INNOVATING NUCLEAR TECHNOLOGY

ANALYSIS AND MEASUREMENT SERVICES CORPORATION

Electromagnetic Compatibility Overview

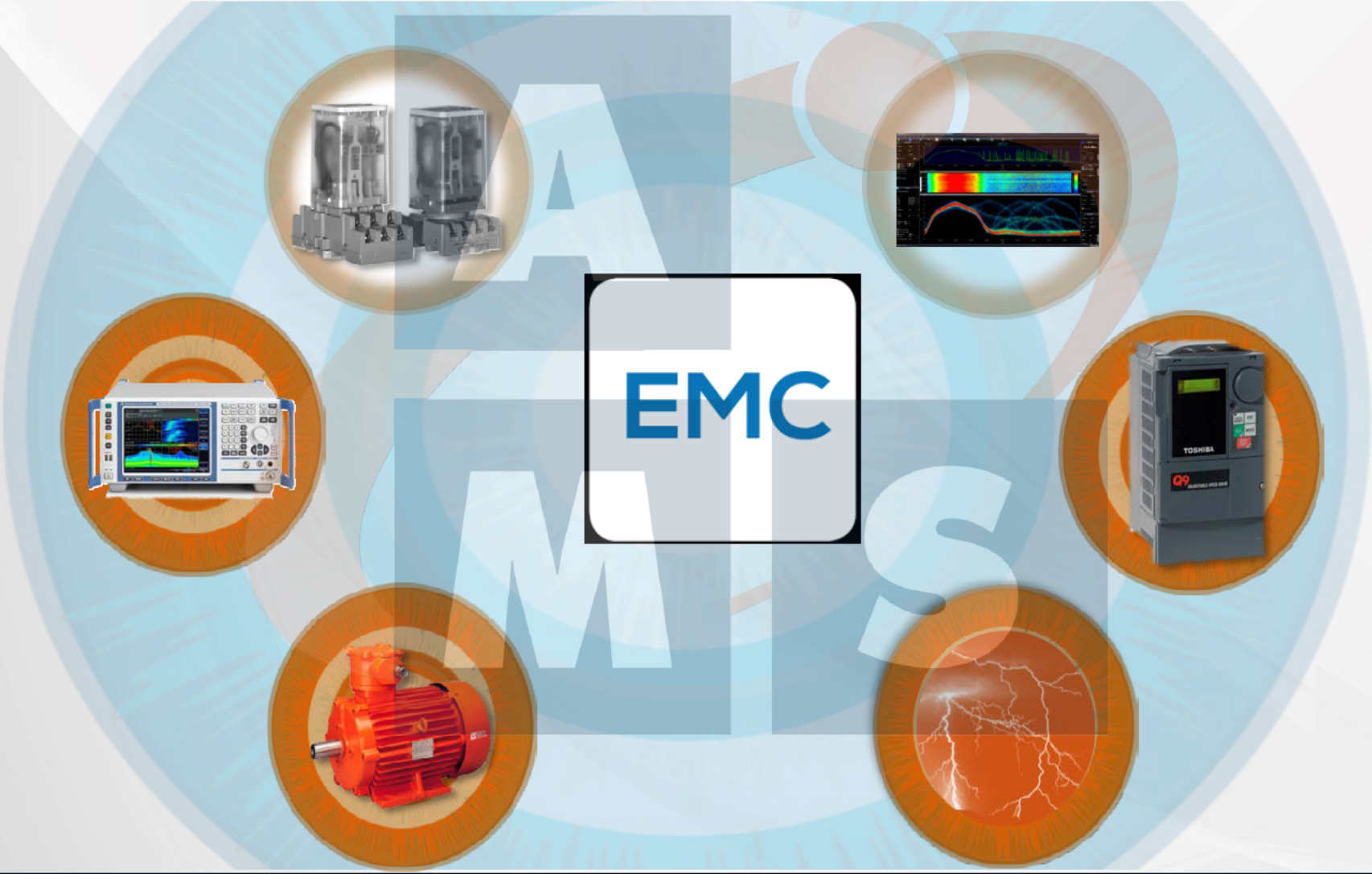
Instrumentation and Control Testing and Troubleshooting Course for TVA

Presentation Topics

- Define Electromagnetic Compatibility (EMC)
- Identify the three components of an EMC problem
- Myths Surrounding EMC
- EMC Best Practices
- Standards Used for EMC Qualification

Point Form	Integral Form
$\nabla \times \mathbf{H} = \mathbf{J}_c + \frac{\partial \mathbf{D}}{\partial t}$	$\oint \mathbf{H} \bullet d\mathbf{l} = \int_S \left(\mathbf{J}_c + \frac{\partial \mathbf{D}}{\partial t}\right) \bullet d\mathbf{S}$ (Ampère's Law)
$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$	$\oint \mathbf{E} \bullet d\mathbf{l} = \int_S \left(-\frac{\partial \mathbf{B}}{\partial t}\right) \bullet d\mathbf{S}$ (Faraday's Law; *S Fixed*)
$\nabla \times \mathbf{D} = \rho$	$\oint_S \mathbf{D} \bullet d\mathbf{S} = \int_v \rho \, dv$ (Gauss' Law)
$\nabla \times \mathbf{B} = 0$	$\oint_S \mathbf{B} \bullet d\mathbf{S} = 0$ (Nonexistence of Monopole)

What is Electromagnetic Compatibility?



