Grounding & Bonding — Why it is done
And How to Install Properly

The technical information provided herein is to assist qualified persons in planning and installing electric service to farms and residences. **Qualified person** is defined in Article 100 of the National Electrical Code (2008 edition) *as one who has the skills and knowledge related to the construction and operation of the electrical equipment and installations and has received safety training to recognize and avoid the hazards involved.* Qualified persons are encouraged to review the National Fire Protection Association (NFPA) 70E-2004, Standards for Electrical Safety in the Workplace, for electrical safety training requirements. **A person who is not qualified should not attempt the planning and installation of electric service.**

Note: Any reference to "Code" or "Code Handbook" in the following information refers to the 2008 National Electrical Code and the NEC 2008 Handbook respectively.

A home's electrical Service Equipment is a critical component of the home's electrical wiring system. Not only does it have to be sized properly to carry the electrical load, but it has to be installed properly. In addition, all of the home's branch circuits and feeders — along with various metallic systems found within the home — have to be connected properly back to the Service Equipment in order to safeguard the occupants of the home.

This discussion identifies what constitutes the Service Equipment; what grounding is; the various types of grounding electrodes, the systems that have to be bonded, and a thorough discussion on why bonding is performed.

For this discussion, we will be referring to a residential home, where a 120/240-volt single phase 200 amp electrical supply from a cooperative transformer is delivered to the home via either overhead or underground conductors. At the home, a meter base is mounted outside and a 200 Amp Main Breaker Panel is located immediately adjacent inside the home.

SERVICE EQUIPMENT

The Code defines Service Equipment as *the necessary equipment, usually consisting of a circuit breaker(s) or switch(es) and fuse(s) and their accessories, connected to the load end of service conductors to a building or other structure or an otherwise designated area, and intended to constitute the main control and cutoff of the supply.*

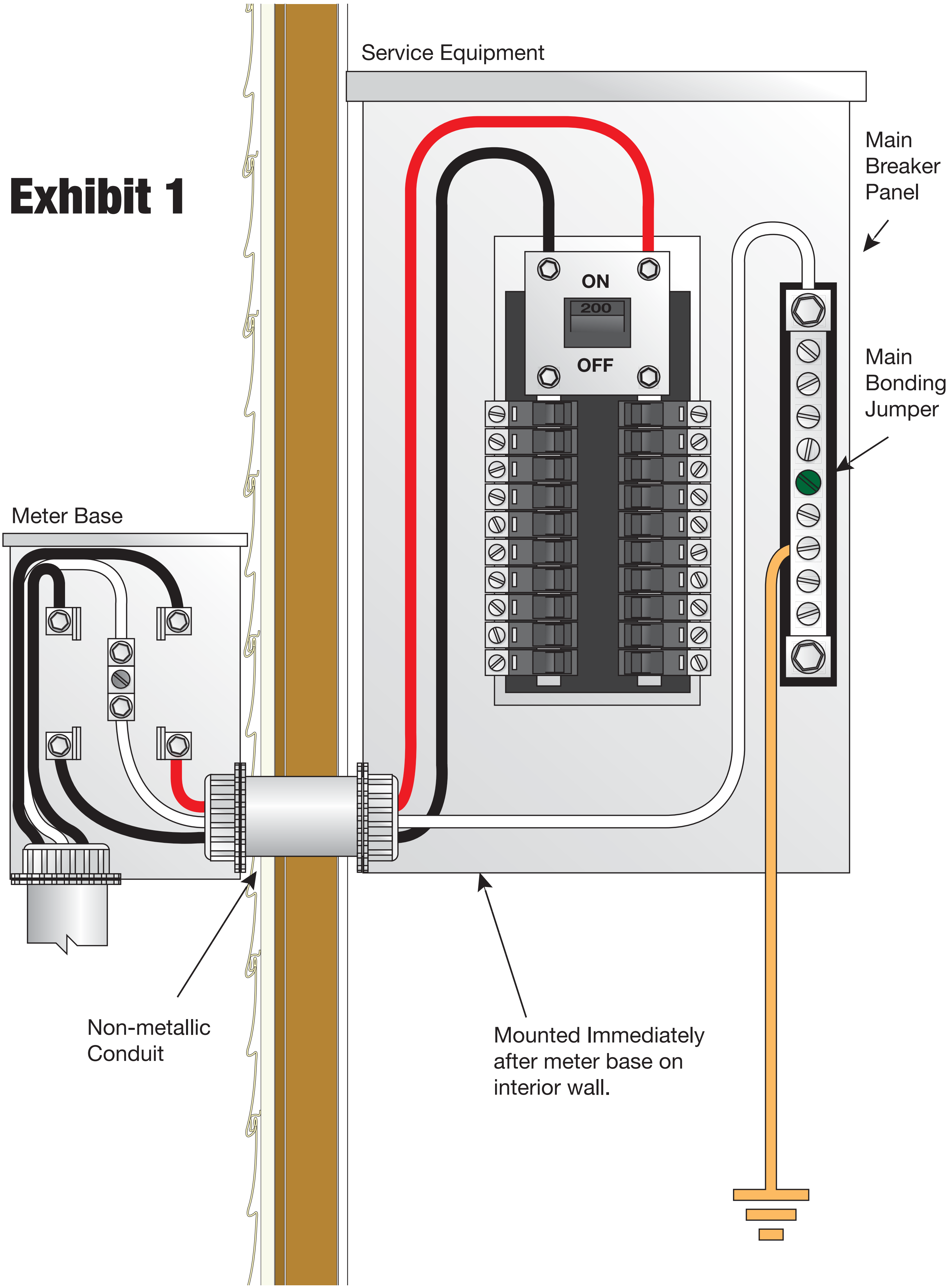
In our example, the Service Equipment for the home is the 200 Amp Main Breaker Panel. However, if this 200 Amp Main Breaker Panel can't be immediately installed on the other side of the wall from the meter base, the electric cooperative may require a 200 Amp Main Disconnect be installed immediately after the meter base. *(Note: The authority having jurisdiction — in many cases that is the electric cooperative — will determine what the length of run can be between meter base and the Main Breaker Panel before a Main Disconnect is needed. The Code does not specify this length.)* See exhibits 1 & 2.

If a Main Disconnect is installed, the electrician would also need to install inside the home a 200 Amp Lug Main Panel ("Lug Main" means without a Main Breaker). In this type of arrangement — the Service Equipment would consist of just the Main Disconnect — and not include the lug main breaker panel inside the home.

It is interesting to note that even though the meter base is usually installed when the Service Equipment is installed — the Code does not recognize it as part of the Service Equipment according to 230.66.

