Application Report
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Ground Loop Break Circuits and Their Operation

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ABSTRACT

Ground loops can be introduced when different components in audio systems are connected with standard audio cables, and these loops can cause annoying interference. In many cases, the interference can be reduced significantly with a "ground loop break" (GLB) circuit including a low-value resistor and differential amplifiers. This paper explains this approach and how to design a GLB circuit.

Contents

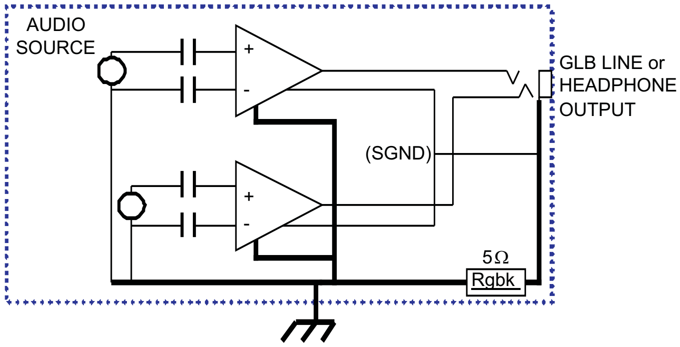
1 Introduction

Connecting a standard audio cable between 2 grounded components in an audio system can result in audible and annoying interference. When this happens, it is because the cable shield has introduced what is usually called a "ground loop", an extra ground connection between 2 components with different internal ground potentials. The difference between these potentials occurs along the audio cable shield (ground connection). It is indistinguishable from the normal signal, so it creates interference.

Fortunately, the interference may be reduced significantly by inserting a low resistance between the ground of one of the 2 components and the ground of its audio jack and using differential amplifiers to bridge the ground potential difference. This is called a "ground loop break" (GLB) circuit. This paper describes GLB circuits and explains how these circuits work, what the possible reduction might be, and how to avoid a potential crosstalk problem. Appendix C describes how the interference occurs.

2 GLB Output Circuit

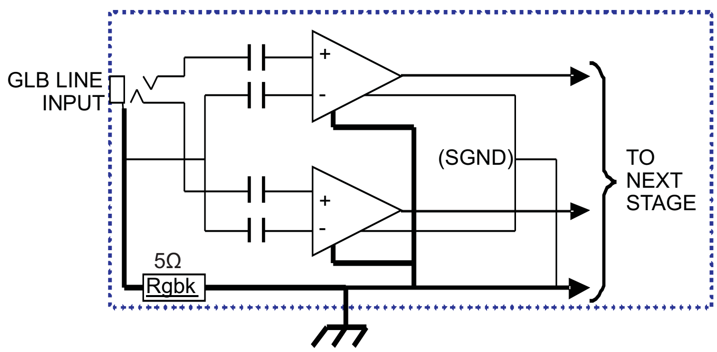
The following schematic illustrates a GLB output for driving line inputs or headphones. The circuit uses a low value GLB resistor, Rgbk, typically 5 to 20 ohms, plus two differential amplifiers. (**SGND**) is the ground reference of the differential amplifier inputs. Power supply, charge pump and logic pins and circuits are omitted for simplicity (for a specific device, refer to the data sheet and EVM users guide). Gain of the differential amplifiers is set as required for the application.



This circuit may be implemented very easily with Texas Instruments' TPA6132A2 or several other devices in the TPA613x family. An implementation with TPA6132A2 is shown in Appendix A. These devices are good choices for GLB circuits because they provide compact, integrated solutions with high CMRR. Members of the DRV60x family and TPA4411 are also good candidates for use in GLB output circuits. (For additional implementations of GLB circuits, see Appendix B.)

3 GLB Input Circuit

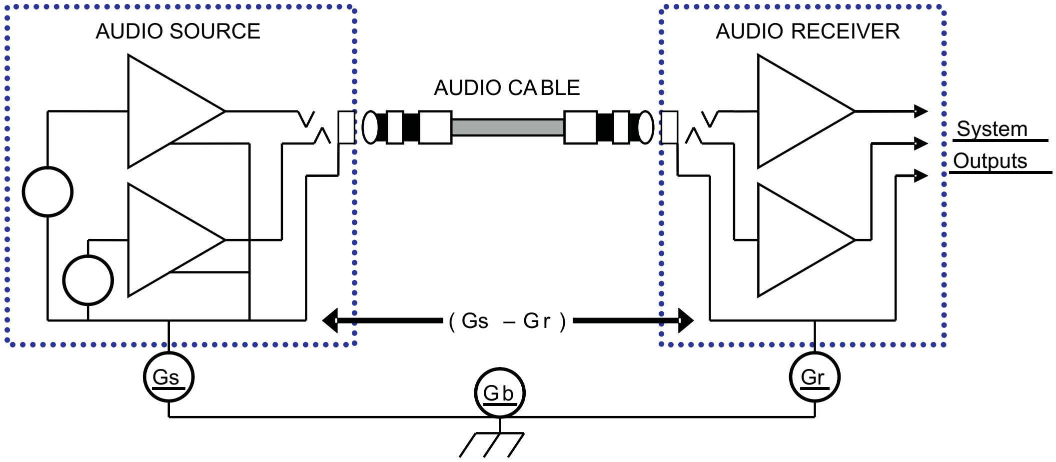
The following schematic illustrates a GLB line input. As before, the circuit uses a low value GLB resistor, Rgbk, typically 5 to 20 ohms, plus two differential amplifiers. (SGND) is the ground reference of the differential amplifier inputs. Again, power supply, charge pump and logic pins and circuits are omitted for simplicity; and, gain of the differential amplifiers is set as required for the application.



