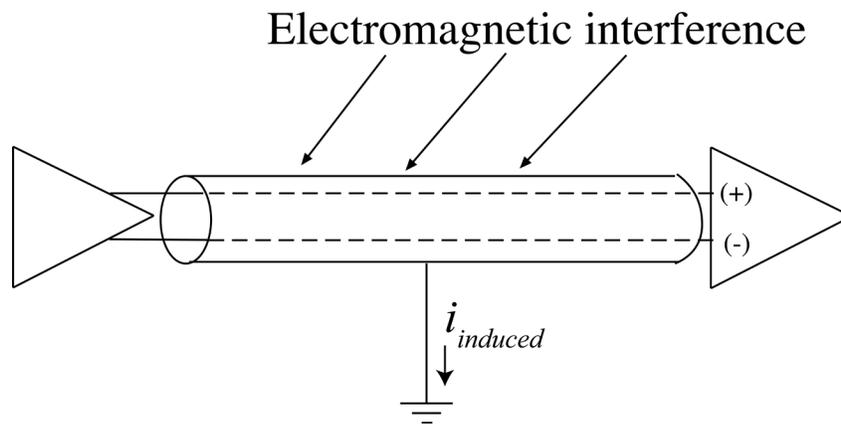


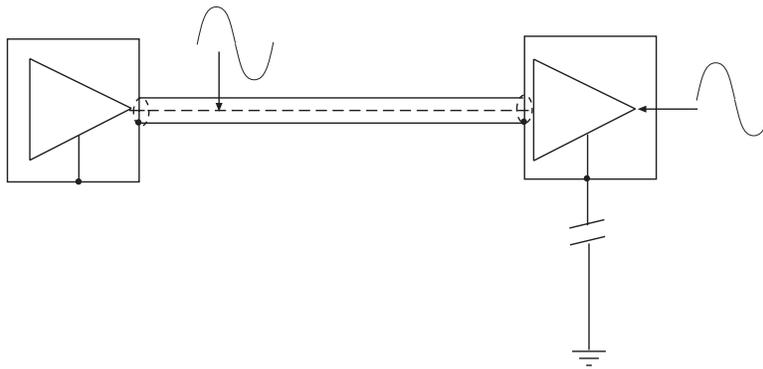
Device Interconnection

An important, if less than glamorous, aspect of audio signal handling is the connection of one device to another. Of course, a primary concern is the matching of signal levels and impedances between the devices, but there are additional considerations. Not only are wire and connectors of differing types involved, the grounding of a device is potentially affected by all the other equipment to which it is connected. Interconnection practices are important because all signals must be transmitted from device to device and noise added in the process can be very difficult to eliminate once it becomes part of the signal. By using properly shielded and grounded connections, a high quality audio signal can be preserved, even in very large systems. While this discussion relates to analog connections, there are similar concerns in digital systems that we will address later.

Shielding: Noise sources couple into wires by induction (like a transformer) and by capacitive coupling. These noise signals are produced by the 60 Hz power-lines, by radio transmitters, computers, electric motors, and many other electrical sources present in the environment. Shielding is a method of protecting audio signals from radiated noise by providing a low impedance pathway to ground for the unwanted electromagnetic signals. Audio signals are always transmitted on shielded cable (except for high power, high level, low impedance signals like power amplifier connections to speakers), thereby reducing or eliminating the problem of noise coupling.



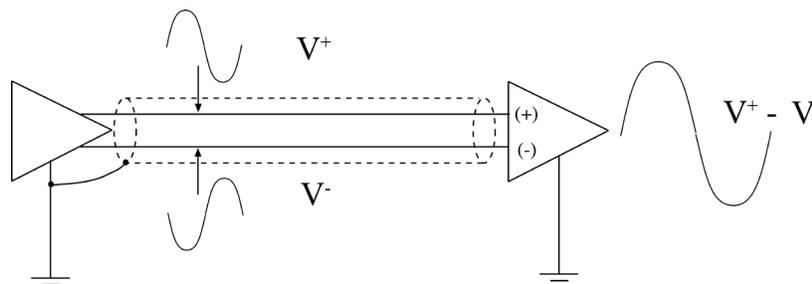
The shield is usually a braid of copper wire (or metal coated plastic) surrounding the wire or wires that conduct the audio signal. The signal return path must be conducted by the shield in two-conductor cables (“unbalanced.”) In three-conductor cables (“balanced”), the signal is carried on two wires and the surrounding shield is separate. In order for shielding to provide protection against noise pickup, it must be connected to ground via a low impedance connection. Since noise induced from magnetic fields creates currents in the shield that must be carried to ground, any impedance in the shield connection to ground will result in a voltage drop (Ohm’s Law) causing the shield to carry a non-zero voltage which may become part of the transmitted signal, especially in unbalanced circuits.



