Appendix C
Differential, single Ended and pseudo differential Audio signals

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Differential and pseudo differential Signals

There is some confusion around about the terms balanced/unbalanced and differential/single ended, so it's worth to have a look on this terms.

Outside the audio world, the terms balanced/unbalanced and single ended are used rarely (only HF use it, as far as the writer know). More common is the term "differential" for all signals not reffered to GND.

Differential signals

Differential signals consist of two driven signal lines with the same signal, of wich one is inverted in phase. They can be related to a common point, e.g. GND or PE wich is the third wire.
That's a fine thing for signal transportation, they are very common and widely used, e.g. Ethernet or USB connections are always differential and also in the professional audio world they exist as signal connections for AES/EBU, the professional counterpart of S/PDIF. See [1] for further informations.

Also, in the audio world, analog connections made by "XLR" cables are (normally) differenrtial (see balanced signals).
Beside, there exist signals in the audio world called differential, wich can be found on Audio ADCs and DACs wich behaves like described earlier.

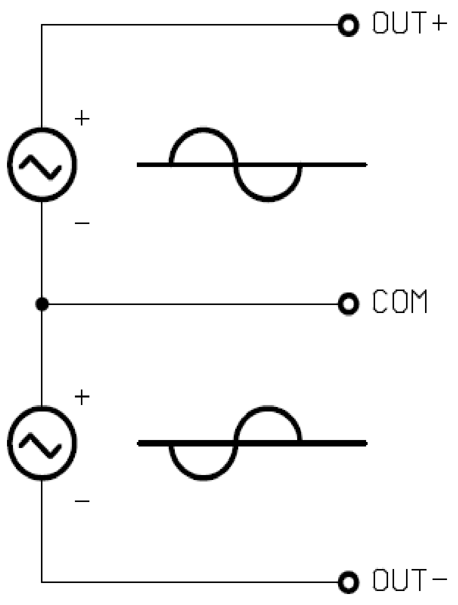

fig. 1: differential signal

Single ended signals

Single ended connections have only one signal line and refer it to GND (or other fixed levels). This is the most common signal handling type.

Almost all digital stuff, beside the differential connections mentioned earlier, and most analog circuits are build single ended and refer to a fixed level, mostly called GND.

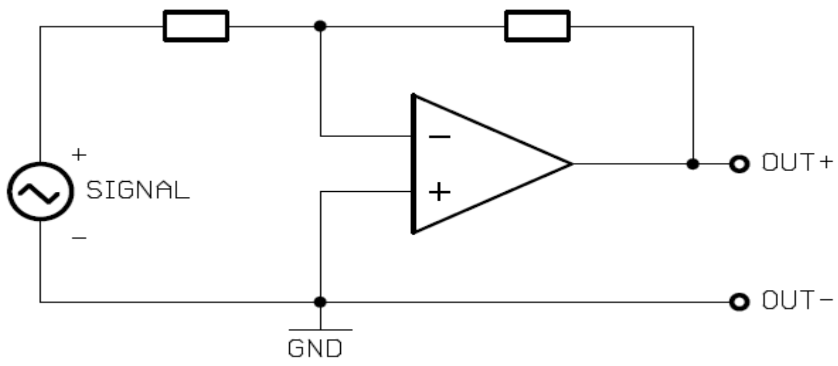

fig. 2: single ended signal

Balanced signals

In the audio world, differential connections (see above) are called "balanced" connections, like analog XLR connectors, but it seems, that it is only valid for cable connections.

In most cases, a third signal or wire exist. In principle, the 3rd wire can be completely ignored and be left away, but in real world you must set a point in the receiver not to go out of it's Common Mode Range. In the past, as operational amplifiers were not widely used, transformers do the receiver/substractor job, but nowadays transformer coupling seems to be dead because of big size, noise pick-up and not least because of cost. Opamps will do the job, but they have the drawback of not accepting very large voltages at their input pins. So, the 3rd wire is necessary to set a usefull midpoint, mostly PE or GND.

Unbalanced signals

In the audio world, single ended connections (see above) are called "unbalanced" connections, like analog Cinch connectors, but it seems, that it is also only valid for cable connections.

Single ended and differential signal stages

Single ended signal stages have one input, one output and one common point. The signal present between the input and the common point is amplified, filtered or whatever you need and then put out to the output wich is refered to the common point.

As you can see, there are many terms for almost the same things, but they should not be intermixed if you want to avoid confusion about it.

