Grounding and Electromagnetic Interference Refresher

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Agenda

- Safety Moment
- Ground, Neutral, Common and Return
- Neutral and Safety Ground in low voltage AC systems
- Electrical Grounding Systems Review
- What is EMI – Electromagnetic Interference
- The 4 types of EMI and how to spot them
- Mitigation tools
- Mitigation tricks
- The Best Solution: The Grounding Plan

Electrical Safety
AC Voltage Detector

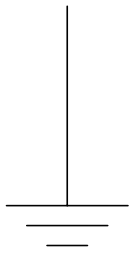
- Every Home owner SHOULD own one and know how to use it
- Detects the presence of an electrical field around any wire or fixture which is connected to an AC source.
- It never touches the wire, and typically has both an LED and an audible noise
- AC detectors can be used even if no current is flowing through the wire in question
- When the tip glows red and the unit beeps, you know there's voltage
- Cost: About $10 to $40

Ground, Neutral, Common and Return

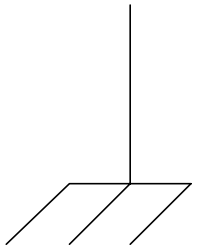
- Earth Ground, Frame Ground, Neutral, Common and Return

- Over half of all problems in electrical, electronic and control systems are caused by misunderstanding or a lack of understanding of Earth Ground, Frame Ground, Neutral, Common and Return

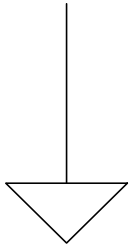
Earth Ground



Frame Ground

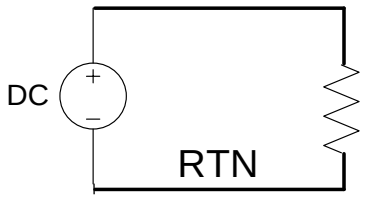


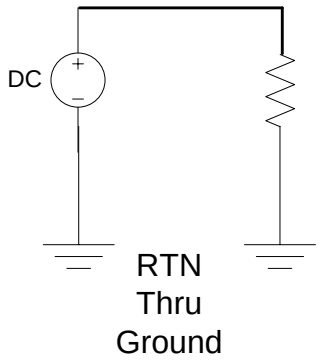
Common

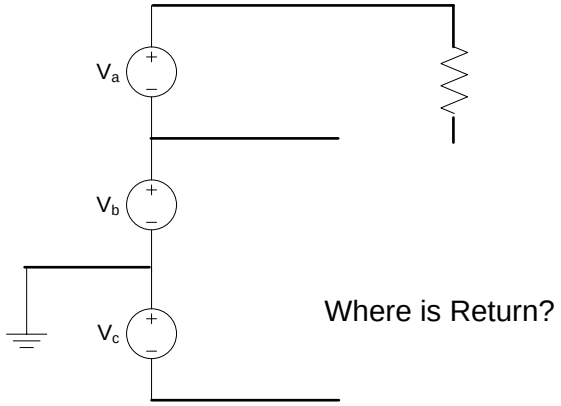


Return

- EVERY UNIT OF CHARGE THAT LEAVES AN ELECTRIC SOURCE MUST COME BACK TO THAT SOURCE
- Every unit of charge is constantly trying to find its way home
- By forcing the charge to take a certain path home (i.e. thru the load) we can make the charge do work
- The path back to the source is Return – not Ground

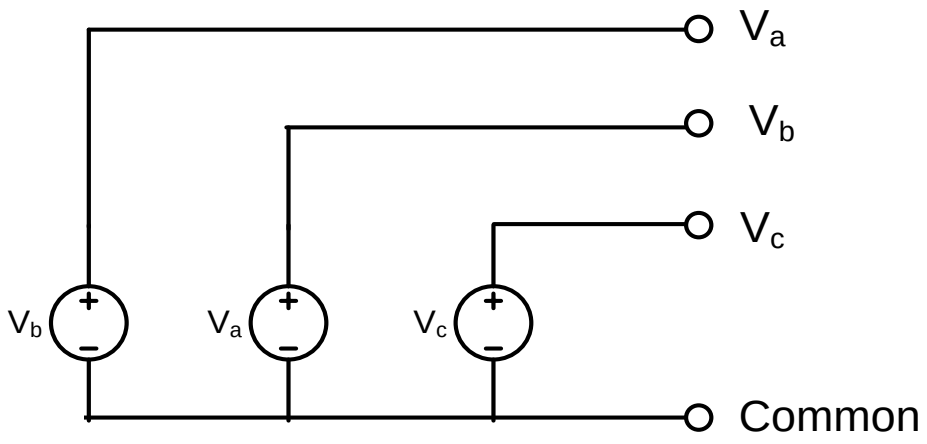






Common

- Common
  - An agreed upon Return path for one or more sources
  - Most important in DC systems with several voltages



Chassis or Frame Ground

- An Electrical Common that is also a metal frame of a piece of equipment
- The Frame of an Automobile is common or frame ground for the cars electrical system
- Older Musical equipment used the frame as DC common and AC Neutral
  - Story Time: The Hot Mic Story

Earth Ground

- Common for the AC power Grid
- Current really does flow thru the Earth
- By definition Earth is 0 volts
- The reference point for voltage measurement of the power grid
- Also used as the designated potential for “Safety Ground”

