INNOVATING NUCLEAR TECHNOLOGY

ANALYSIS AND MEASUREMENT SERVICES CORPORATION

Electromagnetic Coupling Mechanisms

Instrumentation and Control Testing and Troubleshooting Course for TVA

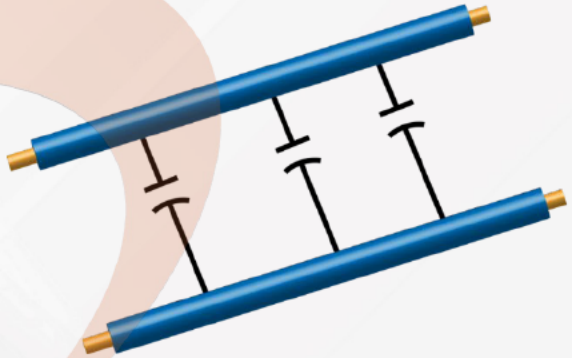
Presentation Overview

- Describe the four basic ways circuits are electrically coupled
- Define signal ground loop and evaluate a circuit to determine if a signal ground loop exists
- Analyze a circuit to determine if electric field or magnetic field coupling could be a problem
- Specify proper shielding for electric field interference
- Specify proper actions to eliminate magnetic field interference

EMI Coupling Mechanisms

Four types of basic coupling problems

- **Conductive interference**
  - Sharing physical connections



- **Electromagnetic interference**
  - Electric fields
  - Magnetic fields
  - Plane waves

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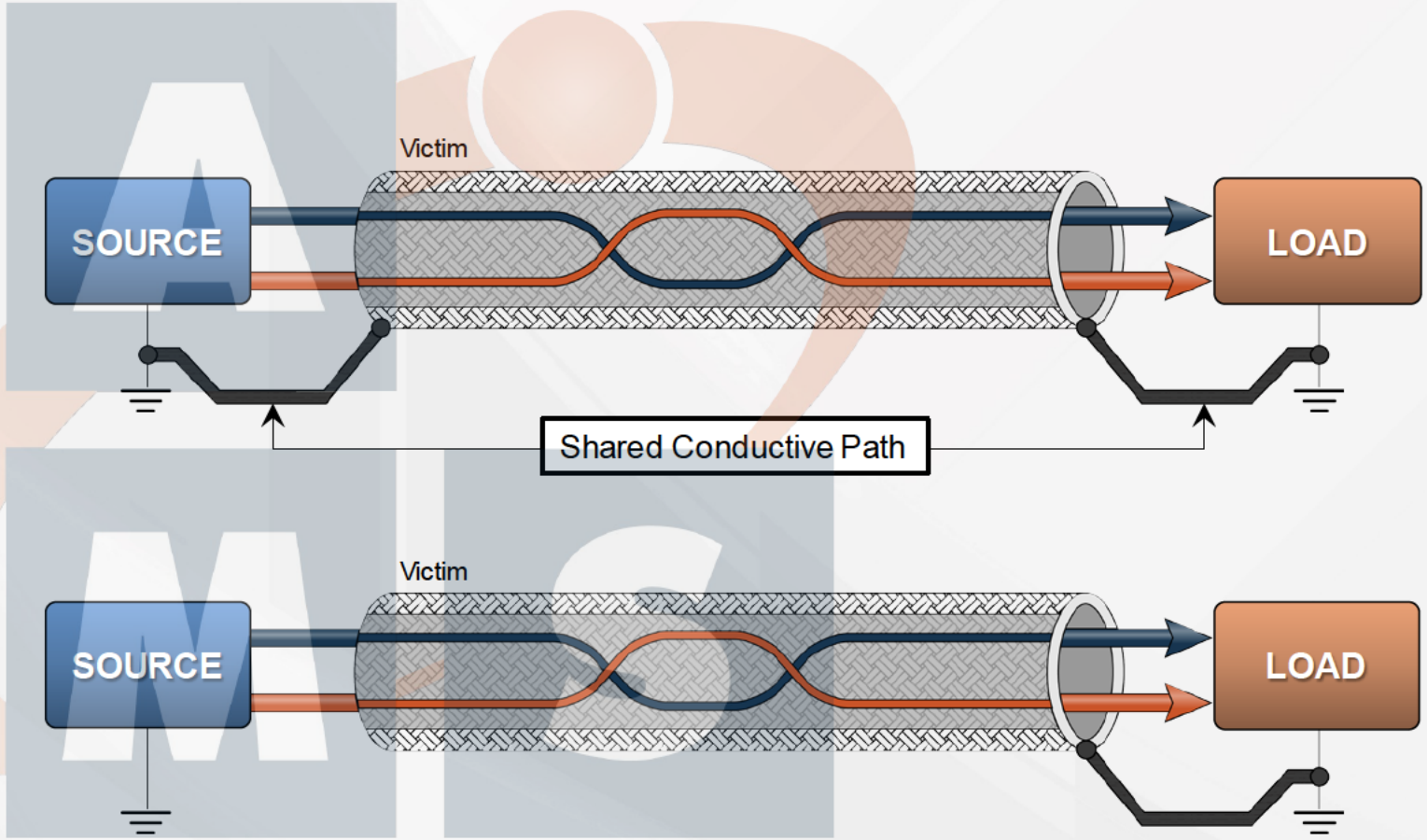
Conductive Coupling

- **Conductive coupling occurs when two or more circuits share the same signal/return conductive path.**
  - Ground plane/ground loop



Conductive Coupling Consequences

- **Conductive coupling causes current to flow in part of a victim circuit**

- **Victim perspective**
  - For a current sensing circuit, unless the aggressor current flows in the same path, it will not be a problem
  - For a voltage sensing circuit, any voltage drop due to current flow on a circuit conductor will add to the source voltage and create an error

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Electric Field (Capacitive) Coupling

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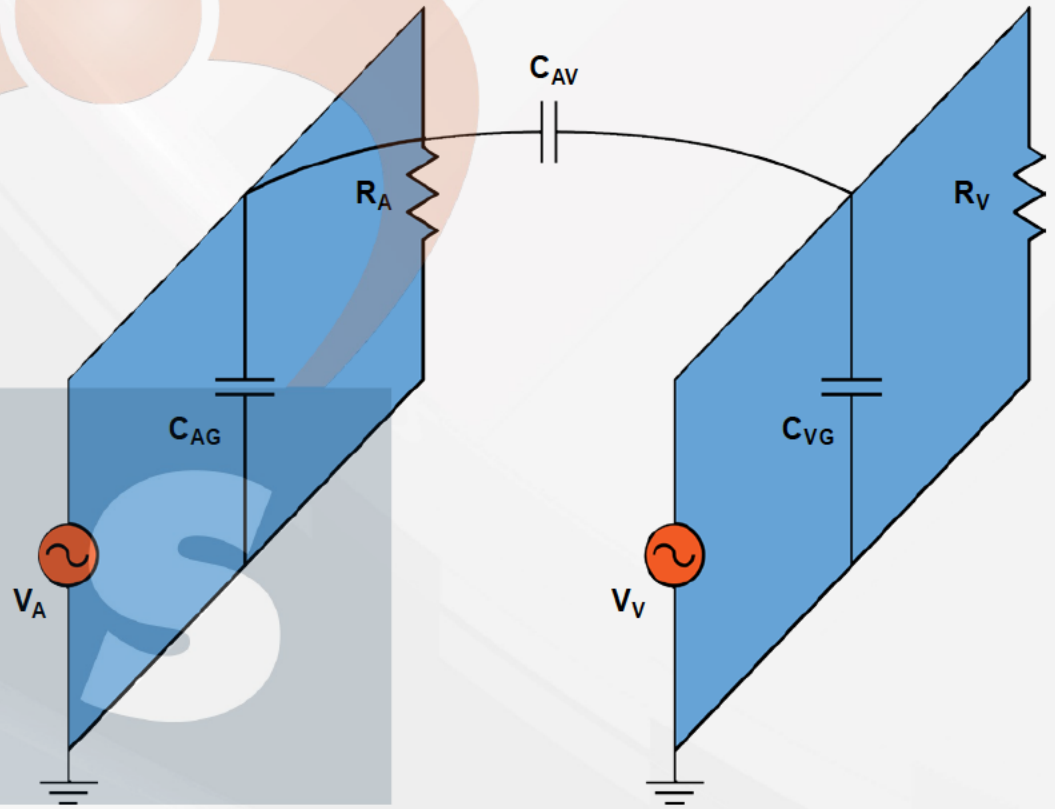
Electric Field Coupling

- Electric fields are fields generated between two dissimilarly charged points or conductors
- Electric fields couple via capacitance between parallel wires
- Can induce current on nearby conductors
- Typically found in circuits with:
  - High voltage/Low current
  - High impedance
  - This phenomenon generally is encountered in closely spaced (near field) situations



