Safety First!

Part 2 — Grounding.

This article is the second of a multipart series on safety, excerpted from the* 2017 ARRL Handbook*. Part 1 can be found in the November 2016 issue, on pages 39 – 43.

As hams, we are concerned with at least four kinds of things called "ground," even if they really aren't ground in the sense of connection to the Earth. These are easily confused because we call each of them "ground." They are:

1) Electrical safety ground (bonding)

2) RF return (antenna ground)

3) Common reference potential (chassis ground)

4) Lightning and transient dissipation ground

Electrical Safety Ground (Bonding)

Power-line ground is required by building codes to ensure the safety of life and property surrounding electrical systems. The National Electrical Code (NEC) requires that all grounds be *bonded* together; this is a very important safety feature, as well as an NEC requirement.

The usual term one sees for the "third prong" or "green-wire ground," is the *electrical safety ground*. The purpose of the third, non-load current carrying wire is to provide a path to ensure that the overcurrent protection will trip in the event of a line-to-case short circuit in a piece of equipment. This could either be the fuse or circuit breaker back at the main panel, or the fuse inside the equipment itself.

There is a secondary purpose for shock reduction: The conductive case of the equipment is required to be connected to the bonding system, which is also connected to Earth ground at the service entrance, so someone who is connected to "Earth" (for example, standing in bare feet on a conductive floor) that touches the case won't get shocked.

An effective safety ground system is necessary for every amateur station, and the code requires that all the "grounds" be bonded together. If you have equipment at the base of a tower, for example, you need to provide a separate bonding conductor to connect the chassis and cases at the tower to the bonding system in the shack. The electrical safety ground provides a common reference potential for all parts of the ac system. Unfortunately, an effective bonding conductor at 60 Hz may present very high impedance at RF because of the inductance, or worse yet, wind up being an excellent antenna that picks up the signals radiated by your antenna.

RF Ground

RF ground is the term usually used to refer to things like equipment enclosures. It stems from days gone by when the long-wire antenna was king. At low enough frequencies, a wire from the chassis or antenna tuner in the shack to a ground rod pounded in outside the window had low RF impedance. The RF voltage difference between the chassis and "Earth ground" was small. And even if there were small potentials, the surrounding circuitry was relatively insensitive to them.

Today, though, we have a lot of circuits that are sensitive to interfering signals at millivolt levels, such as audio signals to and from computer sound cards. The summary is that we shouldn't be using the equipment enclosures or shielding conductors as part of the RF circuit.

Instead, we design our systems to create a common reference potential, called the "reference plane," and we endeavor to keep equipment connected to the reference plane at a common potential. This minimizes RF current that would flow between pieces of equipment.

Some think that RF grounds should be isolated from the safety ground system — *that is not true! All grounds, including safety, RF, lightning protection and commercial communications, must be bonded together in order to protect life and property.* The electrical code still requires that antenna grounds be interconnected (bonded) to the other "grounds" in the system, although that connection can have an RF choke. Remember that the focus of the electrical code bonding requirement is safety in the event of a short to a power distribution line or other transient.

Common Reference Potential (Chassis Ground)

For decades, amateurs have been advised to bond all equipment cabinets to an RF ground located near the station. That's a good idea, but it's not easily achieved. Even a few meters of wire can have an impedance of hundreds of ohms (1 μH/meter = 88 Ω/meter at 14 MHz). A better approach is to connect the chassis together in a well-organized fashion to ensure that the chassis-to-chassis connections don't carry any RF current at all, as in Figure 1.

Lightning Dissipation Ground

Lightning dissipation ground is concerned with conducting currents to the surrounding Earth. There are distinct similarities between lightning dissipation ground systems and a good ground system for a vertical antenna. Since the lightning impulse has RF components around 1 MHz, it is an RF signal, and low inductance is needed, as well as low resistance.

The difference is that an antenna ground plane may handle perhaps a few tens of amps, while the lightning ground needs to handle a peak current of tens of kiloamperes.

