

# Electric Frequently Asked Questions



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## Electric Codes

Electrical codes arose in the 1880s with the early commercial introduction of electrical power. Many conflicting standards existed for the selection of wire sizes and other design rules for electrical installations. The intention of wiring safety codes is to provide safeguarding of persons and property from hazards arising from the use of Regulations may be set by local city, provincial/state or national legislation, perhaps by amendments to a model code produced by a technical standards-setting organization, or by a national standard electrical code.

The first electrical codes in the United States originated in New York in 1881 to regulate installations of electric lighting. Since 1897 the U.S. National Fire Protection Association, a private nonprofit association formed by insurance companies, publishes the National Electrical Code (NEC). States, counties or cities often include the NEC in their local building codes by reference along with local differences. The NEC is modified each three years. It is a consensus code considering suggestions from interested parties. The proposals are studied by Committees of engineers, tradesmen, manufacturer representatives, fire fighters, and other invitees.

## Knob & Tube Wiring

Knob and tube wiring was the earliest standardized method of electrical wiring in buildings, in common use from about 1880 to the 1930s. It consisted of single insulated copper conductors run across interior walls or within ceiling cavities, passing through joist and stud drill-holes via protective porcelain insulating tubes, and supported along their length on nailed-down porcelain knob insulators. Where conductors entered a wiring device such as a lamp or switch, they were protected by flexible cloth insulating sleeving. The first insulation was asphalt saturated cotton cloth, then rubber became common. Wire splices in such installations were twisted for good mechanical strength, then soldered and wrapped with friction tape (asphalt saturated cloth), or made inside metal junction boxes.

The ceramic knobs were cylindrical and generally nailed directly into the wall studs or floor joists. Most had a circular groove running around their circumference, although some were constructed in two pieces with "pass-through" grooves on each side of the nail in the middle.

By wrapping electrical wire around the knob and then twisting the wire, the knob securely and permanently anchored the wire. The knobs separated the wire from potentially combustible framework, facilitate changes in direction, and ensure that wires are not subject to excessive tension. The wires were also in air, thus could dissipate heat well.

Ceramic tubes were inserted into holes bored in wall studs or floor joists, with wires running through them. This kept the wires from rubbing against the wood, or being compressed by the wood as the house settled.

Other ceramic pieces would typically be used as a junction point between the wiring system proper and the more flexible cloth-clad wiring found in light fixtures or other permanent, hard-wired devices. When a generic power outlet was desired, the wiring could run directly into the junction box through an insulating sleeve called loom.



Example of Knob and Tube Wiring from a 1930's house.

#### Disadvantages

Historically, wiring installation standards were less stringent in the age of knob-and-tube wiring than today. Compared to modern electrical wiring standards, the main shortcomings of knob-and-tube wiring are: knob-and-tube wiring never included a safety Grounding conductor; did not confine switching to the hot conductor (the so-called Carter System places loads across the common terminals of a three-way switch pair); it permitted the use of in-line-splices in walls without a junction box. Compared to modern thermoplastic wiring insulation, the K&T wiring was less resistant to damage, and had a higher temperature rating.



Knob and tube wiring at a museum display

Older homes may have knob-and-tube wiring for all or part of their electrical system. Such wiring may require replacement and modernization, as they are generally inadequate for modern levels of power use. As power use increased following the Second World War, first-generation wiring systems became susceptible to abuse by frustrated homeowners who would avoid repeatedly blowing fuses by overfusing the circuits, thus subjecting the wiring to damage due to higher levels of current. Or overfusing because K&T was rated for use in air, so 14AWG copper could handle 20 amperes, whereas in cable it is rated 15 amperes.

Knob-and-tube wiring may also have been damaged by building renovations. Its rubber insulation will be dried-out, thus brittle when handled, or it may have been damaged by rodents or carelessness (for example, hanging objects off wiring running in accessible areas like [basements](#)). Currently the United States [NEC](#) forbids use of [insulation](#) over knob-and-tube wiring, so energy efficiency upgrades to home insulation also requires replacement of the wiring in affected homes.

