

Ground systems

Arrakis Systems inc.

application note



Purpose of this Ap Note

This application note is designed as a practical aid for designing, installing, and debugging low noise, high performance audio broadcast studios and facilities. It is intended for use by novice and experienced “technical” people alike, including managers.

The application note focuses on the basic principles of audio “systems” design. Simple mathematical models are used only as they illustrate a principle. We find that it is the proper understanding and application of basic principles that results in a professional audio installation. It is often only through an application of basic principles that a problematic installation can be corrected.

In preparation for writing this application note, we have performed an extensive review of available technical literature and product manuals on these subjects. The review underlined the complexity of modern audio systems design and that this is a field under constant change. Combining audio products from the broadcast, consumer, music, commercial sound, and now personal computer industries into a single facility is a challenge. These different industries have different product design goals that have resulted in an inability to simply “plug and play.” It would be thought that it would be possible to simply purchase equipment and off the shelf interconnection cables to assemble an audio facility. However, variations in audio levels, impedance, connector designs, AC and audio ground systems, and other factors make this difficult. The purpose of this application note is to help to provide enough of an understanding of the underlying principles to be able to overcome these obstacles.

Arrakis Systems has been building professional radio consoles since the late 1970's and digital audio source equipment since the early 1990's. We are a leading manufacturer and innovator in the professional broadcast audio industry. We have accumulated experience with thousands of studios in diverse conditions around the world.



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Danger- Shock & other hazards

Electronic products may contain potentially lethal voltages and currents and should be serviced by trained and experienced personnel only. Any installation, test, or calibration procedures in this document that require access to the interior of the equipment should be performed by qualified personnel only.

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Having difficulty contacting Arrakis? Refer to the website (www.arrakis-systems.com) for current contact information

GROUND SYSTEMS

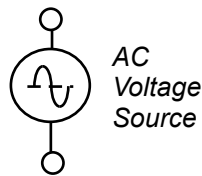
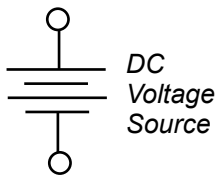
3.0 What is Voltage, Current, & Resistance ?

a) VOLTAGE

Voltage is defined as an electrostatic potential (Voltage) difference between two points. If you connect a wire between those two points a current of electrons will flow. It is measured in "Volts".

There are two basic types of voltage sources.

- (1) DC Sources- direct current
(a Battery or DC power supply)
- (2) AC Sources- alternating current
(AC wall outlet)



b) CURRENT

Current is a flow of electrons. It is defined as flowing from a positive (+) potential to a negative (-) potential. It is measured in "Amps"

c) RESISTANCE

Resistance is the impedance to the flow of electrons. It is measured in "Ohms".

d) OHMS LAW

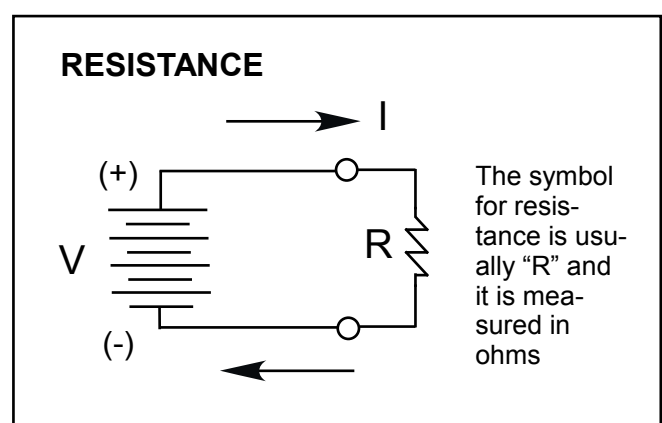
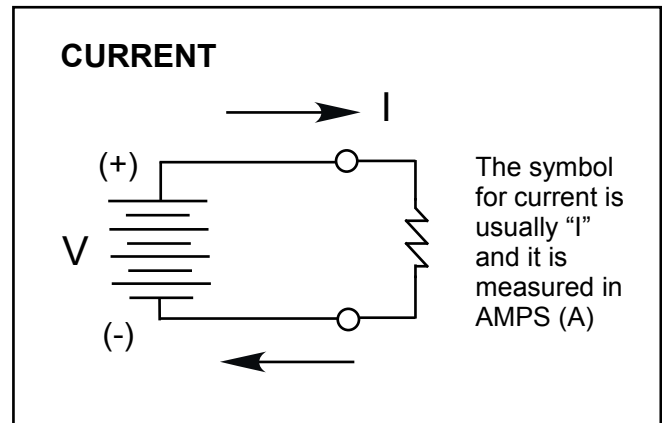
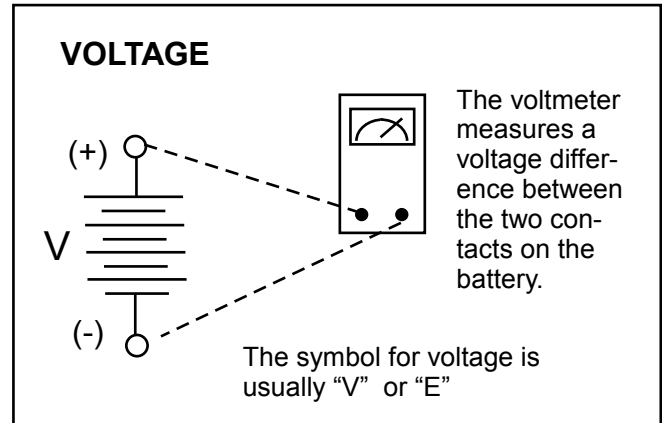
There is a relationship between voltage, current, and resistance.