EMC is Comprised of Two Parts

- **Emissions –**
  How much electromagnetic energy a device generates

- **Immunity –**
  How much electromagnetic energy a device can withstand

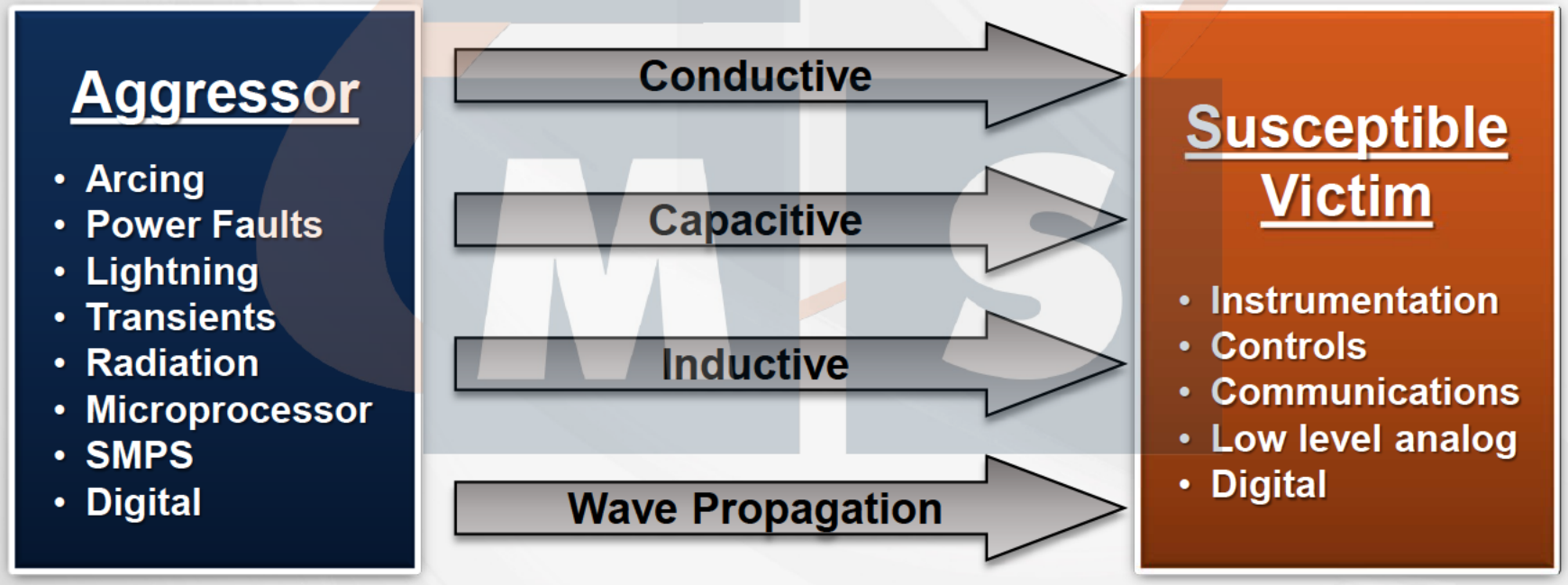
EMI Terminology

COMMON DESCRIPTION	FORMAL DESCRIPTION	COMMON CAUSE
Harmonics	Conducted Low Frequencies	Non-Linear AC Loads, Inverters
Surges	Surges	Direct or Indirect Lightning Strikes, Power Faults
Spikes	Electrical Fast Transients/Bursts	De-energizing Inductive Loads, Switch Arcing
Electrostatic Discharge	ESD (Electrostatic Discharge)	Movement Between Insulator and any Other Material
RF (Radio Frequency)	Radiated Electric Fields	Radio Transmission, Spark Gaps

What is an EMC issue?

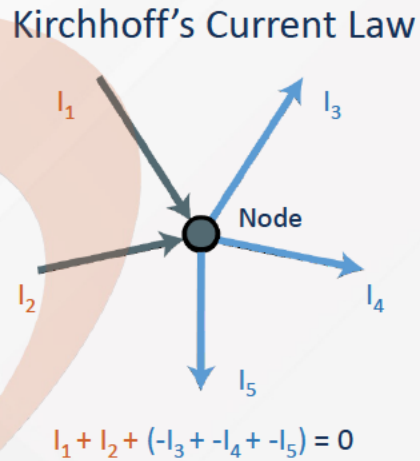
1. System or equipment that is a source (Aggressor) of the Interference
2. System or equipment that is susceptible (Victim) to the Interference
3. Coupling (Path) conducted or radiated