### **What is UL listing?**

The UL stands for "Underwriters Laboratory". It used to be an Insurance Industry organization, but now it is independent and non-profit. It tests electrical components and equipment for potential hazards. When something is UL-listed, that means that the UL has tested the device, and it meets their requirements for safety - ie: fire or shock hazard. It doesn't necessarily mean that the device actually does what it's supposed to, just that it probably won't kill you.

The UL does not have power of law in the U.S. -- you are permitted to buy and install non-UL-listed devices. However, insurance policies sometimes have clauses in them that will limit their liability in case of a claim made in response to the failure of a non-UL-listed device. Furthermore, in many situations the NEC will require that a wiring component used for a specific purpose is UL-listed for that purpose. Indirectly, this means that certain parts of your wiring must be UL-listed before an inspector will approve it and/or occupancy permits issued.

### **What are the different voltages: 110/115/117/120/125/220/240?**

One thing where things might get a bit confusing is the different numbers people bandy about for the voltage of a circuit. One person might talk about 110V, another 117V or another 120V. These are all, in fact, exactly the same thing... In North America the utility companies are required to supply a split-phase 240 volt (+-5%) feed to your house. This works out as two 120V +- 5% legs. Additionally, since there are resistive voltage drops in the house wiring, it's not unreasonable to find 120V has dropped to 110V or 240V has dropped to 220V by the time the power reaches a wall outlet. Especially at the end of an extension cord or long circuit run. For a number of reasons, some historical, some simple personal orneriness, different people choose to call them by slightly different numbers. This FAQ has chosen to be consistent with calling them "110V" and "220V", except when actually saying what the measured voltage will be. Confusing? A bit. Just ignore it.

One thing that might make this a little more understandable is that the nameplates on equipment often show the lower (ie: 110V instead of 120V) value. What this implies is that the device is designed to operate properly when the voltage drops that low.

208V is *\*not\** the same as 240V. 208V is the voltage between phases of a 3-phase "Y" circuit that is 120V from neutral to any hot. 480V is the voltage between phases of a 3-phase "Y" circuit that's 277V from hot to neutral.

In keeping with 110V versus 120V strangeness, motors intended to run on 480V three phase are often labeled as 440V...

### **What does an electrical service look like?**

There are logically four wires involved with supplying the main panel with power. Three of them will come from the utility pole, and a fourth (bare) wire comes from elsewhere.

The bare wire is connected to one or more long metal bars pounded into the ground, or to a wire buried in the foundation, or sometimes to the water supply pipe (has to be metal, continuous to where the main water pipe entering the house. Watch out for galvanic action conductivity "breaks" (often between copper and iron pipe). This is the "grounding conductor". It is there to make sure that the third prong on your outlets is connected to ground. This wire normally carries no current.

One of the other wires will be white (or black with white or yellow stripes, or sometimes simply black). It is the neutral wire. It is connected to the "centre tap" (CEC; "center tap" in the NEC ;- ) of the distribution transformer supplying the power. It is connected to the grounding conductor in only one place (often inside the panel). The neutral and ground should not be connected anywhere else. Otherwise, weird and/or dangerous things may happen.

Furthermore, there should only be one grounding system in a home. Some codes require more than one grounding electrode. These will be connected together, or connected to the neutral at a common point - still one grounding system. Adding additional grounding electrodes connected to other portions of the house wiring is unsafe and contrary to code.

If you add a subpanel, the ground and neutral are usually brought as separate conductors from the main panel, and are not connected together in the subpanel (ie: still only one neutral-ground connection). However, in some situations (certain categories of separate buildings) you actually do have to provide a second grounding electrode - consult your inspector.

The other two wires will usually be black, and are the "hot" wires. They are attached to the distribution transformer as well.

The two black wires are 180 degrees out of phase with each other. This means if you connect something to both hot wires, the voltage will be 220 volts. If you connect something to the white and either of the two blacks you will get 110V.

Some panels seem to only have three wires coming into them. This is either because the neutral and ground are connected together at a different point (eg: the meter or pole) and one wire is doing dual-duty as both neutral and ground, or in some rare occasions, the service has only one hot wire (110V only service).

