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You'll never understand grounding by reading the Code book no matter how you arrange the sections. It's like driving an automobile, you first had to learn how to drive it before being handed the book of rules and going to take the exam for a license.

This book is written for an electrician to understand *why we ground* before we ever start explaining what the Code says.

It has been rumored that only three people have ever understood grounding, and they disagreed. I'm writing this book for the student preparing to become an electrician so the mystery of grounding will not follow them throughout their career as it has mine.

Sometimes too much emphasis is put on one's knowledge of Code rules and sizing of bonding jumpers, electrode conductors, etc. Before one can discuss proper sizing of grounding conductors, you must first understand the reasons for grounding a system, theory, Ohm's law and what takes place when a fault condition occurs in the system.

It is not possible to use electricity without involving some risk. It is impossible to prevent dangerous voltages to ground on an electrical system unless we do away with electricity completely because we cannot prevent a fault condition from occurring. The job of the electrician is to hold that risk to a minimum by installing protection which will reduce the existence of voltages to ground on equipment to a minimum and hold the fault condition to a minimum time duration.

We must understand what a circuit is. An electrical circuit is a path or route of least resistance in which electrons flow from the source of supply to accomplish the electrical work and flow through the circuit back to the source of supply.

Grounding is an electrical circuit. The grounding circuit can be conductors or in some cases a conduit system is the grounding circuit. The **mechanical** connections of fittings, conduits, boxes, etc. are just as important as the **electrical** connection of the circuit wires. Each mechanical fitting is a part of the equipment grounding circuit path and must be connected with just as much care as the electrical circuit conductors. Very few faults occur in a short-circuit between wires. The point of **connection or termination** is where most faults take place.

90% of all failures are from line to metal enclosure. Only 10% are between conductors of the circuit (line-to-line) (line-to-neutral) short circuit.

There are two types of grounds for the protection of electrical wiring systems:
1. The service ground
2. The equipment ground

The **service ground** is intended to limit the voltage on the circuit from lightning or other causes which may impose a higher voltage than it was designed to handle and to limit the maximum potential to ground due to normal voltage. Planet earth is a conductor, although a very poor one in dry conditions. The electrical potential of earth is considered to be zero. Therefore, when a metal object is **grounded** to earth, it is forced to take the same zero potential as earth. Any attempt to raise the potential of the grounded object will cause current to pass over the grounding connection until the potential of the object and the potential of the earth are equalized. Grounding ensures that the grounded object cannot take on a potential differing from the potential of earth.

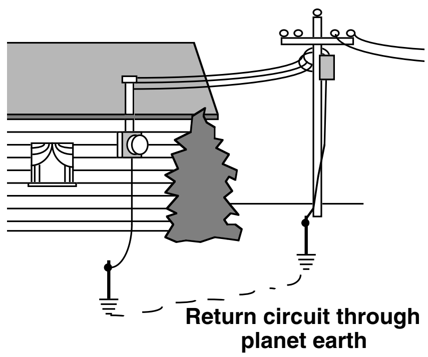
The **equipment ground** is intended to prevent an objectionable potential above ground on raceways and equipment enclosures and to provide a low-impedance path of sufficient capacity for the fault currents to travel back to the overcurrent protective device (fuse or circuit breaker).

Grounded circuits protect people and equipment. When grounding is **improperly** installed, the results can be from "dirty electricity" to the damaging of electrical equipment or minor physical harm to a person or even death in some cases.

How does a person get shocked? By exposure to two conductive surfaces which have a potential difference between them. Bonding these two surfaces together with a conductor will limit the potential difference between them to the voltage drop of the conductor.

A common fantasy is that planet earth is a magic sponge of enormous capacity. Anything undesirable, including unwanted currents and voltages will bury themselves in the earth and be forgotten. Planet earth does not have the ability to accept and store man generated currents, but acts as a conductor to return them to their source. The principles of Ohm's Law apply to this circuit as in other more common circuits.

The return circuit through planet earth is of highly variable resistance due to changing conditions, such as moisture content of the soil, temperature (conductivity of ice is less than that of water), etc.



Approximately what would be the shock exposure to a person coming into contact with a 120 volt circuit that has faulted to the equipment?

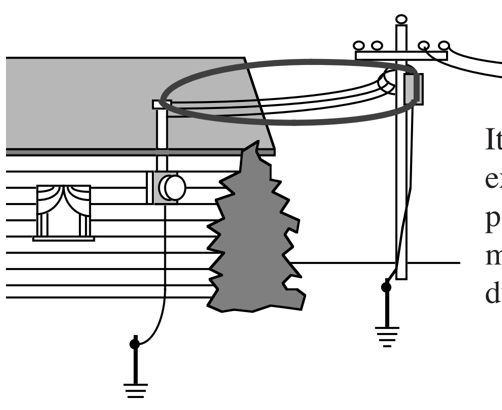
If each ground rod is assumed to have a resistance of 100 ohms, the total resistance of the ground return circuit would be 200 ohms. By Ohm's Law 120v ÷ 200Ω = .6 amp flowing. E = I x R = .6 amp x 100Ω (ground rod earth resistance at the house) = 60 volt shock hazard.

If a second ground rod is driven and connected in parallel with the first ground rod at the house and the earth resistance is reduced to 50 ohms, 120v ÷ 150Ω = .8 amp flowing. E = I x R = .8 amp x 50Ω = 40 volt shock hazard. The shock hazard has been reduced but is still too high to be considered acceptable. The fault current is so low that it will not open any overcurrent device (fuse or breaker).

The earth connections are of primary value in protecting the electrical system from lightning and high voltage involvement. The earth resistance should be as low as possible for this reason.

Most of the protection provided by the so-called ground system has nothing to do with planet earth. It's called the equipment grounding system (**the green or bare wire**). This is the part of the ground system that carries the **faults** to open the overcurrent device (fuse or circuit breaker).

Planet earth carries very little fault current as the equipment grounding circuit will provide a return path of much less resistance back to the source than the high resistance of planet earth.



It should be emphasized that extreme care should always be exercised to maintain the integrity of the **equipment grounding** path. Failure to maintain this grounding path of least resistance may lead to a shock hazard for people, destruction of equipment due to arcing, and a fire hazard to property.

The electrical trade is a profession. It's not a matter of "getting by" in your work.

A roof that leaks, paint that peels or a drain that is stopped up won't cause physical harm or death. But, improper electrical work can.

The writing of this book on grounding was an exercise in discovery for myself. Discovering the ground rod does not provide a path for the current to open the circuit breaker, a #12 conductor may see currents of several thousand amperes, two ground rods in parallel did not lower earth resistance to 25Ω, the ground path must be effective and continuous at all times, etc.

I have witnessed a machine operator losing his arm due to accidental starting of a machine resulting simply from a 120v grounded circuit having the black wire grounded instead of the white wire in a control circuit.

No, it's not a matter of "getting by", it's a matter of education, the electrician must have the wisdom to recognize the responsibility to keep technically proficient. In the world today with the increasing threat of legal liability, one must motivate themself to that extra effort that education requires.

Think where this world would be without electricity, but when you pick up the newspaper you read of the tragedies, the electrical fires and accidents.

Remember the Code is the minimum safety standard, you can always do more than the minimum. Required GFCI circuits have been slowly adopted by the Code for the reason of escalating the cost of the building. But the plumber can sell the home owner three bathrooms with gold fixtures and that is justified! A $20 GFCI could save your life.

As you are well aware there are many "jackleg", "handyman", "jack of all trades" electricians making electrical installations everyday and that is one reason I also have a part time job as a legal consultant investigating electrical fires and deaths.

Go ahead, strap on that toolbelt and call yourself an electrician, but before you do, realize you are a member of the skilled trades electrical profession; a professional. Are you ready?

Furthering your education is purely a voluntary matter for many. If it's not required, they're not interested. An electrician should always be demonstrating a conscious and persistent effort toward personal development and growth.

The quality of American life depends upon the safety and effectiveness of electrical application.

Grounding has been a subject very misunderstood and improperly installed as you will soon learn. Grounding must be taught and must be understood by everyone in the electrical industry. It is our insurance policy.

In a conversation with Joe McPartland, the leader in electrical education, I asked: "Joe, have you ever felt lost when you didn't have the answer to a question?" Joe's response to my question is one I'll always remember. He stated: "I don't feel as bad not knowing the answer as I do having never been asked the question." Questions motivate the mind.

The idea comes to you as the discovery, you don't possess it anymore than a climber possesses the mountain.

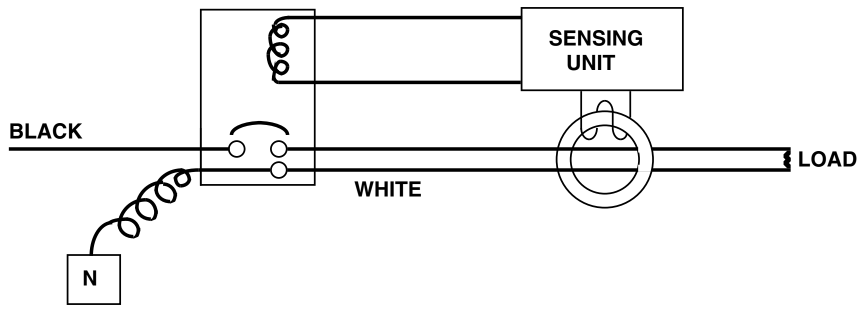
It's what we think we already know that often prevents us from learning.

As an electrician, It's what you know after you know it all that counts.

If you can read a book, thank a teacher. If you can read a book at night, thank an electrician.

A GFCI has a built-in differential transformer which uses a magnetic field to measure the flow of current on the black wire and the flow of current on the white wire.

Under **normal** conditions, the current flow would be the same in both wires. But, with a ground -fault leak to metal conduit, the current in one wire **does not equal** the current flowing in the other wire. When this happens, the induction in the secondary winding of the transformer will cause the sensing unit to operate the GFCI.

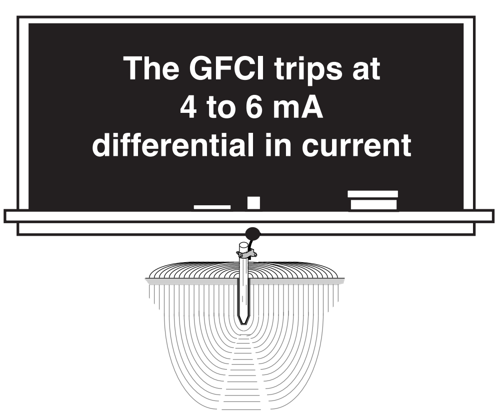


The GFCI will trip at **4 to 6 milliamperes**. The GFCI constantly monitors the flow of current in a circuit. If the current going out to the load differs by **.005 amperes** from the current coming back from the load, the GFCI acts quickly and disconnects the circuit.

As you can see, the GFCI tripping between 4 to 6 mA is **less** than the 15 mA which could cause a person to have "muscular freeze" during an electrical shock.