A typical lightning stroke is a pulse with a rise time of a few microseconds, a peak current of 20 – 30 kA, and a fall time of 50 μs.

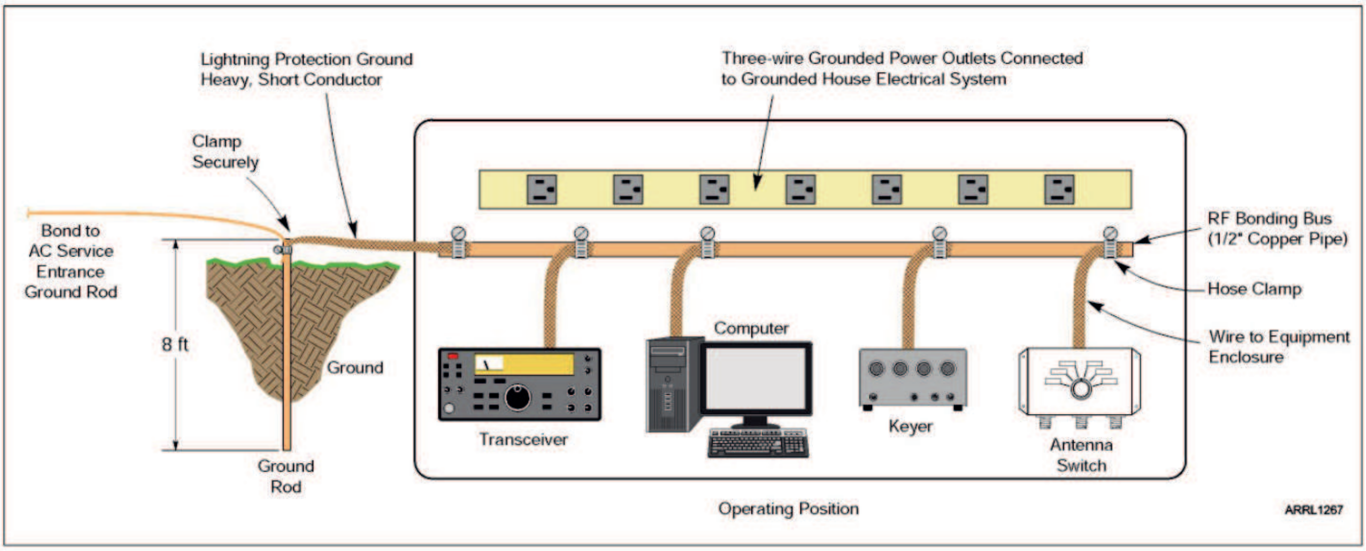

Figure 1 — An RF bonding bus connects all of the equipment enclosures together to keep them at the same RF voltage. If the bus is connected to a lightning protection ground, use a heavy conductor, fastened securely. All ground rods must be bonded together and to the residence's ac service entry ground rod. The RF bonding bus should also be connected to the ac safety ground.

The average current is not all that high (a few hundred amps), so the conductor size needed to carry the current without melting is surprisingly small.

However, large conductors are used in lightning grounds for other reasons: to reduce inductance, to handle the mechanical forces from the magnetic fields, and for ruggedness to prevent inadvertent breakage. A large diameter wire, or even better, a wide flat strap, has lower inductance. The voltage along a wire is proportional to the change in current and the inductance:

$$|V| = L\frac{di}{dt}$$

where

di/dt = rate of change in current, about 20kA/2µs for lightning, or 10^9 A/s, and

L = the inductance.

Consider a connection box on a tower that contains some circuitry terminating a control cable from the shack, appropriately protected internally with overvoltage protection. If the connection from the box to ground is high inductance, the lightning transient will raise the box potential (relative to the wiring coming from the shack), possibly beyond the point where the transient suppression in the box can handle it. Lowering the inductance of the connection to ground reduces the potential.

