Electrical Transients

Learning Objectives

Upon completion, the student should be able to:

- Predict how a transient will travel on cables/conductors.
- Specify the important features of an RF transmission line.
- Determine how to prevent conductors from appearing as antennas.
- Identify the impact of a ferrite bead placed on a single conductor or on both conductors of a circuit, with respect to the signal and the EMI being carried on the conductor(s) .

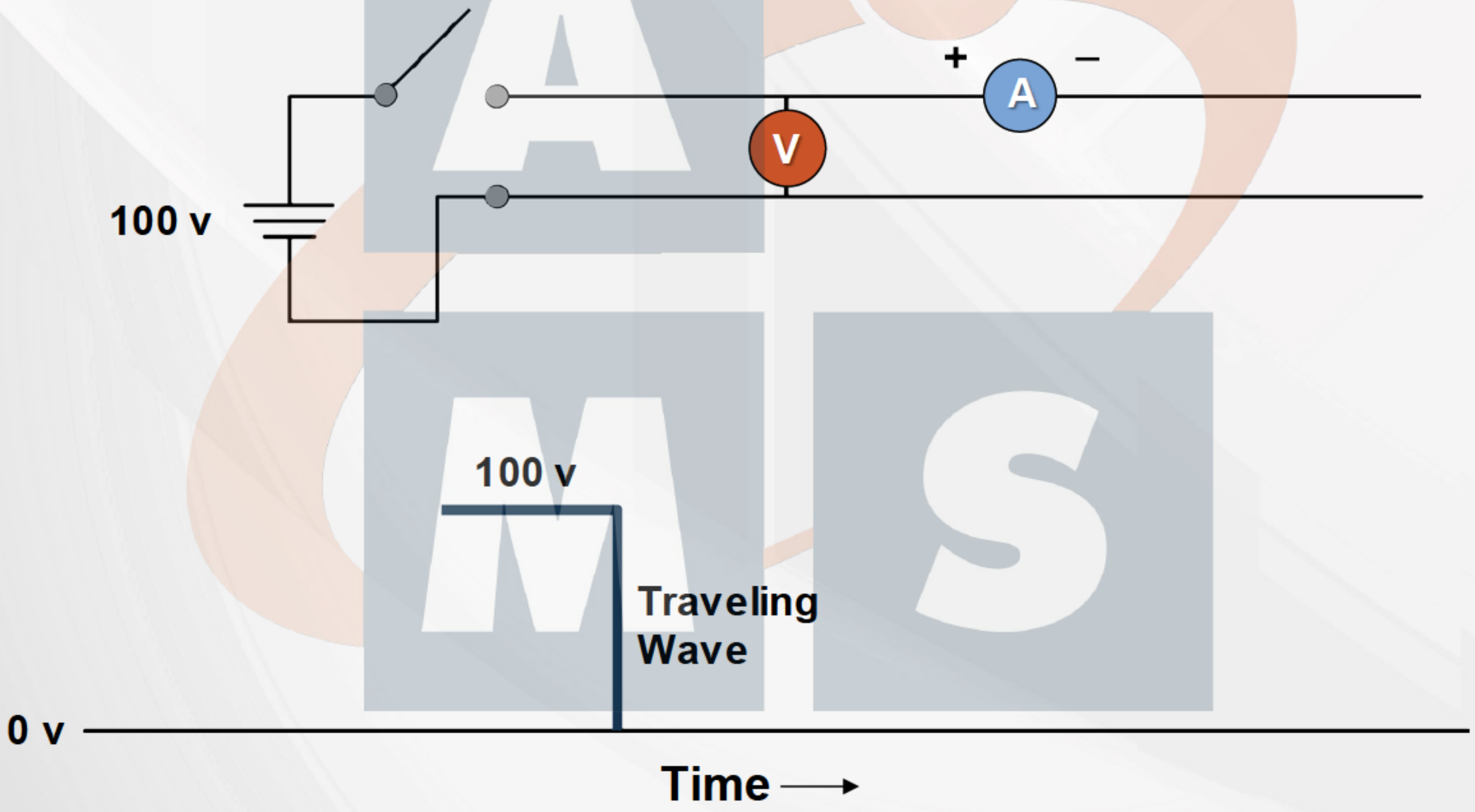
EMI Transient Coupling

- 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

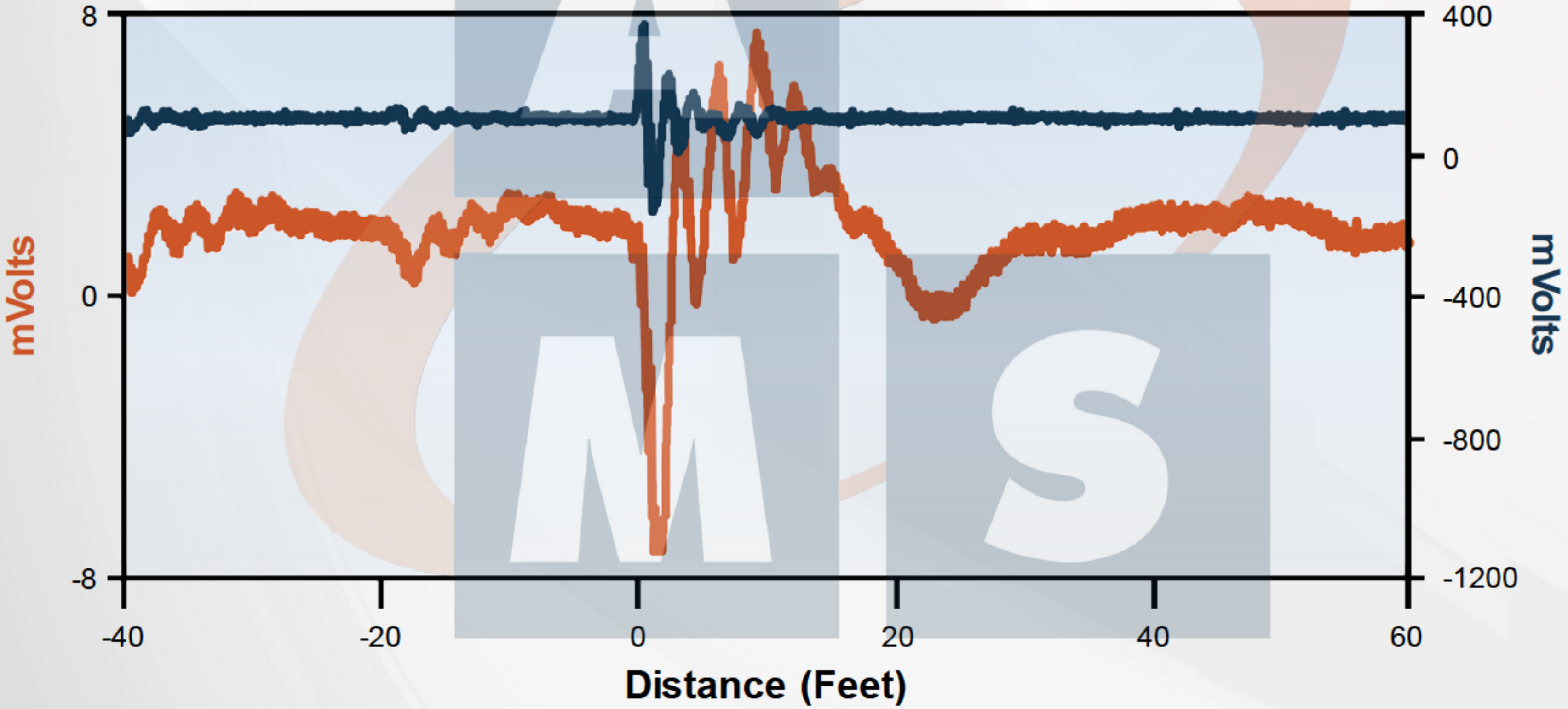
Definition of EMI Transient

A transient is created every time a voltage is switched



Transient Coupling Between Cables

Example of source (600mVp-p) and victim (20mVp-p) from a plant (similar to Experiment 1):



