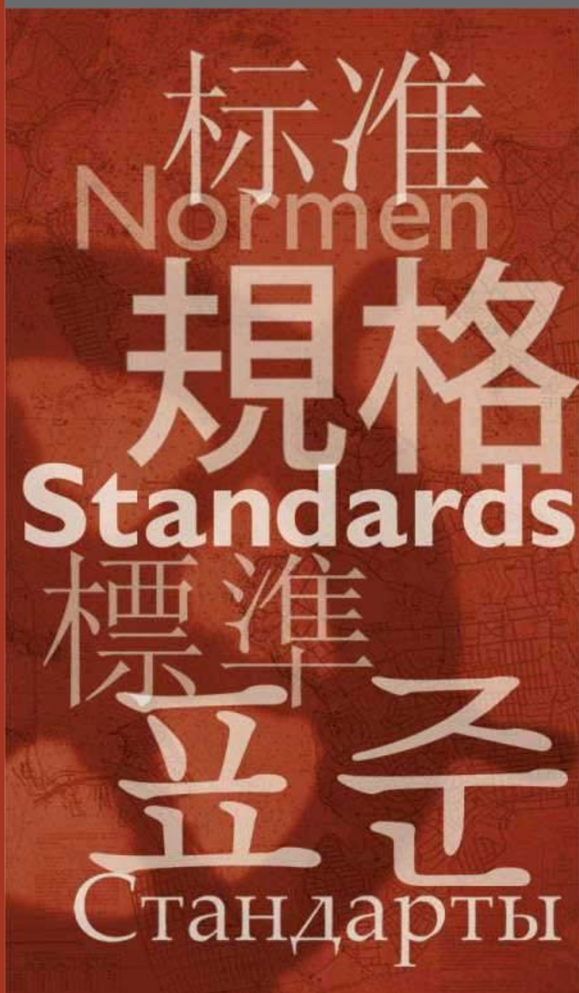
EMC for Semiconductor Manufacturing Facility, Equipment Electromagnetic Compatibility and E33 Directions



EMI Issues in Semiconductor Environment

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What is EMI?

- **<u>E</u>**lectro**<u>M</u>**agnetic **<u>I</u>**nterference is electromagnetic emission that causes equipment malfunction
- No matter how strong emission is, if it doesn't cause problems, it is not an interference, i.e. not EMI.
- Therefore, the impact of EMI is judged not only by how much emission is generated, but also by how it gets from "here" to "there" and by how immune the equipment is to EMI.
- For simplicity of this discussion we will call all electromagnetic emission "EMI," though it is technically incorrect

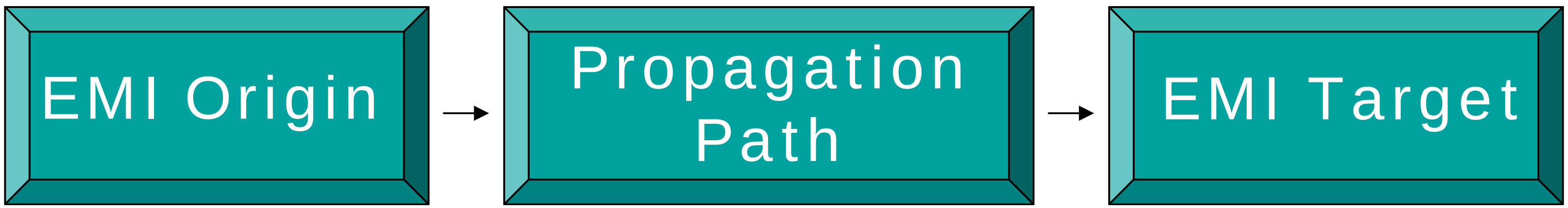
Electromagnetic Field is Natural Phenomenon

- Electricity and magnetism were not invented – they were discovered
- Earth has strong magnetic field
- Lightning and other atmospheric phenomena create electric and magnetic fields
- Sun experiences electromagnetic storms
- There is no place in the Universe without electromagnetic fields

How EMI Manifests Itself

- Outright equipment lock-up
- Tools do things they weren’t supposed to do
- Software errors
- Erratic response
- Parametric errors
- Sensor misreading
- Component damage