Must have all three components for EMI to occur

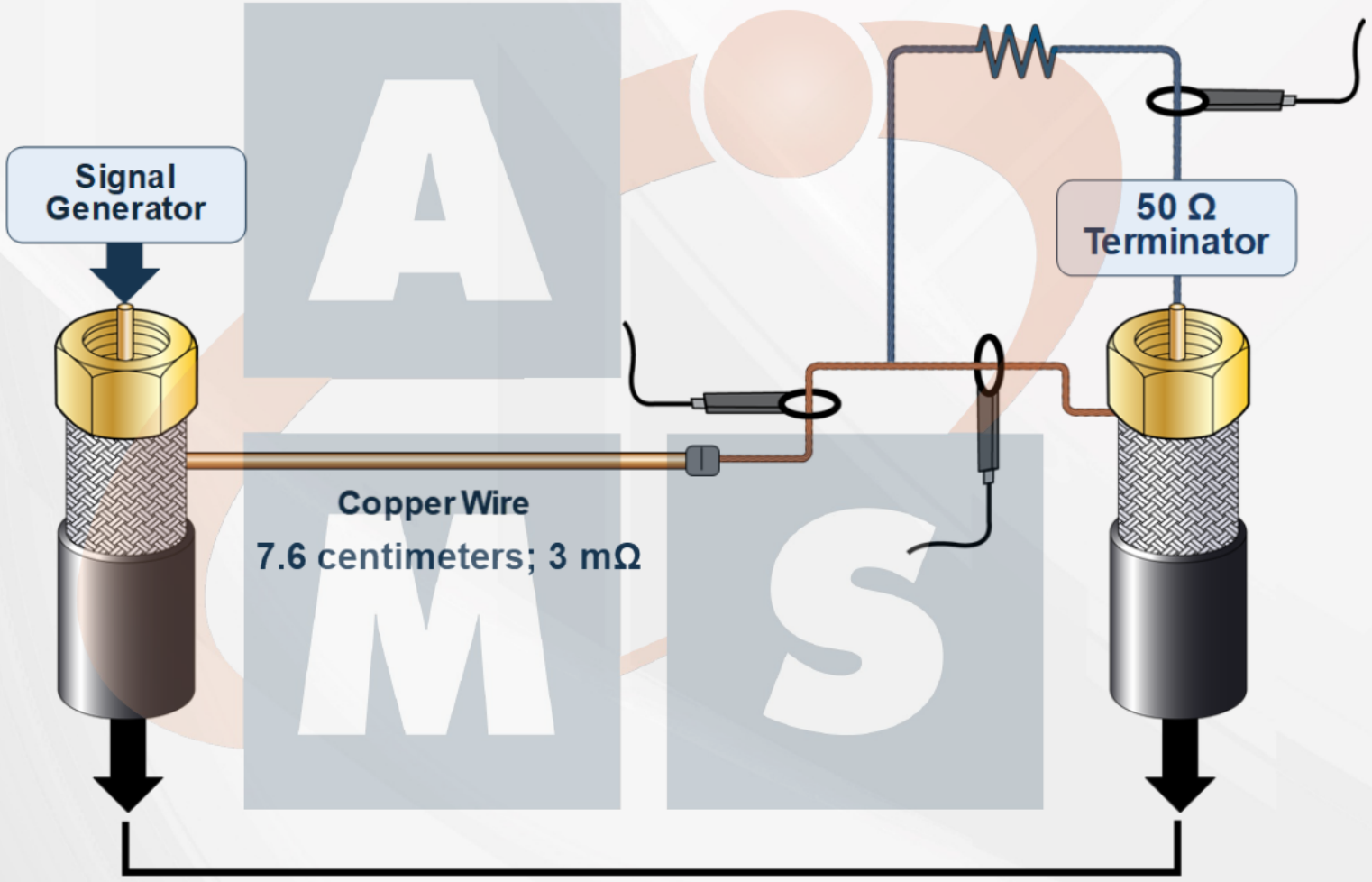


Myths Surrounding EMC

- **Current Path**
  - Does noise Take Path of Least Resistance?
- **Drain Noise**
  - Can noise be drained to earth/ground?
- **Shielding**
  - Do shields have to be continuous?
- **Cable Routing**
  - Is cable routing important?



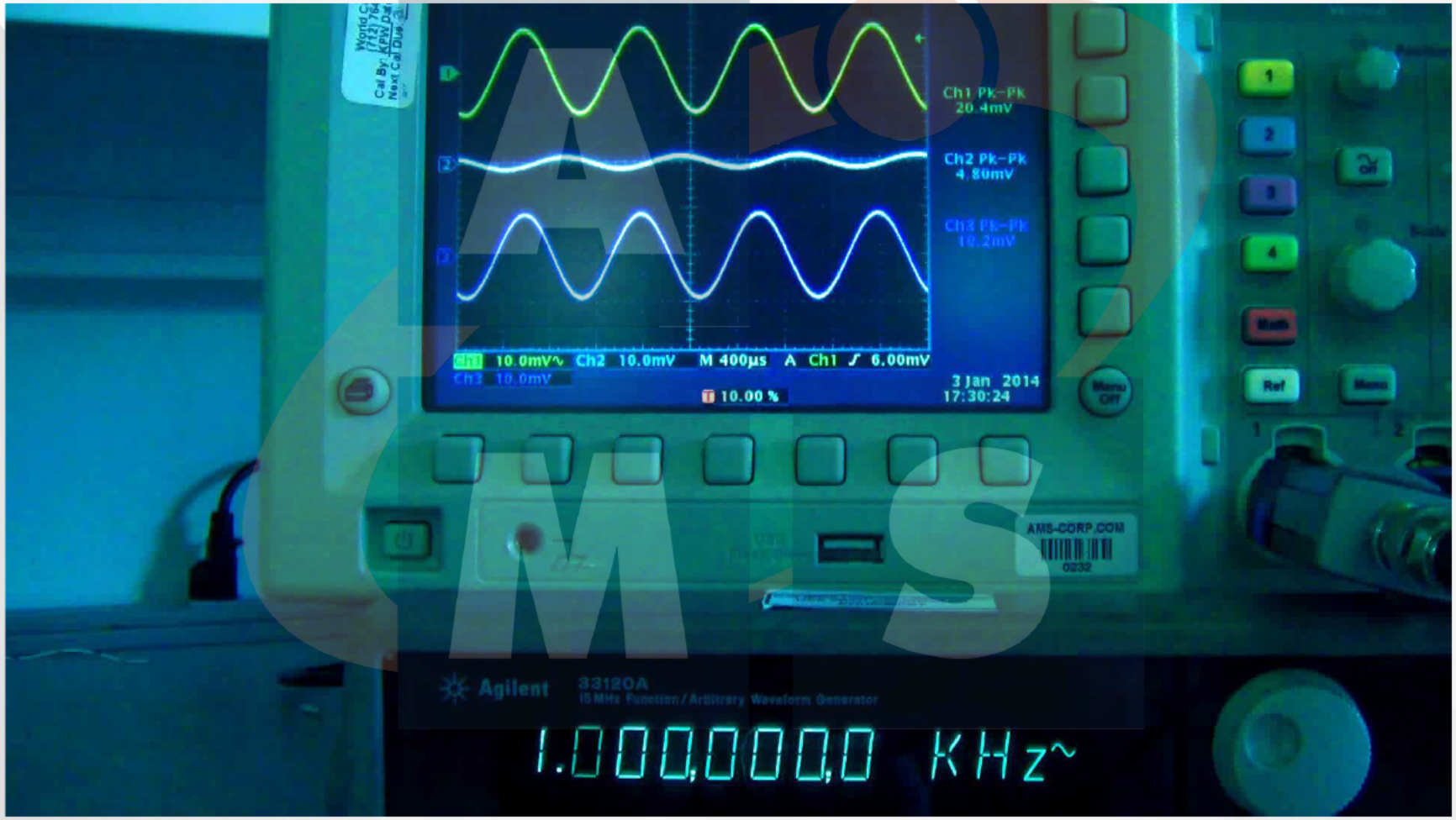
Myth 1: Noise Takes Path of Least Resistance



