INNOVATING NUCLEAR TECHNOLOGY

ANALYSIS AND MEASUREMENT SERVICES CORPORATION

Design Considerations to Control Electrical Transient EMI

Instrumentation and Control Testing and Troubleshooting Course for TVA

Learning Objectives

- **Upon completion, the student should be able to:**
  - Understand the different types of EMI
  - Identify practical solutions for mitigating noise
  - Understand the performance of ferrite beads and capacitors
  - Determine the frequency content of a signal
  - Items to look for during a walkdown of EMI issues
  - Introduction of measurement of voltage and current signals

Types of EMI

- Steady-state versus transient
- Natural or man-made
- Conducted on cables versus radiated through the air
- Power or signal related? or both

COMMON DESCRIPTION	COMMON CAUSE
Harmonics	Non-Linear AC Loads, Inverters
Surges	Direct or Indirect Lightning Strikes, Power Faults
Spikes	De-energizing Inductive Loads, Switch Arcing
Electrostatic Discharge	Movement Between Insulator and any Other Material
RF (Radio Frequency)	Radio Transmission, Spark Gaps

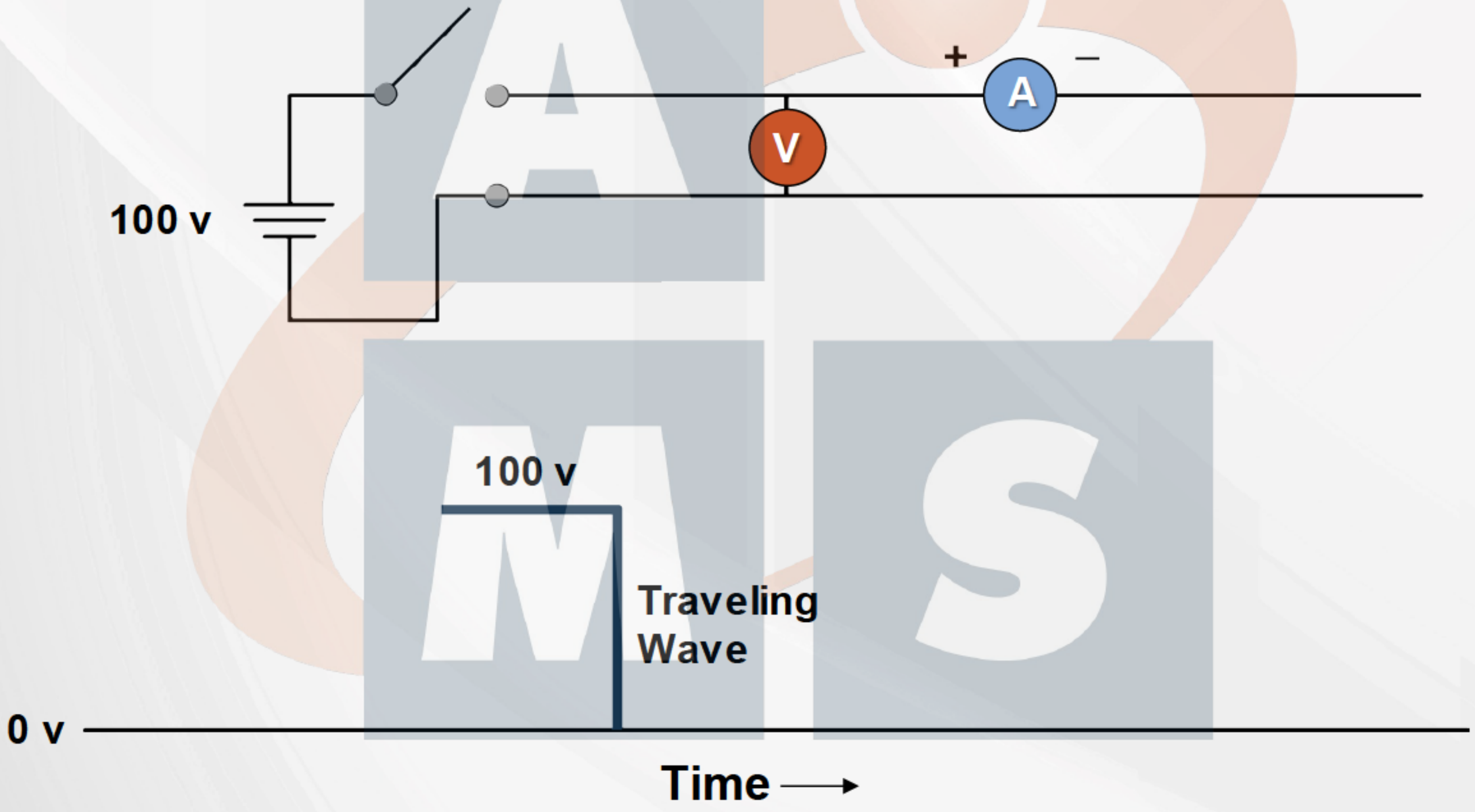
EMI Transient Coupling

- Transient tends to be a burst of high frequency energy
- Far field conditions typically exist
- Energy radiates through the air or is conducted on RF transmission lines