$$\begin{aligned} \text{Voltage} &= \text{Current} \times \text{Resistance} \\ \text{Volts} &= \text{Amps} \times \text{Ohms} \\ V &= I \times R, \quad I = V / R, \quad R = V / I, \end{aligned}$$

e) POWER

Power is measured in Watts and is:

$$\begin{aligned} \text{Power} &= \text{Amps} \times \text{Volts}, \\ P &= I \times V \end{aligned}$$



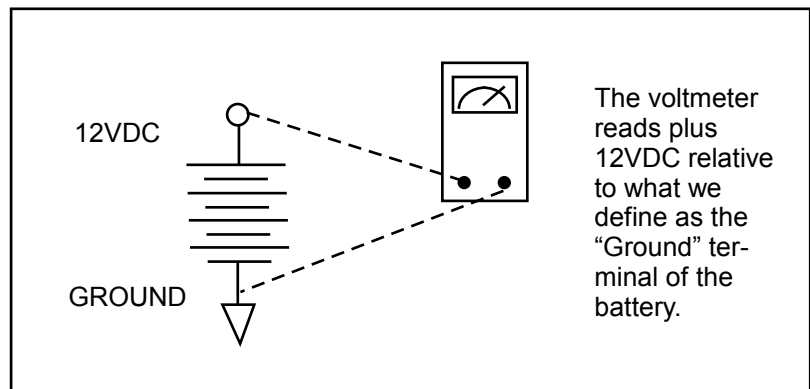
GROUND SYSTEMS

3.1 What is Ground ?

a) GROUND IS SIMPLY A REFERENCE POINT

Ground is simply a POINT that we reference voltage measurements to.

A voltage is a potential difference between two points, such as across the terminals of a battery or power supply. It is usual to refer to one terminal of a power supply as "Ground" and the other as a voltage such as +12VDC or -12VDC (volts direct current)



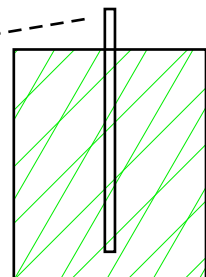
b) WHAT IS EARTH GROUND ?

In most places, our planet itself (earth) is conductive. It is the one conductor that is available nearly everywhere. We therefore name it "Earth Ground" and define it as our universal voltage reference. Our power systems use it as a voltage reference only and not as a current conductor. To achieve an earth ground reference connection, we usually simply drive a copper rod into the ground.

In most cases, a simple ground rod is sufficient. However, there is quite a science to attaining the best possible earth ground connection. In some cases it requires multiple ground rods, chemicals placed into the soil, and other significant measures. There are even large areas of the planet that are floating from earth ground due to insulating rock structures. This is why it is not unusual for someone to be electrocuted miles from a lightning strike. In those areas, the lightning must travel over the surface of the ground for a long distance before returning to true earth ground.

From the standpoint of most electrical codes, a ground rod is considered acceptable if the resistance between it and actual earth ground is less than 25 ohms. Therefore a large resistance can exist between two ground rods only a few feet apart.

***EARTH CONNECTION-** good quality copper-clad rod, 6-10 feet long, driven into compacted or undisturbed soil.*



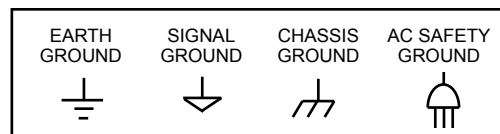
GROUND SYSTEMS

3.1 What is Ground ? (continued)

c) GROUND SYMBOLS

Because of the several types of ground systems in a broadcast facility, there are several types of "Grounds." Each ground has its own symbol.