EMI Management: Comprehensive Approach



All components must be considered for successful EMI management

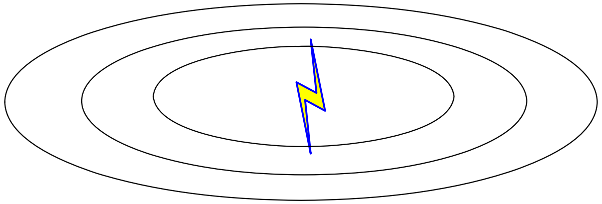
EMI Sources in Cleanrooms

Sources of EMI in Cleanrooms

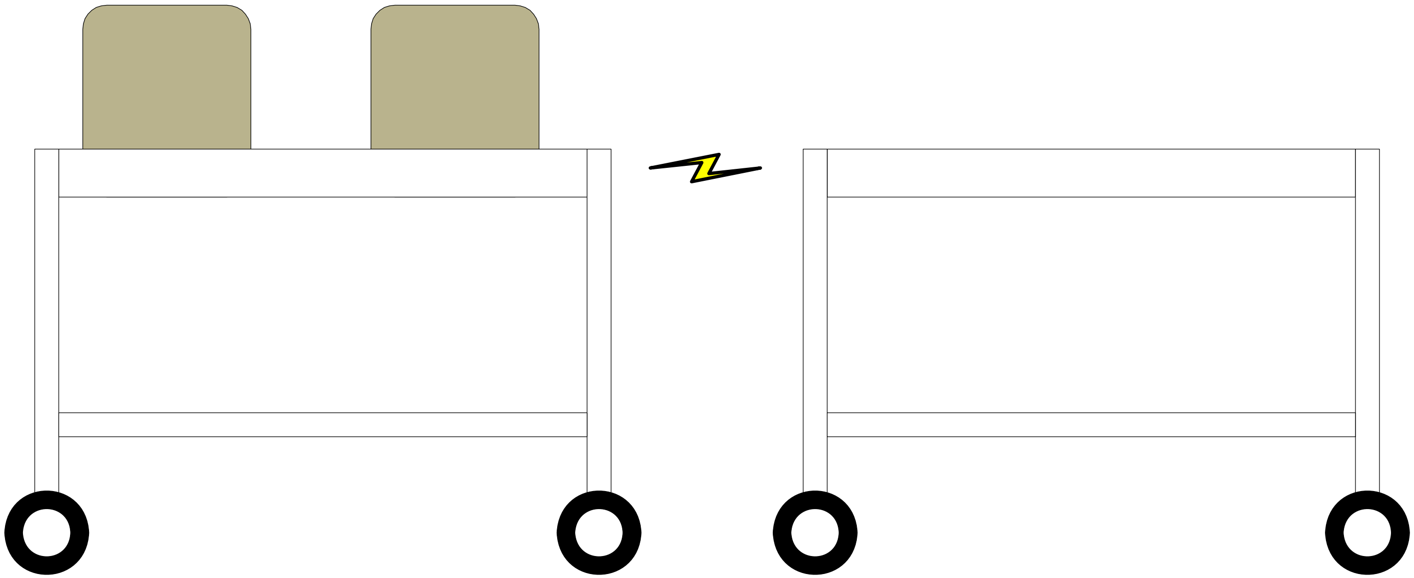
- ESD Events
- Poorly-designed equipment
- Poorly installed equipment
- Poorly maintained equipment
- Mobile phones and walkie-talkies

ESD-Caused EMI

- ESD Event is rapid current surge: causes magnetic field
- ESD Event is rapid drop of voltage: causes electric field
- Combination: electromagnetic field
- ESD Events cause strong ground and power line currents -- EMI via conductive path
- ESD-induced EM fields have broad spectrum, high energy and rapid rise time -- good candidates for EMI



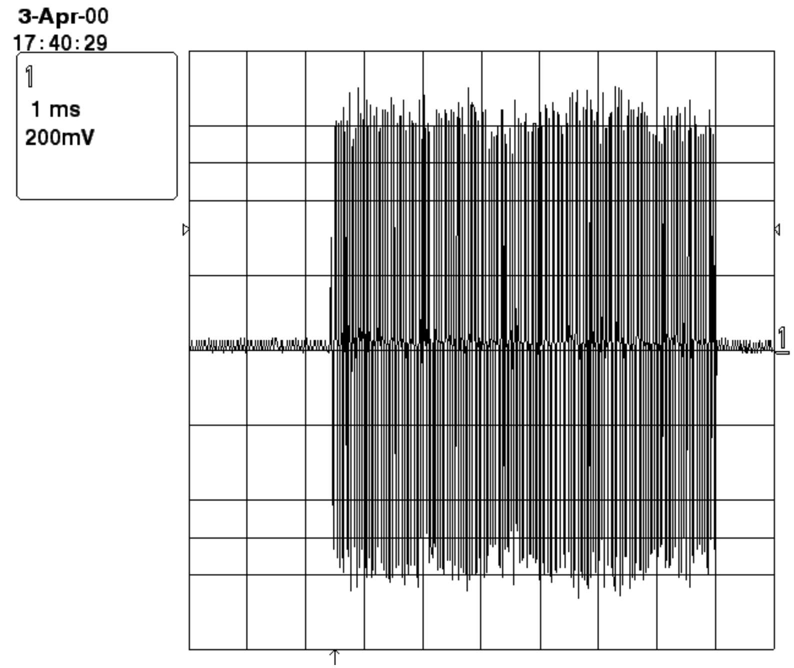
ESD-Caused EMI in Cleanrooms – Example

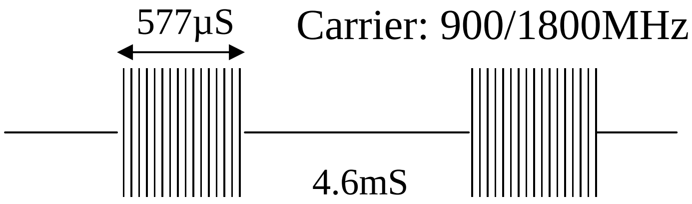


- Wafers are charged to the limit
- SMIF pods with wafers are placed on steel cart
- Cart is charged by the wafers via capacitive coupling
- Wheels are insulators – cart cannot discharge
- EMI propagates throughout the fab causing lockup of wafer handlers