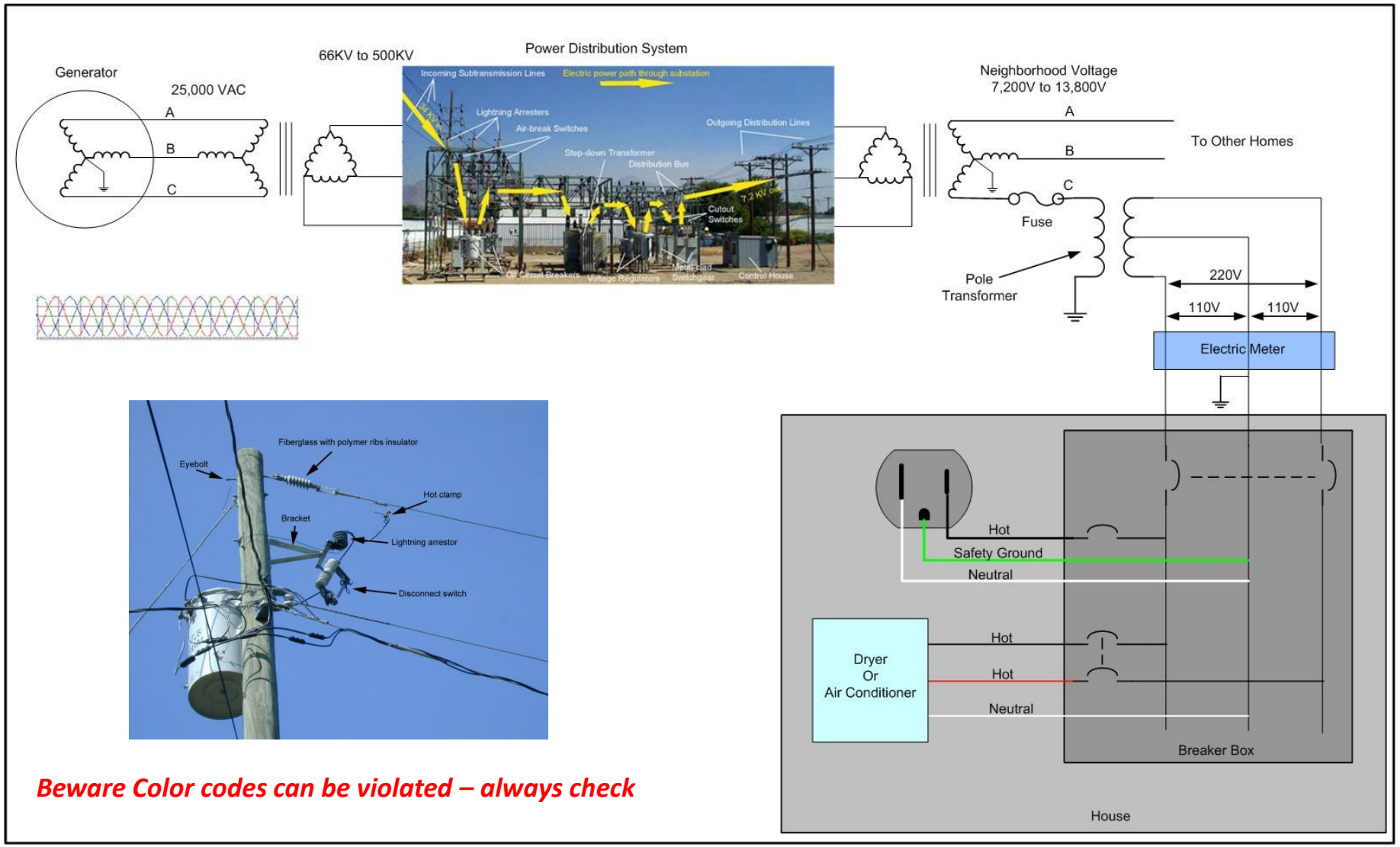
Neutral

- Neutral is Common for an AC system
  - Usually at the same potential as Earth Ground and electrically between the 3Ø sources
  - Electrically speaking Neutral does NOT have to be the same potential as Earth Ground
  - Some 3Ø Systems may not have a Neutral (Delta)
  - In a balanced 3Ø System no current flows in the Neutral
    - Common mode noise (harmonics) and zero sequence current flows in the Neutral
- In industrial systems the code calls for Neutral and Safety Ground to be at the same potential, but **NO current flows in the Safety Ground wire**

Safety Ground

- The Safety Ground (**Green** or **Green/Yellow** Wire) Is designed to trip the circuit breaker in the event that the shell of the device becomes energized
- The Safety Ground is at the same potential as Neutral
- No current should flow in the Safety Ground

Neutral and Safety Ground in low voltage AC systems



Beware Color codes can be violated – always check

Ground Fault Circuit Interrupters

- GFCIs reduce the likelihood of fatal shocks
- Detect small amount of earth current and automatically switch off the power
  - Designed to trip on 5ma difference between the Hot and Neutral line
- Used with extension cords and portable tools
- Use in wet or damp locations
  - Outdoors
  - Bathroom
  - Kitchen
- There are portable versions

GFCI outlet

Arc Fault Circuit Interrupters

- AFCIs reduce the likelihood of fire by opening if an arc is detected
- An AFCI distinguishes between a harmless arc incidental to normal operation of switches, etc., versus a potentially dangerous arc
- The electronics inside an AFCI breaker detect characteristic frequencies, usually around 100 kHz, caused by wire arcing, which are sustained for more than a few milliseconds.
- NEC now requires AFCI for most home circuits

EMI Mitigation – The Black Art?