Earth Ground	(typically a stake into the ground which is the main station ground)
Audio Signal Ground	(the electronic ground inside a piece of electronic equipment)
Chassis Ground	(the metal cabinet of a device is grounded for safety)
AC Ground	(the ground [return] wire in the AC power system)
AC safety Ground	(the third prong on a 3 prong AC plug and outlet)



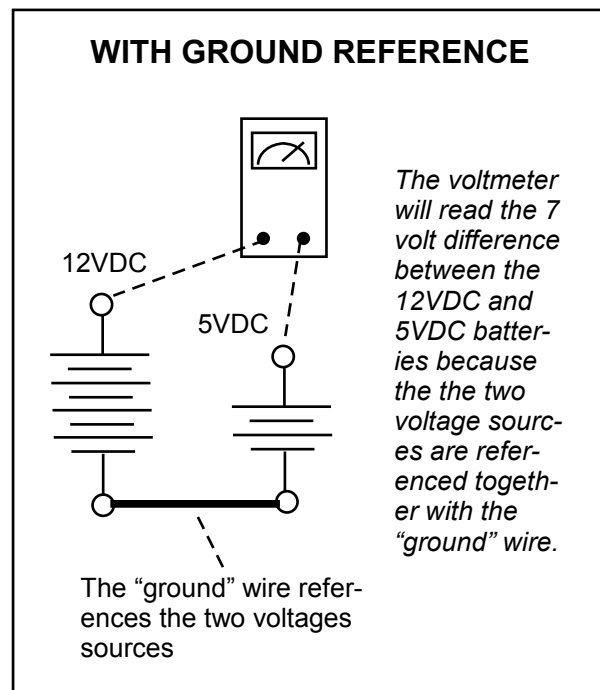
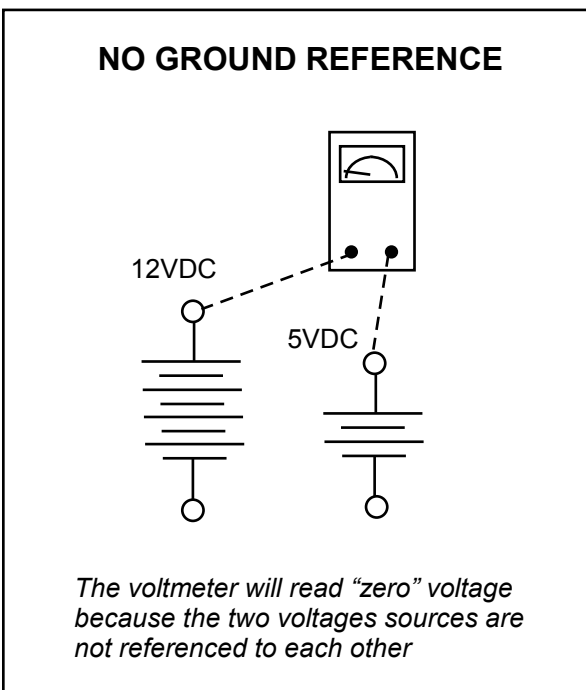
GROUND SYSTEMS

3.2 “Ground Wires” reference Two or More Power Sources

For two power supplies to work together, we connect their “Ground” terminals together with a wire. If the two power supplies are not connected together (referenced to each other), then a voltmeter will not even read a voltage difference between them.

In a broadcast studio, there are several different voltage sources: AC power to the audio equipment, DC power supplies in each piece of equipment, AC power to the lights, etc. The ground on each of these voltage sources is connected together (referenced) through one or more wires we call “ground wires.” All of these voltage sources are then connected to the main “Earth Ground” which is the main ground reference for the facility.

In an ideal situation, the ground wire only references the two power supplies to each other and there are no currents flowing through it. In real world situations, the power supplies are often coupled in various ways and a current flows through the ground wire.



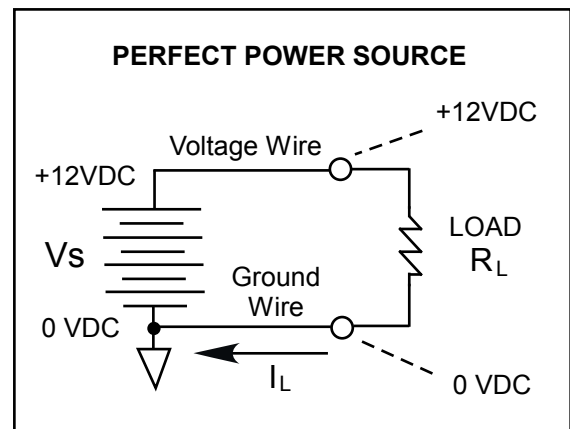
GROUND SYSTEMS

3.3 Current carrying Ground Wires are Not Perfect

a) There are ground wires that only reference two power sources together and ground wires that are intended to carry current. Voltage sources such as AC or DC power systems are designed to provide power to equipment (the load). Two wires are connected from the voltage source to the equipment. One wire is the "Voltage" (Hot) wire and the other wire is typically defined as the "Ground" wire. This type of "Ground" wire carries current and is the return path for current from the load.

b) PERFECT POWER SOURCE

In a perfect power distribution system there would be zero resistance in the wires that connect the power source to the load equipment. All power would be delivered to the load and no voltages would be dropped in the wires.