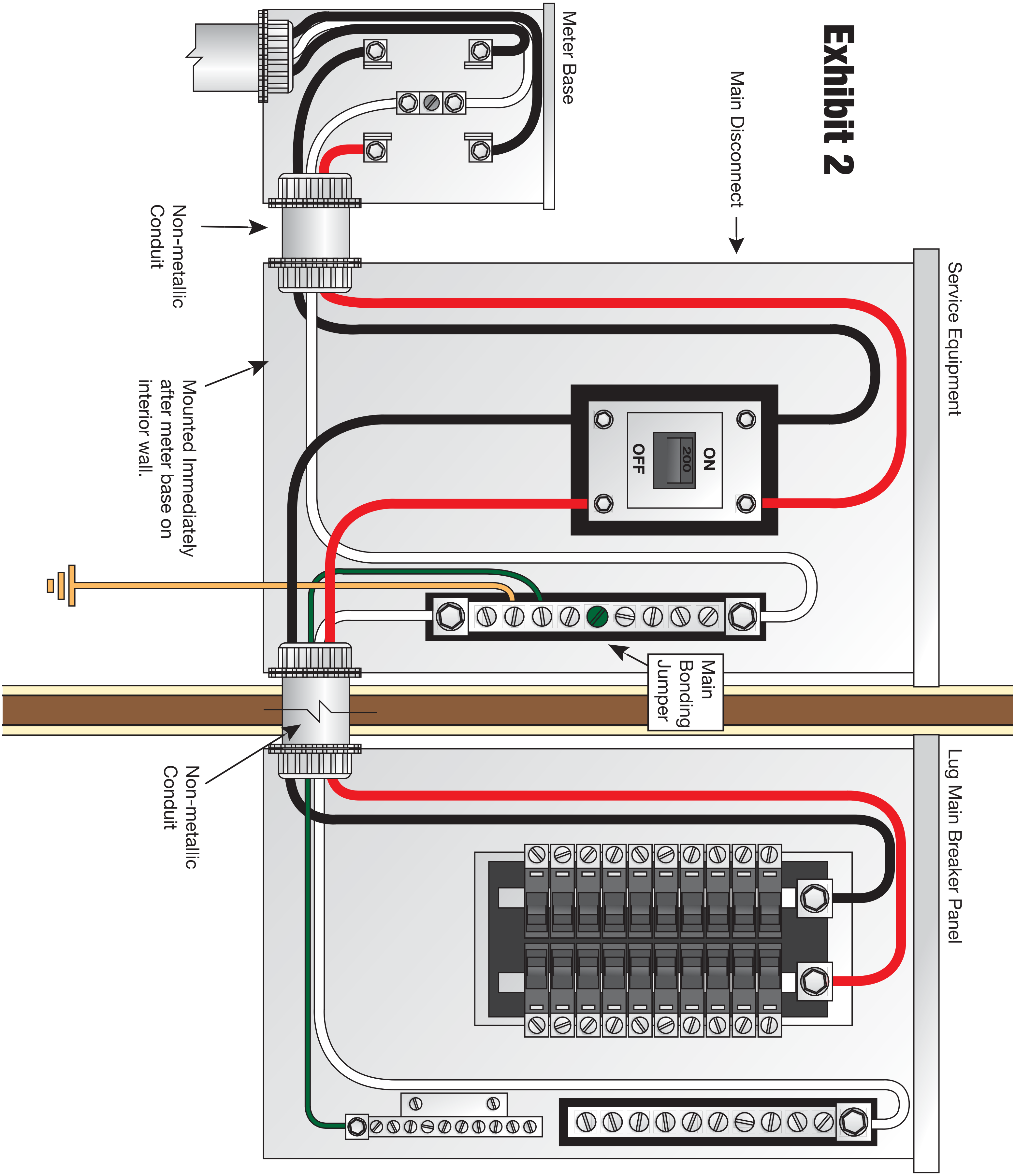
Also, when installing conduit between the meter base and the Service Equipment, non-metallic conduit is preferred over metal. The reason is simple. The neutral terminal in the meter base is by design connected to the metal enclosure of the meter base — and the neutral conductor is bonded to the metal enclosure of the Service Equipment. So, when one use metallic conduit between the meter base and the Service Equipment, any neutral current between the meter base and the Service Equipment is being shared by both the neutral conductor and the metallic conduit — because in essence — they are in parallel.

Exhibit 1



Service Equipment
Main
Breaker
Panel
ON
200
OFF
Main
Bonding
Jumper
Meter Base
Non-metallic
Conduit
Mounted Immediately
after meter base on
interior wall.

Exhibit 2


Main Disconnect
Meter Base
Service Equipment
ON
200
OFF
Non-metallic Conduit
Mounted Immediately after meter base on interior wall.
Main Bonding Jumper
Non-metallic Conduit
Lug Main Breaker Panel

GROUNDING AND BONDING

"Grounding" and "bonding" are important elements of a building's electrical wiring system. They each have different functions, but they work together to make the building's electrical wiring safe.

The Code defines "grounding" as the *connecting to ground or to a conductive body that extends the ground connection* — and the Code defines "ground" as *the earth.* Basically, grounding is connecting to the earth. The Code defines "bonded" or "bonding" as *connected (connecting) to establish electrical continuity and conductivity.*

Let's examine these two important integral parts of electric wiring closer in detail.

Grounding

In our home example, a typical electrical installation will require the electrician to connect the house's wiring to the earth. This practice is called "grounding" and it is done to **limit the voltage imposed by lightning, line surges, or unintentional contact with higher-voltage lines and to stabilize the voltage to earth during normal operation** as documented by 250.4(A)(1) of the Code.

Grounding is necessary to prevent fires starting from a surface arc within the home. If the outdoor wiring supplying the home should be struck by lightning, proper grounding by the electrician directs that voltage into the earth where it dissipates.

Because 250.26 of the Code requires the neutral conductor of a single-phase, 3-wire system to be grounded, in our example, the electrician will normally use a bare copper wire to connect the neutral conductor (often called the grounded conductor) to a grounding electrode that has direct contact with the earth.

Location of the Grounding Connection

Each premises wiring system supplied by a grounded ac service shall have a grounding electrode conductor connected to the grounded service conductor — at each service — according to 250.24(A) of the Code. Basically, this is saying each building that is served electricity shall have its service connected to the earth.

250.24(A)(1) of the Code allows this grounding connection (earth connection) to be at various locations. It says *the grounding electrode conductor connection shall be made at any accessible point from the load end of the service drop or service lateral to and including the terminal or bus to which the grounded service conductor is connected at the service disconnecting means.* See exhibit 3.

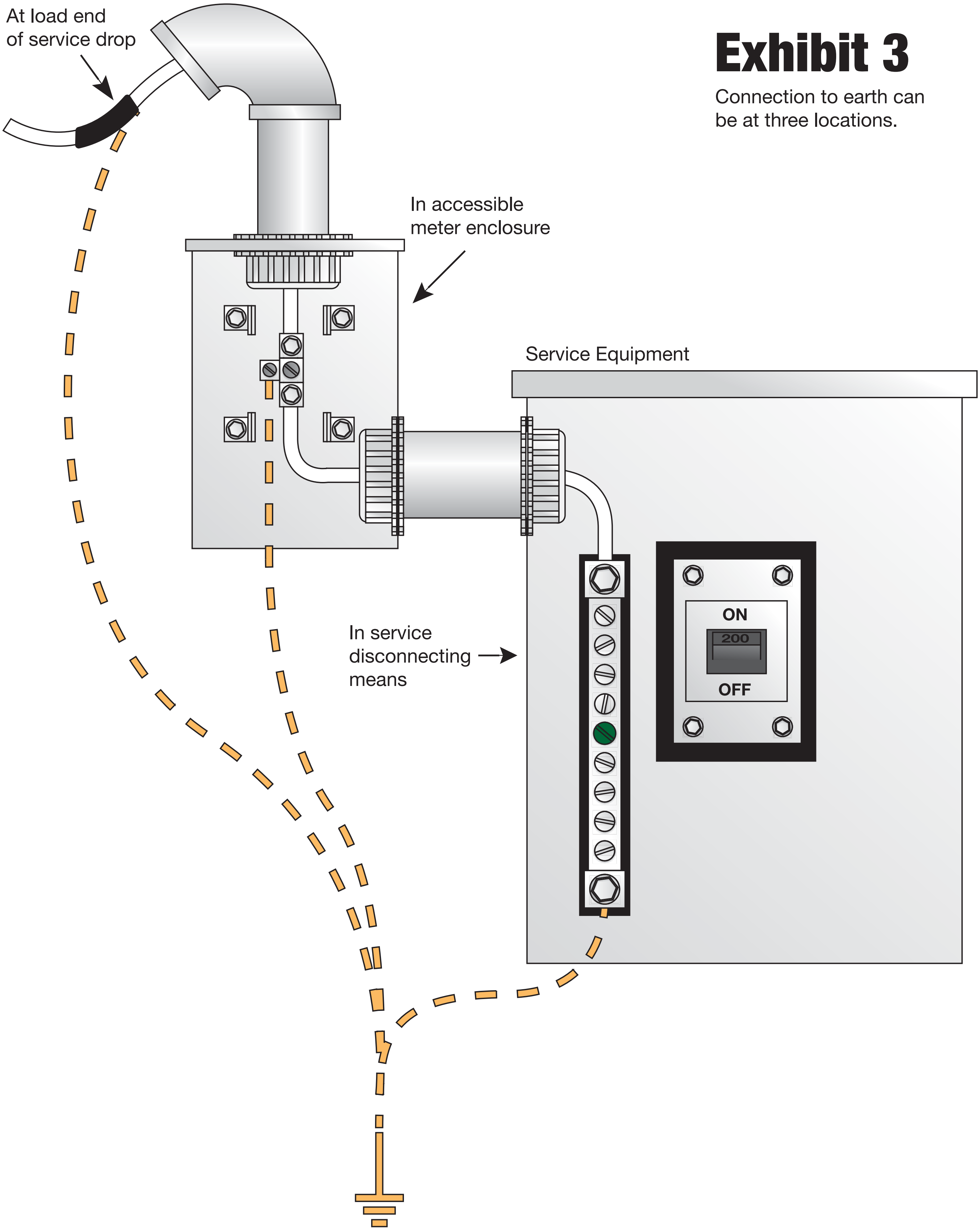
Please note that the Code does not indicate that a meter base enclosure is not an accessible location for terminating a grounding electrode conductor. These enclosures are sometimes viewed this way because of the seal that the cooperative puts on them to place a legal jurisdiction over the unmetered conductors contained in the enclosure.

