Ultimate-Preamplifer

by

Analog-Precision

http://www.analog-precision.com/

NOT ALL BALANCED INPUTS ARE CREATED EQUALLY !

CONTENTS

Not all balanced inputs are created equally !

INTRODUCTION

Traditionally balanced inputs are something you usually only see on pro-audio equipment. However, in recent times more balanced inputs have started to appear on domestic audio equipment and for good reason. The main advantage of a well implemented balanced interconnect system is its immunity to unwanted common mode noise. If the amplifier and connecting equipment conform to the AES48 standard there should be immunity to ground loop noise as well which usually plagues the unbalanced interconnection system.

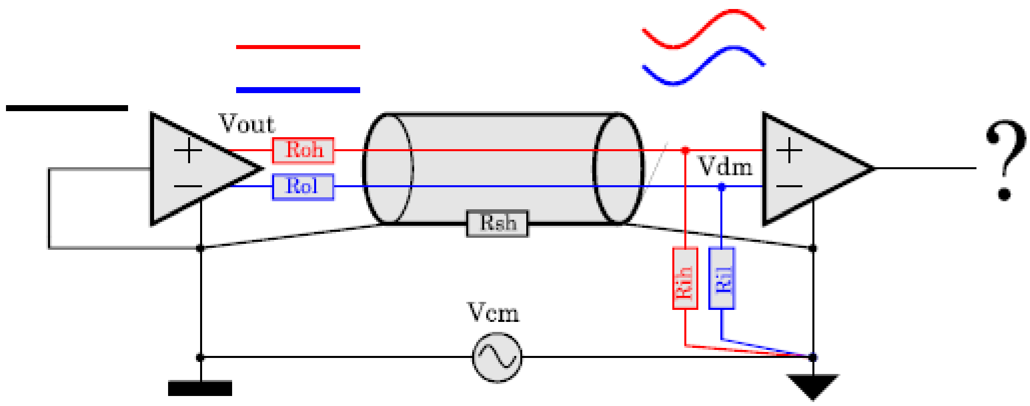
Recently I have had the unfortunate experience of dealing with a problematic customer who claims that he has had problems with noise ever since he purchased the Ultimate Preamp. It seems that both unbalanced and balanced connections cause noise in his system whereas he did not experience this with his previous DSP setup which somehow has to always be connected through a mains isolation transformer in order to remove the noise from his system ! The use of a mains isolating transformer to suppress unwanted noise in the system is itself is a red flag for potential ground noise issues. I believe his electricity supply seems to be some sort of off-grid solar PV system with battery backup driven by an inverter so no doubt there is plenty of noise flowing through the mains wiring which is getting into the amplifier via the mains wiring.

Since these problems can be tricky to fault find short of being at the premises the next best thing is to recreate the fault in the lab using identical equipment. After numerous attempts at requesting that the offending amplifier or similarly designed amp be sent to our labs, no amplifier has materialized. I have not received any communication from the manufacturer of the amplifier nor do I have a schematic or wiring diagram of how this amplifier is connected. The best I can do is to try and find a similar schematic on the internet. It appears that luck is on my side. Whilst it is probably not the exact same schematic of the amplifier under question hopefully it should be similar enough to throw some light on the issue. More about this later.

Whilst most amplifier manufacturers have adopted the AES48 standard for balanced interconnects it appears that this manufacture hasn’t and continues not to.

WHEN IS A BALANCED INPUT NOT A BALANCED INPUT ?

The theory of signal transmission using a balanced connection system has been covered in detail elsewhere so we will only cover it in brief. For those not familiar with the balanced system it is recommended that the material sited in the reference section at the end of this document be read in conjunction with this document.



Referring to the diagram above it can be said that perfect balanced is obtained when Vdm is zero irrespective of Vcm. To achieve this the following relationship must be satisfied:-

Roh/Rih = Rol/Ril

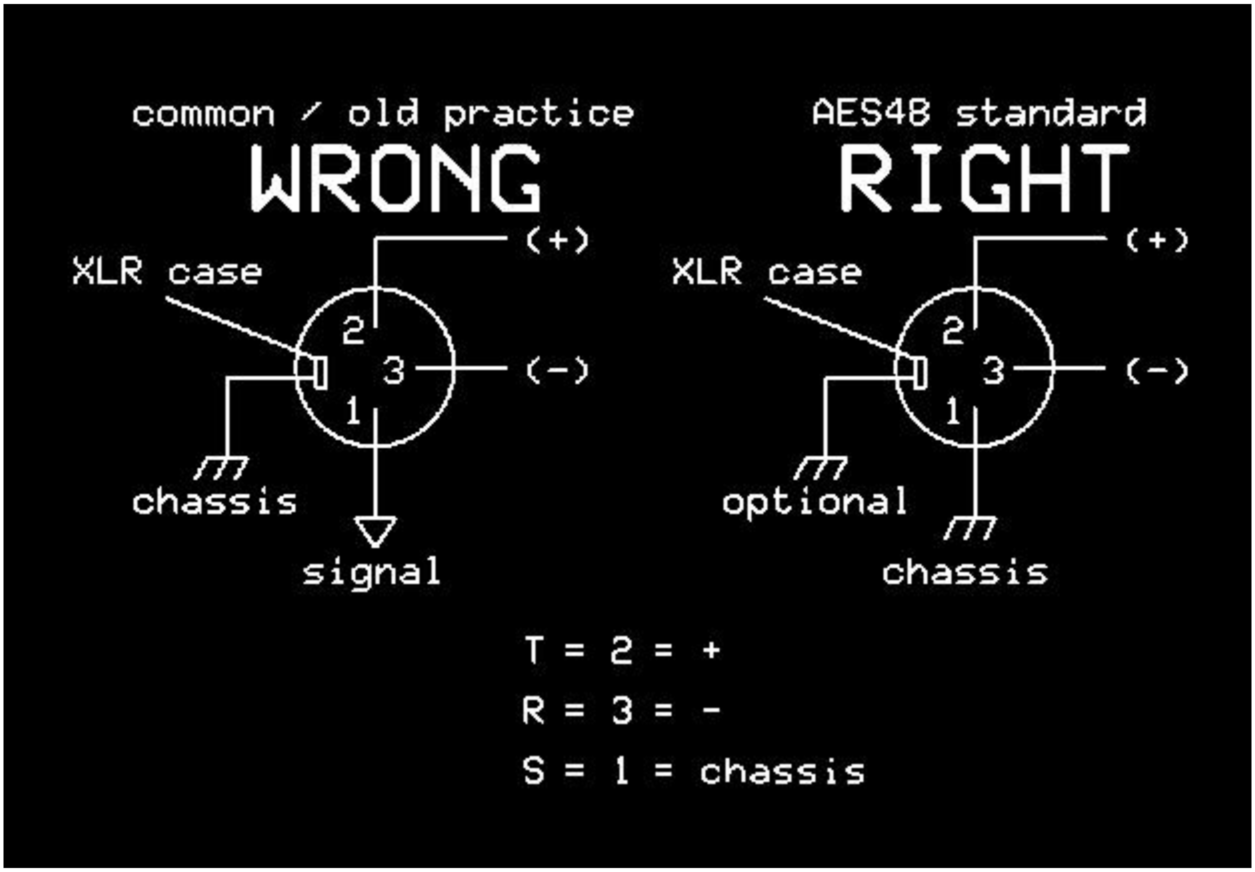
When this occurs, the bridge formed by the four resistors is said to be in perfect balance and the transmission of the differential signal is immune to any common mode disturbances.

AES48 AND WHY IT IS A SENSIBLE STANDARD

The Ultimate Preamplifier is wired up in accordance with the AES48 standards for balanced interconnects. This means that Pin 1 on all of the XLR balanced input and output connectors on the back of the Preamp are hard wired to the chassis and the safety ground. If any amplifier that is connected to the Ultimate Preamp has problems with hum, buzz or any other interference then most likely, pin 1 on that piece equipment has not been correctly dealt with. Basically Pin 1 should be used to connect one piece of equipment to the other using the braided shield of a twin shielded interconnect cable. It essentially can be viewed as an extension to the shielding provided by the equipment metal case itself. It does not matter if ground loop currents flow through the shield connection because the shield does not carry any signal information and the balanced inputs of the connecting equipment should be designed to provide immunity to any common mode interference on the shield and wiring.

Inside the equipment, pin 1 should be connected directly to the chassis and under no circumstances should it be connected or routed through to any sensitive electronics which could amplify this noise in any way ! It is a simple concept and yet many amplifier designers keep making the same mistake again and again and again with dire consequences. The following diagram illustrates the right and wrong way of dealing with pin 1 on the balanced connector.

http://pin1problem.com/



Not all balanced inputs are created equally !

WHY USE A MAINS ISOLATING TRANSFORMER ?

It's interesting to note that the power amplifier vendor in this case supplied or recommended that the customer use an isolation transformer to fix any noise issues he had with these power amps connected to other equipment.

One look at the specs (reproduced below) of a typical commercially made mains isolation transformer to see why this was a recommended solution or should I say 'kludge' and the smoking gun becomes very apparent ! It appears that the isolation transformer was the easiest solution to the problem of breaking an earth-loop without having to modify any equipment ! However as the references at the end of this document highlight, that breaking a ground loop at one point does not necessary solve this issue as other loops can be easily created by connecting other equipment into the system so the problem can rear its ugly head further down the chain. It's just better to do it right from the start !

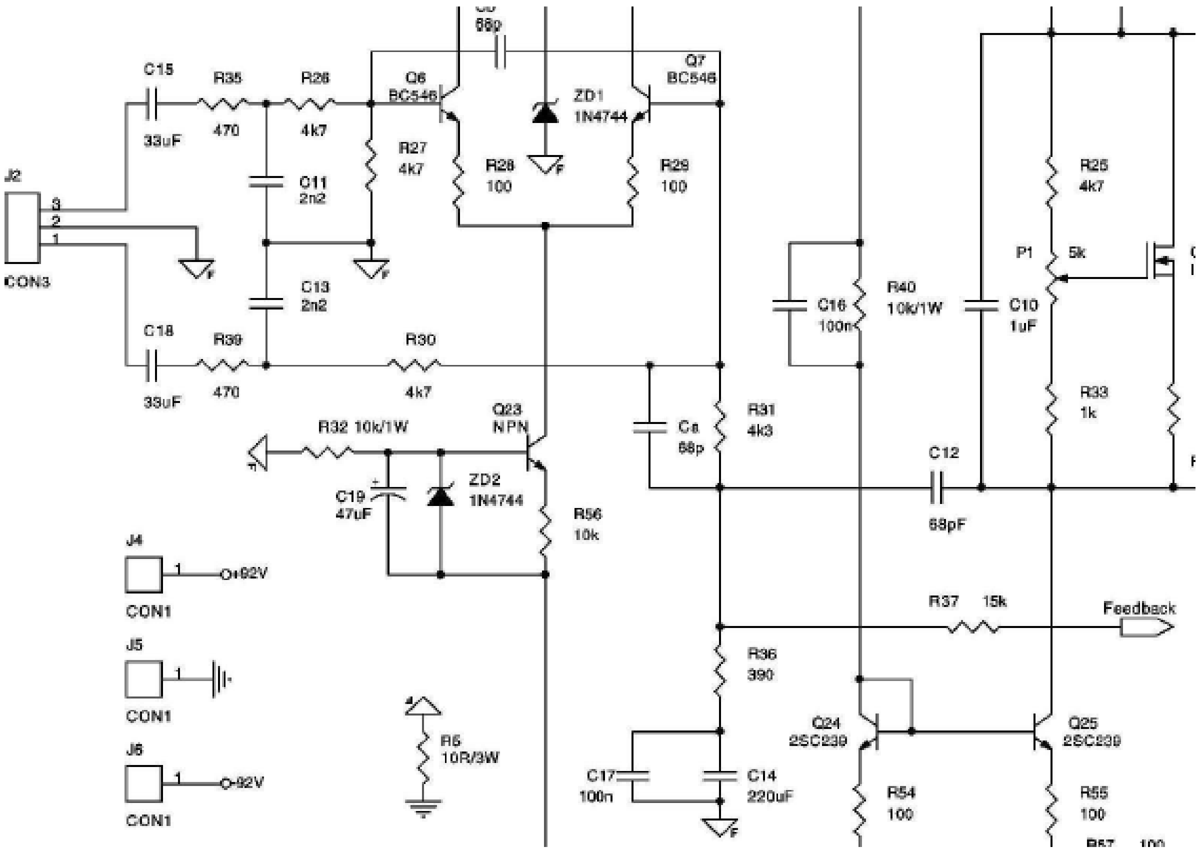
300VA MAINS ISOLATION TRANSFORMER WITH ELECTROSTATIC SCREEN

- Australian Made Quality Units
- All units are enclosed
- All units include a noise minimising electrostatic screen, suitable for audio noise reduction.
- Applications include Earth Loop removal in audio systems and the elimination of boating electrolysis.
- Input voltage 240V ±10% 50Hz. Australian flexand plug
- Output voltage 240V Unregulated. Australian female chassis socket

AN AMPLIFIER CASE STUDY

Since we don't physically have the amplifier to test the next best thing would be to simulate it using an advanced circuit simulator. For the sake of copyright, I will not reproduce the circuit in its entirety nor name the manufacturer. The whole purpose of this document is to highlight the pitfalls of some amplifier designs and why those designs that provide a balanced input should not be relied on to be truly balanced and provide high common mode rejection and immunity to common mode noise ! In fact some amplifier makers just ignore one of the balanced signals and feed the other along with the shield into an unbalanced amplifier ! This is just a pointless exercise and nothing more than a gimmick!