The GFCI will **not** prevent a person from receiving a shock, but the shock will be minor.

As the name implies, ("Ground-fault Circuit Interrupter"), the GFCI does not protect a person that touches **both** wires at the same time. The device protects from ground-faults not short-circuits. Phase-to-phase short-circuit protection is the responsibility of the overcurrent device.

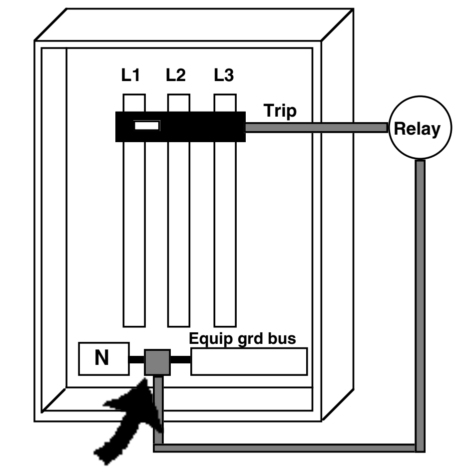


GFCI TEST MONTHLY?

It's marked on the receptacle. The instructions sheet that came with the GFCI states this also.
Are we telling the occupants of the dwelling this is to be done?

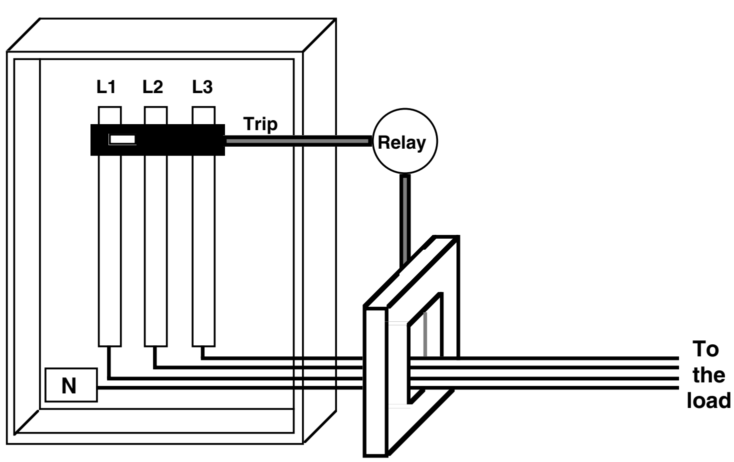
Ground-fault protection of **equipment** is a system designed to provide protection of equipment from damaging line-to-ground fault currents by operating a disconnecting means to open **all ungrounded conductors** of the faulted circuit. This protection is provided at current levels **less** than those required to protect conductors from damage through the operation of a supply circuit fuse or breaker.

The sketch below shows ground-fault protection used to protect the service by using a current transformer that monitors the current flowing on the equipment grounding conductor. When a predetermined amount of current flows on the grounding conductor, the current transformer will energize the relay which will cause the overcurrent device to open.



The sketch below shows another type of ground-fault protection for the service. A magnetic type ground-fault protector has all the phase conductors and the neutral passing through an iron ring. An unbalanced condition between phase conductors, (more current going to the load than is returning from the load) will cause the sensing unit to energize the relay and trip the overcurrent device. An unbalanced condition between the phase conductors and the **neutral** will **not** trip the overcurrent device.

The ground-fault protection does not provide phase-to-phase short-circuit protection. This is the responsibility of the fuse or circuit breaker.



A GFCI should never be by-passed. On construction sites, workers have been known to by-pass a GFCI circuit because of **nuisance tripping**.

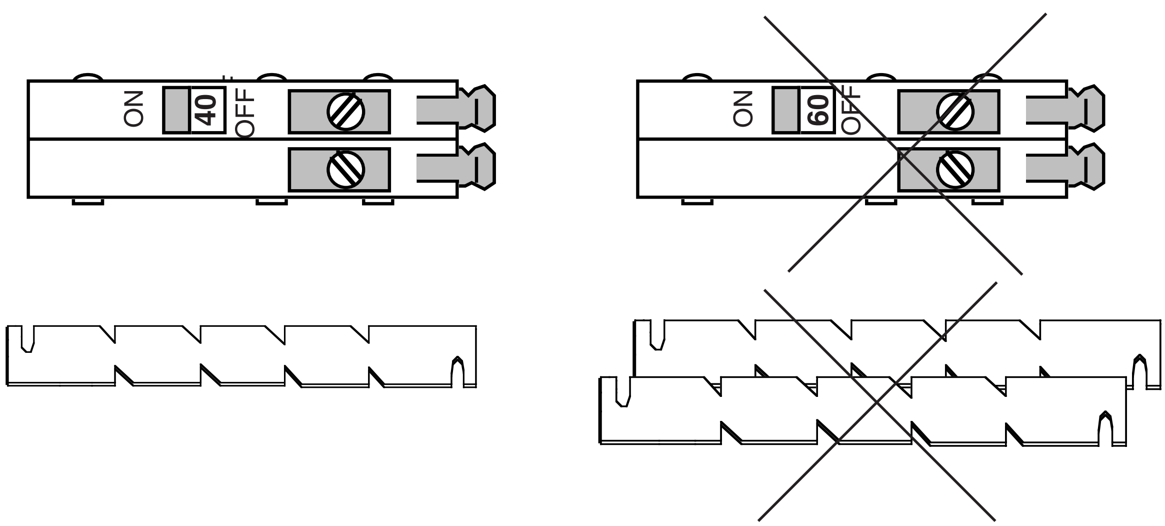
When a GFCI trips, it means you have a difference in current flow between the two circuit conductors, usually due to a ground-fault leakage. Extremely long cords or runs of wire or cable can cause nuisance tripping.

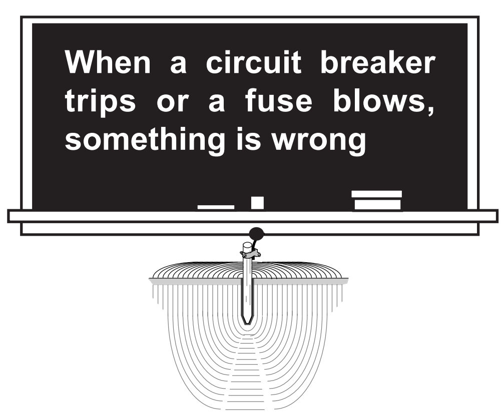
When you by-pass the GFCI circuit, you have eliminated the **safety protection for people.**

When a circuit breaker trips or a fuse blows, **SOMETHING IS WRONG!**

It's not a case of the "breaker being weak" or "a bad batch of fuses" as I've often heard. **Something is wrong**!

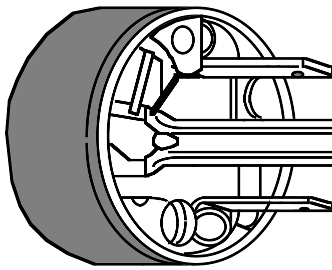
It's not a matter of installing a **larger** size breaker, or doubling the fuse links to keep the load operating. When a breaker trips or the fuse blows, it becomes a matter of an **electrician** trouble-shooting a problem and solving it. The next time a breaker trips or a fuse blows, become a trouble shooter, rather than a **"parts changer".**





Today, plugs and receptacles are polarized, which means the pins on the plugs and receptacles are opposite in size so they can only be plugged into one way.

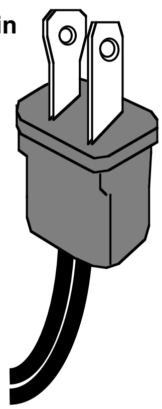
The male cap-plug shown below shows the "U" shaped grounding pin (green) is longer than the current-carrying pins. The reason for this is, when the cap is plugged into a receptacle, the grounding connection is established before the current-carrying pins make contact. And when the cap is unplugged from the receptacle, the current-carrying pins are disconnected first, before the grounding connection is disconnected, thereby assuring a continuous effective grounding path. The equipment grounding pin provides first-make, last-break contact for the equipment.

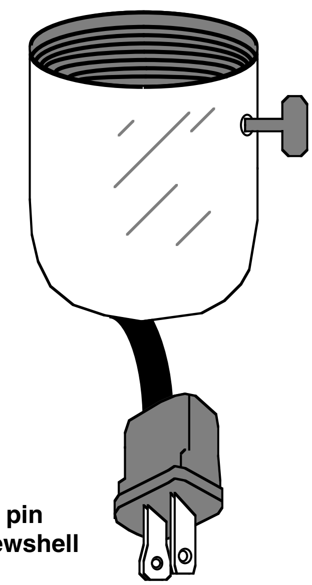


Grounding pin is longer

The two-pin male cap-plug shown below has one pin that is wider than the other pin. The wider pin is the **grounded pin**. These plugs are often used for table lamps.

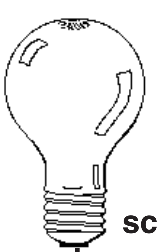
Grounded pin is wider





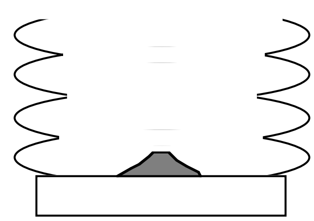
The wider grounded pin connects to the screwshell of the lampholder.

The white grounded wire is always connected to the screw-shell of a lampholder. The black ungrounded (hot) wire is connected to the base of the lampholder.



screw-shell
base

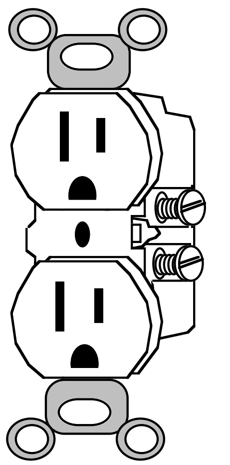
White grounded wire connects to screwshell

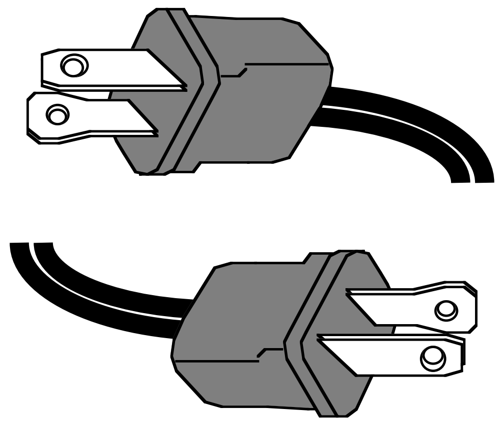


Black hot wire connects to base

Proper polarization will assure that the screwshell of a lampholder will not be **hot**. If the black (hot) wire was attached to the screwshell, you could receive a shock when changing a light bulb.