However, any way you look at this connection location, it is still accessible (by definition) to workers and others, by legal means. In other words, just notify the cooperative and access can be granted beyond the seal. Besides, this earthing connection is made in the meter base before it is energized and before the seal or lock is installed. Some local jurisdictions may not permit the connection to be made in the meter base enclosure, but that is not the intent of the Code — the Code does allow it.

Here is a suggestion. If one would always make the earth connection in the Service Equipment, it would always be according to Code. And it would always be easily accessible to an insurance agent/electrical inspectors inspecting the electrical wiring, and to electricians troubleshooting future grounding issues if they arise. However, it is stressed that the best procedure is to verify with the electric cooperative where they want the earth connection.

Exhibit 3

Connection to earth can be at three locations.



Grounding Electrodes

Because grounding electrodes are absolutely essential to direct dangerous high voltages to the earth, 250.50 of the Code requires several different items of a building to serve as grounding electrodes. Building a system of electrodes adds a level of reliability — and helps ensure system performance over a long period of time — instead of relying on a single grounding electrode to perform its function over the life of an electrical installation.

All of the following 7 electrodes that are present at a building shall be bonded together to form the entire grounding system:

1. Metal underground water pipe (including any well casing bonded to the pipe)
   - Pipe has to be in direct contact with the earth for 10 feet or more
   - Metal can be steel, iron, cast iron, stainless steel
   - Code doesn't define whether the water piping is for potable water, fire protection sprinkler system, irrigation, etc. — so all of these different water systems have to be used as grounding electrodes
   - Interior metal water piping located more than 5 feet from the point of entrance to the building shall not be used as part of the grounding electrode system — or as an conductor to interconnect other electrodes that are part of the grounding electrode system.
   - Continuity of the grounding path shall not rely on water meters or filtering devices or similar equipment according to 250.53(D)(1) of the Code. Bonding jumpers shall be connected around meters, filtering devices and similar equipment.
   - If metal underground water pipe is used as the sole grounding electrode system, according to 250.53(D)(2) of the Code, it has to be supplemented with other grounding electrodes as listed in this section. The reason for this is based on the possibility of using a plastic water pipe in the future when the original metal water piping fails — leaving the electrical system without any grounding electrode. The supplemental electrode can be connected to any of the following:
     - Grounding electrode conductor
     - Grounded service conductor
     - Metal service raceway
     - Metal service enclosure
2. Metal frame of the building
   - Frame has to be in direct contact with the earth for 10 feet or more
   - Frame must be connected to an acceptable electrode; or other approved means of establishing connection to earth
3. Concrete-encased electrode

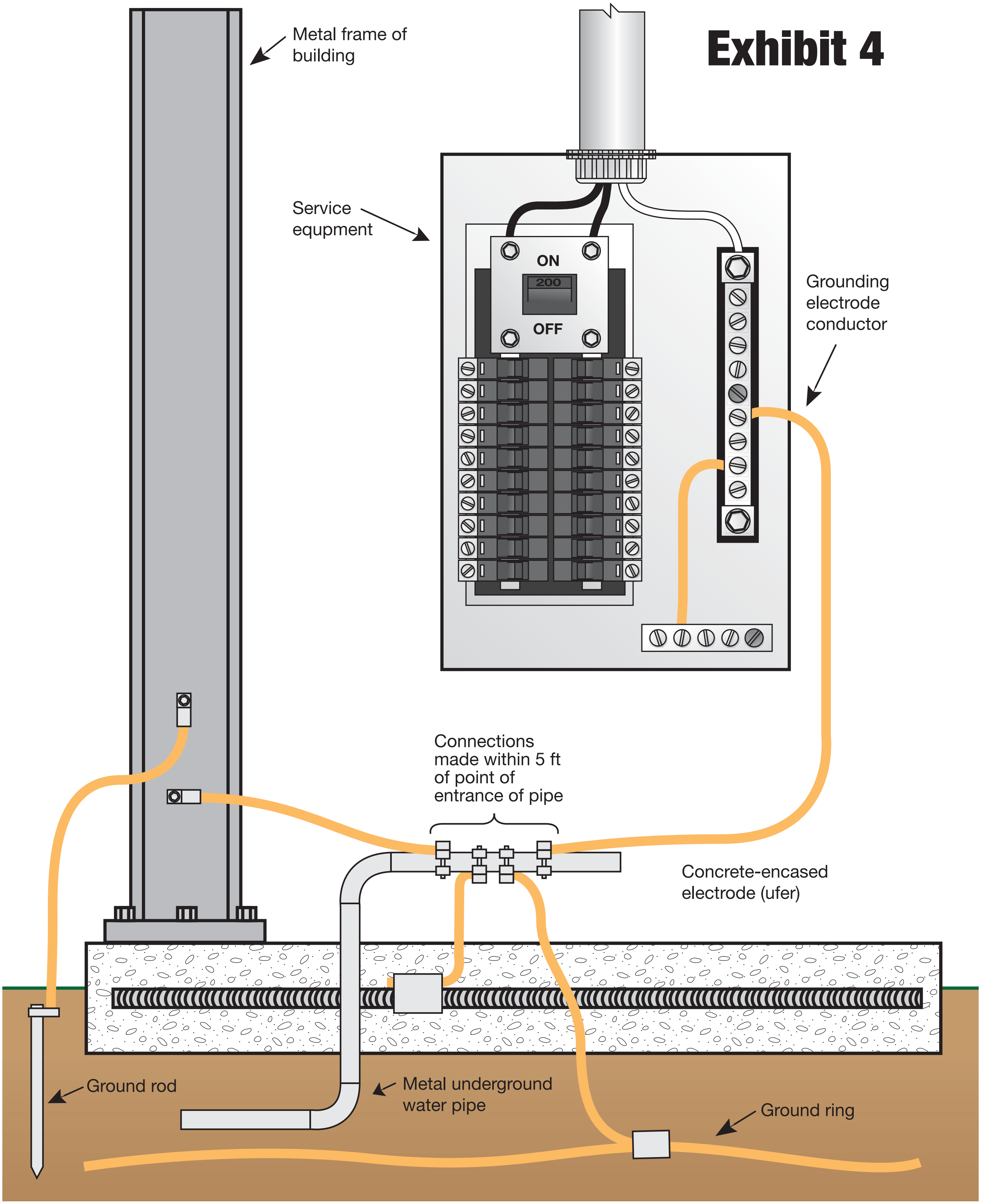
   Note: This electrode is commonly referred to as the "Ufer ground"; and concrete-encased is referring to the electrode being part of the building's footing or foundation. According to the Code Handbook…*If a concrete-encased electrode is not present at a building, it is not required that one be installed. An exception does exempt buildings where access to a concrete encased electrode would involve some type of demolition or similar activity that would disturb the existing construction. Because the installation of the footings and foundation is one of the first elements of a construction project and in most cases has long been completed by the time electric service in installed, this rule necessitates an awareness and coordinated effort on the part of designers and the construction trades in making sure that the concrete encased electrode is incorporated into the grounding electrode system.*