The following partial schematic appears to be a similar design to the amplifier under question.



On closer examination the balanced input is implemented in identical fashion to a typical opamp difference amplifier with some modifications due to the power output stage and the requirements of stability. In essence by well matching the resistors at the input and feedback stage one should be able to achieve a fairly good common mode rejection at low frequencies although how well this performs at higher frequencies will be entirely limited by the component matching, loop gain and frequency response of the output stage which probably won't be anywhere near as good as implementing it with a differential amplifier using a wideband opamp that feeds directly into a proceeding power amplifier stage.

On further examination pin's 3 and 1 of CON3 are the noninverting and inverting inputs of the power amplifier respectively whilst pin 2 is connected to the shield of the balanced interconnect. However, pin 2 of CON3 does not connect directly to the amplifier chassis ground but rather via a 10 ohm 3 watt resistor and there in lies the rub. In this amplifier implementation the shield of the twin shielded balanced cable connects directly to the input 'ground' pin of the amplifier. This makes it susceptible to any noise on the shield of the balanced input cable. How susceptible it is will be revealed in the following simulations.

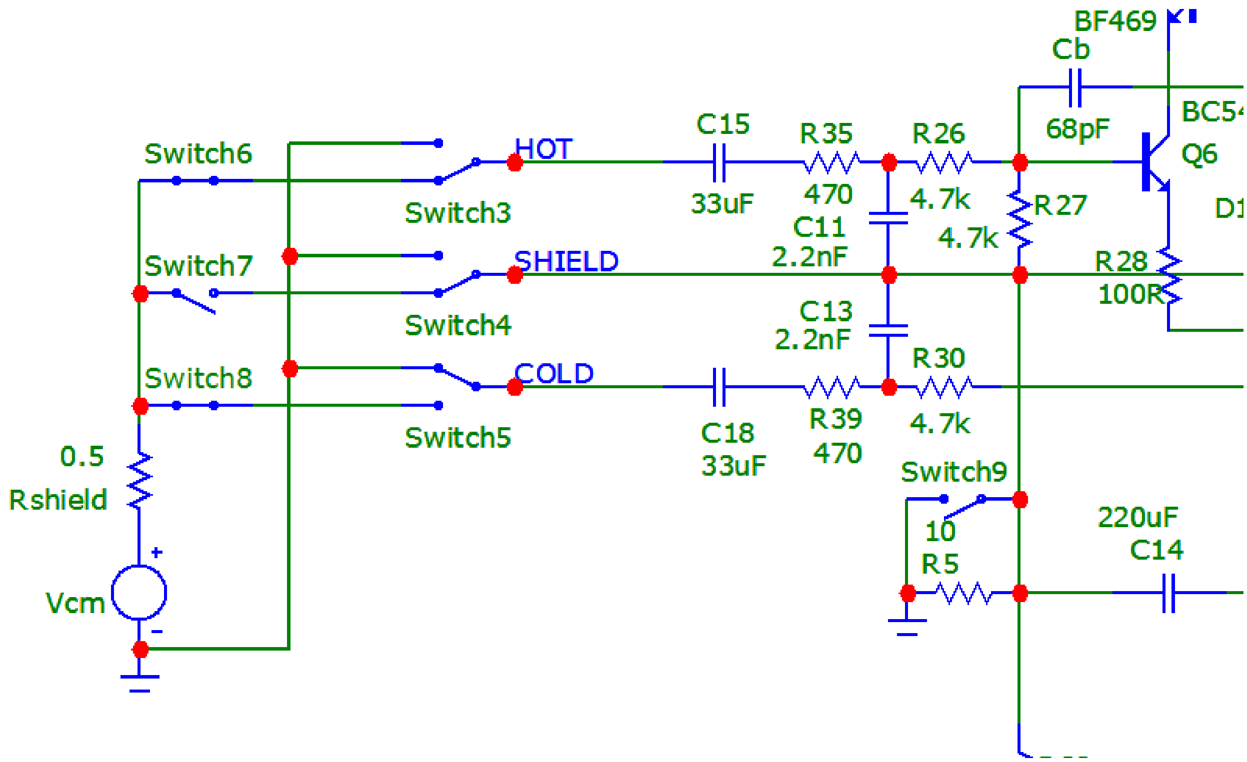
SIMULATION SETUP AND CONDITIONS

We setup the amplifier in accordance with the manufacturers recommendations for normal use. Each of the output mosfets in the amplifier is biased according to recommended setup of 80mA each and the rail voltage is set at +/- 92V as per the schematic. The speaker offset voltage as measured by the simulator is around 32mV.

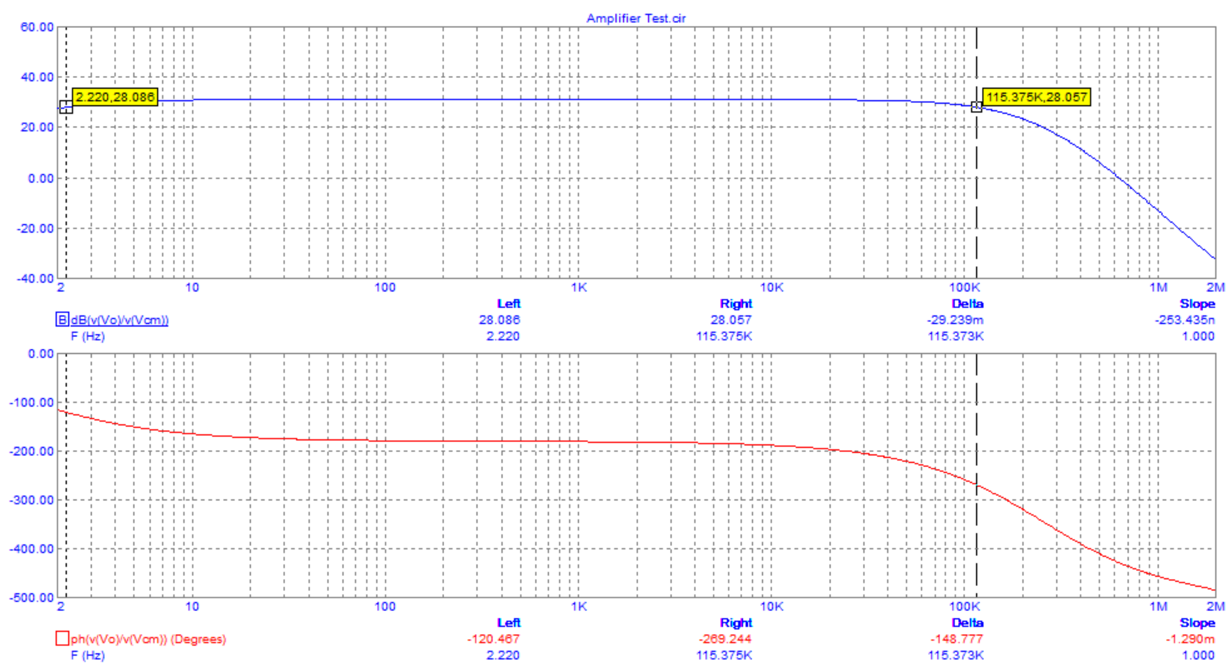
To simulate a variety of different input configurations we have added switches to the simulator that allows us to quickly switch between different connection and test scenarios.

BALANCED INPUT FREQUENCY RESPONSE SIMULATION

First we will simulate the amplifier frequency response with an 8 ohm load. We do this by applying a test source between the hot and cold inputs of the amplifier.



As one can see from the frequency response the mid-band differential gain is approximately 31dB and the -3dB points are at 2.2Hz and 115kHz respectively. Above 115KHz the amplifier frequency response rolls off with a 3 pole or 18dB per octave response.



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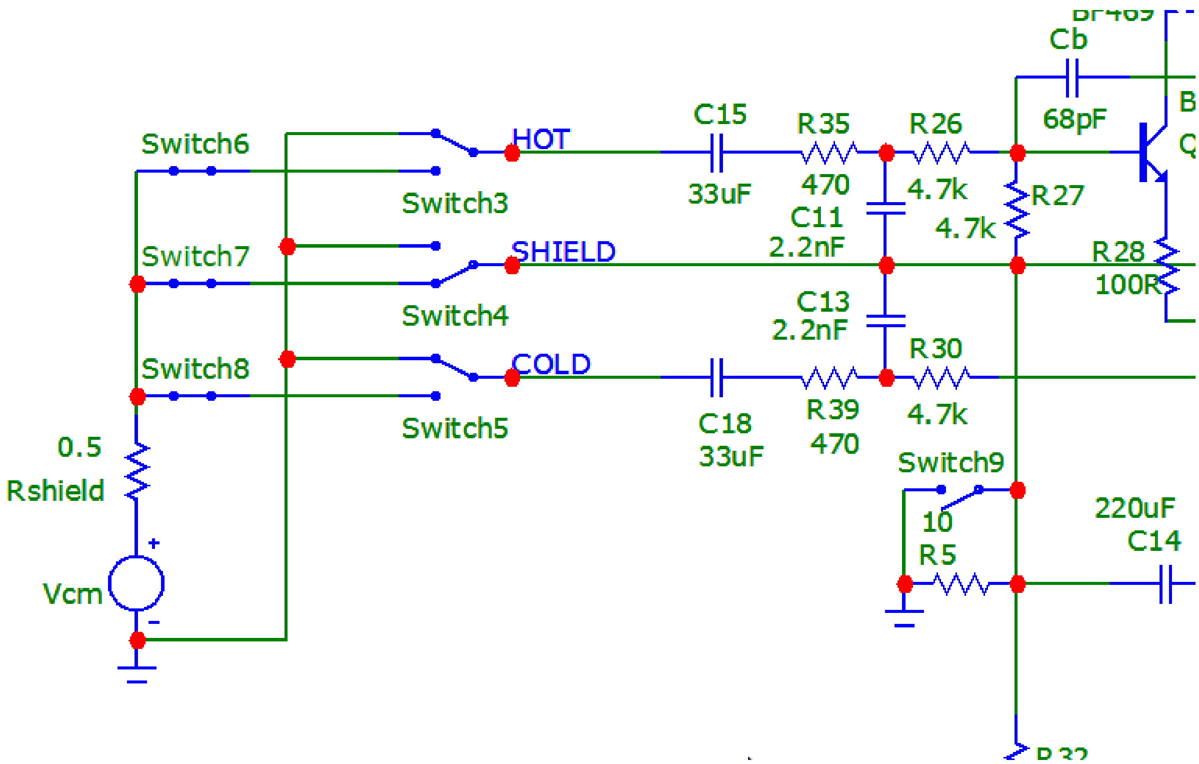
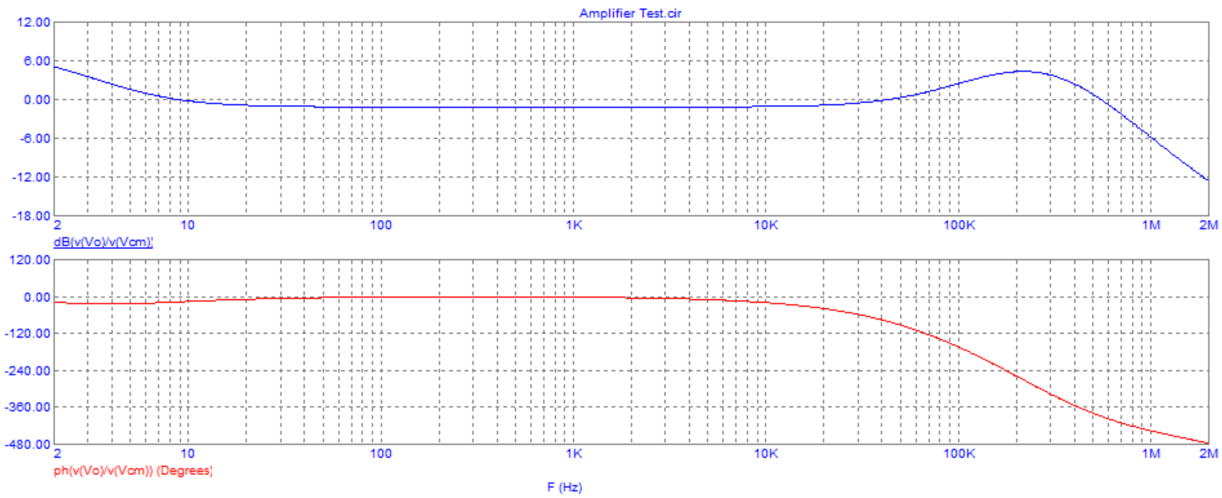
SHIELD NOISE INJECTION SIMULATION