Using **balanced** signal connections are a fine thing, but often **differential** stages are not practical in circuit design.
You would need twice the opamps you need for a single ended design and also all parts in filterstages double if done differential.Taking boardspace and cost into account, the signal stages would be designed in the single ended way.

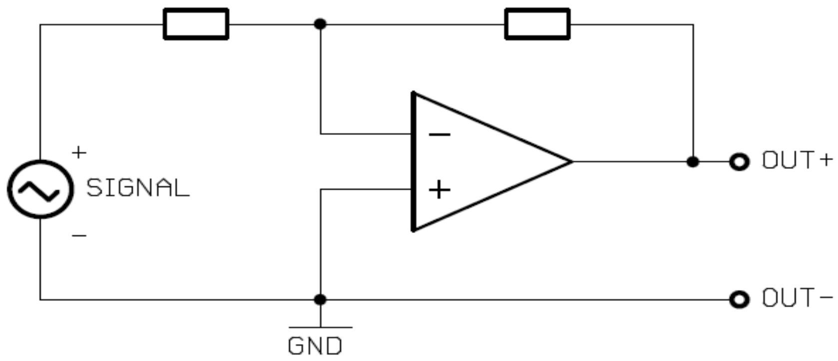

fig. 3: single ended signal stage

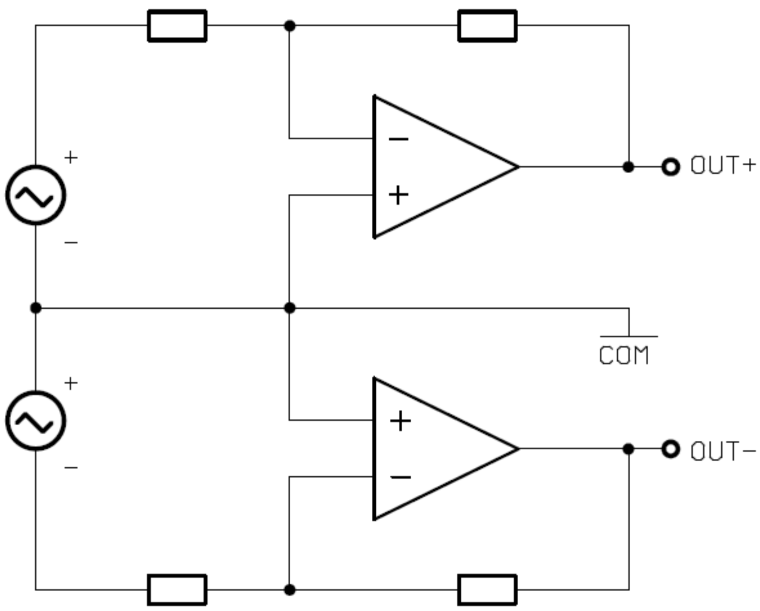

fig. 4: differential signal stage

Pseudo differential signal stages and connections

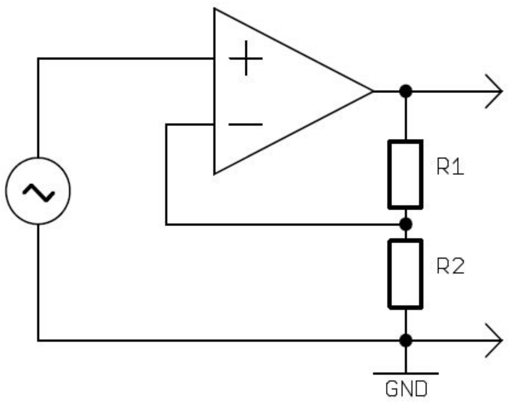

fig.5a standard (single ended) GND

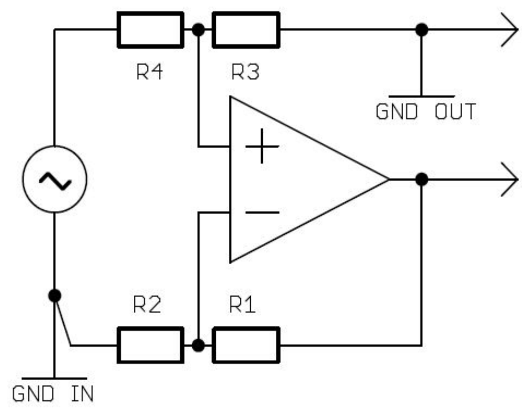

fig.5b pseudo differential GND converter

While designing, in simulation or in real life, tracks and connections are made by a simple piece of wire, called GND.

But this simple piece of wire was not invented yet. Using thick traces and copper bars is only the attempt to cover the nonperfectness of the desired connection, with the result of never reaching it.