This electrode must be:

- Encased by at least 2” of concrete
- Located horizontally near the bottom of the concrete encasement or installed vertically
- A #4 AWG or larger bare copper conductor at least 20 feet in length OR a reinforcing rod not less than ½” in diameter made of bare, zinc galvanized or other electrically conductive coated steel material at least 20 feet in length. This 20 ft measurement can be accomplished by bonding reinforcing rods together with the usual steel tie wires or other means like welding.

4. Ground Ring
   - Must encircle the building
   - Must have 20 feet in contact with the earth
   - Must be bare copper not smaller than #2 AWG
   - Must be buried not less than 30 inches — according to 250.53(F) of the Code
5. Rod and Pipe Electrodes
   - Must not be less than 8 feet in length
   - 8 feet of this electrode must be in contact with earth
   - Diameter and material
     - not smaller than ¾ inch if of pipe or conduit material and outer surface must be galvanized or otherwise metal-coated for corrosion protection
     - not smaller than 5/8 inch if of stainless steel and copper or zinc coated steel
     - not smaller than ½ inch if of stainless steel and copper or zinc coated steel and is listed
6. Other listed electrodes
7. Plate electrodes
   - 2 square feet of surface must be exposed to earth
   - Must be installed at least 30 inches deep

Exhibit 4



Metal frame of building
Service equipment
ON
200
OFF
Grounding electrode conductor
Connections made within 5 ft of point of entrance of pipe
Concrete-encased electrode (ufer)
Ground rod
Metal underground water pipe
Ground ring

If none of these 7 types of grounding electrodes exist, then one or more of the following grounding electrodes must be installed and used (see descriptions above):

- Bare Copper Ground Ring
- Rod and pipe electrodes
- Other listed electrodes
- Plate electrodes
- Other local metal underground systems or structures (e.g., underground metal storage tank, metal well casings not bonded to metal water pipe)
- **It is important to note that metal underground gas piping systems are <u>not permitted</u> for use as grounding electrodes according to 250.52(B) of the Code.**

The connection of grounding electrodes to the grounded conductor can be performed in three ways as shown in exhibit 5.

1) Grounding electrode conductors can run individually from the grounded conductor directly to a grounding electrode.
2) A grounding electrode conductor can run from the grounded conductor to a grounding electrode. Then from that point on, bonding jumpers can be used to connect other grounding electrodes in a daisy chain fashion.
3) A combination of (1) and (2).

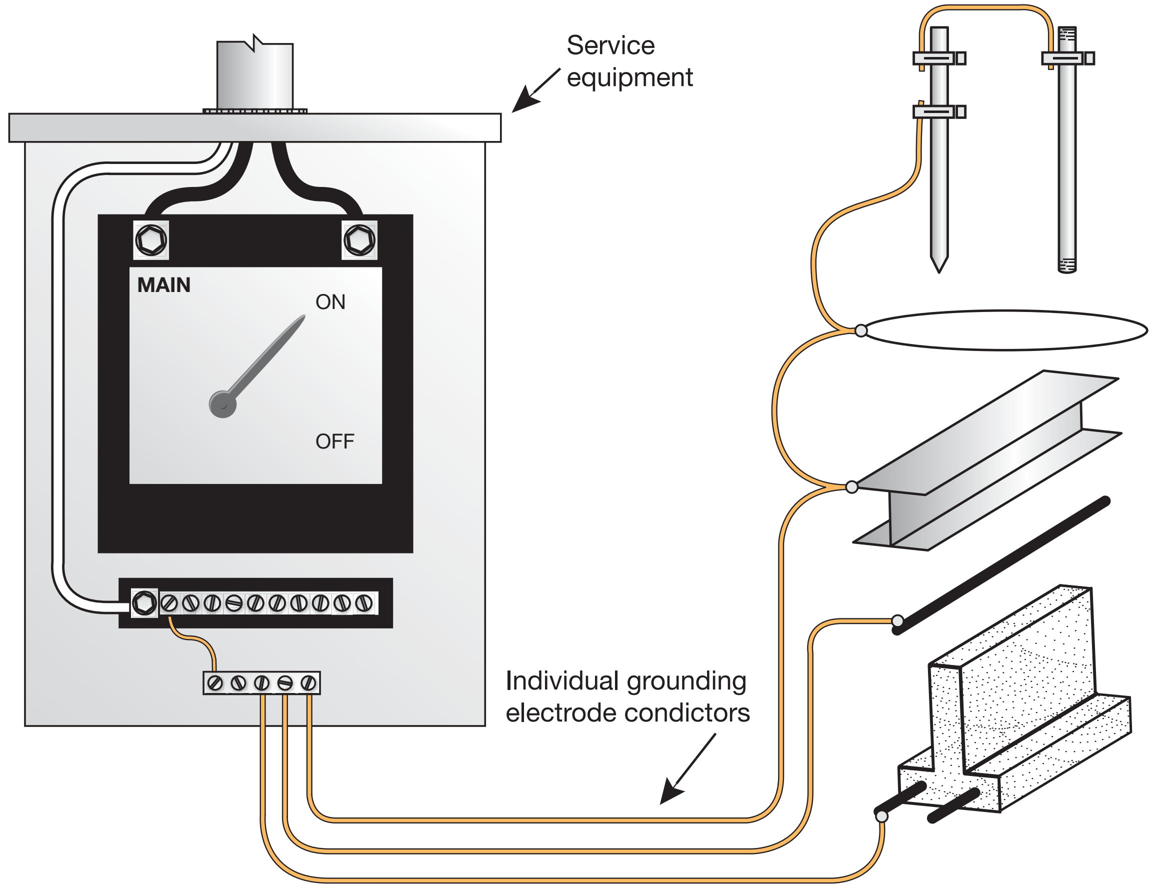
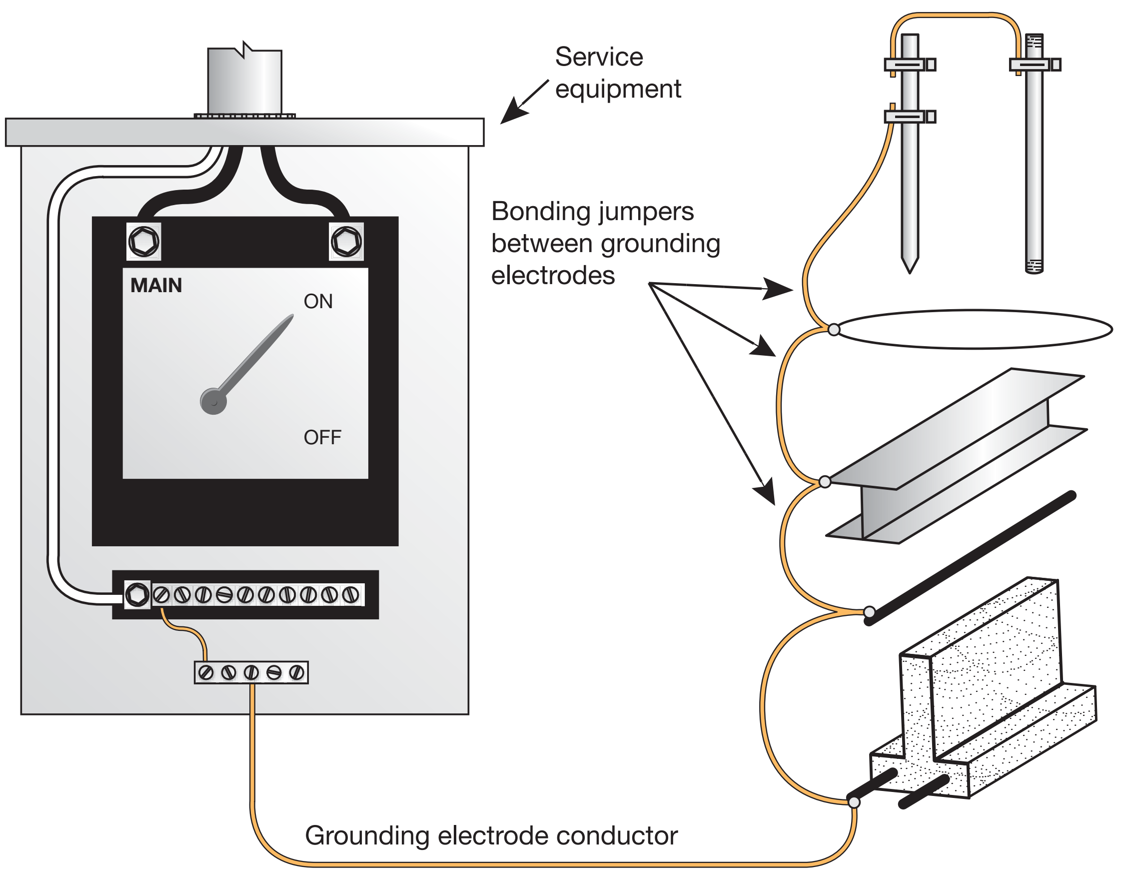