EMI from Mobile Phones

- Frequency range: 800, 900 and 1800MHz
- GSM phones produce emission in bursts
- High emission levels (~10V/m)
- Easily creates disruption in sensitive equipment in immediate proximity





GSM Phone Transmission Pattern

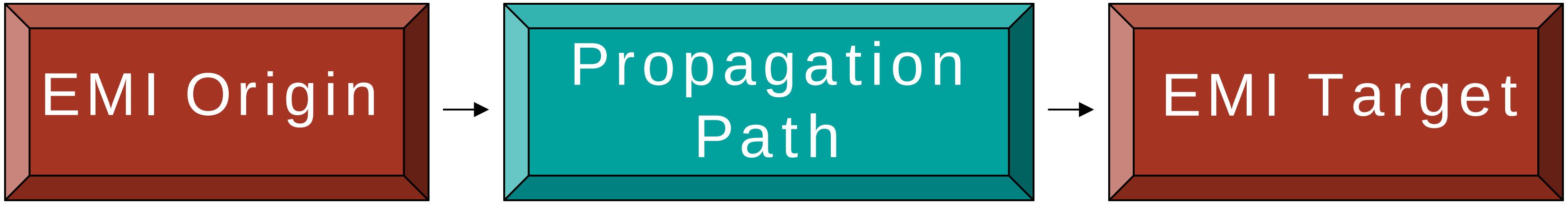
EMI Caused by Equipment

- Every electric or electronics device generates electromagnetic field
- If this field is too strong and has certain properties, it is good candidate for EMI
- Poorly-maintained equipment is good source of EMI (DC brush motors, bad grounding)
- EMI-generating equipment often causes problems for itself

Properties of Electromagnetic Fields in Cleanrooms

Origin	Frequency Range	Envelope
Equipment	10kHz...2GHz	Continuous and transient
ESD Events	10MHz ...2GHz	Transients
Mobile Phones, WLAN	0.8..1GHz 1.8..1.9GHz 2.4..2.5GHz	Pulsed

Propagation of EMI



Propagation of Electromagnetic Emission

- **Radiated**
  - Electromagnetic field composed of electric and magnetic fields propagates via air path just as emission from a mobile phone would reach the base station
  - This field would create voltages and currents in any metal object, i.e. wire, PCB trace, etc.
- **Conducted**
  - The most neglected type of propagation
  - High-frequency currents move via power, ground and data cables and inject undesirable signals into equipment
- **Mixed**
  - Radiated emission generates signals in wires and cables. These signals are then injected into equipment via conductive path

Radiated Emission Equipment Shielding

- Used for both reduction of emission and improvement of immunity
- Tool panels (shielding) are often left open after maintenance
- Sometimes panels are not connected to ground (painted mounting, etc.)
- Anodized aluminum is not a conductor!
- Dissipative surfaces are not EMI-conductive!

Conducted Emission: Propagation via Wires and Cables

- Common conduits:
  - Ground wires
  - Power cables
  - Network cables
- A signal originated in one spot can propagate through the entire fab via these conduits

Equipment Susceptibility to EMI

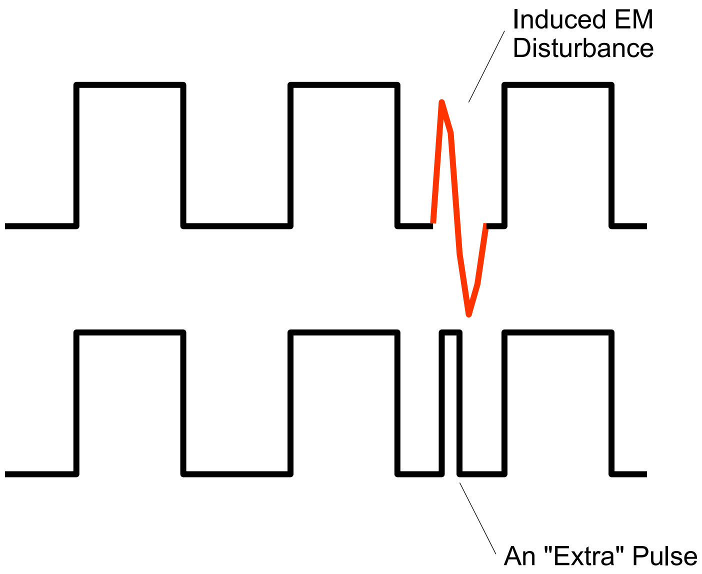
EMI-Caused Equipment Failures

Three Basic Types of Failures

- Fatal failure due to overstress
  - direct ESD discharge
  - very high EMI-induced signals (EOS)
- Latch-Up
  - induced voltages are outside of supply rails
  - often recoverable after power-cycling
  - sometimes causes overheating and failure
- Injection of false signals
  - Induced signal is comparable to legitimate signals

