Ground rules: earth, chassis, and signal ground

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In analog design, the relationship of a signal to ground is of fundamental concern (and can create issues in digital designs, too.) However, "ground" as a concept can be confusing as it relates to three different situations: chassis ground, signal ground, or earth ground. All three indicate connecting to a point of (theoretically) *zero voltage*, but within a different context: chassis ground for a device, signal ground for very low voltage signals within a device, and earth ground for a power system.

Figure 1: There are three different electrical symbols for ground, indicating context within a schematic. Source: Wikipedia.

But ground as *zero voltage* is theoretical; only a conductor with zero impedance will have zero voltage. In reality, a ground plane or rail will usually have varying voltages at negligible levels. The unusual cases are where issues develop because the "zero" voltage of ground isn't near zero at all. This is most likely if the circuit or device happens to operate with high amperage draws, or in cases where the ground plane, conductor, or rail has a high impedance (i.e., the "grounding" material or "ground conductor/rail" is *not* a good conductor of electricity.) Ohm's law is in effect, regardless: V=IR. Current flow (I) through any material with resistance (R) will have a voltage (V) other than zero. Wires and traces have resistance in the real world and do affect how a return path ("ground") plays out for return rails, for instance. Common sense says that connecting wires such that resistance of the wiring is

additive (in series) in a return path for one device, but not others, creates a different voltage at "ground" for that one device (V=IR).

A chassis ground is a ground-collection point that connects to the metal enclosure of an electrical device. A chassis ground may be used for shielding and grounding to prevent electrical shock. Mains' earth ground and the (theoretically) 0V power rails are all tied together and connected to the chassis at that one point. For example, with multilayer printed circuit boards, one or more of the conducting layers may be used as a chassis ground. A chassis ground is typically only made at one point. This prevents a return current path through an available but undesirable means and prevents current circulating through the chassis. Current circulating through the chassis can induce a "ground loop." But if the chassis is only grounded at one point, current cannot flow through the chassis, and the relationship between magnetic flux and electricity cannot be exercised. Ground loops, which cause induced EMF (noise), are especially problematic for noise-sensitive applications such as instrumentation and audio.

Ground loops often occur when connecting multiple electronic devices together because no two grounds are ever exactly at the same potential, which induces flow. Even a very low (voltage) potential difference causes current to flow from one unit's ground to the other unit and back to the first unit through the additional ground connection provided by the power distribution network. Although the impedance in a loop ground is only a very small fraction of an ohm, this is enough to cause issues such as noise and interference. A common solution to ground loops is a star distribution, where an arbitrary "lowest voltage potential ground" point is chosen. Star distribution has all interconnected components connected in a radiating pattern outward from "ground." If a star distribution is carefully done, signal wiring between equipment grounded to the star will be at zero potential, thus avoiding ground loops.

A signal ground is a reference point from which a signal is measured. There may be more than one reference ground in a given circuit. A clean signal ground, or a ground connection without injected noise, is essential to electrical equipment that must accurately detect very small voltage levels or differences, such as those in medical equipment. When there are multiple paths for electricity to flow to ground, the duplicate ground paths pick up interference currents and transform the currents into voltage fluctuations. The ground reference in the system is then no longer a stable potential and noise becomes part of the signal.

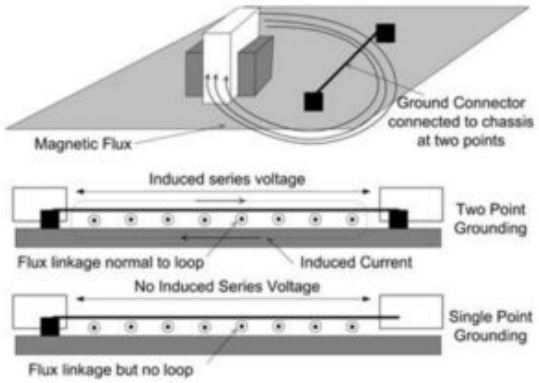

Figure 2: In an ideal world, all points labeled "ground" are at exactly zero volts. Given a path, electricity will flow. Electricity and magnetism are interrelated, a good thing since motors depend on that relationship to work, but not good when current flow is unwanted. Source: The Circuit Designer's Companion, Peter Wilson.

Printed circuit boards (PCBs) can inherit grounding problems from automatic layout programs. Signal ground, or the 0V signal reference voltage, should be on the PCB and not grounded off the

PCB where it can pick up external noise.

Signal voltages are much smaller than the voltages entering the system on point-of-entry (POE) power modules, for instance. Common sense says that signal ground is isolated from the chassis or power ground. The signal ground may also be split between digital and analog sections of a system. Signals can suffer from ground-injected interference when input signal grounding is external to the PCB where the signal lives. Ground-injected interference is possible to ignore if the signal is much larger than the injected noise, however. Grounding for signal integrity on PCBs is a detailed subject that cannot be covered in this venue, however.[i]

Earth ground harks back to the practice of using a grounding rod driven into the earth's surface for safety reasons. A common context for earth ground is in household electrical systems, where current leaves the main circuit panel through a hot wire and flows to receptacles and lights as electricity is consumed (or otherwise diverted through a viable path), and a return path is provided back to the panel through a neutral wire. Grounding adds a third wire (a ground wire) to provide a path for current that is unable to complete the circuit. An exposed conductor wire, for instance, can create a situation where the current could flow through a person's body in a path to ground if not for the ground wire, which instead safely dissipates the current to the earth and hopefully trips a fuse due to excessive current draw to earth ground.

It is especially important to have earth ground if high voltages are involved. If electrical equipment has a failed component that causes the live voltage to come in contact with a conducting chassis, for example, the equipment may continue to operate due to the internal isolation of systems, but the first person that touches the chassis becomes a path to ground and will suffer serious injury or even death. Even if a fuse is in the path from the live voltage source, it still takes micro or milliseconds for the fuse to blow and open the circuit, preventing flow. Therefore, earth ground and fault interrupters are most often in evidence wherever high voltages are at play.

It's clear that the concept of ground is fundamental to electrical concepts and in practice. Consequences vary when dealing with very high voltages versus small signals, ground loops can play out in any situation where grounding has an established path, and books have been written on the subject. But it's not until one has experienced troubleshooting for hours, only to find a loose screw (affecting chassis ground) or a misplaced trace (signal ground) to be the cause that one really understands how electrical ground is taken for granted.

[i] Wilson, Peter. *The Circuit Designer's Companion*. 3rd ed. Oxford: Newnes, 2012. Print.

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