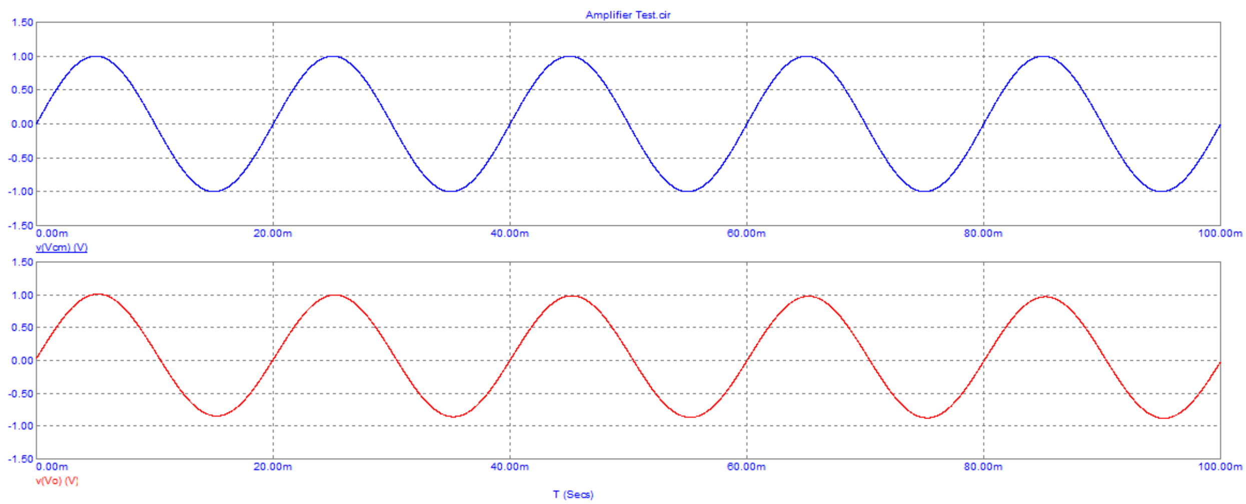
In this simulation we inject a signal directly into the shield input on this amplifier as though it was connected to a source unit that was wired in accordance to the AES48 standard. The ground loop currents flow around the shields between equipment and generate a potential drop along the shield which is modelled by the Vcm voltage source. We allow for a net DC resistance (Rsh) of around 0.5 ohms to model the resistance of both the shield and connectors.



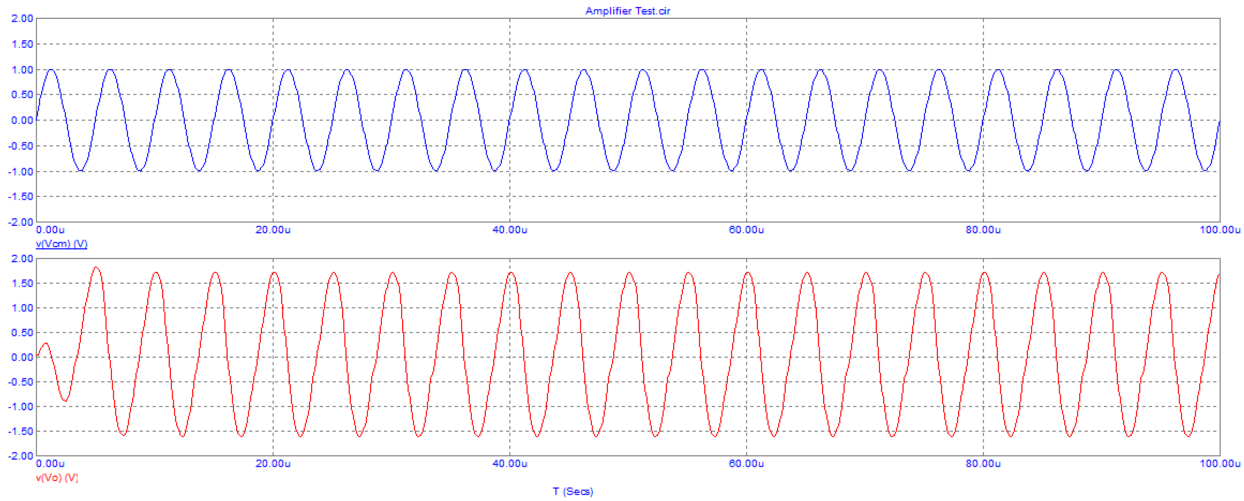
As can be seen from the frequency response below this amplifier has absolutely no immunity to ground loop noise ! In fact any noise on the shield would be buffered by the amplifier and passed straight to the speaker even right up to 2MHz or more ! Worse still it tends to amplify noise between 30KHz and 600KHz. Ouch !



To confirm this with our simulator we inject a 50Hz sinusoidal signal into the shield and see what comes out of the amplifier speaker terminals. As can be seen in the following simulation, the 50Hz signal (top blue trace) is passed directly to the output and speaker (bottom red trace) ! This amplifier has no immunity to ground loop noise or any harmonic content !



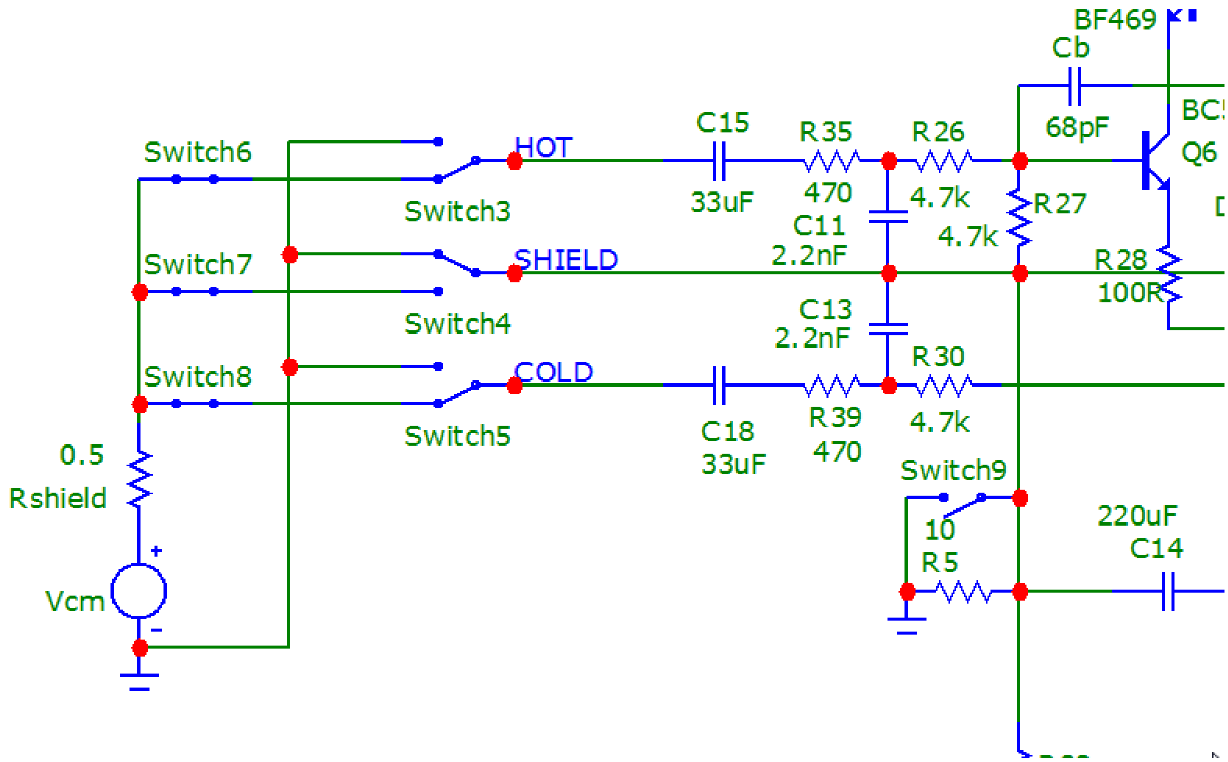
At the peak of the frequency response at 200 KHz the shield noise is amplified by a little over 4dB as evidenced by the results from the following simulation.



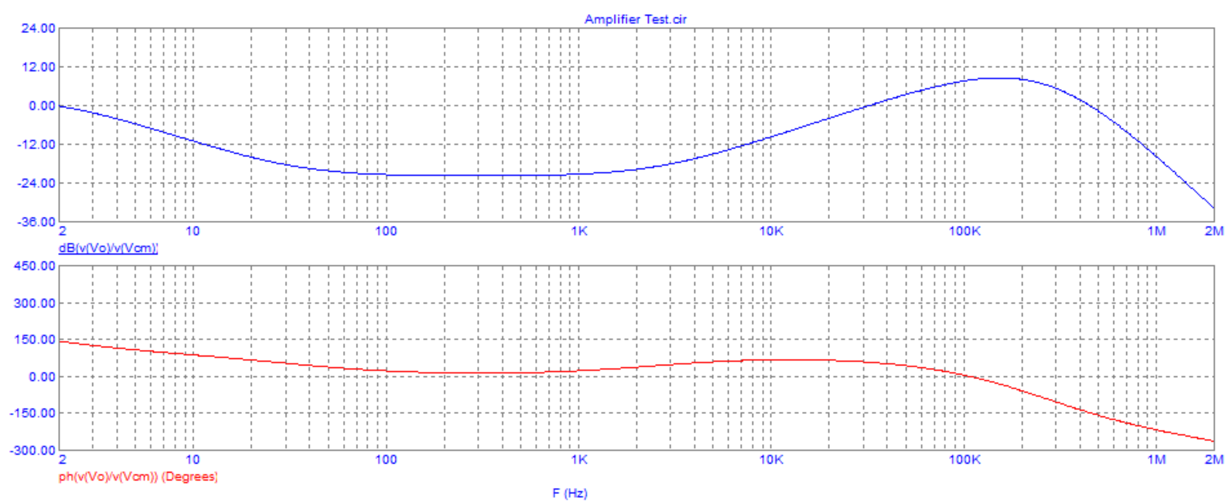
All in all this amplifier provides little or no immunity to shield induced noise and is totally incompatible with any equipment that conforms to the AES48 standard for the balanced interconnection system. This however should not be surprising since the shield is connected directly to the amplifier module and injects noise directly into it !

COMMON MODE REJECTION SIMULATION

To test the common mode rejection of this amplifier we tied the hot and cold pins together and inject the same signal into both input pins whilst the shield input is connected to ground as it would be if it was connected to any source equipment that conforms to the AES48 standard such as the Ultimate Preamplifier.