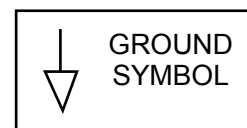
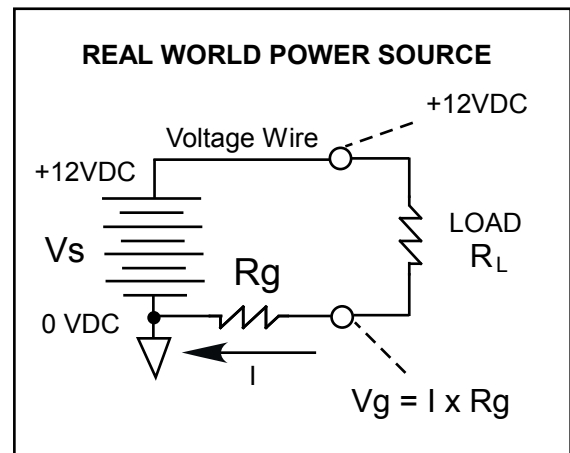


c) REAL WORLD POWER SOURCE

In the Real World, the power and ground wires each have a finite resistance. The current flowing through the ground wire will therefore have a voltage drop and the "Ground" at the load will not be zero volts.

The load equipment usually receives most of power, but the effects of the non-zero ground voltage can create hum and noise in audio signals in the equipment.

EXAMPLE- Assume a typical 110VAC cable, with 50 feet of #12 cable, drawing 10 amps. A #12 wire has a resistance of about 2 ohms per 1000 feet. The example would have about 1/10th of a volt of 60 cycle AC on ground at the audio equipment. This is about 1/10th of the audio signal itself in most audio equipment and would be very objectionable if it was coupled into the audio.



GROUND BASICS

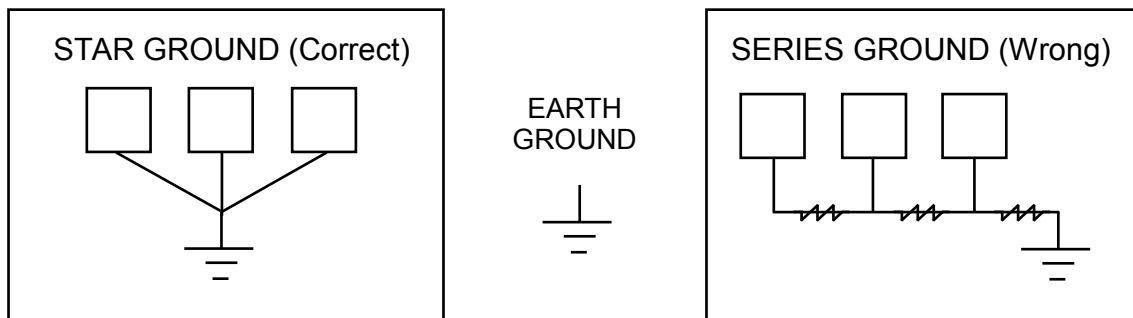
3.4 More than Two Ground wires requires a “Star” Ground

a) If more than two ground points are being connected together, then care must be taken to not have the ground current in one load pass through the ground wire of another load. If it does, the resistance in the ground wire will cause an interaction between the two loads.

b) STAR GROUND- is designed so that the ground current in one device is not running through the ground cable of another.

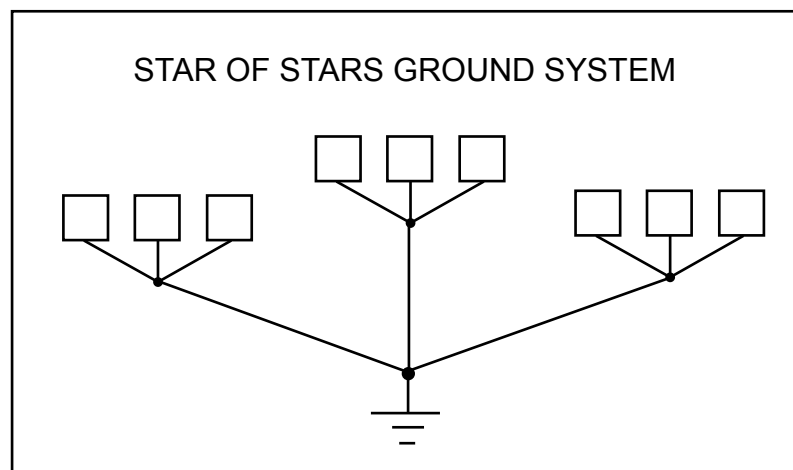
c) SERIES GROUND- allows the ground current in one device to generate a ground voltage in the next device in line. Series ground systems should be avoided wherever possible because they add noise to your audio signal.

d) STAR OF STARS- is used in a large grounding system where it is impractical to take each piece of equipment a long distance to create a single “Star” ground. In those situations, multiple “Stars” are connected together into another “Star.”



