Letter to the editor

Hans Polak writes:

Dear editor,

I have read Burkhard Vogel's article on a Poor Man's Measurements Amplifier (PMMA) in L|A Volume 7 with great interest.
The reason for writing you is that I have built up quite some experience with balanced input circuits with high gains for Moving Coil cartridges, and would like to offer some comments that I hope will be useful.

1) The LT1028 is equipped with an input current cancellation system. The result is that the input of the LT1028 can either be sourcing or sinking current. When adding together 4 different OpAmps, their bias currents can go from anything between -360 and +360 nA resulting in +/- 3.6 mV offset into the used 10k resistor. The difference between the positive pair OP1 and OP3, and the negative pair OP2 and OP4 can thus be 7.2 mV in the most extreme situation, causing an offset of 7.2 V at the output, enough to create a nightmare in offset nulling.
A solution I have used was to match OpAmps in pairs, having the same direction of input current and having a bias current within a factor 2 or less.
In your case this would mean matching OP1 /OP2 and OP3/OP4 which will cause the bias currents through R3 and R4 to be far more similar and because of this as a bonus the offset will be less prone to temp changes.

2) The resistance presented to the input source of the PMMA at low frequencies differs significantly to that at VHF frequencies. Since your PMMA does not have an EMI filter, it might very well be that radio-frequencies are causing DC offsets and instabilities. You can check this quite easily by putting your cell phone next to the PMMA and calling your number. Looking at the DC shift at the output of the PMMA, will give you a direct indication whether you need to place an EMI filter at the input to get rid of this potentially nasty problem.

3) I did not find any mentioning of local power supply decoupling for each OpAmp. My experience is that balanced amps are far more sensitive to an absent decoupling cap because both OpAmps being within the same feedback loop. Each OpAmp should at least be decoupled with 10 nF to 100 nF, else you may be experiencing strange and unexplainable behaviour.

4) When I put the four input opamp circuit in LTspice, without the 22 pF compensation cap, I see an oscillation around 1MHz, so these capacitors seem to be vital for proper functioning. As a side remark, I believe the gain of the first stage is not 1000x as you mention, but 500x. This is multiplied by 2 by the second stage.

5) I would be uncomfortable with up to nine trimpots in such a system!
To start with the gain setting, one trimpot would have been enough – just as 500+500=1000, so is 501+499.
Since offset on the input multiplied by the gain of the input amps exceeds by far the offset from OP5-OP7, I see no reason at all for the latter to be nulled.

With the OpAmps matched, you will need at the most two pots, one for OP1 to null OP1/OP3 and one for OP2 to null OP2/OP4.

Hans Polak,
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Burkhard Vogel replies:

Dear Hans Polak,

I very much appreciate your deeper look into my solution of a balanced low-noise measurement amp. Your remarks are useful because they can/will improve things, especially for those audio enthusiasts and DIYers who want to develop something similar that could solve their balanced measuring needs. In addition, this is a good chance to correct some article bugs too.

I will reply to your six points as follows:

1) Neither did I simulate the whole design nor did I take paired LTs. Nevertheless, just to better understand how it works/behaves, I also checked versions with a) LTs for OPs1 & 2 plus OP27 for OPs3 & 4, b) all 4 op-amps as OP27 or c) all 4 as OPA627.
Rather quickly one thing became clear: with 4 un-selected LTs I fell into the offset voltage trap you're mentioning. Fortunately, only one of them was the troublemaker. I changed it and by accident, I've got a reasonable offset voltage result at the output. The other op-amp types didn't show these problems that massively. I agree, in general, paired LTs would make sense the way you've described it.

   BTW, to overcome the described problems electronically do you have any idea for an elegant DC servo solution?

2) While testing the pmma I had several cell phone calls. I couldn't identify the problem you're raising. Generally, I'm sure it is a valid thing to tackle but for me the fight against vagabonding hum interferences is of much greater importance. However, a professional solution should have input EMI filters.

3) Of course, each op-amp should have two supply voltage decoupling Cs. I didn't mention this point because it's a general design rule for op-amps. However, you can identify most of them on Vol. 7's zoomed front page: their colour is something between yellow and orange.

4) With the shown 22p compensation caps I could stop a wild oscillation. Here, I don't think that simulation really helps because the pcb, wiring, and case layout has a huge influence on the stability too. I guess T&E will be the only solution to find stability.
Concerning 1st stage gain: the gain is 500. I found two bugs in my article, one on page 142, last paragraph, 2nd line: 500 should be 250 and on page 148, point 9), line 2: "500 each …" should be "250 each …".

5) Mainly, with the high number of offset trim pots I could study all DC and gain related corners of the circuit, especially in cases of lower gains. Therefore, the OP5&6&7 trim pots become necessary too. Thus, I would not recommend decreasing the shown number of trim pots in overall gain cases ≤100.
6) There is no corresponding information in the LT data sheet. However, to check the frequency response I've fed the input with a white noise signal (with 3 different generator output resistances: 2kΩ, 1kΩ, nearly 0Ω). I could not find a visible reduction at 20kHz (note: the reductions shown eg. in Figs 17 & 18 come

from the measurement system's 20kHz brick-wall filter – and I thought until receiving your letter – without punishment by an input resistance decrease).
Thus, with its increase of +20dB/dec towards lower frequencies the negative impact based on the op-amp's input resistance reduction effect at 20kHz seems to be rather small, but it can be calculated via the respective SN error. Here, this error is an SN improvement and - if being of importance only - it must be compensated in any SN calculation, like we have to do it with eg. frequency independent voltage dividers at the input of amplifiers.

With your LT input resistance values {100kΩ at 20kHz (I also add the results for a -10% worst-case = 90kΩ } the calculated errors for the white noise referred SN in B_{20k} become

- 0.04 (0.05) dB for 2kΩ DUT output resistance,
- 0.02 (0.03) dB for 1kΩ and
- 0.00 (0.00) dB for 0kΩ.

I guess these numbers allow ignoring this kind of impact in B_{20k}.

Some folks may use the pmma for a broader bandwidth than B_{20k}, eg. B_{100k} with 100kHz. I add the respective error results too, however, we should keep in mind that A-weighting measurements do not make sense here, because the filter transfer function is not defined >20kHz! In fact, in this broad bandwidth the frequency dependent decrease of the op-amp input resistance plays a bigger but still ignorable role in a ± 0.5dB exactness environment. It leads to the following calculated results:

- DUT o/p 2kΩ → 0.19 (0.24) dB,
- DUT o/p 1kΩ → 0.10 (0.13) dB,
- DUT o/p 0Ω → 0.00 (0.00) dB.

I hope things become a bit clearer now.

Burkhard Vogel
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