Decreasing Capacitive Coupling

1. Reduce source voltage and/or frequency

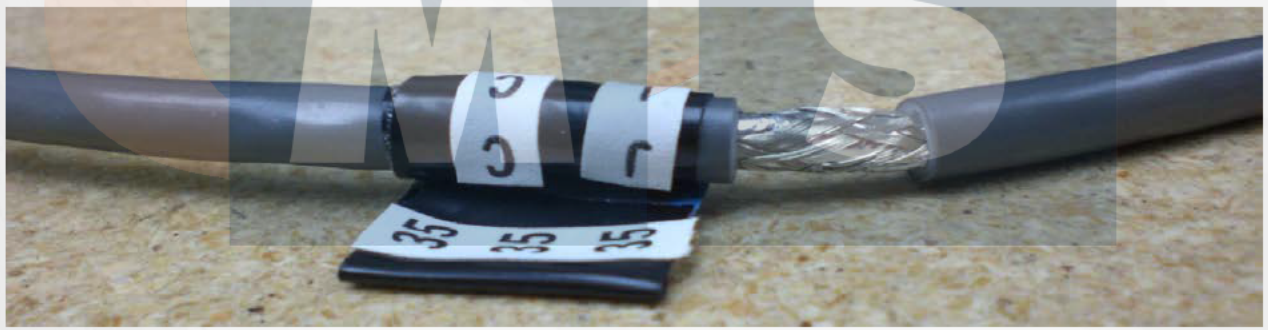
2. Lower victim circuit impedance

3. Reduce capacitance between circuits
   - Separation, Orientation, Length and Shielding

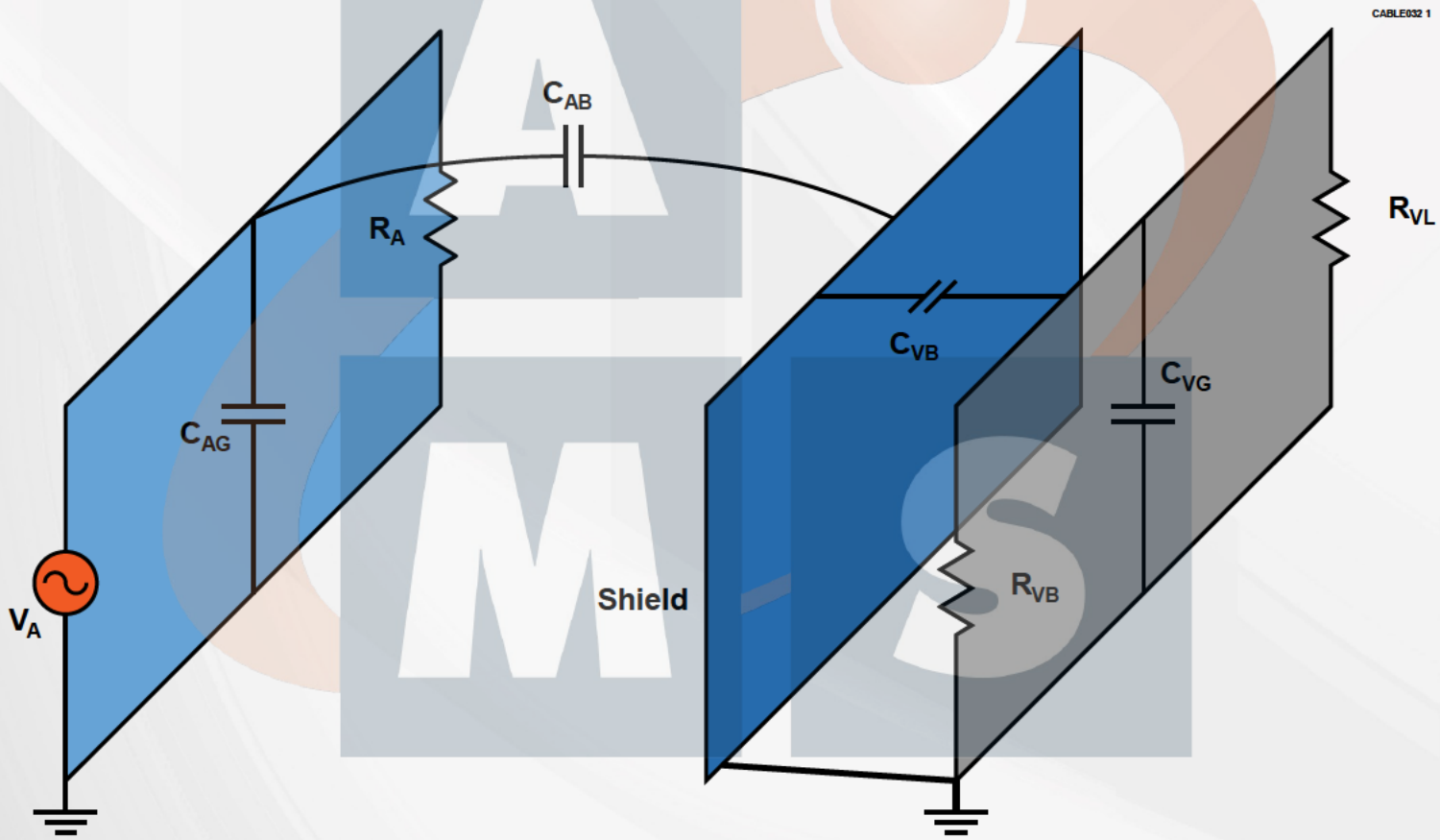
Electric Field Shielding

- **Surround each circuit with conductive material and connect to circuit common (ground)**
  - Or insert conductive material shield between circuits, similarly “grounded”.

- **Twisting circuit conductors together does not help significantly**

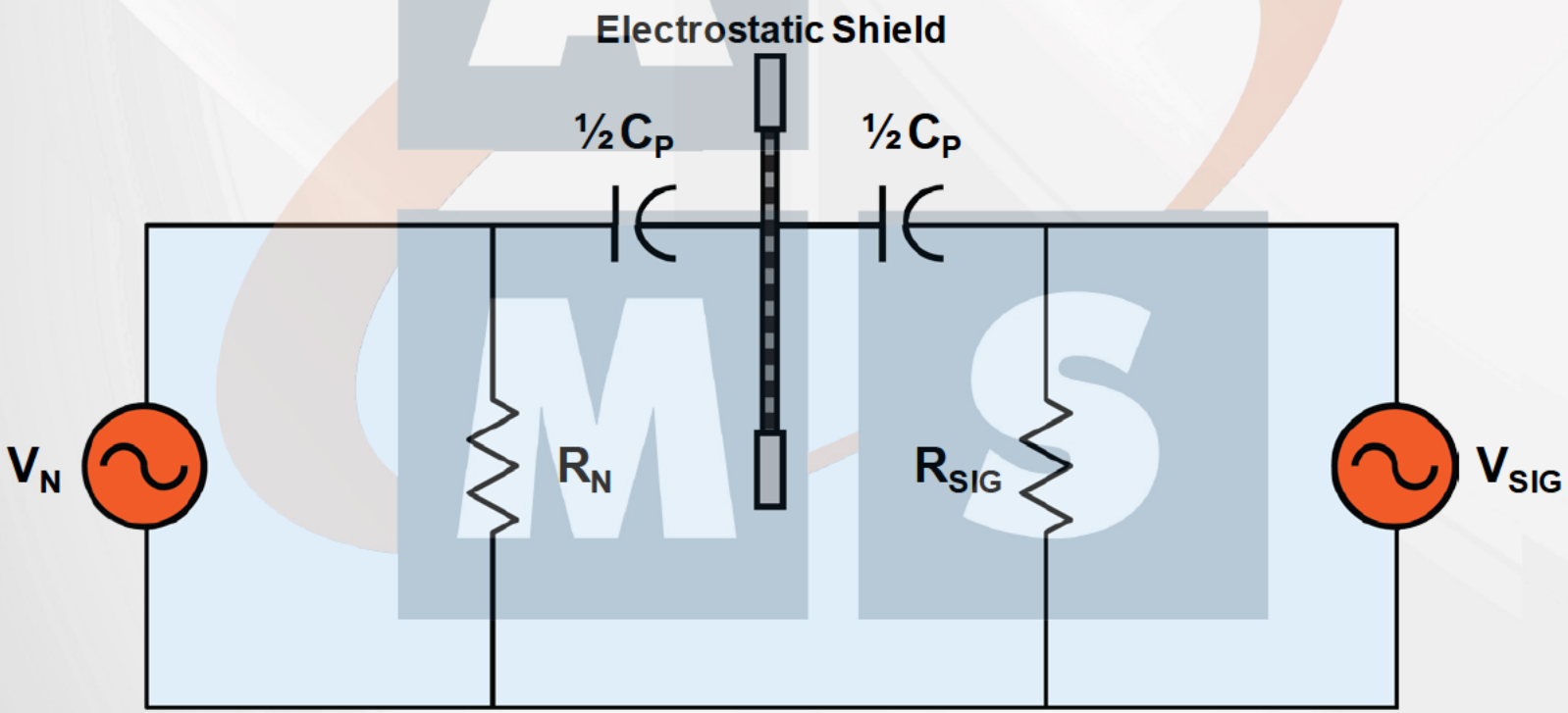


Low Frequency Electric Field (Capacitive) Shield



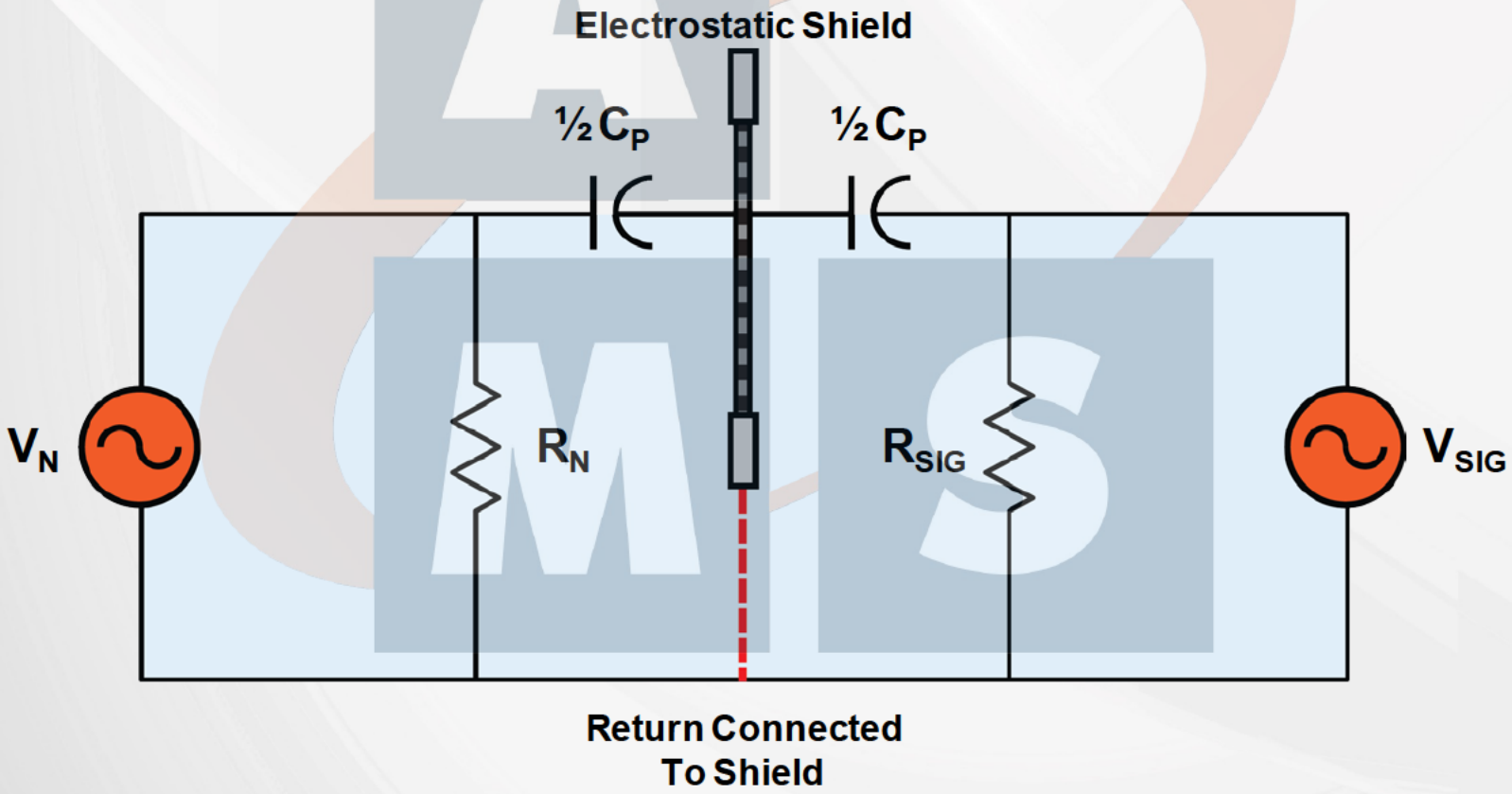
Improper Shielding

Installing conductive shield between two circuits does not eliminate coupling.