MUST UNDERSTAND BEHAVIOR OF ELECTROMAGNETIC WAVES TO EFFECTIVELY DEAL WITH EMI TRANSIENTS

EMI Transient Coupling

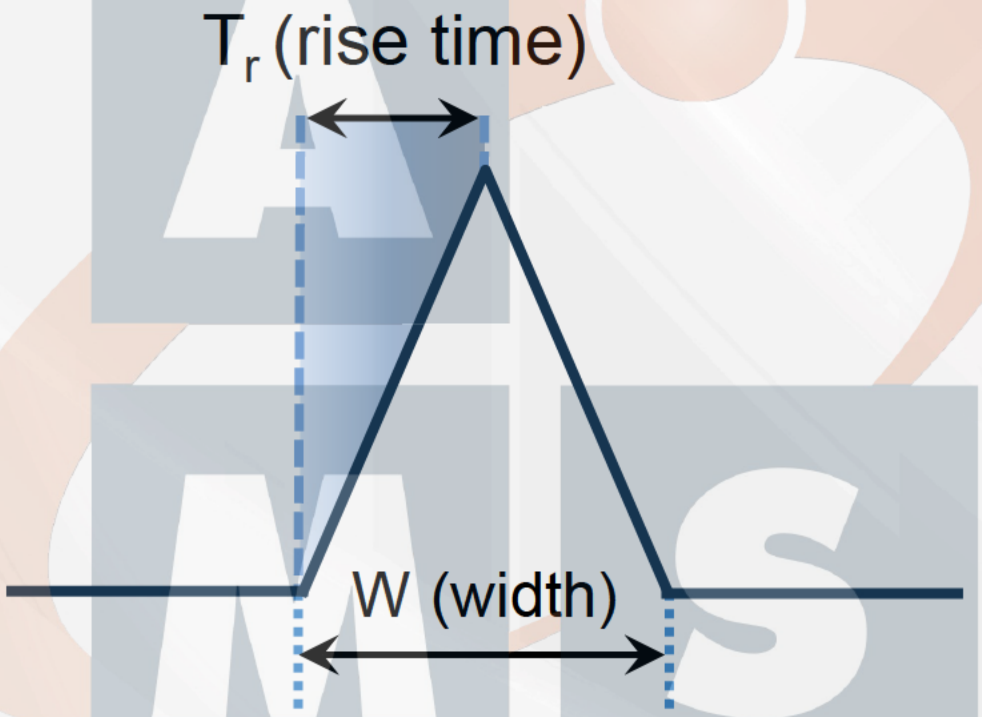
A transient is created every time a voltage is switched



Determining Frequency Content from Waveform Data

- **The reciprocal of the rise time divided by 3 will give the approximate high frequency content of the signal.**
  - Frequency information can be used in designing the fix for the EMI.
  - Verify measured rise time is less than rise time of the digital oscilloscope.

Equivalent Frequency of Transient



$$Max\ Freq \approx \frac{1}{T_r\,(3)}$$

$$Fundamental\ (Min)\ Freq = \frac{1}{2W}$$

What do these signals actually look like?

- **120 Vrms signal**
  - Waveshape
  - Peak amplitude
  - How to measure with an oscilloscope
  - What does the current look like? V=IR right?

- **Practical Demonstration**

What do you protect against?

- **What drives your requirements?**
  - Are they always the same?
    - What levels do you expect to see?
      - How can you assess or verify the levels?

How do you protect a system?

- **What level of protection**
  - Component, Board, Chassis, System, Cabinet, Plant
- **Who specifies/designs the protection**
  - Procurement, Plant Engineering, EOC, Vender
- **How do you verify the protection**
  - Analysis, Test, Other
- **When do you verify**
  - FAT, SAT, Install, Other

COMMON DESCRIPTION
Harmonics
Surges
Spikes
Electrostatic Discharge
RF (Radio Frequency)

Types of EMI Protection

- **Inherent design addresses EMI**
  - Signal processing filtering, slow response circuits, error checks and retries, robust signals
- **Build equipment to minimize potential for EMI**
  - Cable types, cable routing, shielded enclosures, “adequate” grounding
- **Add components to reduce level of EMI**
  - Powerline filters, filter capacitors, ferrite beads, chokes, surge suppressors
- **Keep EMI away from the equipment**

Inherent Design for EMI

- Often not an option for plant personnel
- Not interesting from an EMI standpoint (for this class)
- IEEE 1848 has some information and guidance

Build Equipment to Minimize Potential for EMI

- Grounding
- Shielding
- Cable Routing

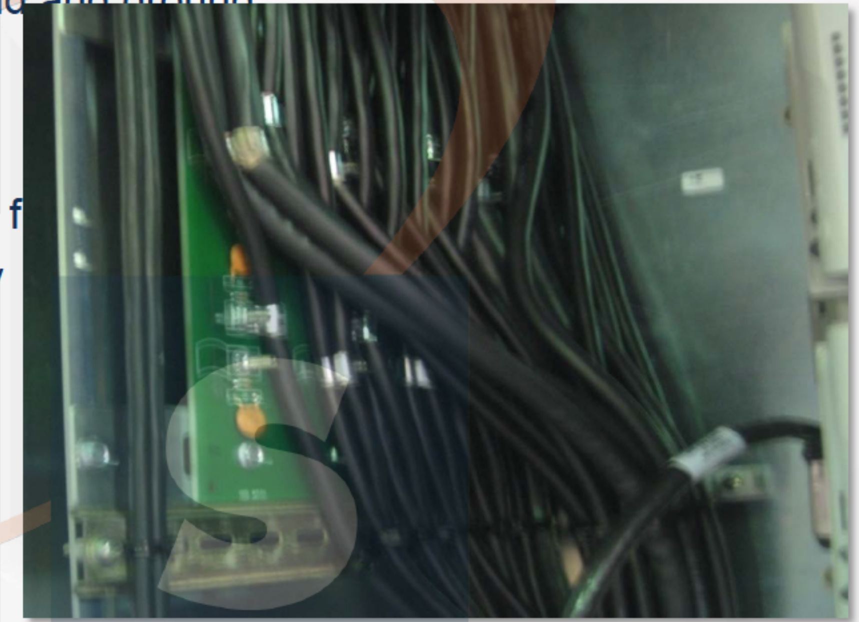
Use Proper Grounding

- **Proper grounding can significantly reduce EMI problems. Location, Location, Location!**
  - Single-point connection to ground at lower frequencies to avoid ground loops
  - Low impedance ground connections to EMI reference ground planes can serve as reflective filters for higher frequency traveling waves (transients) - multiple grounds may be used
  - Low impedance ground connections to large, conductive surface areas can serve as dump for electrostatic discharges