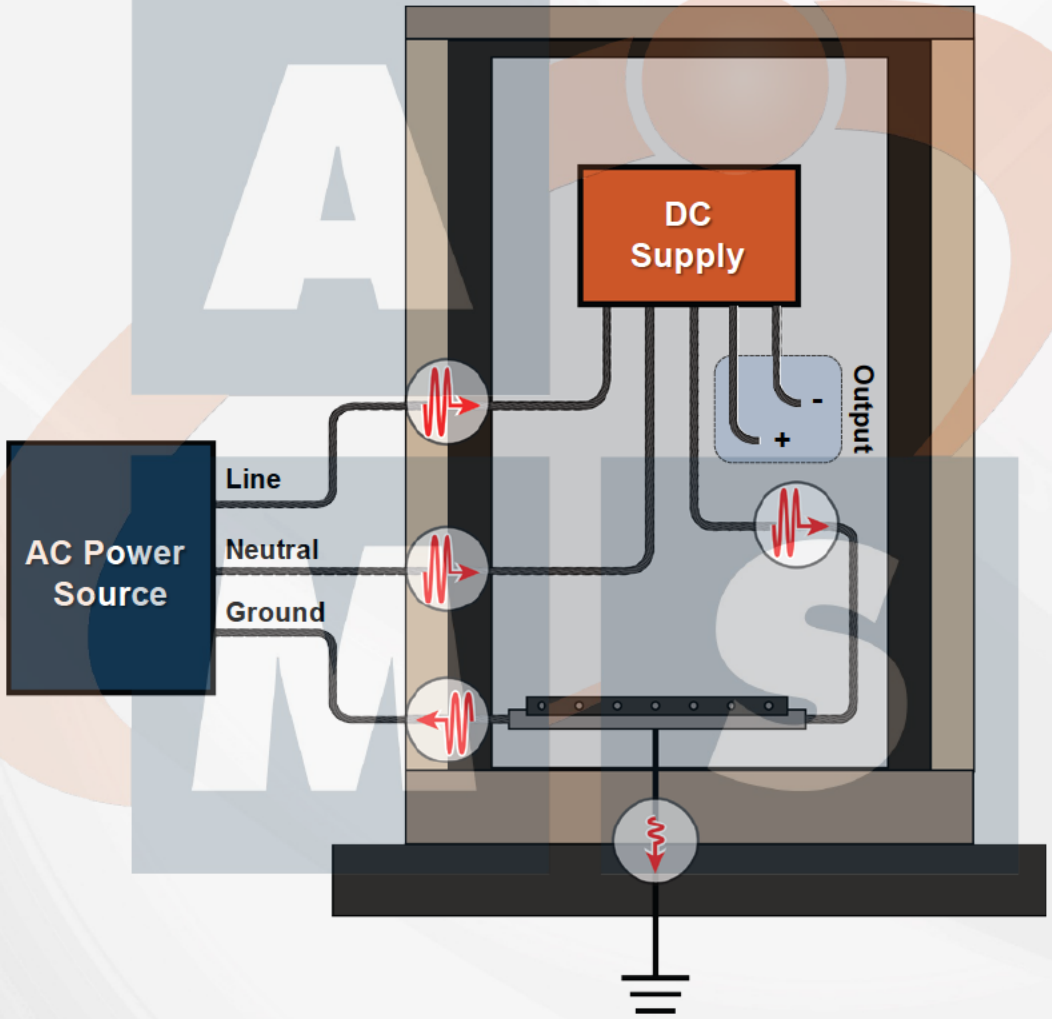
Where does Current Flow?