- Electromagnetic Interference (EMI) occurs any time one electrical signal influences another unintentionally
- EMI Mitigation is not a black art!
  - It is a simple application of physics that consistently obeys well know laws
  - The mystery is a result of not understanding the basics

Back to Basics - Impedance

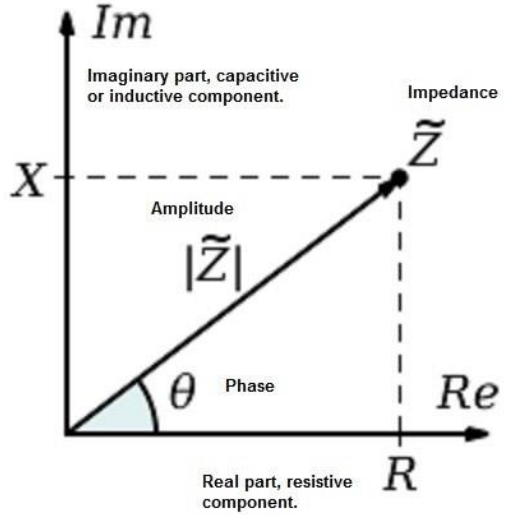
- We have all been told that electricity follows the path of least resistance

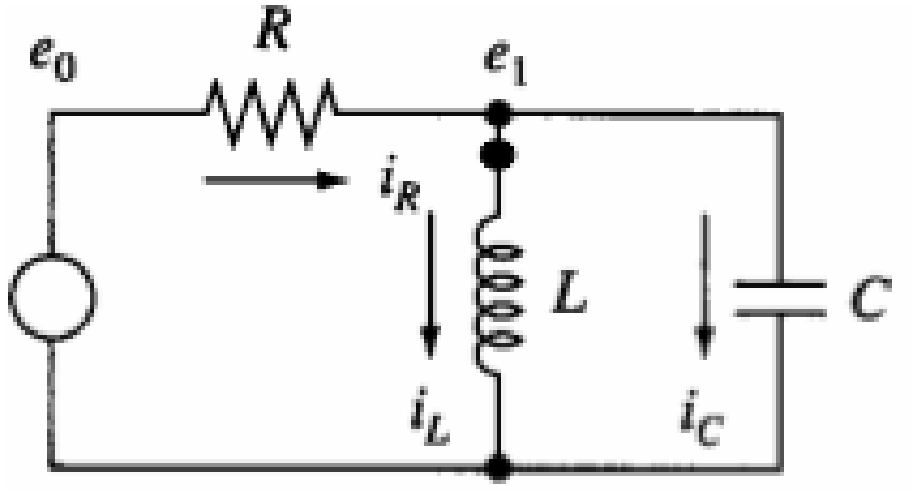
  THIS IS NOT TRUE

- Electricity follows the path of least ***impedance***
  - Depending on frequency the path may not be apparent
  - This is the main cause of EMI and Noise in electronic systems

Back to Basics - Impedance

- **Electrical impedance** is the measure of the opposition that a circuit presents to a current when a voltage is applied
- Impedance extends the concept of resistance to AC circuits
- When a circuit is driven with steady state direct current (DC), there is no distinction between impedance and resistance
- Rise time for pulses has an “Effective Frequency”