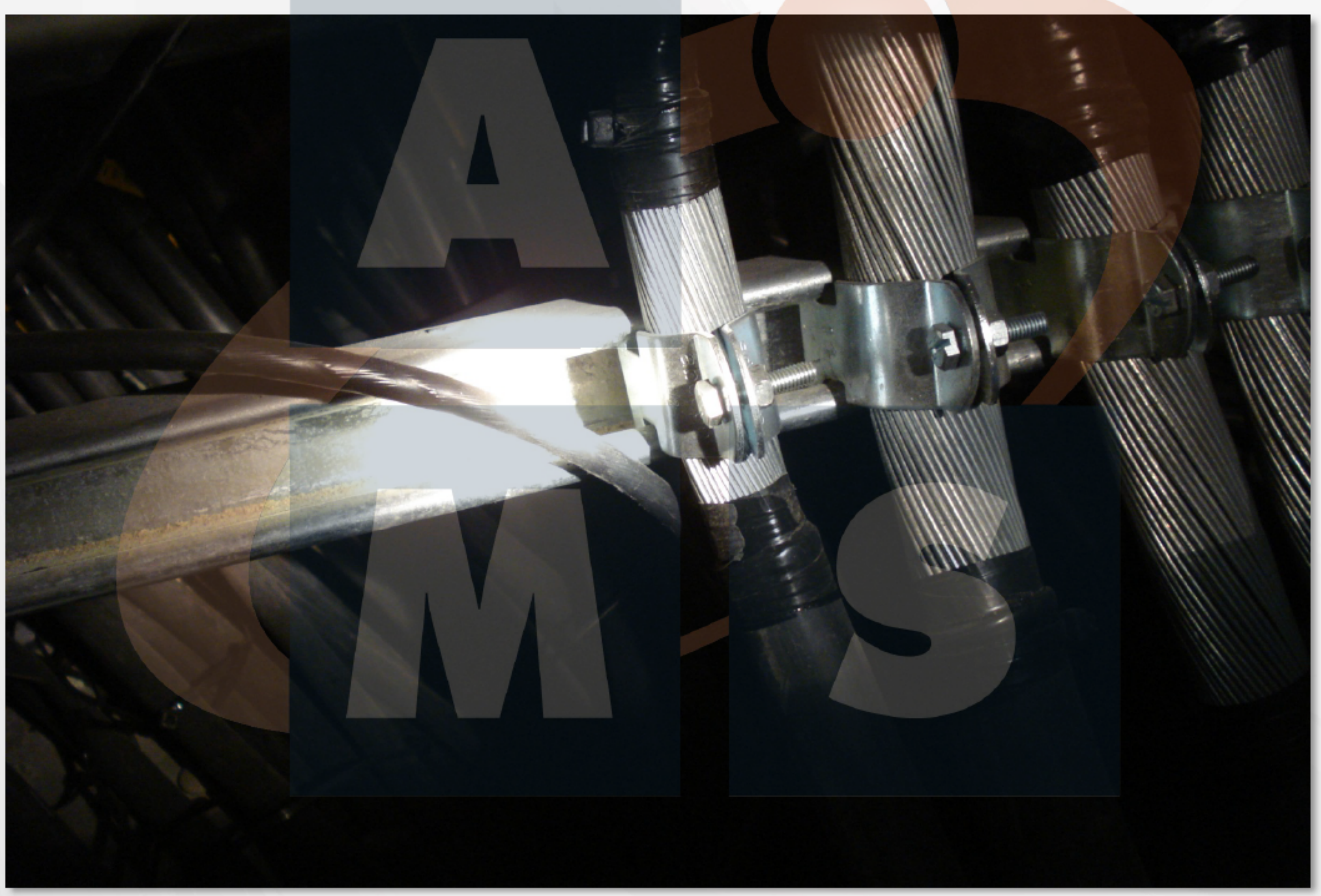
Shield Grounded through PCB as it Enters the Cabinet

- **Good concept**
  - Minimizes EMI entering and radiating in the cabinet
  - Maintains shield beyond this connection point up to the terminal block
  - Allows for insertion of a capacitor between the shield and ground

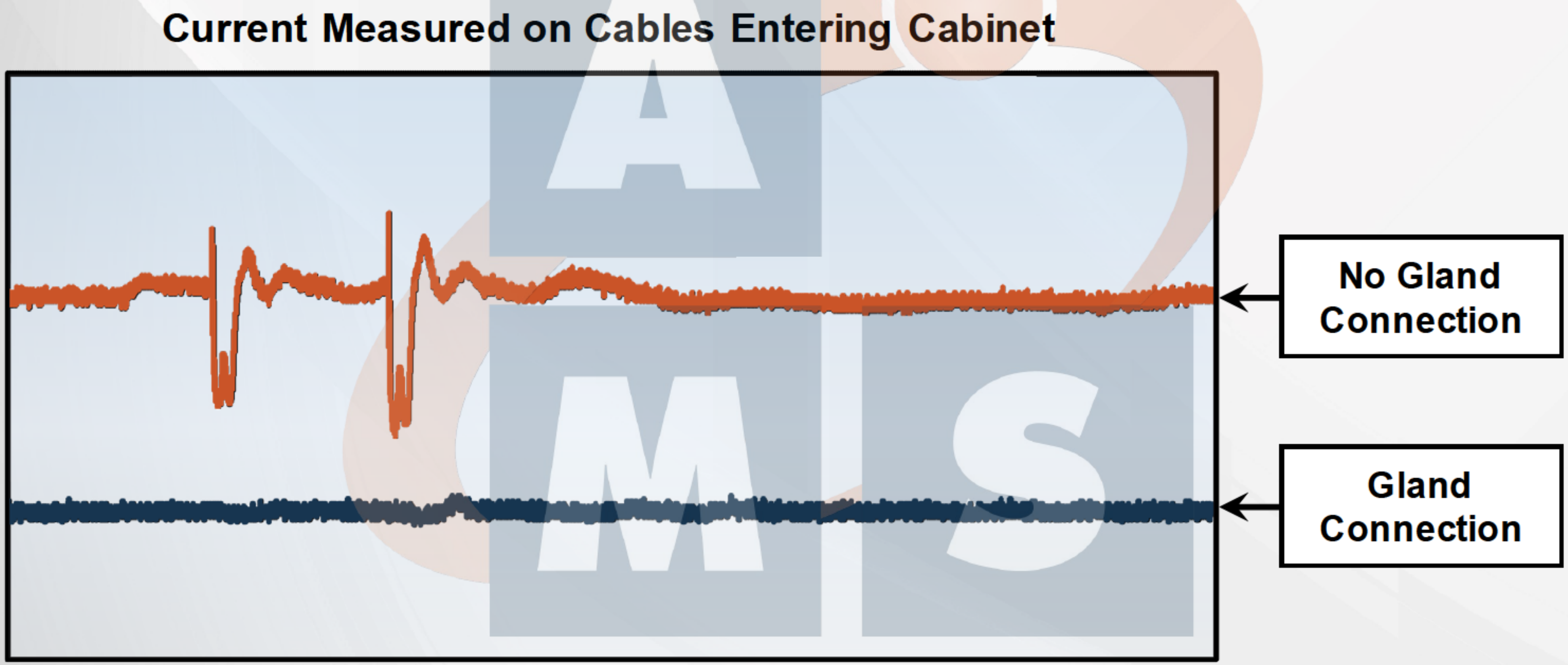
- **Drawbacks**
  - Impedance of PCB traces may be an issue for high f
  - Prefer connection be made at the cabinet boundary



