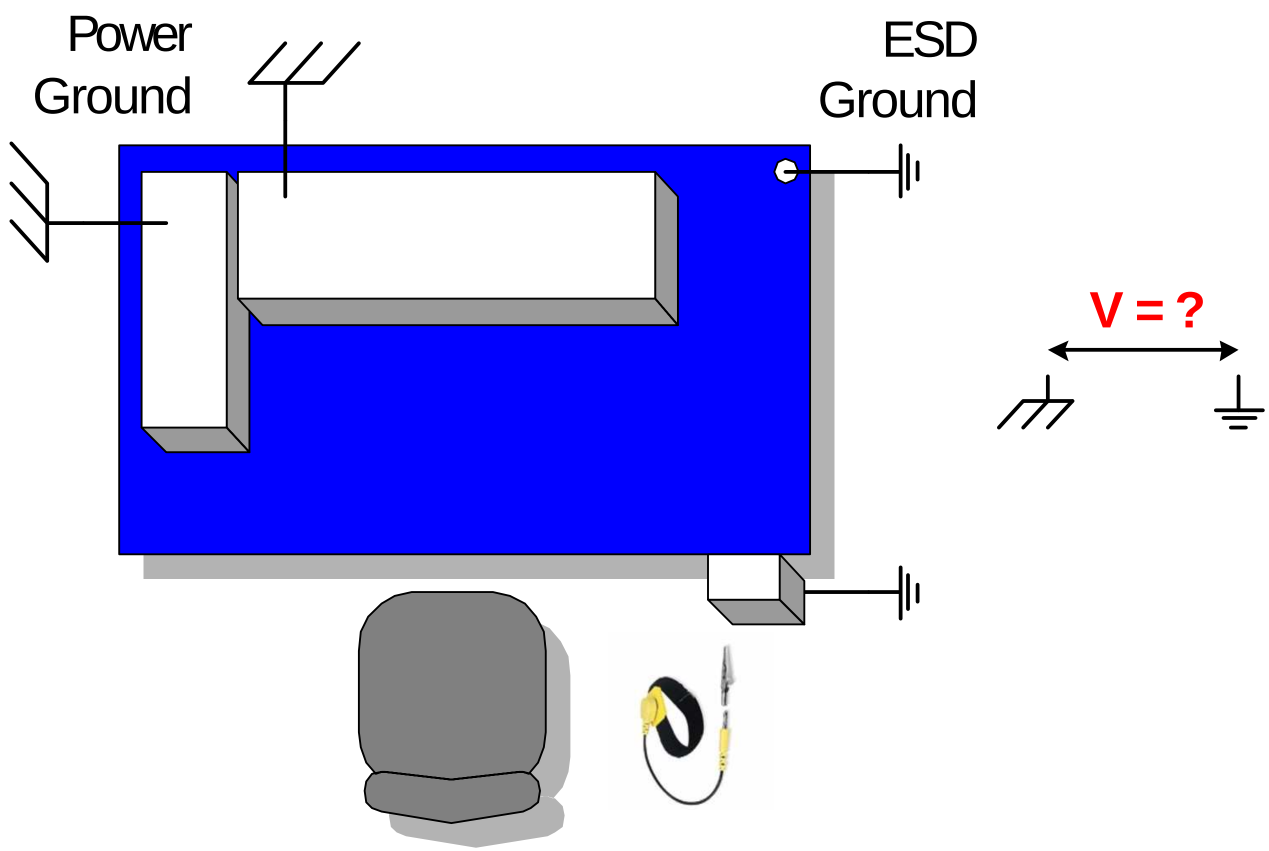
Two Grounds?



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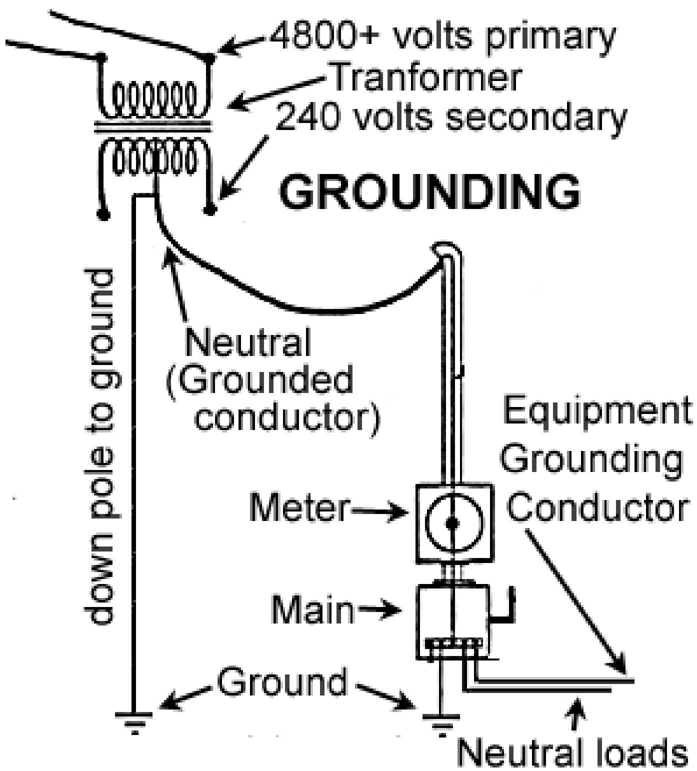
Ground and Neutral



- Are They the Same?
- Can Neutral be used as Ground?
- Do I need Neutral if I have Ground?

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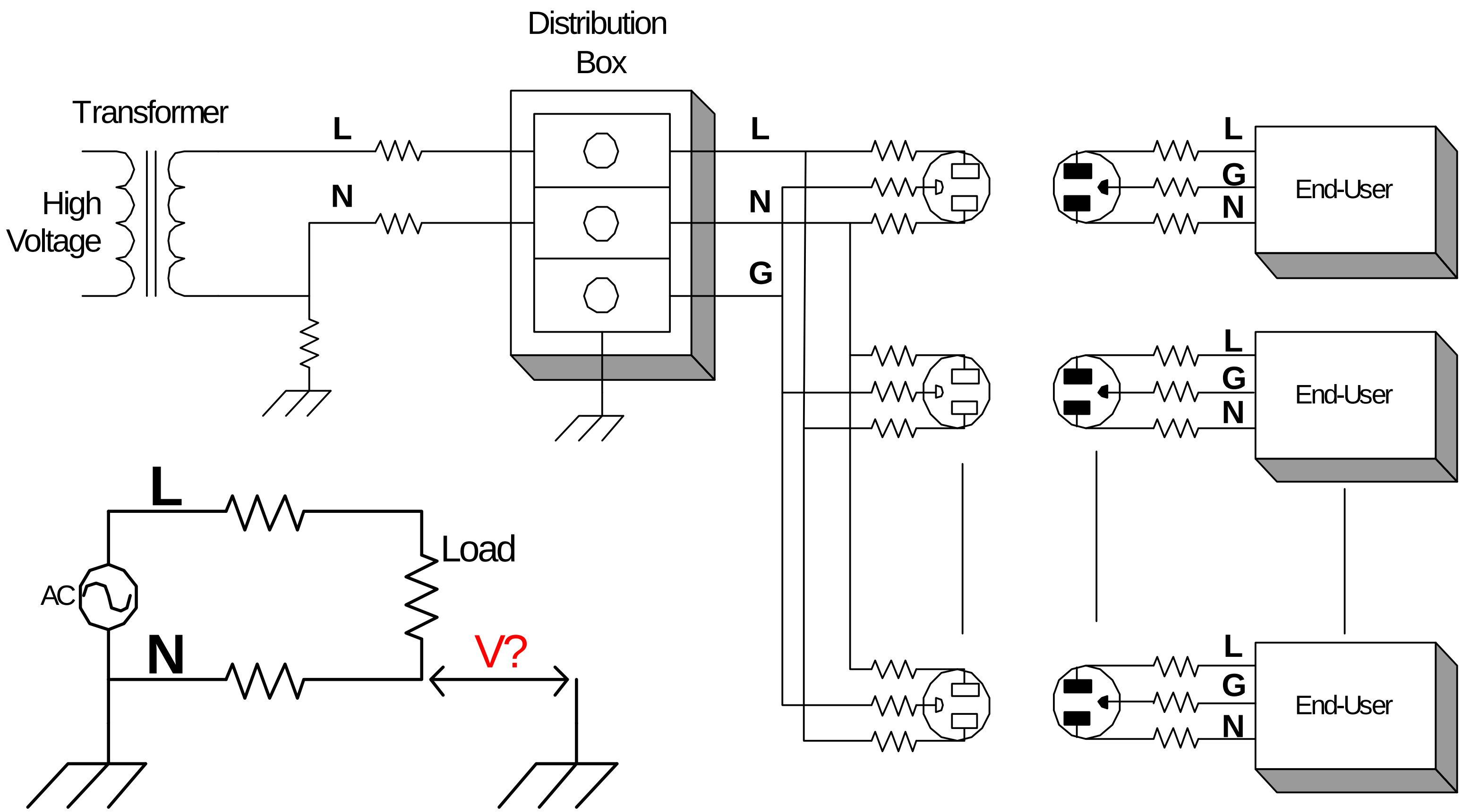
Typical Power Distribution