Members of the TPA613x and DRV60x families and TPA4411 are good candidates for use in GLB input circuits. (Again, for additional implementations of GLB circuits, see Appendix A.)

4 How GLB Circuits Work

The following schematic illustrates an audio system with a ground loop between 2 components. The schematic includes an audio source (for example, MP3 or CD player, computer, or navigation device), an audio receiver (for example, stereo system, TV, or vehicle audio panel or head unit), and an audio cable connected between them to form the ground loop. The ground reference for the system is taken to be the ground of the power source, Gb. The audio source and receiver components are at different ground potentials Gs and Gr with respect to Gb.

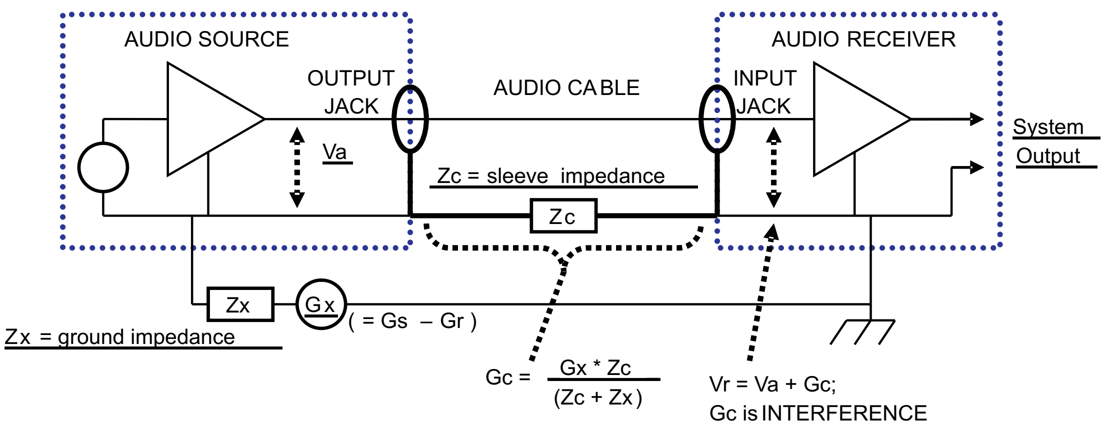


The schematic is simplified below to make analysis easier. The simplified circuit is monaural, and the ground reference is shifted to the audio receiver, since this is the device that produces the audible interference caused by the ground loop. Zc is the total of audio cable sleeve impedance and jack contact impedance, and Zx is the total impedance in the ground connections between the source and the receiver. Gc and Gx are ground potentials between the source and receiver and at the source end of the audio cable and jacks. Gx = Gs – Gr in the preceding schematic.

Va is the intended output from the audio source to the receiver, relative to its local ground, but the input signal relative to receiver local ground is (Va + Gc), where

$$Gc = \frac{Gx \times Zc}{(Zc + Zx)} \quad (1)$$

is the noise at source local ground relative to receiver local ground.



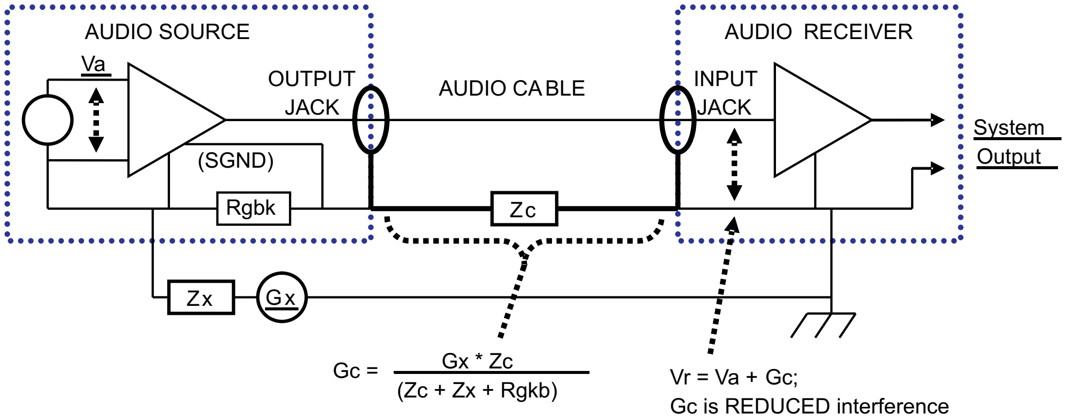
Gc, part of the ground potential Gx, appears across the audio jack sleeve contacts and the audio cable shield, adding interference to the input to the receiver. Reducing this requires 2 steps.

