Grounding and shielding for protection systems

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Summary

Properly grounding and shielding machine protection systems create unique challenges in large plants. When installing a protection system, numerous obstacles must be considered that are not an issue with smaller systems. Following best practices is not possible in many installations. As such it is important to know the limitations of each plant and plan the installation around them.

The consequences of poor grounding and shielding include: lightning vulnerability, false vibration spikes during switchgear activation, false vibration signals that appear even when the machine is off, loss of communications and false trips caused by interference (such as keying a radio near a sensor).

When designing a good grounding and shielding system keep in mind two clichés:

1 When thinking of weak signals and signal integrity, ***current follows the path of least resistance***.
2 When thinking of high energy and safety, ***current will follow any path to ground it can***.

When troubleshooting a potential ground fault issue, keep in mind that ground faults are safety hazards. Use proper isolation techniques until the ground fault can be identified and corrected. Do not attempt to correct the ground fault if you are not trained on proper procedures including Lock Out Tag Out, Arcflash hazards etc.

Definitions and terms

Bonding strap

A special type of ground cable that is made of braded wire to form a rectangular shaped strap. Commonly used when the ground must be able to both absorb high frequency noise and high amounts of current.

Braid shield

A type of shielded cable where small wire strands are weaved around the signal conductors. The tighter the weave (i.e. the smaller the gaps in the weave) the better the quality of the shield

Conduit

A protective pipe for cable. Although the primary purpose of conduit is physical protection, conduit can be used as a shield if properly installed.

Current

The flow of electrons between two objects of different potential, analogous to flow rate in a pressurized fluid system.

Foil shield

A method of shielding where the signal conductor is wrapped in aluminum foil.

Ground(ing)

A low impedance path to an object that can absorb a large amount of current (usually the earth) for safety and as a return path to complete the circuit in single ended systems. Usually ground is considered the reference or ***zero point*** for measuring voltage and is analogous to ***ambient pressure*** in pressurized fluid systems.

Ground bounce

An intermittent ground fault that occurs when a local ground temporarily ceases to act like a ground. They usually result from the connection between the local and main ground being overwhelmed by an energy surge, such as a lightning strike or switchgear activation.

Ground loop

A continuous ground fault where current flows in wires and bars that are supposed to be ground. They can be caused by equipment failure, ungrounding equipment to mask noise or by a multi-point ground where a connection between two different sources of power is unintentionally created.

IE (Instrumentation Earth)

In plants that use a multi-point ground, this is the ***clean*** ground used for sensitive instruments to protect them from noisy electrical equipment.

IS (Intrinsically Safe)

A system whose design has been certified to not cause a release of energy sufficient to cause ignition (e.g. a spark), even under fault conditions.

Multi-point ground

A grounding philosophy where ***clean*** and ***dirty*** electrical circuits are grounded to separate paths to prevent contamination.

PE (Protective Earth)

In multi-point grounding systems, this is the safety ground for high voltage equipment.

Shielding

Surrounding a weak signal with a protective path to ground to absorb any electrical interference and keep that interference away from the signal. This in effect creates an antenna surrounding the signal conductor so that any interference is absorbed to ground before it reaches the signal.

Single point ground

A grounding philosophy where all components are tied to ground at the same point to prevent ground currents from a ground bounce or loop.

Voltage / potential

The amount of electrical energy stored in a volume of electrons, analogous to pressure in a fluid system. Similar to pressure, all instruments capable of measuring voltage give a relative reading. Also similar to pressure, unless stated otherwise, pressure readings are assumed to be relative to ambient and voltage readings are assumed relative to ground.

Single point ground verses multi-point ground

Modern best practice calls for a ***single point ground***. However, most plants have a multi-point ground, due to the realities of a large plant, and legacy best practices. Most plants have separate ground bars for PE (Protective Earth), IE (Instrumentation Earth) and if using Zener safety barriers, IS (Intrinsically Safe) grounds. An issue is that a protection system will access all of these grounds. The protection system itself can form a parasitic bridge between those grounds, making the protection system vulnerable to ground faults and transmitting noise from PE to IE. The reason for this is the protection system powers the sensors. Considering this, the protection system should be grounded to IE. However, as the protection system has an accessible connection to high voltage, most electrical codes dictate it will be connected to PE. Regardless of which ground is directly connected to the protection system, there will be at a minimum a coupled or indirect connection to other grounds, as the protection system powers the sensors and electrical current must return to its source. As long as both grounds are ***in sync***, this is a non-issue and the system will work fine. However, if there is a ground fault, the protection system will be an unintentional link between those two grounds. There are two main types of ground faults:

1 Ground bounces are intermittent, and caused by an event that overwhelms the grounding system.
2 Ground loops, which are caused by equipment failure or installation issues, will last until the issue is fixed.