Electromagnetic Waves Exist in Far Field

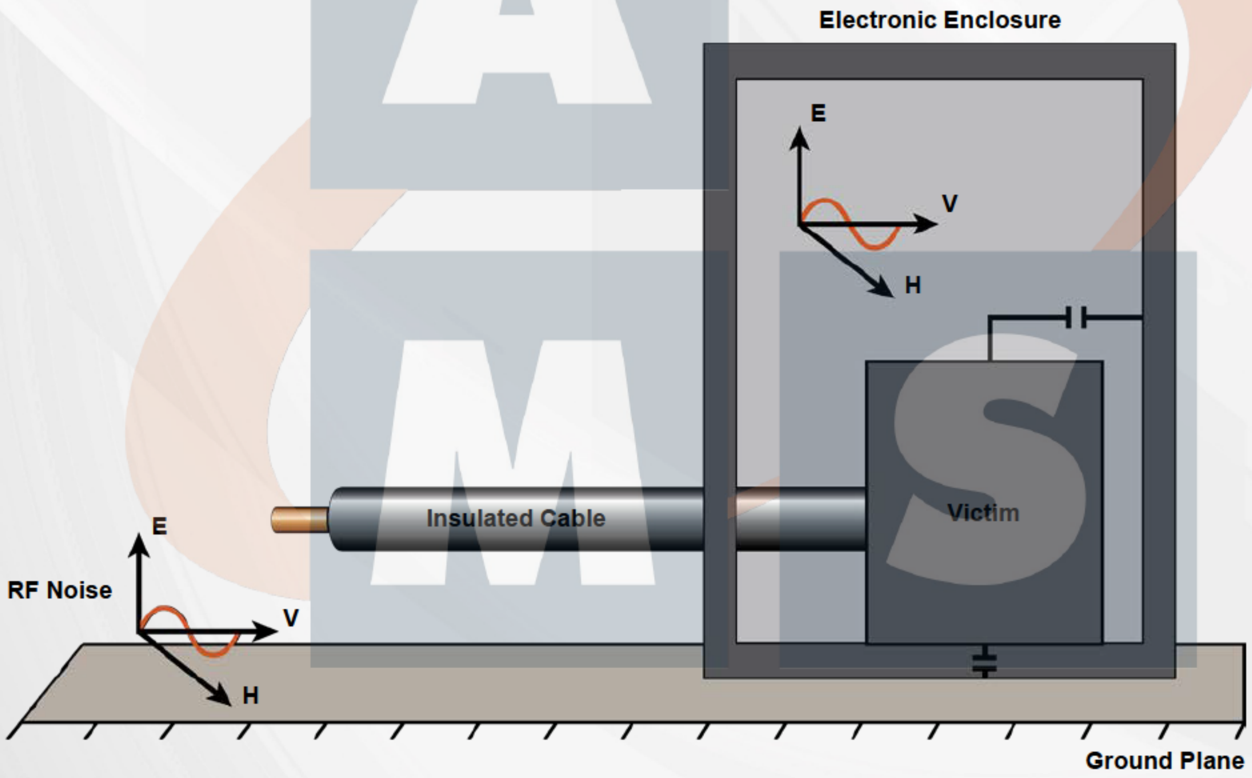
- Exist as burst of radio frequency (RF)
- Electromagnetic waves have clearly defined electric (E-Field) and magnetic (H-Field) field vectors with an impedance

$$\text{Impedance} = \frac{\text{E-Field}}{\text{H-Field}}$$

- Electromagnetic waves may be radiated in free space or guided on radio frequency (RF) transmission lines

Transient EMI Travels as a Guided Wave

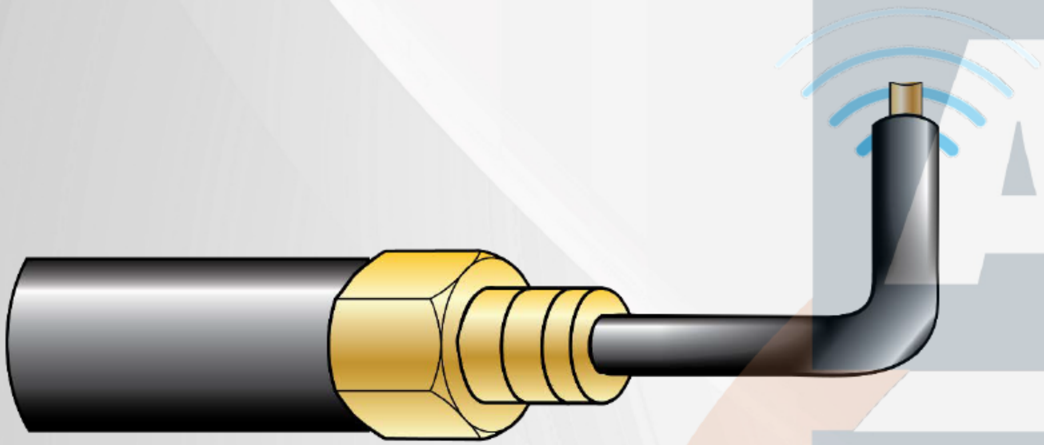
Plane wave EMI may be conducted on stray conductors acting as a transmission line which may travel into undesired areas



Guided Transients

- Concentrated energy
- Reflections can double voltage or current at end of long cable/transmission line
  - Can increase EMI at remote location
- Conductor at end of an RF transmission line will re-radiate EMI transient as an RF burst
- Example:
  - Time Domain Reflectometry (TDR)