To find a soultion, let's go back to the roots:

A voltage is defined as the difference between to points and a signal is not more or less than a voltage between two points. So, all is dependent on the points you select. Normally, you select something like GND as one point where you rely on and all voltages are the difference to this point (fig. 5a). Coming to hardware, you should make a very big single point of a material with near zero resistance and then connect all GND connections directly to it. That sounds a bit impractical and it is impractical and also impossible. So, we must consider something else.

A practical way to handle this, is to "measure" the signal at the source points and then work with the difference (fig. 5b) . For the next stage, the previous one is the source. Now you handle real differences between two points and in theory, you can completely left GND away, because it isn't necessary for the signal. Whatever noise or distrotions are in the GND line, you can ignore them, because they are not related to the signal anymore.

This is a fine thing and can surprisingly done with only two additional resistors. Converting a single ended (GND-referenced) opamp stage into a pseudo-differential one only means to add two resistors to make a differential amplifier.

In fig..5a , you must rely on undistorted GND connections, in fig.5b, you can select whatever point you want for GND_IN and GND_OUT, as long as they are somewhere in the common mode range of of he opamp. Now your also able to connect the negative input at R2 directly to the negative input of the source.

The ratio distortions are supressed by the amplifier (fig. 3b) is called CMRR (Common Mode Rejection Ratio). This CMRR is dependent on the error the resistances have in value to each other, so using 1% resistors will result in 40dB worst case and using widely available 0.1% ones will end up in 60dB.

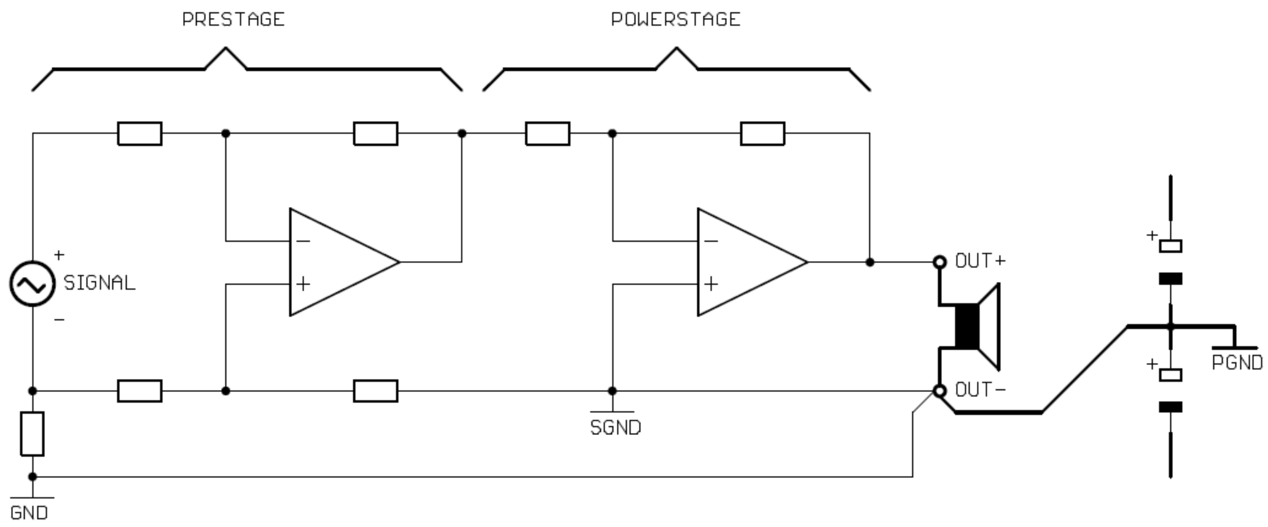

fig. 6: simplified amplifier using pseudo differential connections

In fig. 6 , you can see an example amplifier using pseudo-differential technic and takes the advantages of this topology.

If you design the SGND track as a single track, beginning at the source and ending at the negative speaker terminal (and only there !), things are almost perfect. This arrangement can be called "Pseudo differential", because of working with a differential voltage but only "one" line (our special SGND) wich is not inverted in phase.

Very important by design is now, that the negative input of our difference amplifier is directly connected to the point, the previous stage has it's negative output or better it's local GND. Don't connect anything else to SGND than signal related circuits. Even the Opamp's decoupling should be done on the PGND or the GND line.

So, I think an example would help a bit how much this helps:

e.g. Your GND track has a resistance of 10mR and non signal related currents of 1mA are flowing (not unusal even in small signal stages) resulting in 10mR*1mA=10µV of distortions in your signal. If the signal is 1Vrms, you get a SNR (Signal to noise ratio) of 1V/10µV = 100dB. Not that good, especially this is not the power stage but the small signal stage !