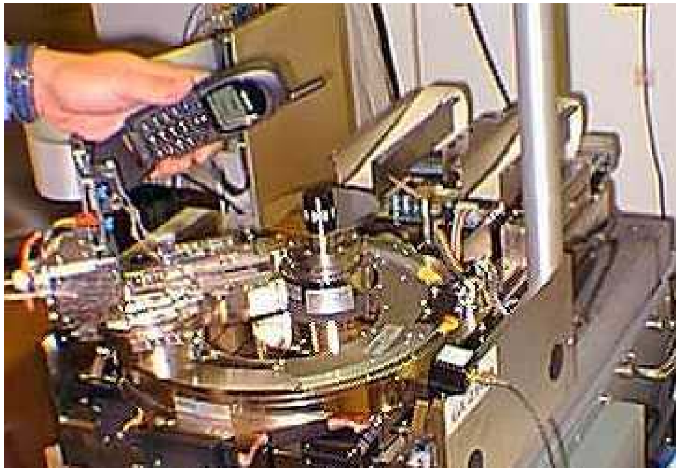
Equipment Lock-Up: False Signals

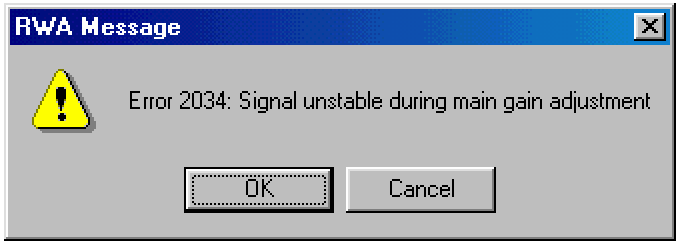
- Electromagnetic fields induce seemingly legitimate signals into electronics circuits which leads to circuit malfunction
- Often, the electronics circuit does not suspect that it was affected by EMI
- Today’s high-speed circuits are much more susceptible to ESD-induced high-speed transients
- Virtually impossible to reproduce – difficult to diagnose



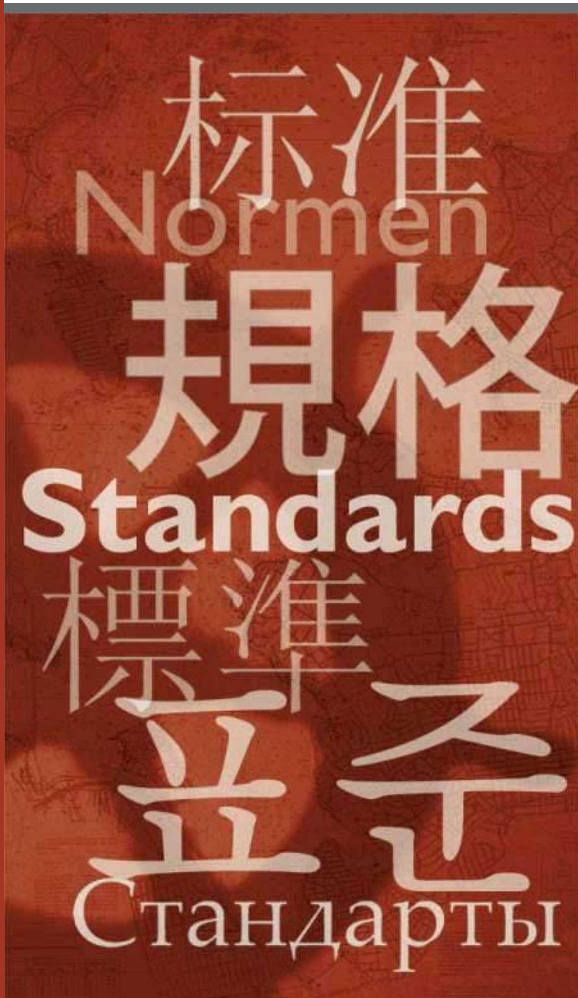
Sensor Malfunction

- Strong electromagnetic fields induce voltages and currents in circuits
- In sensors such signals can affect legitimate signals and cause false readings
- Consequences:
  - disrupted process
  - good components failed
  - bad components passed

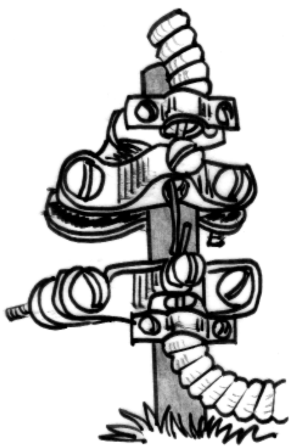




TDMA mobile phone caused false readings in sensor of magnetic head tester and finally caused error message after failing several good GMR heads



Ground and EMI



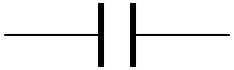
EMI Grounding: What is Different?

- For static dissipation and for safety ground should provide conductive path to “zero” potential

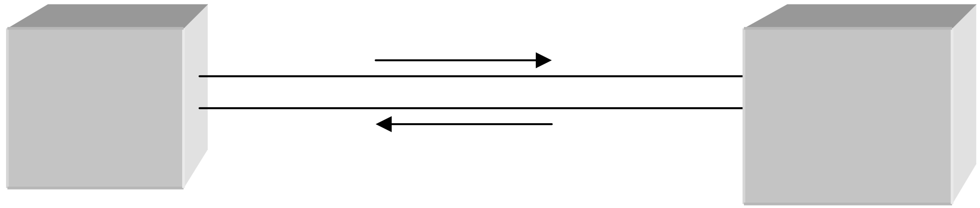
In order for it to be good EMI ground, it also:

- Should be able to offer very low impedance at high frequencies
- Should be able to conduct all the high-frequency residual signals
- Should not channel EMI from one tool to another

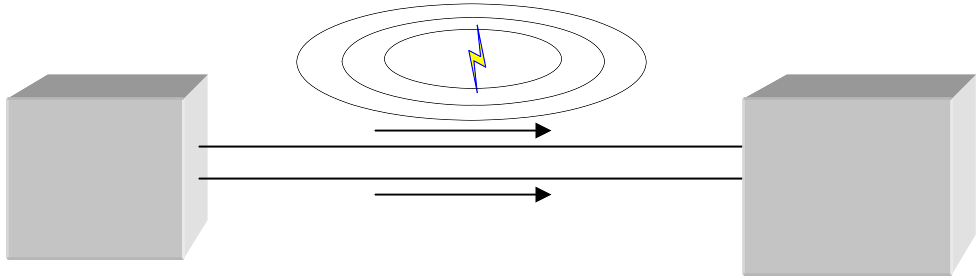
Electrical Circuits Behavior at Low and at High Frequencies

Examples:	Capacitor 	Long Wire
Low frequencies and DC:	Open circuit (infinite resistance)	Short circuit (low resistance)
High frequencies (MHz and GHz):	Short circuit (low impedance)	Open circuit (high impedance)

Common-Mode vs. Differential Signals



- Differential Signal (between two wires in a pair)
- Carries signal
- Also carries noise, predominantly <1MHz



Common-mode signal under all circumstances must be fought

- Common-Mode Signal (between each of two wires and the ground)
- Caused by EMI – use ferrite chokes to suppress

Why Multimeter Reads Random Resistance and Voltages on Ground?

- Quality of grounding is typically tested with an ohmmeter
- Ohmmeter works from DC to up to ~3000Hz (typically)
- For EMI (Megahertz and up), ohmmeter is useless
- High-frequency signals get rectified by multimeter circuit and produce DC voltages that emulate “extra” resistance, often “negative”
- Specially-designed instruments can ignore high-frequency components and measure only the required parameter

What Does the Standard Specify?

ANSI/ESD-S20.20-1999

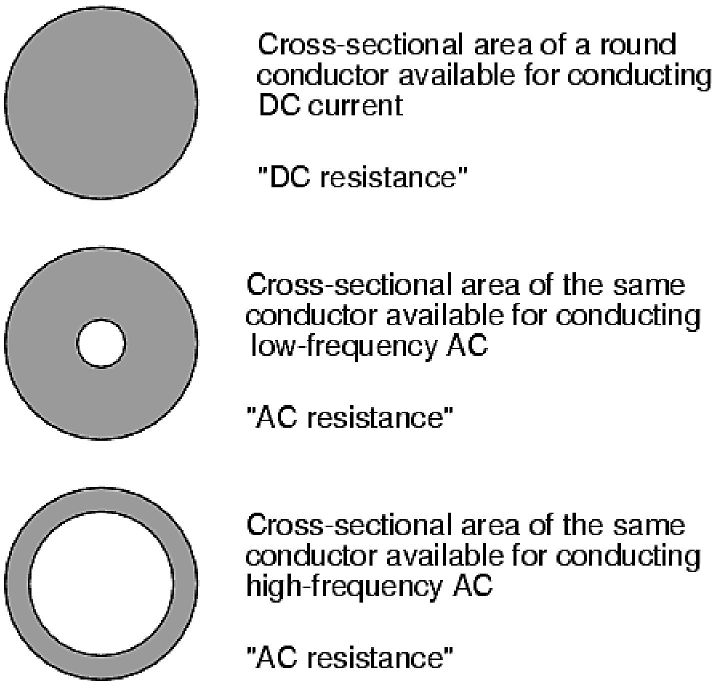
Table 1- ESD Control Program Technical Requirements Summary

(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

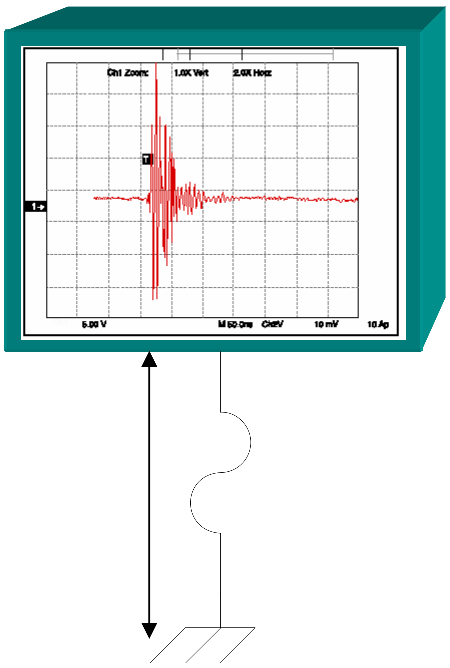
Skin Effect and Other Wiring Issues

- At high frequencies the current flows only on the outside of the wire, i.e. skin effect.
  - Use multi-stranded wires
- Any wire is an inductor that has high impedance at high frequencies
  - Low inductance is achieved by good length-to-width ratio.   The wider the ground strap, the lower is the inductance
  - Use wide flat braided cables for grounding