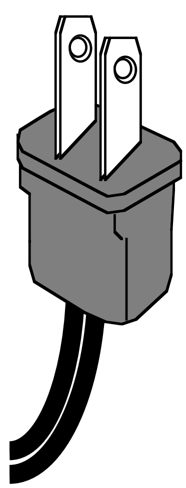
The duplex receptacle shown below has a **wider slot** for the grounded male pin. The grounded pin on the plug cap is **wider**. The male plug can only be plugged into the receptacle **one way.**

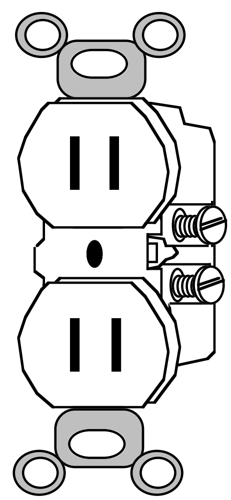




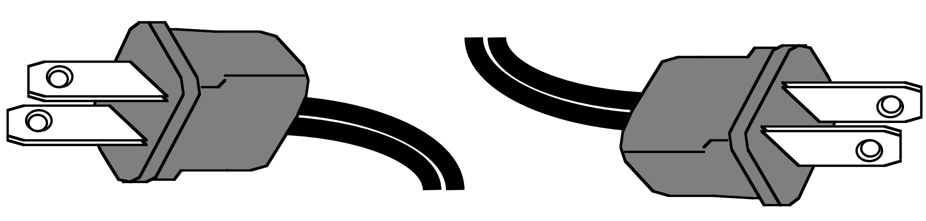
Shown below is the old style two-pin duplex receptacle with both slots the same width. The male plug has both pins of the same width.

Pins are the same size in older styles.



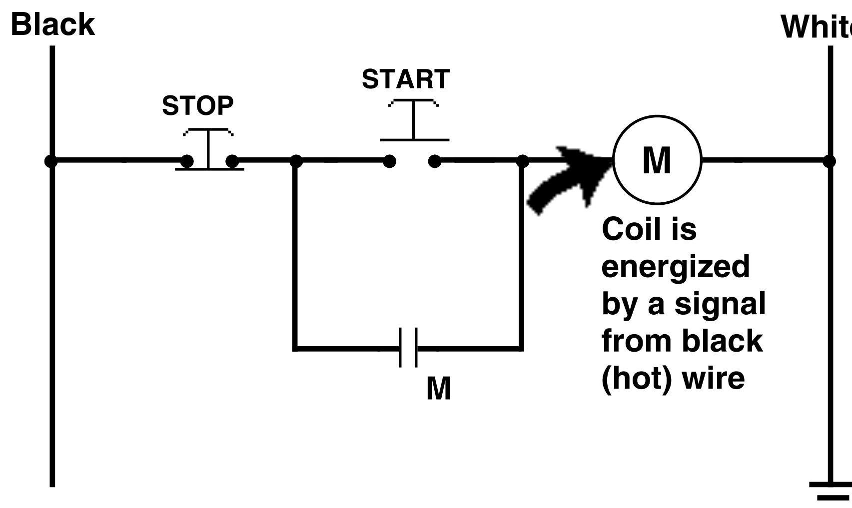


Without a polarized plug and receptacle, the plug can be plugged in either way. The grounded wire can now be broken through a switch, fuse, etc. The screwshell to a lampholder now becomes energized. Now you can see the reason for polarization: **SAFETY!**

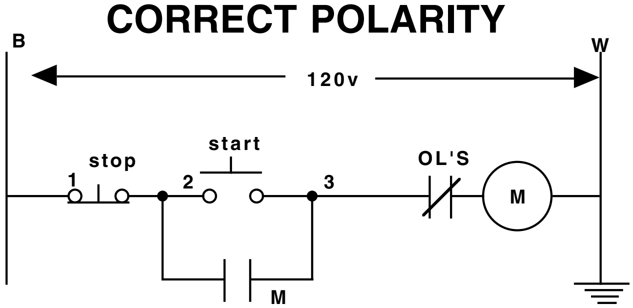


Where one side of a motor control circuit is grounded, it shall be so arranged that an **accidental ground** in the remote-control devices will not start the motor.

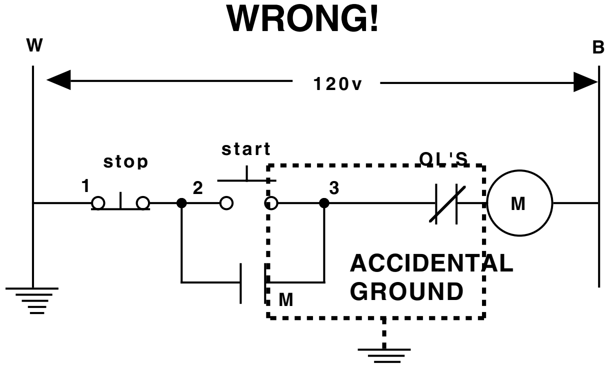
The control circuit shown below is connected **correctly**. The coil must receive a signal from the START button to energize.



CORRECT POLARITY



WRONG!



If the polarity of the black and white is *reversed,* the coil can become energized by an *accidental ground* in the control wiring.

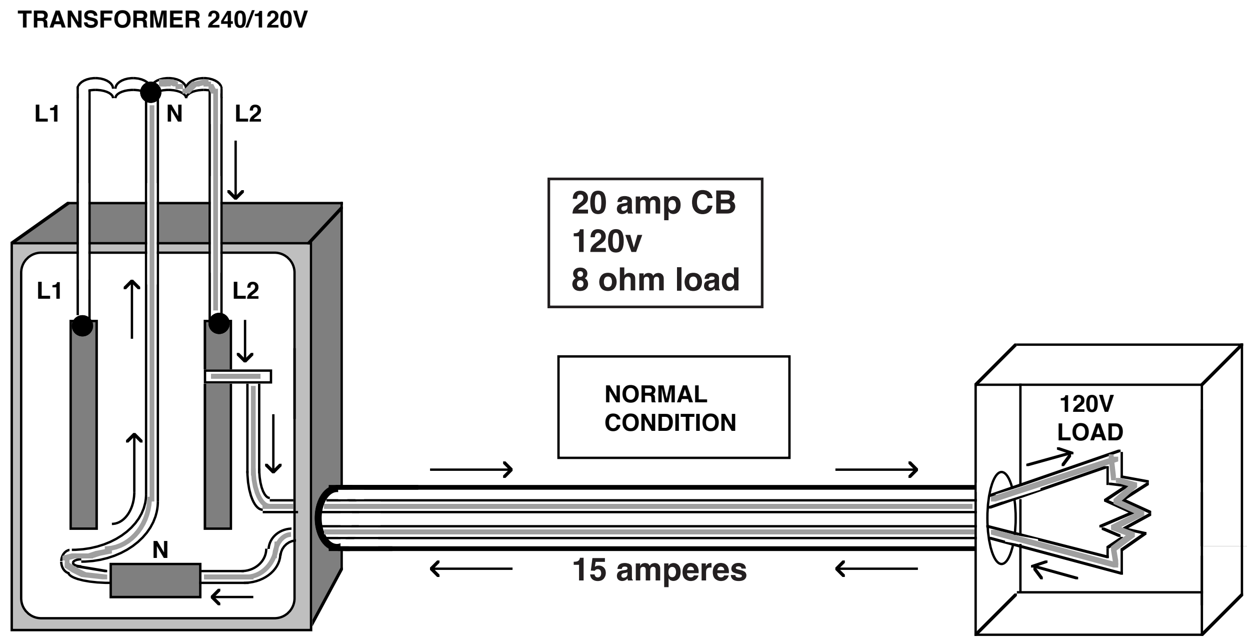
When I worked as a maintenance electrician, I was a witness to this when troubleshooting a machine that had a starting circuit go to ground and accidentally energized an air valve sending the cutters across cutting off the hand of the machine operator.

The polarity of the black and white was *reversed,* the coil can become energized by an *accidental ground* in the control wiring.

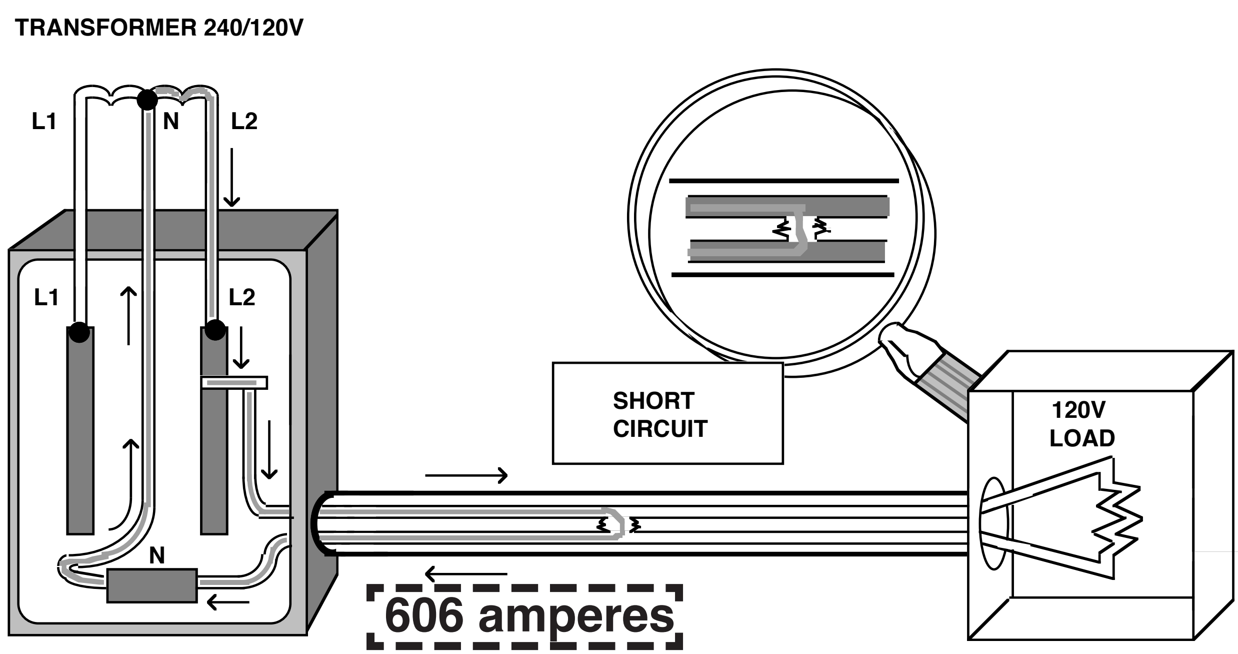
According to maintenance records, the machine had ran for several months okay and then one day it developed a ground energizing a relay coil with the wrong polarity.

The circuit shown below is a normal condition a 20 amp circuit breaker, #12 conductor, 120 volt supply to a full load of 8 ohms.

Using Ohm's law to find the current: $I = E \div R = 120v \div 8\Omega = 15$ amperes normal flow of current.