- Insert a resistance greater than the shield impedance of the audio cable between local ground and audio cable ground in either the source or the receiver. This will reduce the noise potential across the audio cable ground, because most of the noise will appear across the resistor.
- Add differential amplifiers to reproduce the desired signal directly at the output jack to the audio cable or directly from the input jack at the audio cable, bridging the ground potential difference.

The resistance inserted in series with the audio cable shield is called a "ground loop breaking" resistor, Rgbk. (More properly it’s a "ground noise reduction" resistor, but "ground loop breaking" is a more popular and familiar description.) The resistor can be inserted at either the source or the receiver, so it is necessary to consider both cases.

5 Ground Loop Noise Reduction at an Output

The revised schematic below includes Rgbk inserted between local source ground and the sleeve (ground contact) of the output jack to the audio cable, and it includes a differential amplifier to transmit the original source signal to the output jack.



The original interference is

$$\frac{Gx \times Zc}{(Zc + Zx)} \tag{2}$$

Interference with GLB is

$$\frac{Gx \times Zc}{(Zc + Zx + Rgbk)} \tag{3}$$

So the modified circuit reduces interference by the following ratio.

Interference reduction equals

$$\frac{(Zc + Zx)}{(Zc + Zx + Rgbk)} \tag{4}$$

The reduction can be quantified with typical figures for Zc and Zx and a choice of Rgbk.

- Zc, which includes the impedance of the cable sleeve and the contact impedances in the output and input jacks, can range from 100 mΩ to nearly 1 Ω. It is typically 200 to 300 mΩ. Cable sleeve impedances appear fairly consistent around 100 mΩ. Contact impedances range from less than 100 mΩ per pair in higher quality jacks to nearly 1 Ω in low cost PCB mount jacks.
- Zx appears to be typically around 200 mΩ.
- Rgbk is typically chosen in the range 5 to 20 Ω.
- Then, for Zc = 200 mΩ, Zx = 200 mΩ and Rgbk = 5 Ω, the reduction is the following.
  - Interference reduction equals

$$\frac{(200\ m\Omega + 200\ m\Omega)}{(200\ m\Omega + 200\ m\Omega + 5\Omega)} \tag{5}$$

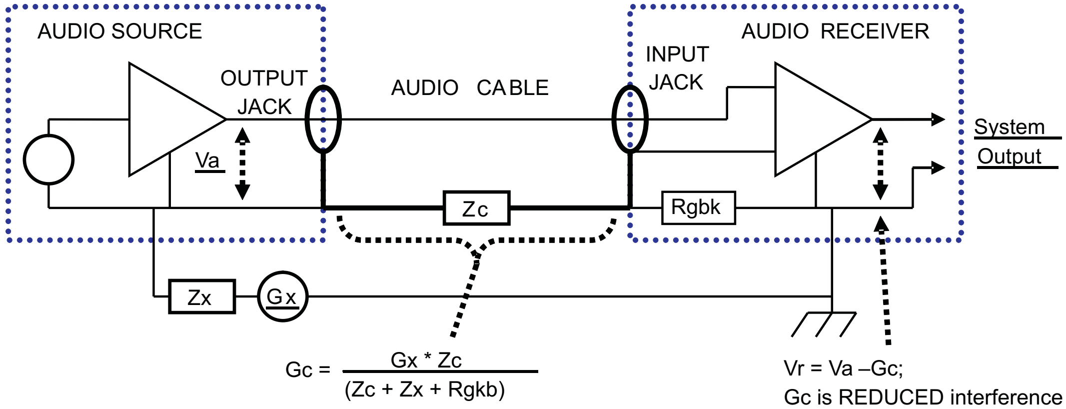
  - Or, interference reduction equals

$$\frac{0.4}{5.4} = 0.074 \text{ or -23dB} \tag{6}$$

- A reduction of 23 dB is very audible and provides a great improvement.

6 Ground Loop Noise Reduction at an Input

The revised schematic below includes Rgbk inserted between local receiver ground and the sleeve (ground contact) of the input jack to the audio cable, and it includes a differential amplifier to transmit the original source signal to the rest of the receiver circuits.



