The G word: How to get your audio off the ground

Bruno Putzeys - April 22, 2014

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My most daunting challenge is an ongoing one. I am trying to expunge my language of words that aggravate, cause hurt, misunderstandings or that are just meaningless blather. Fortunately I've never been one for sexual or racial epithets. Swear words were also easy to leave. Expressions like "dimwit" or "roomtemperature IQ" are much harder to swear off. The one I find most troubling though is the G word. I can't bear to imagine saying it in polite company and yet all too often I catch myself doing it unwittingly. Deep breath... I'm talking about... "GND." There. Forgive me. No more nastiness.

Audio signals are voltages. A voltage is the potential difference developed between two points. We grab a voltmeter and connect the two test leads to probe the two points, or "nodes" that we want to know the potential difference between. We don't just attach one lead and hope to get a reading (**figure 1**).

Figure 1: Honestly, sir, I'm positive we had one of those in the school lab.

GND-think

And yet it is not unusual for audio engineers to think of an audio signal as only one circuit node or wire next to which a voltage is written or a waveform drawn, as though this single node were magically capable of having a voltage all on its own. The second node, it seems, is too unimportant, too obvious to mention. And this is where the rub lies: what on earth is *ground*?

According to GND Gurus the root cause of all hum and buzz problems is current flowing through "the same ground" as that used as voltage reference. So, they suggest, we use "different grounds."

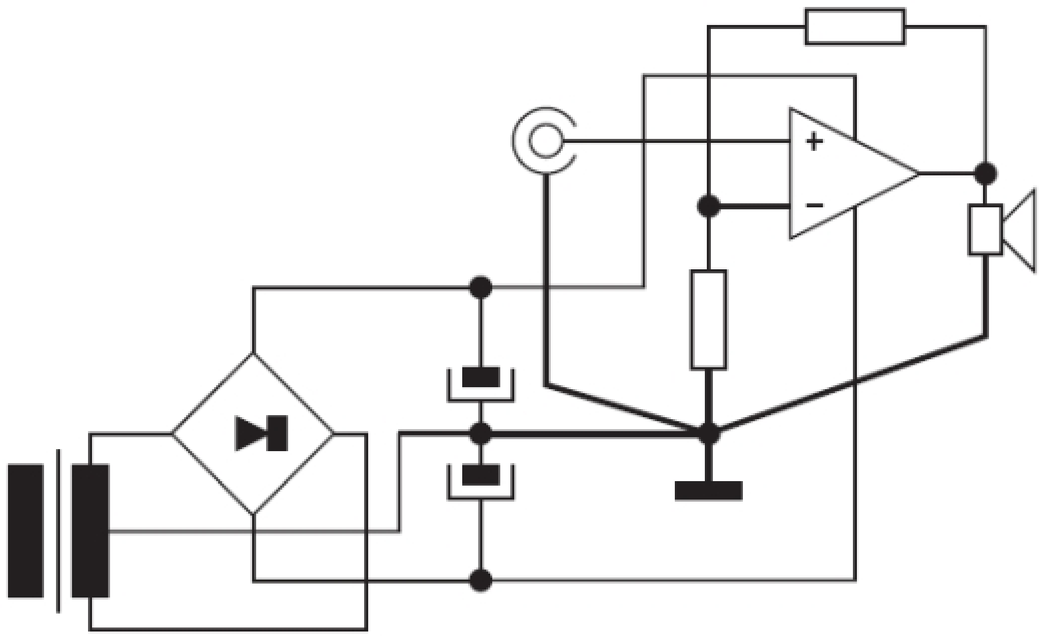

Figure 2: It's got wonderful Powerpoint appeal, though.

The hidden assumption is that a signal is just one wire. But as anyone with a voltmeter knows, the second wire is every bit as important as the first. Still we seem to think it makes sense to use as the second wire the central sewage pipe that also carries waste electrons, supply return currents, shield currents etc., back to the recycling plant. And then we're surprised to find rubbish on it.

The supposed solution is called a "star ground," a common point where "different grounds" connect.

It looks nice at first glance and its practitioners defend it as though it were a fundamental truth (**figure 2**). Practically speaking though it's a nonstarter. It only works at all when it's rigorously done.

You can star a power amp. You can star a preamp. And then you connect the two. Oops. Which of the two stars guards that mythical common potential that all signals in the combined circuit are referenced to? That's where GND Gurus get into their stride. Chains of stars, stars of stars, the whole celestial menagerie (**figure 3**). All hinge on minimizing current flow through the connections that tie the local stars together. And so the saga continues with "floating grounds," disconnecting mains safety earth and whatnot.