Conductor can Radiate Transient



COAX CABLE WITH PIGTAIL

WIRE IN CABINET

Inadvertent Antennas

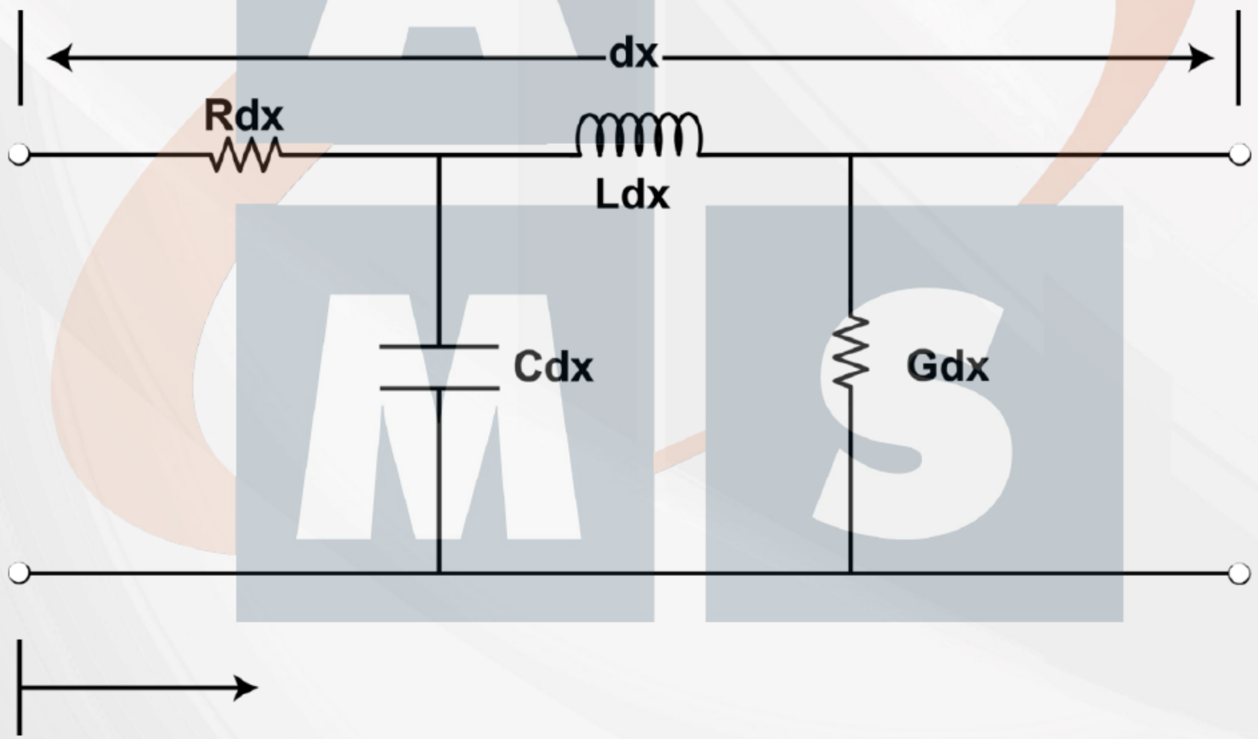
- For a given frequency, cables can become resonant antennas at lengths equal to quarter-wave multiples.
- Electric power plant noise is broadband and can therefore excite any resonant conductor.
- A resonant conductor system will have current maximums and voltage maximums one-quarter wavelength apart.
- A resonant system can be created by any two conductors: the reference need not be earth.
- Inadvertent antennas can be minimized by keeping conductors close to the reference ground plane.

Conductors Becoming Antennas

		BE AWARE	WORRY	PROBLEM
Frequency	Wavelength (air)	1/20th Wave	1/6th Wave	Quarter Wave
20 kHz	49,212 ft	2,461 ft	8,202 ft	12,303 ft
1 MHz	984 ft	45 ft	165 ft	246 ft
10 MHz	98 ft	5 ft	16 ft	25 ft
100 MHz	10 ft	0.5 ft	1.7 ft	2.5 ft
1,000 MHz	1 ft	0.05 ft	0.17 ft	0.25 ft