Figure 1, depicts how a ground bounce can cause a failure of the protection system. In this example, a lightning strike occurs on IE of a multi ground system. Because the rack is grounded to PE, but is powering the sensor connected to IE, the fault current from the ground bounce on IE can flow through the protection system to PE, potentially damaging the protection system in the process.

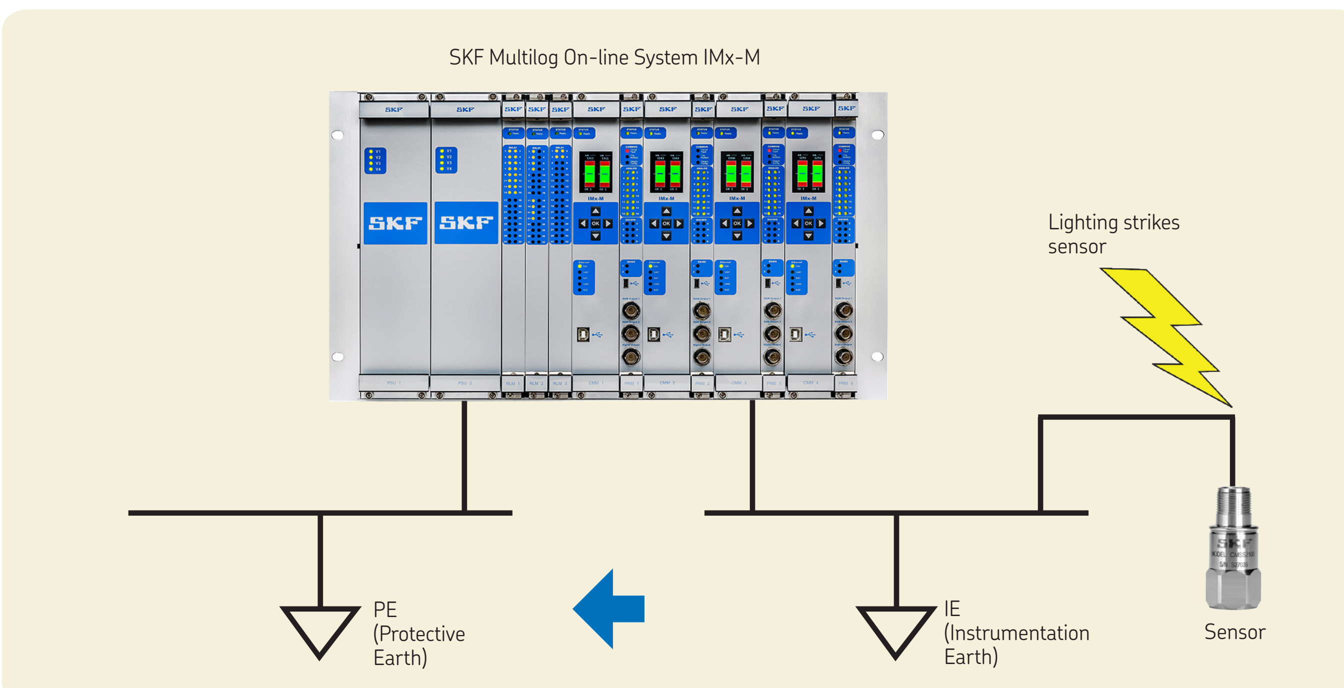


Figure 1. Illustration of how the protection system can sustain damage due to a ground bounce on one of two grounds to which it is connected.

Scenarios that can cause a periodic ground bounce include:

- Lightning strikes
- Shaft voltage accumulation and / or discharge
- Sensor installation that provides a parasitic discharge path for shaft voltage accumulation (i.e. tie wire that runs near the non-isolated part of an isolated bearing)
- Faulty or inadequate isolation from switchgear equipment (including accessories connected to the switchgear, such as arching breakers)
- Defective switches or relays

Symptoms of ground bounces include:

- Repeating spikes in the sensor's signal (especially visible on a waterfall plot) that are not logical to be the vibration signal. Often these will show some broadband spikes, and at low frequency.
- If sensors are installed in an X-Y pair, spikes affecting both sensors simultaneously (which would not happen for a vibration anomaly, such as a bearing fault).