$$X_C = \frac{1}{2\pi fC} \qquad X_L = 2\pi fL$$

$$C = \frac{1}{2\pi fX_C} \qquad L = \frac{X_L}{2\pi f}$$

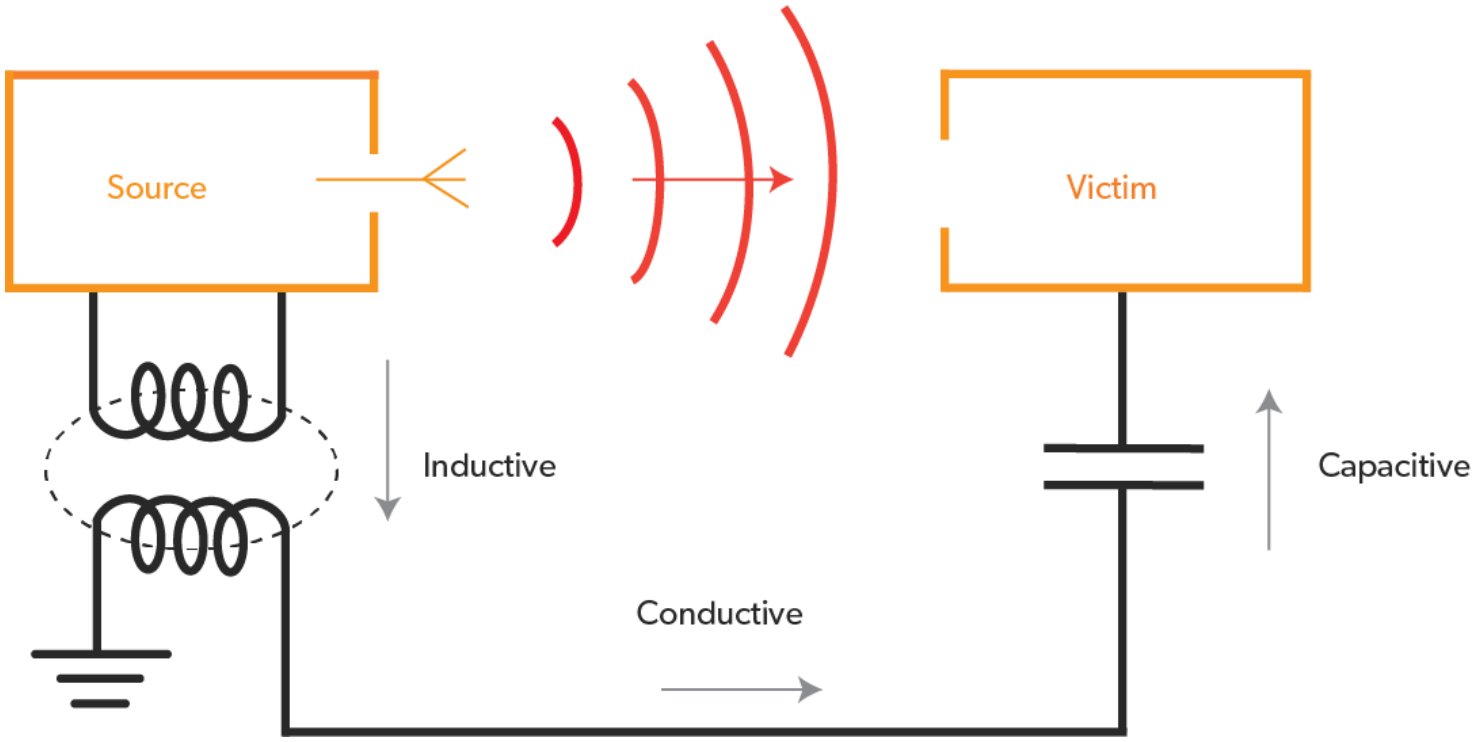
Impedance Formulas

$$Z = \sqrt{R^2+(X_L-X_C)^2}$$ (For Series Circuit)

$$Z = \frac{RX}{\sqrt{R^2+X^2}}$$ (For R and X in Parallel)

The 4 types of EMI

- **Radiated**
  - True radio frequency interference (RFI)
- **Conducted**
- **Capacitively coupled**
- **Inductively coupled**



Radiated Noise

- Recognition
  - Results from “Far Field” interaction with an RF source
  - Must be at least 1 wave length away from source
  - 50Hz/60Hz is NEVER radiatively coupled
    - λ = 3000 miles
- Typical Source
  - Radio transmitter
  - Radio receiver
  - Computer
- Solutions
  - Absorption by lossy dielectric or magnetic materials
  - Total metallic enclosure

Conducted Noise

- Recognition
  - Must have direct contact
  - Unaffected by people or cable movement
  - If the Noise spectrum has a DC level it is probably conducted noise
    - Non-zero average value for noise waveform
- Typical Source
  - Ground loop
  - Power supply
    - Especially switching power supplies
- Solutions
  - Break contact
  - Filter Power Supply

Inductively Coupled Noise

- Recognition
  - Noise on the signal looks like something from another part of the system – has the same frequency and shape
  - Results from coupling between loops in the signal & noise circuit
  - Unaffected by non-conducting, non-magnetic materials
  - Effectiveness of shielding material not changed by grounding

- Typical Source
  - Large ***AC current*** nearby
  - Unnecessary or large loop areas

- Solutions
  - Reduce the noise current
  - Reduce the mutual inductance (i.e. loop area)
    - Twisted pairs
  - Increase signal circuit impedance
  - Use magnetic shielding
    - Mu Metal