Shield Connection Under Cabinet



Avoid the Headache; Prevent EMI from Entering the Cabinet



Shields

- At lower frequencies, E-field shields need a return path to circuit common to be effective
- At higher frequencies, shields must completely envelope the equipment to be effective
- A coaxial cable was not designed as a shielded cable
- The integrity of a coaxial cable will be destroyed if a pigtail is used to terminate it

Cable Shielding Effectiveness for Low Frequencies, <50kHz

- **Twisted wire pair with foil shield & drain wire**
  - Single point ground, long run – Poor
  - Single point ground, short run – Okay
- **Twisted wire pair with braid shield & no drain wire – Best**

Cable Shielding Effectiveness for High Frequencies, > 50 kHz

- Coaxial – Good
- Triaxial – Better (if used as coaxial cable)
- Coaxial with solid outer conductor – Best

Hints on Improving EMI Immunity of Cable Shields

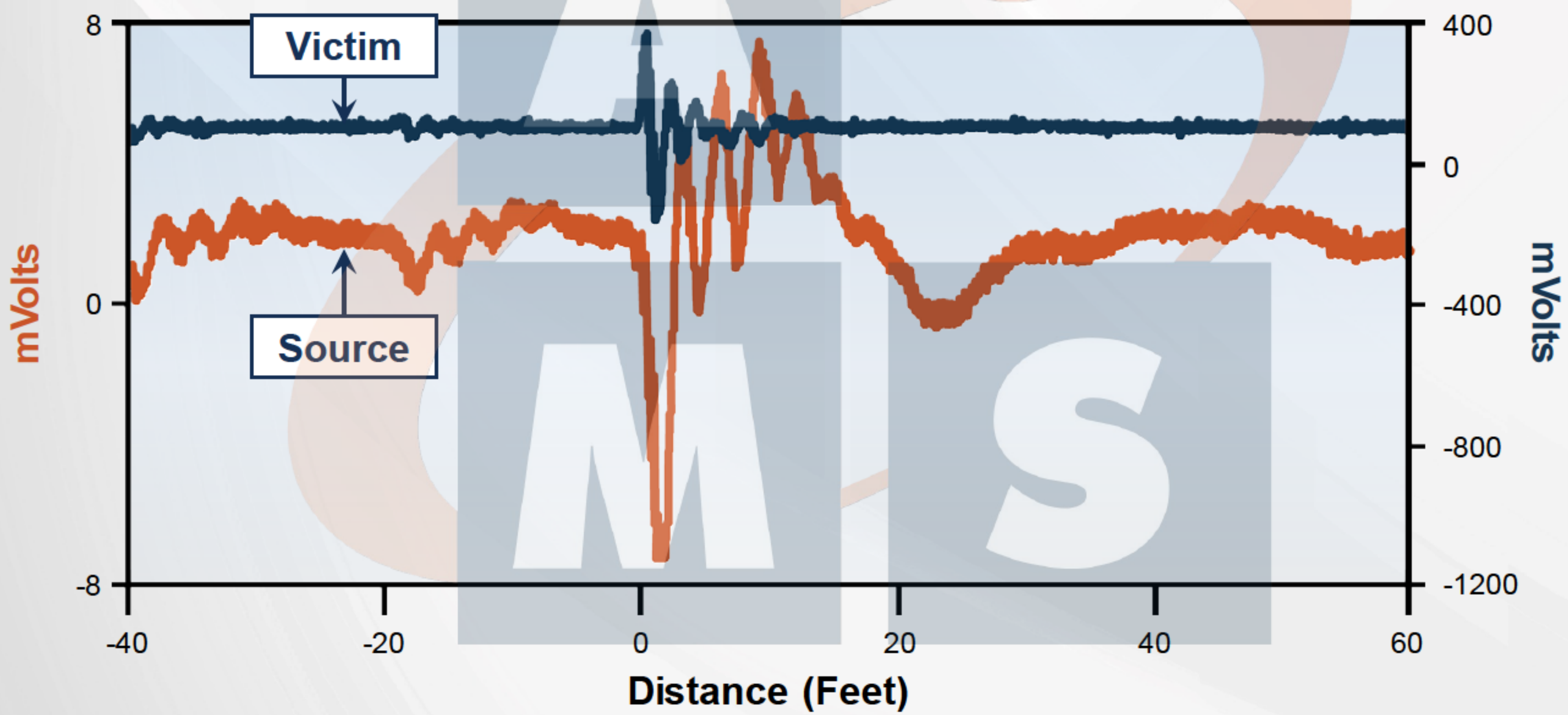
- Ground shields on cables at the point where the EMI is greatest
- Terminating coaxial cables with symmetrical pigtails will eliminate EMI pickup
- Do not place signal loops close to the inside wall of a reflective shield
- Twisted pair wire is very effective magnetic field shielding - do not untwist the wires
- An insulated conductor or even a non-conductor passing through a high frequency shield will destroy the effectiveness of a shield
- A hole in a shield will be a problem only for EMI with a wavelength =< 20 times the largest dimension of the hole

Additional Considerations to Minimize EMI

- Minimize exposed center conductor(s) of cables (a cable exiting a conduit looks like an exposed center conductor)
- Minimize inadvertent antennas
- Recognize surge potential of connecting and disconnecting loads to critical buses

Transient Coupling Between Cables

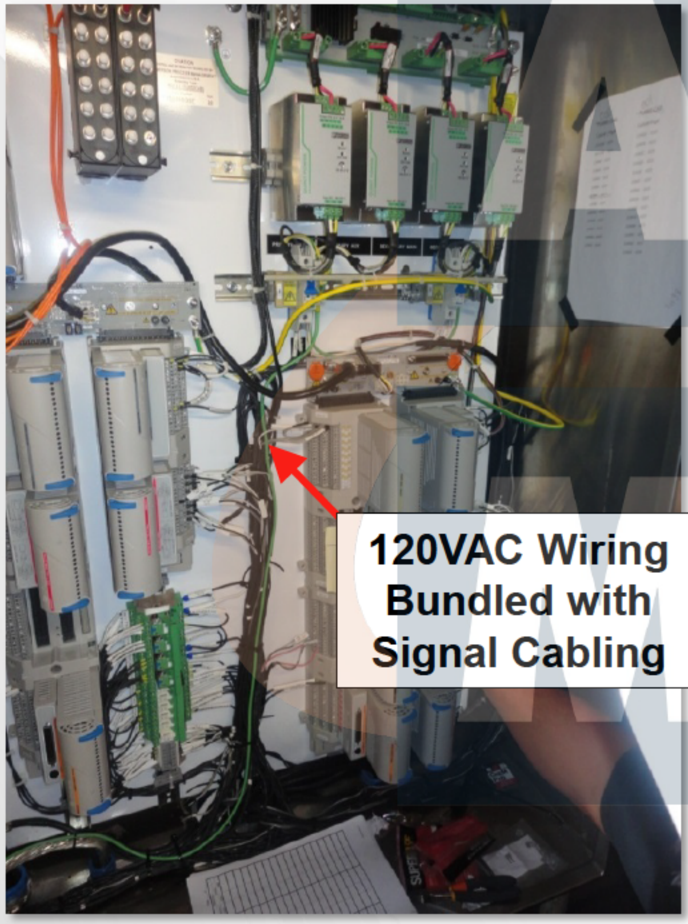
Example of source (600mVp-p) and victim (20mVp-p) from a plant:

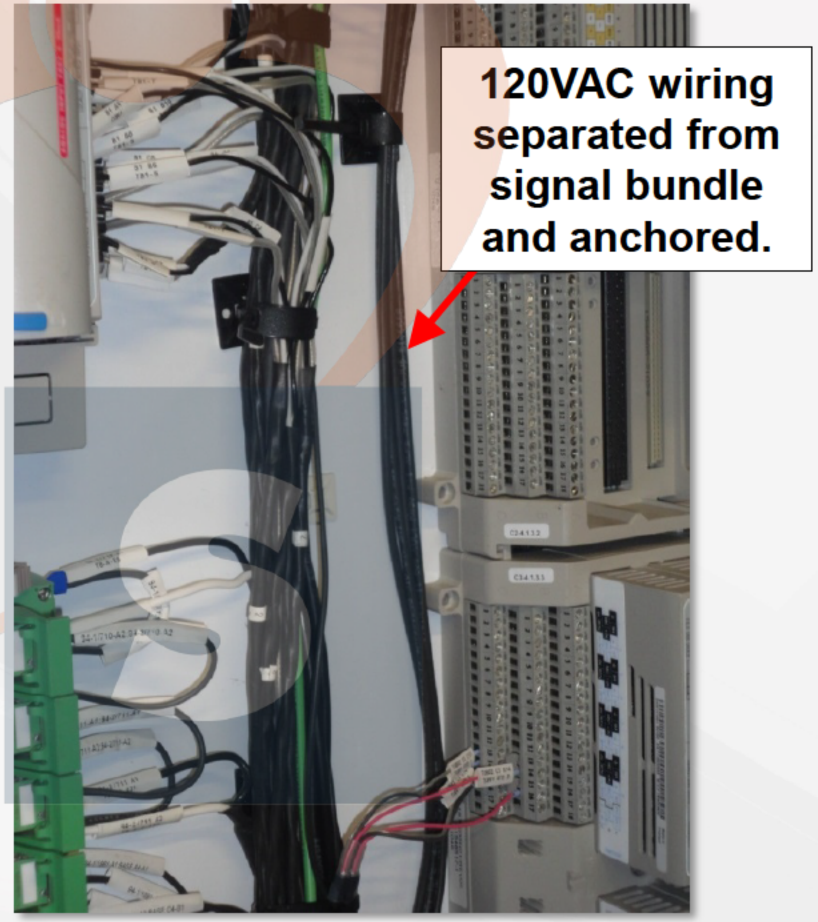


Separating Cables for EMI Reduction

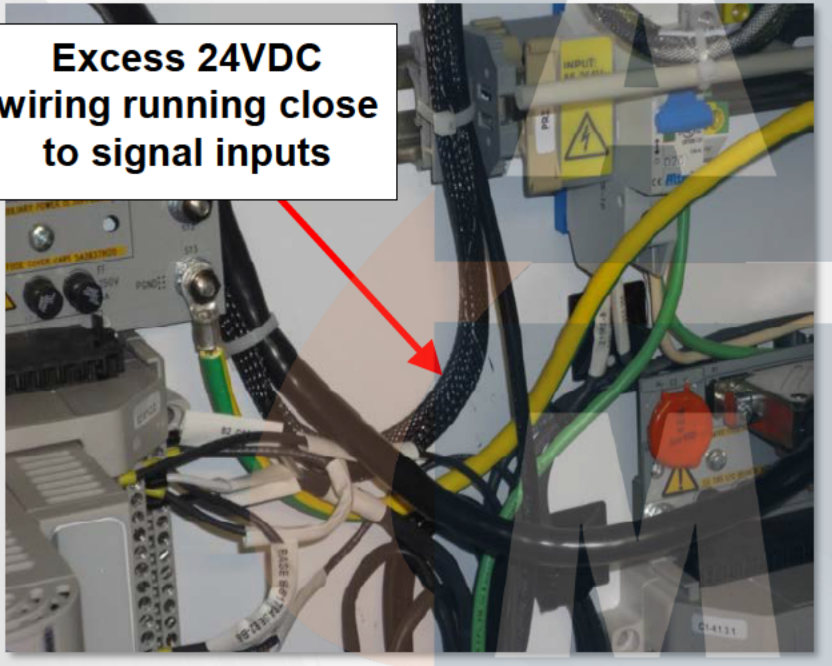
- Separation of cables is effective in reducing electric or magnetic field coupling at lower frequency
- Separation of cables does not significantly affect radiated coupling at higher frequencies
- IEEE 518 and EPRI TR-102323 provide guidance for cable separation