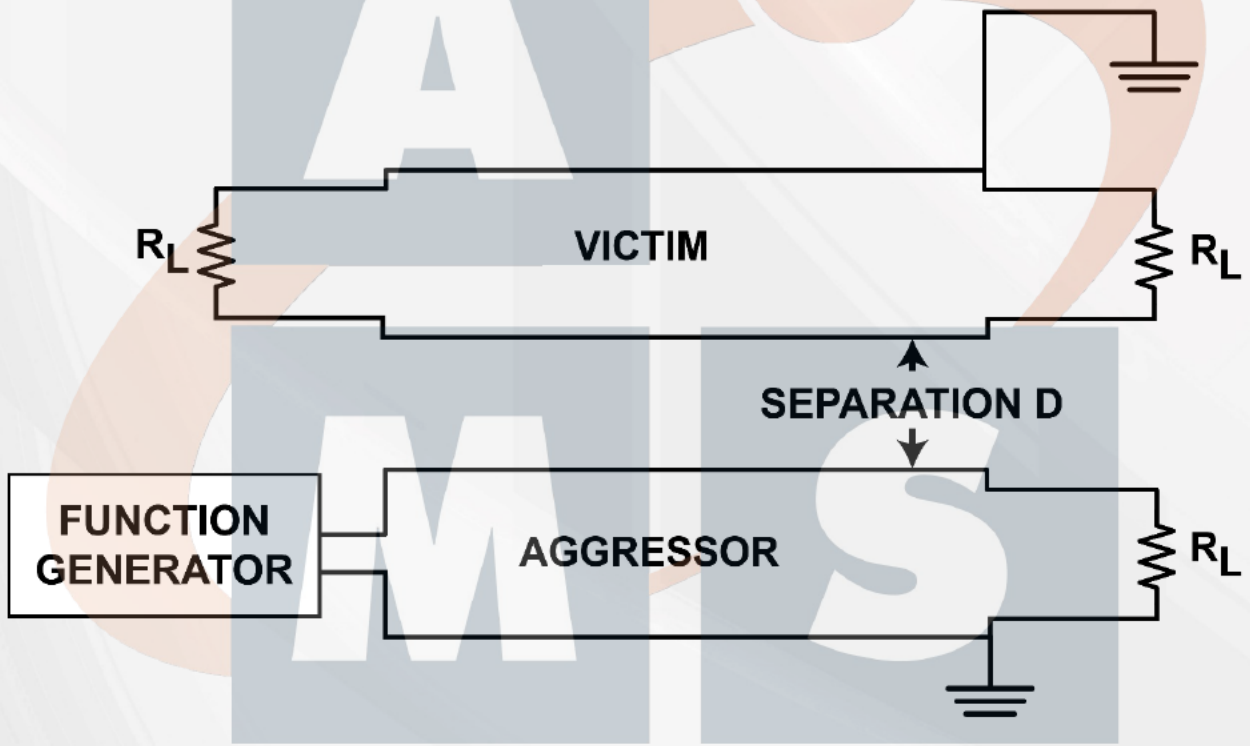
Proper Grounding of Shield

Any conductive plate connected to circuit common limits coupling.



Experiment: Electric Field Coupling

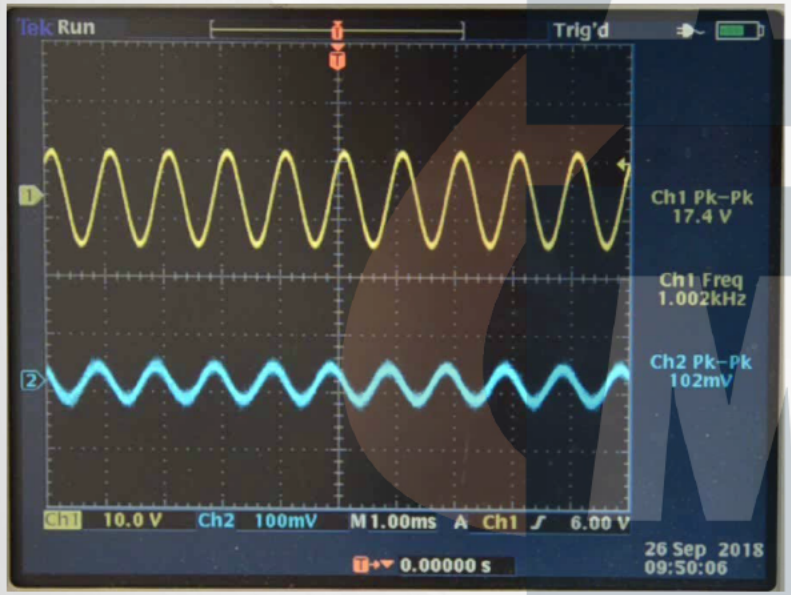
Create two high impedance circuits:



What is the result of the victim circuit as seen on the oscilloscope?