The original interference is

$$\frac{Gx \times Zc}{(Zc + Zx)} \quad (7)$$

Interference with GLB is

$$\frac{-Gx \times Zc}{(Zc + Zx + Rgbk)} \quad (8)$$

So the modified circuit reduces interference by the following ratio. (The sign of the interference is irrelevant, so it is omitted here.)

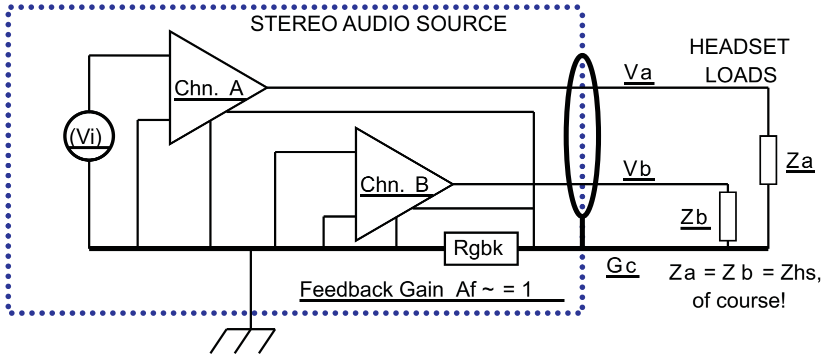
Interference reduction equals

$$\frac{(Zc + Zx)}{(Zc + Zx + Rgbk)} \quad (9)$$

The reduction is the same as the reduction with a GLB output, and it can be quantified the same way.

7 Potential Crosstalk Issue in GLB Headphone Amplifier

A potential issue in a GLB headphone amplifier is elevated crosstalk. The crosstalk is created by the signal developed across Rgbk by currents flowing through low-impedance headphone loads. The schematic below expands our previous circuit to a full stereo system for considering this effect. In the schematic channel A has an input and channel B does not.



Feedback gain Af from Rgbk back through the amplifiers to their outputs is intended to be exactly 1, to offset voltage across Rgbk. But Af has some error. If this error is small, there will be no problem, but if it is large, Rgbk will create crosstalk.

Crosstalk can be analyzed using the schematic above and the following definitions.

- Δ is the fractional error in Af (Af == 1+Δ).
- Va is output voltage of Chn.A and Vb is output voltage of Chn.B.
- Zhs is headset impedance per channel.
- Signal across Rgbk is

$$Gc = \frac{Va \times Rgbk}{(2 \times Rgbk + Zhs)} = Va \times K \quad (10)$$

- Where

$$K == \frac{Rgbk}{(2 \times Rgbk + Zhs)} \quad (11)$$

- Then Vb = Va × K × Δ, and relative crosstalk Xtk = K × Δ.

Of course, it is necessary to understand Δ to quantify the result. This will vary with different amplifier configurations.

Many amplifiers use opamps and discrete 1% resistors to implement differential inputs. Generally amplifier common-mode rejection is very high, and amplifier operation is very linear, so gain error is governed by resistor tolerance. For these amplifiers, the gain error can be as high as 2 to 4%, although typically the gain error is likely to be less than 1%, or –40dB. The calculation that follows uses Δ = 1%, Rgbk = 5Ω and Zhs = 32Ω.

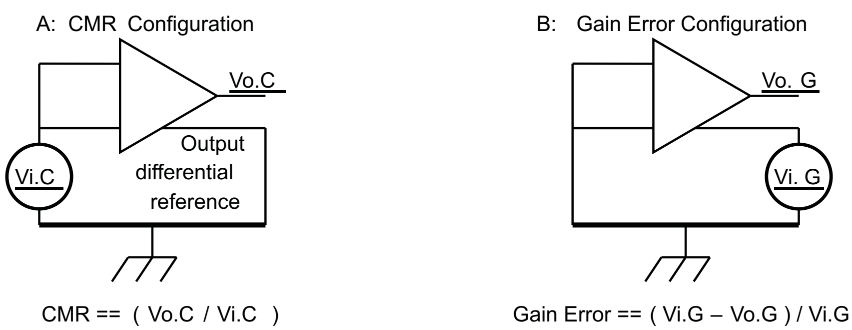
- Then

$$K = \frac{5}{(2 \times 5 + 32)} = 0.12 \quad (12)$$

  and crosstalk Xtk = 0.0012 or –58dB.
- If Rgbk is changed to 10Ω or Zhs is changed to 16Ω, crosstalk becomes Xtk = 0.0019, or –54dB.

These are low figures, but they would cause failure with specifications like the one for Microsoft Vista.

This is less likely to occur with fully integrated devices, in which resistor match is much better than 1%. These devices generally have very high common-mode rejection. Common-mode rejection is the ratio of the output relative to ground divided by common-mode input, (Vo.C / Vi.C), as defined in (A) below. Gain error, the difference between input and output divided by input, is defined in (B) below.



