Ground Fault Circuit Interrupters - How do they work?

Journal Staff

A 20 milliamp current flowing through a person can kill. But it takes 1000 times that current to trip the circuit breaker. GFCI's, quickly interrupt an offending circuit at a 5 milliamp short to ground, making important improvements in electrical safety. Their desirability is evident from the increased use of these devices suggested by each revision of the National Electrical Code. ASHI inspectors report frequently finding defects in GFCIs, perhaps because they're being tested for the first time since installation. [The ASHI Technical Committee is considering a study of this topic. Meanwhile inspectors are encouraged to carefully document GFCI defects in their field notes and reports.] Here is an introduction to GFCI operation and testing.[1]

Inoperative GFCI's

ASHI inspectors are required to test all observed ground fault circuit interrupters (GFCI's).[2] These devices are so often found to be mis-wired or otherwise not functional during home inspections that ASHI's Technical Committee requests and is studying field experience data from inspectors in the US and Canada. Testing is complicated by the observation that in some installations, such as missing electrical ground, the GFCI will in fact work, but will not respond to typical testers which work by shorting the device to ground. The reasons for these problems will be more apparent after reading this article.

What's inside

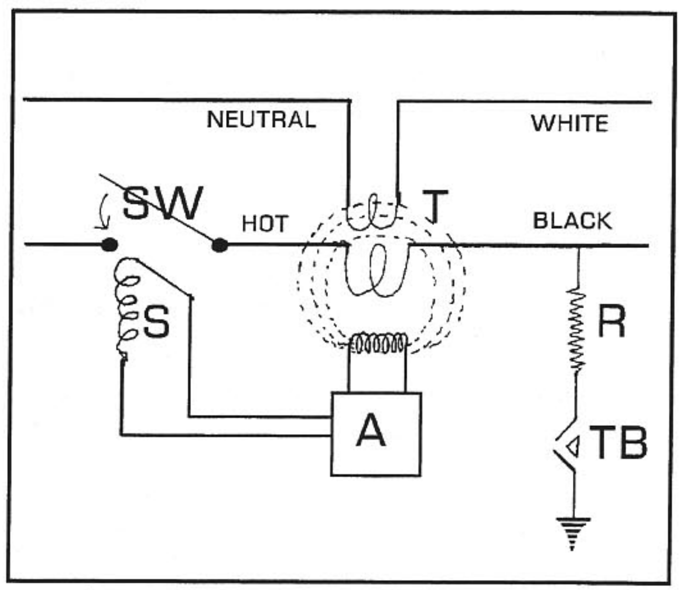
The key components of GFCI's, whether the receptacle form or the device used as a circuit breaker in the service panel, are quite simple:

A small transformer T *[see figure]* senses an imbalance between the hot and neutral legs of the circuit being monitored. Should there be a short or "fault" to ground, such an imbalance will be detected.

An amplifier A powered by the circuit itself, uses a signal from the transformer to operate a solenoid S which opens a switch SW on hot leg of the circuit where it passes through the GFCI.

The amplifier is a transistorized device which is so sensitive that it will pass a balanced current of 15 amps in the primary winding, but will detect a difference of only 5 milliamps (five thousandths of one ampere) as sufficient to trip the solenoid. Operation time of the solenoid is about 1/40 of a second.

A "test" component is added by providing a path through a 25K ohm resistor R and the test-button TB switch to ground.



General schematic of Ground Fault Circuit Interrupters

1 Portions of the theory and illustrations for this article are based on this material from Kensill and Gathers. See "Working with ground fault circuit interrupters," Frank Kensill and Wayne Gathers, Fuel Oil & Oil Heat, May 1983 p.40.

2 ASHI Standards ¶8.1.G.

Design assumptions

This design presumes that proper electrical wiring practices have been followed. But home inspectors find such a wide and interesting variety of modified wiring and wiring installed by untrained mechanics that one would expect them to be skeptical about presuming anything is correct.

For the hot and neutral lines to exactly balance in a given circuit, everything connected to the hot line is also connected to the proper neutral line. One might imagine peculiar house wiring in which a circuit "operates" but uses the hot wire from one circuit and the neutral wire from a different circuit or uses a shared neutral. Are the results predictable in this case? Probably not. See "Fault 5" described below.

Also, to reduce unwanted tripping, the specifications for GFCI's for 15-amp 120V circuits require that the device *not trip* at less than 2 milliamps but *will trip* at 5 milliamps. A precision operation that has to survive in a wide variety of environments. They don't. See "Fault 2" described below.

The test button

Pressing the "test" button on a GFCI device creates an approximately 5 milliamp leakage from the hot leg of the circuit through the resistor to ground. This is intended to simulate contact by a grounded human (eg. standing on a wet floor or touching plumbing) with a live wire (eg. shorted hair dryer or toaster).

The fault through the tester should be detected by the transformer, amplified and used to operate the solenoid to open the circuit. Usually there is a physical "tripped" indicator such as a red flag or protruding "reset" button to indicate that the circuit has operated. Of course if tested with a polarity tester in the receptacle, power to the tester will also show "off" if the GFCI tripped properly.