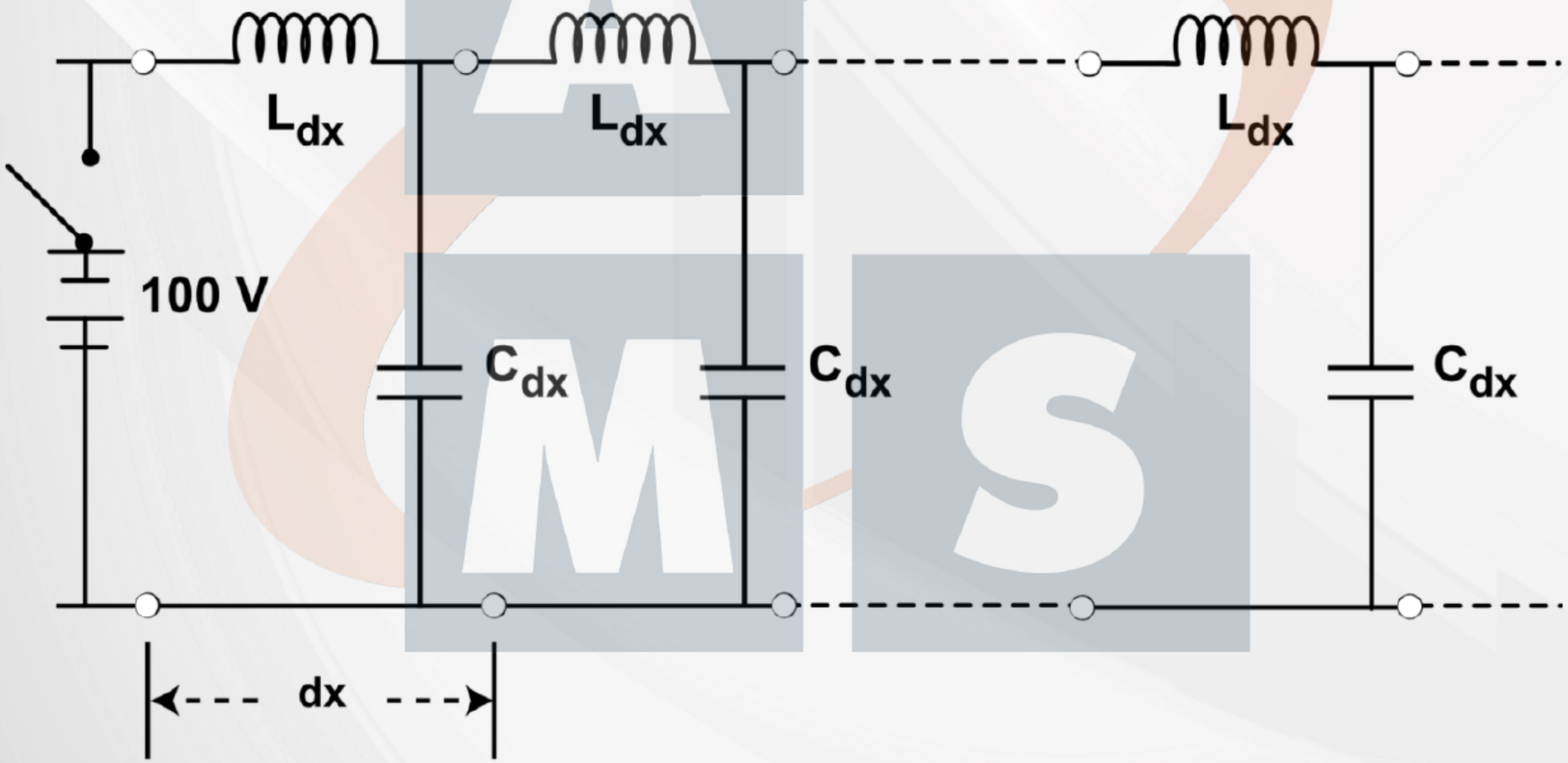
Transmission Line Theorem

A transmission line is two parallel conductors characterized by having inductance, capacitance resistance, and conductance.



Lossless Transmission Line

A lossless transmission line is a transmission line with only lumped (combined) inductance and capacitance.



Effective RF Transmission Lines Examples

- **Two concentric conductors separated by a dielectric**
  - Coaxial cable
- **Conductor over ground plane separated by a dielectric**
  - Lands on printed circuit board
  - Conductors in a cable tray
  - Power lines over earth
- **Two parallel conductors separated by a dielectric**
  - Any multiple insulated wire cable
  - Overhead power lines
  - Outer insulated conductors (shields) on two cables bundled together
  - Two insulated ground wires bundled together

RF Transmission Line Impedance

- **Impedance of RF transmission line with respect to transient or electromagnetic wave.**
  - Relatively low impedance, characterized by series inductance and shunt capacitance.
  - Viewed as pure resistance.

- **Described as Characteristic Impedance.**

Characteristic Impedance

- The impedance presented by a two-conductor transmission line to a transverse electromagnetic (tem) wave in the direction of propagation.

- Also, the impedance a two conductor line would present if it were of infinite length.

Characteristic Impedance (cont)

$$Z_C = \sqrt{\frac{L}{C}}$$

For round parallel conductors in air:

$$L = 4 \times 10^{-7} \ln \frac{D}{d} \text{ H / m}$$

$$C = \frac{10^{-9}}{36 \ln \frac{D}{d}} \text{ F / m}$$

$$Z_c = 120 \ln \frac{2D}{d} \left(\text{if } \frac{D}{d} \rangle 3\right)$$

D = separation, inches   d = diameter, inches

For coaxial cable:

$$Z_C = 138 \log \frac{D}{d}$$

D = outer dia
d = inner dia

For parallel wires:

$$Z_C = 176 \log \frac{D}{d}$$

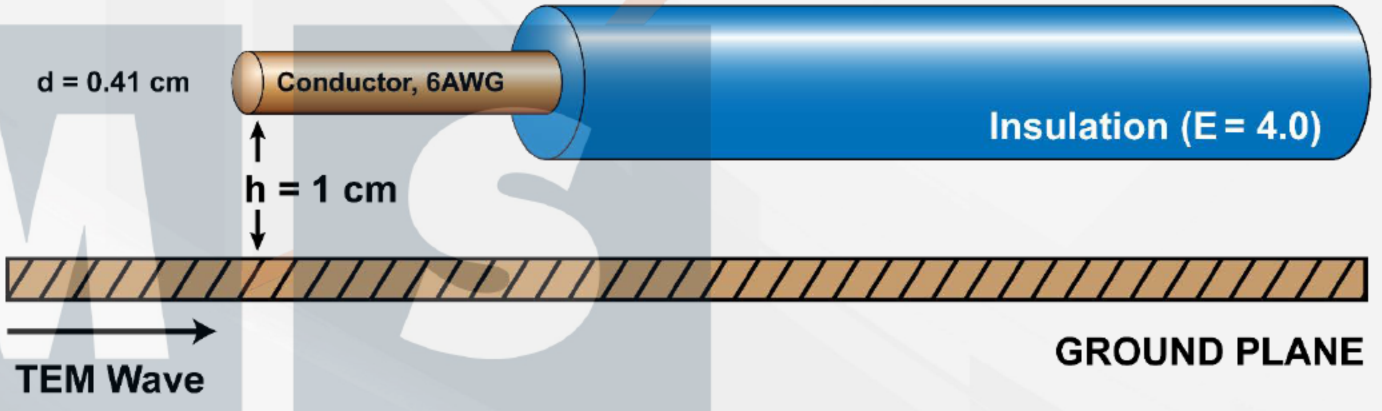
D = spacing
d =diameter

Impedance of Ground Wire to EMI Transient

The characteristic impedance for a 6 awg insulated, soft copper conductor mounted on a ground plane is:

$$Z = \frac{138}{\sqrt{E}} \mathrm{LOG}_{10} \frac{4h}{d}$$

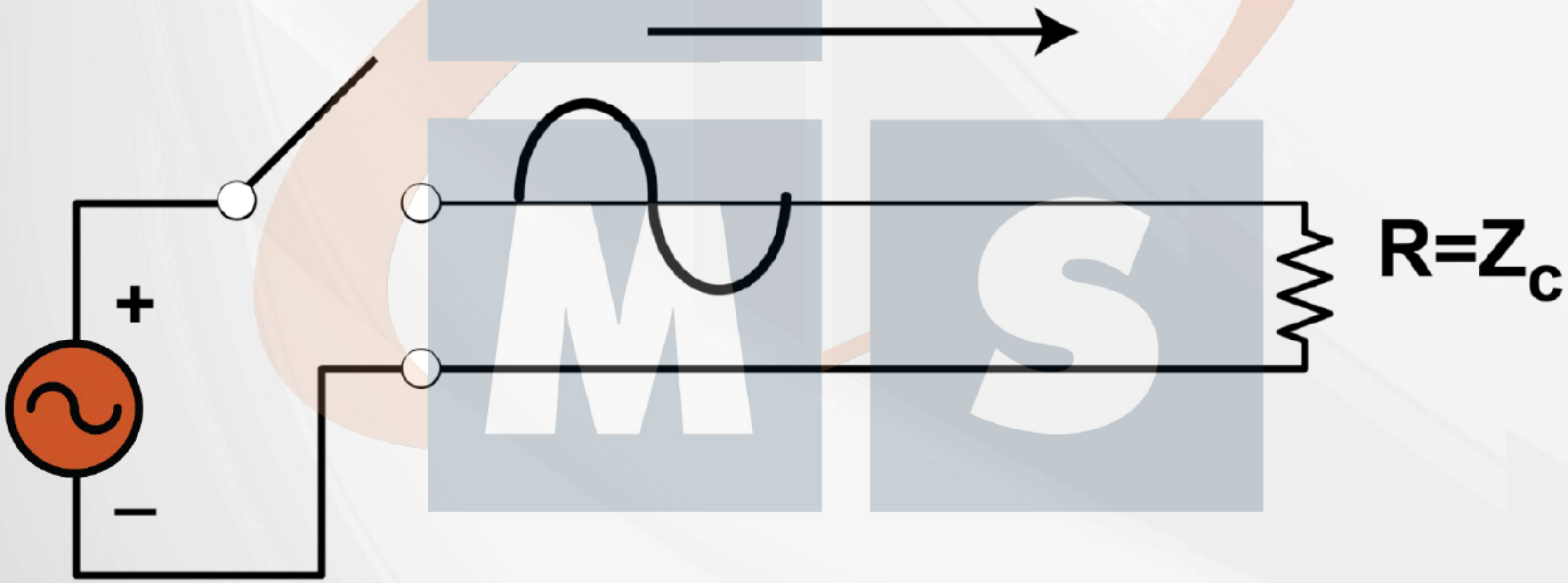
$$Z = 68\ \Omega$$



(Ref: Data for Engineers, 7th Ed. pp. 29-20)

Load Matching Characteristic Impedance Eliminates Reflections

Terminating a transmission line in its characteristic impedance will absorb all transmitted power.