Grounding at Low and High Frequencies

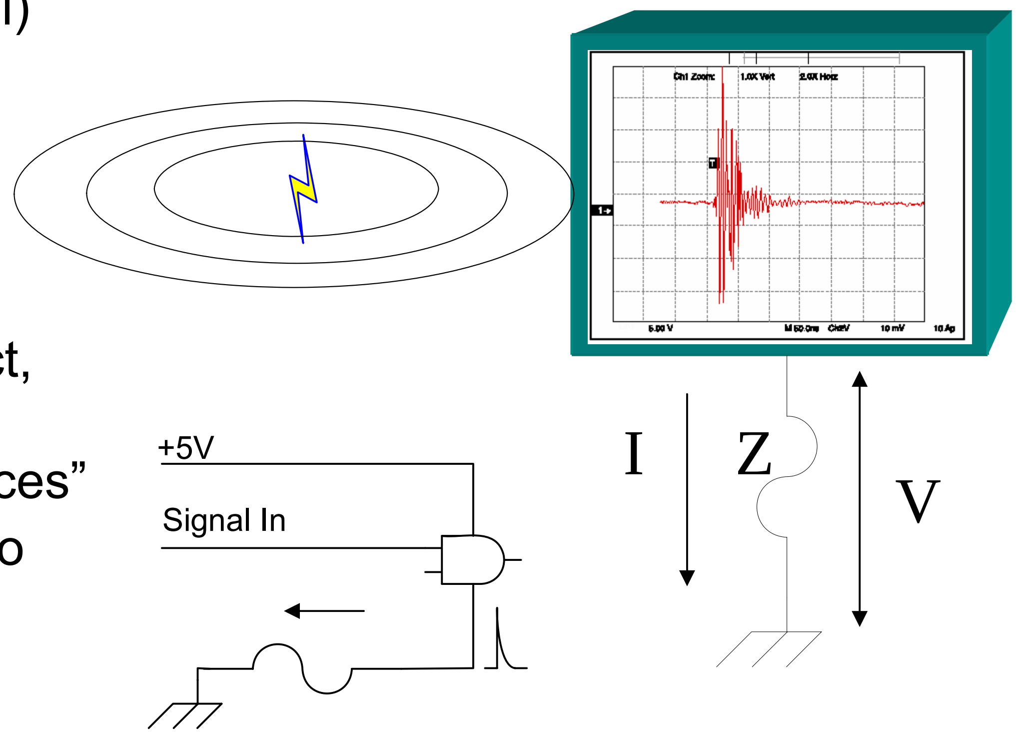
- If ground is done improperly, a ground wire acts as an inductor with high impedance at high frequencies
- High-frequency “junk” doesn’t dissipate into the ground and resides on a workbench or on a tool
- Conventional methodology and tools provide false assurance of “good ground”



Low impedance for DC
High impedance for EMI

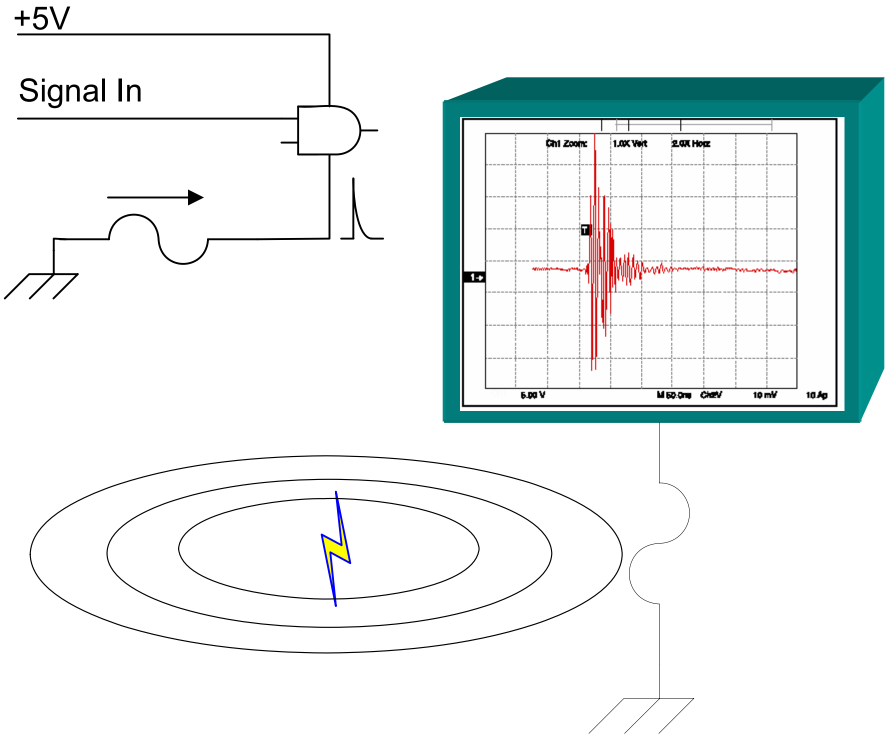
Ground Bounce

- 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"
- Circuit signal levels are no longer valid
- Equipment malfunctions



Injection of EMI into Ground Wires

- EMI induces voltages in long and poorly-done ground wires
- Equipment ground “bounces”
- Circuit signal levels are no longer valid
- Equipment malfunctions



