WHITEPAPER

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Best Practices for Grounding Your Electrical Equipment White Paper

Part 3 of 3:

Examining the role of ground as a voltage stabilizer and transient limiter, along with tips on improving safety and signal integrity .

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Preface

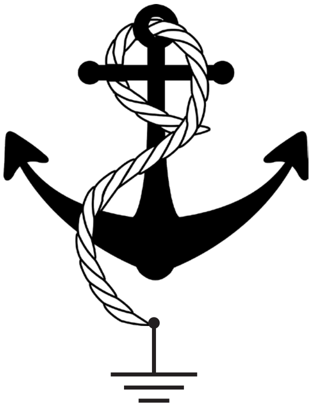
This paper is part three of a three-part series that examines grounding and its role in protecting personnel, protecting equipment, and ensuring the integrity of electrical signals. In this part, we will examine ground and its role as a voltage stabilizer and transient limiter, as well as offer some tips on what you can do to improve your connection to ground to realize benefits to safety and signal integrity.

Part one of this series addressed the concept of grounding, the AC power system and its use of ground, and gave three main reasons why we ground electrical equipment: for safety, to stabilize electrical signals, and to limit transient voltages and current.

Part two of this series reviewed the use of ground as a means of protection from ground faults. We also looked at how ground fault circuit interrupter (GFCI) devices operate to protect us from severe shock.

Grounds as a Voltage Stabilizer

Think of voltage as a force that causes current to flow in any conductor—a greater voltage results in greater force that drives higher levels of current. High levels of current can drive errant circuit behavior, possibly damage equipment, and may even lead to personal injury. We want to ground signals to stabilize them and keep them from floating, and we do this to limit voltage magnitude and variation.

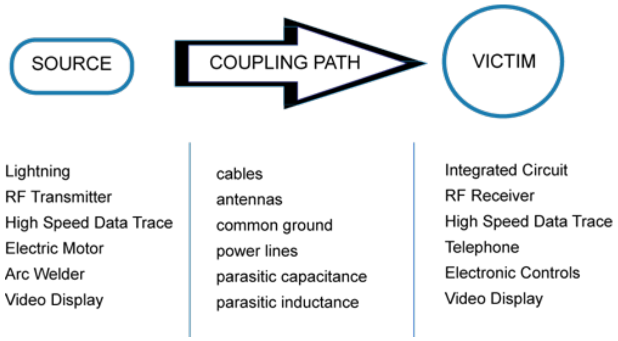


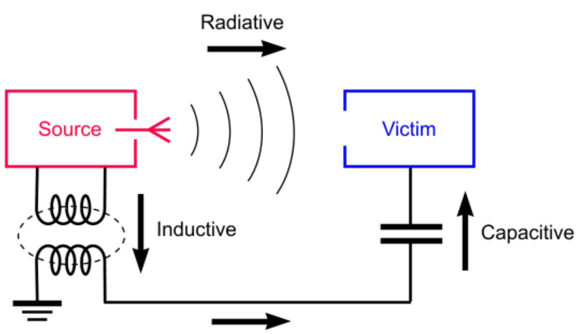
In practice, connecting to ground helps stabilize signals during normal operation, acting like an anchor that limits the magnitude and variation of voltage. On the other hand, like a boat without an anchor, an ungrounded signal will “float”. Floating a signal will generally make it more susceptible to common-mode noise interference. A common-mode signal is a signal that appears “common” to a set of floating points. Common-mode noise signals can be inductive or capacitive coupled from external sources, or they may be driven by the circuits themselves. All electronic circuits are limited in their ability to filter or reject common-mode noise, especially if the potential of a measurement point is allowed to float outside the limits of the circuitry. The end result is that common-mode noise can drive spurious measurements or spurious output behavior. One example of the importance of grounding is with respect to differential mode measurements, such as that used for some types of instruments, like thermocouple amplifiers. If you do not earth ground one lead and anchor it from floating, you will likely note that the measurement appears noisier and more widely variant, and that is assuming that a point of signal measurement doesn’t float outside of the common mode range of the amplifier, at which point it cannot be measured or processed by the circuit properly. This is why you will note that many connection diagrams for differential input pairs will show one lead (usually the minus lead) making a connection to earth ground.

Most electrical equipment and industrial instruments utilize differential filters and transient suppression devices at their wired connections to shunt potentially destructive energy from one lead to another and to steer this energy to ground. This same energy ultimately seeks a path to earth ground where it originated and can typically be dissipated more safely. Failure to apply ground to the circuit at the designated connection will leave the circuit vulnerable to damage, as the circuitry must then absorb and dissipate this transient energy in the absence of a clear path to ground. This connection to ground is very important and will help to extend the life of your equipment—always be sure to identify these connections to earth ground and make sure that you provide a low impedance path to ground at these points to protect your equipment from damage.