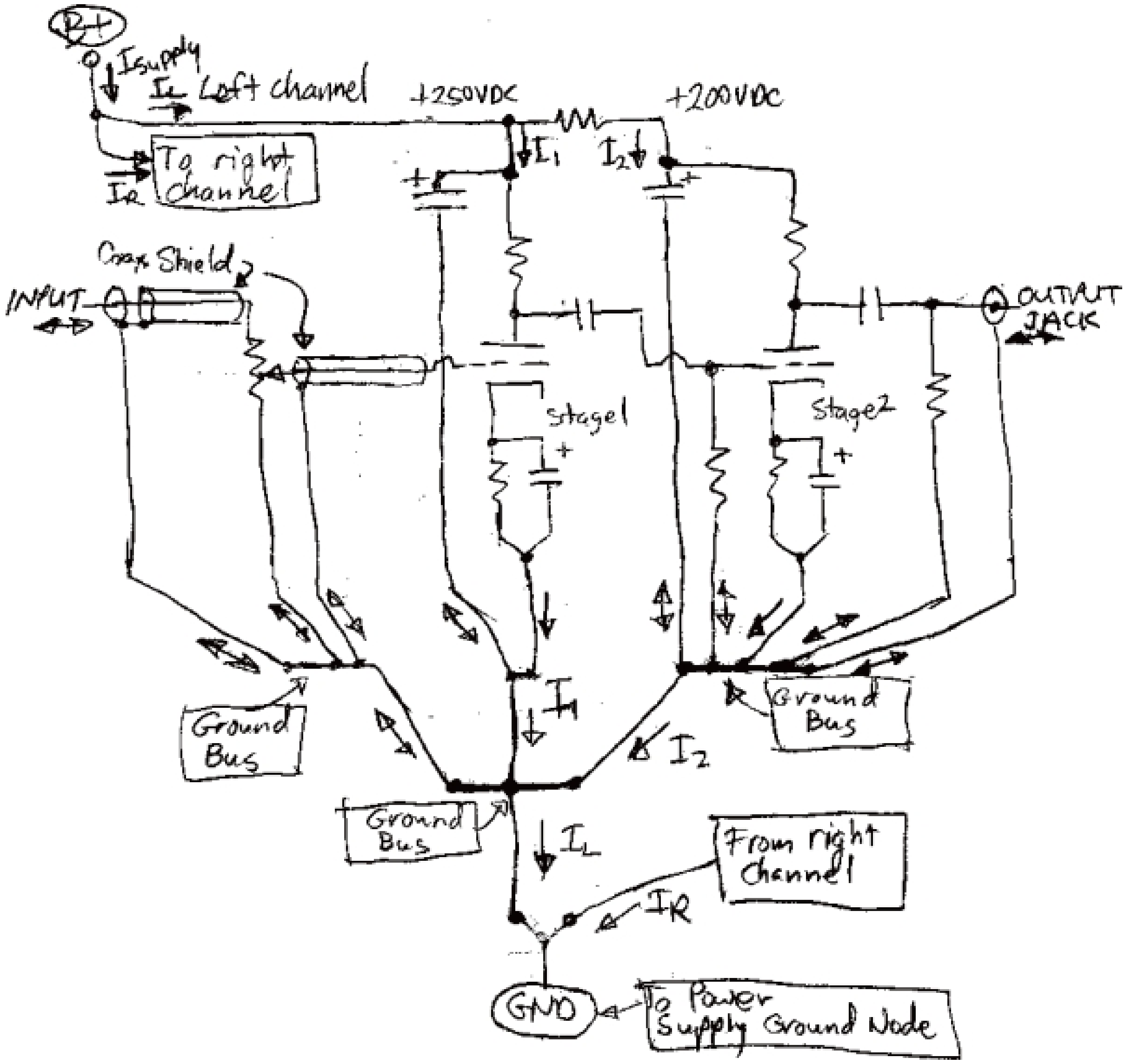

Figure 3: Advanced GND Guruship in action. Yes, I found this on the Internet.

You heard me correctly. Most audio equipment has no safety earth connection simply because we can't seem to imagine signal connections without a common reference.

And often that doesn't even work. Suppose I have a TV, a DVD player and an amplifier. When I want to watch TV I want to hear the sound over my stereo. When I watch a DVD I'd rather run the audio straight from the player to the amp, not through the TV's rotten signal processor. So we connect the video output of a DVD player to the TV and the audio to the preamp and we also connect the TV's audio to the preamp. The dreaded "Ground Loop" scenario.

Other than the most minimalist audiophile stereos there is no way of putting a system together without creating current loops. Current loops are a fact of life. Any scheme to avoid buzz and hum had better not rely on avoiding "ground loops."