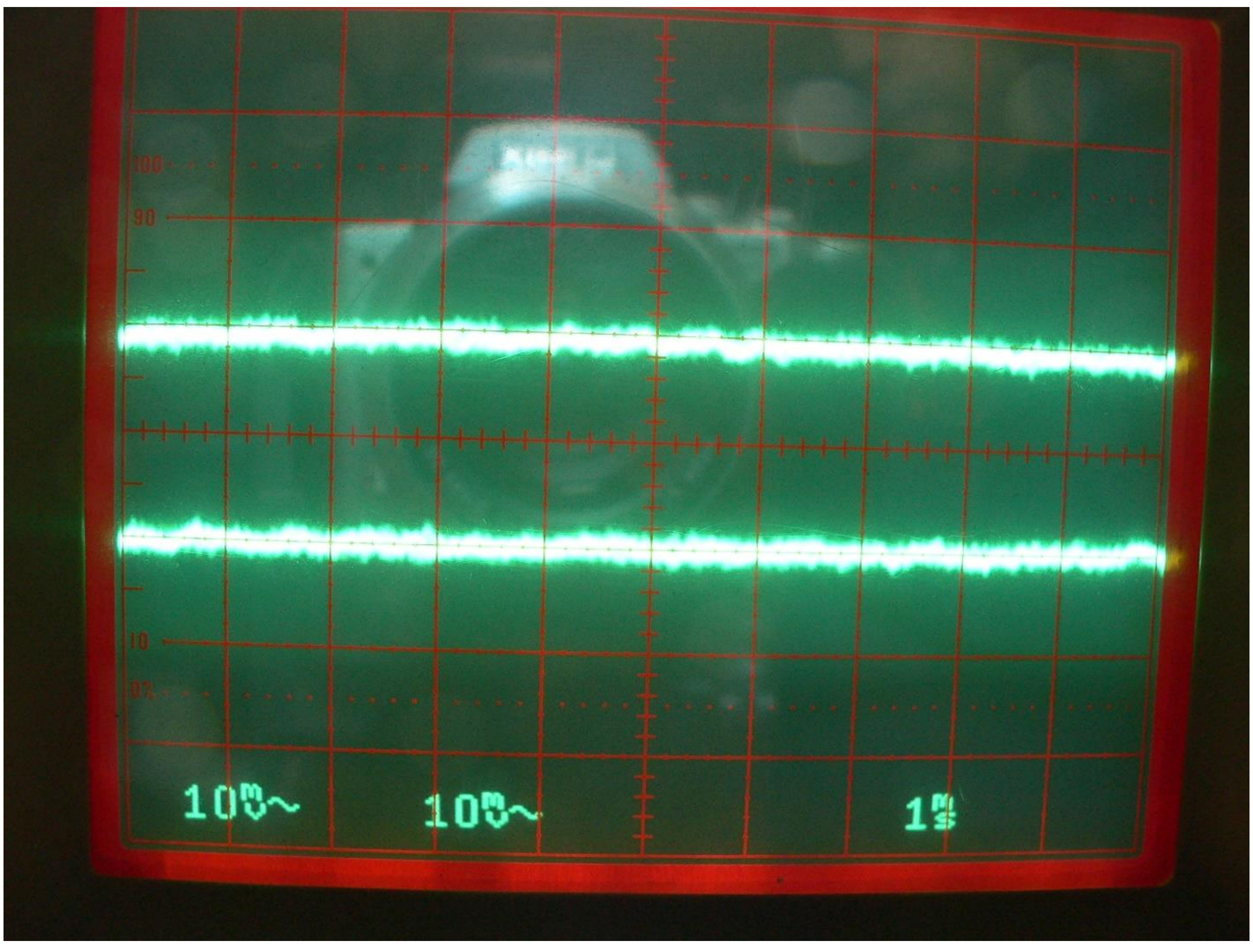


From the simulated frequency response below we can see that the amplifier has very poor common mode rejection (CMR). Best case CMR is not much better than 20 dB and at some frequencies it actually amplifies the common mode noise ! The balanced input on this amplifier is essentially ineffective at suppressing any common mode noise and its effectiveness worsens at higher frequencies which makes it susceptible to common mode noise generated by some DAC's such as the Sabre DAC.

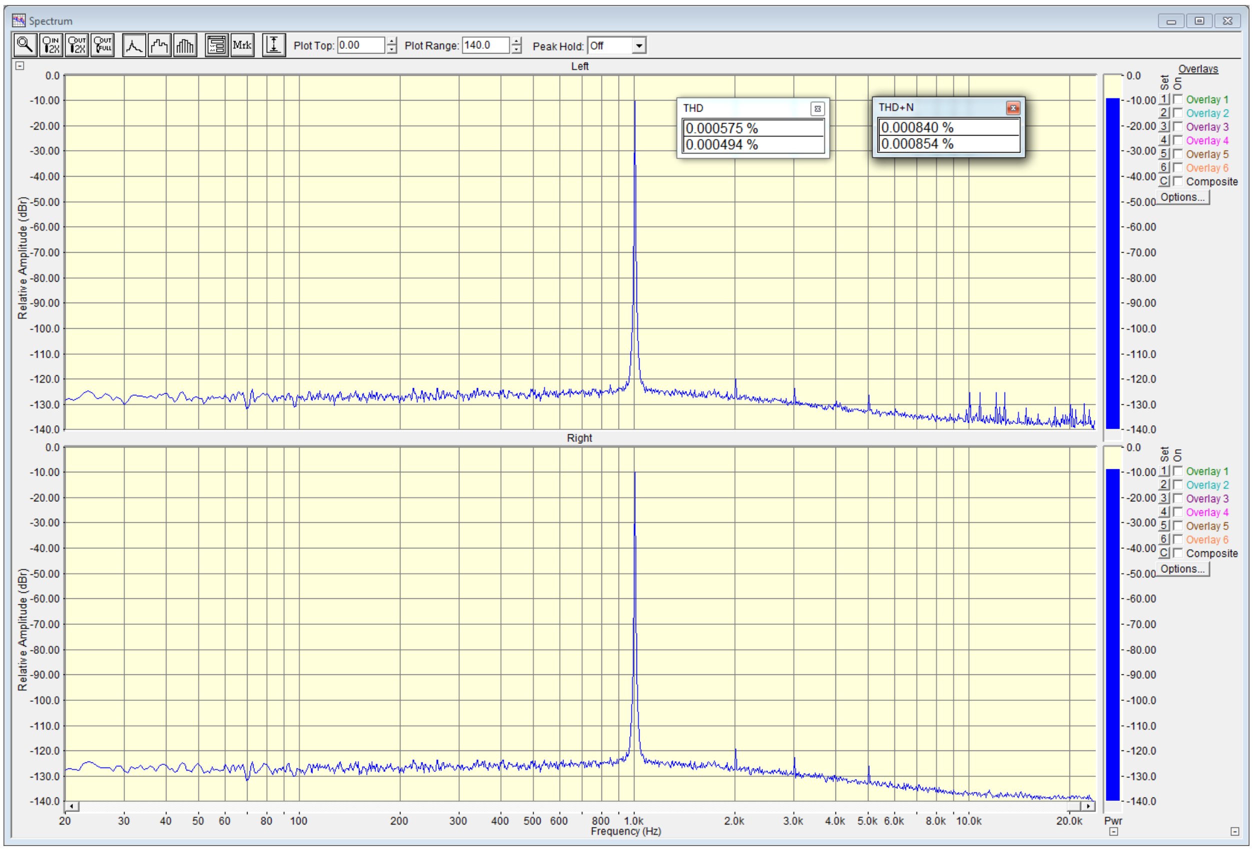


SUPPRESSION OF COMMON MODE NOISE FROM A SIGMA DELTA DAC

The Sabre DAC used in the Ultimate Preamplifier generates a small amount of common mode noise as part of its modulation process. The post DAC processing used in the Ultimate Preamp is based on the reference design from Esstech and as such the common mode noise is passed directly to the balanced outputs. This noise appears to be broad-based in nature and quite audible if not suppressed by a properly designed balanced stage connected to the output of the preamp. However, the noise does not appear at the unbalanced outputs simply because the common mode noise is cancelled by an opamp filter stage implemented as a difference amplifier which is why a proceeding balanced amplifier stage should be designed with the same performance in order to mitigate the noise. It's hard to actually measure the common mode noise because it is only about 1mV p-p in amplitude but as measured using a precision Agilent 6-½ digit multimeter it is of the order of 0.2mV RMS only. Even both digital and analog scopes have difficulty in resolving it !



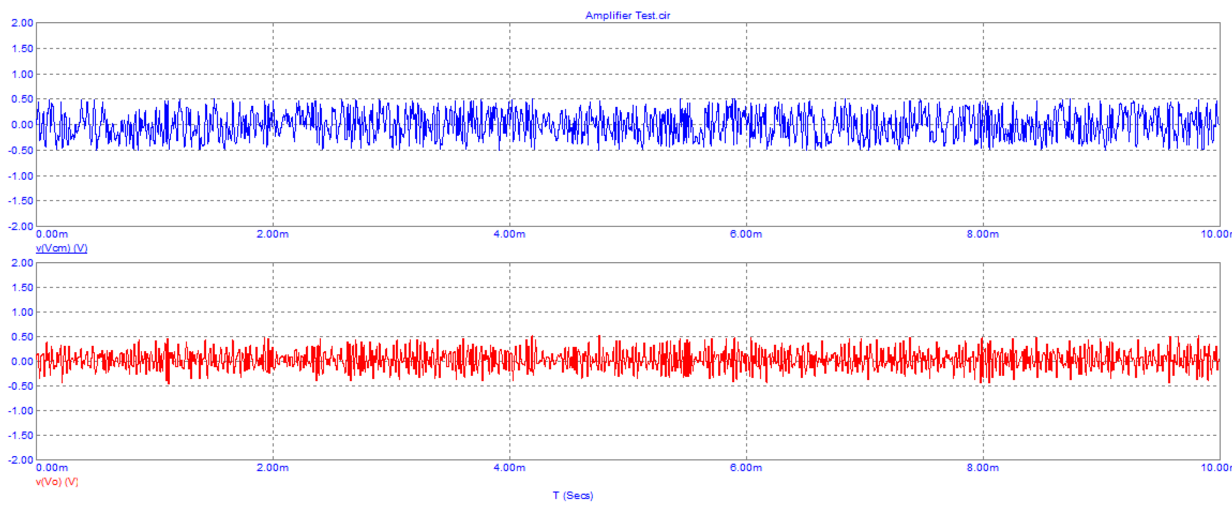
To prove that the noise from the Preamp is common and not differential the first thing to do is to measure the actual output of the preamp using a good quality analyzer with a good quality balanced input. We did this using a Creative Sound Labs EEMU-404 external sound card. As can be seen from the following spectrum for a 1KHz digitally generated sinewave there is absolutely no extraneous noise in the frequency spectrum which indicates that any noise is common to both hot and cold pins of the preamp balanced output. It also indicates that the external sound card has an exemplary and outstanding balanced input stage with high common mode rejection across the audio bandwidth and beyond. This explains why there is absolutely no noise when feeding this otherwise noisy DAC signal into its balanced inputs simply because the balanced input does what it is supposed to do and cancel out the common mode noise that appears at the output of the DAC !



FUN AND GAMES WITH OTHER AMPS

The author has tried various amplifiers with balanced inputs and with varying degrees of common mode suppression. The best case was a tube amp which was used as part of an active speaker system where the tube amp was driving a high efficiency midrange and tweeter horn. With the authors ear right up to the throat of either horn only a very tiny whisper of hiss was generated and it is inconclusive whether this was the common mode noise from the Preamp or noise generated by the amplifier itself. This would indicate that the balanced input on this amp was most likely implemented using a transformer which by its very nature provides excellent common mode rejection. The worst case was a so called 'high-end' solid state amp which drove a set of woofers and produced prestigious amounts of DAC hiss. I suspect that the balanced input was implemented by cheating, using only one of the balanced pair along with the shield and fed to a proceeding amplifier with unbalanced inputs. In this case it was never going to work properly at all !

With regards to the current amp in question in this paper how will this amp perform in the presence of the DAC common mode noise ? Well since we don't actually physically have the amp at our disposable once again we can simulate the noise by injecting a broadband noise signal into the amplifier and seeing what comes out of it. The simulation below shows that random white noise with a 100kHz bandwidth injected into both the hot and cold inputs with equal amplitude at the same time (top blue trace) therefore simulating common mode noise is essentially passed directly to the speakers (bottom red trace). Yes that shhhhhhhh sound in the speaker is the balanced input of this amplifier failing to do what it is supposed to do and essentially filter out any common mode noise !