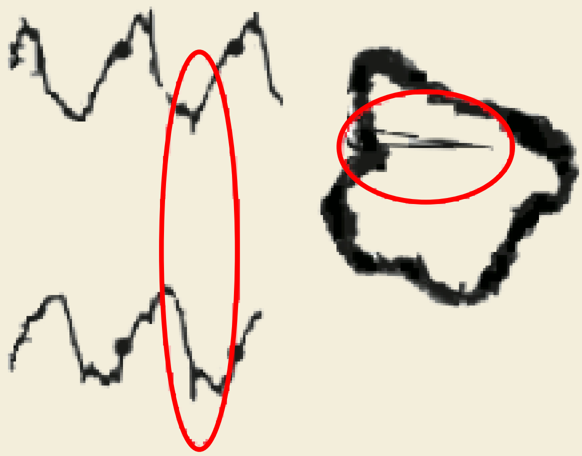


Figure 2. The Orbit Time Waveform plot can reveal the existence of ground bounces if the sensors are installed in an X-Y pair.

- If 2 and 3-wire sensors are installed on the same bearing (such as a proximity probe and an accelerometer or velocity sensor) a spike that is pronounced on the 2-wire sensor, but not as pronounced or not immediately visible on the adjacent 3-wire sensor.
- Vibration spikes that are accompanied by a DC bias shift, followed by a ***ringdown*** of this bias to the normal level.
- Vibration spikes that are accompanied by simultaneous fault detection on an unrelated channel (this means that the ground bounce is so large – it has caused the protection system itself to bounce). These can be discovered by examining the events logs for the protection system.

Scenarios that can cause a ground loop include:

- Violation of bearing isolation due to improper sensor installation. (This is often the case when a sensor is mounted on an isolated bearing, especially if mounting blocks and / or studs are made of conductive material or using a conductive tie wire links the nonisolated part of the bearing to the isolated portion.)
- Installation of a case grounded sensor on machine that is not grounded or not adequately grounded.
- Unequal resistance to ground in a multi-ground system (due to plant age and deteriorating conditions, accidental unground of one of the paths, etc.).
- Faulty switchgear equipment.
- Intentional float (unground) of all or part of the system to mask noise issues.

NOTE: This should never be done, as it is masking issues, not fixing them, and can create a safety issue.

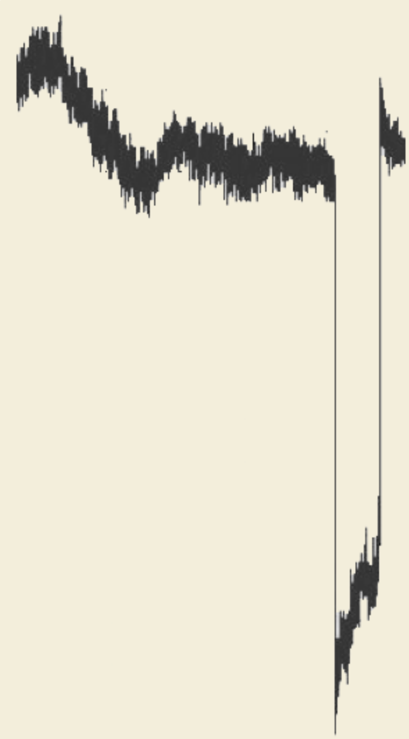


Figure 3. Oscilloscope capture of the Bias Output Voltage. Under normal conditions this should be a constant reading. The shift and "Ringdown" are clues to a re-occurring ground bounce.

- Accidental or undocumented ground paths introduced into the system. Examples:
  - USB and RS-232 are ground referenced protocols, and connection of a computer to these ports can induce a parasitic path to a new ground.
  - Burr inside conduit run or worn insulation causes signal wire to be grounded.
  - Undocumented ground path at a junction box or terminal strip.
- Sharing a single sensor with multiple systems without using a buffer or isolator (a big issue with speed sensors, as often both the protection and control system need access to the speed sensor)

Symptoms of a ground loop include:

- A change in readings, arc or fault status of the protection system that correlates to inserting a cable, closing a switch, a change in relay state, turning on unrelated equipment (including lights).
- Readings that are known to be incorrect, and have a common connection point (connected to the same monitoring card or bearing).
- Verification with battery operated test equipment (which is usually immune to ground loops) yields a different reading than with grounded equipment.