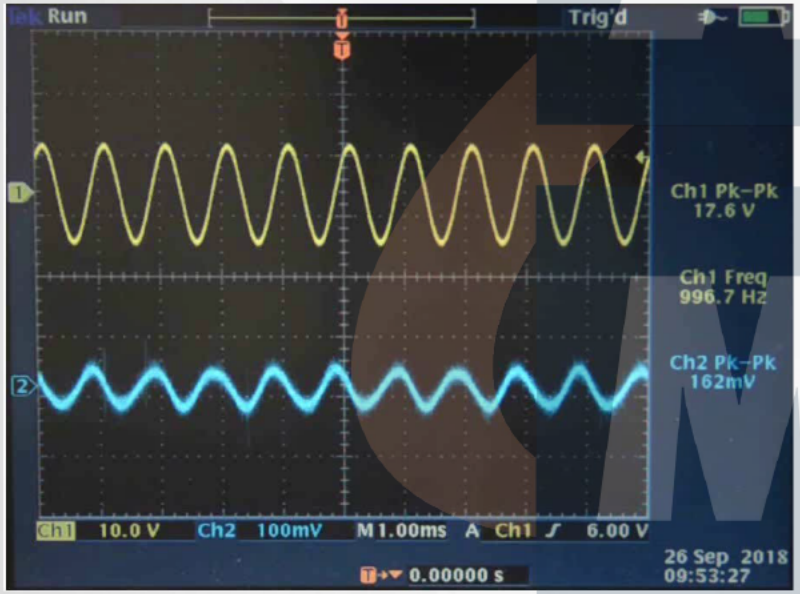
Electric Field Coupling

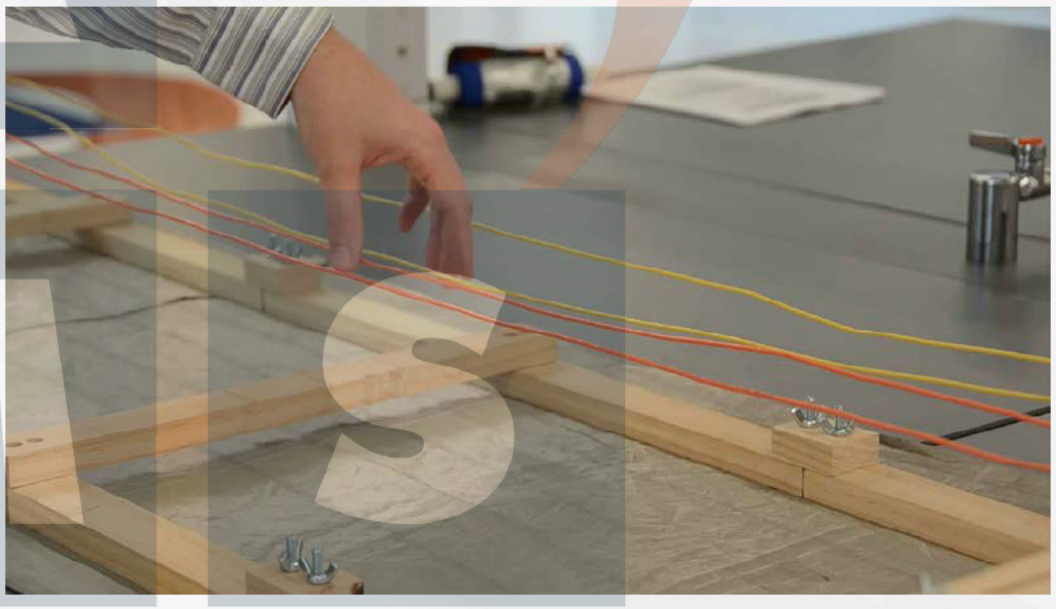
Increasing Frequency



Electric Field Coupling

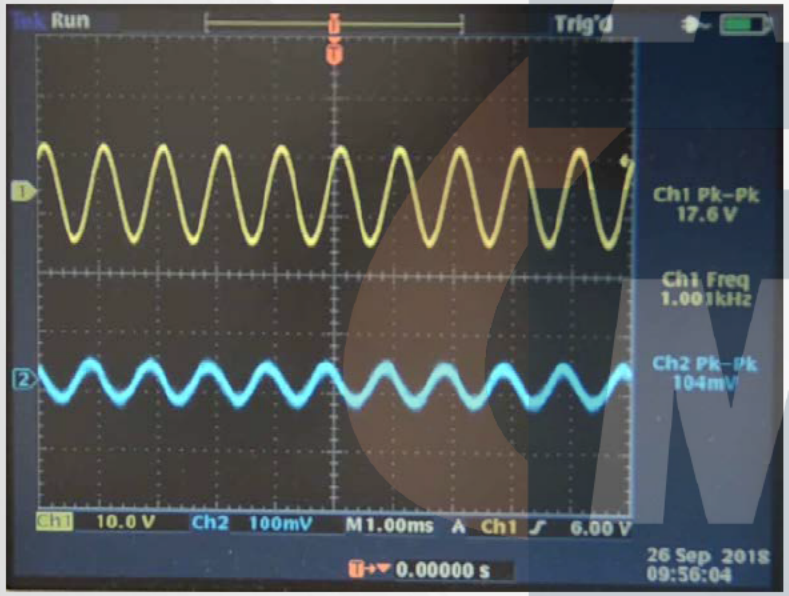
Distance

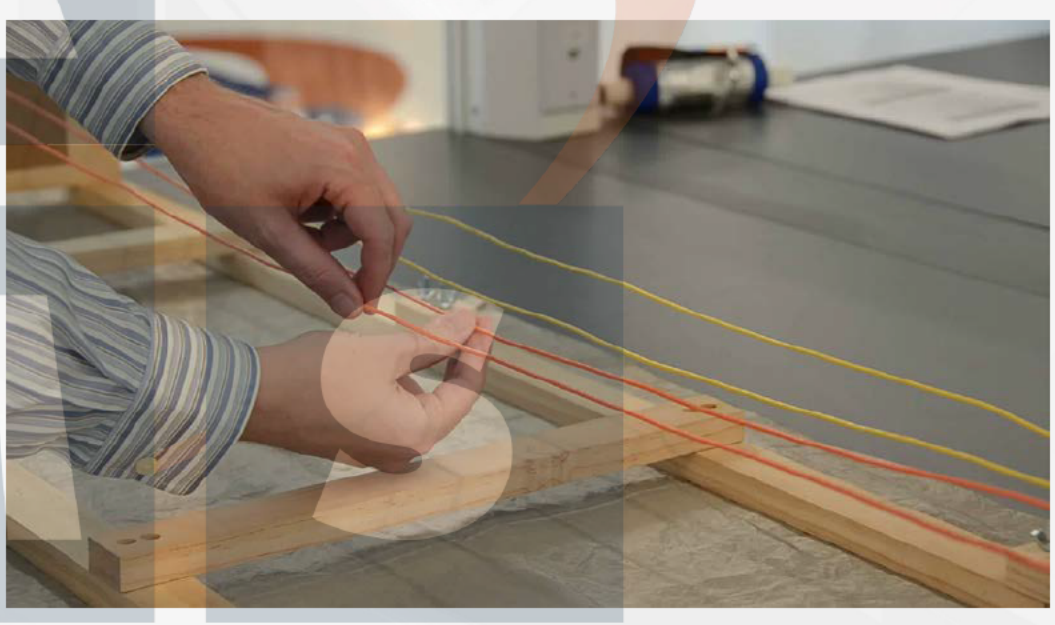




Electric Field Coupling

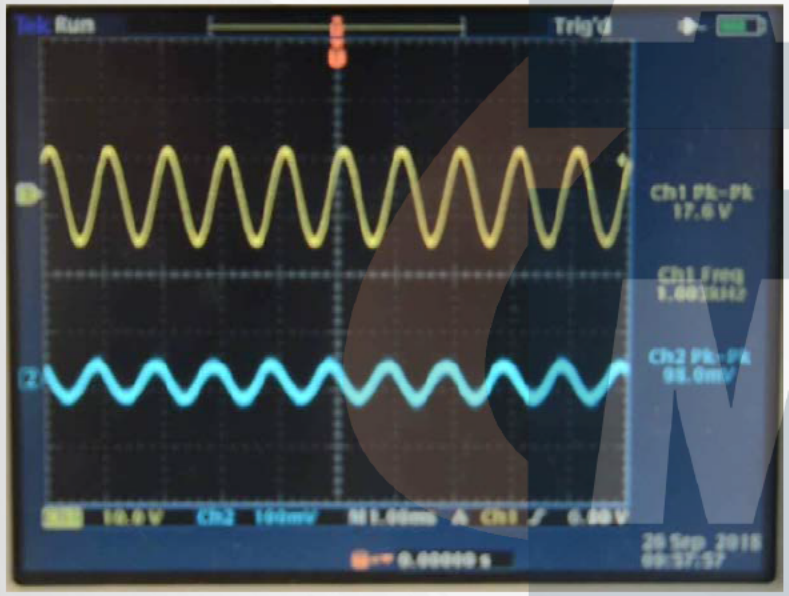
Twisted

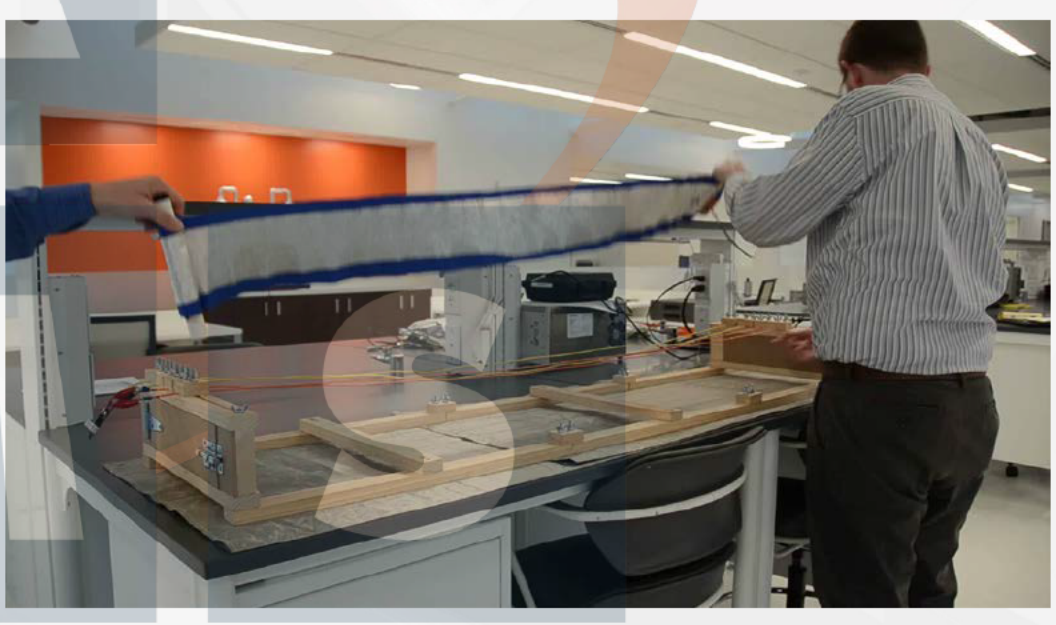




Electric Field Coupling

Shielding





Capacitive (E-Field) Coupling Summary

- Affects high impedance circuits
- Coupling increases with frequency
- Coupling decreases with distance
- Twisting individual circuit conductors does not have a significant impact
- Proper shielding is the best preventative measure

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Magnetic Field (Inductive) Coupling

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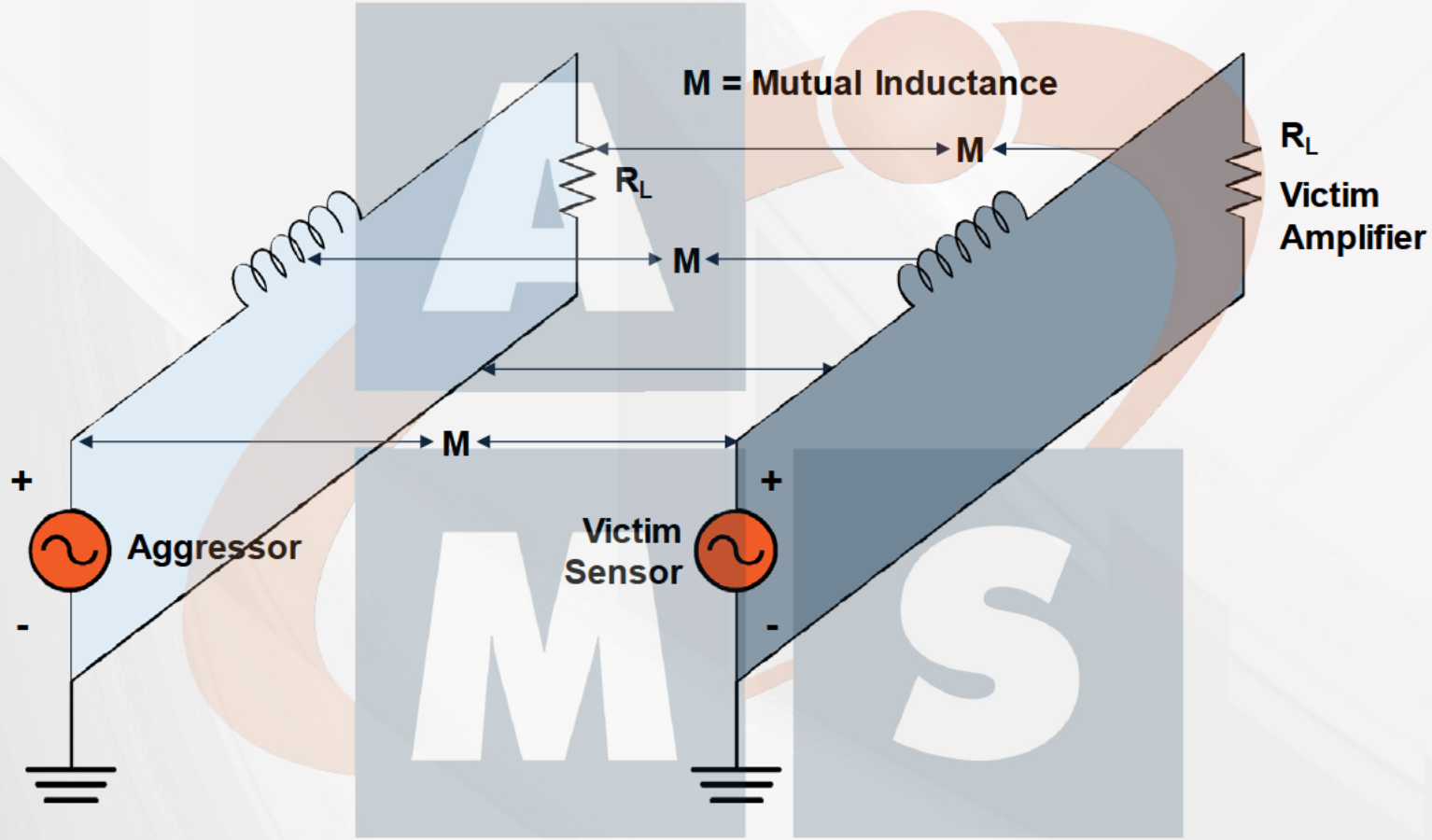
Magnetic Fields

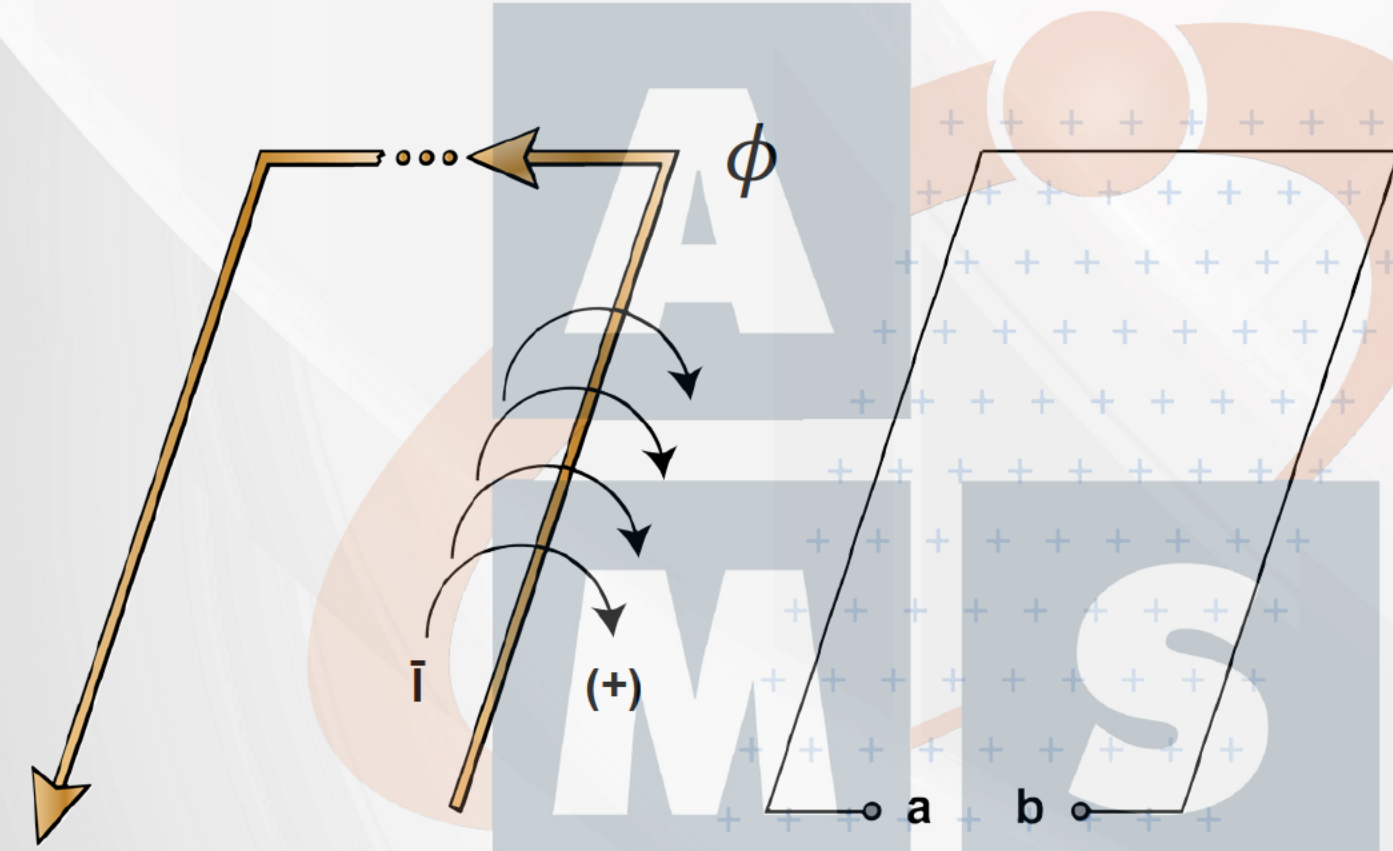
- **Circuits with Significant Magnetic Fields**
  - High Current
  - Low Impedance
- **Magnetic field is caused by charge (current) flow**
- **This phenomenon generally is encountered in closely spaced installations - relates to near field**

Inductively Coupled Circuits



Mutual inductance exists between each wire and every other wire.