The Star of Stars ground system is a compromise in the situation where it is not possible to take every ground individually to the earth ground.

The ground wires in the large star should be much larger than the ground wires in the smaller stars



GROUND SYSTEMS

3.5 A Ground Loop... two Ground Paths is one too many !!!

a) THE GROUND LOOP

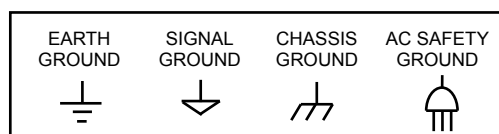
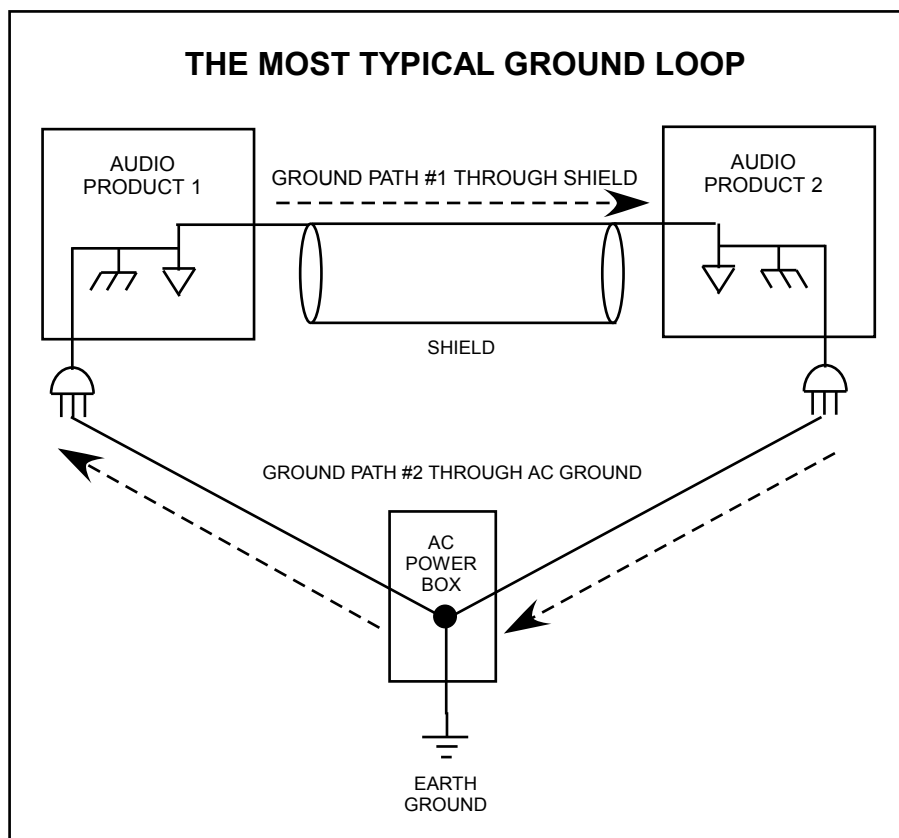
A ground loop exists when there is more than one ground path between two pieces of electronic equipment. The two ground paths form a large loop antenna which picks up noise currents, particularly 60 cycle AC. The resistance in the ground paths converts these currents into fluctuating noise voltage differentials between the two pieces of equipment. If there is an audio signal connection between these two pieces of equipment then this noise is added to the signal voltage.

b) THE MOST TYPICAL GROUND LOOP

The most common ground loop by far in broadcast facilities is between (1) the 3rd wire safety ground and (2) a cable shield that is connected at BOTH ends.

This occurs in balanced professional audio equipment where the metal chassis is connected to the 3rd wire AC safety ground and the chassis ground is connected to the internal audio ground. Some professional audio equipment does not internally connect chassis ground to audio ground and will not have this problem. Most consumer audio equipment is double insulated and will not have this problem.

To break this ground loop do NOT lift the 3rd wire safety ground. Disconnect the cable shield on ONE end only.