Good, Better, Best way to protect against ground bounces and / or faults

Unacceptable

- Floating all or parts of the system to mask noise issues.
- Using machine cases or skids for grounds (unreliable).
- Sharing sensors between two systems without isolation or buffering.

Good

- All sensors (especially the speed sensor) are connected to directly to one and only one system. All other systems either have isolated inputs, use a buffered copy (if both systems are connected to the same ground) or isolated copy of the speed sensor.
- Sensors on generators or other high voltage equipment that relies on isolated bearings for safety use nonconducting (i.e. phenolic) mounting blocks, with tie wire routed as to not violate isolation.
- Take and archive pictures of all sensor installations (especially those in confined spaces), cabinet ground connections, areas with bonding strap, etc., so that if any grounding issues occur they can aid in the investigation.

Better

- Plant walkdown confirms that the actual grounding matches the plant drawings
- Connectors and ports that could accidentally introduce another ground are protected (such as by a locked cabinet door) so that these features cannot be accessed without control personnel being aware of the access.

> **NOTE:** IS grounding practices mandate that such connectors and ports must be made inaccessible.

- If it is known that the plant is subject to ground faults, and the source has not yet been located, a temporary workaround is to install bonding strap between the PE and IE ground bars in the same cabinet (or panel) used by the protection system. This will ensure that when a ground fault occurs, the bonding strap is the path of least resistance and will deflect most of the fault current away from the protection system.

> **NOTE:** This does not fix the root of the problem, only protects the protection system from its effects. It should never be the permanent solution. Never do this on systems where IS ground is involved as this violates IS grounding principles.

Best

- Have a true single point ground. I.E., the protection system uses the same ground as all equipment that is connected to it. In larger plants (that span multiple buildings, for example) where this is not possible, use isolation or surge protectors on all signals that bridge the ground gap to guarantee no ground bounce can occur.

Table 1

Connection protocols that are usually ground referenced, and require isolation for use in live connections or IS installations	Protocols that by specification are node-to-node isolated, and are safe to use for live connections or IS installations
USB	Ethernet
RS-232	RS-485
RS-422	Fiber optic protocols
Buffered outputs	– – –
4 to 20 mA current loop	– – –

Intrinsically safe (IS) considerations

As protection systems cannot be made intrinsically safe themselves (any system powered by 120/240 VAC is capable of causing a spark), other means are often used to guarantee the protection system cannot transfer energy to the sensors in the hazardous area. These may include explosion proof housings, air purged cabinets, etc.; however there are two methods that affect protection system wiring. One method requires Zener barriers grounded to a dedicated IS ground bar for the sensors installed in the hazardous area. This ground bar is not to be used for any other equipment. The Zener barrier acts as a ***dump valve*** to divert any excess current to the IS ground path, and relies on that IS ground path to prevent an explosion. Another method uses galvanic isolators, isolators that are designed to intentionally fail before enough energy can be transferred across the internal transformer. Isolators do not require a dedicated IS ground. There are special considerations for each of these options.

Keep the following points in mind:

