Electrical Wiring

Electric shock and electrocution

A voltage applied to the human body will produce an electrical current, which depends on the resistance of the skin and body tissue, as well as the magnitude of the applied voltage. The voltage required to produce a dangerous level of electrical current in the human body can be estimated by first measuring electrical resistance using very low voltages, then calculating the voltage necessary to produce a potentially lethal level of electrical current using Ohm's Law.

Electrical shock occurs when the human body reacts to the current flow. Extremely small electrical currents below 100 µA produce no detectable sensation, whereas electrical currents up to about 1 mA or so produce a "tingling" sensation. If the electrical current exceeds 5 mA, muscle control is affected, and this can possibly impair breathing or disrupt the electrical activity of the heart muscle--which can lead to unconsciousness and potentially death if the current is maintained. The most serious electrocution and shock risks occur above the "let go" limit. Currents above the "let go" limit sufficiently overpower neuromuscular control that the individual can no longer voluntarily pull away from the voltage source. For most individuals the "let go" limit will be currents at or above 10 mA, although some individuals may be unable to let go for currents as low as 6 mA.

The resistance of human skin varies from person to person and also depends upon external variables such as the surface moisture and the area of contact between the skin and the conducting surface. Typical hand-to-hand resistance is in the range of 1 to 2 kΩ.

Another aspect of shock susceptibility is the AC frequency of the voltage source. Humans and other mammals are most susceptible in the 50 to 60 Hz range since these are the frequencies that appear most likely to cause ventricular fibrillation. Most adults will suffer ventricular fibrillation with hand-to-hand currents below 100 mA.

It may seem counterintuitive, but in some cases a human being may survive a very high voltage electric shock more easily than a low voltage shock because the high induced currents from a high voltage source can cause the heart muscle to clamp down rather than to fibrillate, and the heart may restart itself if the current is removed sufficiently quickly to avoid burns, suffocation, or internal nerve damage--or if CPR is administered right away.

## Basic branch circuits in homes and businesses (U.S.)
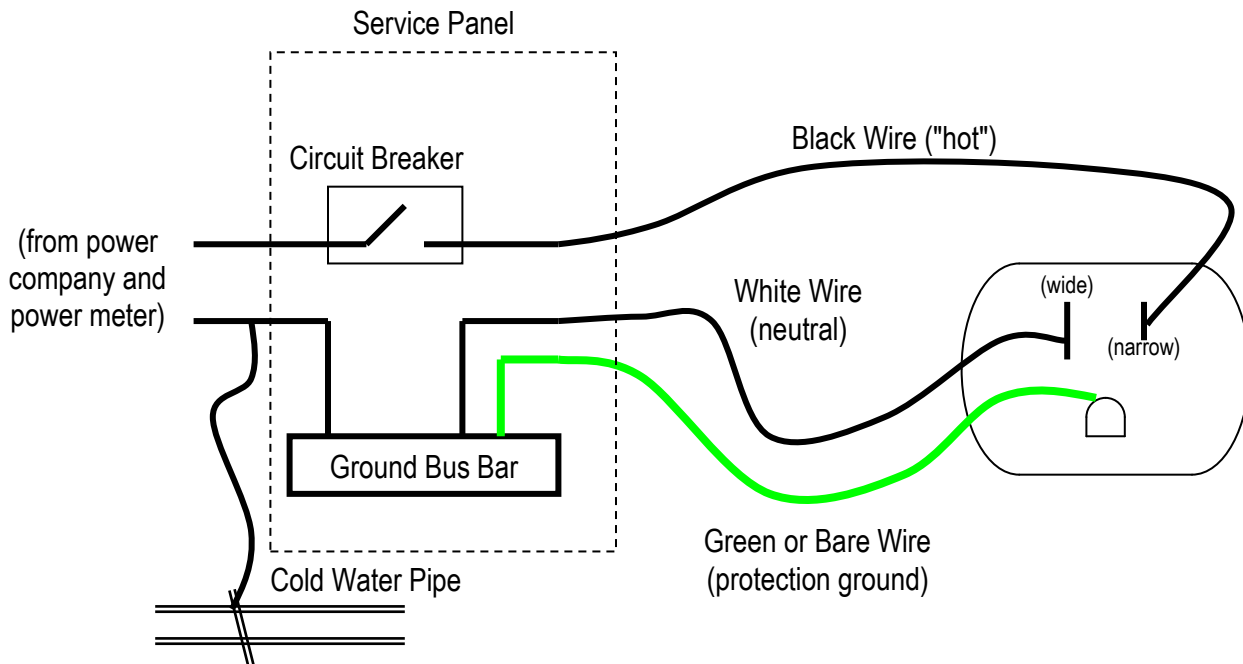
IF the outlet is wired correctly (never EVER risk your life on this assumption!!), the white wire is the "neutral" wire, and it should be connected to the wide blade of the electrical outlet. If no active load is sharing the circuit, the electrical potential should be near zero volts with respect to the earth ground. In the U.S. the black wire ("hot") is 120 volts RMS (root-mean-square) sinusoid, 60 Hz repetition frequency, which means it has peaks ±170 volts respect to the neutral. Keep in mind that the colors are purely customary: the color itself doesn't influence how the electricity flows in the circuit. Again, NEVER ASSUME that the wiring has been installed correctly!