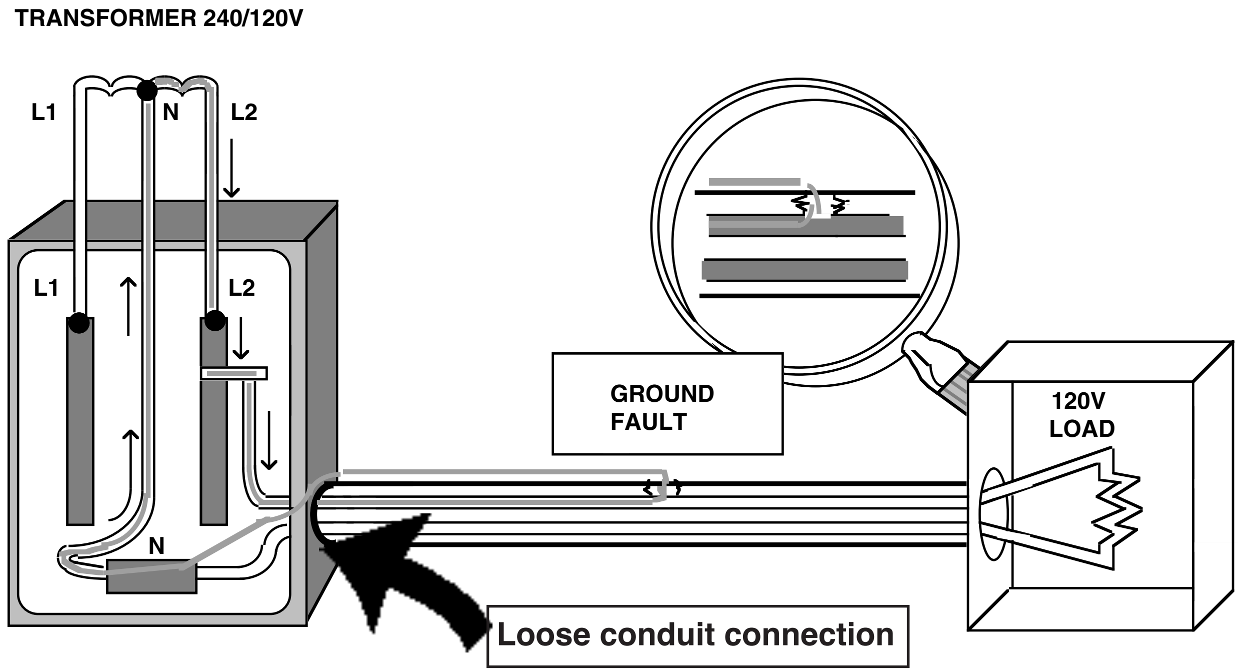
The same circuit is shown below only now it has developed a short-circuit in the conduit 50 feet from the source. Now the load of 8 ohms has been eliminated as the flow will be through the path of least resistance which would be the 100 feet of #12 conductor which is 0.198 ohm. Using Ohm's law, the current flowing in the circuit is: $I = E \div R = 120v \div 0.198\Omega =$ **606 amperes**. Now, you can see how large currents can occur on a simple 20 amp circuit. With the load bypassed the only resistance is the wire itself.



The inrush of 606 amperes will instantaneously trip a 20 amp circuit breaker. A #12 thermoplastic insulated conductor has a maximum short-circuit withstand current of 2,700 amperes for one cycle which is 1/60 of a second or 1,550 amperes for 3 cycles. As you can see with a short-circuit, the current has a direct path back to the circuit breaker with a large amount of current to trip the breaker quickly to prevent further damage to the equipment.

Approximately 10% of all failures are between conductors (short-circuit), while 90% are from circuit conductor to metal enclosure (ground fault).

The same circuit is shown below in a ground fault condition. This example shows the importance of properly connecting the grounding circuit.



A low-impedance path must also be provided when using conduits as the equipment grounding path back to the circuit breaker. **The proper tightness and connections of conduits are just as important as the connections of the circuit wiring**.

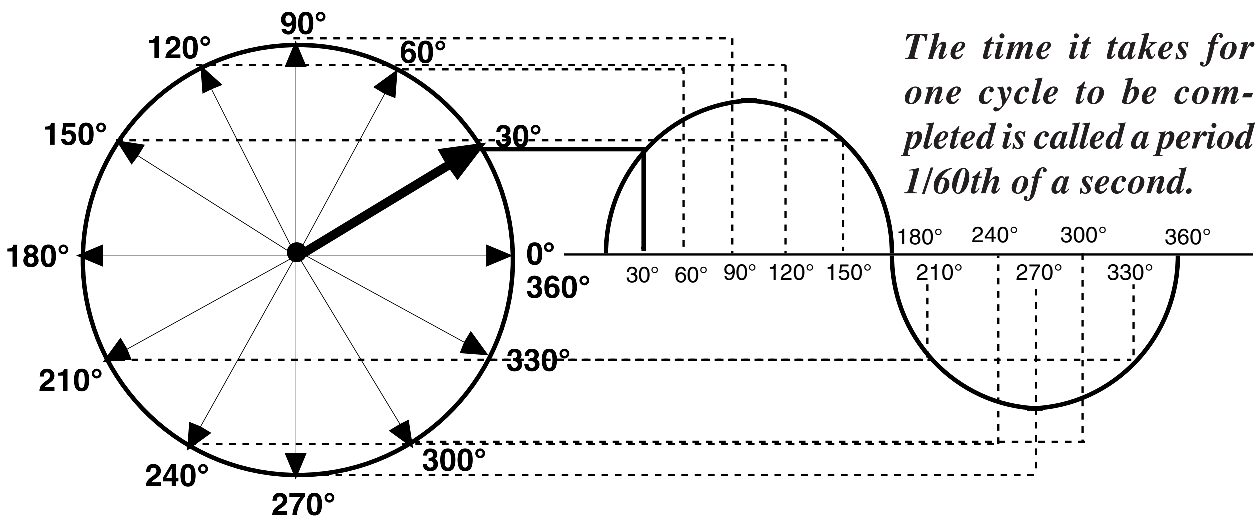
For an example of the importance, in the sketch shown above, a conduit was loosely connected which creates a high-resistance connection and with the resistance of the wire comes to a total resistance of 7.5 ohms.

Now instead of the inrush of 606 amperes as in the case of a short-circuit, we have $I = E \div R = 120v \div 7.5\Omega = 16$ amperes. Not enough current to open the 20 amp rated circuit breaker but enough current to provide a dangerous fault condition.

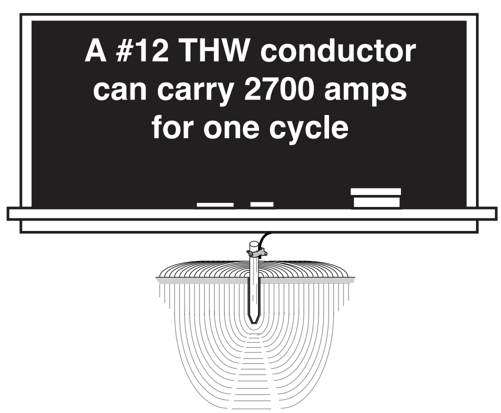
The chart below shows the approximate current that conductors can carry during a ground-fault or short-circuit condition.

Copper, 75° C Thermoplastic Insulated Cable Damage Table

Copper Wire Size 75° C Thermo-plastic	Maximum Short-Circuit Withstand Current In Amperes For					
	1/8 Cycle	1/4 Cycle	1/2 Cycle	1 Cycle	2 Cycles	3 Cycles
#14	4800	3400	2400	1700	1200	1000
#12	7600	5400	3800	2700	1900	1550
#10	12000	8500	6020	4300	3000	2450
#8	19200	13500	9600	6800	4800	3900
#6	30400	21500	15200	10800	7600	6200
#4	48400	34200	24200	17100	12100	9900

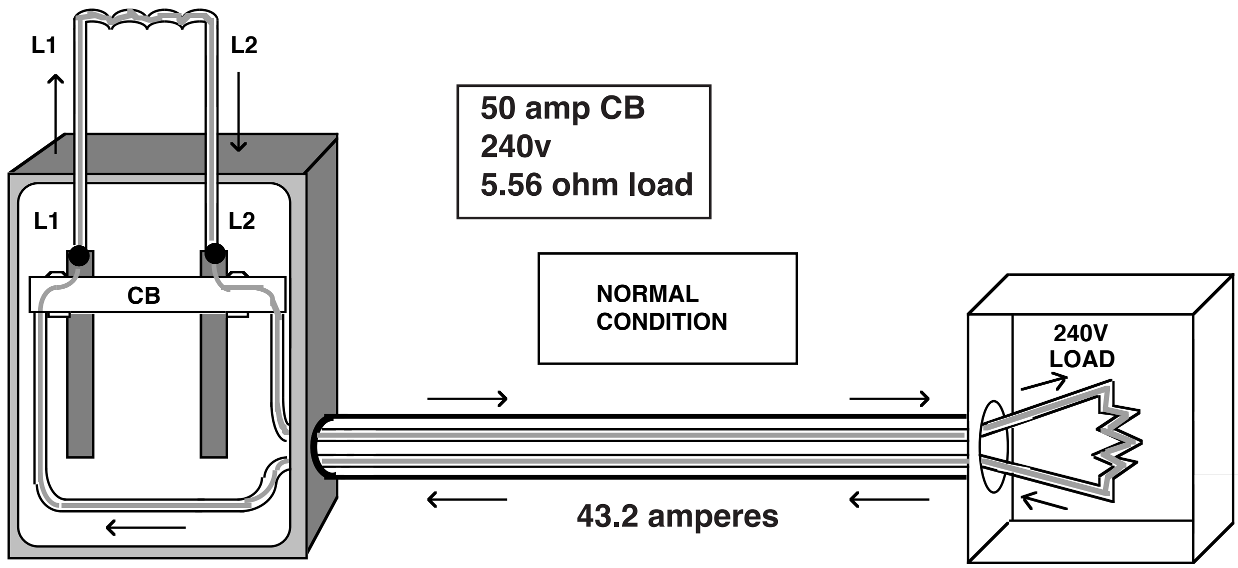


The time it takes for one cycle to be completed is called a period 1/60th of a second.