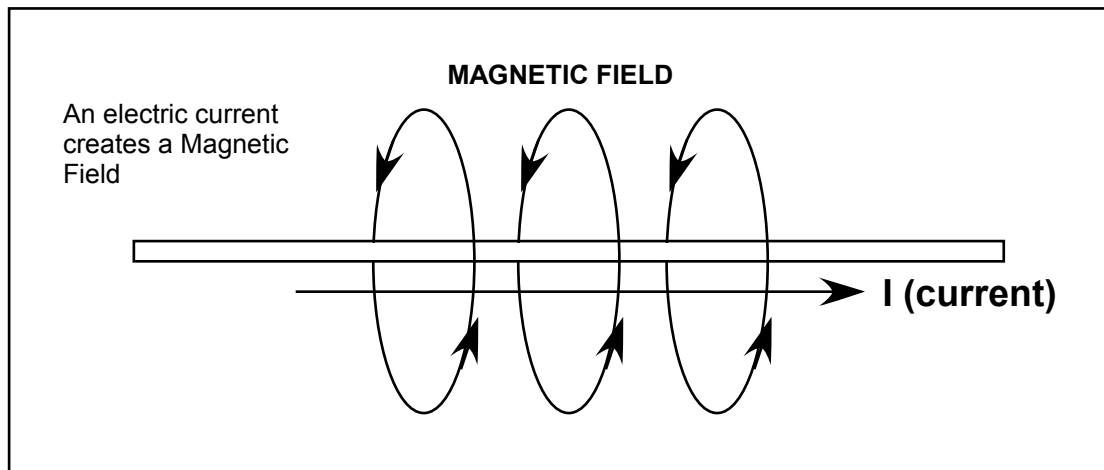


GROUND SYSTEMS

3.6 Ground Currents can cause EM (Electromagnetic) Interference

a) AN ELECTRIC CURRENT CREATES A MAGNETIC FIELD

A magnetic field is created by an electric current. The larger the current, the larger the magnetic field. AC ground and power wires have large currents and create significant AC magnetic fields



b) A CHANGING MAGNETIC FIELD WILL INDUCE A CURRENT IN A NEARBY WIRE

An unchanging magnetic field will not induce a current in a conductor. However, a changing magnetic field will induce a current in a conductor. AC power and ground lines carry AC currents which create changing magnetic fields. These changing magnetic fields will induce an AC current in neighboring wires.

The size of the induced current:

- (1) Decreases by the square of the distance away from the AC power cable
- (2) Increases linearly as a function of the length of cable next to the AC power cable

c) AC POWER AND GROUND CABLES CAN CAUSE EM INTERFERENCE IN AUDIO

If an audio cable is physically close to an AC ground or power cable, then a 60 cycle AC noise voltage can be magnetically coupled into the audio signal cable. For this reason, audio cables should be kept well away from AC power cables.

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3.7 Four Types of Ground Systems in a Broadcast Facility

Because there are several electrical systems in a broadcast facility, there are also several ground systems in the facility. Each ground system fulfills a different function. In a perfect world, all of the ground systems would be entirely independent. They would be “referenced” together through a ground wire connection but there would be no current flow through the ground references. In the real world, these ground systems are coupled together in a number of ways and interact to cause noise in audio signals. Understanding these ground systems is important to be able to properly design and debug an audio facility.

1) AC POWER GROUND

AC power wiring has a “hot” wire (typically 110VAC) and a “ground” wire. The ground wire is the return path for currents in the “hot” wire.

2) AC SAFETY GROUND (Equipment Chassis Ground)

The AC power system has a 3rd conductor which is a “safety” ground. This 3rd conductor is connected to the 3rd prong on the AC outlet. On equipment with a 3rd prong on their AC plug, this safety ground is usually connected to the metal chassis of the product. If something should happen that connects the “hot” 110VAC wire to the metal chassis of the product, then the safety wire will throw the circuit breaker and the lethal voltage will be removed from the chassis.

3) AUDIO SIGNAL GROUND

Each piece of electronic audio equipment has an internal DC power supply which provides a DC voltage (often 12 volts) and a ground to the internal circuits. The audio signals in the product are referenced to the ground in the DC power supply. This is often call the “audio ground,” “circuit ground,” “signal ground,” etc.

4) RF SHIELDING GROUND

The audio signal cables used to connect two or more pieces of audio equipment usually have a metal foil shield surrounding the signal wires inside the cable. This metal shield protects the sensitive audio signal wires from electronic noise that would contaminate the audio signal. The shield is connected to a ground to drain the interfering electronic noise away from the audio signal.