Loop Area

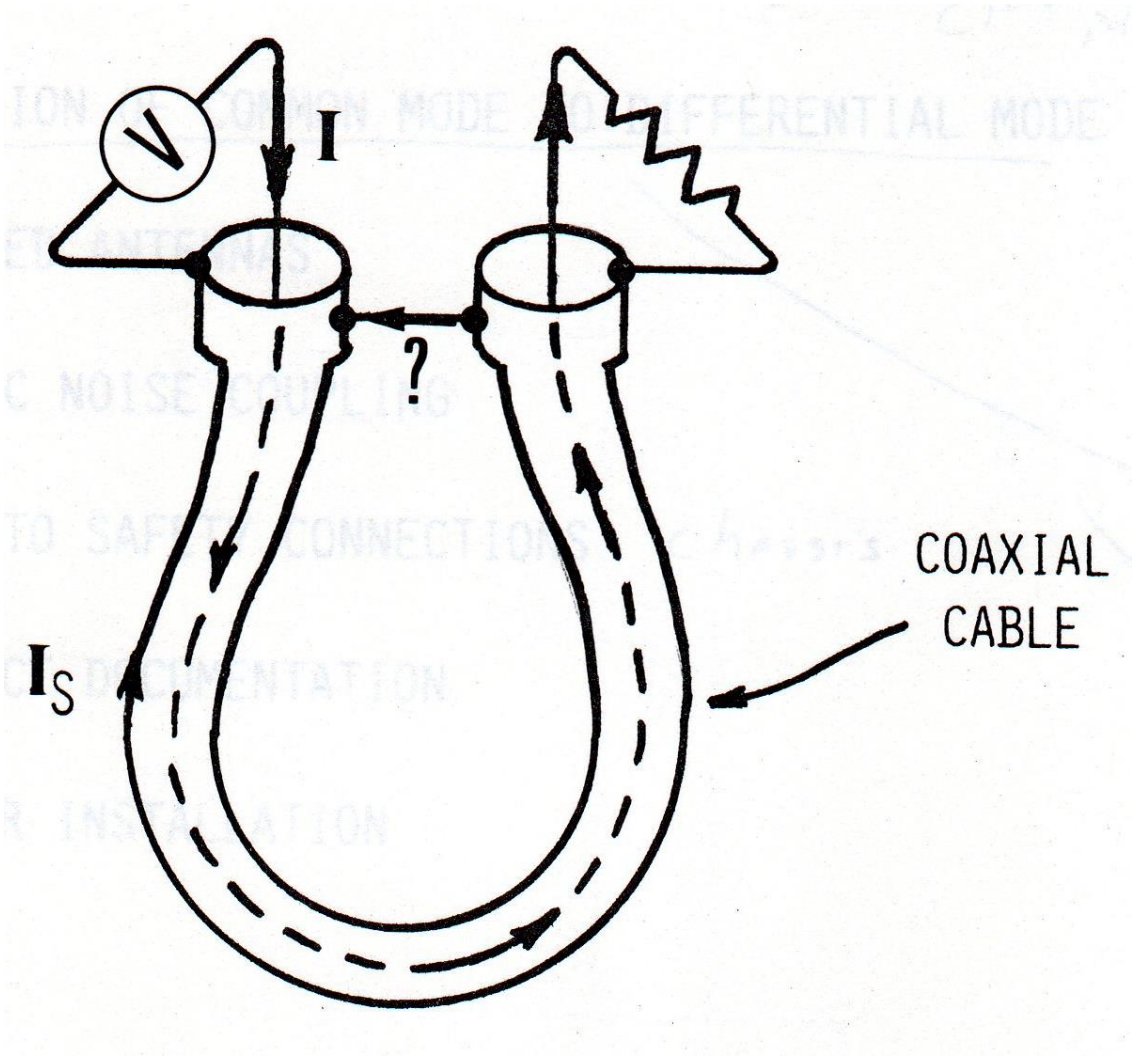
- Every electric current that leaves a source MUST come home to that source!
- The area enclosed by the path of the current is called the loop area

The current in the loop creates a magnetic field
and
A magnetic field can induce a current in the loop

- Interaction of the loop with external magnetic fields creates noise
- The path the current takes, and thus the size of the loop, is frequency dependent

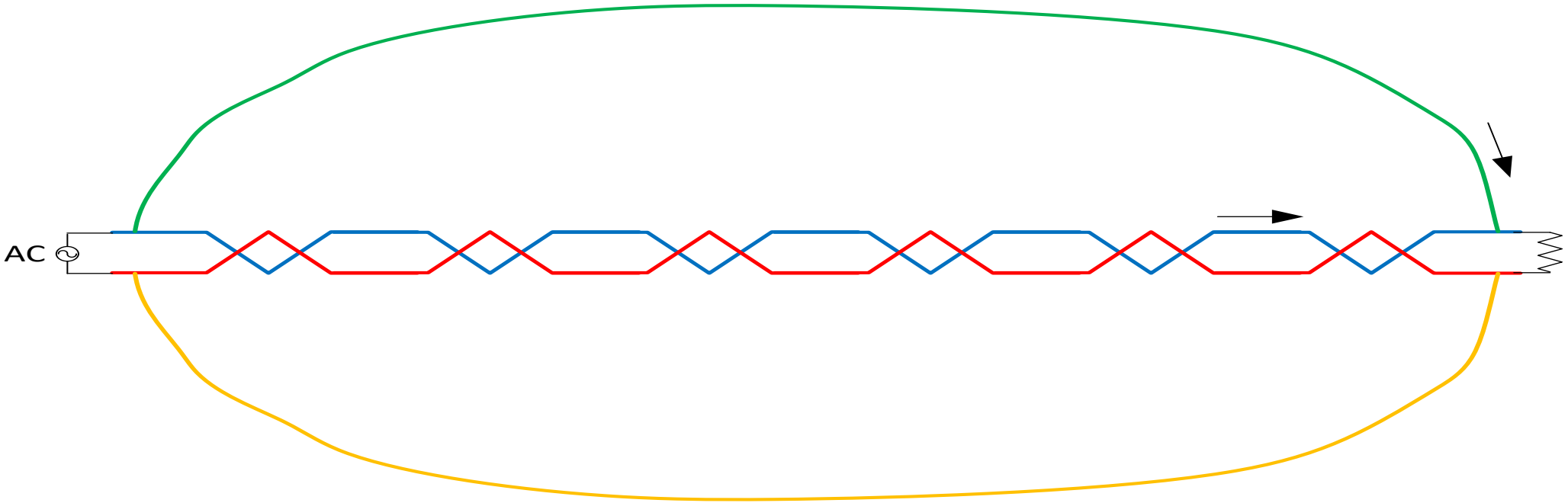
Loop Area

- Where does the current flow at DC?
- Where does the current flow at 10MHz?
- Often clever single point grounding schemes create more noise due to loop area