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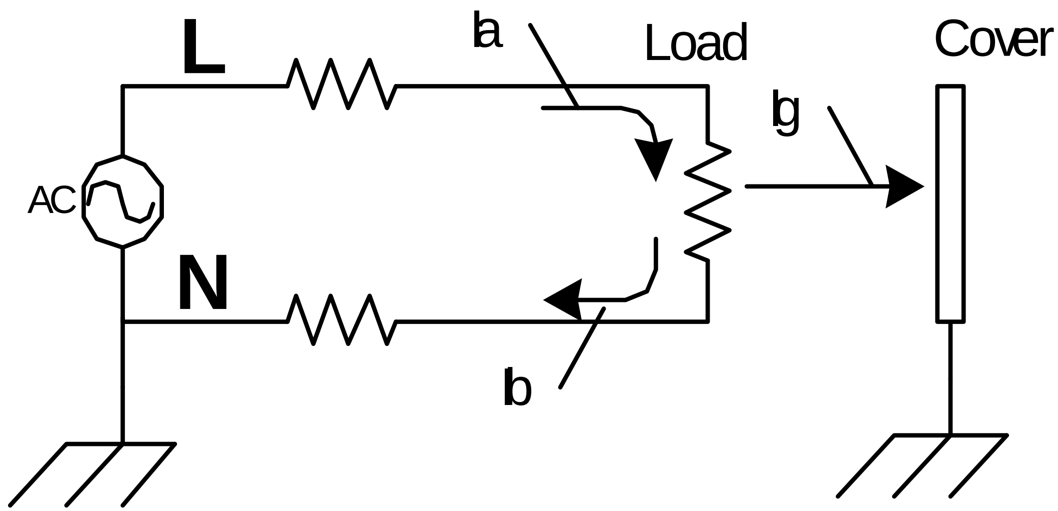
Is There Current on Ground?

- Ia = Ib
- If there is current leakage:
- Ia ≠ Ib
- Ig = Ia-Ib



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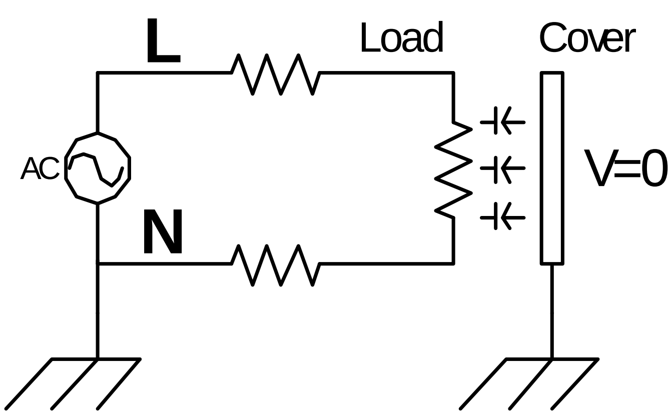
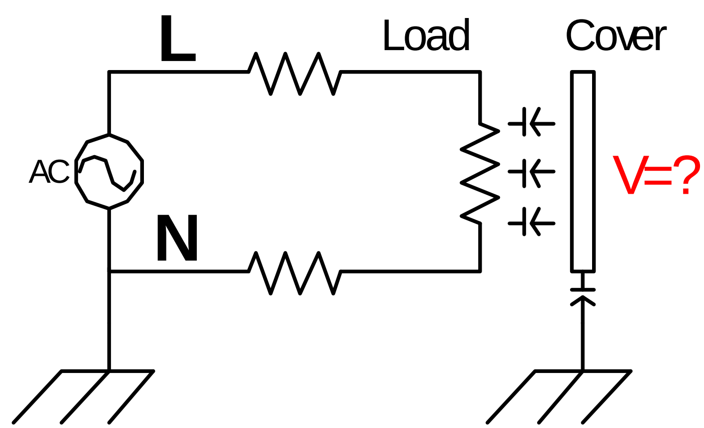
What is the Equipment is Not Grounded?



Tool is grounded



Tool is “floating”

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Specific Issues with Grounding in Power Outlets

- Often, ground and neutral are reversed in power outlets
- The result
  - *Unsafe voltage on ground of the tool (up to ½ of AC supply voltage)*
  - *Unacceptable ground leakage currents*
  - *Equipment malfunction*
  - *Device exposure*
- Ground/neutral reversal is not indicated by a checker

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Excessive Ground Currents

- If tool grounding is done improperly or ground and neutral wires are reversed, significant ground currents may be present in ground wire
- These currents create voltage drop across ground wire and “lift” the tool off the “real” ground
- Now voltage on the tool “ground” may be far from zero
- It is not uncommon to see ground currents up to 10...15A using simple clamp ampermeter
- Voltage on such ground may reach several volts vs. “real” ground thus exposing personnel and components to EOS

From paper presented at the 2005 EOS/ESD Symposium in Anaheim, CA, USA by Vladimir Kraz (Credence Technologies), Patsawat Tachamaneekorn, Dutharuthai Napombejara (both from Seagate)

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HOMEWORK

- Take a clamp amp meter
- Measure current through ground wire of your tools
- Measure current through ground wire of your entire facility
- Compare it with your safety norms
- Treat any deviation as safety violation

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What is Allowable Current on Ground?

- Ideally, ground line should have zero current
- If there is any current on ground, there is 50/60Hz leakage somewhere
- GFI (ground fault interrupt) circuits break the connection if ground current reaches 4..6 mA
- GFI is an emergency circuit disconnect for nearly-fatal and fatal currents!

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Safety Current Limits

AC Voltage, 50/60Hz	Current, mA	
	Man	Woman
Slight sensation on hand, skin irritation	0.4	0.3
Perception threshold	1.1	0.7
Shock - not yet painful	1.8	1.2
Painful shock	9.0	6.0
Painful shock - let-go threshold	16	10.5
Painful and severe shock, muscular contractions, breathing difficulty. Possible ventricular fibrillation effect. May be lethal	23	15