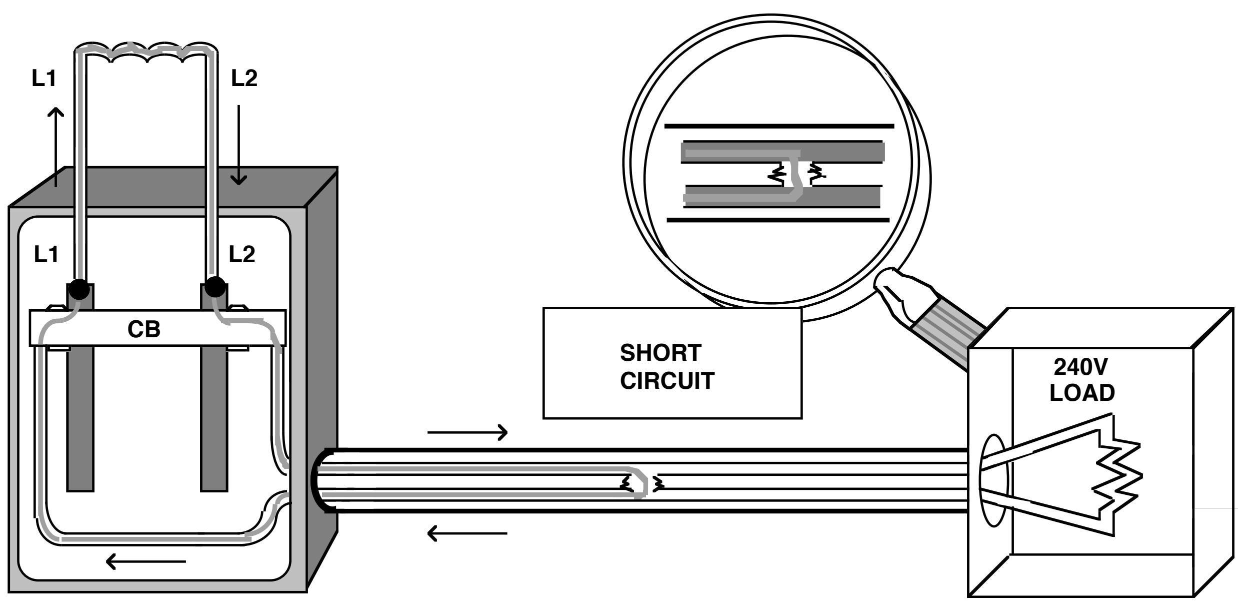
The sketch below is a 50 amp circuit breaker 240v, 5.56 ohm load #4 aluminum wire with no neutral conductor. The normal current flow at full load would be: I = E ÷ R = 240v ÷ 5.56Ω = 43.2 amperes.

TRANSFORMER 240V

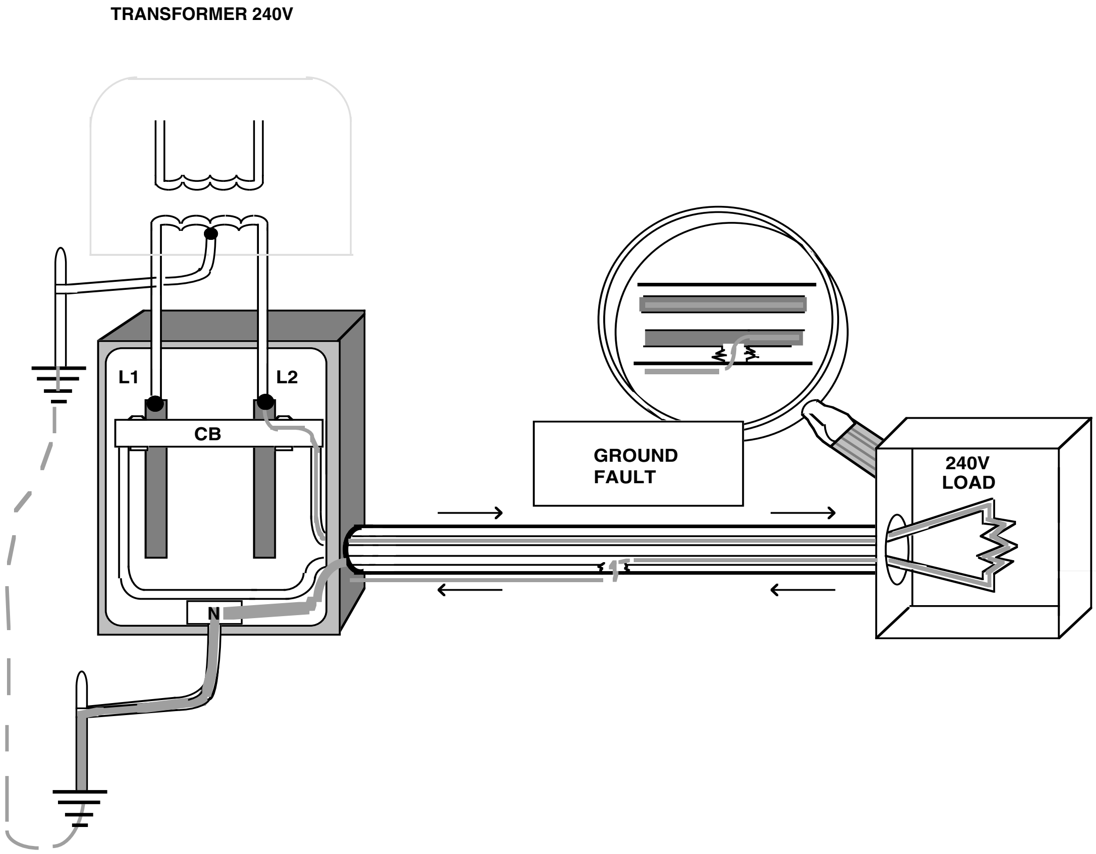


The sketch below shows a short-circuit which elimates the 5.56Ω load in the circuit. If the short-circuit occurred 50 feet from the source, the resistance of 100 feet of #4 aluminum wire would be .508Ω per m/ft x .100' = .0508Ω. I = E ÷ R = 240v ÷ .0508Ω = **4,724 amperes of current flowing**. If #6 aluminum was used, the current flow would be 240v ÷ .0808Ω = 2,970 amperes. If #8 aluminum was used, the current flow would be 240v ÷ .128Ω = 1,875 amperes. You can see how resistance affects the fault current flow in a conductor. The missing neutral conductor plays no part in this short-circuit.

TRANSFORMER 240V



In the preceeding sketch, a neutral conductor was not needed to trip the circuit breaker in a short circuit condition. The sketch below shows a fault-current from line-to-metal. The neutral is grounded at the transformer **but the neutral is not run to the service**.

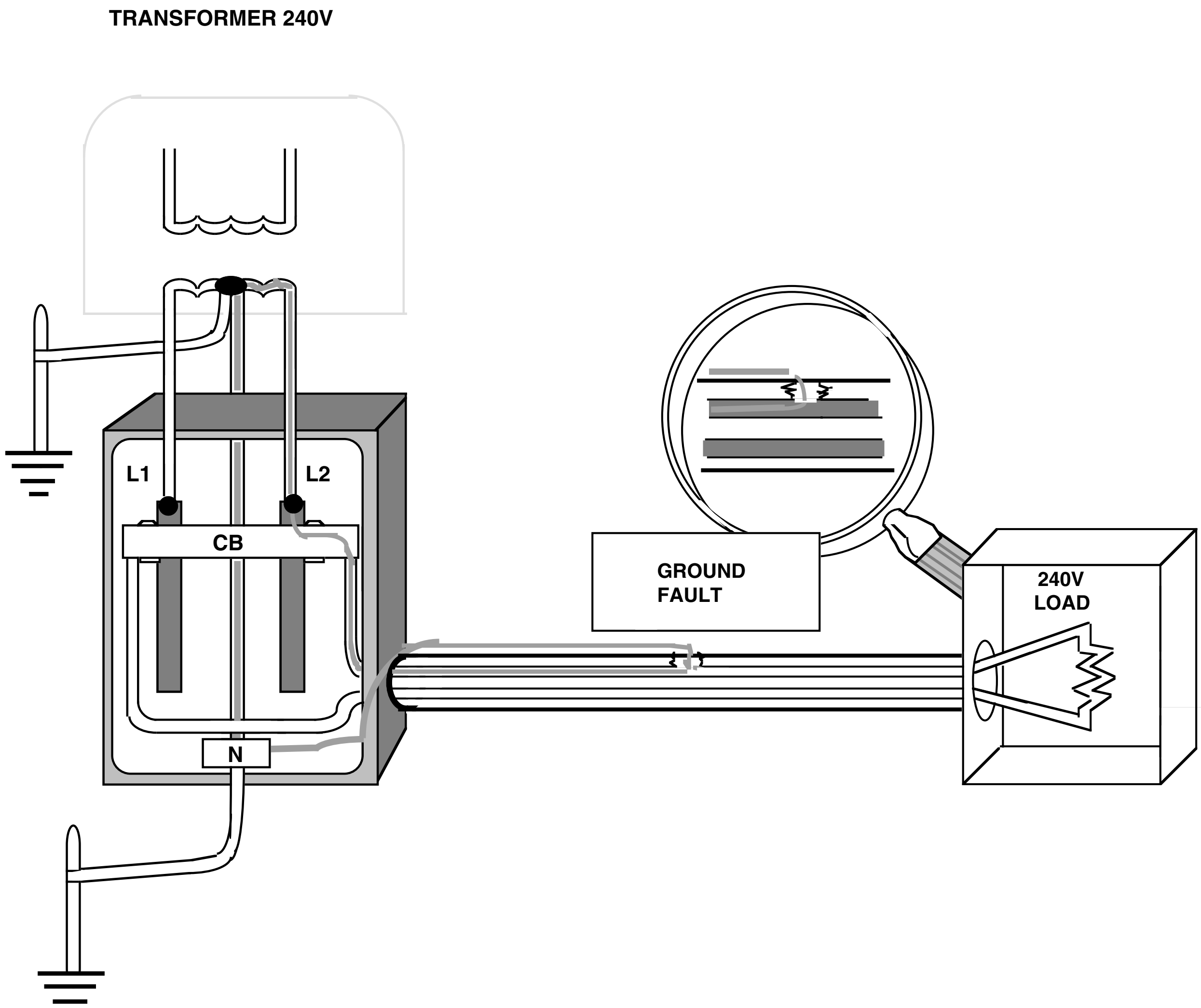


The sketch above shows no neutral conductor from the service panel back to the transformer. The path of fault-current must now travel through the ground rod into the high-impedance earth path to the ground rod at the transformer. Not enough current will ever reach the circuit breaker through this high-impedance path.

OHMIC HEATING

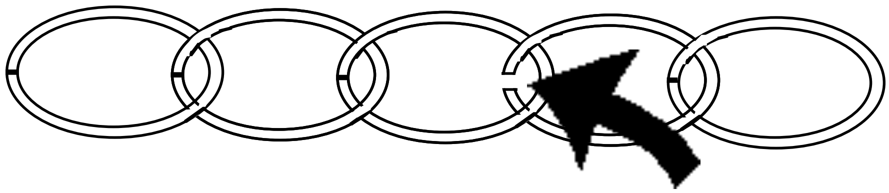
A loose connection causing the voltage to drop at the terminal using the wattage to create heat and carbonize the connection. **The current flow in amperage of 3 to 7 amps is not high enough for a 15 amp fuse or 15 amp circuit breaker to open the circuit.**

There is no protection against the high-resistance, loose connections creating ohmic heat and glow faults in the walls and attics. **No practical circuit breaker could detect such a fault** as there is no measureable characteristic that any circuit breaker could employ to distinguish a glow fault from the normal operation of a branch circuit.