The green (or bare) wire is the protection ground, and the internal wiring of an appliance will have this conductor connected it to the metal chassis of the appliance. The green wire does not conduct any current under normal circumstances, BUT if there is a fault in the appliance allows the "hot" wire to come in contact with the chassis, the protection ground wire short circuits the "hot" wire through the chassis and back to ground, which should draw enough current to trigger the circuit breaker to open, de-energizing the outlet. This protection is important, because without it a fault could energize the chassis, and then a person could get shocked by simultaneously touching the chassis and a nearby grounded surface, inadvertently completing the circuit.

If the branch circuit has a switch, the switch must be in the "hot" portion of the circuit, NOT in the neutral wire. Similarly, appliances with a polarized (wide blade) plug should be designed so that the exposed conductors (like the metal ring of a screw-in light bulb) are connected to the neutral wire, and the "hot" conductor is controlled by the power switch, as shown below. This arrangement has the power switch positioned to de-energize all the components down-stream from the switch, making it less likely a user would get a shock if changing a light bulb or an

internal fuse with the appliance carelessly left plugged in. The appliance will still work if the outlet is not wired with the proper hot and neutral orientation, but it is safer with the correct wide-blade neutral orientation.
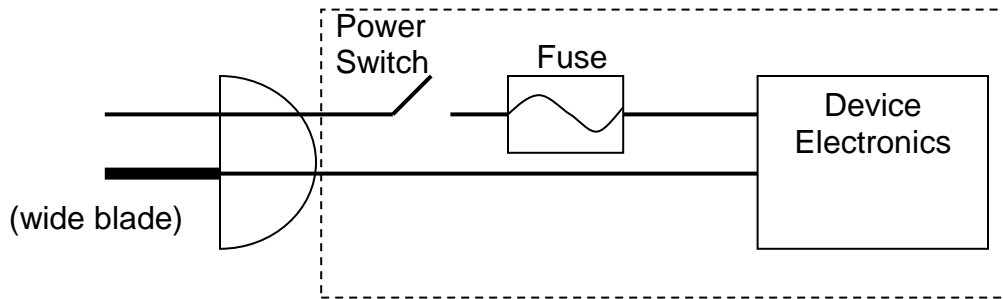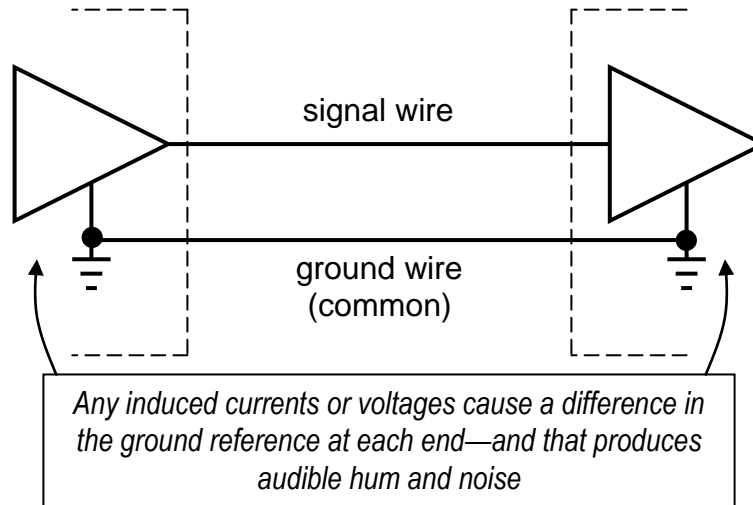

GFCI outlets

Homes and businesses may also have *GFCI* outlets. GFCI stands for *ground fault circuit interrupter*, which describes special circuitry inside the outlet itself that monitors the current in the hot wire and in the neutral wire: if there is even a small difference (typically 5 mA or more) between the hot and neutral current, it means current is leaking somewhere in the appliance (like as a shock current going from the appliance through a grounded person!) and the device will quickly turn off the outlet. Note that the GFCI de-energizes the circuit itself, and does not require sufficient current to trip the upstream circuit breaker. GFCI outlets usually have a reset switch and a test switch on the faceplate. If the GFCI trips, don't just reset it, but check out what might be triggering the imbalanced current. Sometimes electric motors will trip the GFCI even without a fault condition.