Except for a sign reversal, relative voltages from the input nodes to the output nodes are the same, so gain error equals CMR as defined in this figure. In other words, Δ = CMR. In fully integrated devices like members of the TPA613x family, CMR is typically –60dB (0.1%) and lower. The calculation above in which gain error was assumed to be 1% can be updated with this new figure.

- Then, with Δ = 0.1%, Rgbk = 5Ω and Zhs = 32Ω, crosstalk Xtk = 0.00012 or –78dB.
- If Rgbk is changed to 10Ω or Zhs is changed to 16Ω, crosstalk becomes Xtk = 0.00019, or –74dB.

These figures easily comply with specifications like the one for Microsoft Vista.

8 Potential Power Loss in GLB Headphone Amplifier

The ground break resistor Rgbk in series with headphone loads reduces maximum available load power. This is an advantage if it helps limit output power as required to meet various safety specifications. If it reduces power below the levels in those specifications, it can be a disadvantage.

This analysis will assume that maximum output voltage from the GLB amplifiers is fixed. This is often not the case, for a couple of reasons. Voltage saturation drops in output devices depend on load currents. Also, many of these amplifiers use dual power supplies with a negative supply generated from a positive system supply. Usually the negative supply is produced by a charge pump with relatively high output impedance. In these cases increasing load impedance can increase maximum output voltage from the amplifiers, but this is difficult to predict and factor into an analysis.

With fixed output voltage, loss in output power can be analyzed as follows, using Vo as the maximum output voltage from the GLB amplifiers and Vhs as the net voltage across headset loads. It is assumed that left and right output voltages are essentially identical. This is the worst case for output power loss.

- Output voltage with Rgbk is

$$\text{Vglb} = \text{Vo} \times \left(\frac{\text{Zhs}}{(\text{Zhs} + 2\times\text{Rgbk})} \right) \tag{13}$$

- Output power without Rgbk is

$$\text{Po} = \frac{\text{Vo}^{2}}{\text{Zhs}} \tag{14}$$

- Output power with Rgbk is

$$\text{Pglb} == \frac{\text{Vglb}^2}{\text{Zhs}} = \frac{\text{Vo}^2 \times \left(\frac{\text{Zhs}}{(\text{Zhs} + 2\times\text{Pgbk})} \right)^2}{\text{Zhs}} \tag{15}$$

- Power with Rgbk relative to power without Rgbk is

$$\left(\frac{\text{Pglb}}{\text{Po}} \right) = \left(\frac{\text{Zhs}}{(\text{Zhs} + 2\times\text{Rgbk})} \right)^2 \tag{16}$$

For Rgbk = 5Ω and Zhs = 32Ω, this is a factor of

$$\left(\frac{32}{(32 + 2 \times 5)} \right)^2 = 0.58 \tag{17}$$

For Rgbk = 5Ω and Zhs = 16Ω, the factor becomes 0.38.

By themselves, these factors do not provide clear meaning, but they can be translated to output power by assuming some initial output power per channel and computing power with Rgbk added.

- For Rgbk = 5Ω, Zhs = 32Ω and initial power = 50mW, power with Rgbk = 0.58 × 50 = 29mW.
- For Rgbk = 5Ω, Zhs = 16Ω and initial power = 100mW, power with Rgbk = 0.38 × 100 = 38mW.

Note that output power is more nearly the same with the different load impedances with Rgbk added. Power with Zhs = 16Ω is only about 1/3 higher than with 32Ω, rather than twice as high. So Rgbk enables GLB operation, and it also limits power output and provides more constant output power versus load impedance. In many cases these results can be advantages.

Devices like TPA6132A2 limit output power and make it relatively constant versus load impedance to permit complying with new safety regulations regarding potential for hearing damage. These devices use relatively low voltage power supplies and finite power supply output impedance to produce this result. Lower supply voltage provides power limiting, and finite impedance equalizes output versus load. TPA6132A2 limits output power to 22mW with 32Ω loads and 25mW with 16Ω loads at 1% THD+N by using positive and negative 1.8V supply rails with output impedance of about 8Ω. Adding a ground loop break resistor will reduce output power, but not as dramatically as in the example above.

It is easy to predict the result by recognizing that power supply output impedance Zps is in series with the headphone load, just like Rgbk, so it will have the same effect in reducing maximum output power. Relative output power without and with Rgbk can be calculated as the ratio of the result above,

$$\left(\frac{Zhs}{(Zhs + 2 \times Rgbk)}\right)^2 \tag{18}$$

with Rgbk replaced with (Zps+Rgbk), to that result with Rgbk replaced with Zps.