Unbalanced circuit

Unbalanced connections: When a signal is carried as a voltage on a single wire, the circuit is said to be unbalanced. The impedances to ground of the two connections are not equal, hence the term unbalanced. The shield impedance to ground is very low while the impedance of the signal wire to ground is determined by the input impedance of the load. The shield functions as a ground reference connection as well as a shield, which can lead to noise contamination if the connections are not solid at both ends of the cable. This circuit is used in consumer stereo equipment and many lower-cost audio devices: while this type of circuit is cheaper to produce, it is only suitable for short cable lengths and relatively simple setups in which the equipment is not grounded through the power line connection.

Because unbalanced circuits usually have high input impedances (10-50 k Ω), the length of cable permitted is limited due to the capacitance of the cable appearing in parallel with the input impedance. As the length increases, the cable capacitance shunts the input impedance to form a low-pass filter that reduces the high frequency response of the circuit.



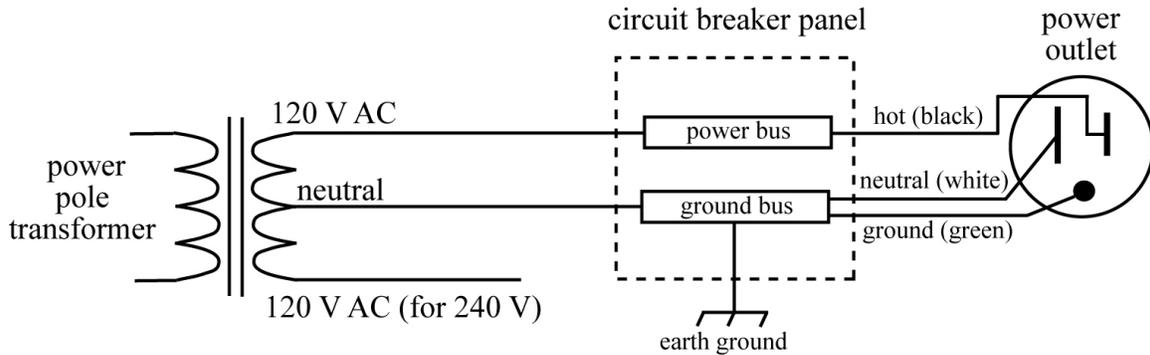
Balanced circuit

Balanced connections: Most professional audio gear includes balanced inputs and outputs. Here the impedances to ground for the two signal conductors are equal or balanced. These connections send signals on two separate wires by splitting the signal into inverted and non-inverted versions of the signal and sending these on separate wires. The receiving input then subtracts the inverted signal from the non-inverted signal, producing a signal of twice the amplitude. This type of input (a differential amplifier) has the benefit of subtracting out any signal common to both conductors (called common-mode signals), which is typical of most induced noise signals. Because of the noise rejection and the fact that balanced circuits are low impedance circuits (5-10 k Ω), very long cables can be used without signal degradation.