Some Useful Formulae

- Long coiled wire is an air-core inductor whose inductance is

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

- where
  - L – inductance in μH
  - r – radius of coil, inches
  - N – number of turns
  - d – length of coil, inches
- As an example, if the “extra” ground wire is coiled to 12” diameter (6” radius), has 5 turns and the length of this coil is 0.75”, inductance of this coil will be

12.2μH

- At 100MHz frequency, impedance of this coil will be:

7661 Ohms

- A current of 1mA going through this ground wire of at 100MHz would generate voltage drop of

7.661 V

Some Useful Formulae

- Inductance of a straight wire at high frequencies can be calculated as:

$$L=0.002d*[\ln\frac{2d}{r}\ -1]$$

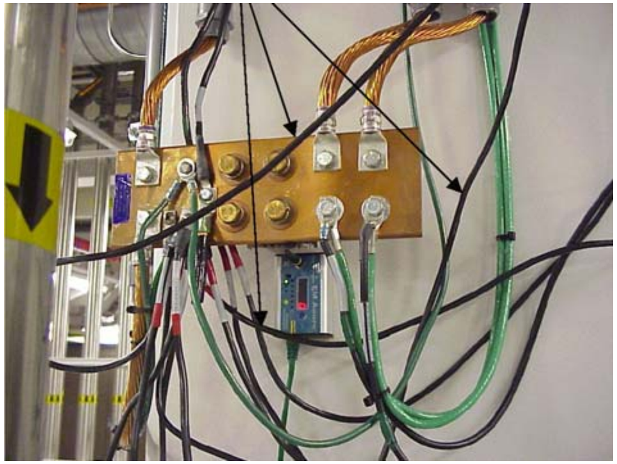
- where
  - L – inductance in μH
  - r – radius wire, cm
  - d – length of wire, cm
- A common 10m (30 feet) ground run of 12 gage solid wire has self-inductance at high frequencies of

17.36μH

- The same 1mA current at 100MHz would create a voltage on this length of wire of

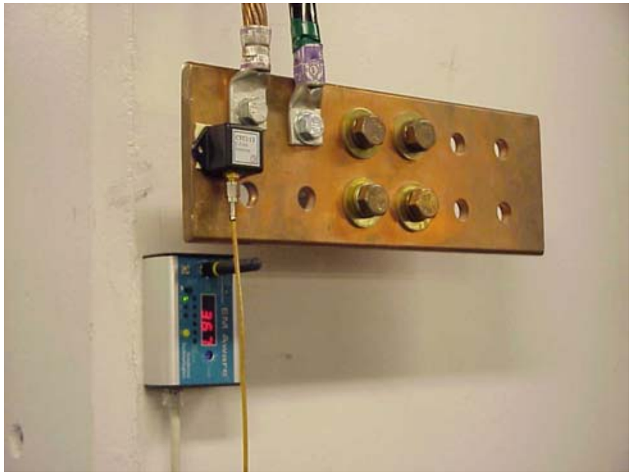
10.9V

Ground Panels



Evenly distribute ground wires.

Isolate "heavy polluters" into separate panels



Heavy load. Not enough "drainage" capacity. Strong interference between different tools.

Light load. Sufficient "drainage" capacity. Little interference between different tools.