- Power with Zps and Rgbk relative to power with only Zps can be calculated to be

$$\left(\frac{Pglb'}{Po'}\right) = \frac{\left(\frac{Zhs}{(Zhs+2\times(Zps+Rgbk))}\right)^2}{\left(\frac{Zhs}{(Zhs+2\times Zps)}\right)^2} = \left(\frac{Zhs+2\times Zps}{Zhs+2\times(Zps+Rgbk)}\right)^2 \tag{19}$$

For Zps = 8Ω, Rgbk = 5Ω and Zhs = 32Ω, this is a factor of

$$\left(\frac{(32+2\times8)}{(32+2\times(8+5))}\right)^2 = 0.68 \tag{20}$$

Resulting output power with 32Ω headphones is about 15mW per channel.

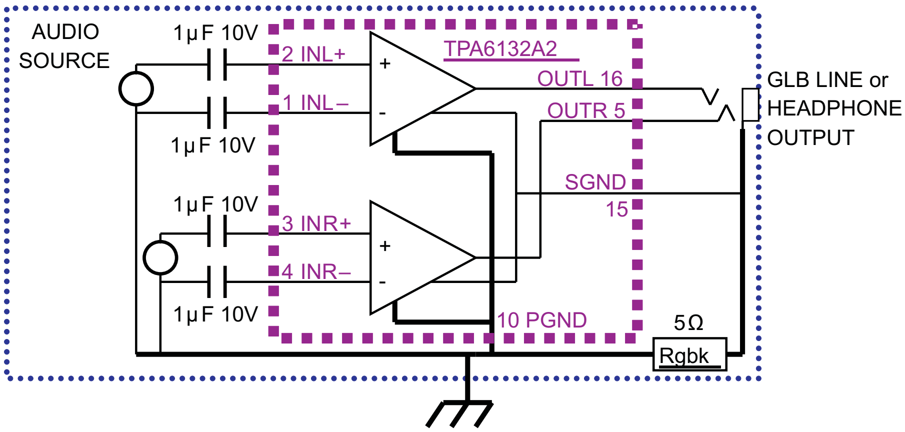
For Zps = 8Ω, Rgbk = 5Ω and Zhs = 16Ω, this is a factor of

$$\left(\frac{(16+2\times8)}{(16+2\times(8+5))}\right)^2 = 0.58 \tag{21}$$

Resulting output power with 16Ω headphones is again about 15mW per channel.

Appendix A GLB OUTPUT CIRCUIT IMPLEMENTED WITH TPA6132A2

The following schematic illustrates a GLB output for driving line inputs or headphones implemented with TPA6132A2. The circuit uses a low value GLB resistor, Rgbk, typically 5 to 20 ohms, plus the 2 differential headphone amplifiers in TPA6132A2. SGND is the ground reference of TPA6132A2 differential amplifier inputs. Power supply, charge pump and logic pins and circuits are omitted for simplicity (refer to the data sheet and EVM users guide for these). Gain of the differential amplifiers is set as required for each specific application.

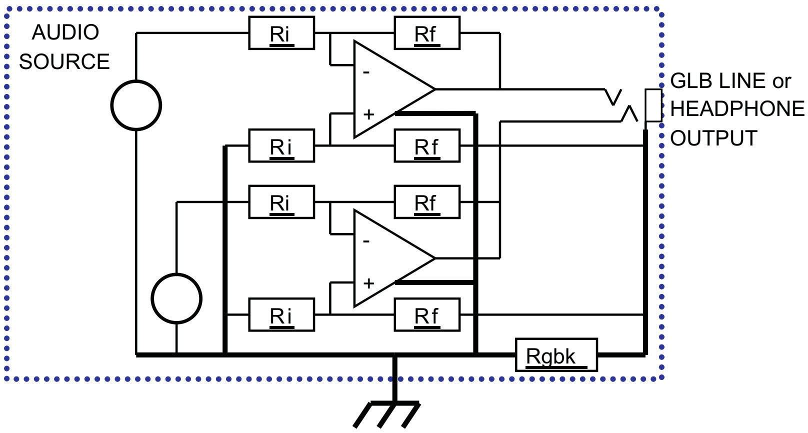


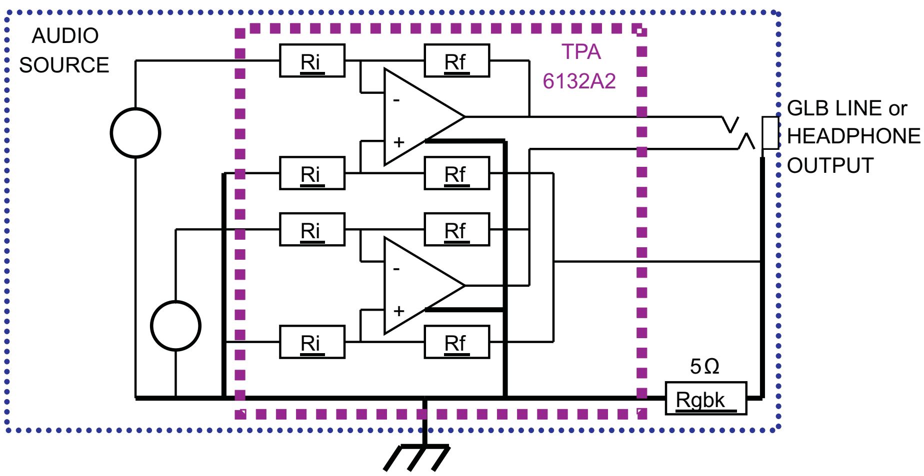
TPA6132A2 and other devices with SGND in the TPA613x family are well suited for this application because they provide a small, highly integrated solution with high-CMRR differential amplifiers. Since the differential amplifiers are completely integrated into the device, there are no resistors except Rgbk to add to TPA6132A2 to complete a GLB output, and the inherent high CMRR of the differential amplifiers prevents crosstalk problems.