The other reason for large conductors on lightning grounds is to withstand the very high mechanical forces from the high currents. This is also the reason behind the recommendation that lightning conductors be run directly, with minimal bends, large radii for bends that are needed, and certainly no loops. A wire with 20,000 A has a powerful magnetic field surrounding it, and if current is flowing in multiple wires that are close to each other, the forces pushing the wires together or apart can actually break the conductors or deform them permanently.

Grounding Methods

Earth ground usually takes one of several forms, all identified in the NEC and NFPA 780. The preferred Earth ground, both as required in the NEC, and verified with years of testing in the field, is a concrete-encased grounding electrode (CEGR), also known as a *Ufer ground*, after Herb Ufer, who invented it as a way to provide grounding for military installations in dry areas where ground rods are ineffective. The CEGR can take many forms, but the essential aspect is that a suitable conductor at least 20 feet long is encased in concrete that is buried in the ground. The conductor can be a copper wire (#8 AWG at least 20 feet long) or the reinforcing bars (rebar) in the concrete, often the foundation footing for the building. The connection to the rebar is either with a stub of the rebar protruding through the concrete's top surface, or the copper wire extending through the concrete. There are other variations of the CEGR described in the NEC and in the electrical literature, but they're all functionally the same: a long conductor embedded in a big piece of concrete.

The electrode works because the concrete has a huge contact area with the surrounding soil, providing very low impedance and, what's also important, a low current density, so that localized heating doesn't occur. Concrete tends to absorb water, so it is also less susceptible to problems with the soil drying out around a traditional ground rod.

Ground rods are a traditional approach to making a suitable ground connection and are appropriate as supplemental grounds, say at the base of a tower, or as part of an overall grounding system. The best ground rods to use are those available from an electrical supply house. The code requires that at least 8 feet of the rod be in contact with the soil, so if the rod sticks out of the ground, it must be longer than 8 feet (10 feet is standard). The rod doesn't have to be vertical, and can be driven at an angle if there is a rock or hard layer, or even buried lying sideways in a suitable trench, although this is a compromise installation. Suitable rods are generally 10 feet long and made from steel with a heavy copper plating. Do not depend on shorter, thinly plated rods sold by some home electronics suppliers, as they can quickly rust and soon become worthless.

If multiple ground rods are installed, they should be spaced by at least half the length of the rod, or the effectiveness is compro-