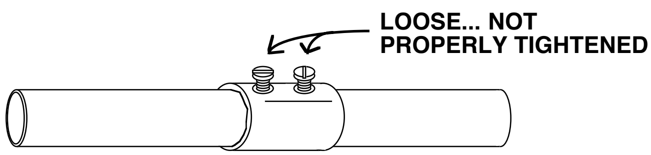


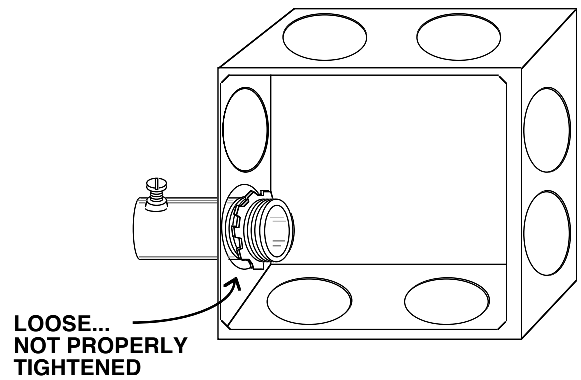
The sketch above shows the 240v circuit with the **neutral conductor** to the service from the transformer. With a fault-current, the current travels the metal raceway through the metal service enclosure through the neutral bus which is bonded at the service to the metal service enclosure and flows through the neutral conductor through the transformer to the circuit breaker. With a properly connected effective grounding path, we will have plenty of fault-current to trip the circuit breaker.

Now you can realize the importance of a neutral conductor being installed with the service conductors **even though there are NO neutral loads**.



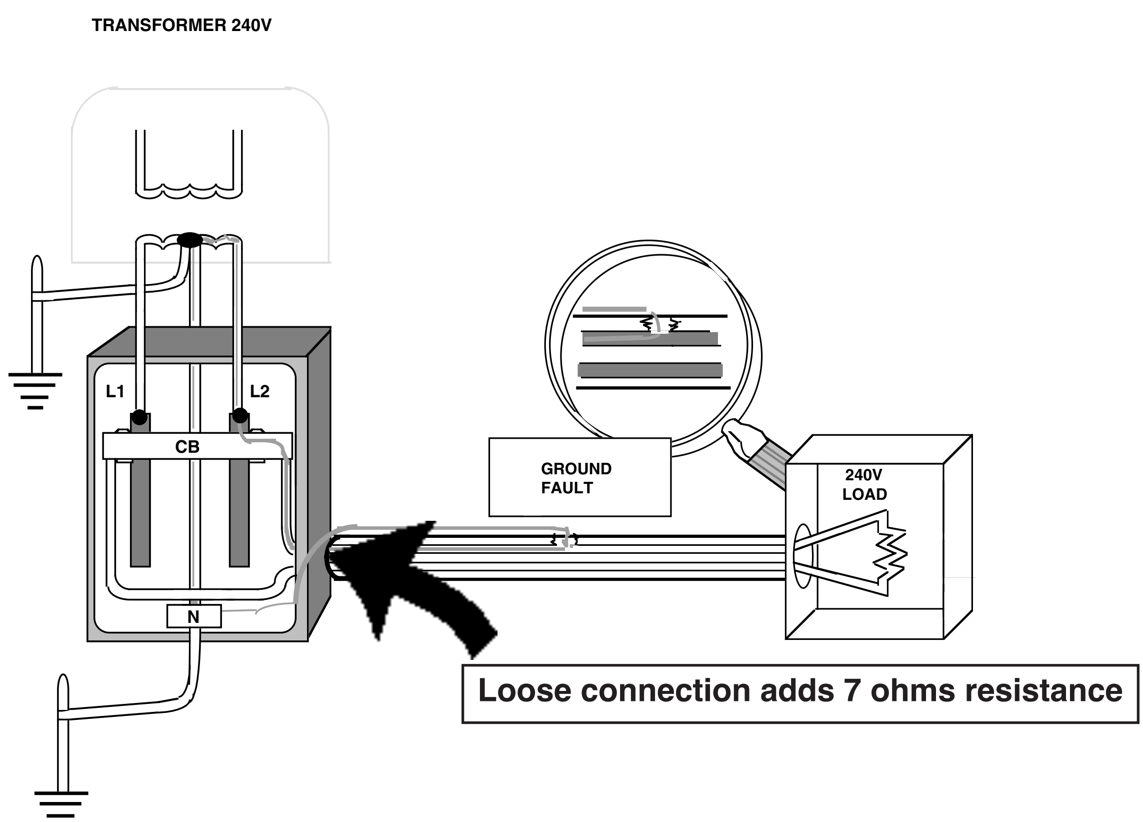
The effective grounding path is like a chain. It is as strong as its weakest link. The mechanical connections of conduits and boxes are a vital factor in the strength of the grounding path.





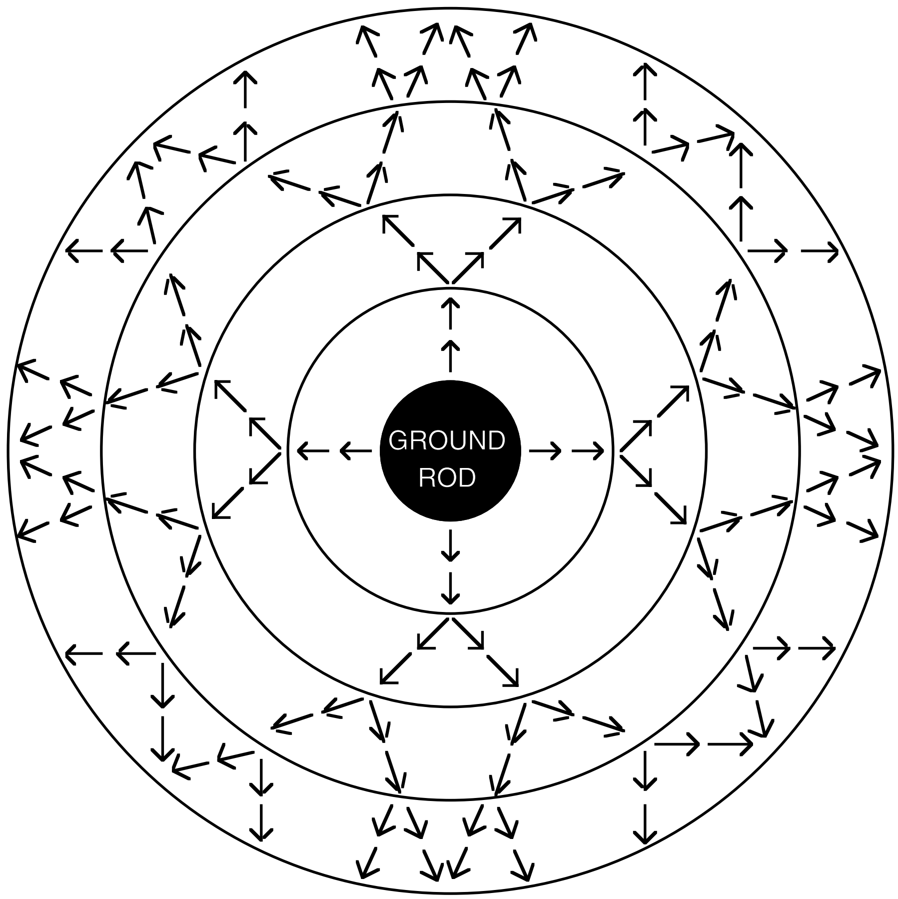
The sketch shown below shows a loosely connected conduit which adds a 7 ohm resistance at the loose connection. The current flow in the ground path would be $I = E \div R$ $240v \div 7\Omega = 34.3$ amperes.

The 50 amp circuit breaker would not trip at 34.3 amperes and the ground-fault is allowed to continue to heat until serious damage may occur.



The electrode is a path into earth for the electrons, the lower the resistance the better the path.

A ground rod driven into earth radiates current in all directions around the rod. Think of the ground rod as being surrounded by **shells of earth**, all of equal thickness.



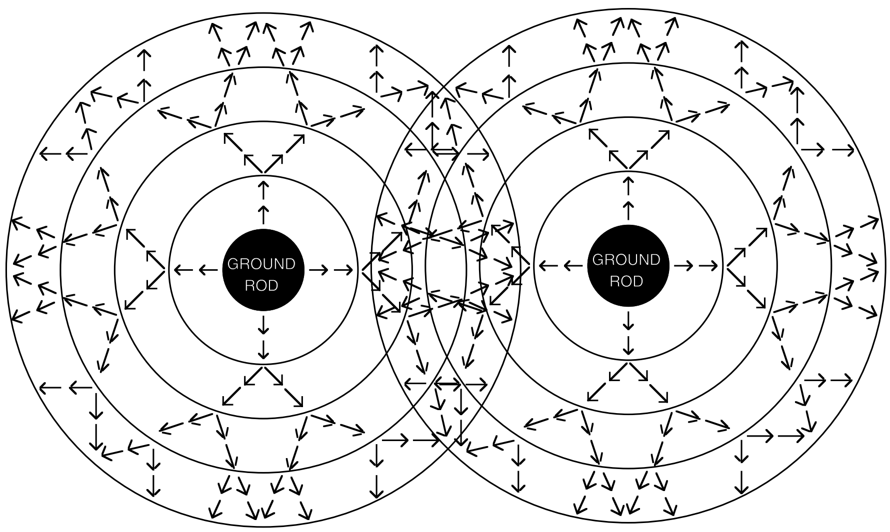
The earth shell nearest to the ground rod has the smallest surface area and offers the **greatest** resistance. The next earth shell is a little larger in area and offers **less** resistance. And each shell on out offers less resistance and so on. Eventually, a distance will be reached where additional earth shells hardly add any resistance to the earth surrounding the ground rod.

If the ground rod to earth resistance is not low enough, there are several ways you can improve it such as: lengthen the ground rod into earth, treat the soil, or use multiple ground rods.

Increasing the diameter of the ground rod has little effect on its earth resistance. Driving a longer ground rod deeper into the earth decreases the resistance. In general, doubling the ground rod length reduces resistance by aproximately 40%.

Two well-spaced ground rods driven into the earth provide parallel paths of resistance. The rule for two resistances in parallel does not apply exactly in this situation. The total resistance is not one-half of the individual rod resistance to earth. Actually, the reduction for two equal-resistance ground rods is about 40%. If three rods are used, 60%, and if four rods are used the reduction is 66%.

When using multiple rods, they must be spaced further apart than the depth they are driven. If spaced too close together as shown below, the earth shell resistance area will be overlapped causing a higher resistance.