Cable Length – 3.2 m (10.5 feet); 153 mΩ
Short section – 7.6 cm (3 inches); 3 mΩ

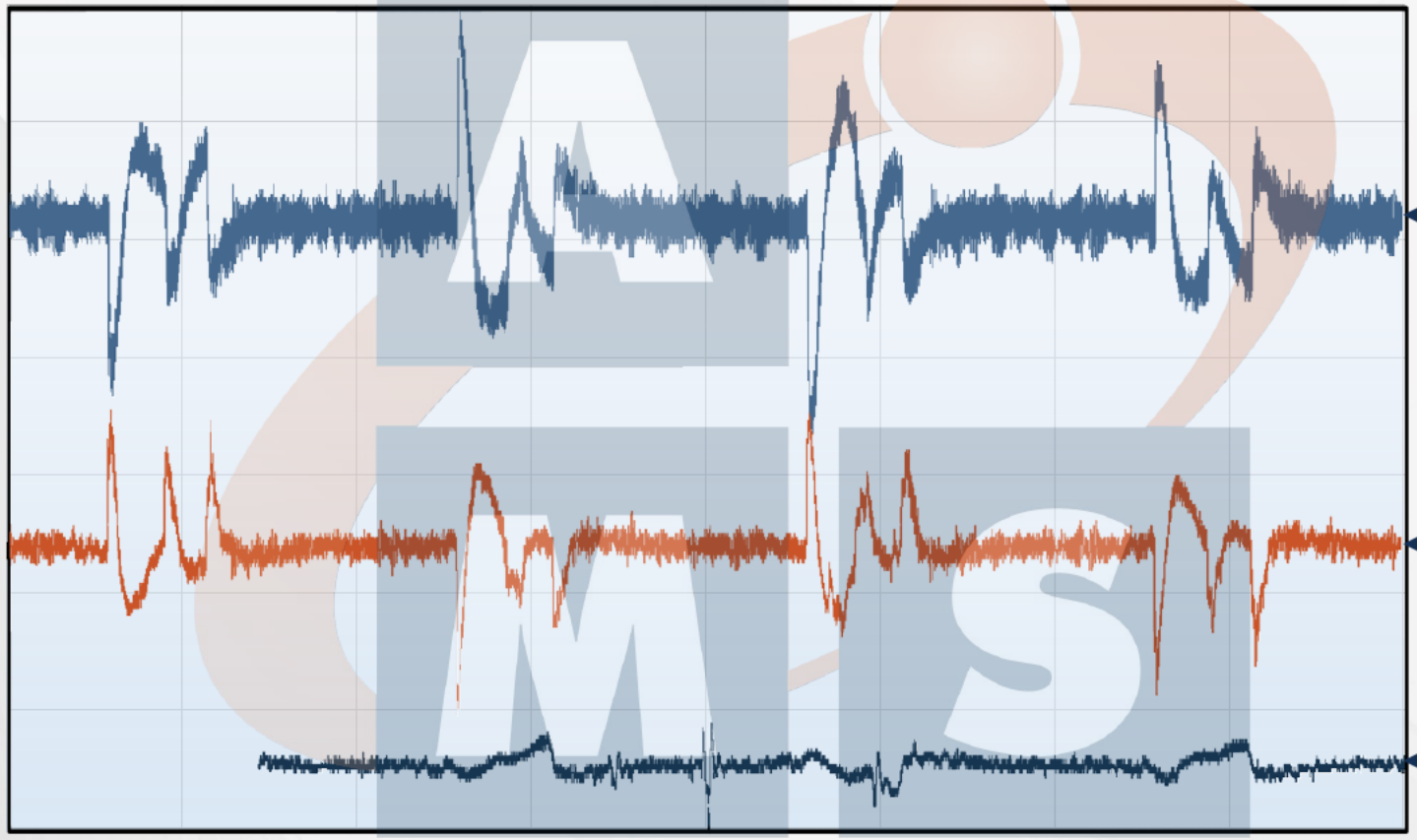
Video: Resistance vs. Impedance



Myth 2: Noise can be Drained to Earth/Ground



Where does the Current Go?



No Current Flows to Ground Grid Connection

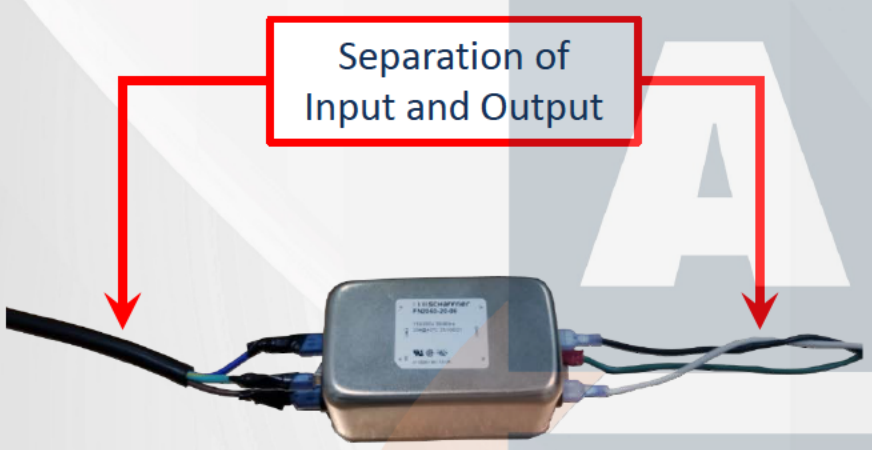
Myth 3: Shields must be Continuous

- Are there EMI-Free Cabinets?
- Do Drain wire lengths matter?
- Is 360° Shielding necessary?

