# Brass Tacks

***An in-depth look at a radio-related topic***



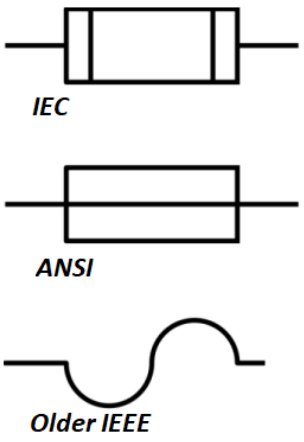
## Fuses and circuit breakers



Some of us can remember a time when household electrical panels were outfitted with an array of ***fuses***. If the resident in such a house happened to plug too many appliances or devices into an outlet, a fuse might ***blow***, and everything powered by the fused circuit would lose power until he replaced the fuse. This often meant groping in the dark for a flashlight, locating an unspent fuse, making his way down to the dungeon where the electrical box is located, and replacing the fuse.

Fun adventures in times gone by, to be sure, but do we still use fuses today? It turns out that, even though single-blow fuses in modern houses and dwellings have largely been replaced by ***circuit breakers***, most vehicles, amateur radio transceivers, power supplies, amplifiers, and a lot more gear still use fuses. The choice to integrate a fuse into a device instead of a circuit breaker is largely decided by space, resiliency, and cost. In today's homes, a circuit breaker will ***pop*** or ***trip*** upon detecting an over-current condition in the electrical circuit.

***The purpose of a fuse or circuit breaker is to protect equipment, prevent a fire, or save a life by interrupting the current in a circuit***. By "interrupting" the current we mean to stop (terminate) its flow by opening the circuit. In both cases, the opening of the circuit is a mechanical operation, ensuring the current is unable to continue flowing without further intervention by an outside influence.




***Fuse drawing symbols***

### Fuse

The typical fuse is a disposable device that opens once, due to the melting of a resistive conductor once a predetermined amount of current (measured in *amperes*, or *amps* for short). Besides being rated for a maximum current (also called ***amperage***), a fuse must also handle a maximum voltage, which factors into its rating.



The resistive material in a fuse melts once it reaches a specific temperature, and can reach that temperature rapidly or slowly, depending on how much current flows through it. This might mean a 10 A fuse can blow if its current reaches 10 amps for 90 minutes (typical), or 10.1 amps for 60 minutes, or 10.2 amps for 30 minutes, for example. (I just made up those numbers to explain the point.) For the temperature in any object to reach a specific value, a specific amount of heat energy is required, and in the case of a fuse, the electrical energy through a resistive mate-

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rial produces the heat measured as temperature.

In reality, manufacturers often publish values describing the amount of energy required to begin melting the resistive fuse conductor by noting the relationship between average energy (measured in joules), average power (measured in watts), and time (measured in seconds):

$$E = P \times t$$ (energy = power x time, or by units **J = W x s**)

You might recall that power in an electrical circuit equals voltage times current, and voltage is current times a constant resistance:

$$P = V \times I = (I \times R) \times I = I^2R$$




Therefore, the energy in a circuit is proportional to the square of the current times the amount of time the energy is applied, assuming the resistance is a constant of proportionality:

$$E = P \times t = I^2R \times t, \text{ or } E \sim I^2t$$

The **$I^2t$** value, which relates the maximum fuse amperage and the maximum amount of time expected before the fuse is expected to blow, is often well-known for fuses of reputable manufacturers, and can be found on their data sheets. It's often called the *melting point*. To ensure a device with sensitive electronics is adequately protected, the **$I^2t$** value of the fuse must be larger than the **$I^2t$** value of the device the fuse is protecting.

The ambient temperature affects the operational value of a fuse, so it's also rated for an environmental temperature range. In other words, the warmer the air is surrounding the fuse or equipment it's protecting, the less current the fuse is able to handle.

## Slow-blow, fast-acting

Directly related to their **$I^2t$** values, some fuses are rated as "slow-blow" and some as "fast-acting" due to their melting times for a given amperage. A "slow-blow" fuse can allow more current through it than its rating for a period of time before melting and opening the circuit. A "fast-acting" fuse opens much more quickly after reaching its current rating.

The last thing you want is for the fuse to blow so slowly that it protects itself at the expense of the equipment, completely defeating the purpose of the fuse. To protect sensitive electronics, some fuses are made with thin resistive conductors that will blow almost as soon as current through the device has reached its maximum tolerance.