If you had two ground rods connected in parallel spaced 10 feet apart, the resistance is lowered aproximately 40%. If the spacing is increased to 20 feet apart, the resistance is lowered to aproximately 50%.

The type of soil is a determining factor in deciding what type of electrode to use. Driven ground rods are generally more satisfactory and economical where rock is 10 feet or more below the surface. Buried plates, strips, grids, and concrete footings are used where rock is encountered at a shallow depth.

Earth conductivity varies with the type of soil, moisture and salt content, and seasonal temperatures. Soils can range from the poor hot dry sand to the moist black dirt. Clay, limestone, shale, sandstone, slate, granite, gravel, etc. are some of the types throughout the country.

Chemical treatment of the soil is a good way to improve the electrode-earth resistance. The **first few inches** away from the ground rod are the most important, as far as reducing the electrode resistance is concerned. Soil resistivity can be reduced anywhere from 20 to 90% depending on the soil texture and treatment.

There are a variety of chemicals suitable, the most commonly used chemicals are common rock salt and magnesium sulfate. Magnesium sulfate is the least corrosive, rock salt is cheaper and does the job but should be applied in a **trench around the electrode**.

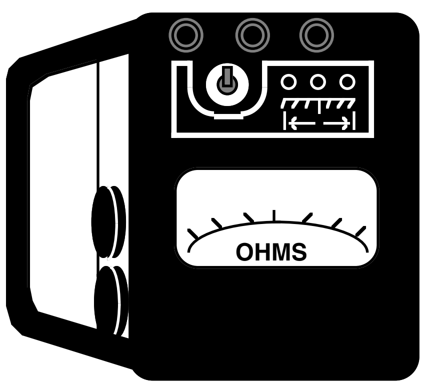
The effects of a chemical treatment may be accelerated by saturating the soil area with water. Chemical treatment of the soil is **not** a permanent way to improve your electrode to earth resistance. Depending on the nature of the chemical treatment, texture of the soil, and the amount of rainfall, will determine when another treatment is required.

Earth resistance tests should be made periodically after the original installation and test to see if the resistance is remaining constant or increasing.

As buildings are expanded, such changes create different needs in the earth electrode. What was a low earth resistance can become obsolete. In many locations, the water table is gradually declining. The electrode systems that were in contact with water may wind up in dry earth of high-resistance.

As you can see, resistance to earth can vary with changes. Such changes can be considerable. An earth electrode that once was good (low-resistance) may not stay that way. To be sure, you must check the earth resistance periodically. In my travels, I have found that this test is very neglected in our industry.

A self-contained portable instrument called an earth tester is used to test the earth's resistance. It is easy to use and very reliable. Basically, there are two test methods: (1) Direct method, or two-terminal test (2) Fall-of-potential method, or three-terminal test. The earth resistance tester comes with instructions on how to make these tests.



Different types of earth resistance tests will be explained in a later chapter.

In any discussion of grounding, the question is always asked, "How low in resistance should the ground be?" The lower the ground resistance, the safer protection you'll have for people and equipment. System ground resistances of less than one ohm may be obtained by the use of multiple electrodes connected together. Some large substations or generating plants require this on the specifications. Resistances in the two to five ohm range are generally found in commercial and industrial buildings. The Code uses 25 ohms as a **maximum** resistance limit for a **single** made electrode.

What is the best electrode for a low-resistance to earth ground reading?

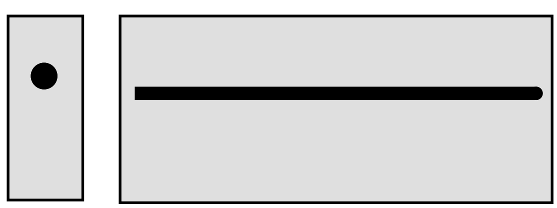
Studies have shown that continuous underground metallic water piping systems have a resistance to earth of **less than three ohms**. The length of piping is an important factor, as the more piping you have in contact with earth, the more area you have to discharge the electrons from a large surge. Local metal underground piping systems, metal well casings, metal building frames, and the like generally have a resistance to earth of substantially less than 25 ohms. For small systems where ground currents are relatively small, the above electrodes are generally used because of the economical cost factor.

Buried plates are the **least** efficient type of the made electrode. Ground rods are generally used and are the most popular made electrodes because of their cost. Plates are expensive compared to rods.

A ground rod driven in sandy type soil does not provide a tight connection (compaction) with earth. I have seen an 8 foot ground rod pulled from the sandy soil with the bare hand. A ground rod driven in sandy soil has a high earth resistance due to this poor contact.

Tests have proven that the "Ufer ground" has very low-resistance to earth readings. Years ago in Arizona, which is usually hot and dry, and the soil being sand and gravel, 24 buildings were grounded with the Ufer ground. Resistance to earth readings were conducted every other month for 18 years. Records that were kept showed the maximum reading was 4.8 ohms and the minimum reading was 2.1 ohms. The average value for the 24 buildings over an 18 year period in the hot dry sand was 3.57 ohms! No servicing was required during this period. The installations used 1/2" steel rebar set in a concrete footing. As a result of these tests, the Code accepted Mr. Ufer's suggestion that a #4 or larger copper wire 20 feet long embedded in a concrete footing be accepted as an electrode.

CONCRETE-ENCASED ELECTRODE



This is an excellent electrode for several reasons: (1) the rebar acts as multiple rods (2) the concrete is in contact with the earth over a large area (3) the weight of the building keeps a good contact pressure to earth (4) concrete in contact with earth retains moisture. Do not use visqueen or any plastic barrier between the concrete and earth when pouring the footing. This would defeat the direct contact with earth. Tests have shown in some installations the resistance was less than **one ohm**.

When designing a ground system where large currents are anticipated to occur to earth, the system must have the capacity to handle these currents without overheating. As we have learned, temperature and moisture conditions surrounding the electrode have a direct effect on the resistivity in this area of the grounding circuit. Currents passing from the electrode into the earth have a definite effect on these two factors; moisture and temperature.

Serious heating and vaporization of the moisture around the rod may occur when large currents are passed. Situations have occured where the earth actually smoked around the electrode as this moisture was being boiled away by the heat from the large currents flowing into the ground rod.

Large currents of long duration are unusual, but this condition could occur from a ground fault that won't trip the breaker. In sandy areas, this heat has been known to actually crystallize the sand into glass. High-resistance produces **heat**.

Ground rods are manufactured in different materials, diameters and lengths. The most common type of ground rod is the copper-clad steel rod. The copper-clad rod permits a copper-to-copper connection between the grounding electrode conductor and the ground rod.

The Code requires rods of stainless steel, copper, or zinc coated steel be at least 5/8" in diameter, unless listed.

Copper-clad rods have: (1) a heavy, pure copper jacket having 0.010" minimum thickness; (2) a copper jacket adherence test; (3) a bending test with no cracking of the copper jacket.

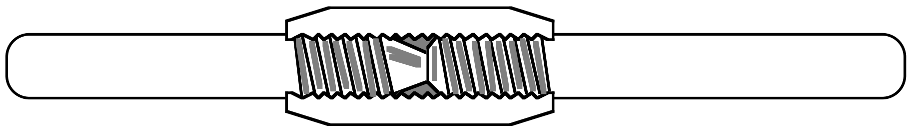
Choice of materials used to manufacture a ground rod will determine the life of the grounding system. Tests show copper to be the most corrosion resistant of all metals tested, in most soils. Ground rods with a copper coating would have a life expectancy of approximately 30 years.

Driving conditions can be a factor in determining the diameter of a rod. The copper-clad rod is the most common and can be driven to a considerable depth without destruction in most conditions.

Ground rods come in lengths 5 to 40 feet. The most common lengths are 8, 10, 12 and 16 feet.

The Code requires a minimum of 8 feet driven into the soil. The 10 foot ground rod has become an established standard as it meets the 8 foot minimum.

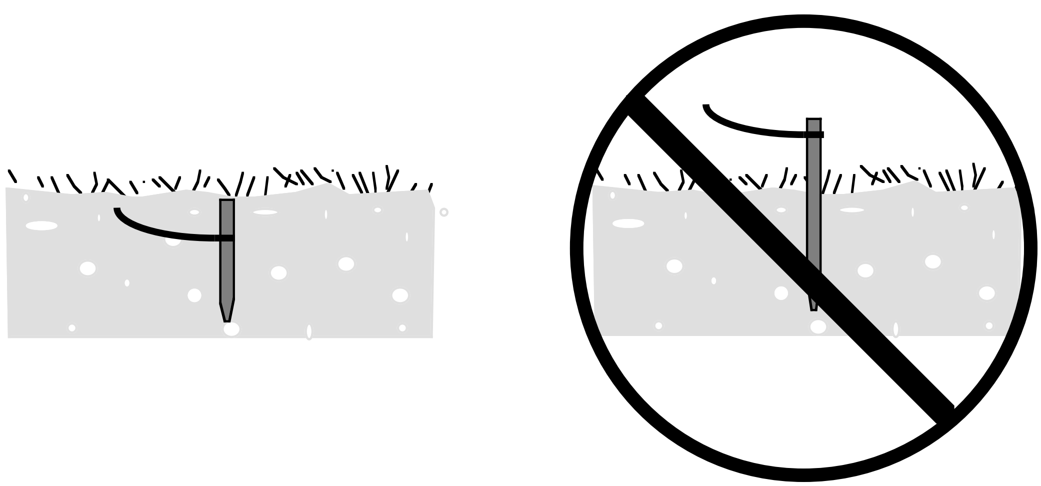
For rods that are required by specifications or such to be driven deeper are available in sections for ease of driving. As each length is driven, a **coupling** is connected to the next length making a continuous rod. A removable stud will absorb the driving blows and prevent the head from mushrooming.



The standard and sectional rods have a machined blunt point on one end and a chamfer on the other end to prevent mushrooming when driven.

Star-shaped ground rods give greater contact surface with the earth. All electrodes should be free from paint, grease, or any non-conductive coating. Iron pipe electrodes are not very desirable as they rust through and lose the important contact with earth.

No unguarded portion of the ground rod should be above earth for safety reasons. The connection between the grounding electrode conductor and the ground rod is a very important safety connection for the grounding system.