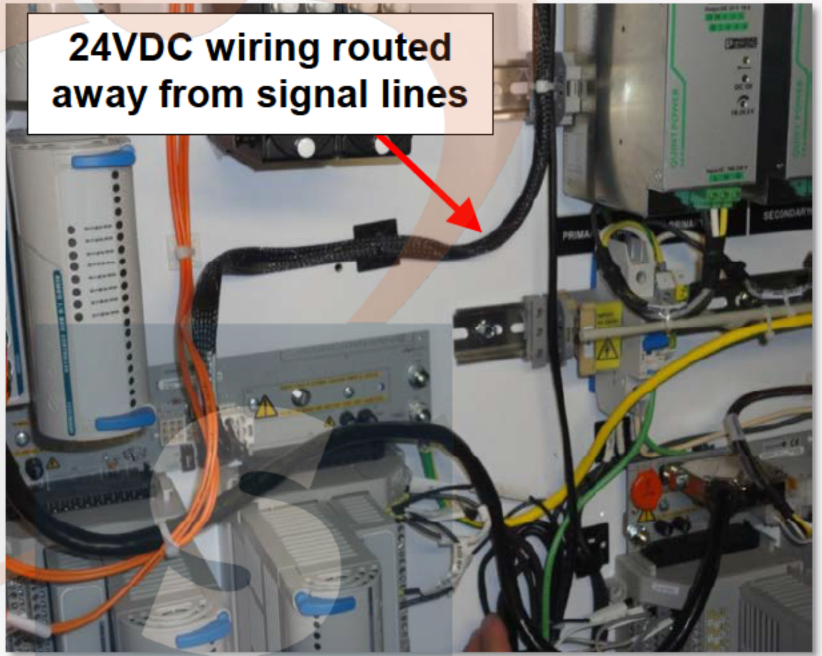
120VAC Power Routing





24VDC Power Routing





Filters Can Prevent EMI

- **Filters can be used as reactive elements to reduce current to a branch circuit or to reduce the voltage to a device as a function of frequency**

- **They do not drain noise to a sump**
  - Reactive components do not dissipate power

Filters Can Selectively Divert Current

- **Unwanted current in a circuit may be eliminated by:**
  - Offering a lower impedance alternate path for the current flow (remember that you must complete a loop)
    - *Difficult to accomplish since current loops tend to be low impedance*
  - Add inductance to block the flow of high frequency EMI currents
  - Add capacitance to shunt EMI voltages/currents

Ferrite Beads

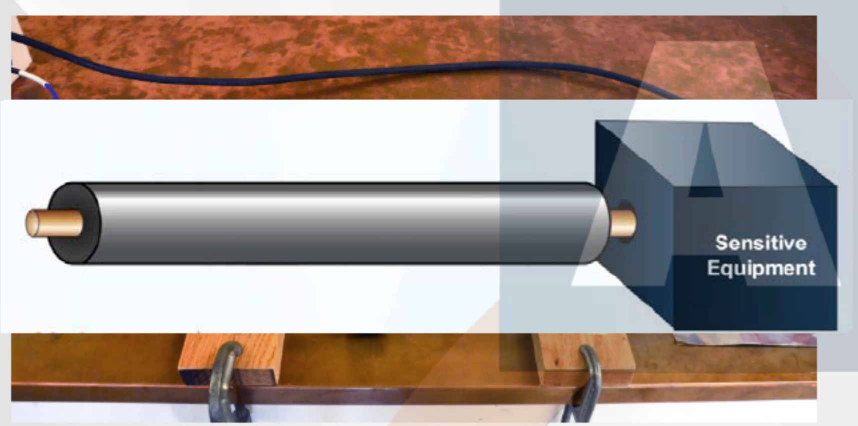
What are Ferrite Beads?

- Ferrites, Ferrite Beads, Ferrite Cores, “Magic Beads”, “Prayer Beads”
- Mixtures of nickel, iron, and zinc oxides
  - Characterized by resistivity and permeability
- Should produce the highest series impedance for the noise frequencies of concern
- Basically, a high series impedance will act to reflect noise away from the circuit you are trying to protect

Ferrite Material Comparison

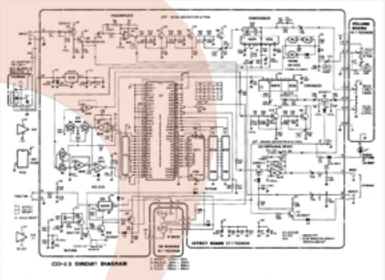
Type	Material	EMI/RFI Suppression Range	Initial Permeability
31	MnZn	1 – 300 MHz	1500
43	NiZn	25 – 300 MHz	800
52	NiZn	200 – 1000 MHz	250
61	NiZn	200 – 2000 MHz	125
75	MnZn	150kHz – 30 MHz	5000
77	MnZn	1 – 10 MHz	2000

Common vs. Differential Mode



Applications of Ferrite Beads

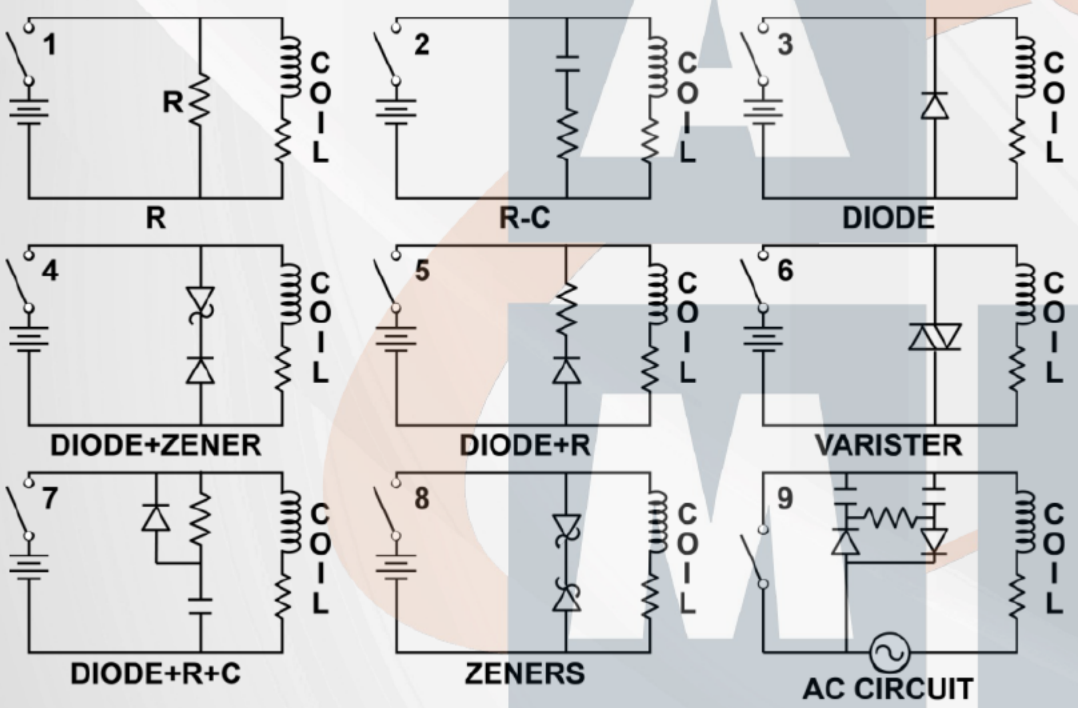
- **Electromagnetic Compatibility**
  - Product Design
  - Minimize Emissions
  - Improve Susceptibility