Single Wire Aggressor



Single Wire Aggressor

Victim

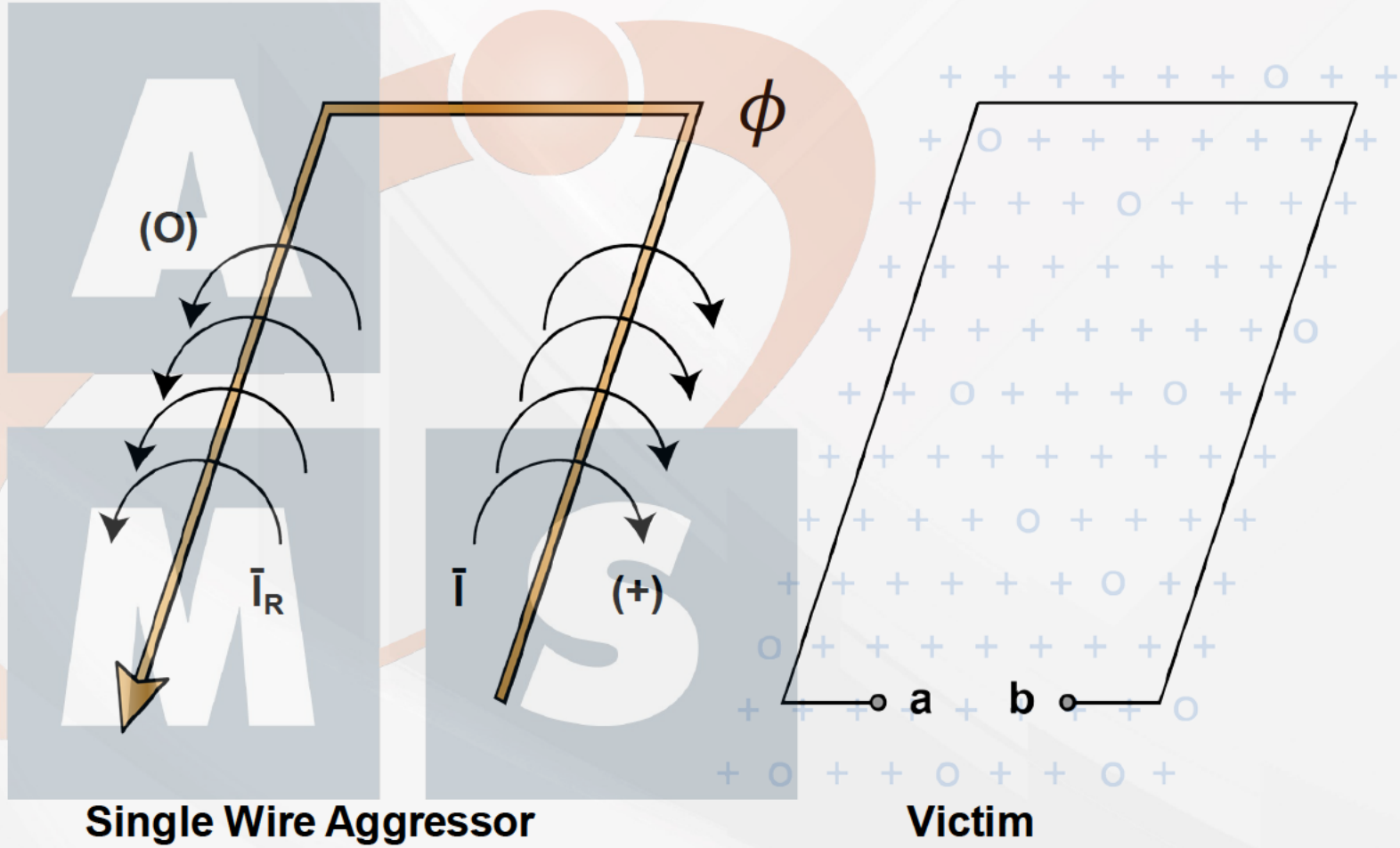
$$E_{a-b} = N\frac{d\phi}{dt}$$

N = 1 Turn

ϕ is proportional to loop area

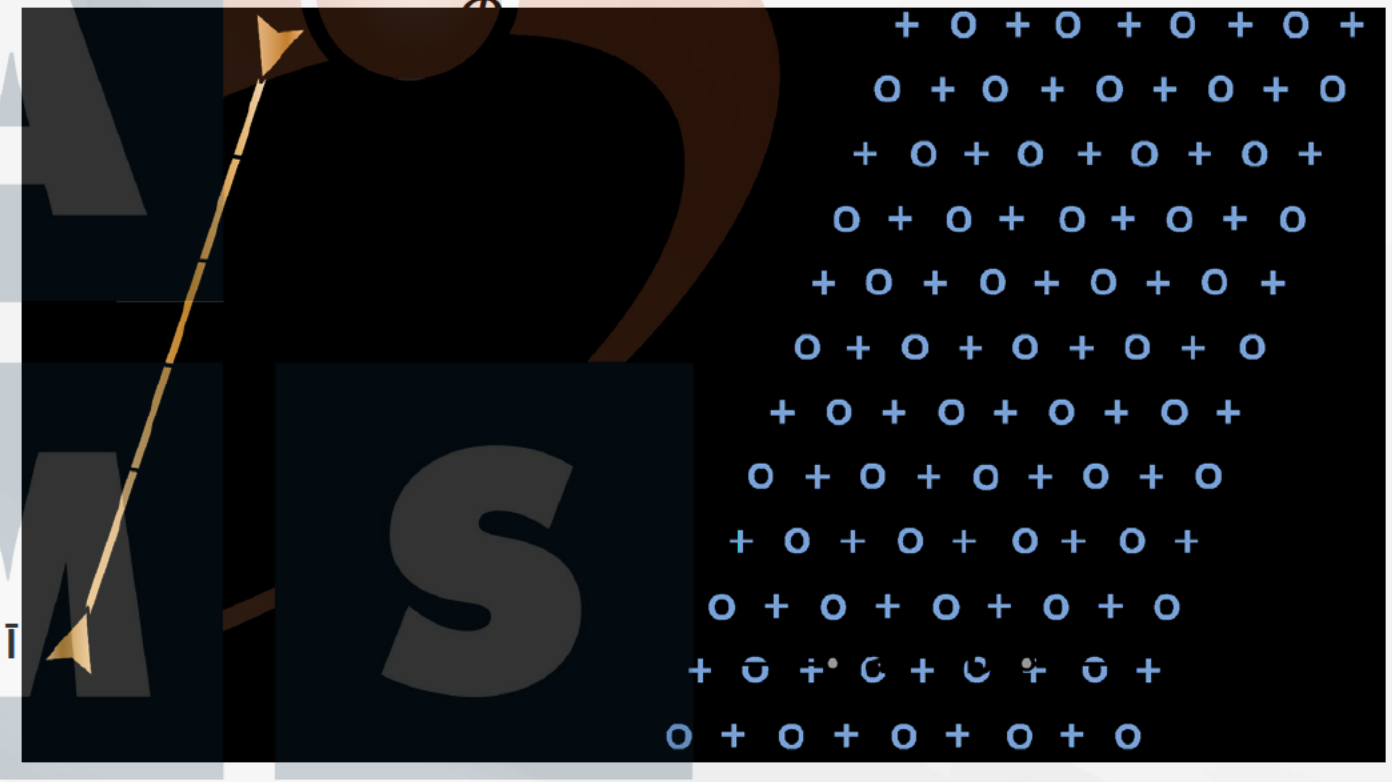
Two-Wire Aggressor Circuit

Net Flux in Loop Decreases as Return Current Conductor is Brought Closer.



Aggressor with Zero Loop Area

Net Flux is Zero when Return Current Conductor Occupies Same Space as Signal Conductor.