Source: U.S. Government

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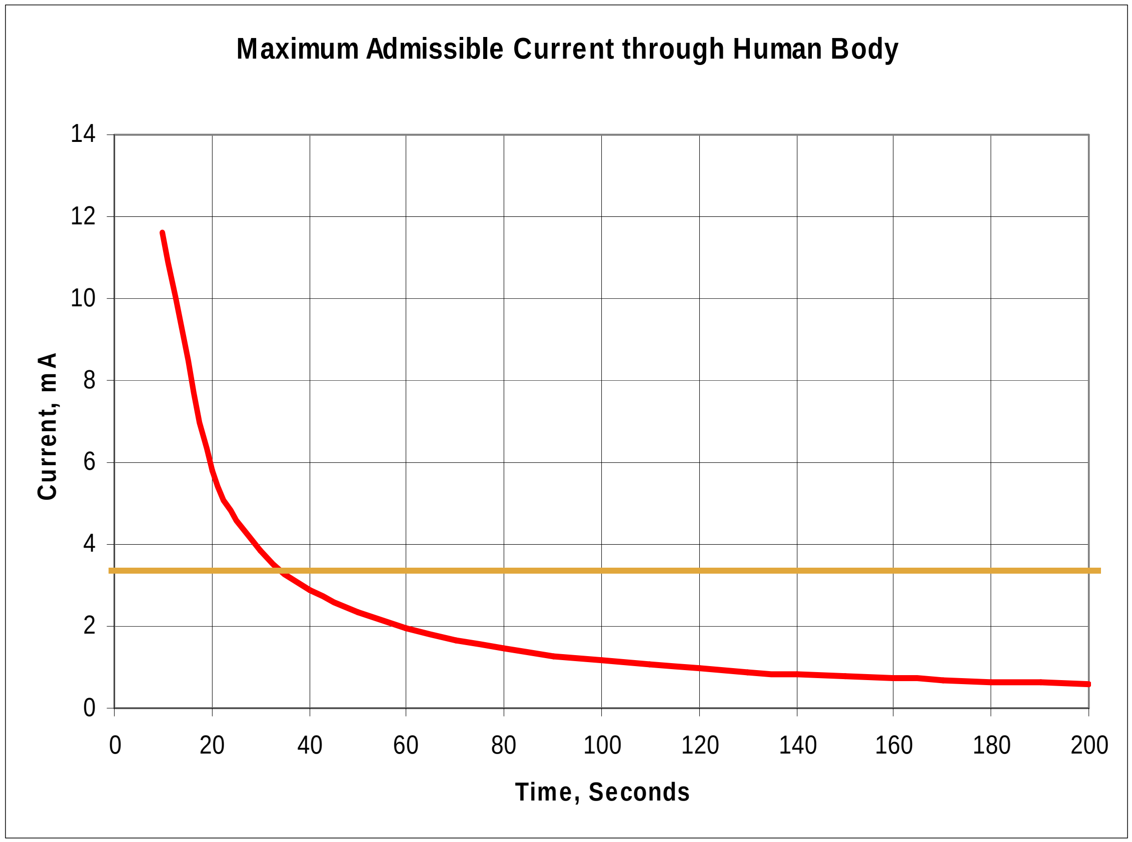
Unsafe Current Exposure

- Maximum safe exposure depends on time of exposure.
- Anything above red line is harmful, if not lethal, to humans
- Even tiny currents cause skin irritation if exposed for long time



Limits for adult male

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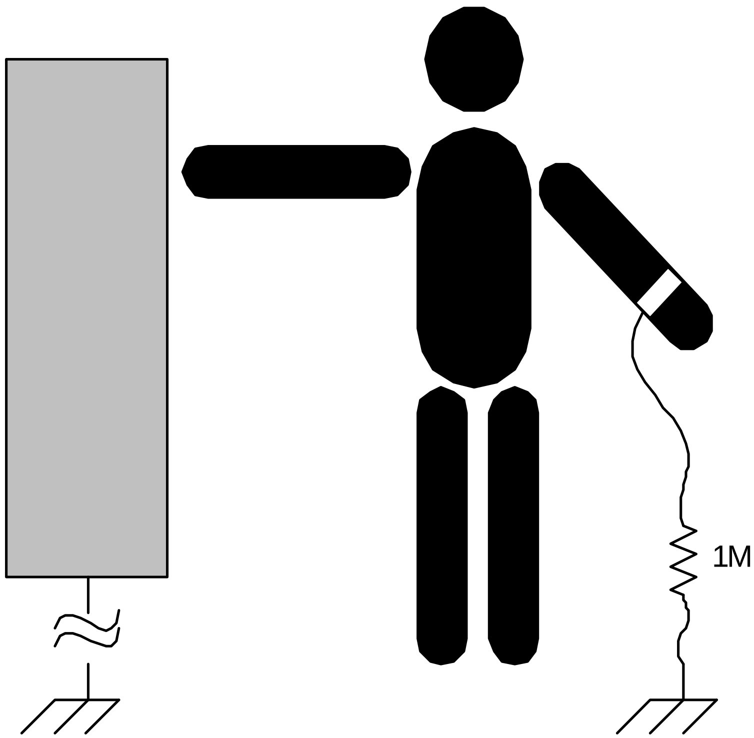
Electrocution via Wrist Strap

- If tool is not grounded or
- If ground and neutral are reversed
- Operator is exposed to electric shock



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Wrist Strap Safety

A good wrist strap must have 1 Meg resistor in each current path

Approved wrist strap with 1 Meg resistor built in

Your buyer's "special" with no resistors

"Good" wrist strap looks exactly like "bad" wrist strap

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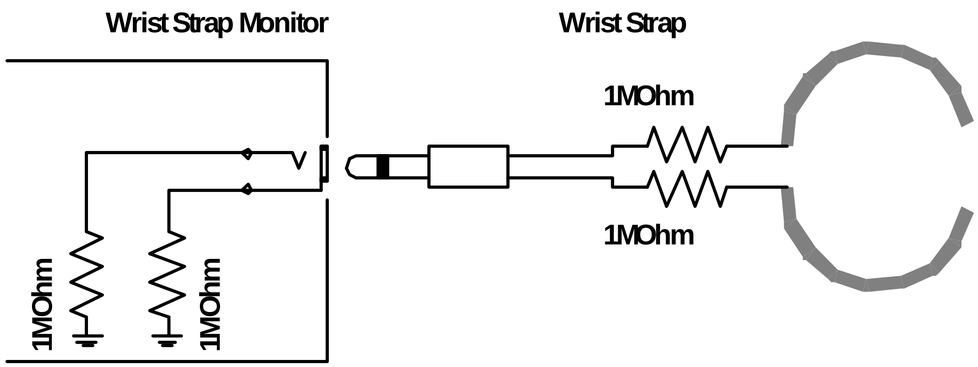
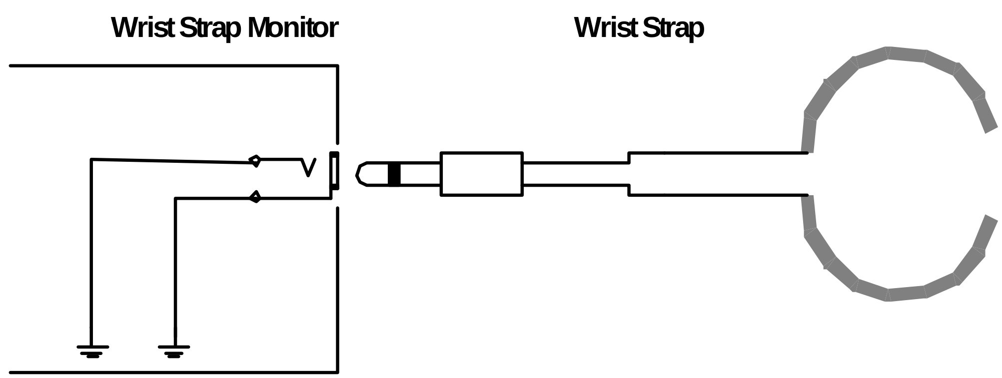
Always Use Safety 1M Resistors in Your Wriststrap Monitors

- Safe monitor



- Unsafe monitor



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Basic Safety Rules for Grounding

- All electrically conductive objects not intentionally energized shall be adequately grounded.
- Ground impedance shall be no more than 25 Ohms according to safety standards (NEC and others) and within 1 Ohm according to many standards in the industry, including ANSI 6.1 and ANSI/ESDA S.20.20
- What are grounding requirements in your company?

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What is the Most Important Thing about Ground?

SAFETY

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Traditional Approach to Ground Quality

- DC resistance to ground
- Periodic Check
- Works only for hand assembly benches
- Assembly of low-sensitivity components
- HBM is the main discharge model

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What Has Changed?