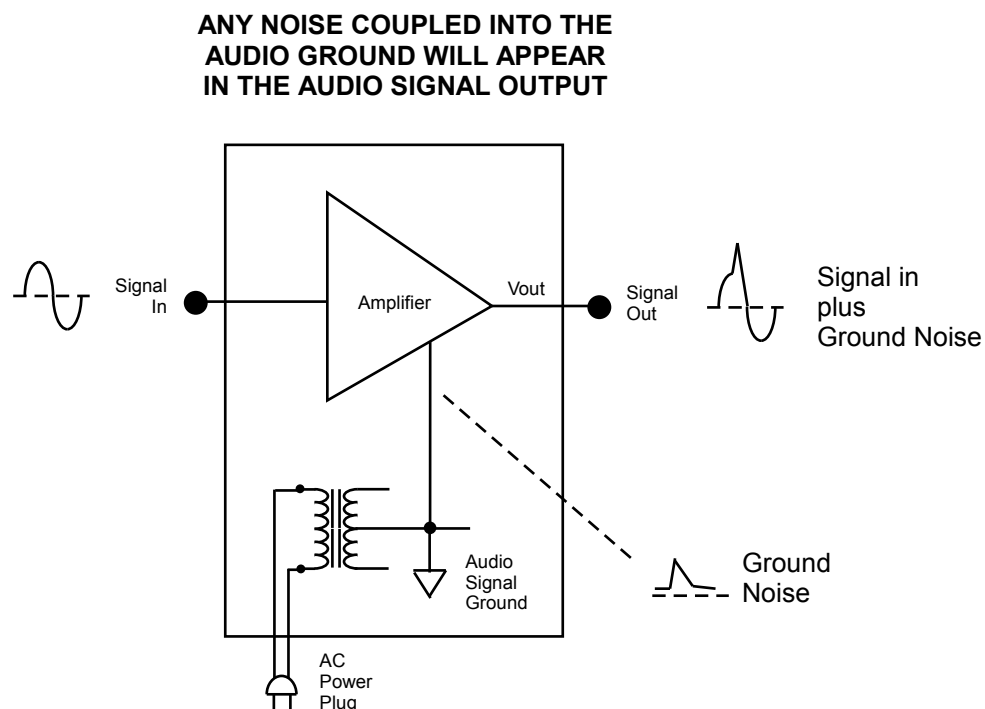
GROUND SYSTEMS

3.8 Audio Signal Ground must be kept Noise Free

Each piece of electronic audio equipment has an internal DC power supply which provides a DC voltage and a ground to the internal circuits. This ground is often called the “audio ground,” “circuit ground,” “signal ground,” etc. The internal audio ground is connected to all of the various circuits inside the device.

Whether the audio equipment is professional balanced equipment or unbalanced consumer equipment, any noise that reaches the audio signal ground inside the equipment will be coupled into the audio signal itself and appear at the audio output of the device. In consumer equipment, the noise will simply be coupled to the output and be amplified by the following pieces of equipment in the signal chain. In professional balanced audio equipment, the noise will appear as a balanced signal (not common mode) and also be amplified by the following audio equipment in the signal chain.

It is extremely important that the audio ground be as free from noise as possible.



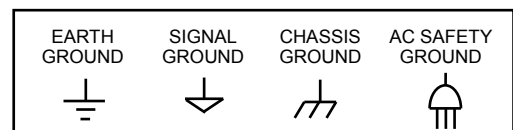
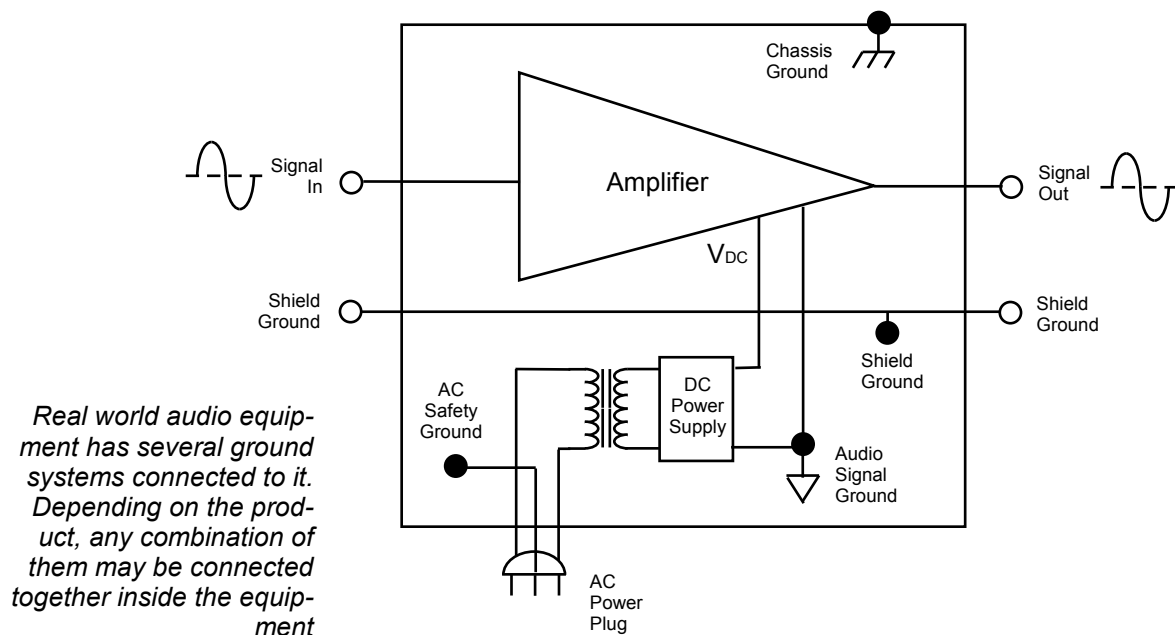
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3.9 Real World Audio Equipment has Mixed Grounds

In real world audio equipment, several ground systems connect to each audio device. Which ones are connected to the audio signal ground vary from product to product. Most consumer products are “double insulated” and do not have a 3rd wire safety ground to introduce noise. However, most professional audio products connect the 3rd wire safety ground directly to the product’s chassis and the audio signal ground which does introduce noise. In consumer products the cable shield ground is the audio signal ground while in professional products, the cable shield may (or may not) be connected to the audio signal ground.