Frequency vs. Critical Length

Frequency	Approximate Wavelength λ	Approximate Antenna Length for Susceptibility ¼λ	EMI Source
20 kHz	50,000 ft	12,500 ft	Power Supply Switching
300 kHz	3,300 ft	825 ft	Relay Arcing
100 MHz	10 ft	2.5 ft	Microprocessor
900 MHz	1 ft	3 in	Radio
2.4 GHz	5 in	1.25 in	Wireless Communication

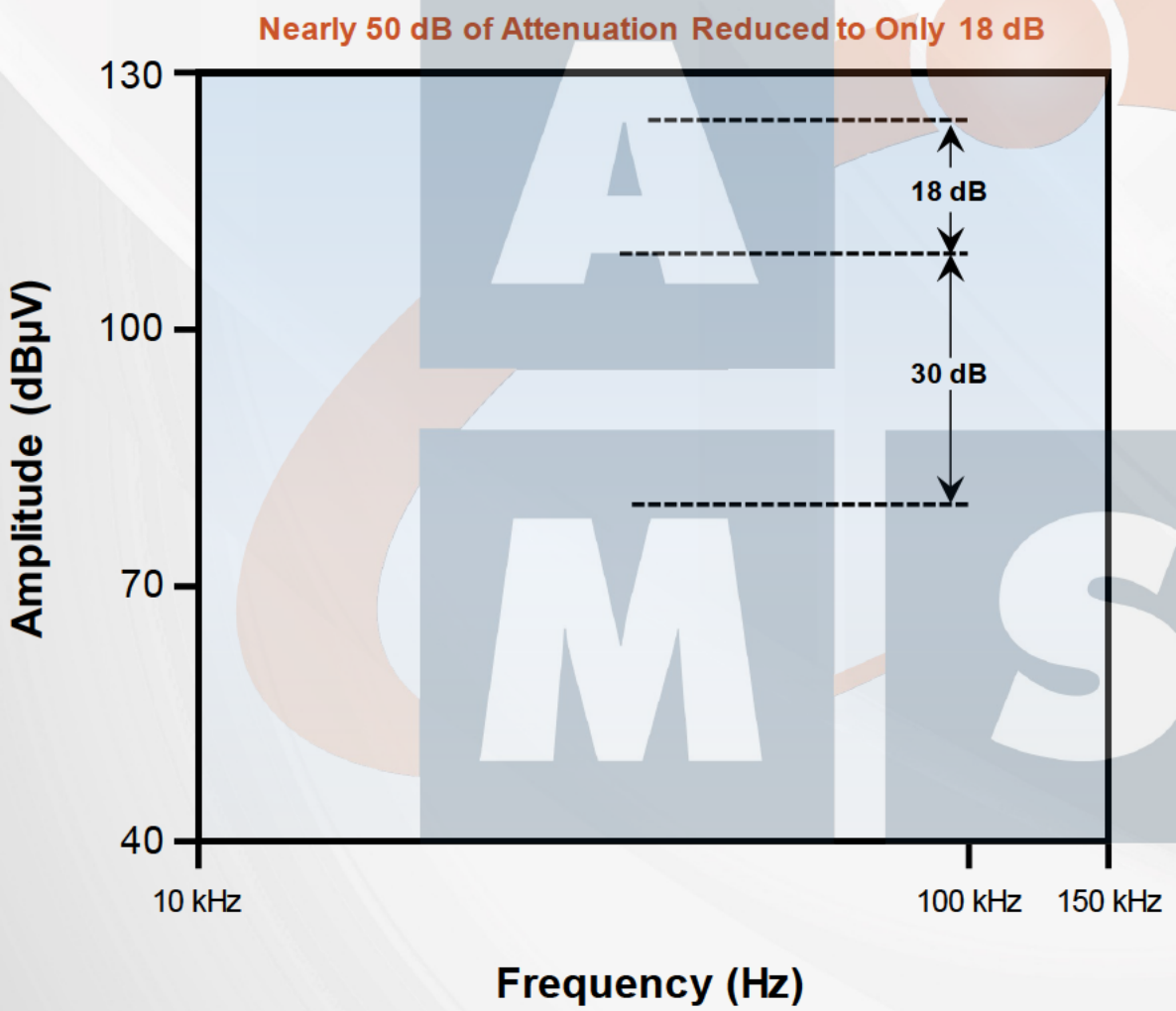
Myth 4: Cable Routing is Not Important



Proper Filtering

Improper Filtering

Effect of Tie-Wrapping Cables Together



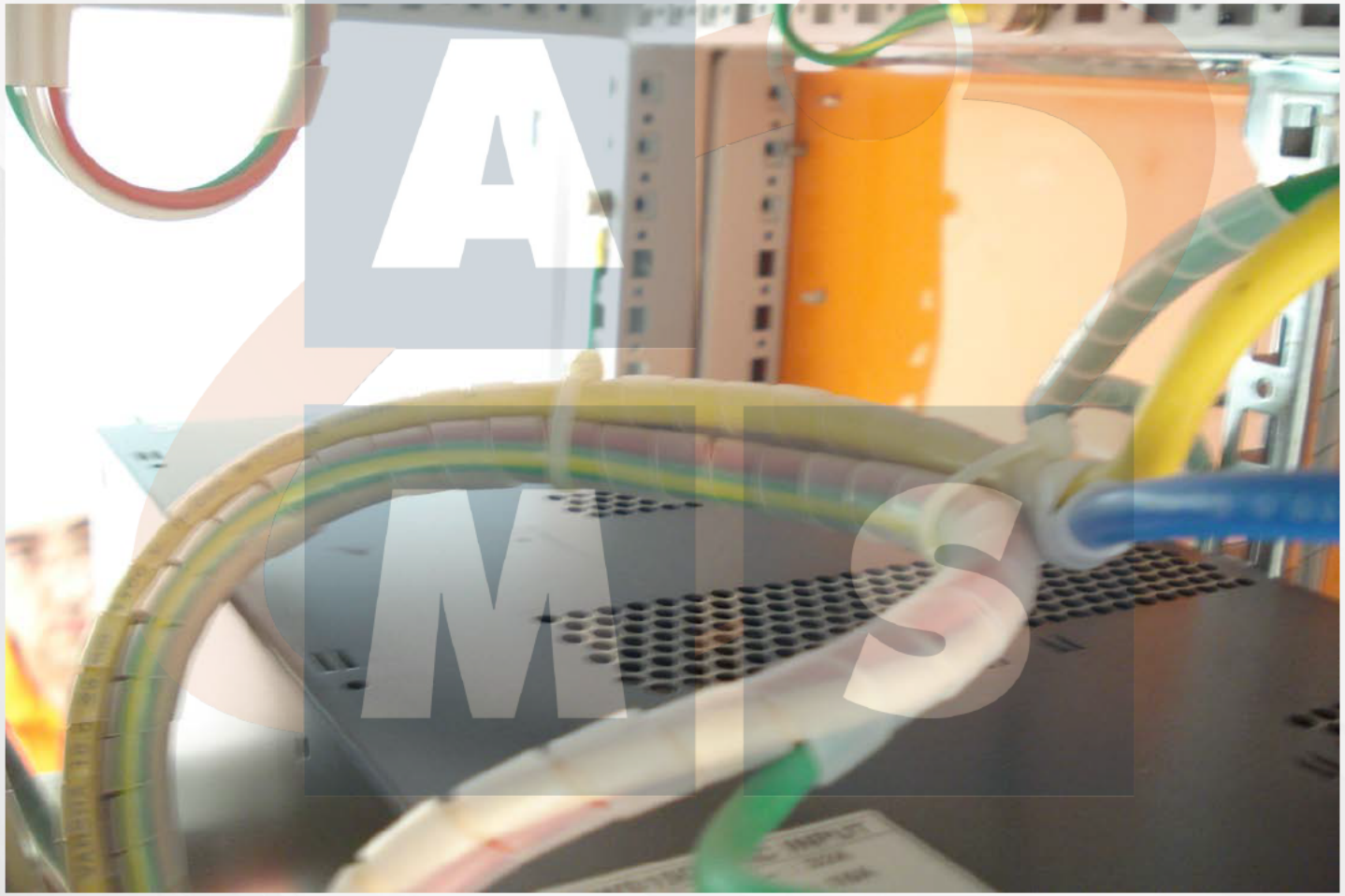
No Filter

Proper Filtering

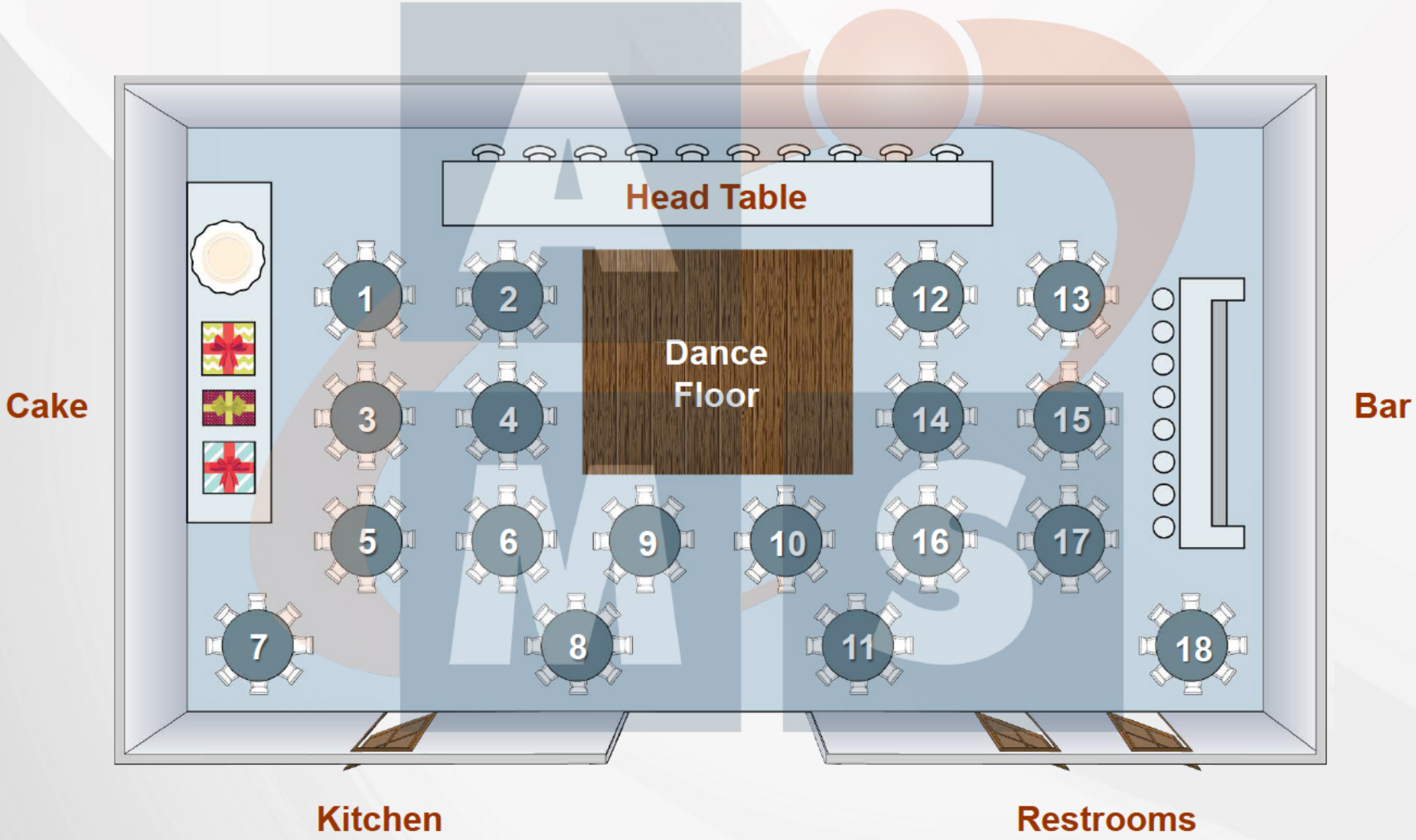
Improper Filtering

Amplitude	Factor
3 dB	1.4 x
6 dB	2 x
10 dB	3.2 x
18 dB	8 x
20 dB	10 x
30 dB	32 x
50 dB	320 x

Input and Output Power Tie-Wrapped Together



Separation is Critical

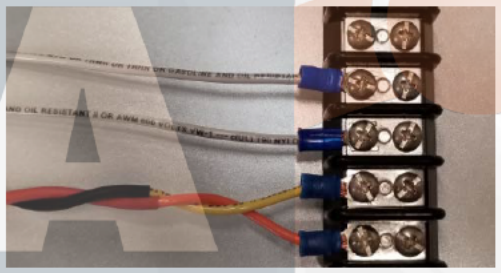


EMC Best Practices can Prevent Most EMI Issues

Power Line Filters
At the cabinet boundary

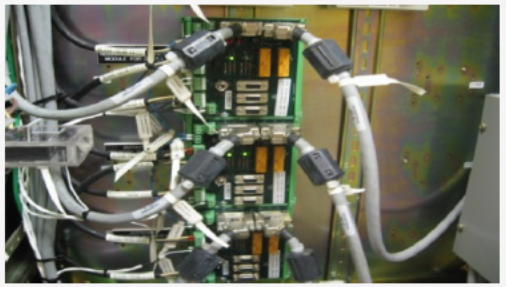
Ferrite Beads
At the cable boundaries

Shield Bonding
Short Leads / EMI Reference

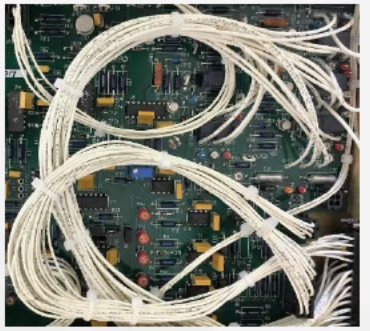


Maintain Twisted