- Automated equipment
  - *Electrical noise due to high-frequency signals*
  - *Electrical noise due to AC mains currents*
  - *More places where components experience metal-to-metal contact*
- More sensitive components
  - *IC sensitivity is getting below 30V CDM*
  - *This is just as important in PCB assembly as in IC manufacturing*

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Quality of Ground Today

- Measuring ground connectivity the usual way is not enough
- Measuring quality of ground only by connectivity is not enough either
- Actual signals on ground must be included in assessing integrity of grounding

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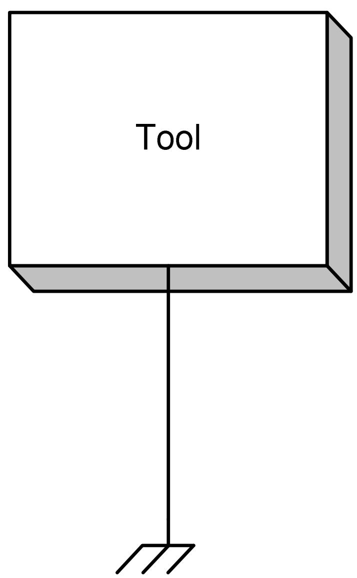
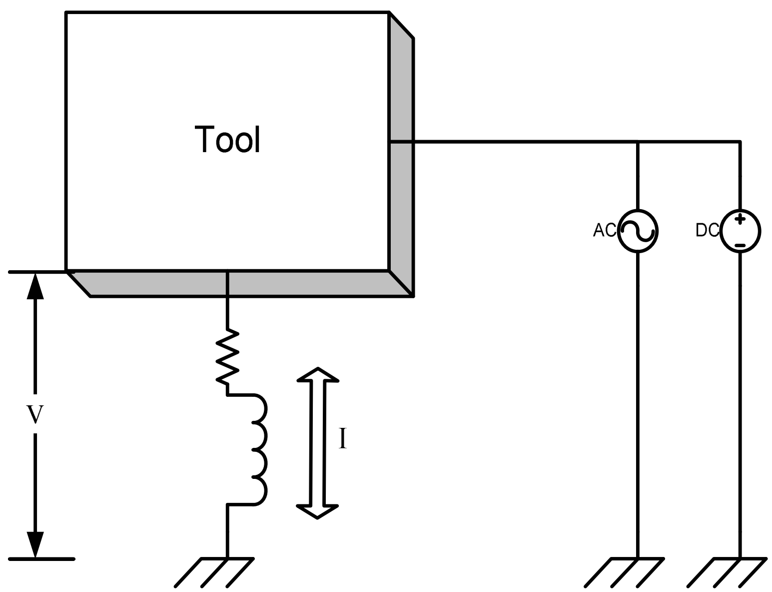
The Secret Life of Grounding





- Simplistic view at grounding
- Realistic view at grounding

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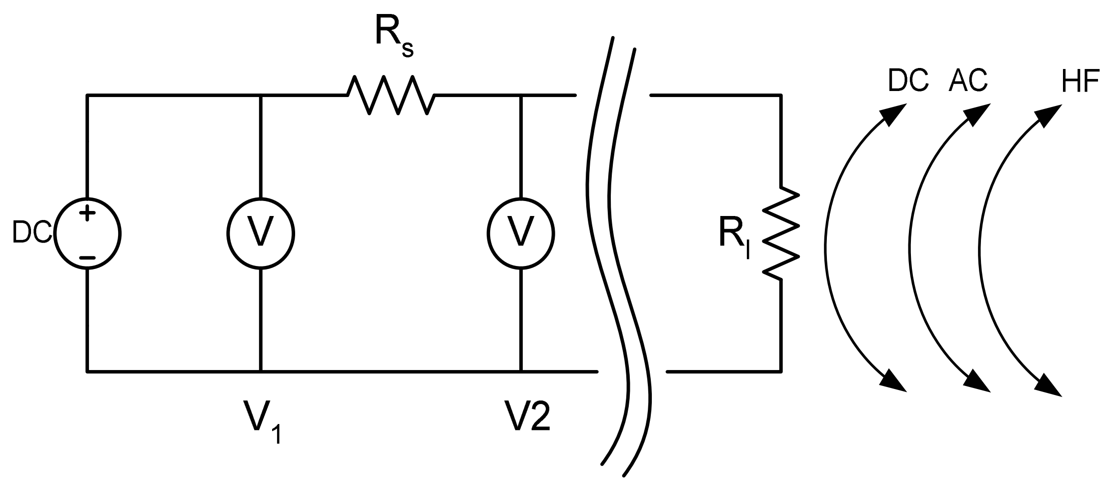
Ground Resistance Measured in a “Traditional” Way



R_l=?

$$R_l = \frac{V_2}{\frac{V_1 - V_2}{R_s}}$$

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What Does the Standard Specify?

ANSI/ESD-S20.20-1999

Table 1- ESD Control Program Technical Requirements Summary

(See paragraph 6.2 for further guidance regarding alternate test methods.)

Technical Requirement	**Reference Paragraph**	**Implementing Process or Method**	**Area 1 Mfg.**	**Area 2 Field**	**Test Method, *Standard or Advisory***	**Recommended Range[5]**
Grounding / Bonding Systems	6.2.1				ANSI EOS/ ESD S 6.1	
		Equipment Ground	R	O	ANSI EOS/ ESD S 6.1	< 1.0 ohm AC Impedance
		Auxiliary Ground	O	O	ANSI EOS/ ESD S 6.1	< 1.0 ohm AC Impedance
		Equipotential Bonding	O	O	ESD ADV 2.0	$< 1.0 \times 10^9$ ohm[6]
		Common Point Ground	R	O	ANSI EOS/ ESD S 6.1	< 1.0 ohm AC Impedance

However convenient it is to measure ground with a multimeter, doing so does not comply with grounding standards

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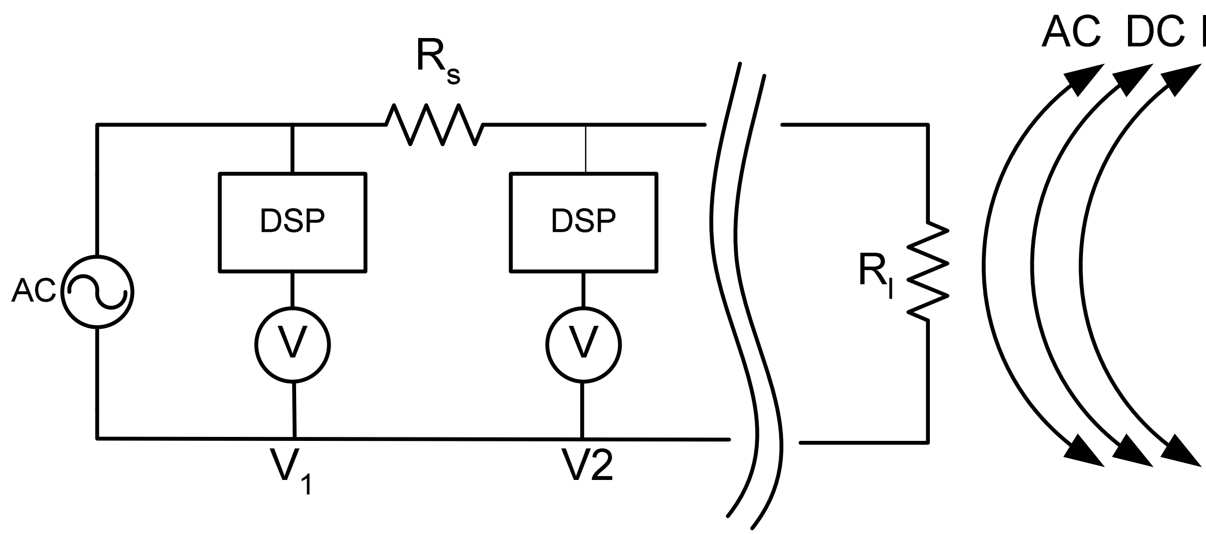
Ground Impedance Measured Correctly



U.S Patent 6,930,612

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Sources of Voltage on Ground

- Miswired ground (neutral and ground are reversed)
- Inductive and capacitive coupling between wires
- Improper ground returns
- Poorly-designed and poorly-maintained equipment
- Bad grounding
- Multiple grounds