Balanced amplifier inputs may be created from differential amplifiers like op-amps or with transformers. Each type has its strengths and weaknesses. Transformers have excellent common mode rejection (CMRR) and

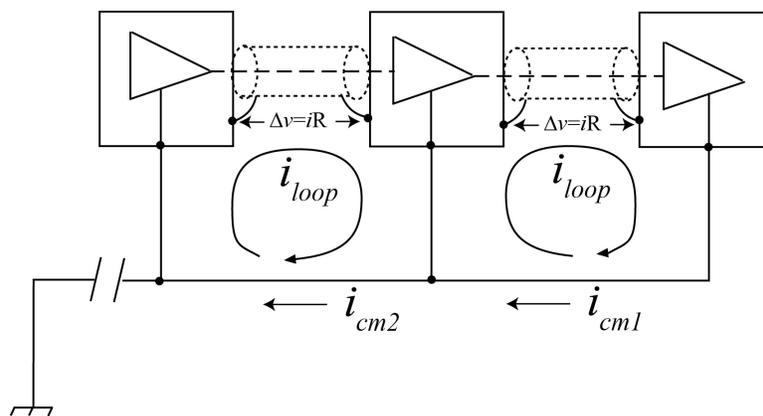
provide complete physical isolation for the two circuits, reducing potential ground loops. They have imperfect frequency response and the best quality transformers are expensive. Active electronic differential inputs have excellent frequency response and are inexpensive, but their CMRRs are not as good and there's no physical isolation. In situations where there is a lot of radiated noise (like venues with dimmers and lots of lighting equipment), transformers may be preferred, while in studios with good grounding and shielding, electronic amplifiers may be more desirable.

Grounding



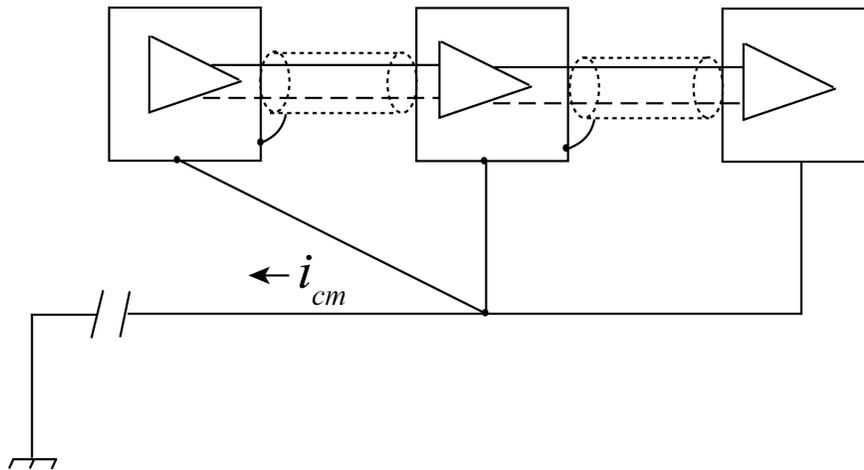
Electrical service circuit from power pole to outlet (simplified)

In our analysis of circuits, the availability of a reliable voltage reference (0 volts) is assumed. Providing this reference may not be as simple as it might seem. Since our audio devices are generally powered with AC electricity, we are tempted to make use of the power system's ground line as our audio ground reference. Power is delivered on a three-wire outlet: one wire carries the high voltage, one provides a neutral return, and another provides a safety connection to earth through the building wiring. (See the June 1995 issue of the J. Audio Eng. Soc. for an in-depth discussion of power and grounding.) Normally, current flows through the "hot" line and the neutral. Both the neutral and ground are connected to a bus bar in the distribution box, which is connected to earth. The difference is that the service current flows in the neutral but not in the ground, which should only conduct current in the case of a major fault in equipment or a break in the neutral connection: the ground is simply seen as a safety connection and small noise currents present on the ground circuit are ignored. Nevertheless, these small currents can generate a voltage drop in the wiring, especially if the lines run hundreds of feet from the service entrance and through multiple sub-panels. We cannot assume the safety ground will always be an acceptable reference voltage, so to minimize noise coupling in a complex circuit like a recording studio special steps need to be taken to provide the necessary grounding.



Ground loops in unbalanced interconnect

The ground loop: Ideally, all devices should be connected to a single, common reference potential known as ground. Since the earth functions as a huge sink for electrons without it measurably affecting its potential (voltage), a copper rod driven into the ground is often used as a ground reference for electronic signals. The voltage of the rod is known as “earth” for obvious reasons. A thick wire is then used to bring this reference voltage into the building and distribute it to the various circuits, where it is then referred to as “ground”. The distinction is that the earth potential doesn’t change, while the local ground potential is affected by voltage drops caused by any current that flows down the connecting wire to earth. If the wire has significant impedance, the currents cause a voltage drop that changes the voltage on the ground circuit.