### **What is a circuit?**

Inside the panel, connections are made to the incoming wires. These connections are then used to supply power to selected portions of the home. There are three different combinations: 1) one hot, one neutral, and ground: 110V circuit. 2) two hots, no neutral, and ground: 220V circuit. 3) two hots, neutral, and ground: 220V circuit + neutral, and/or two 110V circuits with a common neutral.

(1) is used for most circuits supplying receptacles and lighting within your house. (3) is usually used for supplying power to major appliances such as stoves, and dryers - they often have need for both 220V and 110V, or for bringing several circuits from the panel box to a distribution point. (2) is usually for special 220V motor circuits, electric heaters, or air conditioners.

(1) is usually wired with three conductor wire: black for hot, white for neutral, and bare for grounding.

(2) and (3) have one hot wire coloured red, the other black, a bare wire for grounding, and in (3) a white wire for neutral.

You will sometimes see (2) wired with just a black, white and ground wire. Since the white is "hot" in this case, both the NEC and CEC requires that the white wire be "permanently marked" at the ends to indicate that it is a live wire. Usually done with paint, nail polish or sometimes electrical tape.

Each circuit is attached to the main wires coming into the panel through a circuit breaker or fuse.

There are, in a few locales, circuits that look like (1), (2) or (3) except that they have two bare ground wires. Some places require this for hot tubs and the like (one ground is "frame ground", the other attaches to the motor). This may or may not be an alternative to GFCI protection.

## **What is "grounding" versus "grounded" versus "neutral"?**

According to the terminology in the CEC and NEC, the "grounding" conductor is for the safety ground, i.e., the green or bare or green with a yellow stripe wire. The word "neutral" is reserved for the white when you have a circuit with more than one "hot" wire. Since the white wire is connected to neutral and the grounding conductor inside the panel, the proper term is "grounded conductor". However, the potential confusion between "grounded conductor" and "grounding conductor" can lead to potentially lethal mistakes - you should never use the bare wire as a "grounded conductor" or white wire as the "grounding conductor", even though they are connected together in the panel.

[But not in subpanels - subpanels are fed neutral and ground separately from the main panel. Usually.]

Note: do not tape, colour or substitute other colour wires for the safety grounding conductor.

In the trade, and in common usage, the word "neutral" is used for "grounded conductor". This FAQ uses "neutral" simply to avoid potential confusion. We recommend that you use "neutral" too. Thus the white wire is always (except in some light switch applications) neutral. Not ground.

## **What does a fuse or breaker do? What are the differences?**

Fuses and circuit breakers are designed to interrupt the power to a circuit when the current flow exceeds safe levels. For example, if your toaster shorts out, a fuse or breaker should "trip", protecting the wiring in the walls from melting. As such, fuses and breakers are primarily intended to protect the wiring -- UL or CSA approval supposedly indicates that the equipment itself won't cause a fire.

Fuses contain a narrow strip of metal which is designed to melt (safely) when the current exceeds the rated value, thereby interrupting the power to the circuit. Fuses trip relatively fast. Which can sometimes be a problem with motors which have large startup current surges. For motor circuits, you can use a "time-delay" fuse (one brand is "fusetron") which will avoid tripping on momentary overloads. A fusetron looks like a spring-loaded fuse. A fuse can only trip once, then it must be replaced.

Breakers are fairly complicated mechanical devices. They usually consist of one spring loaded contact which is latched into position against another contact. When the current flow through the device exceeds the rated value, a bimetallic strip heats up and bends. By bending it "trips" the latch, and the spring pulls the contacts apart. Circuit breakers behave similarly to fusetrons - that is, they tend to take longer to trip at moderate overloads than ordinary fuses. With high overloads, they trip quickly. Breakers can be reset a finite number of times - each time they trip, or are thrown when the circuit is in use, some arcing takes place, which damages the contacts. Thus, breakers should not be used in place of switches unless they are specially listed for the purpose.

Neither fuses nor breakers "limit" the current per se. A dead short on a circuit can cause hundreds or sometimes even thousands of amperes to flow for a short period of time, which can often cause severe damage.