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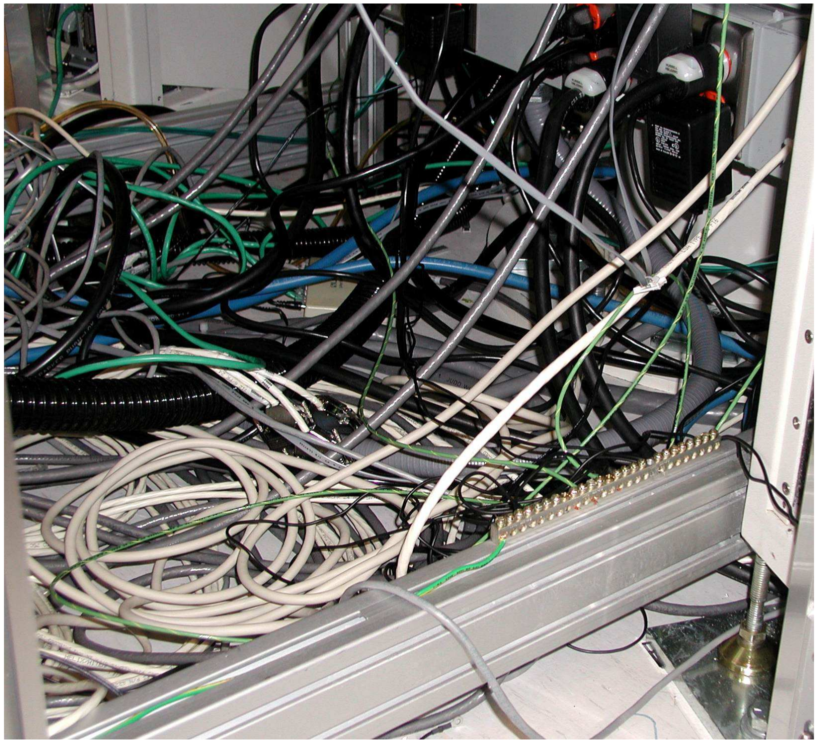
Inductive and Capacitive Coupling of Parasitic Signals

- At higher frequencies crosstalk between wires is more pronounced since capacitive coupling between them has lower impedance
- Bundled wires create inductive coupling between wires with strong currents and ground
- The result is unwanted signals on ground and on supposedly-grounded tool parts
- These unwanted signals are different at different parts of the tool
- A device can be exposed to a difference between these signals



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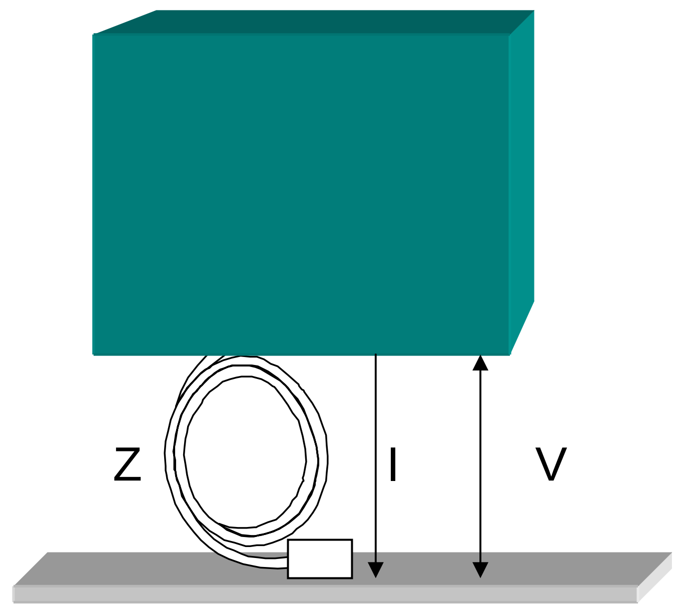
Grounding Wires and High-Frequency Voltage

- For safety purposes and for dissipation of static charges, a coiled or long ground wire is sufficient
- However, such wires have significant impedance at high frequencies
- With currents flowing to/from the tool during normal operation, the tool may have voltage on its “grounded” parts
- 5-turn coiled wire with a 10cm radius and a 1cm thick coil will have impedance of 6.28kOhms at 100MHz. A 1mA current would cause 6.28V voltage across such coil.
- 3m 14 AGW wire has self-inductance of 5.17µH. At 1mA of 100MHz this would cause voltage of 5.17V



Impedance of Coiled Wire

$$L = 0.394\frac{r^2N^2}{9r+10d}$$

Impedance of Long Straight Wire

$$L = 2l\left(\ln\frac{4\cdot l}{d} - 1\right)$$

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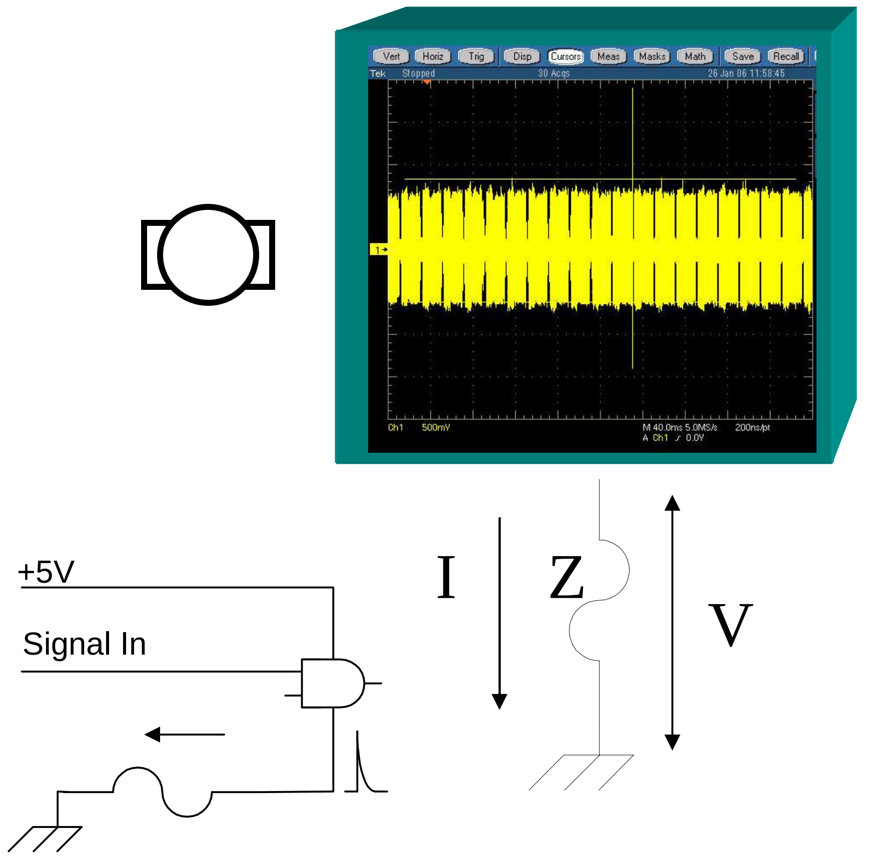
Ground Bounce

- EMI (internal and external) induces voltages in equipment's ground
- Current flows from equipment's ground to facility's ground
- If ground path is imperfect, voltage drop develops
- Equipment ground "bounces"
- Sensitive component exposure
- Circuit signal levels are no longer valid
- Equipment malfunctions



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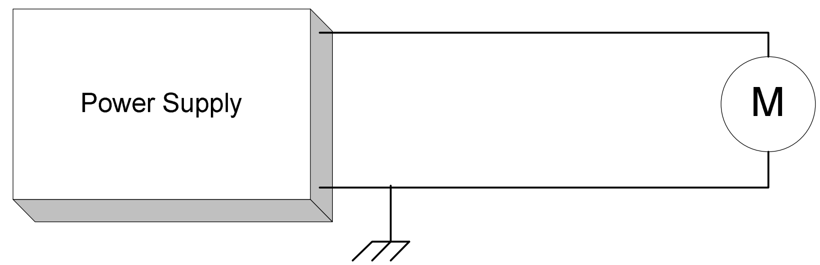
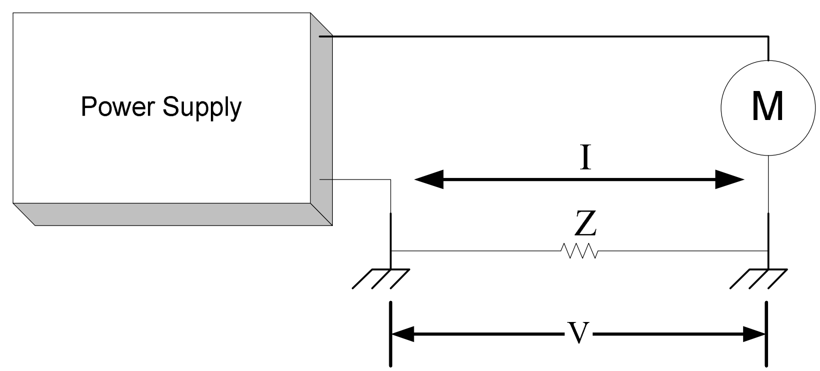
Improper Ground Returns

- Relying on tool's ground for current return for motors, circuits, etc.
- Too thin or too long or coiled ground wires
- Always check for ground currents in your tools!



