ISO-MAX®

TROUBLESHOOTING GUIDE

by Bill Whitlock

1 DYNAMIC RANGE AND NOISE BASICS

The human ear itself has a dynamic range, from the threshold of hearing to the threshold of pain, of about 140 dB. Up to 120 dB of dynamic range may be required in high-end "audiophile" sound systems installed in typical homes *[Ref 1]*. In video systems, 50 dB is generally accepted as a threshold beyond which no further improvement in images is perceivable, even by expert viewers.

The *dynamic range* of an electronic system is the ratio (generally expressed in dB) of its maximum undistorted signal output to its residual noise output or *noise floor*. The *signal-to-noise ratio* or *SNR* is the ratio of a reference level signal output to noise floor. The *headroom* or *overload margin* of a device is the ratio of its maximum undistorted signal output to a reference level signal. Therefore, dynamic range = SNR + headroom if all are expressed in dB.

The usable dynamic range of a system is most often compromised by its noise floor. Noises such as hum or buzz are generally much more irritating to a listener than truly random noise, which is heard as "hiss." Once a signal is contaminated by noise, it's essentially impossible to remove it without degrading the original signal. ***The dynamic range of an entire system can be no better than its weakest link***. Noise must be minimized all along the signal path. In general, each downstream (between source and listener/viewer) device must have a dynamic range 10 to 15 dB better than the source in order to preserve the original dynamic range. Of course, this assumes that the system gain structure is such that the dynamic range of each device is fully utilized.

The *SIGNAL INTERFACES*, rather than the equipment itself, are most likely to degrade dynamic range in the vast majority of systems.

2 UNBALANCED INTERFACE BASICS

An unbalanced interface uses a pair of wires to carry the signal from one device to another. One wire is grounded and the other carries the signal.

Every *output* has an impedance (measured in ohms) called its "output impedance". For practical reasons, real outputs can't have zero-ohm output impedance. Likewise, every *input* has an impedance (measured in ohms) called its "input impedance". For practical reasons, real inputs can't have infinitely-high input impedance.

When an output is connected to an input, a series circuit called a "voltage divider" is formed, where voltage drops are proportional to impedance (see Figure 1). The input impedance of Device B is called a "load" on the output of Device A.

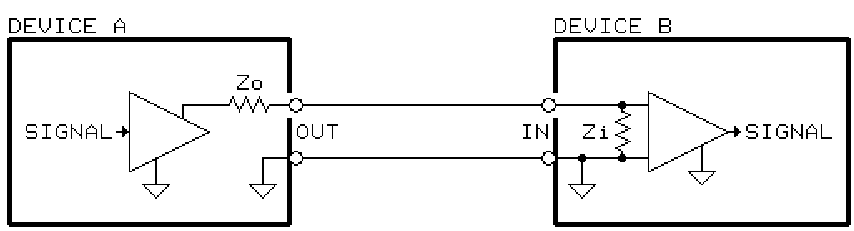


Figure 1 - Basic Unbalanced Interface

Since the purpose of an interface is to transfer maximum signal *voltage* from output to input, it's desirable for Zi to be much higher than Zo. For typical equipment, Zo ranges from 100 Ω to 1 kΩ and Zi ranges from 10 kΩ to 100 kΩ, transferring 90% to 99.9% of the available signal voltage.

Manufacturers and users alike often confuse "output impedance" with "load impedance". Actual output impedance is often missing from spec sheets and, instead, something like "20 kΩ minimum load impedance" is the *only* description of an output.

Actual output impedance can be very important to know. For example, when an output drives a long cable, high output impedance can seriously degrade treble response. The capacitance of shielded audio cable, typically about 50 pF per foot, and the actual output impedance form a low-pass filter. If the output impedance is 1 kΩ (not uncommon in consumer equipment), response at 20 kHz will be −0.5 dB for 50 feet, −1.5 dB for 100 feet, and −4 dB for 200 feet of cable. If the output impedance were lower, say 100 Ω, the effects would be insignificant.

There is a common misconception about "impedance matching" of audio outputs and inputs. This use of a load impedance equal to the source impedance results in maximum power transfer, but the object of an audio interface is to transfer voltage, not power. Matching throws away half the signal voltage and places an unnecessary heavy load on the output.