With GND Wire for Power

Grounding
Follow Safety Codes
Follow EMI Practices



Power and Signal Cable Separation
Cross at 90º or Separate Cabinet Entry



Do Not Tie-Wrap Cables

EMC can be Simplified if you Treat it Like a Program

EMC does not begin and end with qualification testing

It takes an EMC program

- Understand EMC
- Know the Requirements
- System Design
- Construction and Wiring
- Qualification Planning and Testing
- System Installation
- Future Maintenance and Troubleshooting

Why and What is EMC Testing?

- **Ensure the plant environment is compatible with the equipment and vice versa**
  - Immediate vicinity
  - Connected to same power or I/O cabling
- **Emissions Testing – Measure of the EMI generated by a piece of equipment**
  - Conducted
  - Radiated
- **Immunity Testing – Measure of the susceptibility (withstand capability) of equipment to EMI**
  - Conducted and Radiated
  - Replicates surges, electrical fast transients, modulated RF, etc.
  - Test for threats in the actual plant environment

Standards Used for EMC Qualification

Nuclear Regulatory Commission (NRC)

Regulatory Guide 1.180 Rev 0,1,2

Electric Power Research Institute (EPRI)

Topical Report TR-102323 Revisions 0,1,2,3,4,5

International Electrotechnical Commission (IEC)

IEC 62003:2020

IEC 61000

CISPR

Institute of Electrical & Electronics Engineers

IEEE P2425 (under development)

IEEE C62.41

Military Standards

MIL-STD-461 E,F,G

IEEE 603 - IEEE Standard Criteria for Safety Systems for Nuclear Power Generating Stations

- **Defining Electromagnetic Environment**
  - IEEE 473 and MIL-STD461E
- **Evaluation of EME**
  - Conductive, Radiative, Inductive, Capacitive
- **System Design for EMI**
  - Shielding, grounding, routing, suppression, filtering, data quality checks, software techniques
- **EMC Testing**
  - EPRI TR-102323, MIL-STD461E, IEC Tests

Provides a comprehensive approach to addressing EMC

EMC is NOT Rocket Science

- Understand what to look for and how to find it
- Simple design considerations can address most EMI issues
- Treating EMC as a program can help maintain control of the electromagnetic environment

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Thank You

Questions?