Use Straight Braided Ground Wires

Bad for EMI

Long coiled solid wire

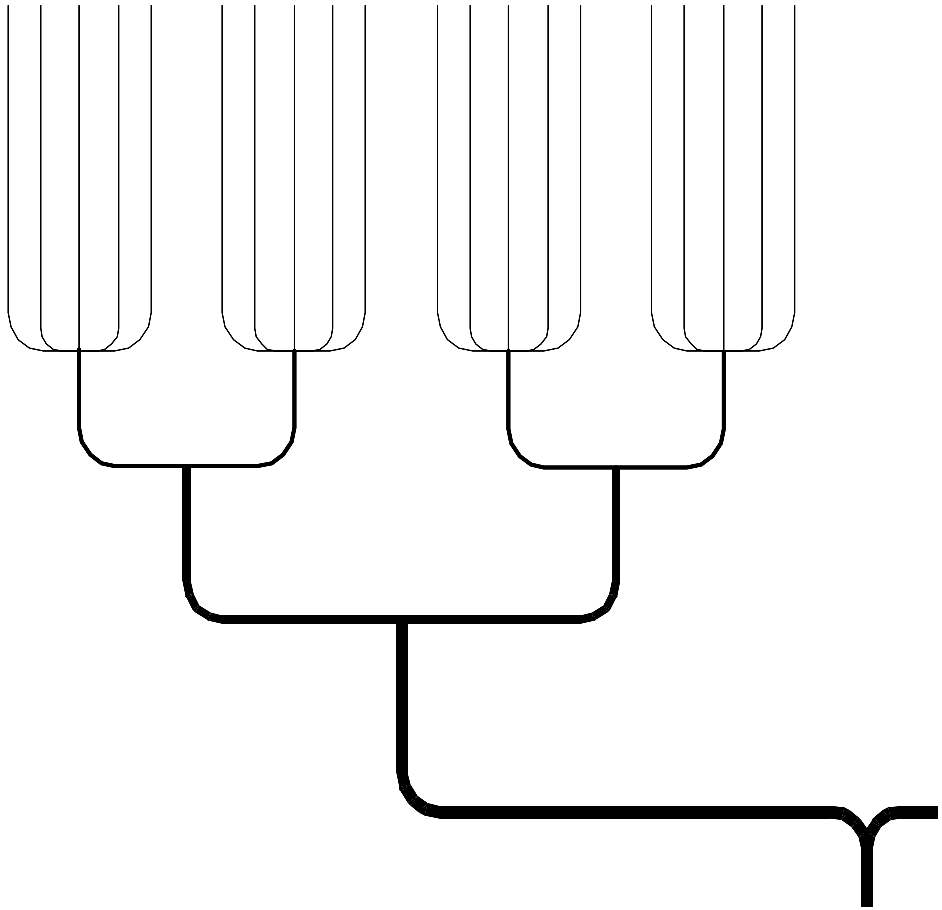
Good for EMI

Short straight flat braided cable

It doesn't cost more to do a good ground!

Ground "Tree"

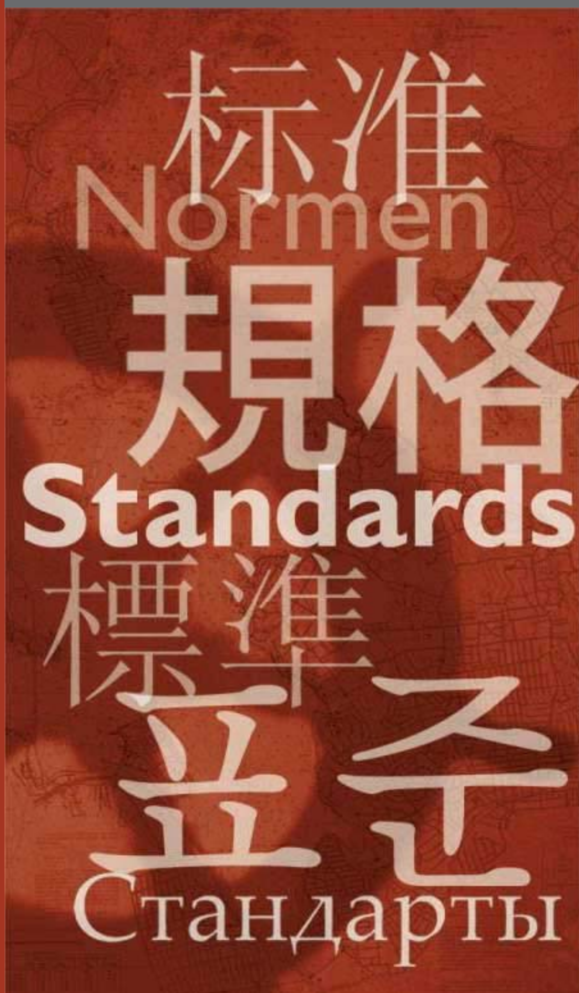
- Make sure that the impedance of ground wires REDUCES as more points get connected to ground



Assuring Good EMI Ground

- Shorten your ground wires
- Straighten your ground wires
- Use large gauge flat braided cable
- Connect it to known good ground
- Do not chain-link many workstations
- Always verify ground quality for EMI
- Do it on a regular basis
- Continuously monitor ground activity

SEMI E.33



Work in Progress

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Summary of SEMI E.33

- This document describes requirements for electromagnetic compliance for semiconductor equipment in the FABs
- This document does not address emission levels in the FAB itself
- This document relies mostly on existing accepted industry standards for emission limits and methodology
- This document also sets its own limits where existing standards are not sufficient

The Need for the Update of E.33

- The original E.33 document was issues in 1994 – it has been 12 years since
- Not only regulatory requirements have changed significantly, but also did the fabrication technology
- Requirements for electromagnetic performance have significantly risen in the past years

Fundamental Changes in E.33

- Updated references to existing EMC standards and regulation
- More specifically, compliance with the requirements of the EMC Directive meets the minimum requirements for conformance with SEMI E33
- Limits for such parameters as ELF are updated in accordance with current process requirements

Fundamental Changes in E.33

- New E.33 clarifies responsibility levels for electromagnetic compliance
- This greatly simplifies relationship between the user and the supplier

Item	Responsibility
Equipment itself	Equipment manufacturer
Equipment in combination with other equipment if supplied (integrated) by one supplier	Equipment supplier (integrator)
Equipment in combination with other equipment if integrated by the end-user	End user
Equipment installation-related compliance and EMI-performance issues	Party responsible for installation
Equipment co-location issues	End user
Equipment after repair and/or maintenance	Party responsible for repair/maintenance
Post-sale additions or modifications made by the user that affect EMC compliance	End user

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What can be Improved in new E.33

- Today majority of the E.33 EMC Task Force are equipment manufacturers
- There is very little input from the users
- We invite users of semiconductor equipment to the EMC Task Force in order to produce a better document reflecting their needs

What is NOT Included in this Revision of E.33

- Electromagnetic environment in the facility – only equipment is covered
- Semiconductor device manufacturing (i.e. back end)
- Frequencies above 1GHz
- Transient emission
- Safety issues
- And others