Unmatched Termination Causes Reflections

Terminating a transmission line in other than its characteristic impedance will cause power to be reflected.

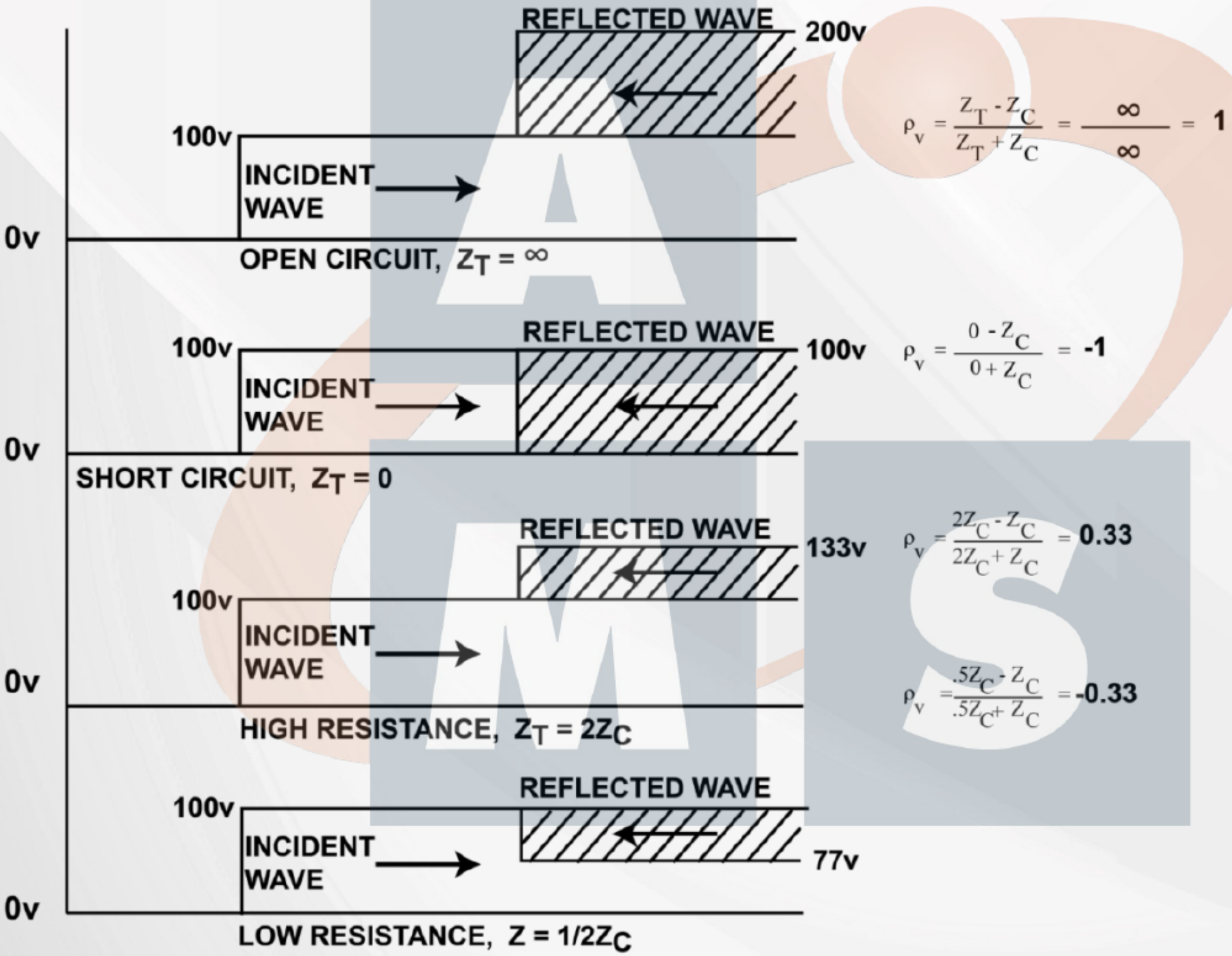
Transmission Line Reflection Coefficient