Using GFCI testers

Our instrument, manufactured by Etcon, tests 15 or 20 Amp 115V single phase 3-wire electrical receptacles or GFCI-protected receptacles (or remote breaker types).[1]

Tests 1 & 2 are performed by plugging the instrument into a receptacle and reading indicator lights. Test 3 is provided by a switch on the instrument.

Test 1 is for correct wiring connections (polarity, presence of ground), using the usual pattern of three test lights.

Test 2 checks GFCI-protected outlets to assure against trip at minimal leakage (1.9 milliamp). If this test trips the GFCI device, there is at least 3 milliamps pre-existing leakage in the circuit or some other defect in the device.

Test 3 assures that the trip mechanism works at 5 milliamps. In general, if test 3 fails, the GFI is defective or the ground and neutral wires are reversed.

Classifying GFCI defects and observations

Fault 1–test no trip: Anecdotal reports suggest that a surprising number, perhaps as many as half, of the GFCI's tested do not trip. Remarkably, it is not rare to find improper original installation which was never detected by the homeowner or installer.[2] We do not yet have frequency data. Failure of the GFCI to trip in response to its own "test" button may or may not indicate a real defect. Readers will see immediately from the diagram that if there is no ground present at the GFCI, the test button does nothing.

Yet the absence of ground has no effect on the operation of the GFCI's transformer and solenoid. It can still work should there occur a *real* short to ground – a ground fault. If the inspector is using a conventional GFCI tester such as the Etcon™ which provides a switched 5 milliamp short to ground, and if there is no ground present, the tester may give a false indication that the GFCI is not functional. More sophisticated diagnostic aids are available from companies selling insepection and test equipment.

Fault 2–trip no fault: Because GFCI's are used in bathrooms and outdoors they are vulnerable to slight current leakage due to moisture or condensation inside the receptacle itself. A "safe" defect is the tendency of these devices to trip when there is not a real fault.

An example of unwanted tripping experienced by contractors and some home inspectors involves extension cords. Using portable GFCI's, an OSHA-recommended practice for all construction trades working in damp or outdoor locations, often leads to accumulation of moisture in the portable receptacle. Water enters through the prong or ground pin openings, and can even follow the plugged-in cord right into these locations. Water on the wires at their connection in the GFCI should cause it to trip. Experienced field repairmen suggest installing sealed hospital-grade connectors on extension cords using GFCI protection.[3]

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1 The instrument used is a CT101 Receptacle & GFI tester manufactured by Etcon® Corp., 7750 Grant St., Burr Ridge, IL 60521 312/325-6100.

2 Simply reading the instructions on the box would prompt the installer to press the test button at least once. Yet we have reports of installations which not only do not operate, but have never operated and were installed improperly to begin with.

Fault 3–fault no trip: This one is the killer, and is one reason that GFCI device manufacturers indicate that GFCIs should be tested monthly. There are electro-mechanical parts in the switch which opens the hot line in response to the signal transformer''s signal. Inspectors well know that electro-mechanical parts exposed to moisture and field conditions are often corroded and subject to failure. Of course, if the GFCI is mis-wired it also will fail to trip when it ought.

Fault 4: new installation, won't reset, never did: This is usually an installation defect, particularly if the GFCI device is a circuit breaker in a service panel.[1] This breaker is designed to trip if the resistance between the neutral wire and ground is less than 4 ohms. If the GFCI trips as soon as it is switched on, but with no load on the circuit, it may be that somewhere on the circuit the neutral (white) wire is grounded on the load side of the GFCI. This is a problem with the circuit to which the GFCI is being added, not a defect in the device.

A wiring defect which could be mistaken for a defective GFCI device is the equipment ground and neutral connected on the load side. The author found this defect when debugging and re-wiring in an apartment in New York City. The "BX" armored cable clamps had been screwed too tightly to the armored cable at every junction box. As a result the armored cable shells had cut into several neutral wires.

Excessive leakage to ground, in excess of 6 milliamps, will cause the device to trip. Leakage between live parts of the system wiring and ground, or between the live side of wiring within equipment and its housing will cause this shutdown. In this case the device is not defective - it's doing its job and has disclosed a fault.

Fault 5: unexplained tripping, will reset sometimes: This is an interesting one which may be traced to a "shared neutral" installation. *When the GFCI's neutral wire is common to two or more separate circuits, the GFCI will trip when a load current exists on any of the other sharing circuits.* This is a hard problem to diagnose but if the inspector is digging into the malfunction, s/he might start by suspecting a GFCI on a multiwire branch circuit. *[See "Multiwire Branch Circuits" in this issue.]*

The GFCI may be installed and work normally until it trips unexpectedly when the occupant plugs something into a receptacle or imposes some other load in another part of the building not associated with the GFCI. In this case if the GFCI is required, the problem can be corrected only by rewiring to separate the two circuits.