- Single point grounding is impossible if barriers are used. This is due to the requirement that the sensors ground to IS ground, but not the rack power supply.
- Regardless of which method is used, there must be 50 mm of separation (at all points, no exceptions allowed) between wires that will enter the hazardous area and wires that will not. Both the rack layout and cabinet design must be designed to not violate this requirement. A common practice is to have separate monitoring modules for the sensors inside the hazardous area and those outside the hazardous area. The sensors going to the hazardous area are then connected to modules on one side of the rack and have the cables routed up from the rack, while all other cables are routed down from the rack. Some countries mandate wires going to the hazardous area be colored blue or striped blue at periodic intervals, while other countries reserve the color blue for other uses, and require hazardous area wires be labeled ***IS*** at a specified interval.
- Power supplies approved for use in IS areas are designed with an isolated flyback transformer, such that the high voltage side can be grounded to PE while the low voltage side (that powers the sensors) can be connected to IS. A protection system that is designed with this in mind will have separate ground connectors that are bridged together for non-IS installations to enable a single point ground. However, this is not enough to prevent indirect or AC coupling of noise to and from the sensors.
- Be advised that if the protection system (and similar equipment) is not explicitly designed to accommodate multi-point grounds, floating (ungrounding) the power supply to the rack can leave the rack chassis vulnerable to a ground fault.
- IS grounds require redundant ground connections certified as able to maintain a resistance of less than 1 ohm with minimal temperature rise while subjected to severe abuse (tens of amps of current for over one minute). All ground paths must maintain a cross sectional area of 4 square milimeters at all points (in US wire gauges this is approximately 10 AWG). This is significant in installing a protection system, as specialty connectors are required. Commodity connectors (spade, lug, etc.) do not meet this requirement.
- If there is a ground fault, IS ground will surely be the stronger ground.
- Any grounded connector or port must be inaccessible or removed. Any live connections (such as a laptop) must be done using an isolated interface.
- Zener barriers will degrade the signal by a non-trivial amount (typically 4%). IS Isolators do not significantly degrade the signal, but add a phase error significant enough to affect integrated and summed measurements (such as Shaft Absolute vibration). When using these devices, expect these errors and keep the protection (relay) logic simple enough to be minimally impacted. It is possible to compensate for the barrier loss in software; however, it is not possible to correct for the phase error introduced.

Shielding

Shielding creates a path of absorption for any electrical interference away from the vulnerable signals by surrounding the signal conductor with metal and to terminate the shield to ground at one end. In large plants, often the run will be broken into segments, with junction boxes along the way. However, the same philosophy still applies; each run segment should be appropriately shielded and terminated. If there is no place to terminate the ground at the interim junction box, the incoming and outgoing shields on the cable should be bonded together as a ***pass through***.

High frequency noise (Radio frequency and above) requires the shield to have 100% coverage, as the waves are very small and can penetrate any crack, seam or gap. However they do not contain much energy and do not require significant thickness of metal to dissipate. Lower frequency noise, (50/60 Hz electrical) cannot penetrate small gaps, but requires cross-sectional area to conduct well enough to dissipate the energy.

Braid shields

Braid shields, being made from round wire, have cross-sectional area, but no braid can provide 100% coverage. As such they are useful for electrical frequency noise, but not ideal for radio frequency noise, which can penetrate the gaps in the weave. IEEE requires a braid shield to have 85% coverage, despite the fact that low end cables with braid coverage of <60% is commonly found and sold as shielded cable. There are cables that have dual layer braid shield that can guarantee >95% coverage. However, these are expensive and only generally used when a cable must run long distances in parallel with electrical cable, without conduit, (such as up the length of a wind tower). API requires that if braid is the only shielding method used, the braid has >90% coverage.