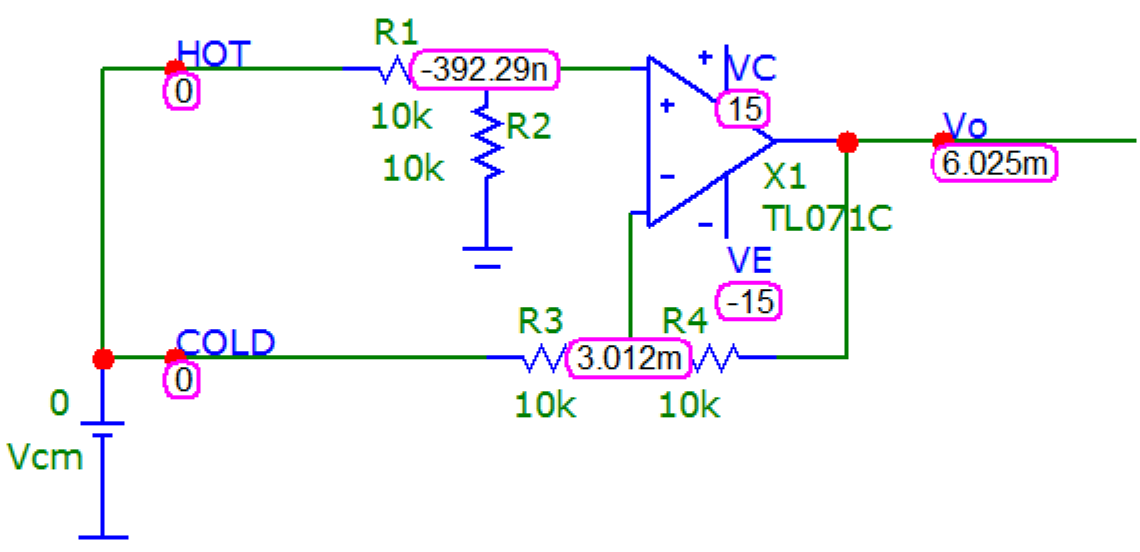
Although we have measured the common mode noise of the order of 0.2mVrms on an Agilent 6-½ digit precision multimeter the next revision of the preamp will see a reduction of the CM noise to negligible levels with a redesigned DAC post processing stage. However this does not let a poorly designed balance stage off the hook !

DEALING WITH A COMMON MODE DC OFFSET VOLTAGE

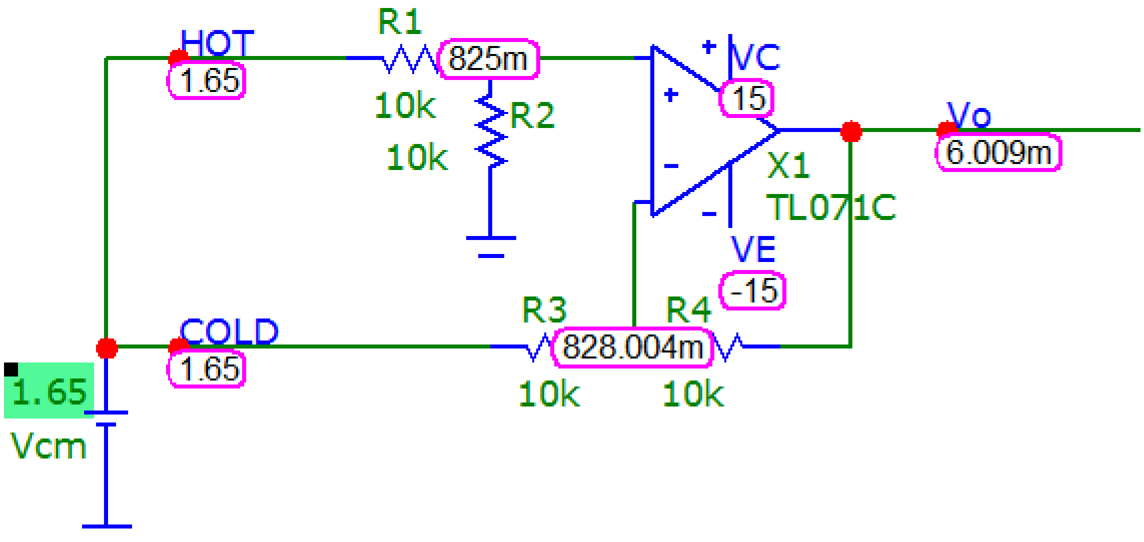
When we shipped the Preamp to this customer we shipped it with the capacitor coupling on the balanced outputs bypassed. This meant that the 1.65 Volt DC offset from the DAC IV converters was present at the balanced outputs. The assumption being, just like the amp we are simulating most power amps are AC coupled on the input or at least that is what I thought to be the normal case. After all there is no point in having more than one coupling capacitor in the signal path because what would the purists think of that ? However it appears that there are a lot of DC coupled power amps around just for the sake of claiming that they don't use any of those pesky capacitors in the signal path !

For the amp we are simulating in this report the DC offset should not be a problem since it is AC coupled at the input with suitable capacitors to filter out any DC offsets. But even with a properly designed DC coupled balanced input this should not be a problem either, since the amplifier should only amplify the difference on the balanced inputs and reject any common mode DC offsets that are within reasonable limits such as in this case. Unfortunately, this does not appear to be the case with the customers amp under question. Even though it claims to be DC coupled it seems to have difficulty dealing with a common mode DC offset on its balanced inputs, with overheating and noticeable transformer hum as a result of a substantial DC offset at the output causing the load to draw an appreciable amount of current. Since we don't have the physical amp in front of us to verify this we can just modify the existing amp we are simulating by shorting out the input coupling capacitors, but first let's see how a simple opamp difference amplifier handles a common mode DC offset on its inputs.

With zero volts or both inputs shorted to ground essentially, we see a residual voltage (6mV) at the output which is in the mV range. This is roughly equivalent to twice the rated offset voltage (3mV) of the opamp at its output as expected.



Now applying the 1.65 Volts common mode DC signal from the balanced output of the preamp to both the hot and cold inputs, again the output sits at a residual of only twice the opamp offset voltage as one would expect since the difference between the two inputs is still zero !



So far the difference amplifier has unity gain for the differential input whilst providing virtually no transmission of any common mode signals. In fact the differential gain is dependent on the ratio of resistors only ie

Differential Gain = R2/R1 =R4/R3

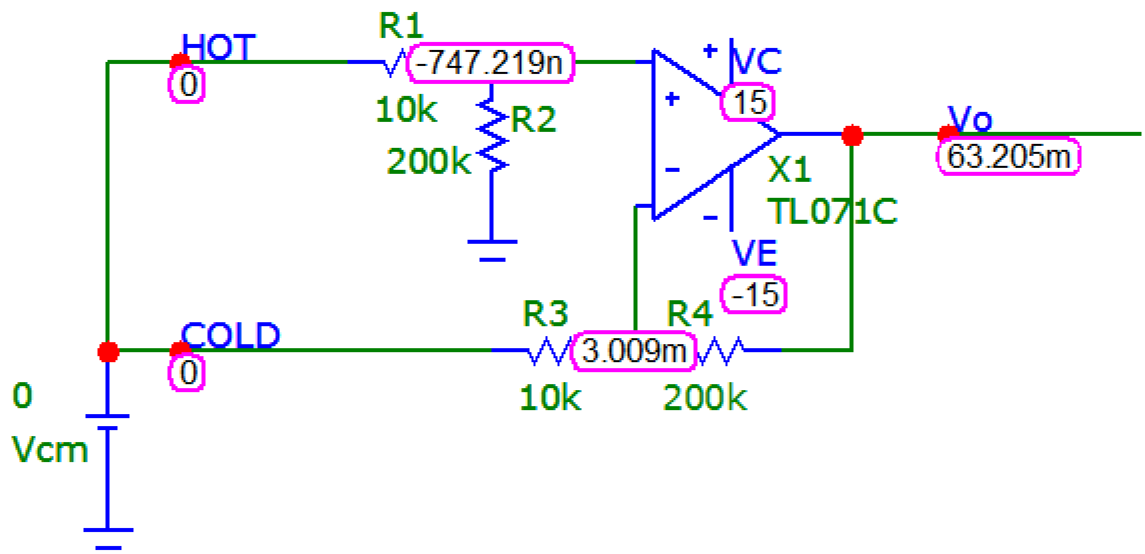
- provided R1= R3 and R2=R4
- and $Vo_{offset} = V_{opamp\_offset}$ *(1+R4/R3)

The take home message is that the output voltage is dependent on how well the resistors are matched and how large the opamp offset voltage is which is usually in the vicinity of a few mV only. A well-designed differential amplifier such as this is designed to filter out any common mode signals including common mode DC signals !

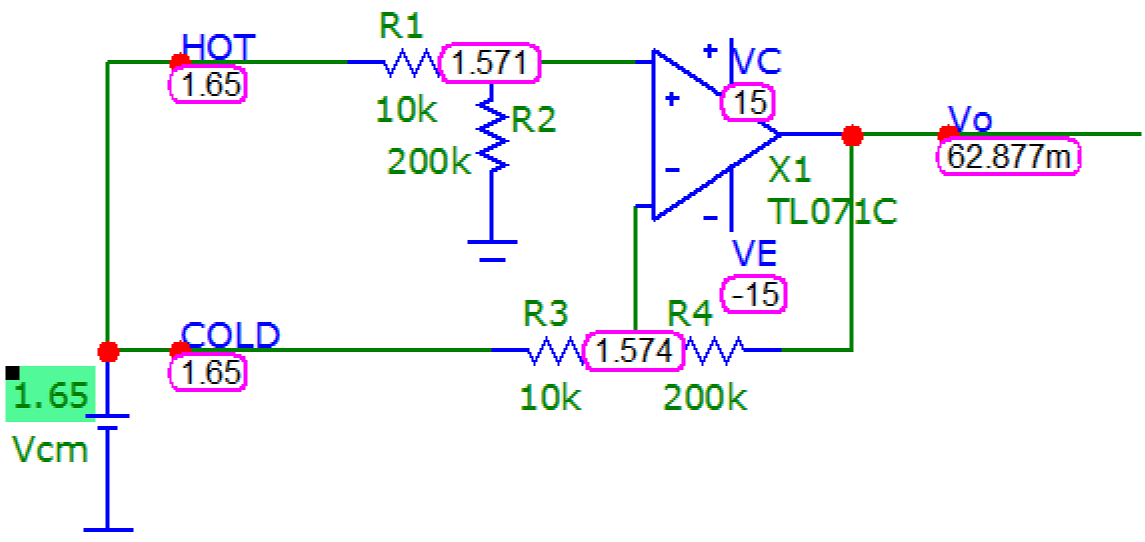
DIFFERENTIAL OPAMP CIRCUIT WITH GAIN

Now let's mimic the actual power amplifier by making our simple difference amplifier have some gain. For about 26dB of gain this would require R2/R1=20 or R2=R4=200k. Again we see the residual output of 63mV is deetermined simply from the relationship:-

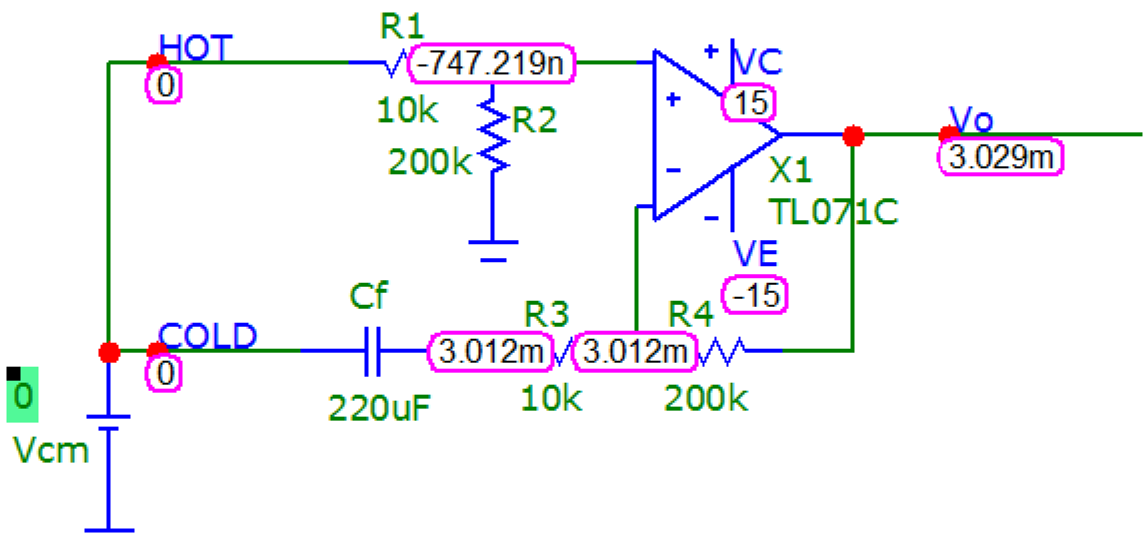
- $Vo_{offset} = V_{opamp\_offset}$ *(1+R4/R3) = 3mV *(1+20/1) = 63mV



With the 1.65V DC common mode offset signal the output is still only determined by the opamp offset voltage and nothing else, provided that all of the resistor ratios are well matched.