Appendix B GLB CIRCUIT IMPLEMENTATIONS

B.1 GLB Output Circuit Implementations

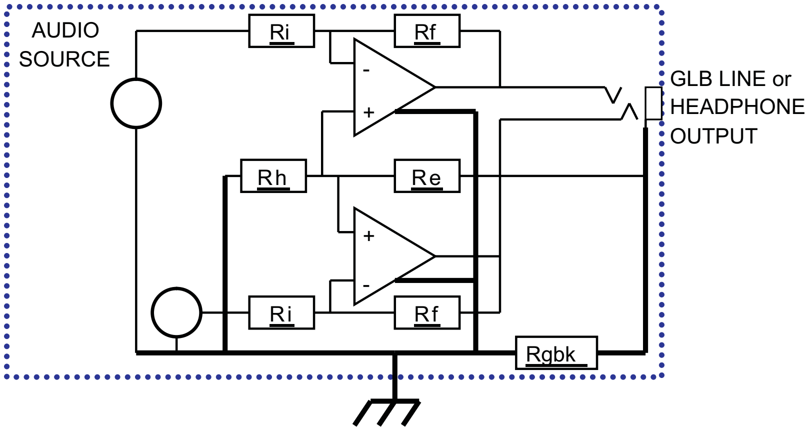
The following schematic illustrates a GLB output for driving line inputs or headphones. The circuit uses a low value GLB resistor, Rgbk, plus standard single-opamp differential amplifiers. Ri and Rf set circuit gain to (Rf/Ri), and Rgbk is typically 5 to 20Ω. The circuit as drawn inverts phase, but the inputs may be reversed at the audio sources if this is a problem.





TI devices like TPA6132A2, DRV602, DRV603, DRV604 make good candidates for use in GLB output circuits.

In many cases it is not necessary or possible to use separate resistor chains at the non-inverting inputs of the opamps, and they are combined into one chain. In this case the circuit must invert the input signal, because the opamp feedback chains must be distinct. Circuit gain is (Rf/Ri). The resistors in the combined chain, Rh and Re, must have the same ratio as Ri and Rf, but their values do not have to be the same. This is because common-mode voltage rejection of this form of differential amplifier depends on ratios and not absolute resistor values.

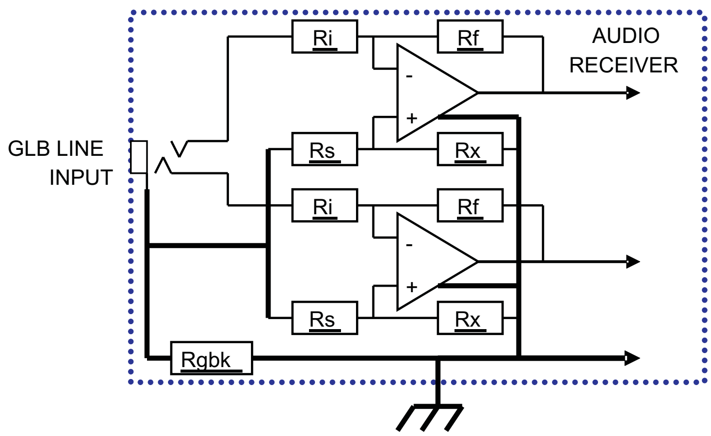


TI devices like TPA4411, DRV600, DRV601 make good candidates for use in these circuits.

