Applied EMI/RFI Techniques

A checklist for mitigating and understanding electrical noise in automation equipment

1. What is EMI, RFI and EMC?

Electro Magnetic Interference (EMI) or Radio Frequency Interference (RFI) is unwanted electrical noise that can interfere with signaling or communication equipment. There are three components to an EMI/RFI system. The noise source, the transmission medium, and the noise receiver or victim. EMI and RFI are very often used interchangeably but EMI is the appropriate term when referring to lower frequencies and RFI is the appropriate term when referring to higher frequencies. For the purposes of this document all noise will be referred to as EMI unless a distinction is necessary.

Electro Magnetic Compatibility (EMC) describes how compatible a device is to EMI. An EMC device will have low levels of EMI emissions so it will not interfere with other devices. An EMC device will also have appropriate shielding and filtering so interference from other devices will not negatively affect the device.

Note: The faster the rise time on a PWM device, the more noise it creates. A drive that has 4 kHz switching frequency has many harmonic frequencies which produce problematic emissions. The harmonic frequencies that affect sensitive equipment the most span from 8 kHz to over 100 MHz. Reducing the PWM carrier frequency reduces the effects and lowers the risk of common mode noise interference. Higher carrier frequencies are less efficient for the drive, but lower carrier frequencies are less efficient for the motor. Restricting the propagation of electrical noise as close to the noise source as possible is the best way to protect sensitive devices from EMI.

2. Types of EMI noise

Common Mode: Noise that is conducted on multiple conductors at the same time and propagates in the same direction. PWM AC drives (almost all VFD drives sold today) can produce high frequency common mode noise.

Differential Mode: Noise that travels on the signal line and ground line in opposite directions. It is induced on a conductor with reference to ground.

3. How EMI is Emitted

Conducted EMI: Lower frequency noise that tends to remain along or within close proximity to the conductor path.

Radiated EMI: Higher frequency noise that may utilize a conductor path and upon meeting a device or cable that acts as an antenna will transmit airborne electromagnetic interference over great distances.

4. Types of EMI Coupling

Capacitive coupled noise: An electric field coupling that is caused when EMI voltage spikes present in the source conductor causes unwanted noise on a parallel victim conductor. Capacitive coupling is more of a concern at high frequencies.

Inductive coupled noise (or magnetic noise): Current based and propagated in the magnetic field in higher current cables. This noisy magnetic field induces current into the victim conductor. Inductive coupling is more of a concern at higher currents.

Common impedance coupling: Transmitted through conductors and occurs when current from two or more sources flow through the same conductor.

5. Sources of EMI

- **A.** PWM amplifiers and DC drives.
- **B.** Servo drives.
- **C.** Variable frequency drives.
- **D.** Switch mode DC power supplies. If the power supply does not have a big capacitor and transformer on it (linear power supply) then it is a switching power supply.
- **E.** Switching of inductive loads (contactor and solenoid coils).
- **F.** Lightning.
- **G.** Static electricity and ESD. Nylon or other polymer based conveyor belts can generate high amounts of static electricity.

6. Victims of EMI

Encoders: Symptoms may include jumping around of encoder counts when still and non-repeatable positioning when moving.

Tachometers: Symptoms may include incorrect speed reporting or unexpected speed fluctuations.

Analog signals and measurement instrumentation: Symptoms may include unexpected voltage spikes, ripple, or jitter on the analog signal causing incorrect and non-repeatable readings. Instead of a 0-10v analog signal, use a 4-20mA if available. A 4-20mA measurement signal is less susceptible to noise than a 0-10v signal.

Communication networks and devices: Symptoms almost always include loss of communication or errors in reading or writing data.

PLCs and other microprocessor devices: Symptoms can include loss of communications, faults or failure in the PLC or processor, digital inputs or outputs to trigger unexpectedly, analog inputs or outputs to report the incorrect value.

