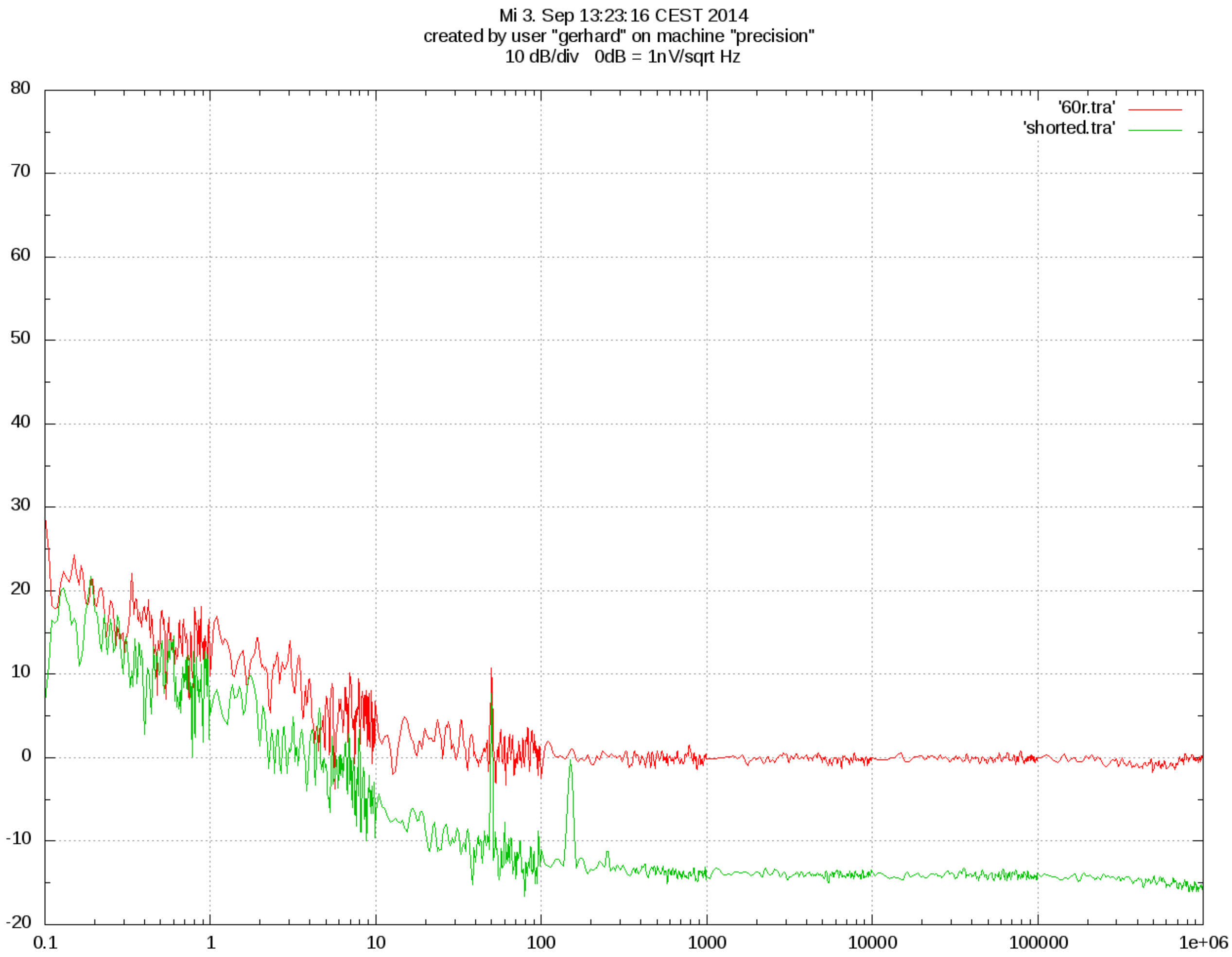
Gerhard W. Hoffmann:

A 220 pV/sqrt(Hz) low noise preamplifier



Voltage noise vs. frequency
green: input shorted
red: noise of 60 Ohms resistor = 1 nV/sqrt(Hz)

ghf@hoffmann-hochfrequenz.de

Hoffmann RF & DSP
Potsdamer Allee 26
D66606 St. Wendel
Germany

Specs:

Gain	20 – 40 – 60 – 80 dB
Gain boost	+6 dB (to make up for 50 Ohm vs. high impedance load)
Lower corner frequency	0.1 - 10 Hz
Upper corner frequency	1 KHz – 100 KHz – 1.3 MHz
Input impedance	10 KOhm
Output impedance	50 Ohms
Coupling	AC
Noise level verification	Internal 60 Ohm resistor that delivers a 1nV/sqrt Hz thermal reference level and an internal input short after the AC coupling capacitor.
Equivalent input noise density	0.9 nV / sqrt Hz for 20 dB gain 220 pV / sqrt Hz for 40 / 60 / 80 dB gain

Note that 10 to 100KHz is the usual bandwidth to specify bandgap references etc.

Controls:

J1	P1, P2	SMA, signal input
J2	P16, P17	SMA, signal output
SW1	P3 , P4	Lower corner frequency
SW2	P13 , P14/n.c./P15	Upper corner frequency, 1P3T
SW3	P12, P8/P9/P10/P11	Gain 20/40/60/80 dB 1P4T rotary
SW4	P18, P19	Gain boost 0 / +6 dB
SW5	P6, P5/ NC / P7	Pos 1: 1 nV/sqrt Hz noise density Pos 2: normal operation (wiper connects to nothing) Pos 3: input short (after dc block)
J3	P24	Battery charger

Principle

A single Analog Devices ADA4898 op amp features a voltage noise density of 0.9 nV / sqrt(Hz). This preamplifier parallels and averages 20 of these op amps to arrive at a noise density of 0.9 / sqrt(20) = 0.9 / 4.472 = 0.201 nV/sqrt(Hz), plus a little bit of noise from the feedback network and the following stages.