$$\rho_v = \frac{Z_T - Z_C}{Z_T + Z_C} \text{ (voltage)}$$

$$\rho_i = \frac{Z_C - Z_T}{Z_C + Z_T} \text{ (current)}$$

Z = Characteristic impedance
C = Cable
T = Termination

Reflected Waves

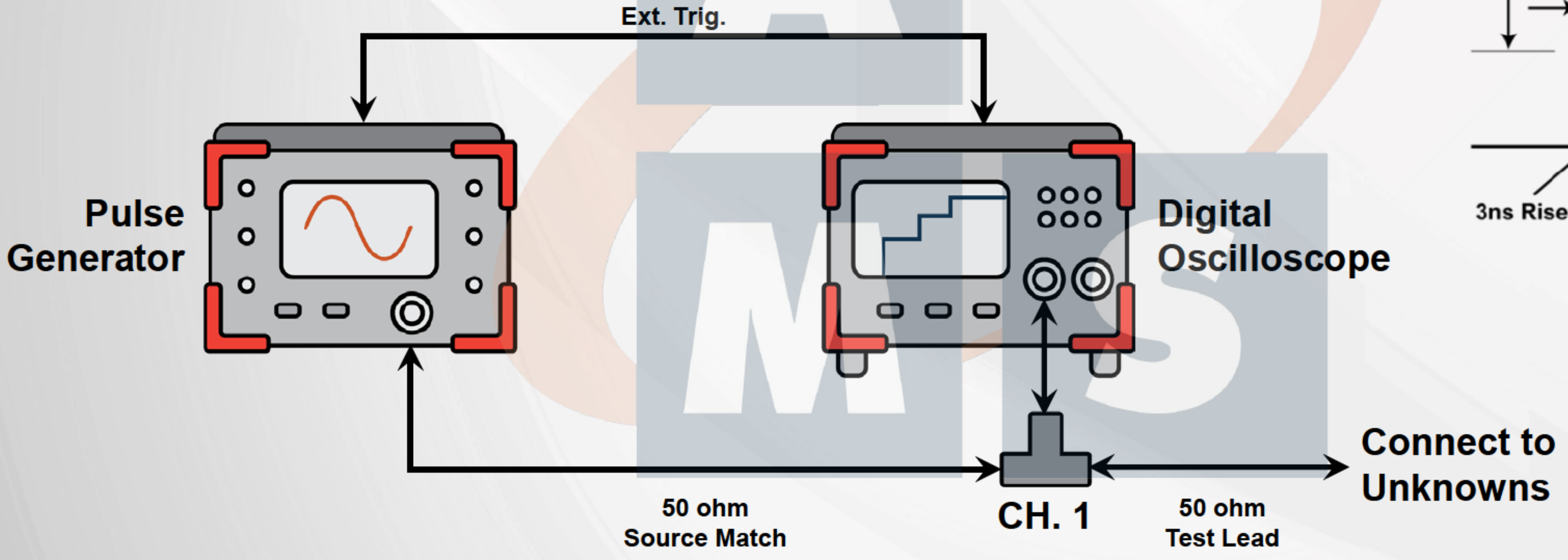


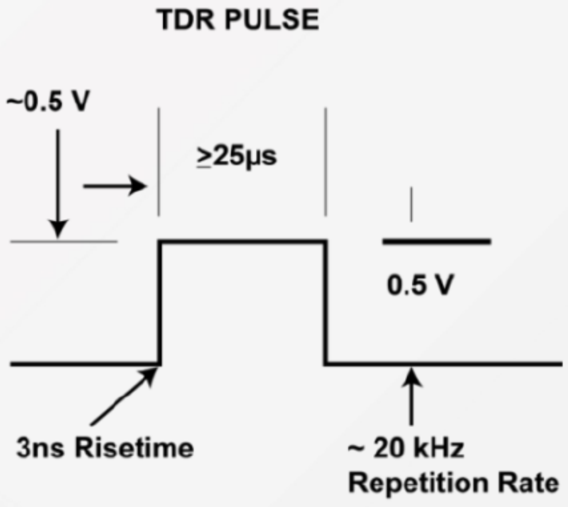
Experiment: Time Domain Reflectometry
Learning Objectives

- **TDR waveform is guided between adjacent conductors separated by insulation.**
- **Size of conductors, distance between them & type of insulation will define characteristic impedance.**
- **Impedance mismatches anywhere in line will cause reflections.**
  - Higher than Z_c causes positive reflection.
  - Lower than Z_c causes negative reflection.
  - Matching Z_c eliminates reflections.
  - Ferrite beads around single conductor of RF transmission line will cause mismatch.
- **Wave continues to travel, ringing, until energy is dissipated in cable losses or load resistance.**

Experiment: Time Domain Reflectometry

Configure simple TDR:





Thank You

Questions?