Correct Connection



Incorrect Connection

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Noisy Tools

- Any electric circuit generates noise and unwanted currents and voltages
- Poorly designed tool generates excessive noise
- When selecting your tools, always select the ones that have passed emission test limits. Your criteria: FCC or CE certification (not just a label)
- If you do not require your suppliers to provide you with good-quality tools, then the noise becomes your problem to deal with

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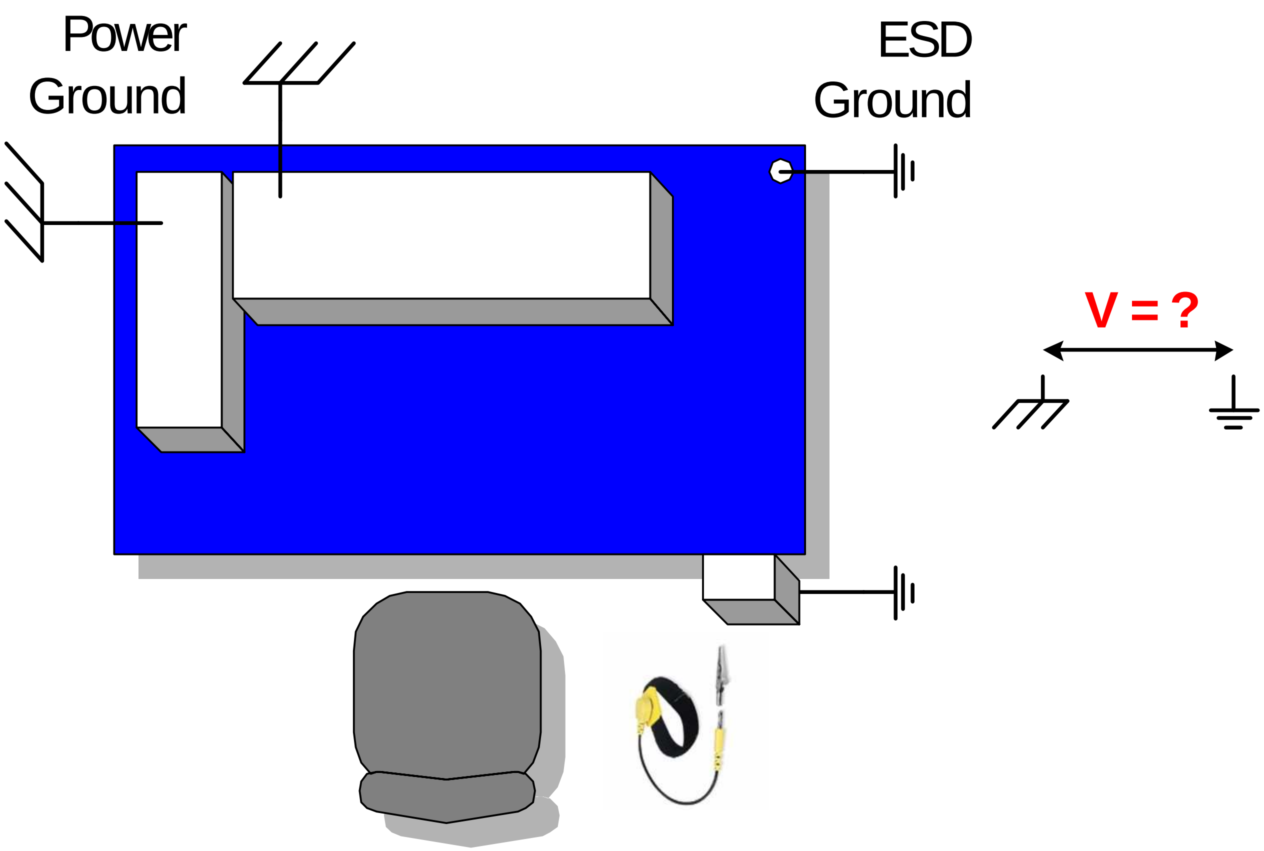
Two Grounds?



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Ground Connection Within Tools

- Relying on connection to ground of the frame of the tool is no guarantee of good grounding
- Every tool is a composite assembly where many metal parts are not always electrically connected together
- Only assurance of good connection between all involved parts guarantees good grounding

Location	Resistance to Ground
Side cover to ground	1 kOhm
Frame aligner mount to ground	20 MOhms
Buffer to ground	520 kOhms
Top cover ionizer to ground	2.2 Ohms
Robot base to ground	6.6 Ohms
Upper Robot to ground	9 Ohms
Equipment case and indexer	200 Ohms
Aligner to ground	400 kOhms

This is the data from a well-run U.S. semiconductor facility
Specification was within 2Ω

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Voltages on Ground Inside Tools

- Due to high resistance in ground path and presence of ground currents, it is not uncommon to find significant voltage between supposedly-grounded parts

3.1 Type A wire bonder

Original without Grounding Modification (Table 1)

	Bond tool head 1		Bond tool head 2	
M/C No.	V_{AC}(mV)	Rtg (ohm)	V_{AC}(mV)	Rtg (ohm)
ORT 001	4.0	6.0	4.0	220
ORT 002	5.5	1.0	**850**	**$1.5x10^8$**
ORT 003	1.8	2.9	1.5	1.1
ORT 004	**480**	**$4x10^7$**	0.4	3.5
ORT 005	58	260	**2300**	**$2.6x10^7$**
ORT 006	**860**	**$1x10^7$**	2.0	2.6
ORT 007	2.4	1.9	2.9	1.7
ORT 008	4.6	5.9	3.7	6.1
ORT 009	2.5	1.6	**400**	**900**

From paper "An Alternative Method to Verify The Quality of Equipment Grounding" by Infineon, ESD Symposium 2005

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Is 1MΩ Resistor Needed?

- Often workbenches and even tools are grounded via 1MΩ resistor with the hope that this resistor will “slow down” the discharge
- Does it really reduce the discharge strength or rise time?

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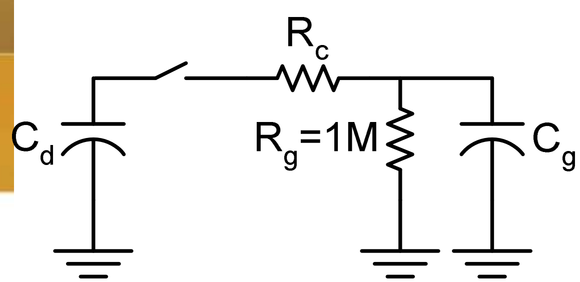
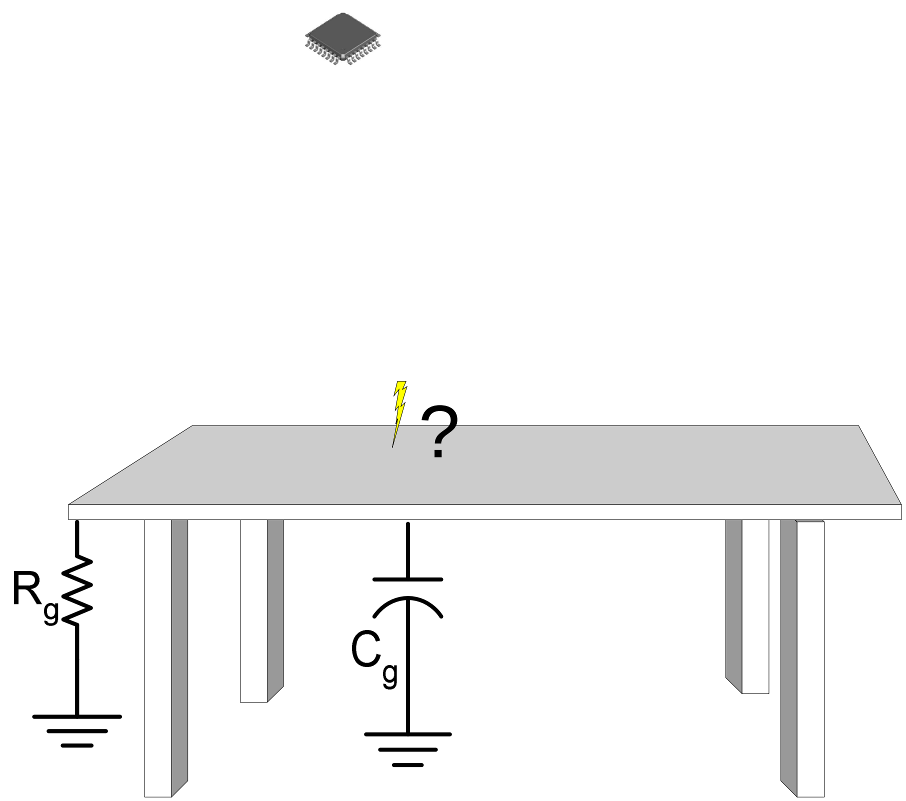
Discharge and 1MΩ Resistor

Would discharge occur if a charged device is placed on metal bench which is grounded via 1M resistor?