7. How to measure EMI

- **A.** Spectrum analyzer
- **B.** EMI analyzer

C. Oscilloscope
   1. FFT
   2. Victim wire measurement to ground

8. How to avoid EMI

A. CABLES

1. Cables with high potential to emit noise are motor cables, mains cables, high DC bus cables, and circuits with switching inductive loads.
2. All cables should be routed close to grounded steel plates or frame components.
3. When control cables must cross motor cables make sure they cross at 90 degrees.
4. No unterminated wires or floating wires. If you have spare wires in a multi-conductor cable be sure to ground the wires.
5. Limit cable lengths of motor leads to as short as possible. The longer the cable the more it acts like a transmission antenna.
6. Long signal cables are also more susceptible to EMI pickup than short cable runs. Therefore, keep all cable runs as short as possible.
7. Wire gauge: as the wire diameter decreases, the impedance increases. Higher impedance wire will broadcast more noise than lower impedance wire. Therefore, when selecting the wire gauge for the motor power wires, power supply wires and ground wires it is better to err on the side of being too thick rather than to thin. All ground wires must be a heavy gauge and be as short as possible. Ground braids will ground out more noise than just stranded wire due to the skin effect at high frequencies. Since high frequency travels on the surface of a conductor the more strands there are the better noise immunity.
8. Minimum distance between motor and signal cables is 10cm for every 10m of cable length when you must run them parallel to each other.
9. Do not daisy chain wires going from one power supply to several amplifiers. Each pair of wires going to each amplifier from the power supply should be twisted.
10. Run common wires of a device in a twisted pair, twisting signal supply and return leads together as close as possible. A cordless drill can be a quick way to twist wires together.
11. Twist cables together. For a brushless motor twist all three motor wires and the motor case ground wire together as a group. For brushed motor or voice coil twist the two wires and case ground wire together as a group. Six twists per foot.
12. Never run signal or control cables in the same conduit or raceway with AC power lines, conductors feeding motors, solenoids, SCR controls, and heaters, etc. The cables should be run in metal conduit that is properly grounded. This is especially useful in applications where cable runs are long and portable two-way radios are used in close proximity or if the installation is near a commercial radio transmitter.
13. Sensitive signal wires within an enclosure should be routed as far as possible from contactors, control relays, transformers, and other noisy components.
14. When running noisy cables in conduit be careful not to attach the conduit to the buildings steel structure. This can often be a lower impedance ground than your

intended system ground, resulting in the entire ground grid of the plant to become noisy. Instead of using conduit try using shielded or armored cable that has a PVC jacket. Use shielded cables on the input and output of a motor drive or noise source.

15. When routing cables avoid creating loops. A loop of wire is a very effective antenna in both transmit and receive modes.
16. Fiber optic signals are not affected by EMI. This can be a good alternative to signal conductors that are very susceptible to EMI.

B. GROUNDING & SHIELDING

1. Proper grounding and shielding is the cheapest and one of the most effective methods to reduce EMI in a system. All grounding points should have large surface areas.
2. There are three basic types of grounding schemes: fully grounded, high resistance grounding, and ungrounded.
    a. An ungrounded system is just that, no grounding conductors. Without the presence of a path for the noise to be controlled, the noise will find another path and it will be a path you don't want.
    b. A high resistance grounded system will have a high impedance grounding conductor. There is a direct path to ground but it is not as good as a fully grounded system. Plus a high impedance conductor radiates more noise. This type of grounding scheme is typically used for applications where ground fault currents need to be minimized.
    c. A fully grounded system is one where there is a proper grounding conductor which provides a direct low impedance path for common mode noise currents.
3. When grounding a drive or other noise source use braided grounding straps on all PE grounding studs and connect to the backplane using the shortest braid possible.
4. The diameter of a grounding conductor is not the only criteria for how you should choose a conductor. For EMI mitigation, surface area of the conductor is the more important factor since high frequency EMI travels on the surface of conductors. Therefore, a finely multi-stranded wire is better than a solid wire. A braid is the best option. Always make sure there is enough ampacity of whatever conductor you choose.
5. Central point grounding reduces the chance for current loops.
6. Ground loops occur when two or more grounding points are at slightly different potentials. This results in high currents through the ground network, allowing more noise to couple to the conductors. Sometimes an unshielded cable can be less noisy than one with a shield that is grounded at both ends if there is a significant ground loop present.
7. The following should be securely grounded at the central grounding point where possible: amplifier case, motor case (if very close to the drive), controller case, power supply case, and cable shields.

8. Braided shielding or double shielding. All shields should be grounded at both ends. Shields grounded at both ends can create ground loops and will amplify noise rather than reduce noise unless there is a designated grounding wire with the cable to keep the ground planes on each end at the same potential. If you must only have one end grounded do so near the source of the noise.
9. Foil shielding on cables will block higher frequencies better since a braid will have holes in the barrier that the high frequency wavelengths can escape through.
10. Braided shielding blocks lower frequencies better since foil has a higher resistance due to it being thinner. The thicker braid suppresses the lower frequency wavelengths better.
11. Foil shielding on cables is good, braid shielding is better, and braid over foil shielding is best.
12. Do not interrupt or cut the shielded braids if at all possible.
13. List of recommended methods of connecting the shield, in order of their effectiveness.
    a. Connect the shield to earth ground at both ends of the cable, usually when the noise source frequency is above 1 MHz. This is best provided there are no ground loops in the shield.
    b. Connect the shield of a cable only at the panel or source of the noise (drive) where the unit is mounted to earth ground.
14. Ground the cable shield with proper 360 degree shield clamps or saddle clamps. Twisting the braid into a pigtail and attaching to the backplane is a less effective way to ground due to the higher impedance.
15. When running analog signal lines, ground the braided shield at the control cabinet end only. Leave the field end of the braid unterminated.
16. When running digital signal lines ground both ends of the braided shielded. If there is a difference in potential on the two grounding points run a separated ground conductor in parallel with the signal line. This will keep ground current loops from forming on the shield. Ground current loops can carry more noise than a conductor that is properly grounded.
17. Run power and motor cables in separate conduit from control and signal cables. If possible, motor leads should be isolated in their own conduit run.
18. If running power and signal wires in the same cable tray is unavoidable, place grounded metal dividers between the power cables and signal cables.
19. Separating noisy cables in an enclosure is a must since there are a lot of unshielded wires in a panel. If you cannot separate the noisy wires from the clean by at least 12 inches, then use conductive barriers between the cable runs.