## Inrush current

Say you have a mobile radio that's connected through a fuse holder to your car battery. And say that mobile radio is specified for a maximum current draw of 15 amps when operating at high power. If you placed a 15-amp fuse in that holder, then you'll likely blow that fuse almost every time you transmit on high power, due to a phenomenon known as *inrush current*, which is like turning on your outdoor water faucet connected to an empty hose. The water rushes in, because there's not much to stop it until it's equalized by the air pressure inside.

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That current in your first radio transmission could well exceed 20 amps, or more, and possibly blow fuse after fuse if you keep using 15 amp fuses in the holder. If you're not sure what value to use, because maybe you're installing your own supply line to the battery, try going 25 amps. But wait...won't that cause a fire if the radio draws too much current? Not likely. The fuse will protect against a short, which could reach up 80 to 200 amps, easily smoking your 25-amp fuse, while allowing inrush current to stretch its legs when you key up your microphone.




Then again, this is another example where a slow-blow fuse at a lower amperage rating might be a better choice, due to the high spikes in inrush current. The slow-blow fuse can tolerate excessive currents for short periods of time, often more time than is required by a sharp increase in current flow when you key up on FM, both protecting the device and the fuse. Your equipment has already been manufactured with its inrush current requirements designed into it.

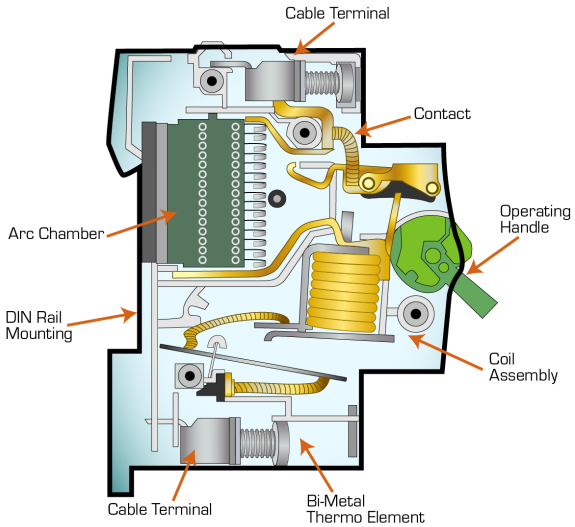
## Circuit breaker



The modern circuit breaker was invented by Hugo Stotz in 1924, but an early version was described by Thomas Edison in a 1879 patent. A circuit breaker is a device that will open its circuit once its current limit is exceeded, and then can be subsequently reset.

Just as there are slow-acting and fast-acting fuses, a circuit breaker can also vary in its opening speed once its current reaches the specified limit. A household circuit breaker is often referred to as a time-delay breaker or thermal breaker, because the element must reach a particular temperature to trip after the specified current flows through it *during an overload*.

While fuses act somewhat one-dimensionally, most circuit breakers operate by two different mechanisms, one thermal and the other magnetic. During an overload, when you plug enough appliances into a circuit that they attempt to draw more current than the circuit breaker permits, the breaker uses a thermal delay to perform in a slow-blow manner. The thermal element heats up and expands until the spring holding the material is overcome, then pops the circuit open. One reason that resetting your breaker immediately following an overload might cause it to pop again is that its element did not have enough time to contract sufficiently to be reset. Waiting a minute or so in that case might allow it to be reset.



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In the event of a short circuit, the internal mechanism trips the breaker by a magnetic mechanism because of the sudden, large current flow. So, during an overload, there's not enough current to trip the breaker magnetically, and during a short circuit, there's not enough time to heat up the resistive metal to trip it thermally. So, the two processes work somewhat independently but produce the same result.

By the way, one thing many homeowners fail to understand is that, in order to reset a tripped household breaker, you must first switch it completely off, then completely on again. It was designed to work that way for safety, to ensure that it could not accidentally reset itself.