Because video and RF signals have much shorter wavelengths than audio, they are true "transmission lines" which must be properly "terminated" with the proper or "characteristic" impedance of the cable at each physical end. Unterminated or misterminated cables can cause reflection of high frequency energy from one end of the cable to the other, causing visible "ghosts" or "rings" in video images. Virtually all video outputs and most video inputs have 75 Ω impedances which properly terminate 75 Ω cables. Some video inputs have a switch marked "hi-z" which raises their impedance to several thousand ohms, allowing them to "bridge" or "loop-thru" a line without terminating it. This can be used, for example, to monitor video sent from a camera to a recorder — the camera terminates one end of the cable, the recorder terminates the other end, and the monitor bridges the cable between them.

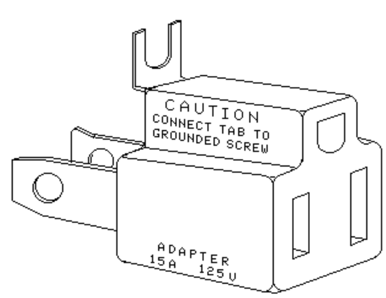
3 POWER LINE AND GROUNDING EFFECTS IN REAL-WORLD SYSTEMS

Significant "noise" voltage will always exist between the chassis grounds of any two devices in AC powered systems, whether safety grounded or not. This must be accepted as a fact of life. This voltage is the dominant noise source in most systems, NOT noise "picked up by cables" as is so widely believed. Power line noise currents are coupled through equipment power transformers and flow in system ground and interface wiring, creating "ground noise" voltages.

Many appliances and consumer electronics are supplied with two-prong AC plugs. Sometimes called "double insulated," these devices are specially designed to meet strict UL and other requirements to remain safe even if one of their two insulation systems fails. Often there is a "one-shot" thermal cutoff switch inside the power transformer or motor windings to prevent overheating and subsequent insulation breakdown. ONLY equipment *originally supplied* with two-prong plugs is safe to operate without safety grounding. Equipment originally supplied with three-prong, grounding plugs MUST NEVER have the safety grounding defeated.

★ DON'T CREATE A LETHAL SHOCK HAZARD ★

Never, never use devices such as three prong to two prong AC plug adapters, sometimes called "ground lifters" to solve a noise problem. A "ground adapter" is actually designed to provide a safety ground (via the cover plate screw to a grounded outlet) in cases where a three prong plug is used with a two conductor outlet. Remember that the audio, video, or other cables which connect equipment together can also carry lethal voltages throughout the system if just one "ground lifted" device fails. There's simply no excuse for "ground lifting" --- the resulting legal liability can bankrupt a business.



As shown in Figure 2, power line noise current flowing in the shield of unbalanced signal interconnects causes a voltage drop which directly adds to the signal. This causes hum and buzz in audio signals and hum bars or "sparkle bands" in video signals. In ungrounded equipment, the coupling is capacitive which tends to make the noise a harmonic-rich “buzz” rather than more fundamental “hum” which is more common when equipment is grounded. Power line harmonics and high frequency noise is created by power supplies in electronic equipment, fluorescent or dimmer controlled lights, and intermittent or sparking loads such as switches, relays, or brush type motors.