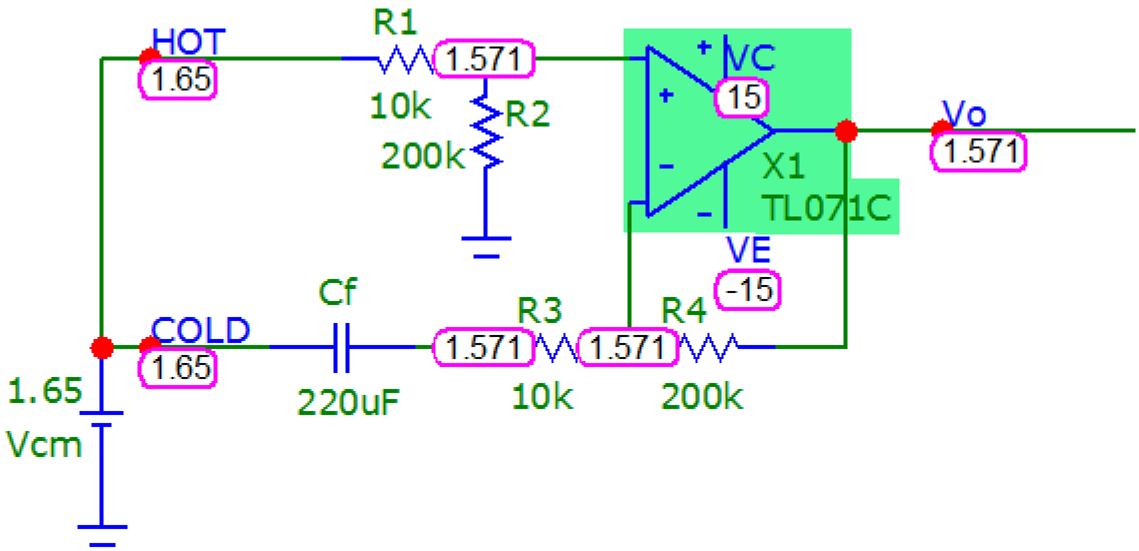


In the actual amp the offset voltage would be a lot higher due to imperfection in matching of the input differential pair, and the input bias current if bipolar transistors are being used. A trick used to reduce the offset voltage in power amps is to insert a capacitor in the lower leg of the feedback divider thus reducing the closed loop gain to unity at DC. Lets see how this effects the circuit above.



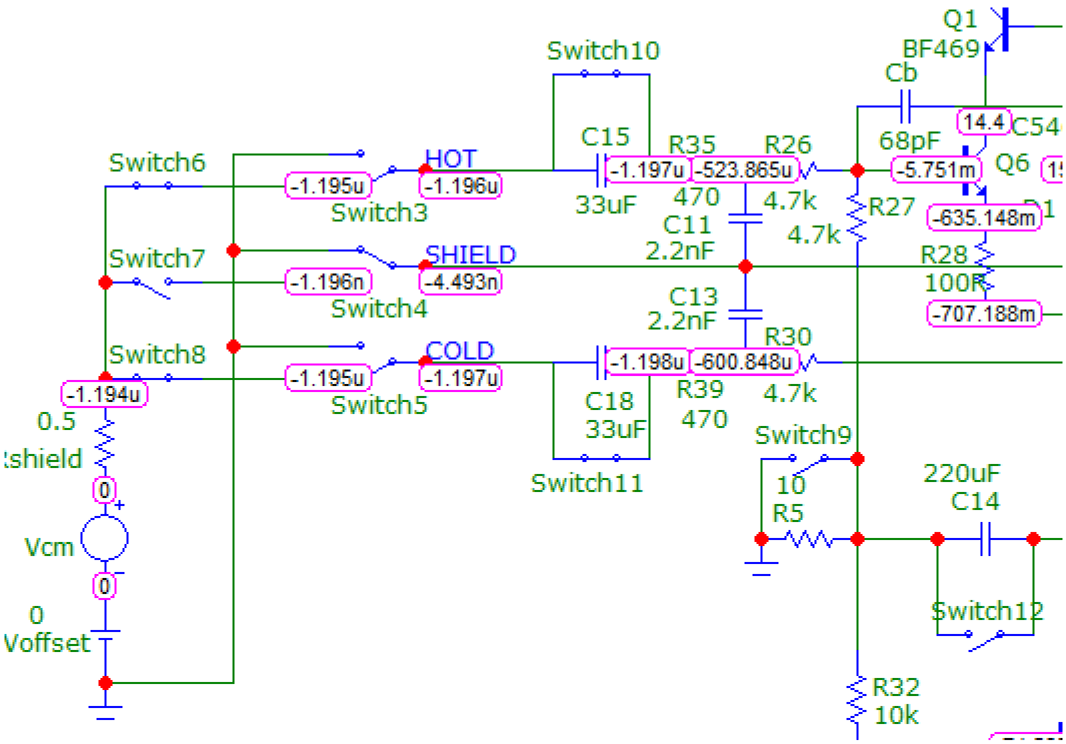
As predicted the output offset voltage is reduced from 63mV down to 3mV offset voltage of the opamp which is 1/21 the offset voltage without the capacitor in circuit ! This is great but there is only one catch ! Whilst the capacitor is essentially a short circuit at audio frequencies, at DC it is an open circuit which puts the difference amplifier out of balance so that it is no longer a difference amplifier at DC. To see the effect with the 1.65 Volts common DC offset from the DAC the output offset voltage can be calculated as:-

Vo_{offset} = R2/(R1 + R2) * Vcm = or 1.571 Volts and this is indeed what we see I the simulation below !

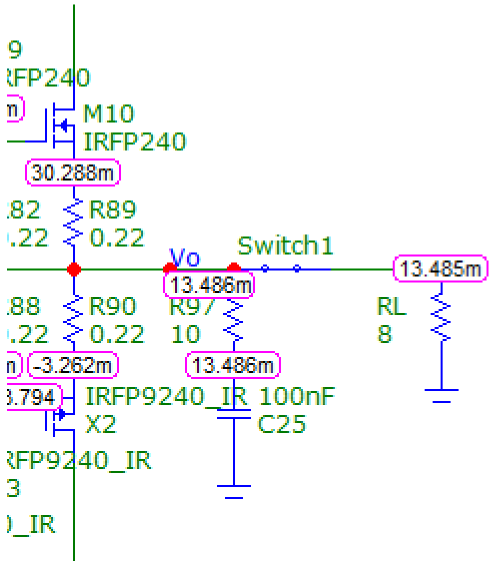


From the above simulation, by including a capacitor in the feedback path we improve the residual offset voltage at the output but we imbalance the differential amplifier at DC so that any DC common mode signals is essentially passed through to the output.

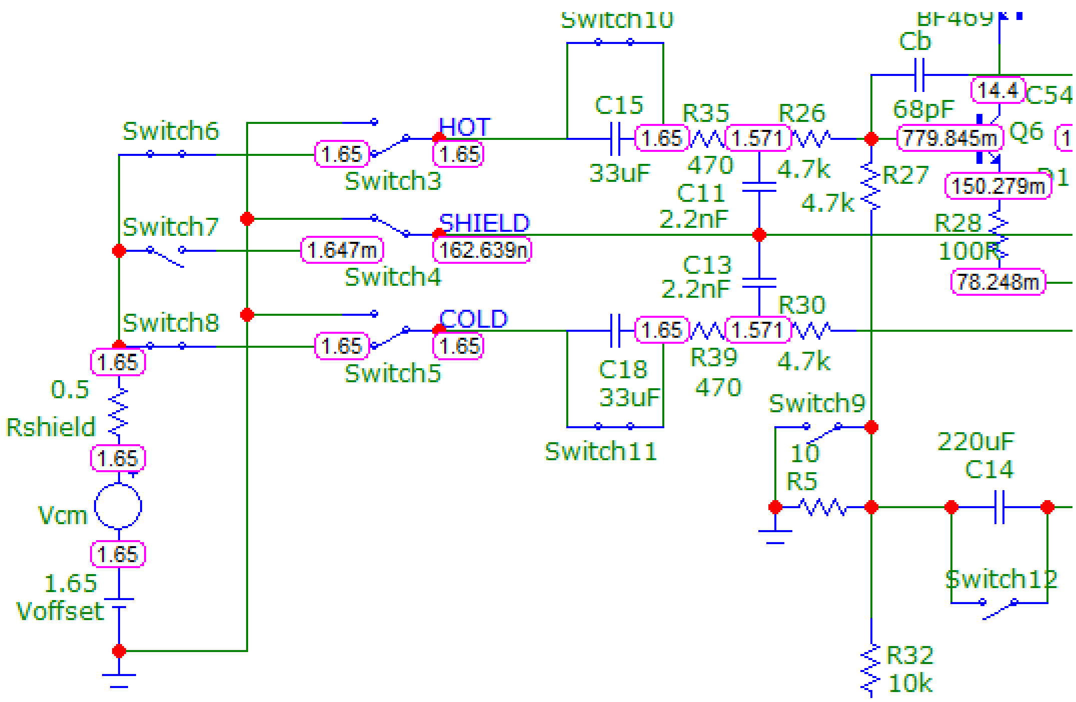
To verify this in the actual amplifier we need to modify the amplifier we are simulating so that it responds down to DC. This can be done by shorting out the two coupling capacitors at the input. As can be see in the following simulation the residual offset voltage is very low so the coupling capacitors are not really needed and have probably been removed in the customers amplifier.



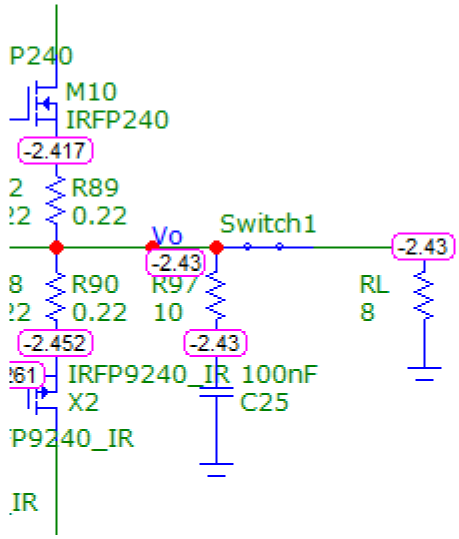
And the output the residual offset voltage is a small 13.4mV only !



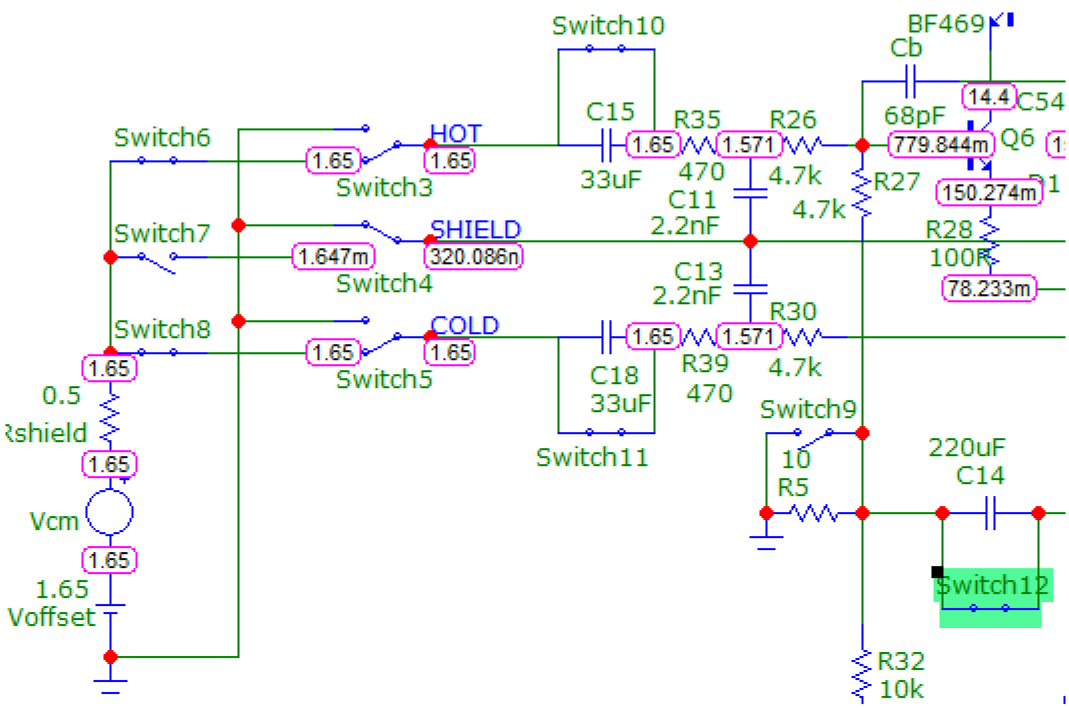
However, let's see how the amp stage now responds to the 1.65V common mode offset voltage from the Preamp.