Service
equipment
MAIN
ON
OFF
Individual grounding
electrode condictors

Exhibit 5


Service
equipment
MAIN
ON
OFF
Bonding jumpers
between grounding
electrodes
Grounding electrode conductor

From Grounding to Bonding

Grounding and bonding work together with each other to make a building's electrical wiring safe. Once the electrician has completed the connection of the grounded conductor to the earth, the focus now moves from the concept of grounding to bonding. This transition is started through use of a device called the Main Bonding Jumper.

250.24(B) of the Code requires the electrician to connect the grounded service conductor to the metal enclosure of the Service Equipment and to the equipment grounding terminal bar within the Service Equipment. This connection can be accomplished through various types of Main Bonding Jumpers — including a wire, bus, screw, or similar suitable conductor.

If the Main Bonding Jumper is a screw, the screw head shall be green-colored according to 250.28(B) of the Code. (Note: If the Main Bonding Jumper is a wire or busbar, 250.24(A)(4) allows the grounding electrode conductor to connect to the equipment grounding terminal bar — instead of to the neutral terminal bar.)

Once grounding has been performed and the Main Bonding Jumper has been connected — the grounded conductor (neutral) — which is attached to the neutral terminal bar in the Service Equipment — is also now connected to the:

- earth
- metal enclosure of the Service Equipment
- grounding electrode conductor
- equipment grounding terminal bar of the Service Equipment

This next statement is critical. **In order for the electrical wiring in the home to be safe, this is the only location in the entire wiring of the home — and in other buildings and structures supplied by this Service Equipment — where the grounded conductor (neutral) can be connected to the other 4 components listed above.** From this point on — when working with branch circuits or feeders supplied from the Service Equipment — all neutral conductors have to be kept separate from:

- all equipment grounding conductors and the metallic parts of branch circuits
- metallic enclosures, equipment grounding conductors, and grounding electrode conductors of downstream disconnecting means

Exhibits 6 & 8 show approved wiring methods and exhibits 7 & 9 show violations.