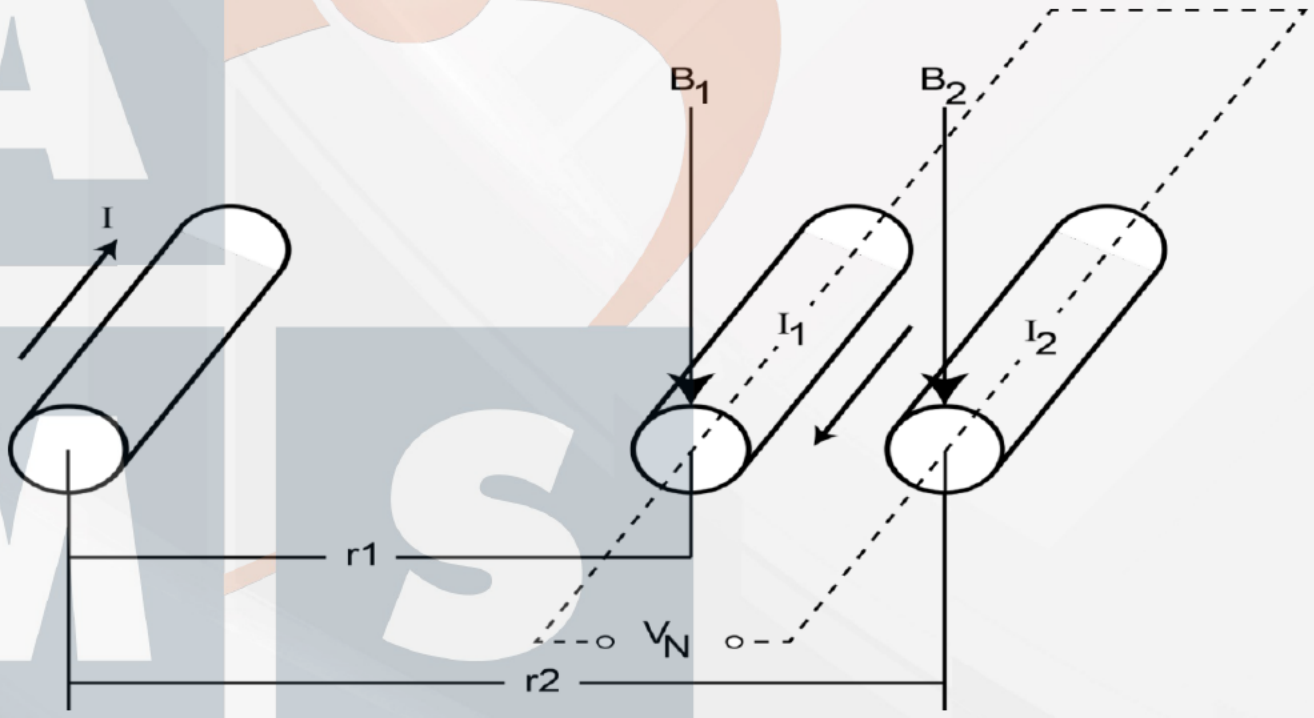


Single Wire Aggressor

Victim

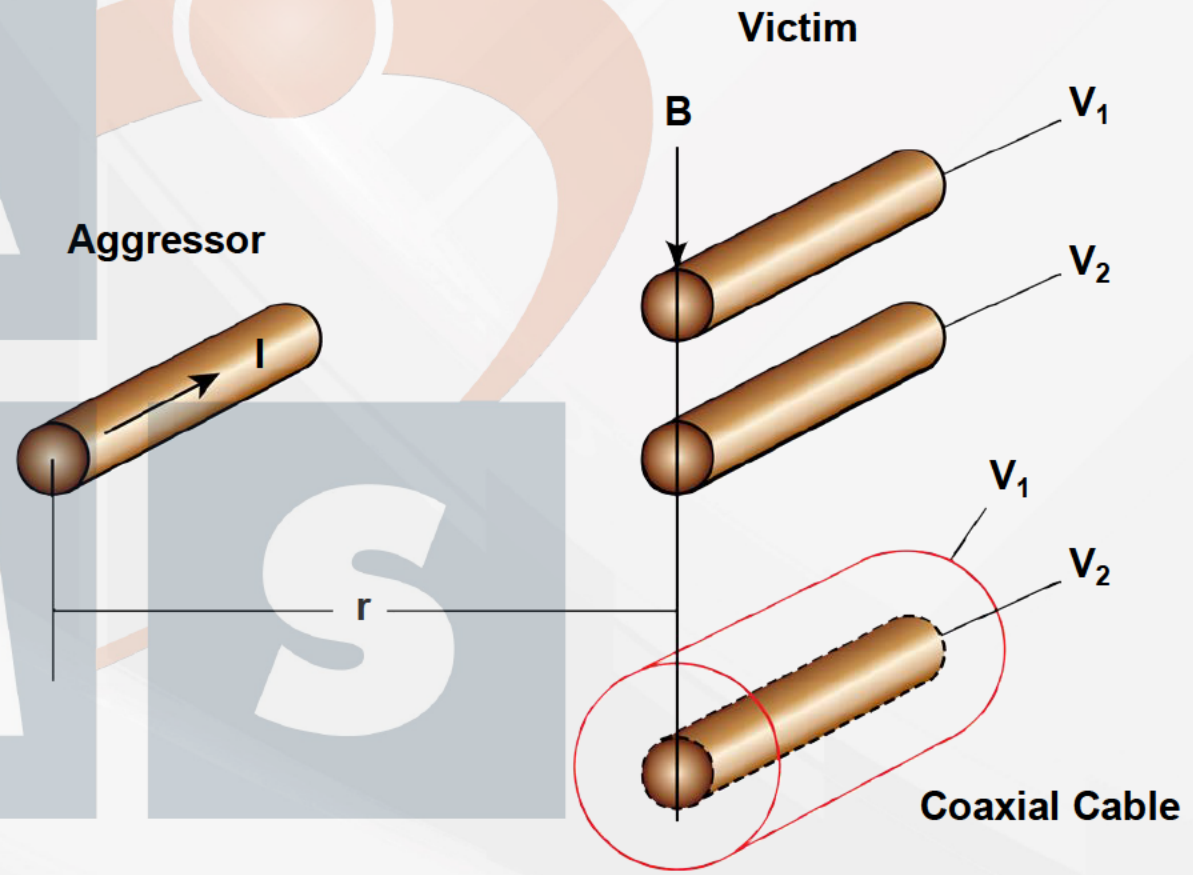
Maximizing EMI Voltage in a Victim Circuit

Induce Different Voltages in Two Separate Victim Conductors, Creating Net Voltage in Loop.

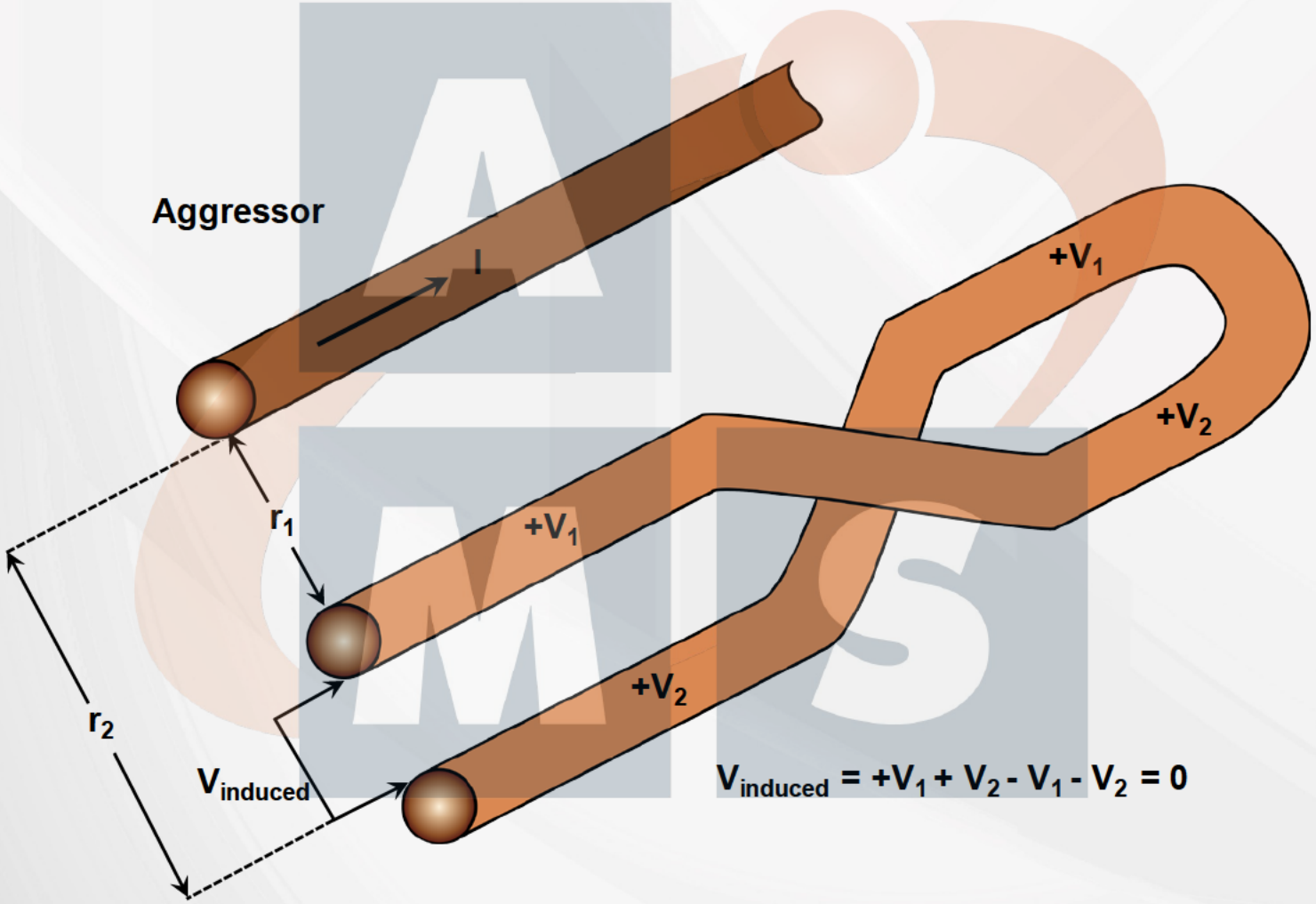


Minimizing Voltage in a Victim Circuit

Induce Identical Voltages in Victim Conductors and Induced Voltage in Loop will be Zero

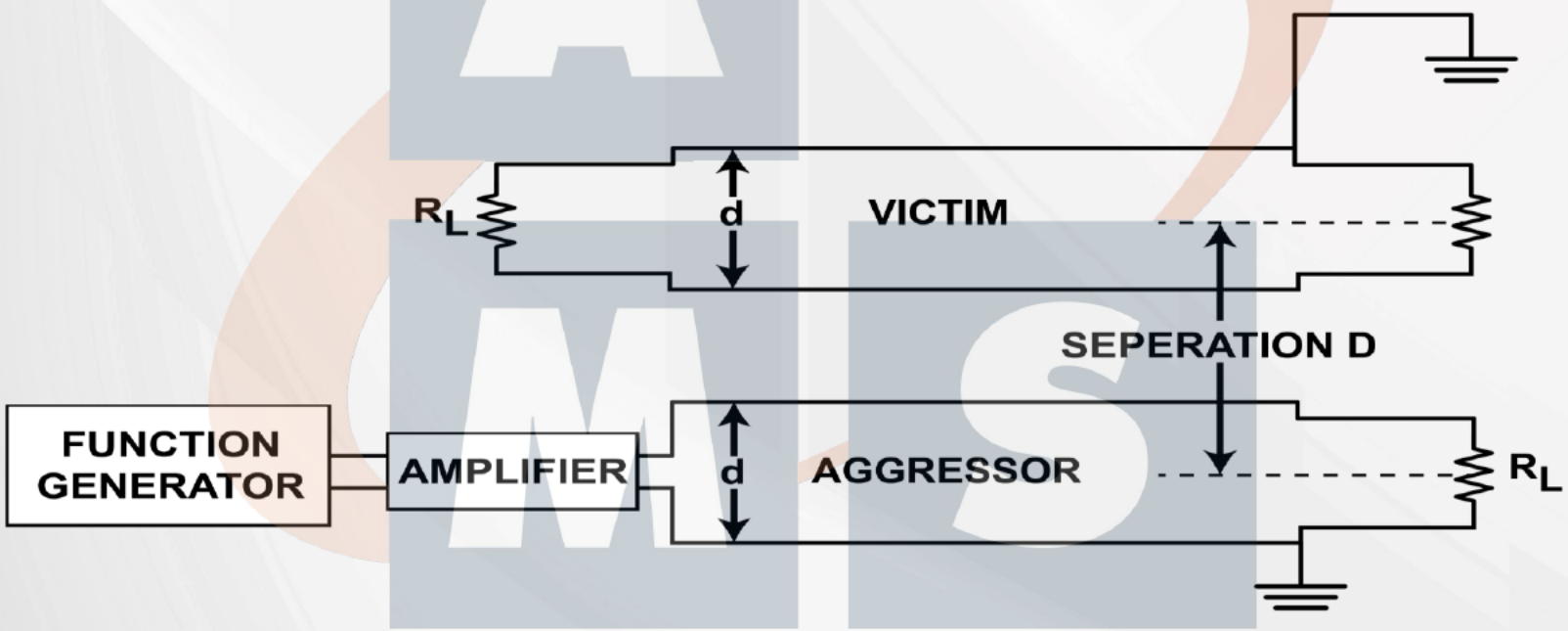


Twisting Victim Conductors Together Nulls Out Induced Voltage



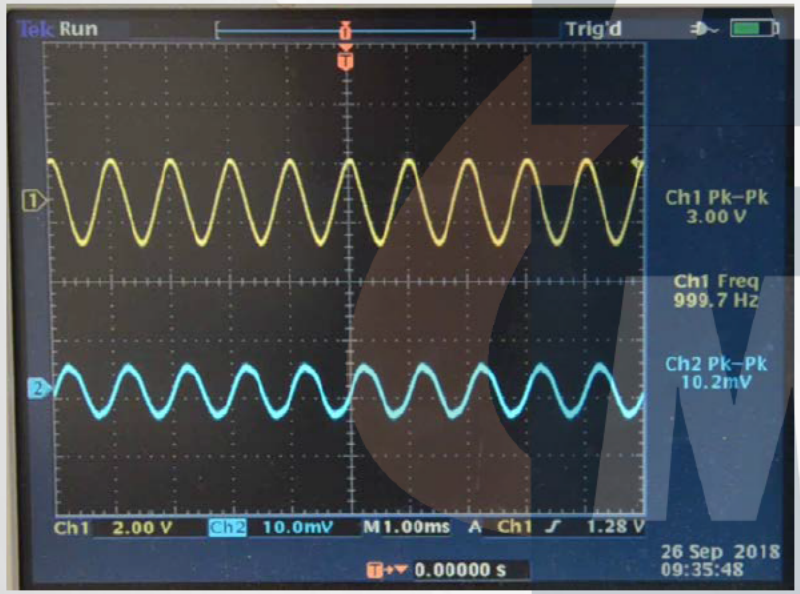
Experiment: Inductive (Magnetic Field) Coupling