### **Why use Breakers? Can't I use fuses?**

Statistics show that fuse panels have a significantly higher risk of causing a fire than breaker panels. This is usually due to the fuse being loosely screwed in, or the contacts corroding and heating up over time, or the wrong size fuse being installed, or the proverbial "replace the fuse with a penny" trick.

Since breakers are more permanently installed, and have better connection mechanisms, the risk of fire is considerably less.

Fuses are prone to explode under extremely high overload. When a fuse explodes, the metallic vapor cloud becomes a conducting path. Result? From complete meltdown of the electrical panel, melted service wiring, through fires in the electrical distribution transformer and having your house burn down. [This author has seen it happen.] Breakers won't do this.

Many jurisdictions, particularly in Canada, no longer permit fuse panels in new installations. The NEC does permit new fuse panels in some rare circumstances (requiring the special inserts to "key" the fuseholder to specific size fuses)

Some devices, notably certain large air conditioners, require fuse protection in addition to the breaker at the panel. The fuse is there to protect the motor windings from overload. Check the labeling on the unit. This is usually only on large permanently installed motors. The installation instructions will tell you if you need one.

### **What is a GFI/GFCI?**

A GFCI is a *ground-fault circuit interrupter*. It measures the current current flowing through the hot wire and the neutral wire. If they differ by more than a few milliamps, the presumption is that current is leaking to ground via some other path. This may be because of a short circuit to the chassis of an appliance, or to the ground lead, or through a person. Any of these situations is hazardous, so the GFCI trips, breaking the circuit.

GFCIs do not protect against all kinds of electric shocks. If, for example, you simultaneously touched the hot and neutral leads of a circuit, and no part of you was grounded, a GFCI wouldn't help. All of the current that passed from the hot lead into you would return via the neutral lead, keeping the GFCI happy.

The two pairs of connections on a GFCI outlet are not symmetric. One is labeled LOAD; the other, LINE. The incoming power feed *\*must\** be connected to the LINE side, or the outlet will not be protected. The LOAD side can be used to protect all devices downstream from it. Thus, a whole string of outlets can be covered by a single GFCI outlet.

## **Where should GFCIs be used?**

The NEC mandates GFCIs for 110V, 15A or 20A single phase outlets, in bathrooms, kitchen counters within 6' of the sink, wet-bar sinks, roof outlets, garages, unfinished basements or crawl spaces, outdoors, near a pool, or just about anywhere else where you're likely to encounter water or dampness. There are exceptions for inaccessible outlets, those dedicated to appliances ``occupying fixed space, *typically refrigerators and freezers, and for sump pumps and laundry appliances.*

The NEC now requires that if you replace an outlet in a location now requiring GFCI, you must install GFCI protection. Note in particular - kitchen and bathroom outlets.

When using the "fixed appliance" rule for avoiding GFCI outlets, single outlet receptacles must be used for single appliances, duplex receptacles may be used for two appliances.

The CEC does not mandate as many GFCIs. In particular, there is no requirement to protect kitchen outlets, or most garage or basement outlets. Basement outlets must be protected if you have a dirt floor, garage outlets if they're near the door to outside. Bathrooms and most exterior outlets must have GFCIs, as do pools systems and jacuzzi or whirlpool pumps.

There are many rules about GFCIs with pools and so on. This is outside of our expertise, so we're not covering it in detail. See your inspector.

When replacing an outlet, it must now be GFCI-protected if such would now be required for a new installation. That is, a kitchen outlet installed per the 1984 code need not have been protected, but if that outlet is ever replaced, GFCI protection must now be added (under NEC). This is explicit in the 1993 NEC, and inspector-imposed in Canada.

Even if you are not required to have GFCI protection, you may want to consider installing it anyway. Unless you need a GFCI breaker (see below), the cost is low. In the U.S., GFCI outlets can cost as little as US\$8. (Costs are a bit higher in Canada: C\$12.) Evaluate your own risk factors. Does your finished basement ever get wet? Do you have small children? Do you use your garage outlets to power outdoor tools? Does water or melted snow ever puddle inside your garage?