The final nail in the star's coffin is that it *only works* at DC. A wire has inductance and two wires have mutual inductance on top of that. Accidentally lay a "dirty" return wire next to a "clean" reference wire and bam, noise. How do we add power supply decoupling? Do we run long wires from the decoupling capacitor to the star and add *exactly as much inductance as we were hoping to get* *rid of* (**figure 4**)?

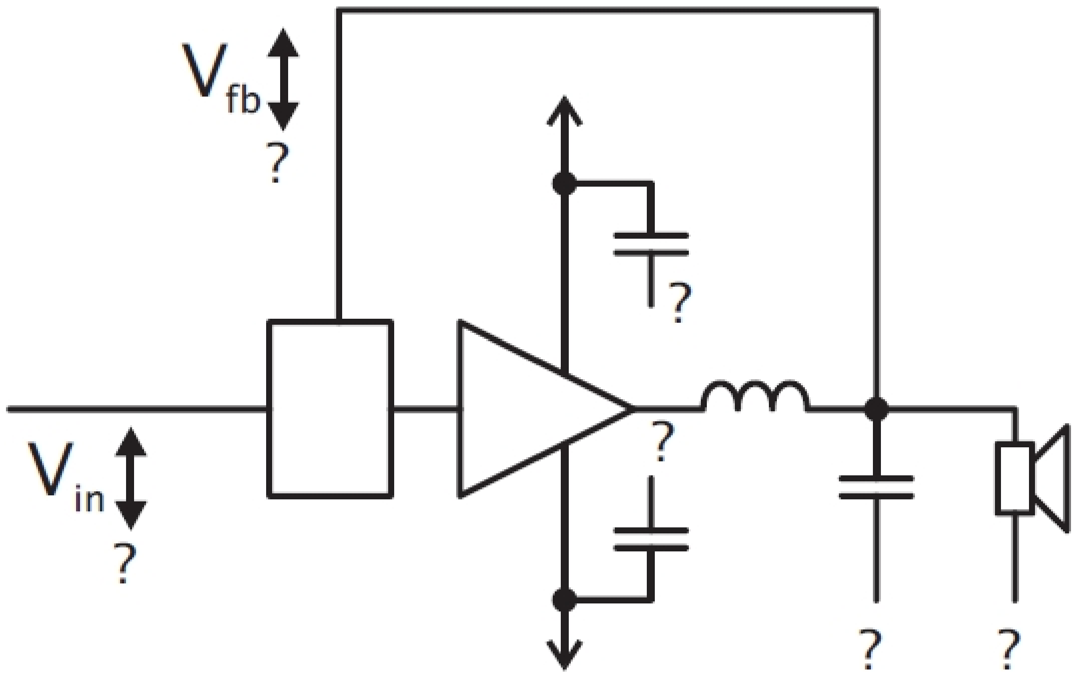

Figure 4: How long can PCB traces be for a decoupling cap before it becomes useless?

With a star you can just about build a mildly comatose class A amplifier. Anything faster and you'll run into stability problems. Try switching circuits and all assumptions go out the window.

In short: any exposé that takes as its premise that hum, noise and distortion have something to do with "grounding" should be stamped on and ground into the ground. We need to design circuits that read voltages like voltmeters: with two wires. The result should not depend on the contents of the local electron tip.[1]

> **Take-home message**
> When a change in "grounding" causes hum, this is because we're naïvely thinking of a signal as one wire. Stars are a band-aid to try to make this flawed assumption work.

[1] Note to non-UK readers, a "tip" is a rubbish dump.

Making a difference

Making a difference
Of course, such a way of working already exists. XLR connectors have an extra pin compared to an RCA connector. Pin 1 connects the chassis while pins 2 and 3 are the high and low terminals between which the signal is measured.

Sadly enough, this too is riddled with confusing semantics, some of which have turned out to be deadly. Balanced, differential, symmetrical, what shall it be? Before I pitch my tent at any one of those three, let me quickly revisit what school books and audio magazines usually make of it.

The source, they say, produces two signals which are each other's mirror image (**figure 5**). Any source of interference will affect both wires equally and the error is eliminated when the receiver subtracts the two signals.