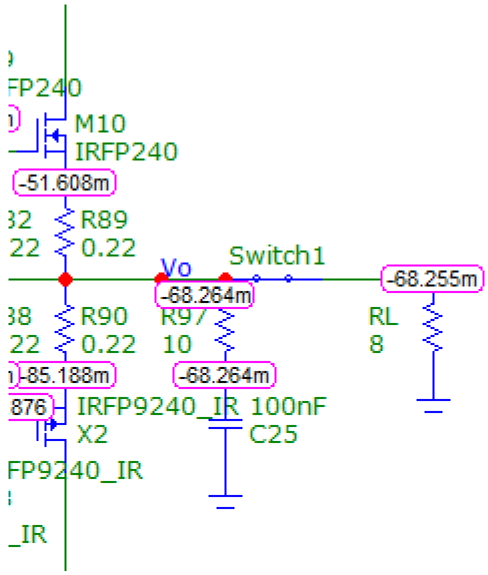
And the output voltage tells the story ! Like the opamp difference amplifier case the DC feedback capacitor unbalances the difference amplifier at DC so basically any common mode input gets passed through to the output terminal !



Now if we short out the 220uF feedback capacitor how does it change matters ?



And as expected the 1.65 Volt common mode DC input is essentially cancelled out with the remaining residual offset voltage at the output most likely dominated by the input bias currents flowing in the long tail pair.



The conclusion is that whilst the inclusion of the feedback capacitor improves the residual offset voltage at the output it severely deteriorates the ability of the amplifier to reject common mode DC input signals such as the 1.65V common mode DC offsets from the preamp. Because of the possibility of problems with other DC coupled amplifiers we now ship all preamps with the output coupling capacitors in circuit so there is no common mode DC offset at the balanced outputs ! A lesson learned the hard way ☹

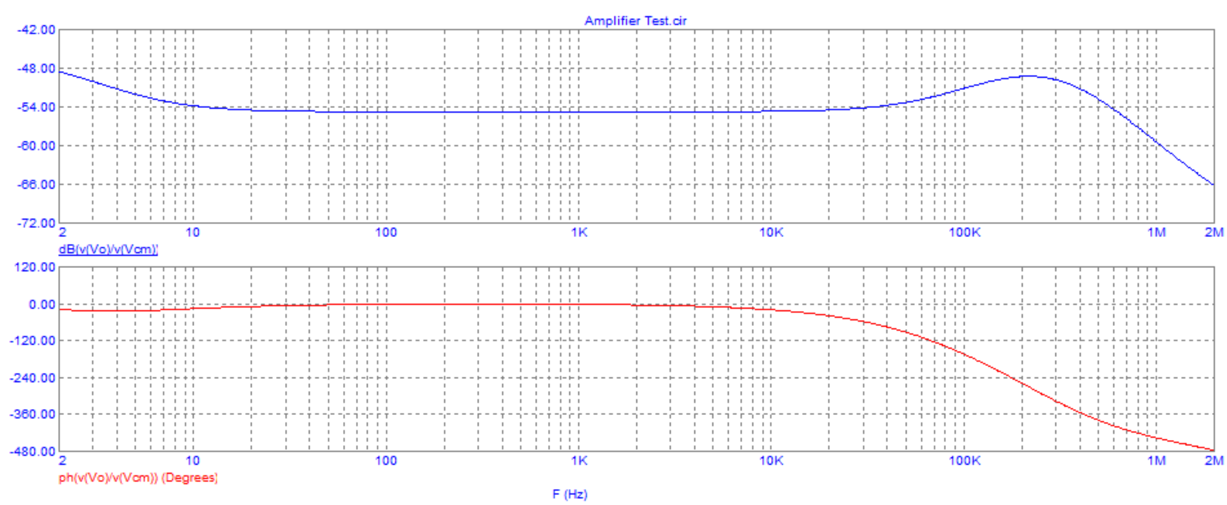
The next revision of the preamp redesigns the post processing DAC stage such that the residual DC offset on the balanced outputs will be of the order of a few mV's only even if DC coupled. Even so we will still ship the preamps with the coupling capacitors in circuit and it is up to the user to reconfigure for DC coupling by shorting out the capacitors with suitable jumpers if so desired !

CAN THIS AMPLIFIER DESIGN BE IMPROVED ?

At first glance it may be possible to modify the amplifier so it conforms to AES48 standards. This would be achieved by lifting the shield from the PCB and then shorting out the 10 ohm resistor.

SHIELD NOISE INJECTION SIMULATION WITH 10 OHM RESISTOR SHORTED OUT

In the AES48 standard the shield is normally connected to pin 1 of the XLR socket on the amplifier which is connected to the amplifier chassis and disconnected from the amplifier module so we do this measurement out of interest sake to see what improvement can be obtained by shorting out the pesky 10ohm resistor on the amplifier board that separates the grounds ! From the results below the immunity to ground noise is in stark contrast to it with the 10 ohm resistor in circuit. An additional 50 dB of common mode noise immunity could be achieved in theory with the 10 ohm resistor shorted out whilst the shield is still directly connected to the board. However, in practice this would be severely limited by voltage drops across the pcb traces which form the shield node on the pcb. Of course in the AES48 connection standard no shield is connected to this point so you could expect total immunity to ground noise injection with no shield connected at all ! In other words leave the shield disconnected from the amplifier module but still have it connected to pin 1 of the XLR input socket.



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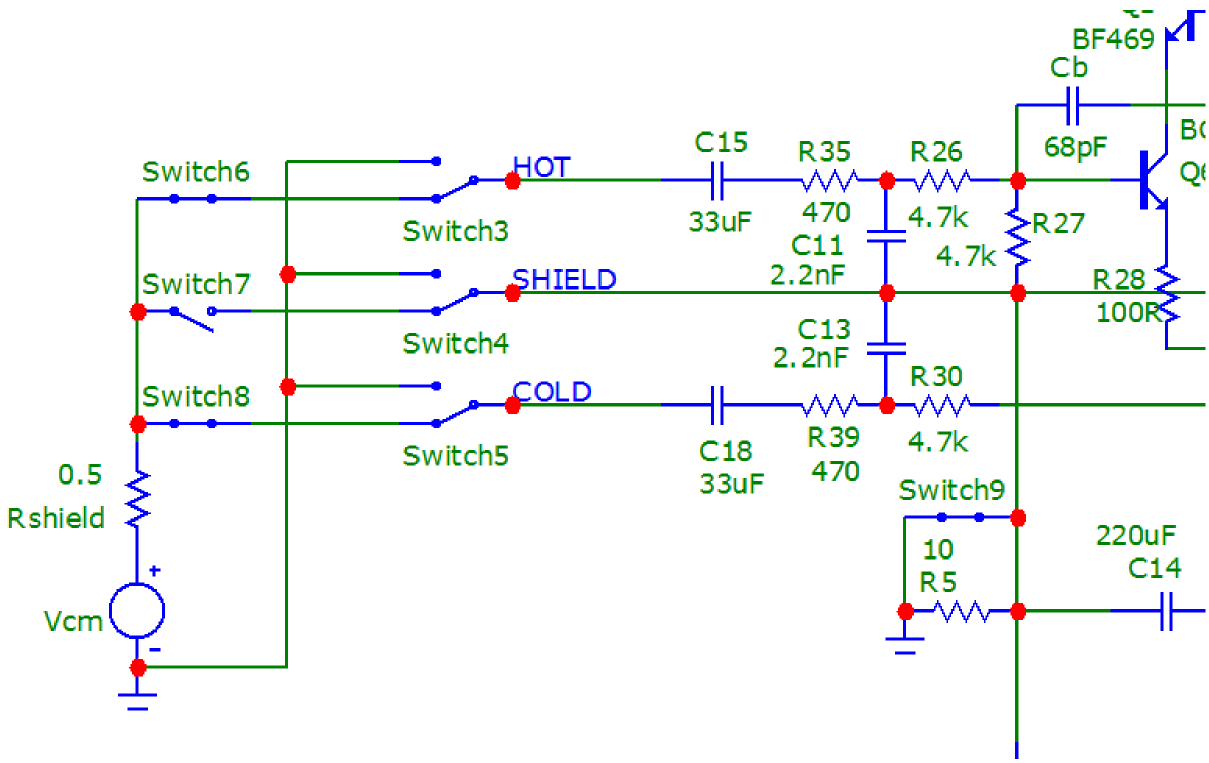
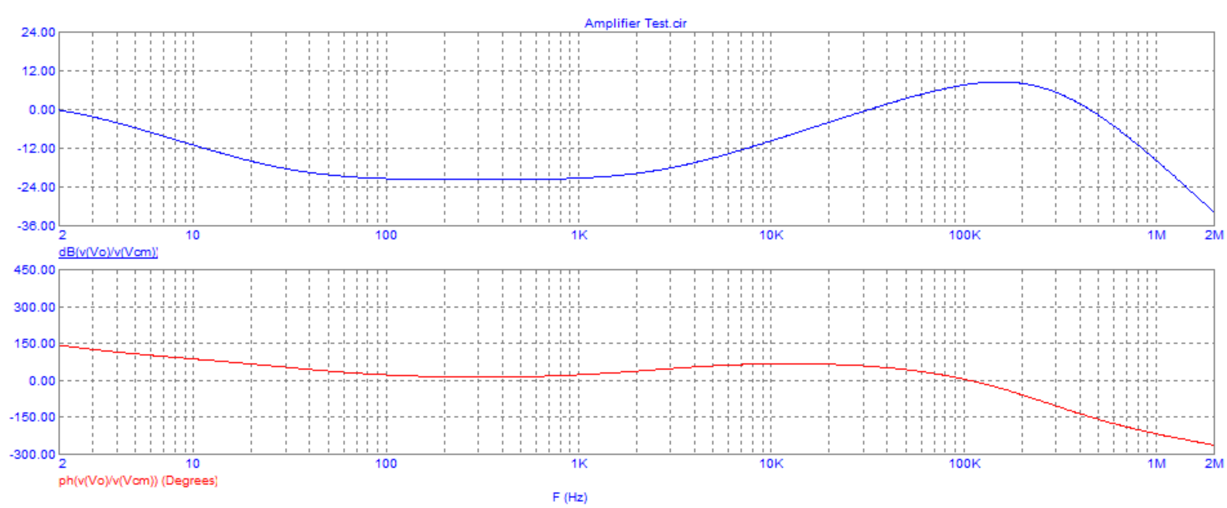
COMMON MODE REJECTION WITH AES48 MODIFICATION

In this configuration we disconnect the shield from the shield connection point on the pcb and as well we short out the 10 ohm resistor.



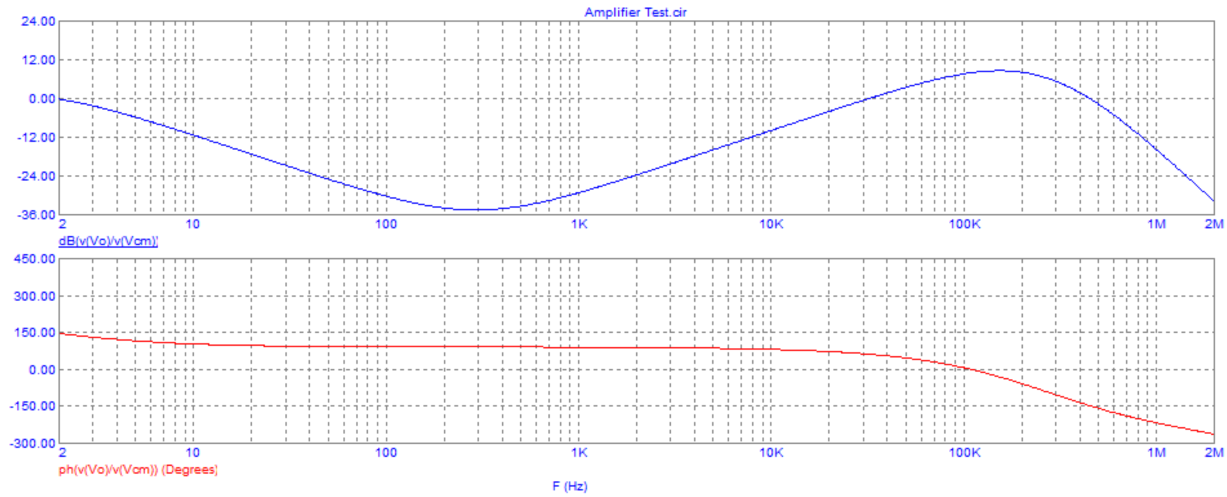
As can be seen from the simulated frequency response below no improvement in the common mode rejection (CMR) can be observed which indicates a limitation inherent in the design of the amplifier itself.