Due to the increased risk of shock, most local electrical codes require GFCI outlets in kitchens, bathrooms, garages, and anywhere else it is likely that water or moisture will be present. Most electrical codes allow GFCI outlets to be installed without a protection ground wire, since the GFCI provides protection directly by monitoring the current imbalance between the hot and neutral conductors themselves.

Balanced and unbalanced signal wiring

Unbalanced signal interconnects, also known as *single-ended* connections, use two wires between the source device and the receiving device. One of the wires is the electrical ground (zero potential) and the other wire carries the analog voltage representing the signal (such as audio) with respect to the ground wire. Thus, the source device (such as an Ipod or CD player) and the receiving device (like an audio amplifier) have their electrical grounds connected together via the interconnection cable.

Unbalanced connections are inexpensive and work reasonably well for consumer devices that are located close to each other, like a stack of gear in a stereo cabinet. However, the unbalanced connection is susceptible to both electric field pickup and magnetic field coupling.

Any induced currents or voltages cause a difference in the ground reference at each end—and that produces audible hum and noise

Electric field pickup is due to the presence of electromagnetic waves, particularly broadcast radio and TV signals, but also emanations from computers and other devices with high frequency switching circuits. The interconnection wiring acts like an antenna, and small radio frequency (RF) currents are induced in the wiring by the electromagnetic fields. Since the receiving device is observing the voltage between the single signal wire and the ground wire, these RF currents can cause a noisy signal in the audio frequency range due to nonlinear mixing in the wiring and the circuitry.

Magnetic field pickup is often caused by nearby wiring in the building's power system. The currents flowing in the building's wiring cause magnetic field loops encircling the conductors, and if the magnetic field passes through the loop created by the two conductors of the unbalanced connection, a 60 Hz hum can be picked up. The problem can also be caused by *ground loops*. A ground loop occurs when different devices are interconnected by unbalanced wiring, forcing the ground reference of each device to be shared. Any currents induced in the ground wire cause a difference in electrical potential at each device, and the receiving device interprets that difference as part of the audio signal. Magnetic field pickup and ground loops can be avoided by keeping interconnection wiring as short as possible, twisting the conductors in the unbalanced cable, and keeping any loops in the grounding system as small as possible.

Balanced signal connections, also known as *differential* interconnects, avoid several of the problems inherent in unbalanced wiring—at the expense of more complicated amplifier circuitry and three wires instead of two in the interconnect cable.

A balanced signal connection has the signal presented as the voltage between two wires, neither of which is the ground potential, and the receiving device has a *differential amplifier* that looks only at the voltage difference between the two wires. The two signal wires are usually twisted around each other during the manufacturing process so that any stray magnetic fields will not couple very well into the signal wiring: each twist would couple the magnetic field in the opposite direction as the prior twist, thereby canceling out any induced signals. A third wire is the ground wire, and typically the ground is used as an electric field *shield* by incorporating a conductive foil or mesh wrapping inside the cable that surrounds the two signal wires.
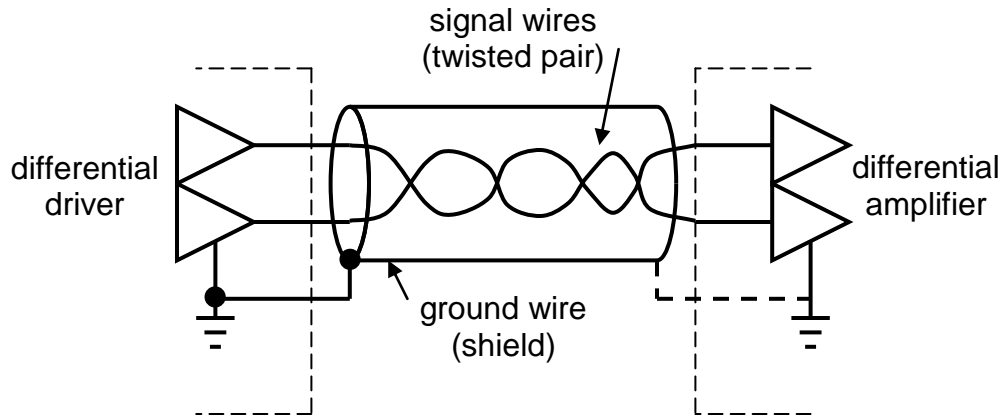
The signal is the difference in voltage between the two signal wires, and NOT referenced to ground. Induced ground currents do not corrupt the signal.

Most professional instrumentation, audio, and signal processing gear is designed with balanced interconnections in mind. Most consumer gear (and even most "audiophile" stereo equipment) uses unbalanced interconnections, mostly because it is less expensive. Care must be taken when using a system in which some devices are balanced and some are unbalanced: it is generally best to use an audio transformer or a "direct box" when hooking up unbalanced gear to balanced system in order to avoid electromagnetic interference and ground loop issues.