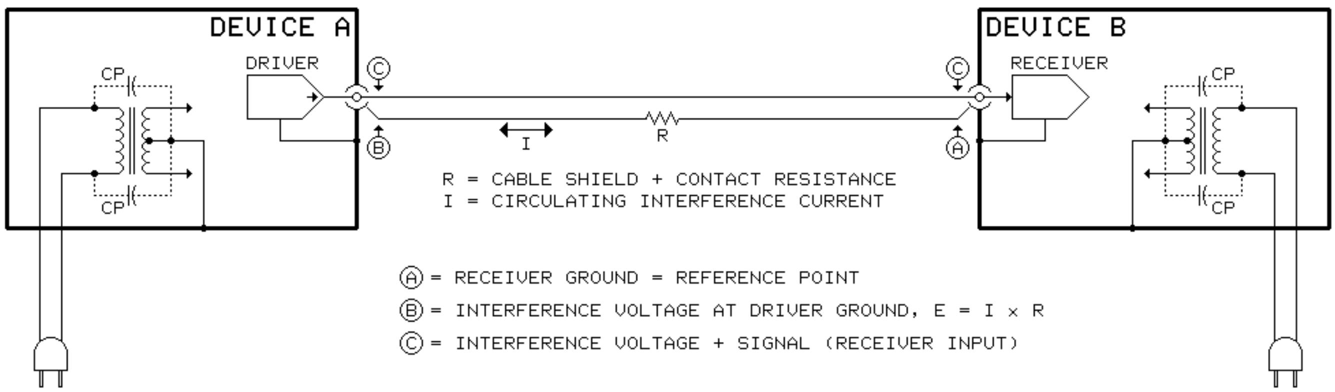


Figure 2 - Common Impedance Coupling in an Unbalanced Interface

As shown in Figure 2, inter-chassis noise current flows in the wire connecting points A and B, causing a small voltage drop to appear across it. The signal actually delivered to device B is the sum of all the voltages in the loop from point A to C, which now includes the noise. Because the wire impedance is "common" to both signal and noise current paths, this coupling mechanism is called *common impedance coupling*.

At power line (hum) frequencies, the impedance of a wire (or cable shield) is effectively equal to its DC resistance. According to Ohm's Law, E = I x R. Therefore, the low frequency noise voltage E depends on inter-chassis current I and the resistance of the cable shield R. Consider a 25 foot interconnect cable with foil shield and a #26 AWG drain wire. From standard wire tables (or actual measurement) its shield resistance is found to be 1.0 Ω. If the interchassis current is 300 µA, the noise voltage will be 300 µV. Since the normal consumer reference signal level is −10 dBV or 300 mV, the noise will be only 20 x log (300 µV / 300 mV) = −60 dB relative to the reference signal. For most systems, this is a very poor signal to noise ratio.

Common-impedance coupling can become very severe between two "grounded" devices, since the ground noise in the building wiring is effectively forced across the unbalanced cable's shield by the parallel connection.

4 TROUBLESHOOTING SYSTEM INTERFACES

Finding out how and where such noises enter the system *can* be a frustrating, time-consuming experience. But a significant part of troubleshooting involves the way you think about the problem. For example, don’t fall into the trap of thinking, just because you’ve done something a particular way many times before, that it can’t be the problem. Even things that can’t go wrong, do.

However, the source of many problems either reveals itself or can be simply deduced if we just gather enough information. It’s important to have as many clues as possible <u>before</u> you try to solve a problem. And write everything down — imperfect recall can waste a lot of time.

Ask lots of questions. Troubleshooting guru Bob Pease suggests these basic questions [Ref 2]:

1. Did it *ever* work right?
2. What are the symptoms that tell you it's not working right?
3. When did it start working badly or stop working?
4. What other symptoms showed up just before, just after, or at the same time as the failure?

Sketch a block diagram of the system. The following is an example:

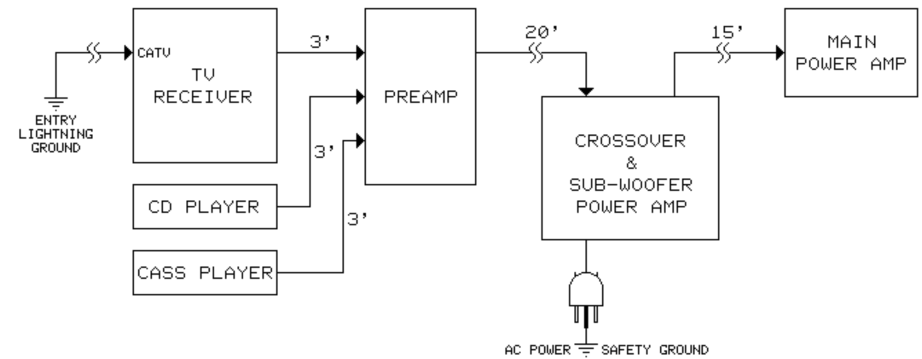


Figure 3 - Example System Sketch

1. Show all interconnecting cables, indicating approximate length. Note any balanced inputs or outputs. Generally, stereo pairs can be indicated with a single line.
2. Note any equipment which is grounded via its 3-prong power plug.
3. Note any other ground connections such as cable TV or DSS dishes.

Use the equipment's own controls, with some logic, to provide additional clues:

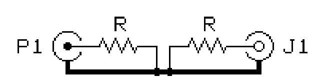
1. If the noise is unaffected by the setting of a volume control or selector, it must be entering the signal path <u>after</u> that control.
2. If the noise can be eliminated by turning the volume down or selecting another input, it must be entering the signal path <u>before</u> that control.