We can try and improve the performance of this design by judicious matching of the feedback resistances which make up the difference amplifier ie

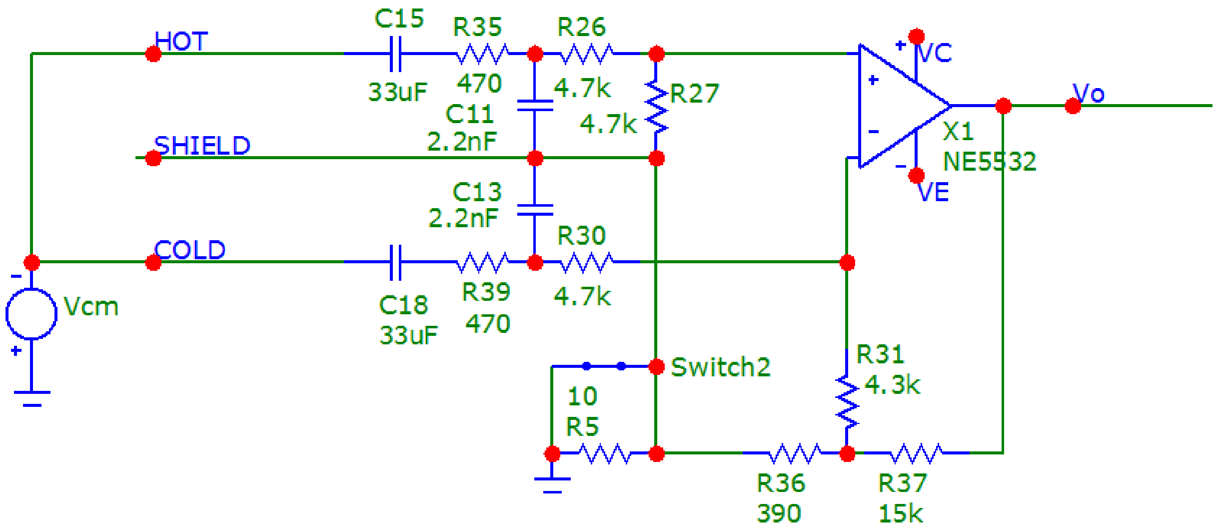
R31 = 4.7k – 1/(1/15k+1/390) = 4.32k

No real improvement in the CMR is to be seen which means the limits are in trying to implement a difference amplifier around a low bandwidth, low loop gain, highly compensated power amplifier stage.

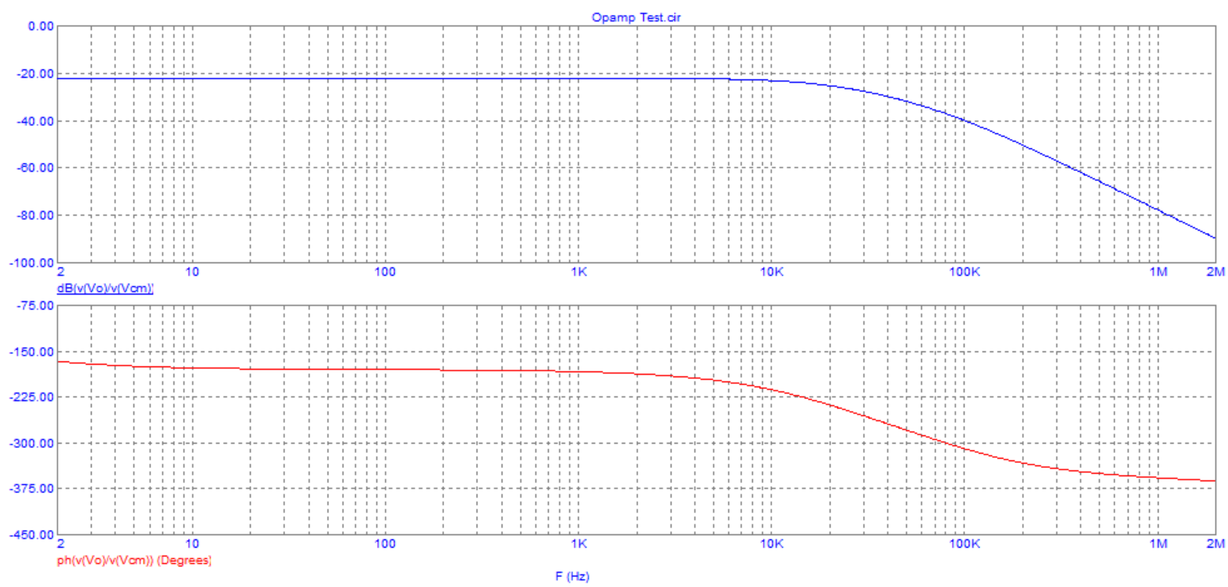


BEST CASE PERFORMANCE

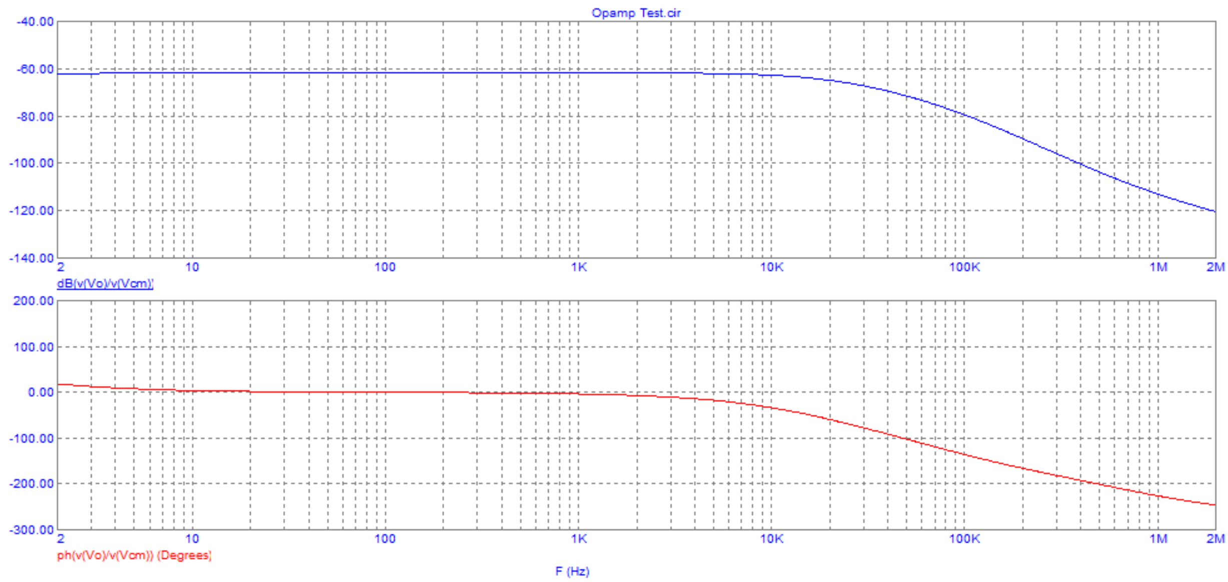
We decided to implement the basic amplifier topology using a NE5532 wideband opamp to see what is possible from this design.



As can be seen in the CMR frequency response although the CMR is not much better than the amp except for the fact there is no peak in the response !



With judicious matching of the feedback network we replaced the 4.3k with a 4.32k resistor with the following results.



As can be seen in the response above the CMR has increased from 20 dB to 60 dB but these same improvements have not been seen with the power amplifier itself which suggests that the open loop gain and bandwidth limit the performance of the amplifier.

IS IT POSSIBLE TO FIX THIS AMPLIFIER ?

This is the million dollar question ! To fix this amplifier we need to address three issues.

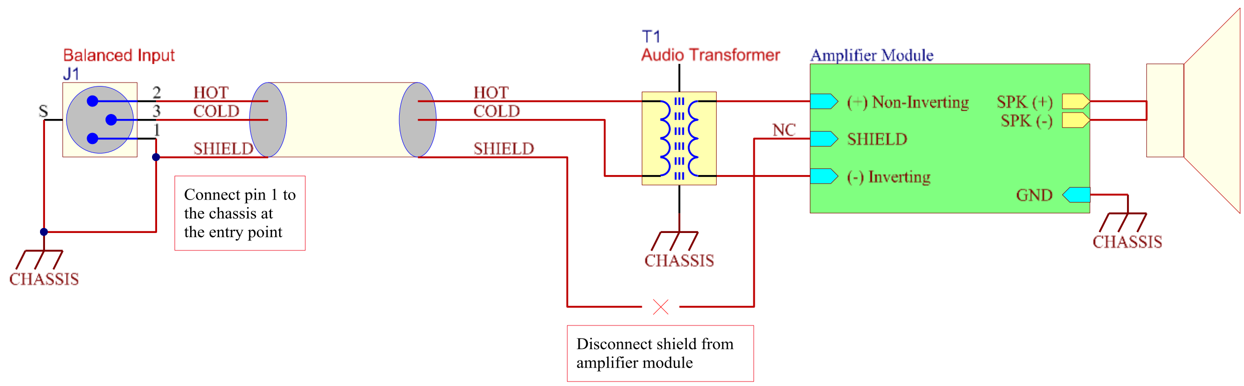
These are :-

- Ground loop noise caused by pin 1 problems due to AES48 compliance of the peripheral equipment it is connected to,
- Common mode rejection of DAC common mode noise from the Preamp of the order of 0.2mV RMS
- Common mode issues due to common mode DC offsets from the Preamp

The solution is very straight forward and is one that has been adopted by many other power amp designers as well as some DAC builders. It involves the use of a high-quality audio isolating transformer like the one shown below which is usually not an inexpensive device but can be very effective in this type of application.

Not all balanced inputs are created equally !

Here's how the amplifier would be modified to use it ! The important features are to connect pin 1 directly to chassis point on the amplifier. The other is to include a transformer between the balanced input pair and the amplifier balanced inputs. Lastly the shield input of the amplifier module should be completely disconnected from the shield of the cable ! The schematic diagram below illustrates the modifications required.



We have not actually tried this so we cannot vouch for its effectiveness but there is no reason why it should not work ! It's probably the easiest and most effective improvement that could be made to this amplifier design and does not involve modifying the source units and lifting grounds !

CONCLUSION

Although we don't physically have the amplifier in front of us the simulations that we have run on a very similar amplifier design has thrown some light on the issues with this amp. A simple resistance measurement between pin 1 of the balanced XLR connector and chassis ground of 10 ohms shows us that this amp has not been designed with AES48 compliance in mind. The mere fact that pin1 terminates to a connection on the amplifier pcb rather than the chassis means that this design is susceptible to shield induced noise and the simulations do confirm this to be true.

The inclusion of a balanced input on this amplifier as a means of amplifying the difference between two signal nodes whilst rejecting signals which are common to both nodes is a very poor implementation of a difference amplifier and as a result is totally ineffective and benign at removing common mode noise from the system ! In fact in some cases it amplifies the noise so its inclusion as a means of reducing the susceptibility to ground induced or common mode noise is nothing more than a gimmick.

By modifying the amplifier in accordance with AES48 standards it should be possible to reduce or eliminate shield induced noise simply by disconnecting the shield at the amplifier module and tying pin1 of the XLR socket to the chassis. This is something I would have experimented with had I had the amplifier in front of me.

However, from the simulations run on this particular power amp, there is little that can be done to improve the poor common mode rejection performance of this amplifier. For the best results the input to this amplifier module should be totally isolated from the external interconnect system either with a precision wideband opamp difference amplifier or by a high-quality audio transformer. Indeed in a previous section we suggest a modification to fix all issues with this amp and any connecting source unit.

For the sake of maintaining "audiophile" status by eliminating a differential opamp stage in the signal path the performance of this amplifier has been compromised. The use of a 10 ohm resistor to separate grounds along with the connection of the shield directly to the board actually worsens the performance and is the very thing warned about in the any discussion of the AES48 standard ! Perhaps the only way this amplifier could be used in its current state is by cheating and lifting the shield connection from the chassis ground at the source equipment which explains the use of a mains isolating transformer by the user to eliminate noise when using unbalanced interconnects !

REFERENCES

- **The G Word, or How to Get Your Audio off the Ground**
- **Dealing with legacy pin 1 problems**
- Pin1 Problem