Star ground with balanced interconnect

The ideal way of connecting devices to the ground reference is the so-called “star” ground, in which each device has a single direct connection to the reference point, forming a star-shaped distribution network. In this way, any currents flowing from a single device to ground affect only that device. In the real world, most equipment is grounded through the power line using a third wire separate from the actual power-handling wires. To assure user safety in the event of a massive device failure, the equipment case is attached to the ground connection. If we then use signal connections containing a ground connection and/or the devices are bolted into a metal rack, we have created multiple potential current paths between the devices. If any of the ground wires actually conducts a current, a voltage difference will be created (by Ohm’s Law) in the wire. The devices then see different reference voltages. This difference becomes part of the audio signal; the so-called ground loop has the effect of adding voltages caused by currents flowing in the ground connections to the signal. Since the currents are generated mainly by inductive leakage from transformers, the ground loop adds 60 Hz sine waves (and harmonics due to distortion) to the audio signal: the resulting hum is a ubiquitous contaminant of audio signals.

So how do we deal with potential ground loops in audio systems? We do so by carefully examining our studio setup in order to eliminate possible multiple ground connections. If we are using rack-mounted equipment, we have three such potential connections between devices: the metal rack-to-chassis connection, the power-line ground connection, and the signal wire ground connection. We must choose one of these and eliminate the others. The power line ground connection is the primary ground connection and is intended to provide electrical safety in case of a major electrical fault. We would ideally like to leave it connected! Unfortunately, it is also one of the easiest connections to break: a simple ground-lift adapter can be inserted between the grounded plug and the wall ground receptacle. It is more difficult to break the physical connection between the chassis and the metal rack unless the manufacturer thoughtfully provides a ground-lift switch or unless we go into the device and install our own ground-lift modification. (There are plastic tabs available that do this, but they must be installed on each piece of equipment in the rack.) Another easy connection to break is the one in the wire with which we connect our signal between devices. In order to decide which grounding connection we will leave and which we will eliminate, we must consider the actual physical setup with which we are dealing. The

preferred way of dealing with potential ground loops and the safety concerns would be to use transformers for signal isolation (leaving the power line grounds connected), but they are expensive and may degrade the sound somewhat if not of the finest construction. In permanent installations, we may be able to run balanced cabling with the shield connected at one end only, still providing shielding but interrupting the redundant ground connection. (It may be necessary to install a capacitor to ground at the disconnected end of the shield to reduce RF pickup.) To maintain safety, the power line ground should never be left disconnected.

Connectors: One of the most common incompatibilities in device interconnection is the issue of connector types. There are three main audio connector types: RCA/phono, phone plug, and XLR or Cannon.



Phono or RCA connector

Phono connectors, also known as RCA connectors, are the typical consumer audio and video connectors. They consist of a concentric plug, with the signal on the center conductor and the shield on the outer conductor. Phono connectors can only be used on unbalanced signals and are not the most reliable of connectors, either mechanically or electrically.

Phone plugs (in both 1/4" and 1/8" diameter) are commonly known as "guitar plugs", since they are used on electric guitars and amplifiers. They are somewhat more reliable than phono plugs and are available in both balanced and unbalanced versions.



Tip-sleeve phone connector

Two conductor types are known as T-S (tip-sleeve), with the signal connected to the tip and the shield connected to the sleeve. These can be used for unbalanced connections only.



Tip-ring-sleeve phone connector

Three conductor types are known as T-R-S (tip-ring-sleeve), with the hot (+) signal on the tip, the cold (-) signal on the ring and the shield connected to the sleeve. The smaller 1/8" diameter phone plugs are to be avoided in pro audio, since they are mechanically fragile and prone to poor connections. They are frequently used on miniature equipment like iPhone/iPad systems. TRS phone plugs are generally used for balanced connections, but they can be used in unbalanced circuits so one must check. They can also be used for unbalanced stereo connections like headphones.