Exhibit 6

Correctly Wired

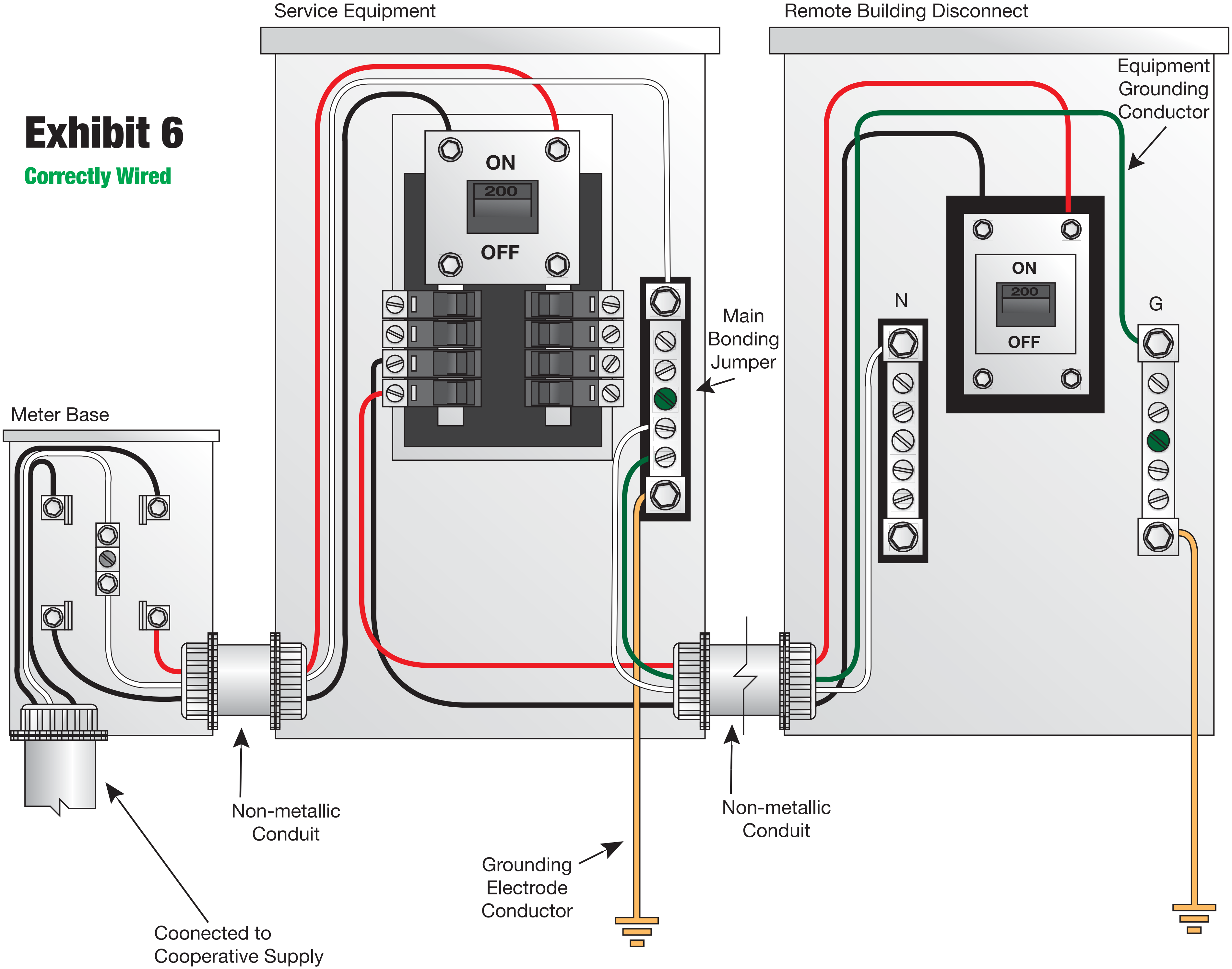


Exhibit 7

Incorrectly Wired

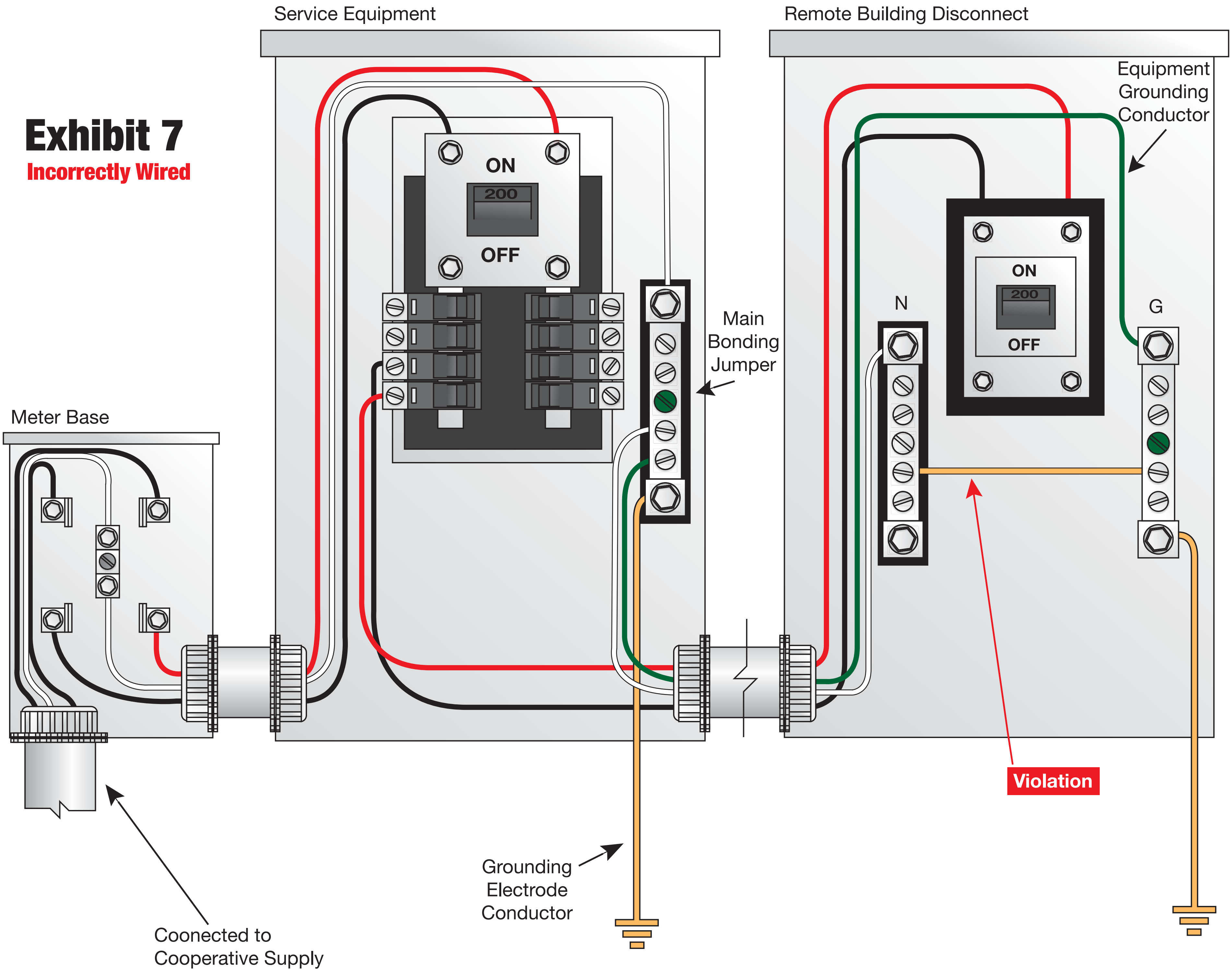


Exhibit 8
Correctly Wired

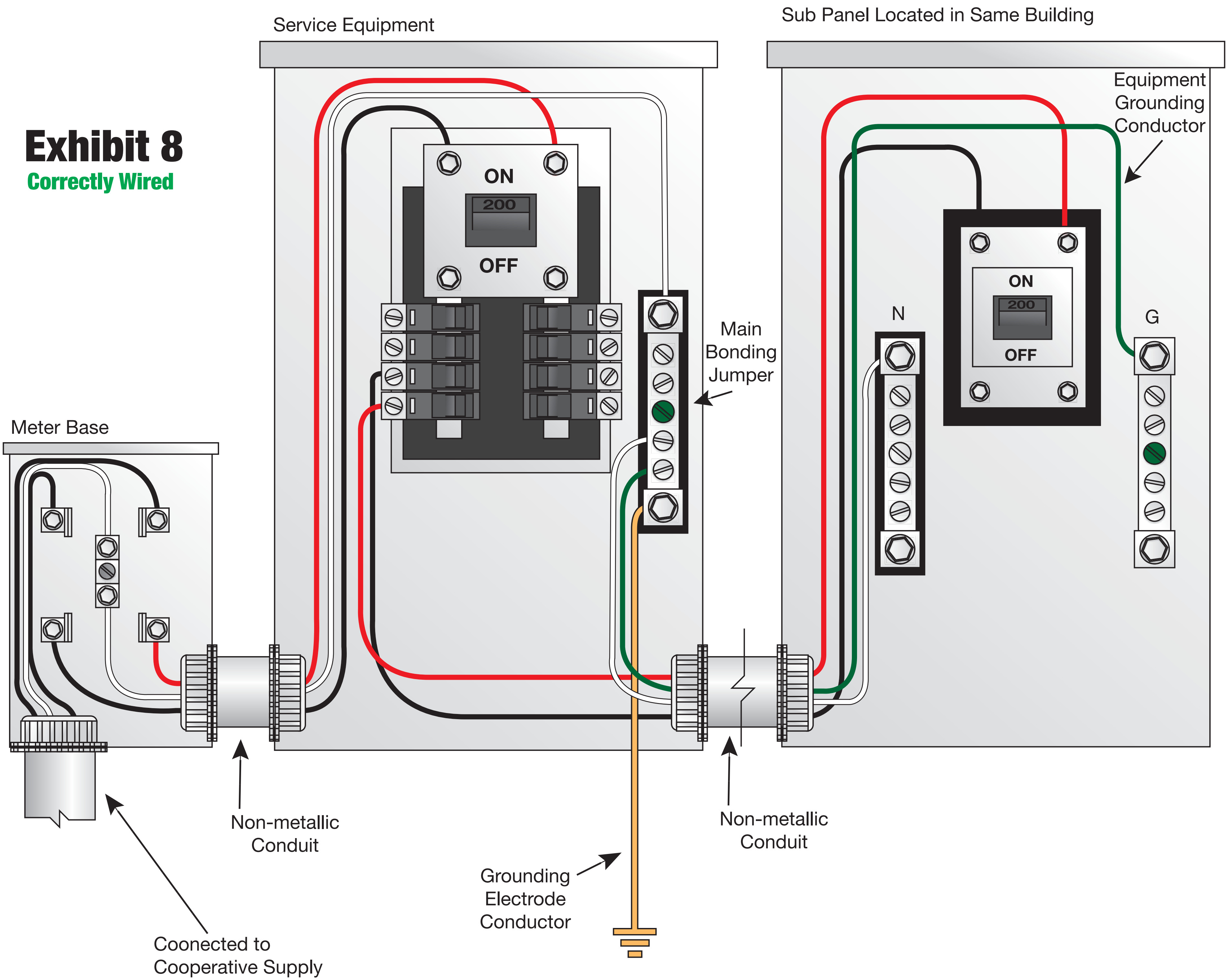
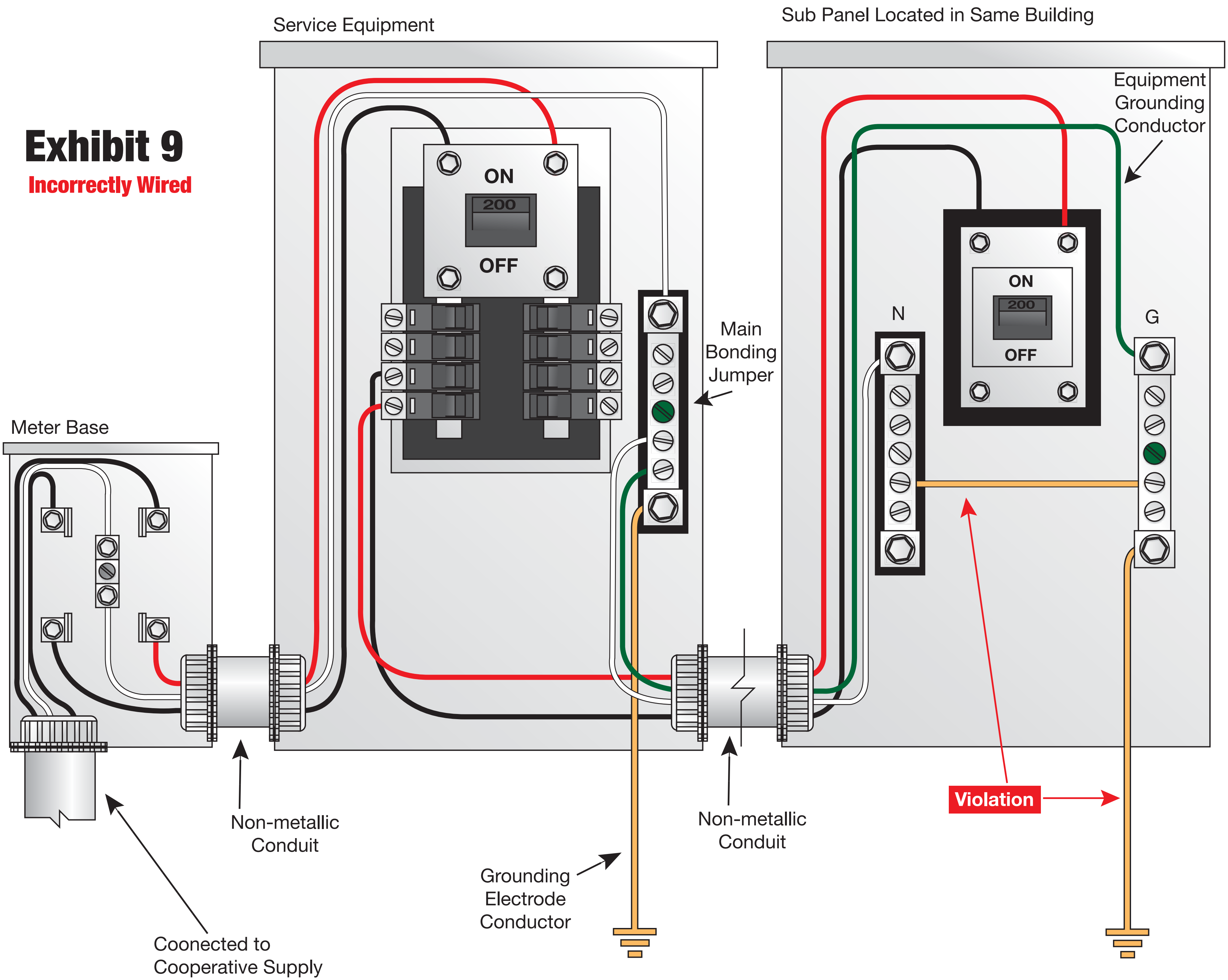