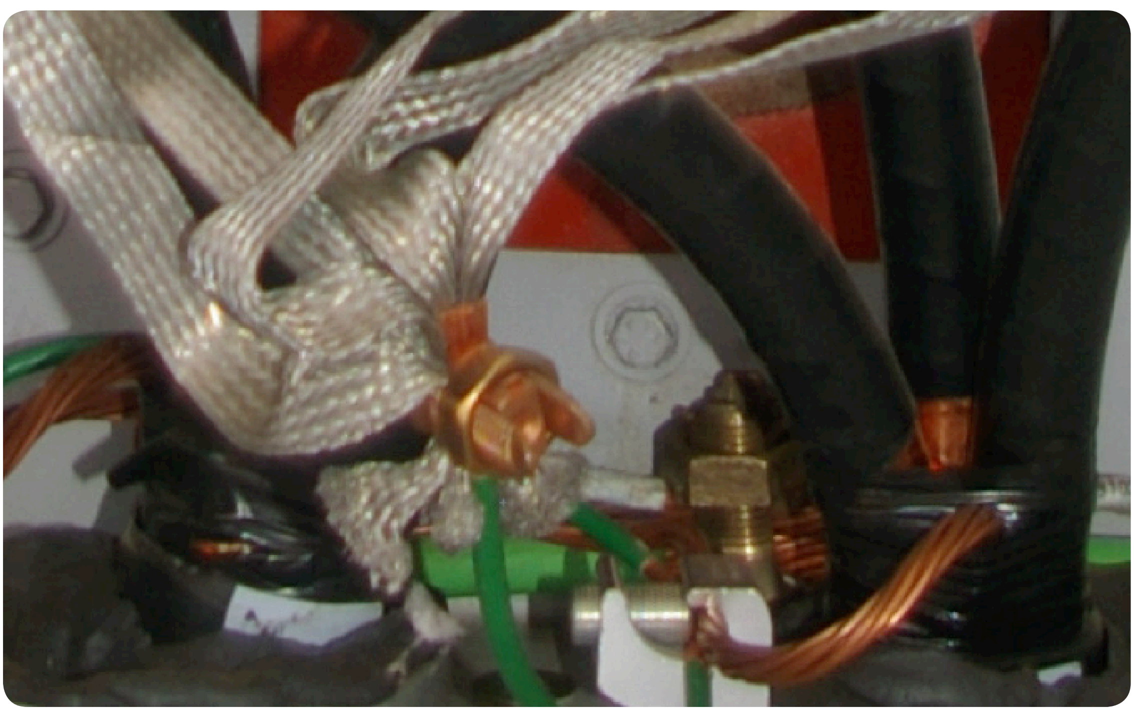


Figure 4. Termination of shielded cable showing bonding strap and specialty connectors to terminate shields to ground without creating bottlenecks.

Foil shields

Foil shields guarantee 100% coverage, as such are adequate for high frequency noise. They are not adequate for electrical noise, as the foil lacks thickness and is only a moderate conductor. A problem with foil shields is the difficulty in terminating the foil. True foil shields will use an oversized foil tape, where the excess foil is then folded around a drain wire to seal the seam. A low cost method of a spiral wrap of the tape around the signal conductors leaves an unsealed spiral seam, and is not considered a shielded cable by most standards.

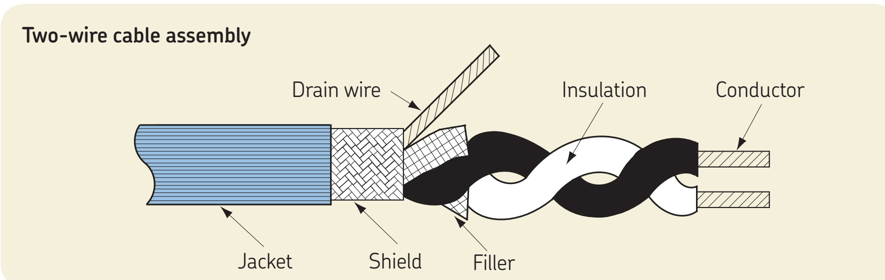


Figure 5. A typical foil shield cable with a drain wire.

Placement

IEEE recommendations call for signal and power cables to be separated by 1,2 meters *(4 feet)* in air, or 1 meter *(3 feet)* in soil. If an exposed cable exists that cannot be protected in the recommended ways, tucking the cable into the corner of an I-beam or angle iron will provide some protection. Cables that are strung tight will have more protection than one that loops or drapes. This should never be relied upon; however, is a known way to improve noise immunity of exposed cables.

Conduit

Conduit made from steel or aluminum can provide an excellent shield. However, it should not be relied upon as the only means, as installation flaws can damage the shield. Points to keep in mind:

- For galvanized pipe, the only means of making a reliable electrical connection is via the threaded ends. As such the fittings should be threaded (not socketed), and not have any breaks.
- Assume flexible conduit has a seam, unless specified as sealed. Most flexible conduit is made from a spiral wrap or from a corrugated sleeve with a seam (which can be sealed, but often is not).
- Cable trays are not sufficient for shielding. While they do have solid sidewalls (and sometimes top shields) that will significantly reduce outside interference, there are too many access points and unsealed seams to rely on trays alone. In addition cable trays do not protect against interference from a cable in the same tray.

Where to terminate

There are some EMC (Electro-Magnetic Compliance) guidelines that specify to terminate both ends of the shield. However, these guidelines were written for small systems, and do not take into account that in industrial environments the ground at the machine end of the cable is generally unreliable. Terminating the shield here could create a ground loop or induce noise onto the signal wire, rather than protect it from noise. For protection systems, it is usually better to use shield pass throughs for the cable junction at the machine, and terminate the shield at the rack end of the cable. There are scenarios where there is good ground available at an intermediate junction box. If one exists, it is acceptable to terminate that cable run at the junction box.