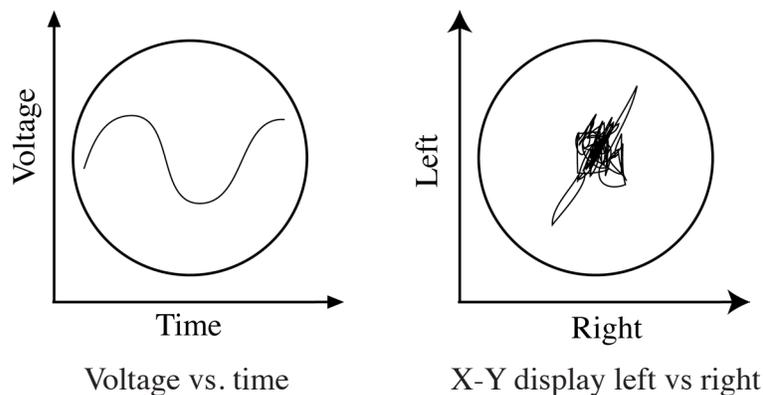
XLR connector

The standard pro audio connector is the XLR type, which is found on low impedance microphones and most professional audio gear. These are the most expensive of the audio connectors, but also are the best in terms of reliability and mechanical strength. The audio type of XLR connector consists of three pins surrounded by a metal shell. Pin 1 is the ground pin, connected to the shield. Pin 2 carries the high (+) signal while pin 3 carries the cold (-) signal. Some older equipment was made with pins 2 and 3 reversed, so one must expressly

check the manual to see what a specific piece of gear uses. To prevent ground loops, the XLR connectors allow disconnection (or “floating”) of the shield connection at one end of the cable. This should only be done for permanently installed equipment where the lifted shield can be properly identified. If an XLR cable is constructed with a shield disconnected to help with ground loop issues, label it clearly to be sure not to use it to connect a microphone. Note that the shield in the wire is connected to pin 1 of the connector, but generally not to the shell. For microphone use, it is desirable to connect the shell since the microphone has no other connections to ground but sometimes electronic devices are wired in such a way that the shell connection results in ground noise introduction.

The Oscilloscope

One of the most useful of audio “tools” is the oscilloscope. It allows us to look at electronic signals. There is sometimes information about signals that is more easily understood by visual examination than by simply listening. The oscilloscope displays signals as voltage versus time. We can select the time axis (or time base) with a knob that lets us determine the time it takes the electron beam to sweep from the left to the right of the cathode ray tube. The signal amplitude is displayed as vertical deflection of the beam and can be measured from a grid of lines printed on the display. The oscilloscope allows us to look at very fast signals, even if their frequency is too high to be audible.



Most oscilloscopes allow several input channels to be displayed at the same time. This allows us to compare two signals, input and output, for example. If we are interested in a stereo signal, it can be displayed in X-Y mode as well as by two separate beams. In X-Y mode one channel is fed to the vertical amplifier and the other is fed to the horizontal amplifier (instead of the time sweep). The result is a so-called vector display of the correlation of the signals. If both signals are of equal amplitude and phase, a straight line of slope 1 is displayed. As the two signals diverge, the display begins to “spread out”. In the case of two signals exactly 90° out of phase (and of the same frequency), the display is a circle, at 180° a straight line of slope -1. In fact, the relative frequencies of the two signals can be calculated from the display, at least for simple sinusoids. One of the more common uses of this system is in the physical alignment of tape recorder heads, which will be discussed later. It is a good idea for the student of audio to spend some time looking at the scope display while listening to music in order to get an appreciation of how audio signals “look and feel”. Of special interest is an examination of the ratio of the peak amplitudes to the average signal amplitude, known as the crest factor. Since short peaks can cause overloads of electronic circuits even when the average level indicated by a VU meter seems to be well within the “safe” range, an visual representation of the electronic signal variations is helpful.

Not only can the oscilloscope display several input signals simultaneously, but many can display the difference between two inputs. This allows the oscilloscope to duplicate the function of the differential (balanced) audio

interconnect. While a common ground reference is required for display of unbalanced signals, the differential amplifier can display a difference signal without such a ground connection, provided the two signals under comparison share a common ground. Oscilloscopes are indispensable for troubleshooting and repair work and testing systems when there are problems.

© 2014 Jay Kadis (For educational use only)