## **Where shouldn't I use a GFCI?**

GFCIs are generally not used on circuits that (a) don't pose a safety risk, and (b) are used to power equipment that must run unattended for long periods of time. Refrigerators, freezers, and sump pumps are good examples. The rationale is that GFCIs are sometimes prone to nuisance trips. Some people claim that the inductive delay in motor windings can cause a momentary current imbalance, tripping the GFCI. Note, though, that most GFCI trips are real; if you're getting a lot of trips for no apparent reason, you'd be well-advised to check your wiring before deciding that the GFCI is broken or useless.

## **What is the difference between a GFCI outlet and a GFCI breaker?**

For most situations, you can use either a GFCI outlet as the first device on the circuit, or you can install a breaker with a built-in GFCI. The former is generally preferred, since GFCI breakers are quite expensive. For example, an ordinary GE breaker costs ~US\$5; the GFCI model costs ~US\$35. There is one major exception: if you need to protect a ``multi-wire branch circuit (*two or more circuits sharing a common neutral wire*), such as a *Canadian-style kitchen circuit*, you'll need a multi-pole GFCI breaker. Unfortunately, these are expensive; the cost can range into the hundreds of dollars, depending on what brand of panel box you have. But if you must protect such a circuit (say, for a pool heater), you have no choice.

One more caveat -- GFCI outlets are bulky. You may want to use an oversize box when installing them. On second thought, use large (actually deep) boxes everywhere. You'll thank yourself for it.

Incidentally, if you're installing a GFCI to ensure that one specific outlet is protected (such as a bathroom), you don't really have to go to all of the trouble to find the first outlet in the circuit, you could simply find the first outlet in the bathroom, and not GFCI anything upstream of it. But protecting the whole circuit is preferred.

When you install a GFCI, it's a good idea to use the little "ground fault protected" stickers that come with it and mark the outlets downstream of the GFCI. You can figure out which outlets are "downstream", simply by tripping the GFCI with the test button and see which outlets are dead.

Note that the labels are mandatory for GFCI-protected-but-ungrounded three prong outlets according to the NEC.

### **What's the purpose of the ground prong on an outlet, then?**

Apart from their use in electronics, which we won't comment on, and for certain fluorescent lights (they won't turn on without a good ground connection), they're intended to guard against insulation failures within the device. Generally, the case of the appliance is connected to the ground lead. If there's an insulation failure that shorts the hot lead to the case, the ground lead conducts the electricity away safely (and possibly trips the circuit breaker in the process). If the case is not grounded and such a short occurs, the case is live -- and if you touch it while you're grounded, you'll get zapped. Of course, if the circuit is GFCI-protected, it will be a very tiny zap -- which is why you can use GFCIs to replace ungrounded outlets (both NEC and CEC).

There are some appliances that should *\*never\** be grounded. In particular, that applies to toasters and anything else with exposed conductors. Consider: if you touch the heating electrode in a toaster, and you're not grounded, nothing will happen. If you're slightly grounded, you'll get a small shock; the resistance will be too high. But if the case were grounded, and you were holding it, you'd be the perfect path to ground...

### **How do I convert two prong receptacles to three prong?**

Older homes frequently have two-prong receptacles instead of the more modern three. These receptacles have no safety ground, and the cabling usually has no ground wire. Neither the NEC or CEC permits installing new 2 prong receptacles anymore.

There are several different approaches to solving this: 1) If the wiring is done through conduit or BX, and the conduit is continuous back to the panel, you can connect the third prong of a new receptacle to the receptacle box. NEC mainly - CEC frowns on this practice. 2) If there is a metallic cold water pipe going nearby, and it's electrically continuous to the main house ground point, you can run a conductor to it from the third prong. You **MUST NOT** assume that the pipe is continuous, unless you can visually check the entire length and/or test it. Testing grounds is tricky - see "Testing Grounds" section. 3) Run a ground conductor back to the main panel. 4) Easiest: install a GFCI receptacle. The ground lug should not be connected to anything, but the GFCI protection itself will serve instead. The GFCI will also protect downstream (possibly also two prong outlets). If you do this to protect downstream outlets, the grounds must not be connected together. Since it wouldn't be connected to a real ground, a wiring fault could energize the cases of 3 prong devices connected to other outlets. Be sure, though, that there aren't indirect ground plug connections, such as via the sheath on BX cable.