Testing to Find Problem Interfaces

Some tests which involve disconnecting cables can now further pinpoint the problem. These tests involve the use of "test adapters" which effectively allow the system to test itself for most noise problems. The tests can specifically differentiate these problems:

1. Common-impedance coupling in the cable,
2. Magnetic or electrostatic pickup by the cables, or
3. Internal common-impedance coupling in badly designed equipment.

The test adapters may be purchased from Jensen as ISO-MAX part numbers TA-R1 for the audio RCA version or TA-R75 for the video RCA version. You may also build them and/or adapt them for use with other connector types as shown in Figure 4. Since these devices do NOT pass signal, they should be clearly marked so that they don't accidentally find their way into a system.



<u>ISO-MAX TA-R1 (Audio RCA)</u>

P1 = Switchcraft 3502 Plug
J1 = Switchcraft 3503 Jack
R = 1 kΩ, 5%, 1/4 W Resistor

<u>For Audio 2C Phone</u>

Use Switchcraft 336A and 345A Adapters with RCA version

<u>ISO-MAX TA-R75 (Video RCA)</u>

Same as Audio RCA, except
R = 75 Ω, 5%, 1/4 W Resistor

<u>For Video BNC</u>

Use MilesTek 10-01015 and 10-01016 Adapters with Video RCA version

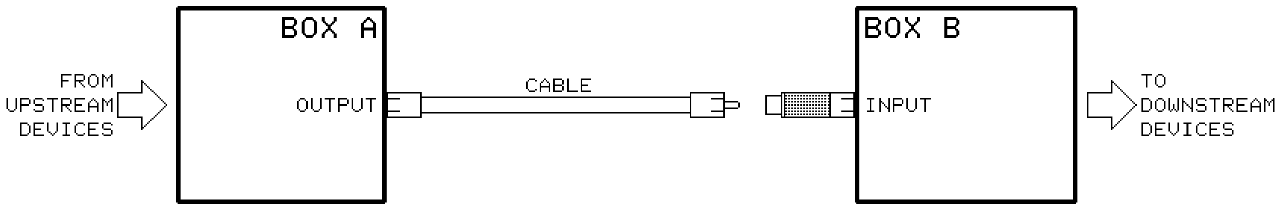
Figure 4 - Test Adapters

Each signal interface is tested using a four-step procedure. If a specific interface or portion of the system has not been identified, start at the inputs to the power amplifiers (for audio systems) or the input to the monitor (for video systems) and work backwards toward the signal sources.

Be very careful when performing the tests not to damage speakers or ears! The surest way to avoid possible damage is to turn off the power amplifier(s) before disconnecting or re-connecting cables for each test step.

Test stereo signal paths using two adapters, using them simultaneously for L and R, as described in the procedure.

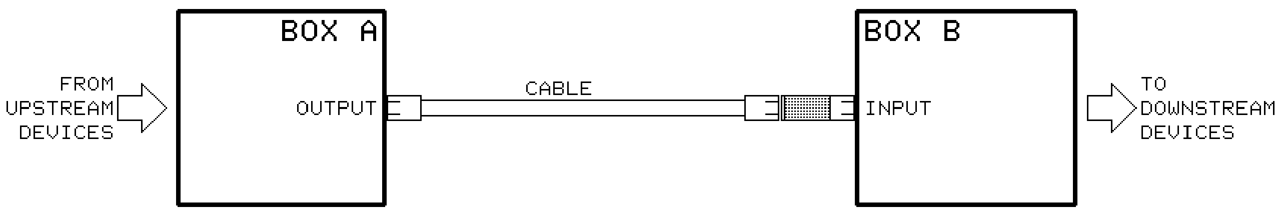
Step 1 – Unplug the cable from the input of Box B and plug in only the adapter as shown below.