Exhibit 9

Incorrectly Wired



Bonding:

Once the electrician has completed grounding of the Service Equipment and the attachment of the Main Bonding Jumper within the Service Equipment, it's time to perform another critical step in the house's electrical wiring. As the electrician installs the branch circuits in the house, focus is now concentrated on making sure that the metal components in all of the branch circuits are connected to the metal enclosure of the Service Equipment — an act called **"bonding".**

Bonding is accomplished when the electrician connects equipment grounding conductors to the equipment grounding terminal bar in the Service Equipment and to the grounding terminals on electrical devices and electrical boxes. If the electrician is using metal raceways and metal boxes to install conductors — the electrician can also use the metal raceway conduit as the equipment grounding conductor, but great care needs to be taken when using this method. Connections at each conduit joint and box must use proper equipment and methods to ensure a solid connection has been made.

When installed correctly, here is a way to visualize what proper bonding does. Imagine taking one lead of a continuity tester and touch a metal component of one circuit (box, enclosure, conduit, locknut, appliance frame, etc.,) — and then take the other (extremely long!) lead anywhere in the building and touch a similar metal component used either in the same circuit or in a different electrical circuit. If bonding was properly performed, the continuity tester would show continuity between the two places being touched. Basically, all metal components have become "one unit."

That's why — even when one is using plastic switch boxes and plastic switch covers for installing switches — the electrician is required to use switches with a grounding terminal and conductors that include an equipment grounding conductor. Because of the possibility of a metal switch cover being used some day, the electrician once again has to ensure that the metal cover has a conductive path back to all metallic parts of its circuit and other circuits and the metal enclosure of the Service Equipment.

You may be wondering if one is using equipment "grounding" conductors and connecting to "grounding" terminals, then why isn't this considered an act of grounding? It's a great question. The best way to answer it is to say it's really **both** bonding and grounding. Grounding and bonding happen simultaneously during the installation of an electrical system and branch circuits. They work hand in hand in order to make it safe.

The Code describes bonding as connecting to establish electrical continuity and conductivity — and describes grounding as connecting directly to ground (earth) or to a conductive body that extends the ground connection. Let's see how they work together.

Consider the example where one connects an equipment grounding conductor in a non-metallic Romex cable to the grounding terminal of a 120-volt duplex receptacle. One can see that bonding is accomplished-- because if an appliance is plugged into the receptacle, the green conductor in the 3-conductor appliance cord is now connecting the appliance frame to all other metal parts of this circuit and to metal parts of other circuits.

However, grounding is also accomplished in this example—because the equipment grounding conductor is acting as "the conductive body that extends the earth connection." In essence, connecting the equipment grounding conductor to the green terminal of the duplex receptacle has satisfied both the Code requirements of bonding and grounding.
In fact, in the Fine Print Note #1 under the Code definition of "Grounding Conductor, Equipment (EGC)"—it states: *It is recognized that the equipment grounding conductor also performs bonding.*

Other Systems to Bond

Because other non-electrical metallic parts may accidentally become energized, 250.104 of the Code requires that anything electrically conductive — such as water piping systems, gas piping systems*, air duct systems, communication systems, lightning protection systems, exposed structural steel members — that are *likely to become energized* must also be bonded to the service equipment. The phrase “likely to become energized” is subject to interpretation by the authority having jurisdiction over an electrical installation project. This Code section also allows the equipment grounding conductor for the circuit that is likely to energize the piping to be permitted to serve as the bonding means — and requires that the points of attachment of the bonding jumper(s) be accessible.

*** Due to problems experienced from bonding CSST (corrugated stainless steel tubing) gas systems as presently required by the Code, the best approach at this time is to verify what the local authority having jurisdiction is requiring regarding bonding CSST gas piping. It is anticipated that the next update of the Code will address these problems.**

Why do we perform Bonding?

Because the metal enclosure of the Service Equipment is already connected to earth, bonding — in essence — also connects all metal parts of circuits and other metallic systems to the earth. But connecting to the earth is not the purpose of bonding. Bonding is performed to protect people from deadly fault current.