Symptoms of poor shielding

- Increase in signal reading when adjacent equipment is turned on.
- Erroneous noise – 50/60 Hz signal components even when machine is off.
- Signal spike when breaker or switchgear engaged.

NOTE: This is also a symptom of a ground bounce, the difference is a ground bounce should affect all signals equally, while a shielding issue should affect the signals whose wires are closest to the noise source more.

- Signal levels that increase or spike when a radio is turned on, keyed or follow a radio or wireless phone's signal.

Troubleshooting shielding issues

There are two general approaches to troubleshooting shielding issues. Both involve mapping out all points where the cabling for the point affected by the noise are accessible (junction boxes and connectors). Starting at the end closest to the sensor, break the connection to the sensor and place a dummy load (such as a resistor), and watch for differences in the noise levels. Restore the connection and move to the next accessible point until the segment of the cable where the noise is being injected can be determined. If there are monitoring points that are and are not subject to interference in the same area. It may be possible to take a similar approach as above, but instead of using a dummy load, swap the connection to the ***good*** and ***bad*** points, until the noise ***moves*** to the other channel.

Shielding, Good, Better, Best

Unacceptable

- Shielding that gives less than 100% coverage (i.e. single layer braid shield without conduit, foil or other means of protection).
- Using machine ground for shield.

Good

- Dual shield cable, foil with drain wire and >60% coverage on braid. 60% is acceptable (but not ideal) in this case as the braid is not the only shield.
- Drain wire is terminated to ground at one end.
- 1,2 meters *(3.9 feet)* separation between signal and power cables.

Better

- Dual shield cable with foil and 85% braid coverage.
- signal cables placed in separate cable trays from power cables, with 1,2 meters *(3.9 feet)* separation.
- Termination is made by both drain wire and by side terminating the weave of the braid.

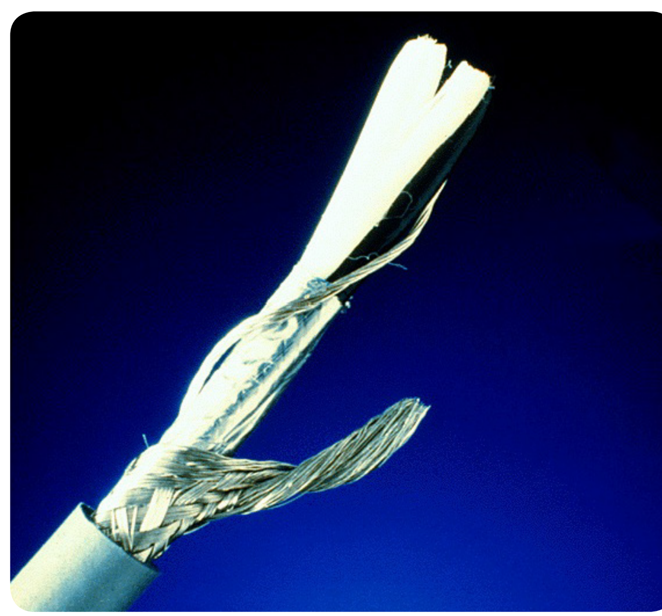
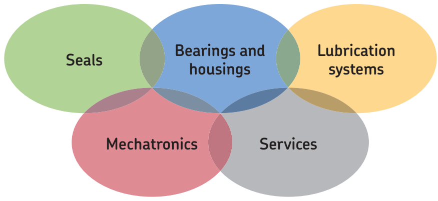


Figure 6. Photo showing one method of separating the braid so that it can be properly terminated. It is important to not just terminate a couple of strands of the braid in a noisy plant environment. Another option is to use a pick to enlarge a hole in the braid and exit the conductors via that hole. Photo copyright by Belden Wire and Cable, used by permission. Belden.com has additional shielding options and information.

Best

- Dual shield cable, either dual braid shield with >95% coverage or foil and braid. Cable in conduit with threaded non-swivel fittings. Drain wire landed directly to ground lug, with bonding strap available to bond both braid weaves and foil. Any exposed cable is secured to angle iron, I-beam or similar. Cables should be trimmed to avoid exposed slack, even if terminated in a junction box (which often does not have a sealed door seam). Cables that cannot be trimmed (i.e. tuned sensor cables) should have the slack wrapped around a toroid choke. This is a measure that is only required in extreme circumstances. However, it is not uncommon for power plants and radio transmission towers to be in close proximity, and sometimes these extremes are necessary.



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