✱ Is the system output quiet? No – the problem is either in Box B or further downstream

Yes – go to next step

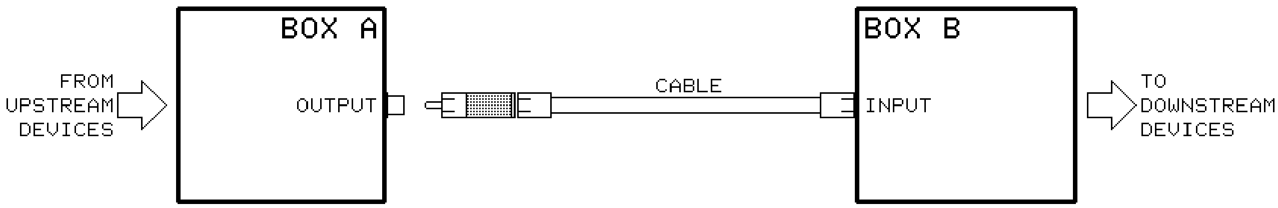
Step 2 – Leaving the adapter in place at the input of Box B, plug the cable into the adapter as shown below.



✱ Is the system output quiet? No – the problem is either in Box B or further downstream. If Box B is a power amplifier driving normal (ungrounded) speakers, this test result means there may be an internal common-impedance coupling problem in Box B. The “hummer” test can be performed to confirm this. See Jensen application schematic AS032 for more details. Have the unit repaired, modified, or replace it with one which is properly designed.

Yes – go to next step

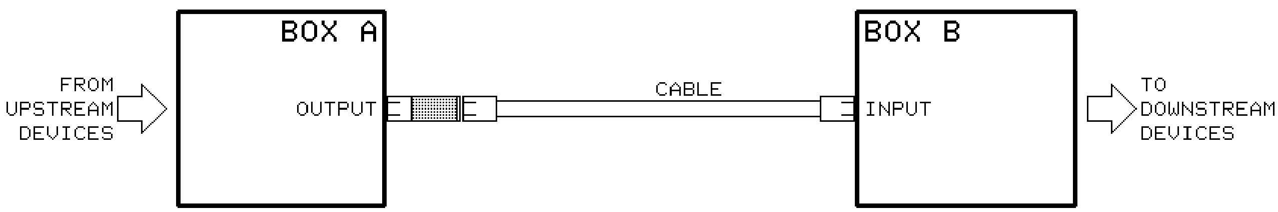
Step 3 – Remove the adapter and plug the cable directly into the input of Box B. Unplug the other end of the cable from the output of Box A and plug it into the adapter as shown below. *Do not plug the adapter into Box A or let it touch anything conductive.*



✱ Is the system output quiet? No – the noise is coupling into to the cable by induction. This is most often caused by a strong magnetic field near the cable. Such magnetic fields are produced by power wiring, power transformers, and TV or computer CRT displays. Electrostatic coupling is also possible, but rare in a cable which has a grounded outer shield. Route all signal cables to avoid such strong fields.

Yes – go to next step

Step 4 – Leaving the adapter in place on the cable, plug the adapter into the output of Box A as shown below.



✱ Is the system output quiet? No – noisy ground currents are being coupled by the common-impedance of the cable shield. Install an ISO-MAX® ground isolator at the input of Box B.

Yes – the noise is coming from (or through) the output of Box A. Perform these same tests on the cable(s) connecting Box A to upstream devices.

5 Systems with Multiple Grounds

If a system contains two or more pieces of grounded equipment, a ground loop may be formed as shown in Figure 5.

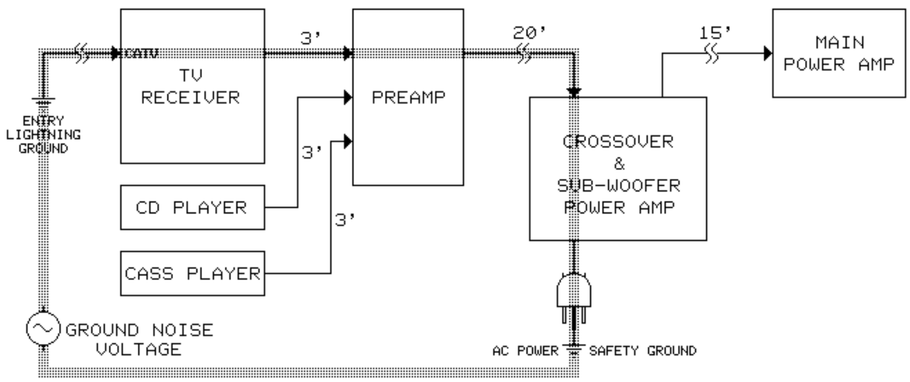


Figure 5 - "Ground Loop" Created by Two System Ground Connections

Because there is often substantial ground noise voltage between the CATV cable shield and the safety ground for the sub-woofer, a relatively large noise current may flow in the shield of any signal cables which are part of the ground loop. In unbalanced interfaces, this current flow results in common-impedance coupling which directly adds noise to the signal. In general, the amount of noise added is in direct proportion to the cable's length. This example system would exhibit a loud hum regardless of the input selected or the setting of the volume control because of ground noise current flow in the 20 foot cable. It might be slightly louder if the TV input were selected and the volume turned up because the ground noise current also flows in the 3 foot cable.