## GFCI—a special circuit breaker

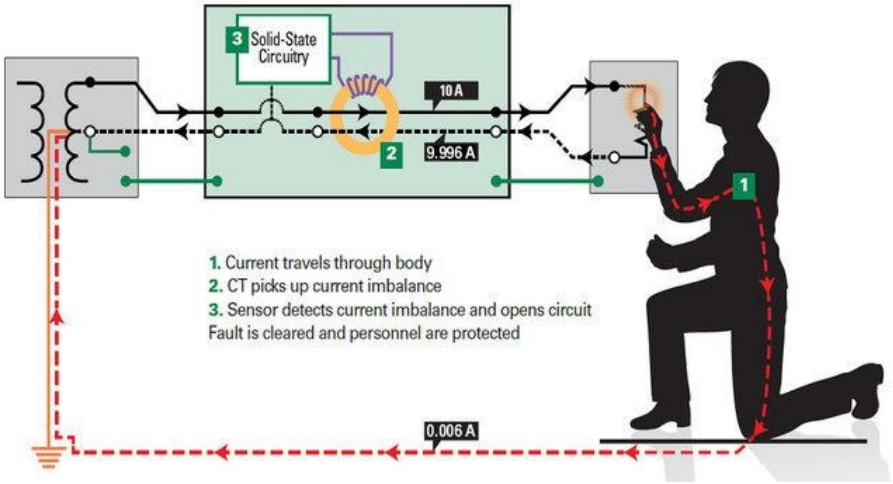
By electrical code, in American homes, all rooms containing running water must be outfitted with a special circuit breaker or special outlet that doubles as a circuit breaker. The **GFCI** (ground fault circuit interrupter) outlet is often easy to recognize by the red and black buttons for testing and resetting the breaker. Its purpose is to open the circuit when a low-current imbalance occurs between the AC supply ("hot" and "neutral") lines.



***GFCI outlet***

For example, if a bathroom appliance somehow got shorted, maybe by the two conductors of its frayed cord touching each other, its 15-amp breaker in the breaker panel would easily sense the short exceeding 15 amps, and trip, opening the circuit to prevent further damage. On the other hand, if one wire of the frayed cord touched your hand, the resistance in your body would be too great to allow enough current through you to pop the breaker at the panel, and so will continue to conduct until you quickly reacted and removed your touch of the frayed wire because of electrical shock, or died.

The GFCI breaker was created to prevent this situation by opening the circuit when a low-current "short" occurs, like when a person gets shocked or when water contacts the circuit. Here's how it works: it's assumed that the two paths of AC (alternating current) always carry the same amount of current at all times during normal operation, whether it's a light load or heavy load, but in opposite directions. That means the net magnetic field around both conductors together are always zero, and that if the net magnetic field was non-zero, that would indicate an imbalance [1], meaning one of the conductors is carrying more current than the other.




If we slip the two AC conductors into a toroid [2], the toroid will pick up the

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net magnetic field emitted by the pair. If we further placed a winding of wires around another part of the toroid, the net magnetic field in the toroid will induce a current in the winding. If the winding wires were then connected to a relay [3] that opened the two AC conductors when current flowed in them, the two AC conductors are now set to open up when there is even a small imbalance in its current between the hot and neutral.

*This GFCI operation assumes some of the current was routed to ground*. If your body attempts to conduct only between the hot and neutral, because you're insulated from ground, you will likely get burned or die until you let go of the wires or the power got cut. In normal cases, it's assumed that a direct, high-current short will trip the breaker back at the panel, while a human body shock will be due to current that's partially routed to ground.

In today's GFCI breakers, that "small imbalance" is as little as 4 mA to 20 mA, and the time one takes to interrupt the circuit is in milliseconds. So, the next time you get the urge to stick your fingers in the light socket, be sure to do so in a GFCI circuit and in bare feet. By the way, many of today's hair blow dryers, curling irons, shavers, and other AC-powered bathroom appliances are outfitted with miniature GFCI breakers on them.

### Relevance

Why is this important to you? After all, you might be a new ham, whose concern at the moment is which radio to purchase and how to use it. There might come a time when you'll be faced with fusing a circuit, or need to replace a fuse or reset the breaker. If the breaker keeps popping after you've reset it, or a fuse keeps blowing after you've replaced it, a problem still exists in the circuit, and ***must be addressed***, or you risk a fire or your equipment or your life.

And when you do need to replace the fuse, which one should you purchase? The answer is ***the one with the*** a) ***form factor*** (physical shape and size), b) ***amperage rating***, c) ***voltage rating***, and d) ***type*** (slow-blow, fast-acting, special enclosure, etc.) ***that is specified by the equipment manufacturer***. Can you substitute the old one for a different kind? Yes, as long as it satisfies the above four criteria.

### Summary

Fuses and circuit breakers are indispensable devices that interrupt their circuits once a temperature or current threshold has been reached in the circuits, and their purposes are to prevent fires and save lives and equipment. A fuse must typically be discarded after it has interrupt a circuit, while a circuit breaker can be reset for repeated interruption. A GFCI breaker is a special circuit breaker that opens up the AC supply if a low-current imbalance is detected between hot and neutral. If a particular fuse must be replaced repeatedly or a particular circuit breaker must be repeatedly reset, a problem remaining in the circuit must be addressed.

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