For electrical equipment, all connections to power are usually grounded at some point. The device may be optionally DC powered, but a conversion from AC to DC still occurs and a path back to earth ground usually exists. Isolated power sources usually ground their DC output power minus terminals. Inside electrical equipment, the power connection is often isolated from other parts of the circuit, such as its inputs, its outputs, its network connection, etc. Noise exists in each of these isolated circuits and takes many forms. In many applications, the DC power supply to the circuit itself will provide a path to earth ground at its DC minus terminal. Many instrument manufacturers recognize this and will often employ isolation capacitors connected inside their own circuits between the various isolated reference planes and the DC minus connection to the device, which is often indirectly earth grounded via the power supply. These capacitors significantly reduce radiated emissions from the device by providing a path to earth ground where transient energy on each of the isolated planes can be shunted through the capacitor on its way to ground. In this way with these devices, the earth ground connection at the power supply often serves as a kind of default path to ground for harmful energy, even if the other parts of the circuit have not been properly grounded. Still, do not be tempted to float isolated portions of your device and rely only on these isolation capacitors to provide protection, as they can never compete with a direct, hard-wired connection to earth ground. It’s always best to refer to your connection diagrams and wire ground connections as recommended.

Ground as a Transient Limiter





Modern powered circuits are awash in transient energy from many sources, coupled via many paths, as illustrated at left. Thus, the potential for encountering unintended voltage rise in electronic equipment is ever present via its connection to power, its exposure to ESD, and even its proximity to other electronic devices (by conductive, inductive, capacitive, or radiated noise coupling). Our connection to ground acts to make our circuits safe and will help to stabilize our signals. This ground connection also limits the potential voltage rise induced on our circuit, typically via lightning, line surges, and even during unintentional contact with higher-voltage.

To help filter the effects of unintended voltage signals, most electronic equipment will utilize differential filters, capacitors, and other transient suppression devices at their wired connections. The purpose of these devices is to shunt potentially destructive energy from one lead to another, usually in an attempt to squelch the imposed voltage and steer the resultant destructive current or charge to earth ground where it can be dissipated more safely. If you fail to connect ground to a designated wired terminal, you leave this energy with no place to go except through your circuit where harmful voltage levels and high transient current levels can wreak havoc and drive damage. So you should think of your connection to ground as an integral part of your circuit's transient protection. Without it, you leave your equipment unprotected and exposed to potential destruction.

For example, lightning occurs when atmospheric charge finds a path to earth. Any circuitry in this path, or in the presence of this path to earth, can be easily destroyed by the high voltages that are developed. Providing a low impedance path to earth for powered equipment will help to minimize the potential destruction of a lightning strike by keeping the resultant voltage increase above earth to a lower potential. Without a connection to ground, the energy will continue to develop its high voltage across a circuit, possibly resulting in damaging levels of current that may ultimately destroy the circuit. A low impedance connection to ground will instead help carry this energy into the earth before it destroys the circuit it is otherwise distributed across in its transfer along a path to earth ground.

Earlier I mentioned that a side benefit of a connection to ground is that it offers EMC benefits by lowering system noise and radiated emissions. It does this the same way that it works to squelch the effects of unintended voltage signals sourced by lightning and other sources—by stabilizing voltages and limiting voltage variations, and by providing a low impedance path to earth ground where transient energy can be safely dissipated. Without a clear path to earth ground, this energy will be forced through the circuit and drive signal error, erratic behavior, and potentially damage the circuit.

Improving Your Connection to Ground

At this point, you should recognize the importance of providing a good connection to ground—for personal safety and protection from electrical shock, to stabilize signals and minimize fluctuations, and to limit the magnitude of induced voltages and peak currents. As an engineer for a manufacturer of industrial instruments, I am often called to task for lowering a product's emissions or raising its EMC immunity with respect to ESD, EFT, and other interference. I can honestly say that most of the time, the solution to these problems lies in the correct application of earth ground. So how do you improve your connection to ground to help realize these benefits in your applications?

To go about improving your connection to ground, you can start by calibrating the way you think about ground. Specifically, you need to think of your connection to ground as a drain that you flush all the unwanted energy in your electrical system down (ground faults, electromagnetic interference, ESD strikes, fluctuations caused by nearby lightning, power line surges, transient noise, etc.). You want this drain to quickly accept unwanted electrical charge from your circuit. Now you wouldn't connect the drain of your home through a straw, or unwanted waste would back up and contaminate your home. Instead, you would want a wide-open pipe leading to your waste-water drain, and you would avoid angles and changes in direction, keeping this pipe as short and straight as possible to help prevent backup. It's the same way with ground—you want a wide-open, short and direct drain to earth that doesn't back "charge" up into your circuit. And just like the drain from your home, you can improve your connection to ground by making it short as possible and by increasing its diameter. Chiefly, with your connection to ground, your goal should be to reduce its resistance and its inductance by using a larger diameter or "thicker" conductor, and by keeping its path as short as possible. Because inductance and resistance both restrict the flow of current (as current through inductance cannot change instantaneously), you want to minimize both the resistance and inductance in your connection to ground so that it can more quickly drain transient energy from your circuit and dissipate it into the earth.