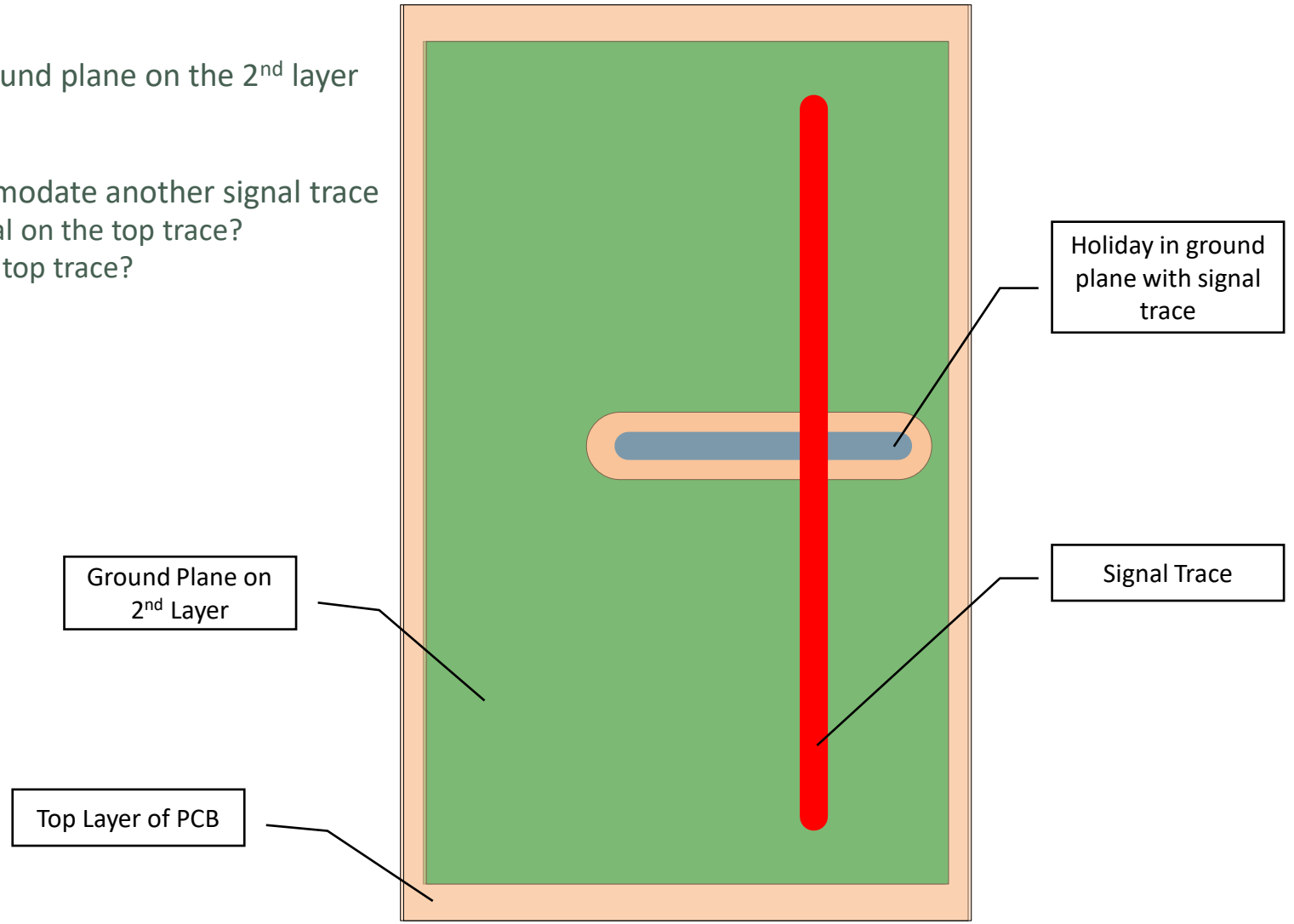
Loop Area

- 4 wires of equal length
  - Red & Blue twisted together
  - Green & Yellow forming a large ellipse
- Where does the current flow a DC source?
- Where does the current flow a AC source?
  - As frequency increases?



Loop Area

- PCB with a signal trace on the top layer and a ground plane on the 2nd layer
  - Where does the return current flow?
- A holiday is added to the ground plane to accommodate another signal trace
  - Where does the return current flow for the signal on the top trace?
  - What happens to loop area for the signal on the top trace?
  - What happens with EMI for both signals?



Capacitively Coupled

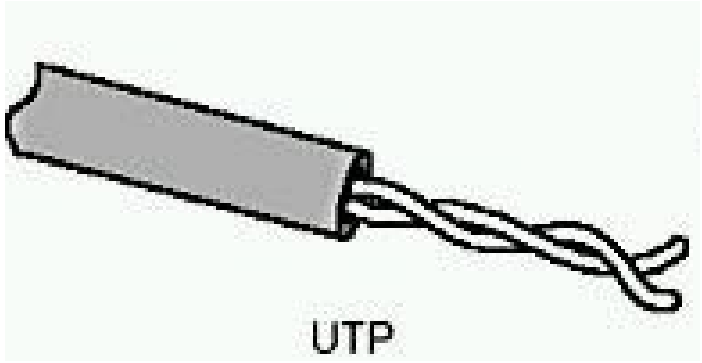
- Recognition
  - High Noise voltage relative to the signal
  - Affected by cable and people locations
  - Floating metal near circuit
- Typical Source
  - High voltage AC nearby
- Solutions
  - Metallic shield
    - Position shield to intercept the noise field and return it to its source
    - Capacitive Shields cause the noise current to bypass the circuit being protected
    - A floating shield is WORSE that no shield
    - Shielded cable
  - Reduce coupling capacitance
  - Reduce circuit impedance