As shown below, the following grounds may be connected to audio signal ground and can therefore introduce noise into the audio:

- (1) 3rd wire AC “Safety” ground
- (2) Cable “Shield” ground
- (3) Chassis Ground



GROUND SYSTEMS

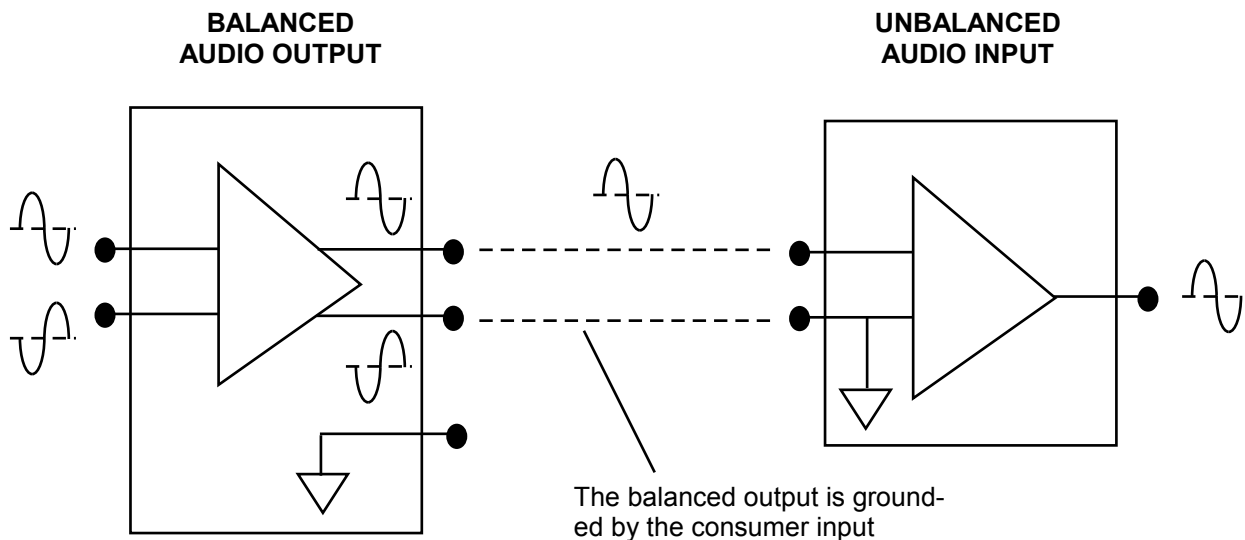
3.10 Crosstalk can be caused by Ground Currents

Crosstalk is when an audio signal from one circuit is audible in another circuit.

Crosstalk is an important audio performance parameter in broadcast facilities. This is because it is important that the audio from one piece of audio equipment not interfere with the audio from another piece of equipment. This manual has been focusing on keeping AC 60 cycle hum out of the ground systems, but it is equally critical that audio signals not appear on the ground systems. There are basically two types of crosstalk (1) Capacitive, (2) Ground Modulation. Capacitive crosstalk increases with frequency at 20dB per decade (6dB per octave). It is not a common type of crosstalk and is most often a characteristic of the audio device itself. Capacitive crosstalk can be identified by a lack of low frequency audio content. Crosstalk from ground modulation is very common and sounds like full bandwidth, low level audio. It is typically caused by the mis-wiring of equipment and by audio power amplifiers driving large ground currents.

THE MOST COMMON SOURCE OF CROSSTALK IS GROUNDING AN AMPLIFIER OUTPUT

One of the most common customer service problems for audio equipment manufacturers is audio crosstalk. This is typically due to mis-wiring the output of a balanced audio device. If one side of a balanced audio output is grounded, the other side will still have signal and the system will appear to work fine because audio passes through the system. However, the side of the balanced output that is grounded will drive large currents into the ground system and modulate ground with the audio signal as shown below.



One side of the balanced audio output is shorted to ground and driving a large current into ground. This large audio current will modulate the ground and may appear as crosstalk in other audio circuits. This miswiring is typically done in one of two ways.

- (1) As shown above, where a balanced output is driving an unbalanced input*
- (2) Where one side of the balanced output is wired to ground by accident*