You might be tempted to "break" this ground loop with a ground lifter at the sub-woofer. DON'T !!

A safe solution is to break the ground loop by installing a ground isolator in the audio signal path from preamp to sub-woofer as shown in Figure 6. A high performance ground isolator, like the Jensen ISO-MAX® CI-2RR, should always be installed at the *receiving* end of the cable as shown.

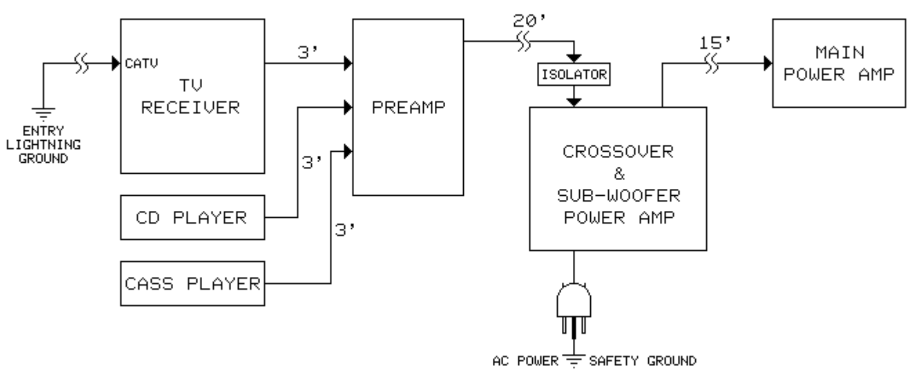


Figure 6 - Using an Audio Ground Isolator to Break the Loop

Another safe solution is to break the ground loop by installing a ground isolator, such as the Jensen ISO-MAX® VR-1FF, in the CATV signal path at the TV as shown in Figure 7.

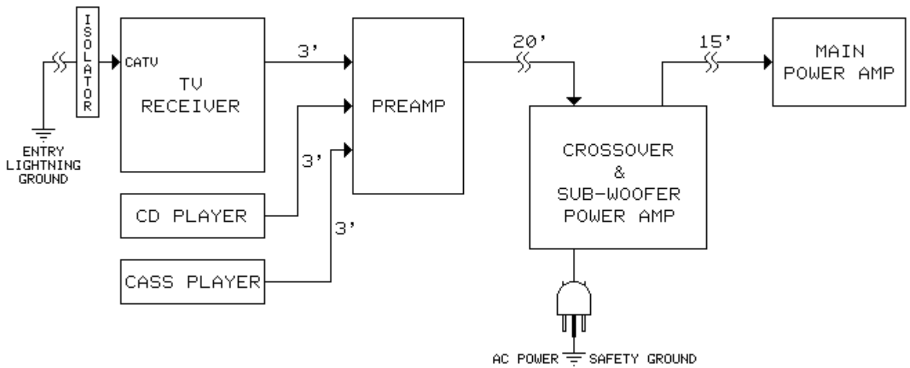


Figure 7 - Using a CATV Ground Isolator to Break the Loop

6 WHEN TO ADD A GROUND CONNECTION

Since most unbalanced interfaces are made to consumer equipment which has no safety ground, isolating the interfaces may leave the chassis "floating" with no ground reference at all. This can allow the voltage between input and output of the isolator to approach 120 volts AC. This is not dangerous but it puts an extreme (and unnecessary) rejection burden on the isolator. The problem is easily solved by adding separate grounding connections to the "floating" gear as shown in Figure 8. This is most easily done by replacing the 2 prong plug with a 3 prong type and adding a (green or green/yellow preferred) wire connected between the safety ground pin of the new AC plug and a chassis ground. If there is any doubt whether a screw, which may be convenient for the chassis connection, is actually grounded, use an ohmmeter to check for continuity between the screw and the outer contact of an RCA connector (which itself can be used if no other point is available).