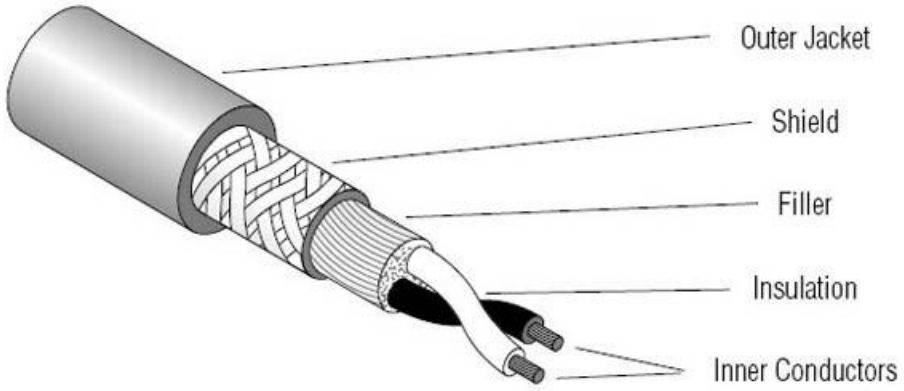
Shielding and Twisting

- What does the shield (screen) on a signal wire do?
  - Protects the signal from ***Capacitively*** coupled EMI by blocking the electric field
  - Works best if connected to signal return at one end only (low to med freq)
  - Connecting the shield to ground on both ends can create a ground loop with a very large loop area
    - Return current is on one conductor of the pair, no current flows in the shield
  - Failing to connect the shield of a CoAX on one end can create a large loop because the current has to take a different return path

Shielding and Twisting

- What does twisting wires together do?
  - Protects the signal from ***Inductively*** coupled EMI by Reducing loop area
  - Only works for signals where signal and its return each use one of the wires
  - Ideal for differential signals





Shielding and Twisting

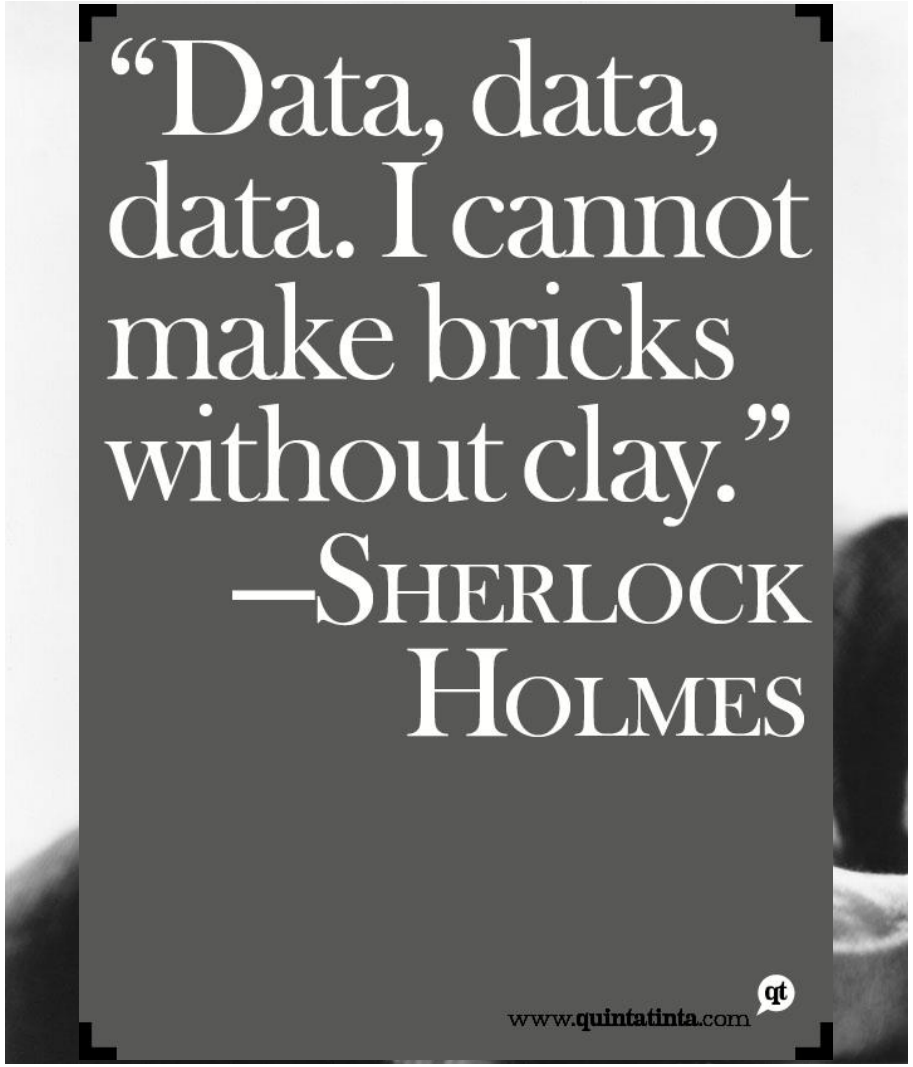
- What does the screen do on a power conductor?
  - Has nothing to do with EMI protection
  - Used as part of the insulation system to smooth out the voltage gradient
  - Screen can be a concentric neutral

What the h#%% is a ground loop?

