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
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 car’s 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
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 known 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”.

\[Z = \sqrt{R^2 + (XL - XC)^2} \quad \text{(For Series Circuit)}\]

\[Z = \sqrt{R^2 + X^2} \quad \text{(For R and X in Parallel)}\]
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
    ▪ $\lambda = 3000$ 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 2\textsuperscript{nd} 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 than 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*)
- [https://www.benderinc.com/](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/](http://www.emc-education.com/)) – the best EMI mitigation classes available
The End

Questions?