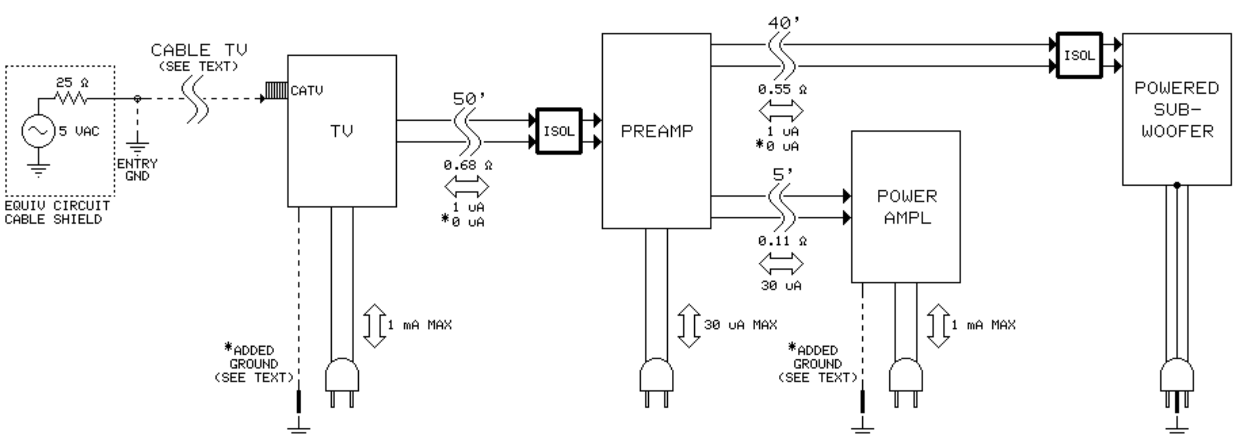


Figure 8 - Grounding "Floating" Equipment when Isolators are Installed *(from Jensen AN004)*

7 More Tips to Reduce Noise

Keep cables as short as possible! Longer cables increase the coupling impedance. Serious noise coupling is nearly certain with 50 or 100 foot cables. Even much shorter cables can produce severe problems if there are multiple grounds. Never coil excess cable length.

Use cables with heavy gauge shields! Cables with shields of foil and light gauge "drain wires" increase coupling impedance. Use cables with heavy braided copper shields, especially for long cables. The *only* property of cable which has any significant effect on audio-frequency noise coupling is shield resistance, which can be measured and compared with an ordinary ohmmeter.

Maintain good connections! Connectors left undisturbed for long periods can develop high contact resistance. Hum, buzz, or other interference which changes when the connector is wiggled indicates a poor contact. Use a good commercial "contact fluid" and/or gold plated connectors to help prevent such problems.

Don't add unnecessary grounds! Additional grounding of equipment will generally increase circulating noise currents rather than reduce them. As emphasized earlier, NEVER disconnect or "lift" a safety ground or lightning protection ground to solve a problem – the practice is both illegal and very dangerous.

Use ISO-MAX ground isolators at problem interfaces! These transformer based isolators magnetically couple the signal while completely breaking input to output connections. This stops the noise current flow in the cable's shield, eliminating common-impedance coupling. A variety of isolators are available for audio, video, and CATV signals.

Special ground isolators are required for digital satellite TV receivers. A lightning safety ground is required for the "dish" antenna. Because DC power for dish electronics is carried by the cable connecting it to the receiver, conventional CATV type ground isolators can't be used because they block DC power. One alternative is to break the ground loop with a special bi-directional coupler which works through window glass. It inductively couples power in one direction and capacitively couples the signal in the other direction. Another is to break the ground loop by inserting a special gas discharge tube based isolator device between the coax grounding block and the earth ground rod. This device effectively opens the ground path, connecting it automatically only when required to discharge high voltages.

Troubleshooting even large, complex systems becomes manageable if testing always uses the technique of working backwards toward the signal sources. Some simple measurements (or estimates) on system equipment and cables make it possible to actually predict hum levels and identify the problem interfaces before a system is installed *[Ref 3]*.

References:

[1] Louis Fielder, Dynamic Range Issues in the Modern Digital Audio Environment, Journal of the AES, May, 1995.

[2] Robert A. Pease, *Troubleshooting Analog Circuits*, Butterworth-Heinemann, 1991.

[3] Jensen Transformers, *Application Note AN004.*