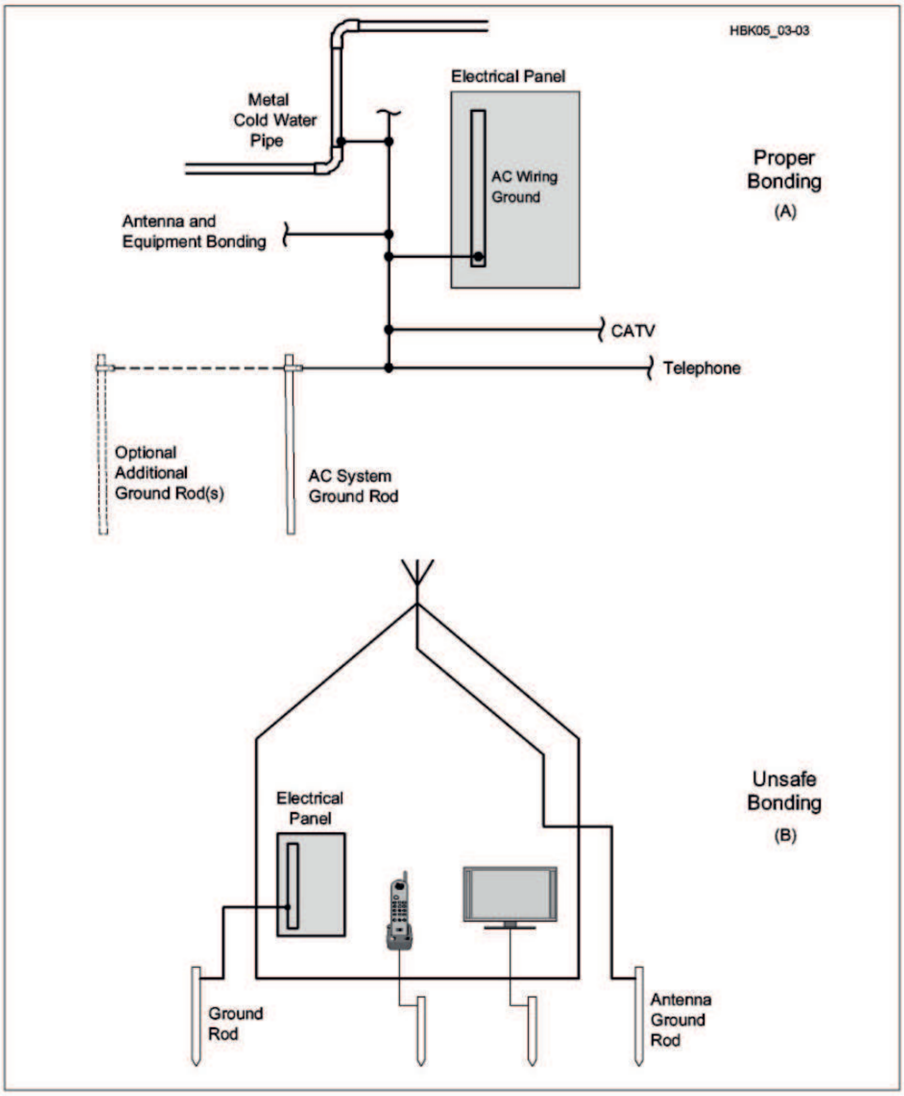

Figure 2 — At A, proper bonding of all grounds to electrical service panel. The installation shown at B is unsafe — the separate grounds are not bonded. This could result in a serious accident or electrical fire.

mised. IEEE Std 142, IEEE Std 1100, and other references have tables to give effective ground resistances for various configurations of multiple rods.

Once the ground rods are installed, they must be connected with either an exothermic weld (such as CadWeld) or with a listed pressure clamp. The exothermic weld is preferred, because it doesn't require annual inspection like a clamp does. Some installers use brazing to attach the wiring to the ground rods. Although this is not permitted for a primary ground, it is acceptable for secondary or redundant grounds. Soft solder (tin-lead, as used in plumbing or electrical work) should never be used for grounding conductors because it gets brittle with temperature cycling and can melt out if a current surge (as from a lightning strike) heats the conductor. Soft solder is specifically prohibited in the code.

Building cold-water supply systems were used as station grounds in years past, but this is no longer recommended or even permitted in some jurisdictions, because of increased used of plastic plumbing both inside and outside houses, and concerns about stray currents causing pipe corrosion. If you do use the cold-water line, perhaps because it is an existing grounding electrode, it must be bonded to the electrical system ground, typically at the service entrance panel.

Ground Conductors

The code is quite specific as to the types of conductors that can be used for bonding the various parts of the system together. Grounding conductors may be made from copper, aluminum, copper-clad steel, bronze, or similar corrosion-resistant materials. Note that the sizes of the conductors required are based largely on mechanical strength considerations (to ensure that the wire isn't broken accidentally) rather than electrical resistance. Insulation is not required. The "protective grounding conductor" (main conductor running to the ground rod) must be as large as the antenna lead-in, but not smaller than #10 AWG. The grounding conductor (used to bond equipment chassis together) must be at least #14 AWG. There is a "unified" grounding electrode requirement — it is necessary to bond *all* grounds to the electric service entrance ground. All utilities, antennas, and any separate grounding rods used must be bonded together. Figure 2 shows correct (A) and incorrect (B) ways to bond ground rods. For additional information on good grounding practices, the IEEE "Emerald Book" (IEEE STD 1100-2005) is a good reference. It is available through libraries.

Additionally, the NEC covers safety inside the station. All conductors inside the building must be at least 4 inches away from conductors of any lighting or signaling circuit except when they are separated from other conductors by conduit or insulator. Other code requirements include enclosing transmitters in metal cabinets that are bonded to the grounding system. Of course, conductive handles and knobs must be grounded as well.