- **Troubleshooting**
  - Protect poor connectors
  - A ferrite is used as a “band-aid”
  - Rework/replace connectors

Coil Surge Prevention

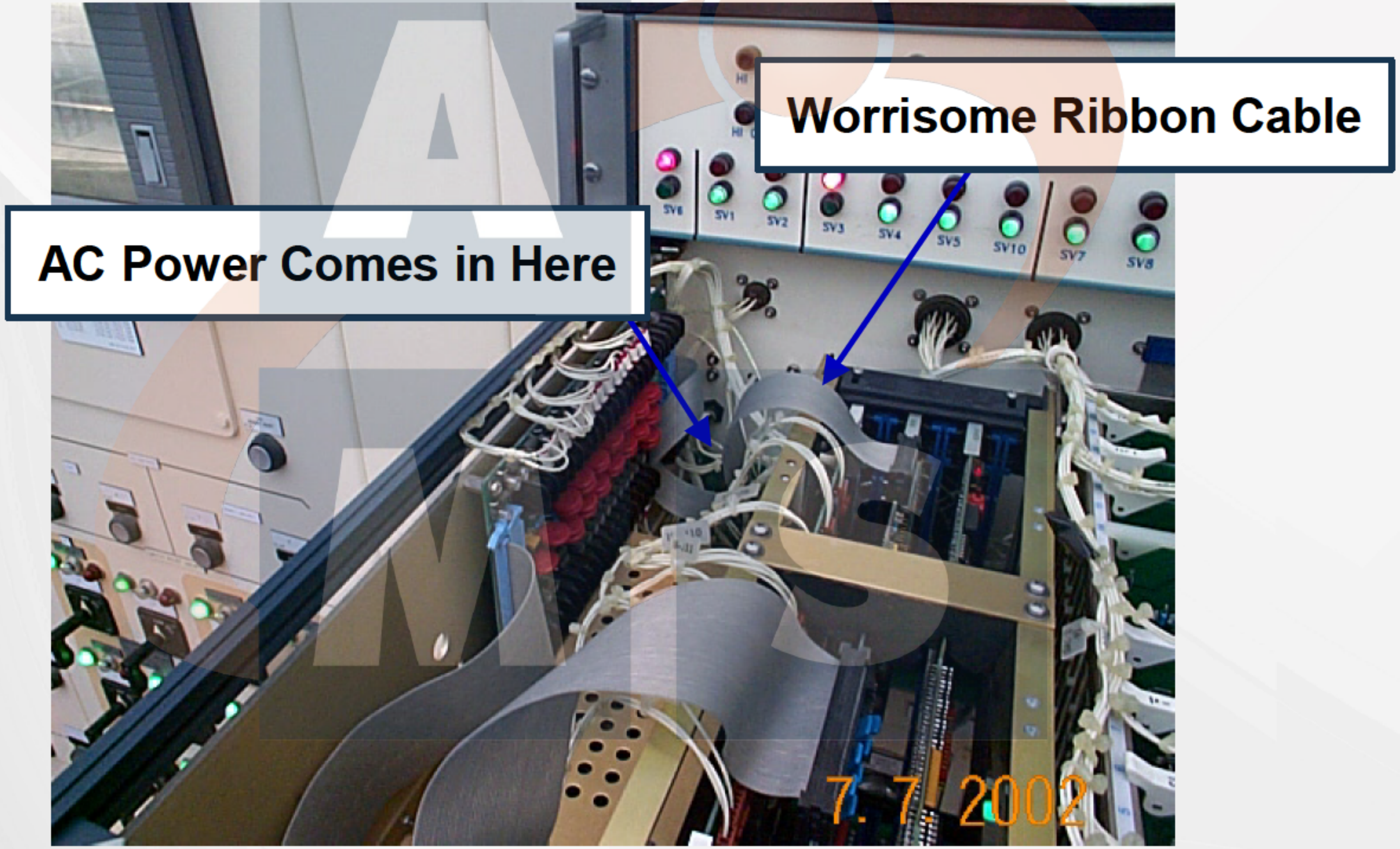
Relay or coil operation can be a major source of EMI transients unless some type of surge suppression is used on the coil.



REF: *Engineer's Relay Handbook, Third edition.* National Association of Relay Manufacturers, Ellcart, Indiana.