All conductors have resistance and voltage across the conductor acts as a force to drive current through the conductor. When you push current through a conductor, you establish different potentials at different points along that conductor related to the IR voltage drop through the conductor. Ideally, you want your ground to deliver nearly the same potential across it (ideally an equipotential voltage of 0V), such that any tie to ground will see the same ground potential. If you fail in this regard, you give rise to unwanted ground currents (ground loops) with possible negative side effects of increased noise and interference in your system. In practice of course, an ideal ground is impossible to attain, but there are still some things that you can do to approximate the ideal. Specifically, you need to pay close attention to how you are making your connection to ground. For example, you can avoid having your circuit grounds connect at different potentials by using a "star" grounding technique.

Star grounding is a concept where each ground connection (represented by each leg of a star) connects outward from the same point (the center of the star). When you wire ground to your circuit, perhaps to each isolated part of your circuit (like input, output, power, etc.), you strive to bring these connections together via separate ground returns to one point (this is the center of your star ground), using short and thick cables to minimize path resistance and inductance effects. The center of your star is usually chosen as the ground return of the power supply to the circuit. It is sometimes chosen as the common chassis connection where a conductive chassis makes its single connection to earth ground.

Some Basic Ground Rules for Wired Equipment

Consideration of ground can be very complex and application specific. But in many of these applications, when we make wired connections to ground and to electrical equipment, there are a few rules of thumb that are helpful:

- For isolated power applications where a connection to earth ground is not apparent, ground should be chosen as the common return path from power supply (DC minus). It may be necessary to hard-wire earth ground to this point if an earth ground connection is not already made by the power supply.
- Do not ground a signal at more than one point. Typically, a signal is grounded at its source (including its shield).
- In general, as stated above, we try to never ground a cable at both ends. But one possible exception to this rule is when we are grounding cable shields in small signal applications. For most applications where only small differences in potential exist between grounds at each end of the cable, our equipment will work better when its shield is grounded at each end of the cable (at a minimum, ground it at the end closest to the noise source). Another exception is where your equipment connects to power, as DC powered equipment will often connect earth ground at the power supply minus terminal, but you should additionally include a connection to ground local to the instrument. This is done not only to stabilize applied voltages, but also because internal suppression devices in the instrument need a local, low resistance, low inductance path to shunt potentially destructive energy.
- For EMC purposes, a wired signal between devices should have earth ground applied at the end of the cable nearest the noise source of the signal, or nearest the noisiest device. Failure to provide a path to ground at the "origin" of the noise may result in the cable and/or its shield becoming an antenna for this noise, increasing its power and spread into other areas of the circuit, as well as potentially increasing system emissions.
- Do not use the chassis of the device as the ground conductor (i.e. make only one ground connection to the chassis). Note that many devices are required by code to have a safety ground connection to their metallic chassis or enclosure, but the chassis should never be used as a return path for load current to the device (for "safety" ground, it is sometimes used only as a return path for fault current). Note that the chassis connection to earth ground is sometimes used as the center of a star grounding scheme for the enclosed circuit.

- Many instruments are housed in plastic enclosures and may not make a connection to earth ground via their chassis. These instruments usually rely on direct-wired connections to earth ground at their terminals, as directed in their connection diagrams. In general, signal connections to these devices should be earth grounded at the end of the I/O cable nearest the instrument. This is because the instrument needs a low-impedance/low-inductance path to earth ground locally, to allow its various filters, capacitors, and transient suppression devices to shunt potentially destructive energy to earth ground without being impeded by high levels of inductance and resistance in the path to earth.
- Do not bundle noisy or high-energy signals or power with low level signals. Route all AC power wires away from sensitive signals and signal paths.
- Do not duplicate ground connections to the main power line at different points—try to connect all AC powered devices to the same power outlet when possible and safe. Similarly, use a star-grounding concept when making ground connections to your circuit.
- Do not combine or bundle isolated signals in the same shield or conduit.
- Do not allow conductive material to float unattached to any ground (it should connect to ground at one point).
- Do not leave unused shielded conductors in a bundled cable disconnected from ground. Ground unused conductors of a bundle at the load. In general, ground the cable shield at the signal source (or at both ends).
- Minimize the length and loop area of the wires that break-out from a bundled or shielded cable, just before the wires make their connection to the equipment.

Conclusion

By now, you should have a heightened awareness of the importance of ground to the safety of personnel and the operation of your equipment. Never float signals or neglect to make ground connections as shown in the connection diagrams for your device, or you increase your risk of electrical shock and may even damage your equipment. Grounding signals will help to stabilize them and help limit induced transient voltages and current. Many electrical problems can trace their generation to a poor, improper, or a missing connection to earth ground. Don't neglect this important connection to realize benefits of increased safety and signal integrity for your wired equipment.

Grounding Resources

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