Create two low-impedance circuits:



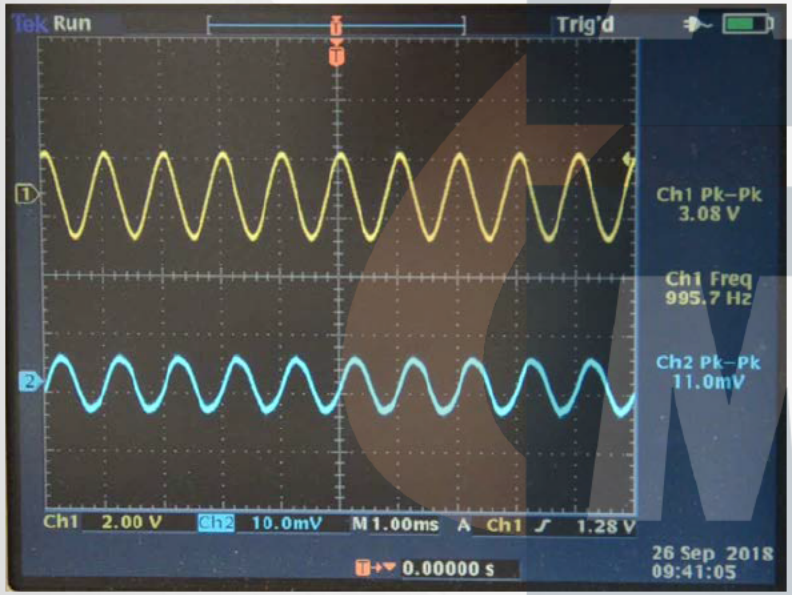
Magnetic Field Coupling

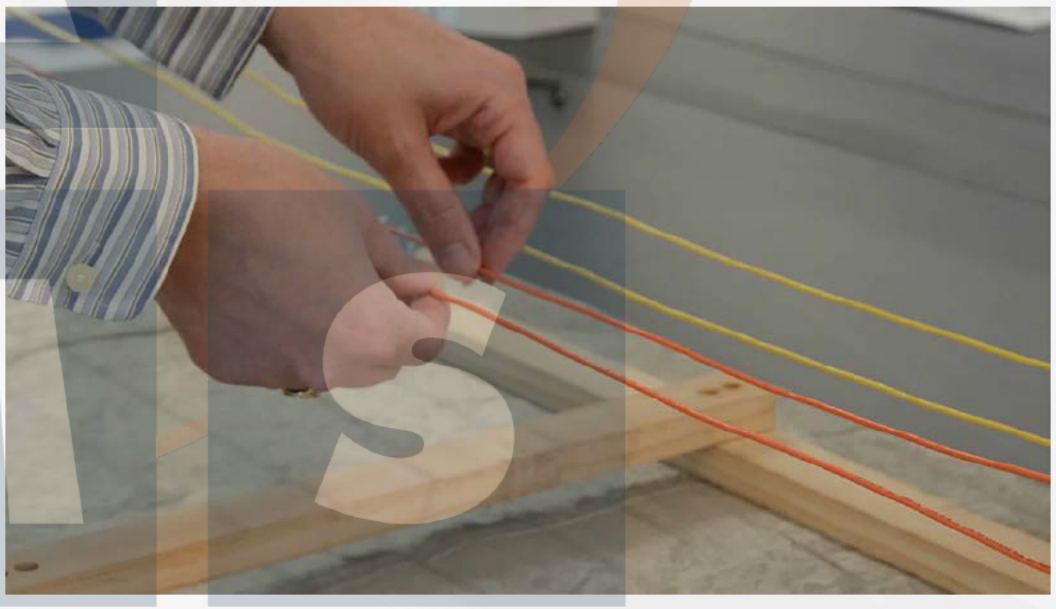
Increasing Frequency



Magnetic Field Coupling

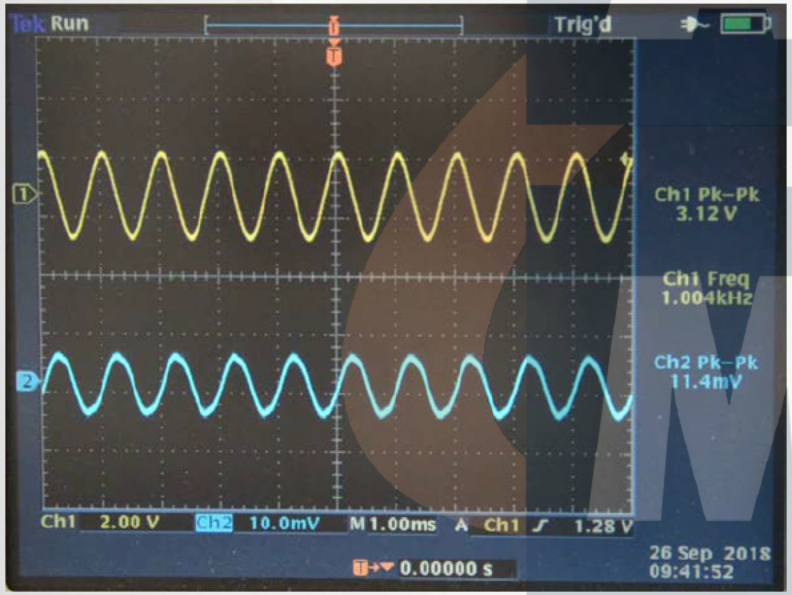
Distance

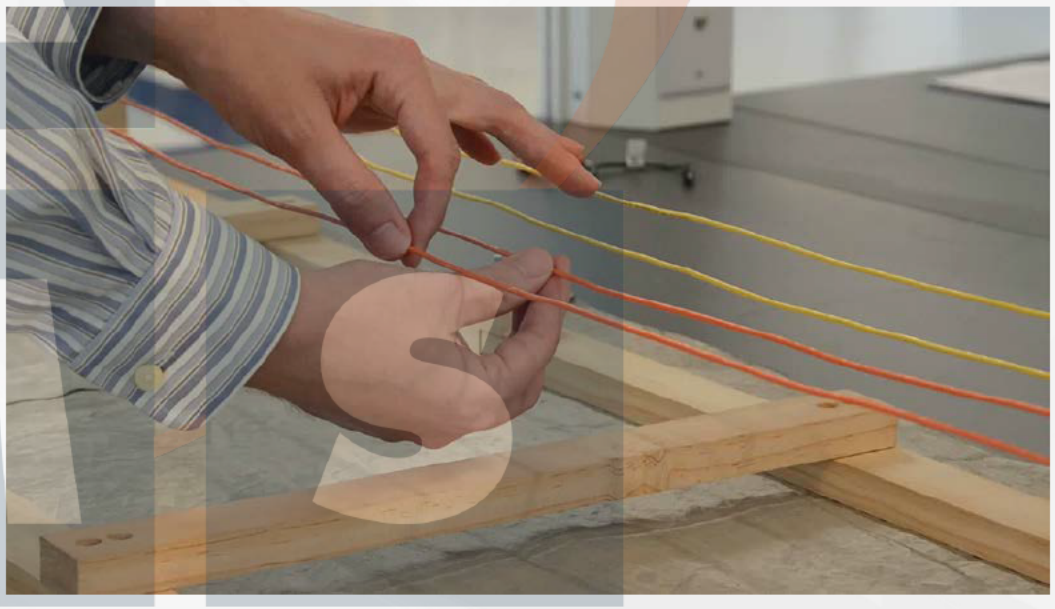




Magnetic Field Coupling

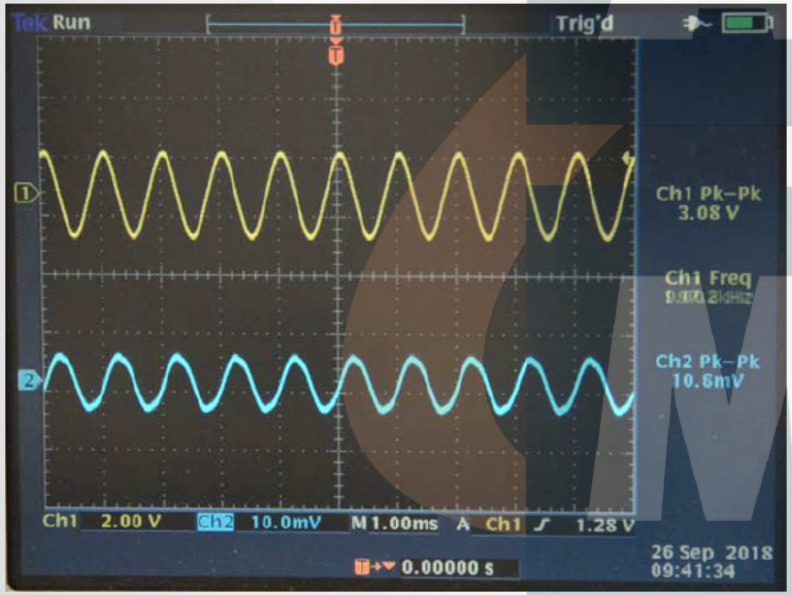
Twisting

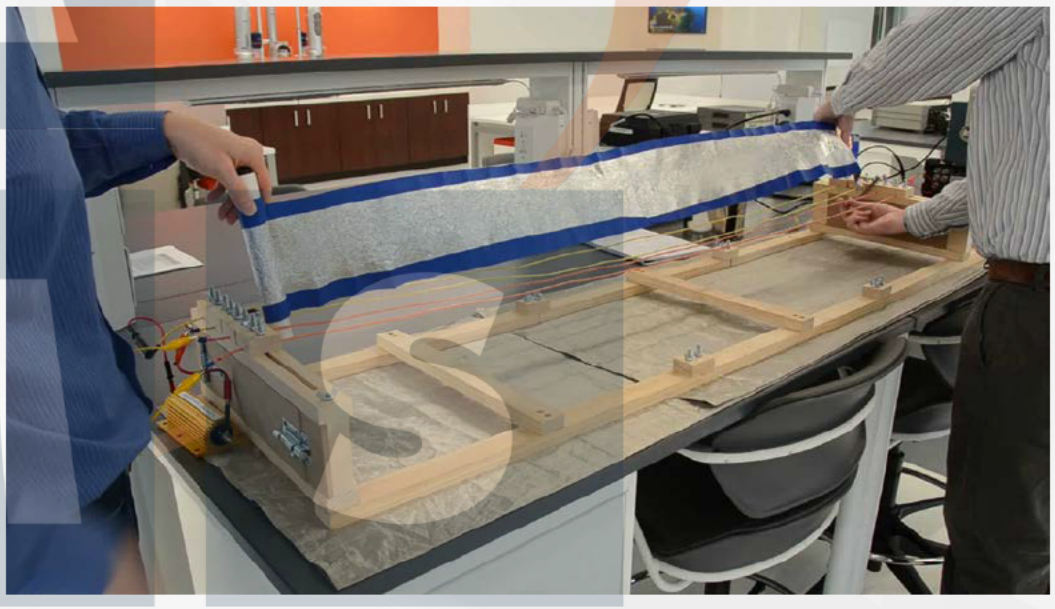




Magnetic Field Coupling

Shielding





Inductive (H-Field) Coupling Summary

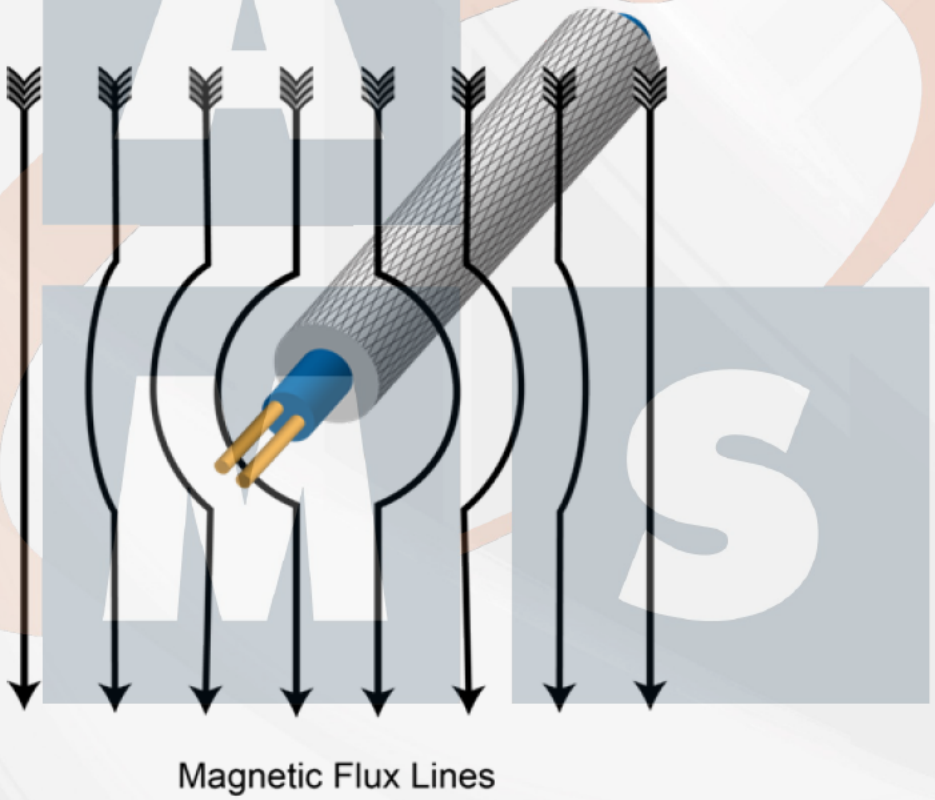
- Affects low impedance circuits
- Coupling increases linearly with frequency
- Coupling decreases with distance squared
- Increases with separation of individual circuit conductors as loop area increases
- Twisting individual circuit conductors together is best preventive measure
- Filtering to increase impedance at high frequency is beneficial

Magnetic Field Shielding

- Surround circuit with magnetic/ferrous material to divert flux

- Twist circuit conductors to eliminate net flux coupling by reducing loop area

Low Frequency H-Field (Magnetic) Shield



Magnetic Shield Effectiveness is Based on Permeability

Material	Relative Permeability
• Air, silver, copper	1
• Aluminum, etc.	1
• (Non-ferrous)	1
• Iron, stainless steel	1,000 – 5,000
• Permalloy	8,000
• Mu-Metal	20,000 – 50,000

Note: permeability may change with frequency and magnetic field saturation

(REF: FAA-RD-75-215, 1, pp. 5-7)

Review of Low Frequency Shields

- **Electric field shield functions as a circuit element**
  - Capacitor (plate) that must be connected to circuit common
- **Magnetic field shield functions as a preferred path for magnetic flux**