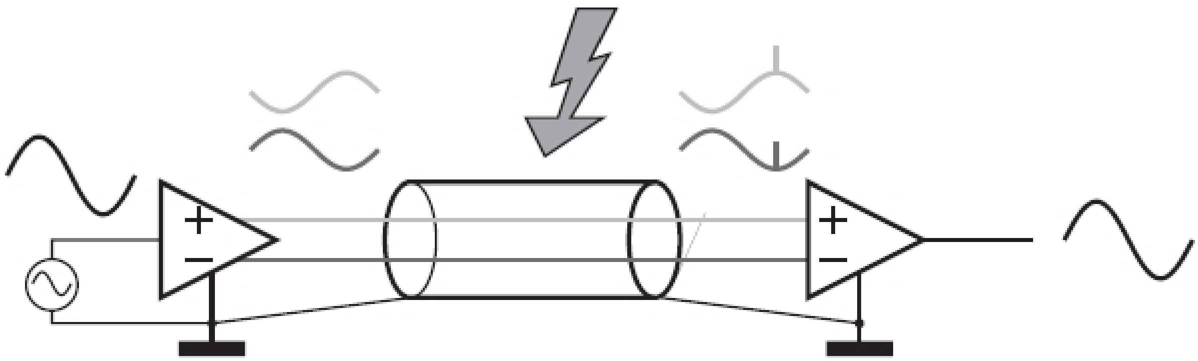

Figure 5: The prototypical explanation of balanced connections.

Note how the authors of this type of explanation have difficulty shedding GND-think. If those two signals are neatly symmetrical, about what potential exactly are they symmetrical? The source's return node? The chassis? Any of those on the receiving side? And does it even matter? The input should only care about the difference between the two. The whole reason why the input measures the voltage between the two wires is precisely because *it's trying to ignore those irrelevant potentials*.

You can cut the amount of circuitry on the transmitting end by half simply by arbitrarily choosing some potential that it has handy anyway and connect one wire there. All it has to do is offset the potential on the second wire to make the difference between the two the wanted output voltage, see figure 6.

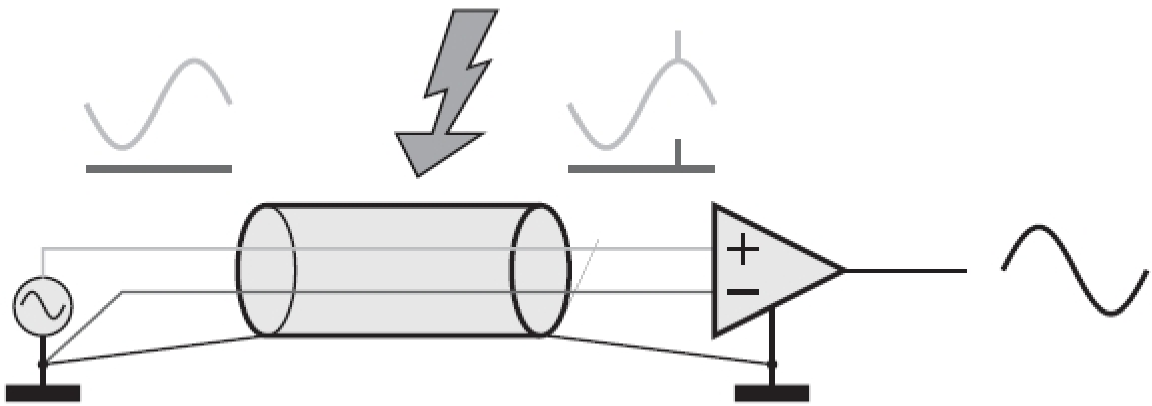

Figure 6: Symmetry is useless.

This is just as good as the previous one. There's no pressing need to drive both wires actively. One will do. On the receiving end it's only the potential difference that matters. If one wire is connected to whatever node the source calls "my zero volts" the receiver duly subtracts the potentials of the two wires, regardless of where its own personal zero volts might be with respect to the source's.

I'm 1.8 m tall when I measure myself standing on the office floor. But this is equally true when I'm standing on a landfill. If you want to know my height, simply subtract the altitude of the refuse horizon from the altitude of my bald patch. There's no need for me to be dug in halfway.

This is seriously good news. To change an output from single-ended to differential all you need to add is an extra wire to carry the reference potential to the receiver. The burden then falls on the receiver to make the subtraction.

Take-home messages
Differential transmission of audio doesn't mean you need to make a symmetrical voltage.
An input that expects a symmetrical signal is not differential because it's trying to involve a third node into the equation whereas voltages are only measured between two nodes.

A word of terminology. The signal that we want to transmit is that measured between the two wires. This is also called the differential-mode signal.

The error signal we want to ignore is the one that gets superimposed on both wires (as measured with respect to the receiver's chassis potential). This error signal may be due to interference en route, but in practice it's mainly the difference between the chassis potentials of the transmitter and the receiver. That error signal is called the common-mode signal.

Coming up in Part 2: The ideal differential input.