GFCI receptacles vs circuit breakers

Ground fault protection is not overcurrent protection. Don't confuse them. A receptacle-type GFCI device protects only against ground faults – an accidental and dangerous short between a live electrical component and ground. GFCIs do not protect against line to *neutral* short circuits nor against electrical overloads. In this case the usual breaker in the service panel provides that protection. The circuit-breaker type GFCI device combines GFCI protection (5 mA line-short to ground), with "usual" circuit breaker functions: line-short to neutral, and overload protection – which may help explain the higher cost of these devices.

Inspection safety and reporting

As with advice in other articles in this *Journal* issue, we advise against touching or testing *any* electrical device before careful visual inspection, confirmation of the presence of the house ground, and assurance that the inspector is standing in a dry, safe location. *[See "Inspector Safety" in this issue.]*

Manufacturers are careful to point out that **there is no known device that can offer complete protection against the hazard of electrical accidents under all conceivable conditions.** For example, a GFCI does not protect a person who contacts both the hot and neutral wires on a circuit![2] For GFCI's installed where no ground is present, some experienced inspectors use special equipment which, connected to a local external ground, can perform the same function as the internal test button and 25K ohm resistor. [3]

The *Journal* advises against any attempts to test GFCI's by making a "real" short - such as a test wire between the hot side of the receptacle and a nearby radiator. This is a dangerous and unnecessary procedure. Stick to the internal test and the use of external GFCI test devices.

When the home inspector determines that a GFCI does not operate properly it should be reported to the property owner as well as the client. This is an unsafe condition.

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10 Kensill and Gathers, op. cit.

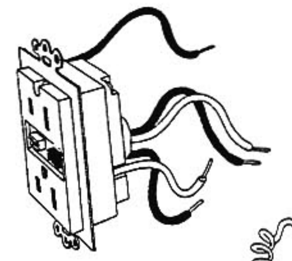
1 "General Electric installation instructions for type THQL/THHQL-GFCI and THQB/THHQB-GFCI Class A Group 1 GFCI's," publication #GEH-3476 Rev.F, General Electric Corporation, Distribution Equipment Division, Plainville, CT 06062.

2 "Fault Finder Receptacle" instruction booklet from Bell Electric, a division of Square D Company, Chicago, IL 60632, undated.

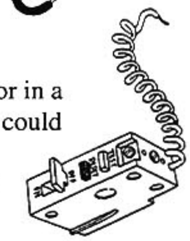
3 ASHI Member Robert A. Stead, Southbridge MA, uses a Wiggleston™ tester to connect from the hot side of the receptacle to an available ground such as a radiator. Note that he is *not* using a simple test wire - a very dangerous procedure.

➤ GFCI's – PLUGGING IN TO ELECTRICAL SAFETY

Upgrade your electrical system with GFCI Protection



A ground fault circuit interrupter is an electrical device, either a receptacle (wall plug socket) or a circuit breaker (in the electric panel) which is designed to protect people from electric shock in a wet or damp environment. Ground fault circuit interrupters (GFCI) have been around since the early seventies. However older homes, even if there has been remodeling, and sometimes even newer homes, are constructed without the benefit of these safety devices.



Suppose for a moment that you decide to use an electrical appliance in a bathroom or in a garage that does not have a GFCI-protected receptacle. In a damp environment you could be badly shocked or even electrocuted if the appliance you've plugged in finds an electrical path to ground through your body. This can happen with some appliances even if they are not themselves damaged.

If an appliance is plugged into a GFCI-protected circuit, the electric current passing through the circuit is carefully monitored by the GFCI device. If the current varies by more than 5 milliamps (5 thousandths of an ampere – an amount so small that normal people may never notice it) the circuit is shut off immediately, preventing injury or death.

If your house does not have GFCI protection an electrician can add it, usually easily and at very modest cost. This is an important safety improvement. Electrical wiring and device installation should be handled by a qualified electrician. In many areas electricians are licensed.

Where to look for GFCI protection

- All outdoor receptacles that are within 6 feet of the ground, and receptacles at hot tubs and spas; receptacles and equipment around swimming pools
- All bathroom receptacles
- All garage receptacles within reach except one marked and used for a freezer
- Receptacles within 6 feet of the kitchen sink
- One or more receptacles in the basement or crawl space areas
- Receptacles and supplies for fountain or pool pumps and related equipment
- Regardless of Code requirements, we suggest that wet bars and lighting in high-risk areas such as where easily touched while standing in a spa, bath tub or shower should all be protected.

Effective dates of some Electrical Code requirements

January 1, 1973–GFCI's required for outdoor receptacles. February 5, 1976–added bathroom receptacles. April 2, 1980–added garage receptacles. July 30, 1986–added one in basement and near kitchen sink. May 18, 1990–current: bathrooms, some bathroom lighting, garage receptacles, outdoor receptacles, basement receptacles, unfinished area crawl space and basement receptacles, kitchen receptacles near sink, boathouse receptacles, pool, spa, hot tub receptacles, equipment, lighting, and fixtures, and hydromassage bathtubs.

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Other more complete suggestions for protection, and some detailed exceptions to the general rules above are found in the current edition National Electric Code published by the National Fire Protection Association, 1-800-344-3555.

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