- Ground loop: an unwanted current in a conductor connecting two points that are supposed to be at the same potential (i.e. Ground) but are actually at different potentials
  - Ground loops can be detrimental to the intended operation of the electrical system
  - Mostly a problem for instrumentation
  - Generally caused by multiple ground paths – such as connecting a cable shield to the wrong place
  - Usually creates loops with large loop area that cause induced EMI

90% of EMI Mitigation is Troubleshooting

- Sherlock Holmes once said: "*when you have eliminated the impossible, whatever remains, however improbable, must be the truth*"
- Do not assume anything!
  - Before you apply power – is it wired according to the drawing
- Always check and verify the power – from the wall all the way to the far end of the system – all voltages
- Make damn sure the test leads and jumper leads have continuity!
- Chase the demon
  - Cut the system in half – determine which side is good and move on from there
  - Keep a log
    - Time/date, Action, Results
  - When your stumped make a list
    - Symptom, possible cause, test, result

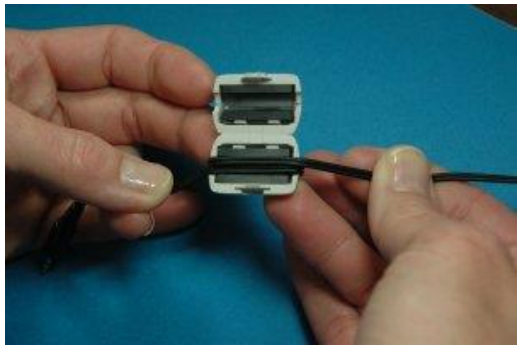


Bobbles, Beads and Other Tricks

- Ground unused ADC inputs
  - Unused ADC inputs will float and mimic the signal next to them and contaminate legitimate signals
- Capacitor between the signal and return
  - Choose Cap value to suit noise
  - If all else fails try a 0.1µF Cap between signal and return

Bobbles, Beads and Other Tricks

- Ferrite beads
  - A passive electric component that suppresses high frequency noise
  - An Inductor specifically designed to have maximum reactance at the noise frequency
  - Ferrite beads are one of the simplest and least expensive types of interference filters to install on preexisting electronic cabling
  - Several styles to choose from
    - In line
    - Differential
    - Wrap Around



Electric and Magnetic Field Probes

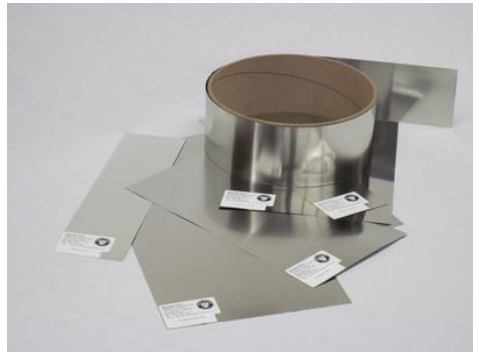
- Electric and Magnetic Field Probes are connected to an Oscilloscope and used to detect electric and magnetic fields

- Electric and Magnetic Field Probes are made by several companies – the best are made by the Van Doren Company (http://www.emc-education.com/)

- It takes practice to correctly understand what the probe is telling you

Mu Metal

- Mu-metal is a nickel–iron soft ferromagnetic alloy with very high permeability, which is used for shielding sensitive electronic equipment against static or low-frequency magnetic fields
- It is produced by the MAGNETIC SHIELD CORPORATION (www.magnetic-shield.com)
- There are several other similar products sold by other companies
- Available in braid, flex-conduit, sheets, shielded wire and several other forms
- Very expensive
- Must be applied correctly to be effective



The Solution: The Grounding Plan

- A grounding plan is a simple document used to coordinate the grounding, shielding and EMI needs of the Whole Team.
- For Example – A subsea project will have a riser team, corrosion control team, subsea controls team, topside power team and subsea power team.
- Address and state:
  - What is/is not electrically isolated from ground
  - How will fault current return to the source – is the shield/armor needed for fault current
  - Where shields are connected for which type of signals
  - Insure electrical control and power ground scheme does not interfere with corrosion control
- Can often be accomplished with a simple diagram

Codes, Standards and Additional Help

- API 14F(Z) - Recommended Practice for Design and Installation of Electrical Systems for Offshore Production Platforms
- IMCA D 045, R 015 - Code of Practice for The Safe Use of Electricity Under Water
- IMCA R 005 Rev. 1 – High Voltage Equipment: Safety Procedures for Working on ROVs
- IEEE Std 45™-2002 IEEE Recommended Practice for Electrical Installations on Shipboard
- IEEE 142 Recommended Practice for Grounding Industrial and Commercial Power Systems (*Green Book*)
- National Electrical Code (NEC) & National Electrical Code Handbook
- https://www.benderinc.com/ check out the literature section – lots of good stuff
- **The Art of Electronics** by Paul Horowitz & Winfield Hill
- **Troubleshooting Analog Circuits** by Robert Pease
- Van Doren Company (http://www.emc-education.com/) – the best EMI mitigation classes available

The End

Questions?