A ground-fault occurs when a metal part is energized that shouldn’t be. According to the tenth edition of the Soares Book on Grounding and Bonding, a ground fault is *an unintentional, electrically conducting connection between an ungrounded (energized) conductor of an electrical circuit and the normally non-current-carrying conductors, metallic enclosures, metallic raceways, metallic equipment, or earth.*

This metal part may be the metal normally found in an electrical circuit — such as boxes, conduit, metal switch or receptacle covers, or the frame of an appliance. However, it may also be metal not found in an electrical circuit — such as air ducts, faucets, network cabling, etc.

Not only does the metal part have dangerous voltage on it from the ground-fault, it also has deadly fault current. The only safe way to get rid of this dangerous voltage and the resulting fault current — before someone makes contact with the metallic part — is to open the overcurrent protection devices in that circuit (trip a breaker or blow a fuse). To make the overcurrent protection devices respond to a ground-fault, there has to be an **effective ground-fault current path from the ground fault to the electrical supply source.**

Effective Ground-Fault Current Path from the Ground-Fault:

According to 250.2 of the Code, an effective ground-fault current path is *an intentionally constructed, low-impedance electrically conductive path designed and intended to carry current under ground-fault conditions from the point of the ground-fault on a wiring system to the electrical supply source and that facilitates the operation of the overcurrent protective device or ground-fault detectors on high-impedance systems.*

(As a quick review, opposition to current in an AC circuit is called “impedance”. A low impedance path then is a path that offers little opposition to current flow — whether it is normal current or fault current.)

The electrician accomplished this effective, permanent and low-impedance path when all the metallic parts were bonded together and also bonded to the Service Equipment!

However, there is a catch. This low impedance path is only as good as its "weakest link". To provide adequate safety, the effective ground-fault current path has 3 requirements according to 250.4(A)(5) of the Code. This path has to be

- electrically continuous
- able to safely conduct any fault current likely to be imposed on it
- enable the operation of the circuit-protective devices.

That's why every connection in a circuit is critical. This ground-fault path goes through boxes, conduits, wiring, pull boxes, and locknuts, etc. It only takes one poor connection such as a loose screw in a terminal bar or a loose wire nut or a loose locknut to break a link in the fault current chain.

INCORRECTLY WIRED

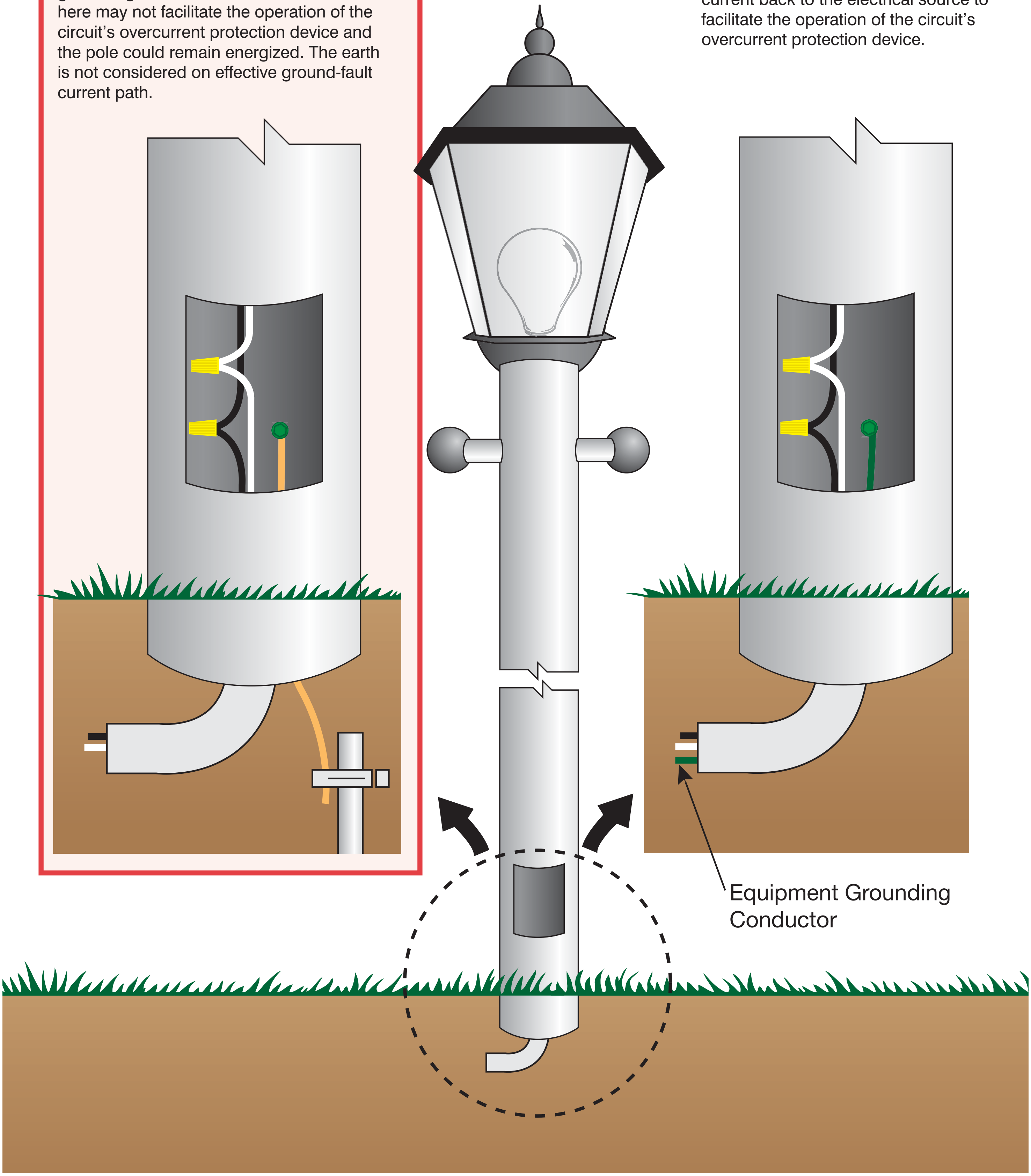
DANGER

If this metal pole becomes energized, the grounding electrode connection shown here may not facilitate the operation of the circuit's overcurrent protection device and the pole could remain energized. The earth is not considered on effective ground-fault current path.

Exhibit 10

CORRECTLY WIRED

An equipment grounding conductor must be included with the circuit conductors in order to carry fault current back to the electrical source to facilitate the operation of the circuit's overcurrent protection device.



Fault Current Returns to the Electrical Supply Source

Contrary to popular thinking, fault current does not try to go to the earth. Fault current returns to its electrical supply source. That is why it was mentioned earlier that bonding is not done to connect metal parts to the earth. The fault current is trying to get back to the XO terminal of the transformer.

Metallic parts of electrical equipment that are only in contact with the earth — and not physically connected to the electrical supply source — may not provide a low impedance fault current path to clear ground faults. In other words, electrical equipment only connected to the earth may not blow a fuse or trip a breaker in case of a ground-fault and could remain energized!

In fact, in 250.4(A)(5) and 250.4(B)(4), the Code prohibits using the earth as the effective ground fault current path. For this reason, one cannot install a metal pole light outdoors and then connect a piece of bare copper from it to a ground rod — and think it is a safe condition — because it is not safe. Without establishing an electrically conductive path back to the electrical source to conduct safely away any fault current that might occur, that well intended electrical installation is endangering lives!

Summation of Grounding and Bonding

Grounding is the physical connection of building's grounded service conductor to the ground (earth) for the purpose of limiting any voltage caused by lightning, line surges, or unintentional contact with higher voltage lines. Grounding is not done in order to clear ground-faults.

Bonding is the intentional creation of an electrically conductive low impedance path of all metal parts of a circuit back to the circuit's electrical source. Bonding is done in order to clear ground- faults through the quick opening of overcurrent protective devices.