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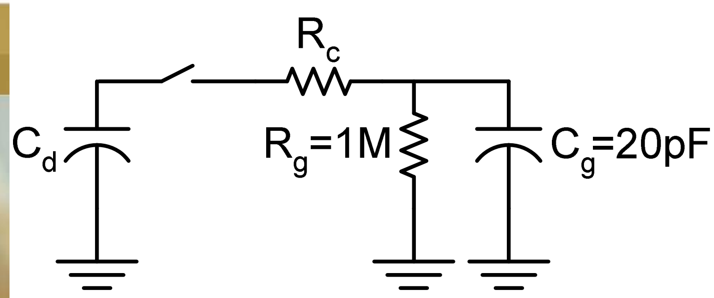
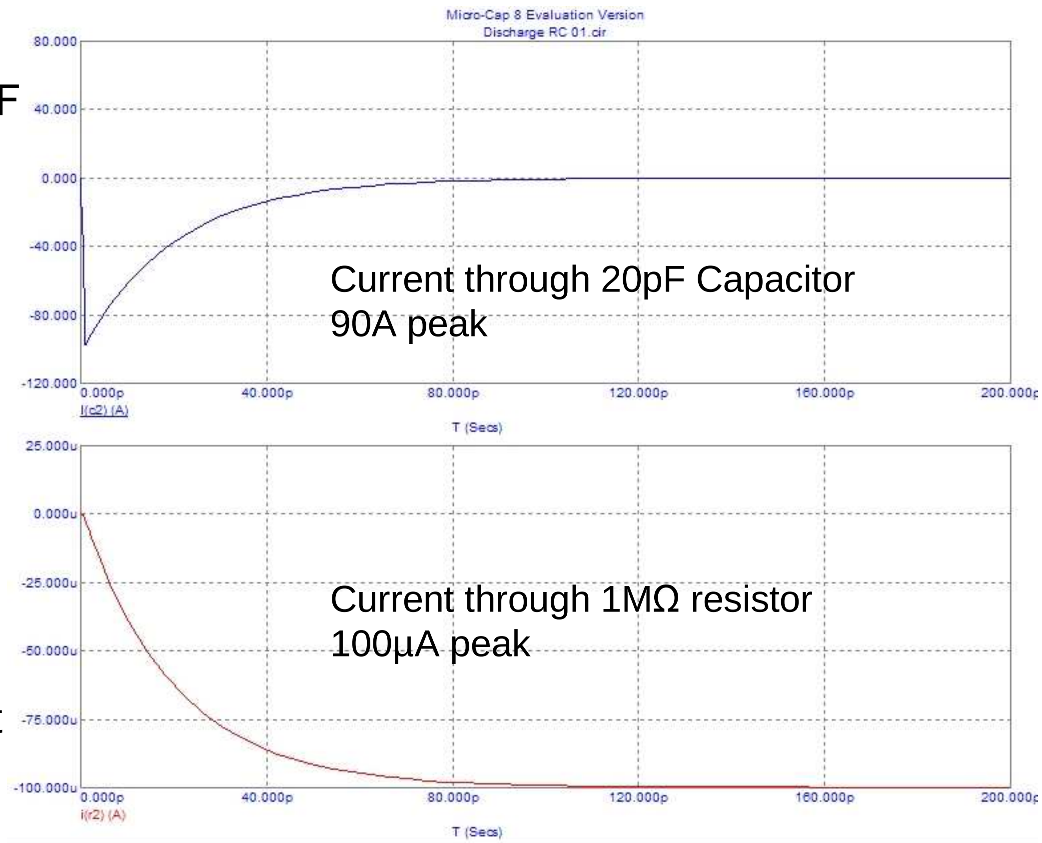
Discharge and 1MΩ Resistor



$$X_C = \frac{1}{2\pi f C}$$

$$i_C(t) = C\frac{dv_C(t)}{dt}$$

As seen from this circuit simulation, the discharge current due to capacitance is significantly higher than the current due to resistance



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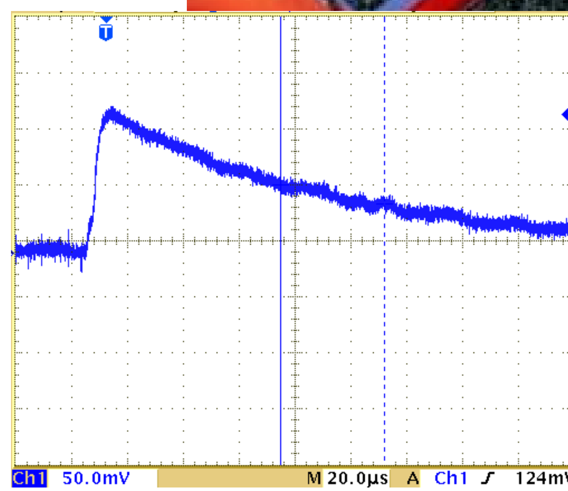
Discharges and Dissipative Material

Would a discharge occur when a device contacts dissipative material?

YES!



- Properties of material determine the waveform of the discharge

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Discharges to Dissipative Materials

- Discharges to dissipative materials have slower rise time – *good*
- Discharges to dissipative materials have longer discharge time, i.e. more energy – *bad*
- When selecting dissipative materials, don't settle just for resistivity data – this could be misleading
- Always check for discharges to the material
- Recommended resistivity values 10^9 to 10^{10}

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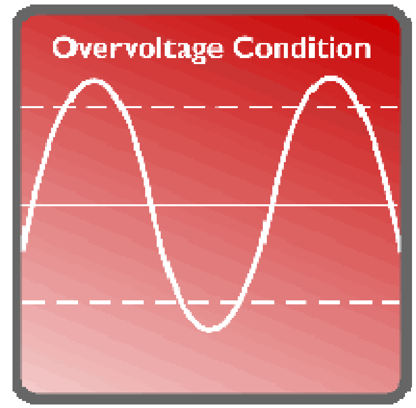
EOS – Can be Worse than ESD



- EOS, or Electric Overstress, occurs when two conductive parts that have continuous supply of voltage differential come into contact
- Unlike Electrostatic Discharge, the energy does not dissipate in few nanoseconds – it is being supplied continuously
- EOS can offer very high current (AD, DC, High Frequency) for prolonged periods of time thus providing high energy levels
- Because of that, damage due to EOS can sometimes be inflicted easier than by ESD
- EOS exposure often goes unnoticed because EOS does not require high voltage to be present – damage can occur just at few volts differential

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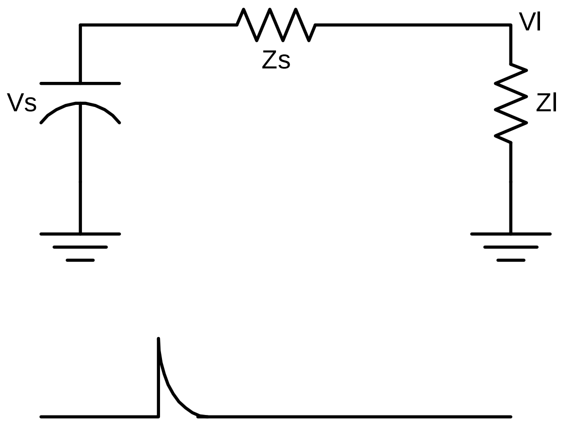
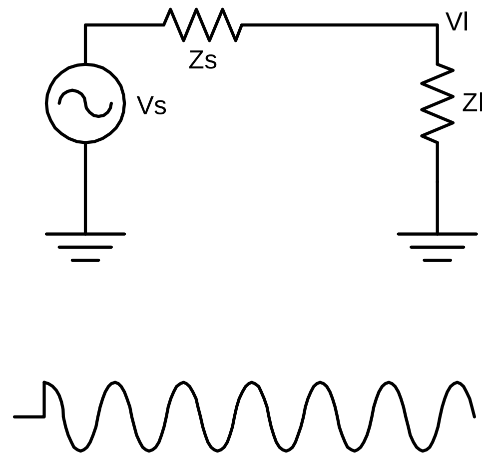
ESD Event vs. Voltage Source