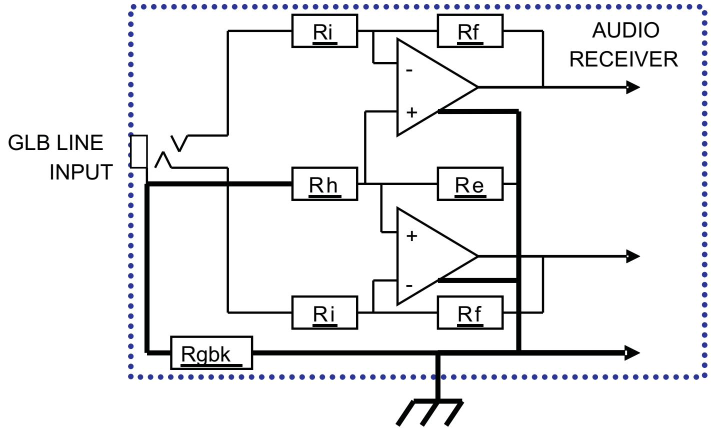
A side note: a GLB output may be implemented with an audio subsystem, codec or other device with an available mono input that can be summed to its outputs. It is simply necessary to connect this input to the junction of Rgbk and the HP jack sleeve and set its gain to the outputs to 1.

B.2 GLB Input Circuit Implementations

The following schematic illustrates a GLB line input. As before, the circuit uses a low value GLB resistor, Rgbk, plus standard single-opamp differential amplifiers. Ri and Rf set circuit gain to (Rf/Ri), and Rgbk is typically 5 to 20Ω. The circuit as drawn inverts phase, but the inputs may be reversed at the audio inputs if this is a problem.



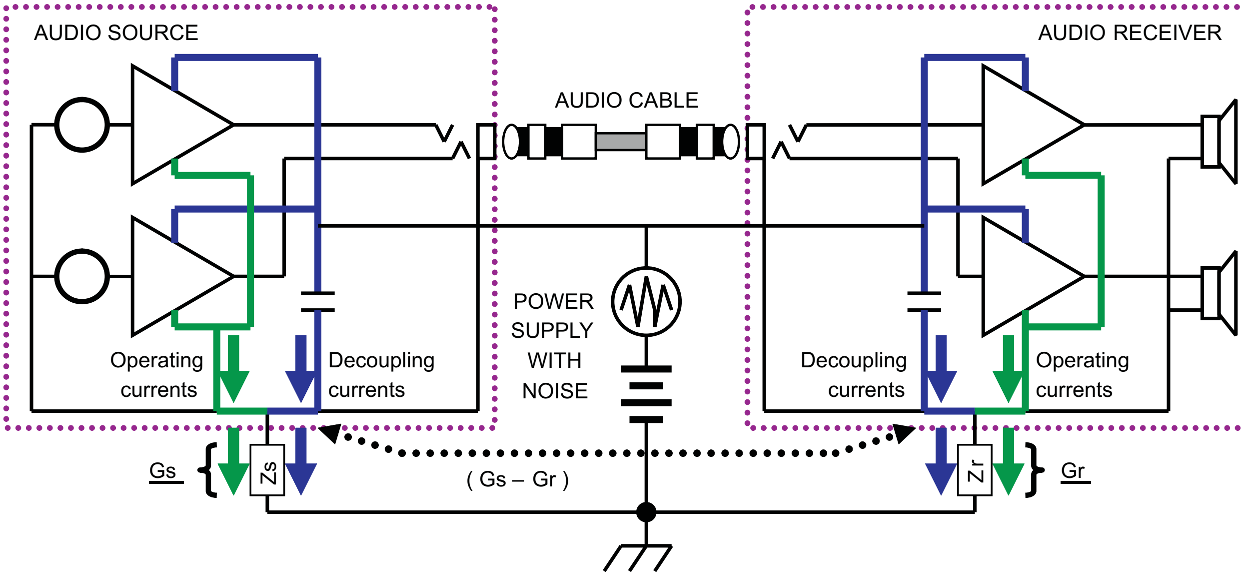
As before, in many cases it is not necessary or possible to use separate resistor chains at the non-inverting inputs of the opamps, and they are combined into one chain. In this case the circuit must invert the input signal, because the opamp feedback chains must be distinct. Circuit gain is (Rf/Ri). Again, the resistors in the combined chain, Rh and Re, must have the same ratio as Ri and Rf, but their values do not have to be the same.



Again, a GLB input may be implemented with an audio subsystem, codec or other device with an available mono input that can be summed to its outputs. It is simply necessary to connect this input to the junction of Rgbk and the input jack sleeve and set its gain to the outputs to –1 times channel gain.

Appendix C HOW GROUND LOOP INTERFERENCE OCCURS

Grounded audio components generally carry significant currents in their ground returns. These currents are produced by power supply ripple and component operation. They create potentials between the local grounds of the audio components and system ground that add interference in audio signal connections between components. This is illustrated in the drawing below.



The power source to the system components may be AC mains or a vehicle battery. In either case, there are 2 ways for a ground connection to produce potentials at the local grounds of components. Power source AC voltage or ripple drives currents through decoupling and other circuits of a component into its ground wire, and operating currents produced by the component are returned through the ground wire as well. All ground returns have finite impedance, so these currents create a potential along the ground wire. These currents and impedances differ from component to component, so ground potentials differ from component to component as well. We consider a ground loop to be a connection between 2 of these potentials.

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