  - Warps magnetic field around the protected circuit
  - Does not have to be grounded to be effective (is normally grounded for personnel safety reasons)

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Electromagnetic Wave (Plane Wave) Coupling

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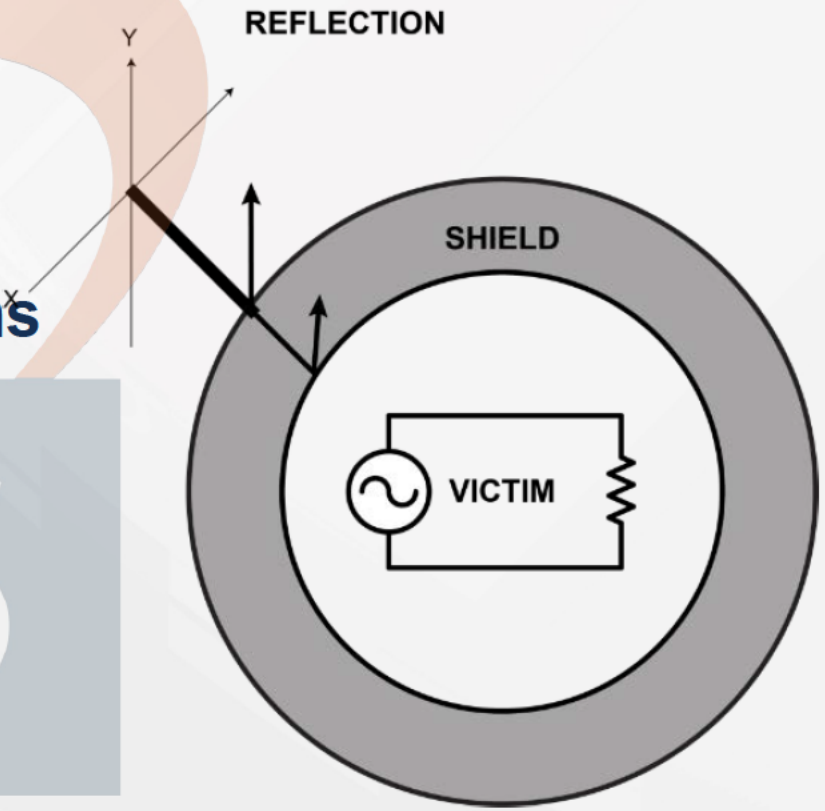
Plane Wave Coupling

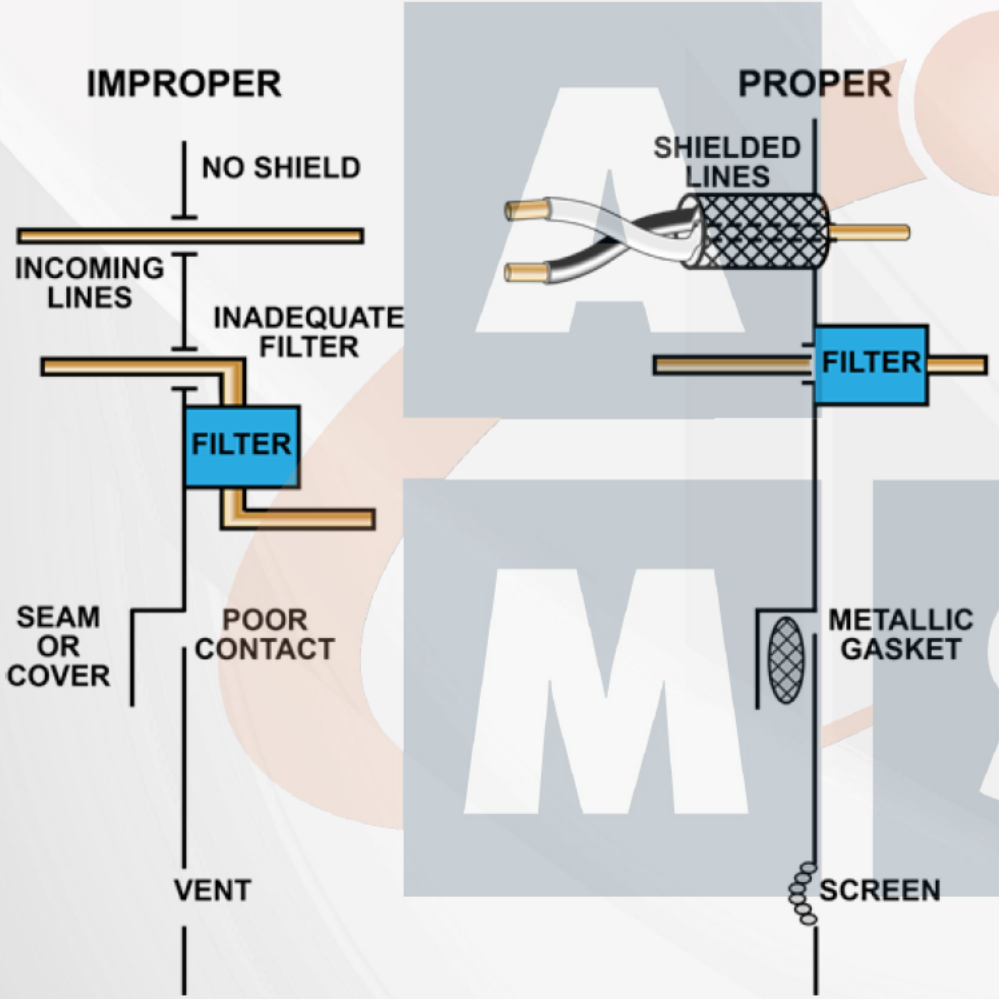
- Plane or electromagnetic waves come from RF transmitters or cable/equipment RF energy radiation
- Typically a far-field phenomenon
- Electromagnetic wave shield causes reflections
- Shield must completely enclose victim



Requirements for Plane Wave Shield

- Holes must be small relative to wavelength of excluded frequency
- Antennas cannot penetrate boundary (antenna is any insulated, unfiltered conductor)
- Current must flow freely on all planes to cancel magnetic fields

Shield Penetrations are Greatest Problem



COMMENT

ALL IN COMING LINES SHOULD BE SHIELDED WITH SHIELD SOLIDLY CONNECTED AT PENETRATION - OR FILTERED.

FILTERS SHOULD BE PART OF SHIELD WALL SO THAT UNFILLTERED LINES DO NOT ENTER SHIELDED ENCLOSURE.

METALLIC GASKETS SHOULD BE USED ON SEAMS, DOORS, OR COVERS.

METALIC HONEYCOMB SCREENS SHOULD BE USED ON VENTS

Preventing EMI Coupling to Coaxial Cables

- Terminate with 360º bonding
- Prevent damage such as tight bends
- Do not use pigtails before shield termination
- Prevent moisture/contamination to maintain shield integrity
- Use Ferrite beads for poor/degraded connectors

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Thank You

Questions?