C. FILTERS

1. Isolation or noise mitigating transformers can be used at the supply of the machine in order to assist EMI from radiating in or out of the machine.
2. Place filters as close to the noise source as possible with the shortest length of cable feasible. These wires should also be twisted together.
3. When mounting the filter use zinc coated or tin plated screws.

4. An AC Line Filter can filter noise and keep it from getting onto the AC power grid. An AC line filter should be mounted directly to a grounded frame or backplane. The filter should be mounted as close to the point where the AC power enters the enclosure as possible. Also the AC power cable on the load end of the filter should be routed as far from the AC power cable on the supply end of the filter and all other cable and circuitry to minimize RF coupling.
5. Ferrite Suppression Cores, Toroid Cores, or Chokes such as the Roxburgh Toroids, can be used to attenuate common mode noise. Take the motor leads and wrap them around the suppression core as many times as reasonably possible, usually 4 times is adequate. Make sure to strip back the cable shield and only wrap the motor wires. There will be two wires for brushed motors and three wires for brushless. Wrap the motor wires individually around the suppression core at 120 degrees from each other and leave the motor case ground wire out of the loop. The suppression core should be located as near to the amplifier or drive as possible.
6. Inductive Filters or Line Reactors added in series with the motor are used to increase the load inductance in order to meet the minimum load inductance requirement of the amplifier. They also serve to counteract the effects of line capacitance found in long cable runs and in high voltage systems. These line reactors can be used in place of ferrite suppression cores.
7. Do not operate other mains equipment on the output of a mains filter when the filter is used for a motor drive. Motor drives require their own filter. In some highly sensitive EMI applications it may be necessary to use an EMI mains filter on each drive.
8. If powering single phase equipment from a filtered three phase supply, be sure to keep the current draw balanced between phases. An unbalanced current draw within a three phase filter will degrade the ability of the filter to suppress unwanted EMI effectively.
9. Switching of inductive loads such as a relays, contactors, pneumatic solenoid coils and other dry contact switches produces high RFI. The use of free-wheeling diodes across DC operated devices and the use of RC snubbers across AC operated devices can reduce EMI/RFI emissions greatly. Suppression diodes and RC snubbers must be placed directly at the source of the RFI emission or coil.
10. Slow acting switches should be replaced by fast acting or snap action switches, or better yet solid state relays where possible. A slow acting switch can have more bounces causing more arcs. A slow acting switch will also have an undetermined state for a longer period of time resulting in the conductor becoming an antenna for a brief period of time. The opening of a switch while carrying current will cause an arc. This arc created a wide spectrum (or broad bandwidth) of EMI. When opening the current flow to an inductive device the arc has a much greater voltage potential with the same wide spectrum of EMI resulting in greater transmissions of the unwanted noise.

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D. ENCLOSURE

1. An electrical enclosure also serves as a Faraday cage when properly grounded. All noise sources should be in a steel enclosure to help prevent the propagation and radiation of harmful noise.
2. Use a zinc plated backplane to provide a good ground. Don't use a painted panel. If you must use a painted panel remove the paint anywhere you attach grounding screws or mount devices with a metal chassis. Zinc will not corrode unlike the surface of a panel that had the paint scraped off. A corroded bond will have an increase in resistance which will make grounding less helpful. Stainless steel can be used also but it has a higher resistance than zinc so it is an inferior alternative to zinc. Anodized, yellow chromatized, and painted backplanes are not a good choice for EMC systems due to their inferior conductive properties.
3. Doors on an enclosure can act as antennas and should be grounded using a steel braid. If the door is large, two or three grounding braids per door may be required. Each grounding strap must bond directly to the enclosure. Daisy chaining these straps is not effective at reducing EMI as much as each one having a separate bonding point.
4. Proper layout on the backplane of equipment is very important. Noise sources should be contained to one far end of the panel. Any power or motor cabling entering or leaving the enclosure should do so quickly and not snake around the inside of the enclosure where it can induce EMI onto sensitive devices.
5. The enclosure should be made from magnetic steel for best radiated EMI protection. Stainless steel is not as good a choice for EMI protection as magnetic steel but may be required in some applications.
6. A well-grounded enclosure can shield most EMI but the small openings from cable glands and door seals can leak noise. EMI gaskets and cables glands can aid in attenuating this noise leakage.
7. Separate incoming and outgoing power by using separate entry and exit points from the enclosure.
8. For highly complex systems, using a separate enclosure for motor drives from all the control logic circuitry can help greatly.