ESD



- ESD Event lasts nanoseconds
- ESD Event happens only in the beginning of the electrical contact

EOS



- EOS Event can last as long as the device is in electrical contact
- This adds potential fatigue element to the voltage or current exposure of the device

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Nature of EOS Signals in the Tools

- Unlike ESD, EOS exposure is not caused by a discharge of limited accumulated charge
- Mechanism of EOS is radically different from those of ESD:
  - *The energy of EOS signals is not determined by the accumulated charge but rather by the practically unlimited supply*
  - *The time characteristics of the resulting current is continuous or periodic signal rather than an impulse or a sporadic signal.*
  - *EOS sources have low output impedance meaning that the resulting current may be quite significant.*
- Conventional models do not apply to EOS exposure

From paper presented at the 2005 EOS/ESD Symposium in Anaheim, CA, USA by Vladimir Kraz (Credence Technologies), Patsawat Tachamaneekorn, Dutharuthai Napombejara (both from Seagate)

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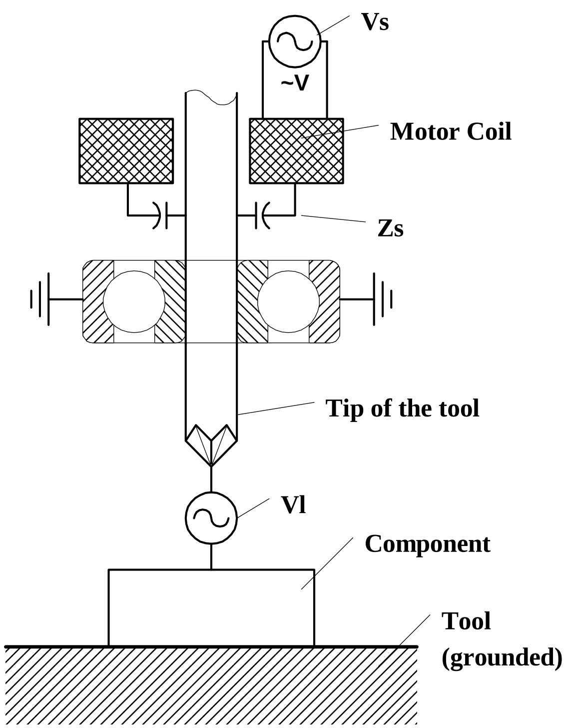
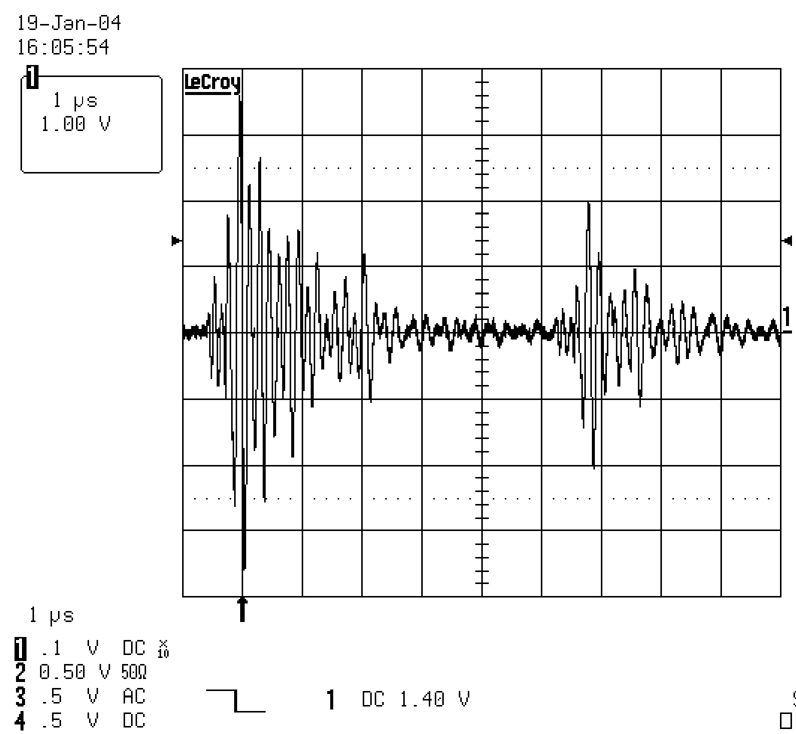
Examples of EOS Signals on Ground in Tools

Electric screwdriver with long grounding wire routed together with power lines

Assembly





From paper "EOS Exposure of Magnetic Heads and Assemblies in Automated Manufacturing" by Credence Technologies and Seagate, ESD Symposium 2005

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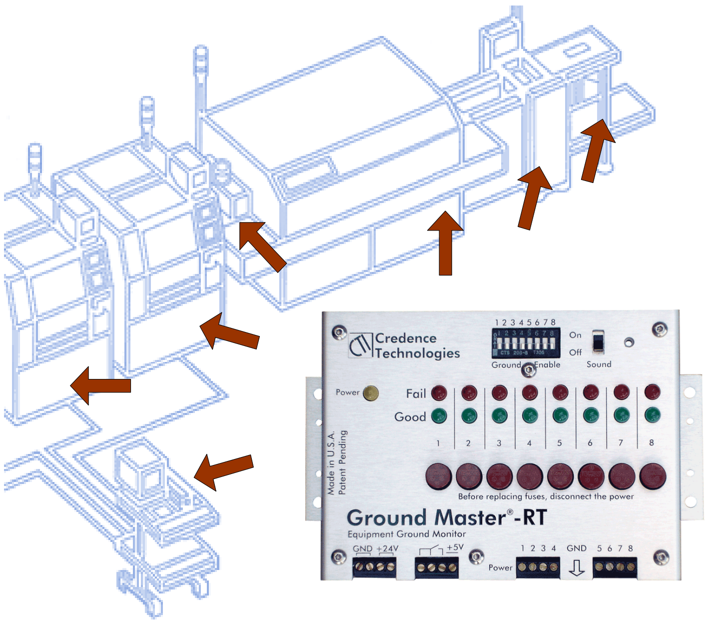
Assurance of Proper Ground in the Tools

- Tools are composite – they are assembled from many separate parts
- Product line may consists of several tools
- Ground connections can be missing
- Ground connections can be broken
- Ground connections can be disconnected during the maintenance and not reconnected back
- Grounding of all parts of the tool must be periodically checked
- For critical applications and safety, ground must be monitored continuously
- Do not assume!



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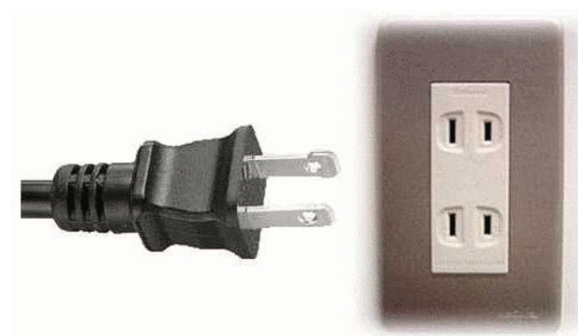
An Example of EOS: Ungrounded Soldering Iron

- If the ground in a soldering iron is not good, its tip can develop voltages up to a half of the mains
- This voltage may be able to provide high current into the board whenever the tip touches any conductive pad
- This can happen with the best irons on the market

Iron Man EOS Monitor



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Proper Grounding Control

- Grounding is one of the essential components of ESD/EOS control
- Grounding cannot be left to chance
- Control of grounding no longer can be limited to occasional check of connectivity by a multimeter
- The following is necessary to assure good grounding in today's production:
  - *Presence of known good ground*
  - *Ground wiring with full understanding of ground network, ground currents and EMI*
  - *Separation between wires carrying noisy signals and ground*
  - *Measurement of ground connectivity using acceptable methodology and tools*
  - *Verifying ground connection by measuring voltage between different ground points (common zero potential)*
  - *Verifying ground connection within the tool*
  - *Continuous monitoring of ground*

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