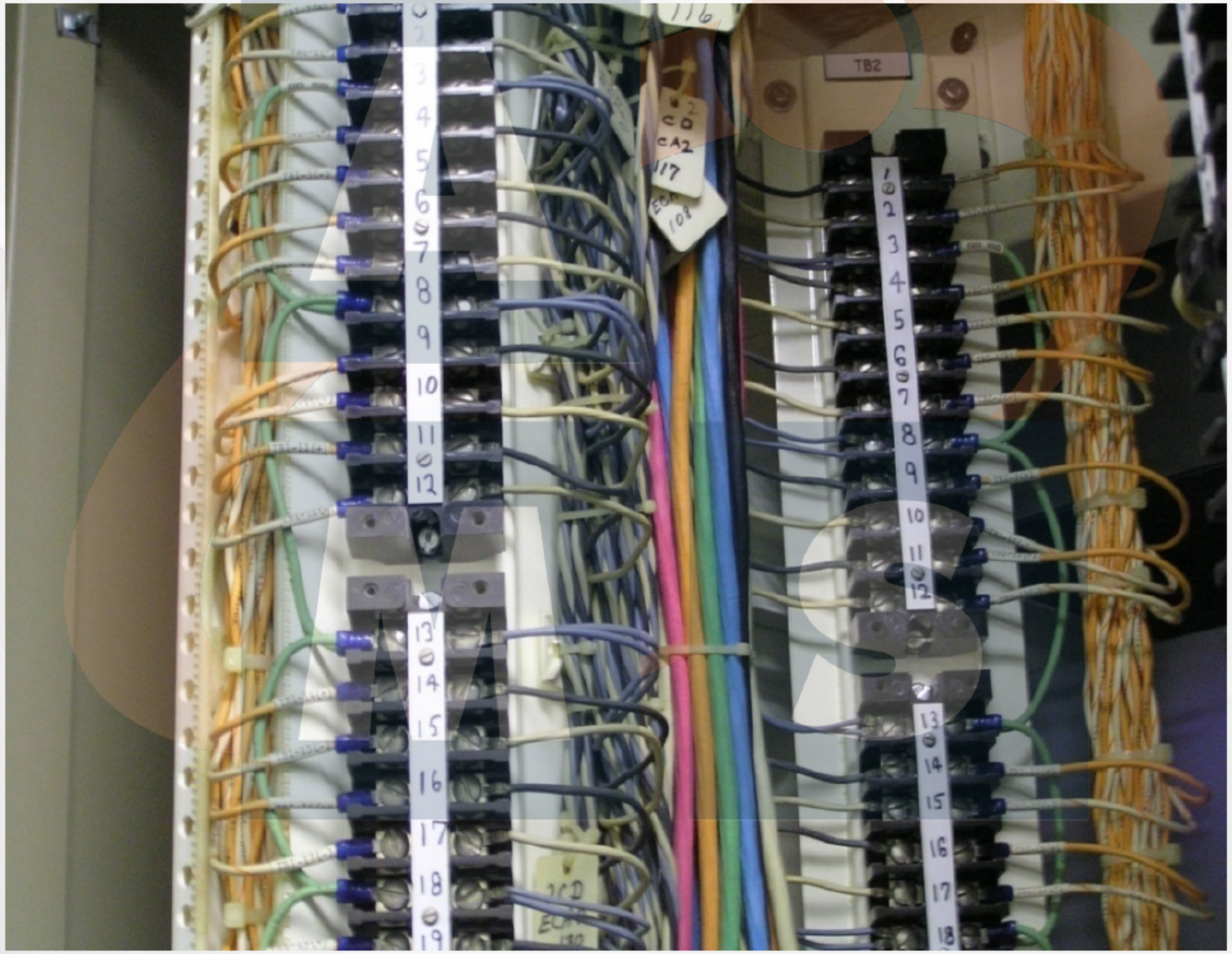
1. Resistor — return path for current from collapsing magnetic field of coil. Keeps voltage from building up. Consumes DC power. Causes longer release time.
2. Resistor/capacitor network — does not consume DC power but still causes longer release time. Need large capacitor.
3. Diode — excellent suppressor. Polarity, sensitive. Increases release time.
4. Diode plus zener — excellent suppressor. Polarity, sensitive. Does not affect release time or coil life.
5. Diode plus resistor — resistor can adjust release time.
6. Varister — excellent suppression. Draws small DC current normally. Conducts on surge voltage. Proper selection does not affect release time.
7. Resistor plus capacitor plus diode — can be excellent suppression without affecting release time. Must be selected for coil.
8. Back to back zener — excellent suppression. Not polarity sensitive. Does not affect release time.
9. AC coil network.

Poor AC Power Entry for Microprocessor



Power Leads Twisted in Wire Bundle - Good

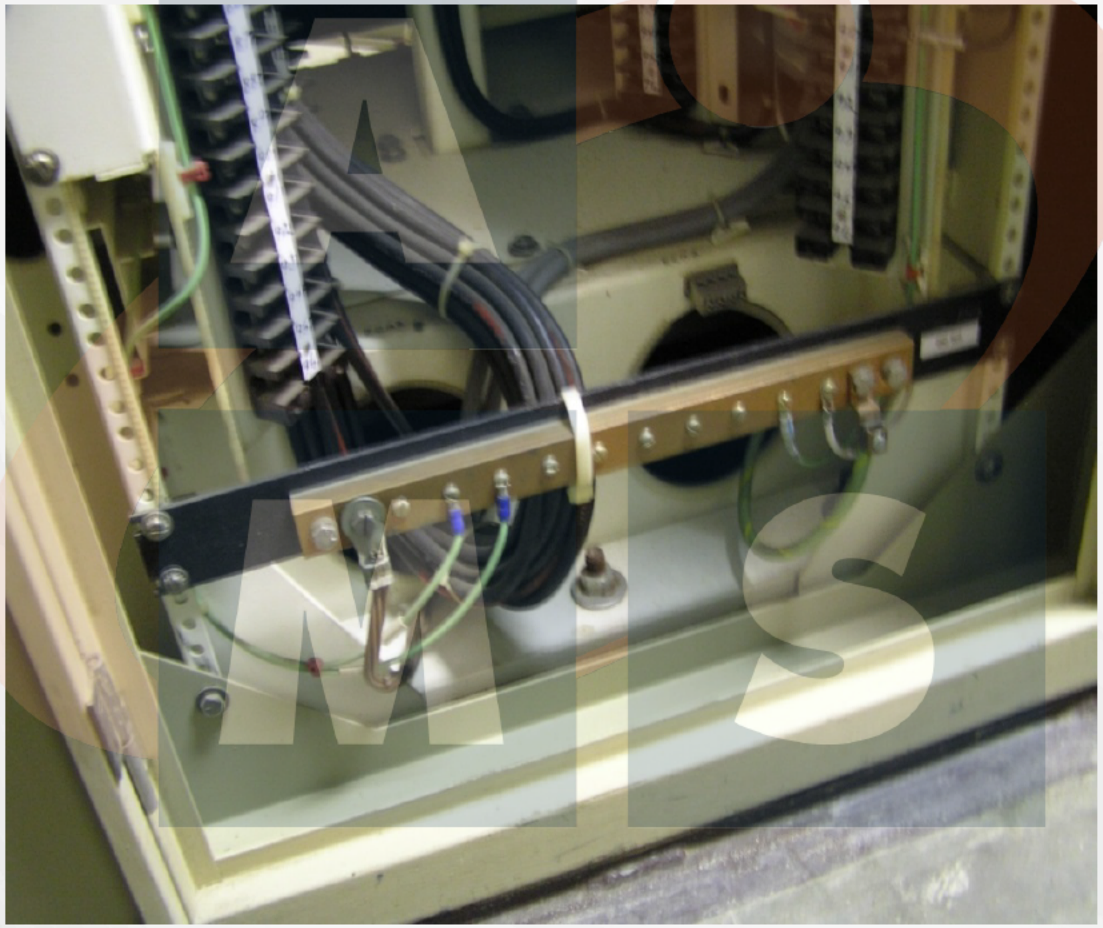
Shields Have Been Removed at Bottom of Cabinet - Poor



Ground Wire Bonded to Cabinet — Good & Bad

I/O Cables to Cabinets Become Antennas — Poor

Ground Bus Isolated from Cabinet - Poor



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Thank You

Questions?