The CEC permits you to replace a two prong receptacle with a three prong if you fill the U ground with a non-conducting goop. Like caulking compound. This is not permitted in the NEC.

The NEC requires that three prong receptacles without ground that are protected by GFCI must be labelled as such.

See the next section about computers on GFCI-protected groundless outlets.

### **What about surges, spikes, zaps, grounding and your electronics?**

Theoretically, the power coming into your house is a perfect AC sine wave. It is usually quite close. But occasionally, it won't be. Lightning strikes and other events will affect the power. These usually fall into two general categories: very high voltage spikes (often into 1000s of volts, but usually only a few microseconds in length) or surges (longer duration, but usually much lower voltage).

Most of your electrical equipment, motors, transformer-operated electronics, lights, etc., won't even notice these one-shot events. However, certain types of solid-state electronics, particularly computers with switching power supplies and MOS semiconductors, can be damaged by these occurrences. For example, a spike can "punch a hole" through an insulating layer in a MOS device (such as that several hundred dollar 386 CPU), thereby destroying it.

The traditional approach to protecting your electronics is to use "surge suppressors" or "line filters". These are usually devices that you plug in between the outlet and your electronics.

Roughly speaking, surge suppressors work by detecting overvoltages, and shorting them out. Think of them as voltage limiters. Line filters usually use frequency-dependent circuits

(inductors, capacitors etc.) to "tune out" undesirable spikes - preventing them from reaching your electronics.

So, you should consider using suppressors or filters on your sensitive equipment.

These devices come in a very wide price range. From a couple of dollars to several hundred. We believe that you can protect your equipment from the vast majority of power problems by selecting devices in the \$20-50 range.

A word about grounding: most suppressors and EFI filters require real grounds. Any that don't are next to useless.

For example, most surge suppressors use MOVs (metal oxide varistors) to "clamp" overvoltages. Yes, you can have a suppressor that only has a MOV between neutral and hot to combat differential-mode voltage excursions, but that isn't enough. You need common-mode protection too. Good suppressors should have 3 MOVs, one between each pair of wires. Which means you should have a good solid ground. Eg: a solidly connected 14ga wire back to the panel. Not rusty BX armour or galvanized pipe with condensation turning the copper connection green.

Without a ground, a surge or spike is free to "lift" your entire electronics system well away from ground. Which is ideal for blowing out interface electronics for printer ports etc.

Secondly, static electricity is one of the major enemies of electronics. Having good frame grounds is one way of protecting against static zaps.

If you're in the situation of wanting to install computer equipment on two wire groundless circuits take note:

Adding a GFCI outlet to the circuit makes the circuit safe for you. But it doesn't make it safe for your equipment - you need a ground to make surge suppressors or line filters effective.

### **Are you sure about GFCIs and ungrounded outlets? Should the test button work?**

The NEC, section 210-7(d), and CEC, section 26-700(9), are quite explicit that GFCIs are a legal substitute for a grounded outlet in an existing installation where there is no ground available in the outlet box.

But your local codes may vary. As for the TEST button -- there's a resistor connecting the LOAD side of the hot wire to the LINE side of the neutral wire when you press the TEST button. Current through this resistor shows up as an imbalance, and trips the GFCI. This is a simple, passive, and reliable test, and doesn't require a real ground to work. If your GFCI does not trip when you press the TEST button, it is very probably defective or miswired. Again: if the test button doesn't work, something's broken, and potentially dangerous. The problem should be corrected immediately.

The instructions that come with some GFCIs specify that the ground wire must be connected. We do not know why they say this. The causes may be as mundane as an old instruction sheet, or with the formalities of UL or CSA listing -- perhaps the device was never tested without the ground wire being connected. On the other hand, UL or CSA approval should only have been granted if the device behaves properly in *\*all\** listed applications, including ungrounded outlet replacement. (One of us called Leviton; their GFCIs are labeled for installation on grounded circuits only. The technician was surprised to see that; he agreed that the NEC does not require it, and promised to investigate.)