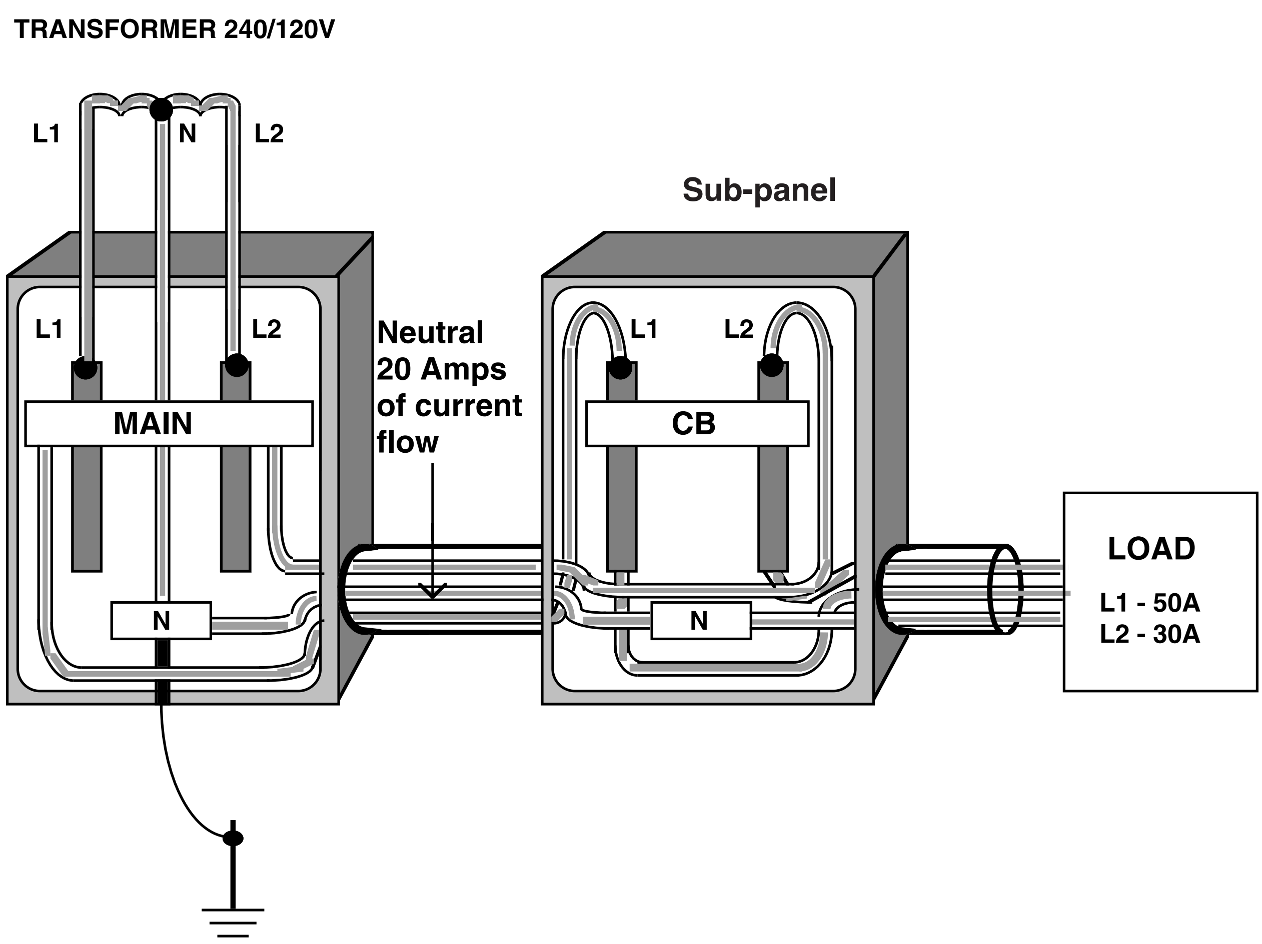


System grounding means that the service neutral conductor, grounding electrode conductor, service entrance equipment, and all metallic pipes, must be **bonded** together at the **service**. The **equipment grounding conductor** or raceway is bonded to the neutral and grounding electrode conductor at the neutral block in the **service equipment panel only.**

The number one **violation** of grounding is the bonding of the grounded neutral at sub-panels and other locations throughout the electrical system.

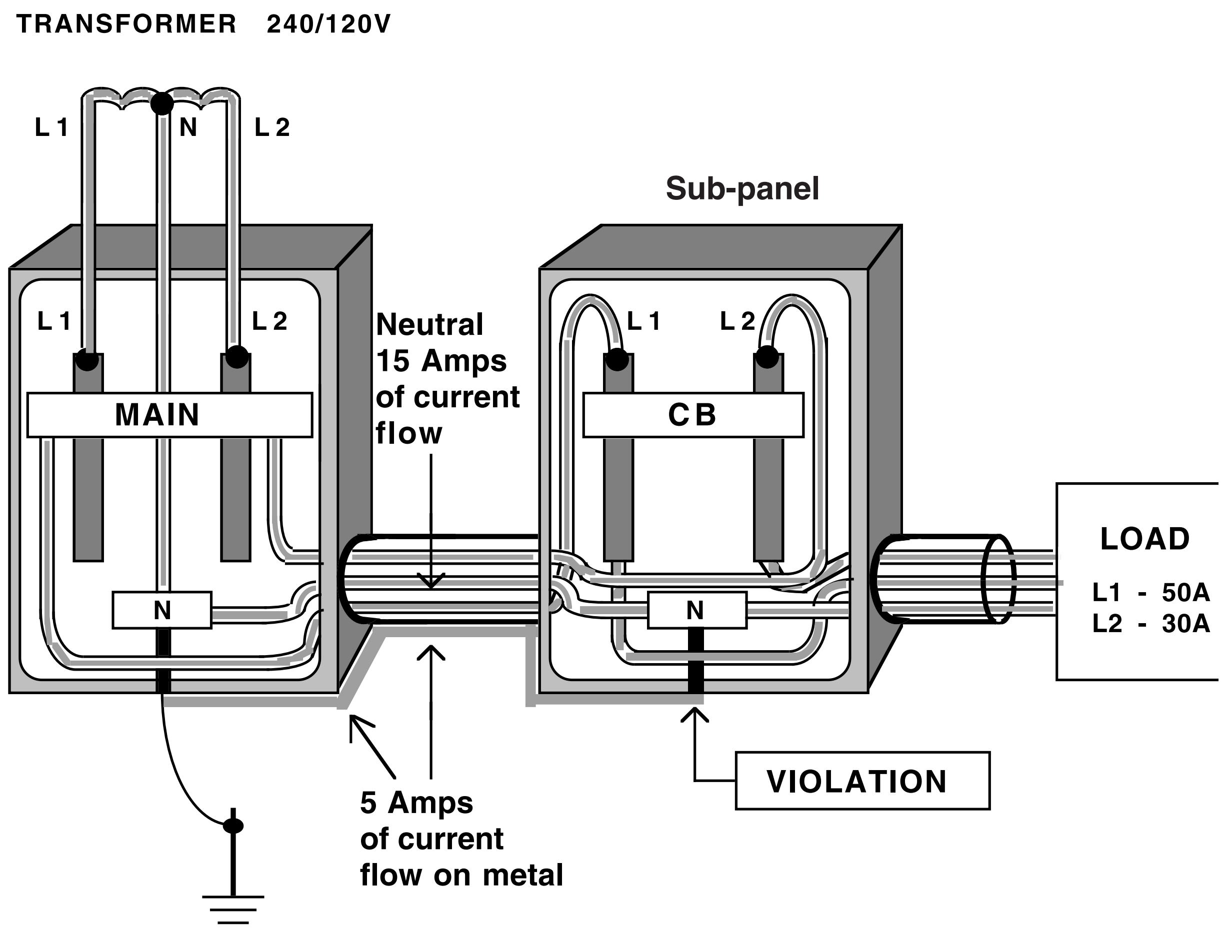
The main bonding jumper in the service equipment panel may be a wire, bus, screw or similar connector. Generally, installing the **bonding screw** through the neutral block to the service panel is the most common main bonding jumper used.

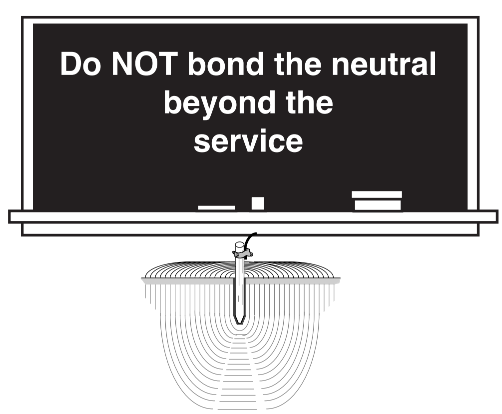
The sketch below shows the neutral bus in the service panel properly **bonded** to the panel and electrode. The sub-panel has the neutral bus isolated from the panel. This is the correct procedure. L1 has a load of 50 amps, L2 a load of 30 amps. The neutral will carry the **unbalance** of 20 amperes.



The sketch below shows a common **violation** of bonding. The neutral bus in the sub-panel is bonded to the panel. When the neutral is bonded beyond the service, it puts the neutral and the conduit in a parallel path, both carrying current. Some current flows in the neutral conductor and some current flows over the metal conduit and panel. The resistance of the conduit is approximately three times greater than the neutral conductor, this allows 1/4 of the current (5 amps) to flow over the conduit with 15 amps flowing in the neutral conductor.

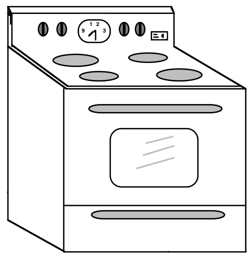
This is a **VIOLATION.** No current except ground-fault current is permitted to flow through metallic equipment.

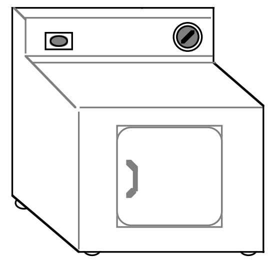




There was **one exception** that permitted bonding the grounded (neutral) conductor to the metal frame of cooking equipment and clothes dryers.

The Code requires for ***new*** branch circuits, they shall include the grounding wire. The 3-wire is only for **existing** circuits.





The past Codes permitted connecting the **grounded** circuit conductor to the frame of ranges, wall-mounted ovens, counter-mounted cooktops, clothes dryers, and outlet and junction boxes which are a part of the circuit for these appliances mentioned. When of the following conditions were met:

1. The supply circuit is 120/240v, single-phase, three-wire **or** 208/120v from a three-phase, 4-wire.

2. The grounded conductor is not smaller than #10 copper or #8 aluminum.

3. The grounded conductor is insulated; OR the grounded conductor is uninsulated (bare) and part of a Type SE service-entrance cable and the branch circuit originates at the service equipment.

4. The grounding contacts of receptacles furnished as part of the equipment are bonded to the equipment.

The past rule has a long history, it has been in the Code since 1947. It was estimated in 1983 that there were 40 million electric ranges and 34 million clothes dryers connected to the 3-wire system using the grounded circuit conductor bonded to the frame for equipment grounding, with an excellent safety record.

Questions were asked, why does the washing machine have **both** a grounded conductor and an equipment grounding conductor when the clothes dryer sitting right beside it only requires the grounded conductor? The grounded conductor to a dryer is permitted to serve a dual purpose by being used also as the **equipment grounding conductor**. The Code has changed this for new circuits.

This book has explained the **equipment grounding conductor** and its function in the grounding circuit. All receptacles are now required to have a grounding pin for this added protection.