Using pseudo differential technic and 1% resistors, the ratio would be 80dB+40dB = 120dB or with 0.1% resistores unbelievable 140dB !

So bringing this to the output stage with 1mR resistance, 4A charge pulses for the main electrolytics and 20V signal, you would end up in 4mV distortion in your GND connection, resulting in 74dB related to the signal. A bad result. Using a pseudo differential signal will give you another 40dB (1% resistors) ending up in 114 dB. This sounds better and it is not far away from what is possible.

So, in amplifier design, your input stage should (if necessary) receive differential signals with respect to PE (protection earth) wich are then translated into a pseudo-differential signal, related to the Speakers GND connection.

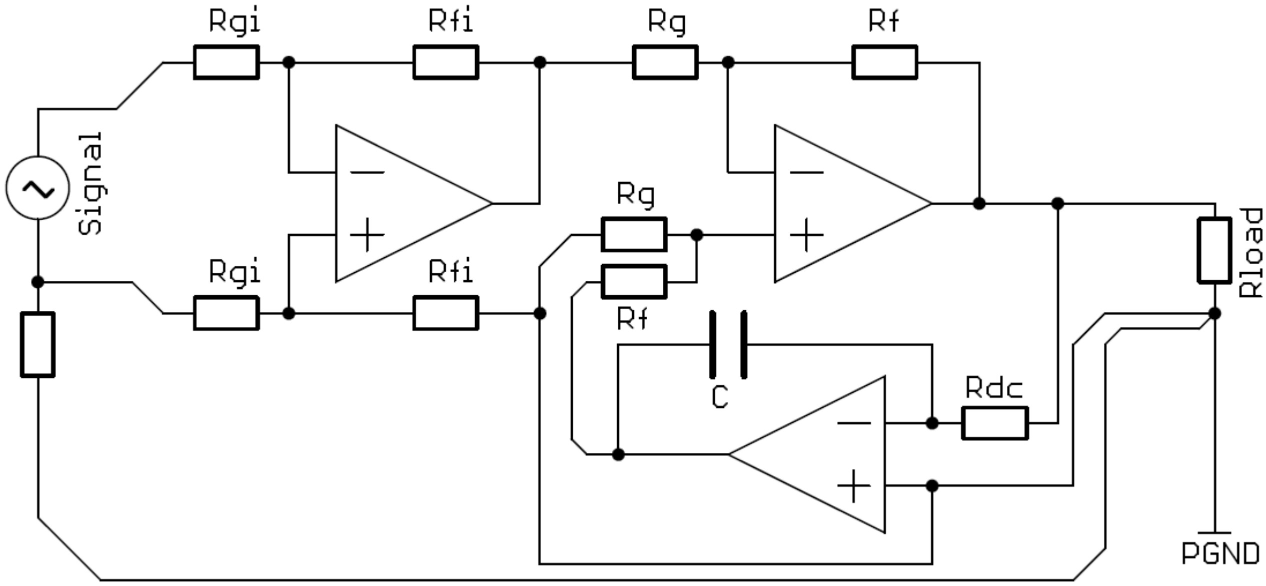

fig.7 simplified grounding sheme with DC-Servo

In fig. 7 you can find a simplified circuit with a DC-Servo included. The DC-Servo consist of Rdc and C and it's output is directly fed into the "SGND" connection of the differential output node.

Additional, the power stage's input is done in the differential way, mostly because of to be able to put in the DC-Servo's output.

So, where all the values given come from ?

A 10mR track resistance results of a copper track on a 35µm PCB layer wich is 1mm wide and 20mm in length. That sounds as a very practical design, isn't it ?

The 1mR would be reached by a 5mm wide track wich is 10mm long on the same 35µm PCB.

Now it's clear where all the GND-bars of solid copper comes from....

Where all the "distortions" come from ?

If you connect your "GND" connection to the signal GND and the GND where your connect the blocking capacitos (100nf each) and your opamps stabilizing electrolytics and some resistors to GND from the opamps outputs (like the ones used for noninverting circuits), you get a mixture of signal dependent currents and non-signal dependent ones.... if you not carefully connect the big supply capacitors you get additional high frequency spikes... and as longer you think as worse your "GND" will be. So using a single "GND" plane in Audio design will give bad results.

The word GND is an abbreviation for

Generator for

Noise and

Distortion

[1] https://en.wikipedia.org/wiki/Differential_signaling