That does not come for free: at the same time, current noise gets worse by the same factor. This limits the usefulness of this amplifier to low impedance signal sources such as power supplies, voltage references or control voltages from op amp outputs etc.

The input bias resistor was chosen to be 10k, as high as possible while keeping the DC offset within a few 100 mV after 40 dB of gain. For a lower corner frequency of 10 Hz we then need an 1.5uF coupling capacitor, for 0.1 Hz we already need 150 uF, which costs quite a lot in terms of money and space. Since I found no adverse effects with 50V X7R capacitors, I did not stay with Mylar as in Version 1.1.

The 20 amplifiers come as 10 pairs of ADA4898-2 that are space and cost effective compared to AD797 or LT1028. The first stages have a voltage gain of 10 and deliver their output via 20 pcs of 360 Ohm resistors. The feedback resistors are only 50 Ohms to keep the impedance level and the voltage noise low. Since we expect only small AC voltages at this point, loading of the op amps is no issue.

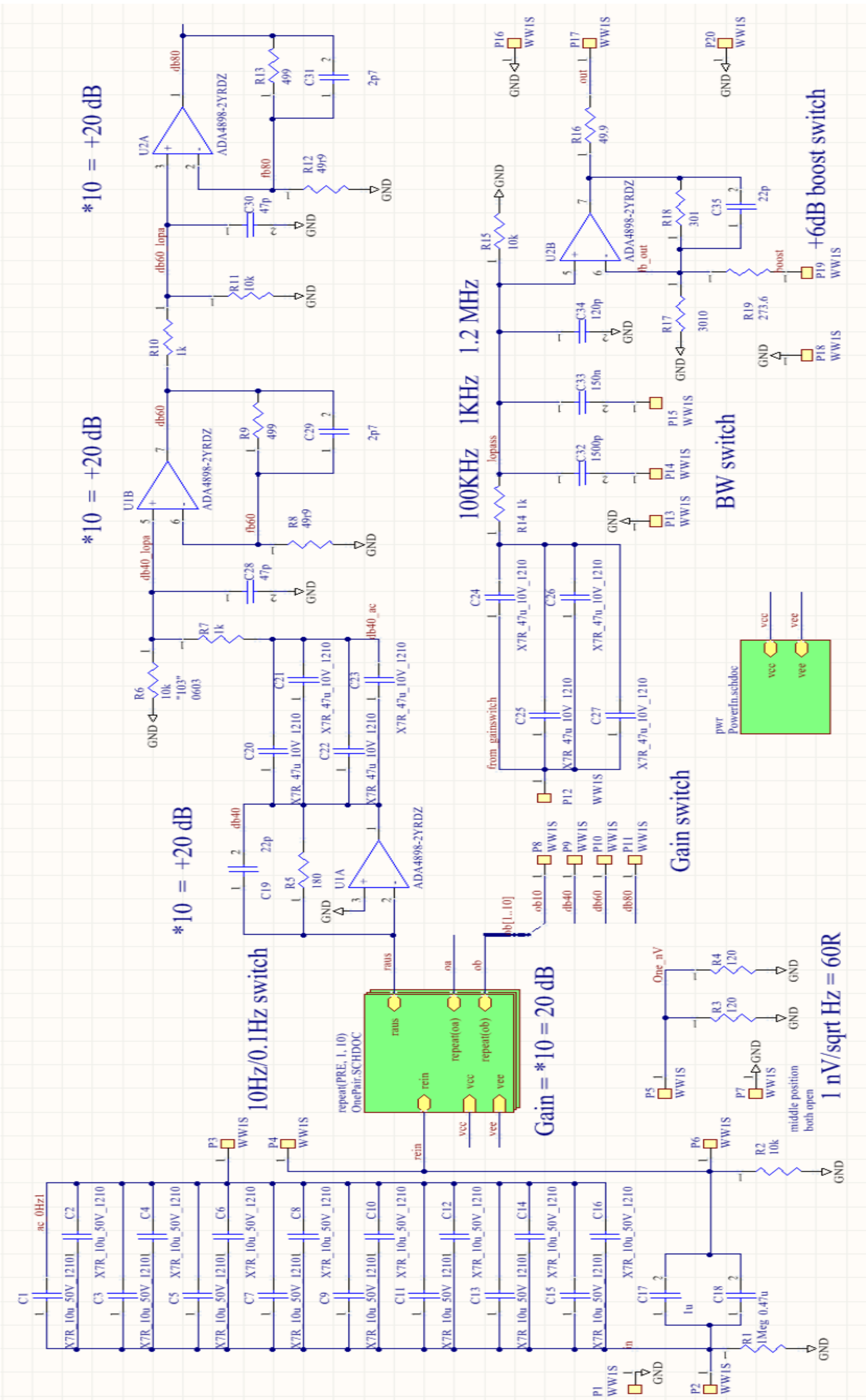
The second stage is an inverting amplifier that sums the currents delivered by the 20 first stages. The feedback resistance is 180 Ohms, so the voltage gain of the 2nd stage is 180 / (360/20) or a factor of 10. If one would use less input amplifiers, the gain of the 2nd stage would also drop in proportion. The feedback resistor then would have to be proportionally larger to keep the 20 dB gain. (Or the 1st stage output resistors should be smaller.)

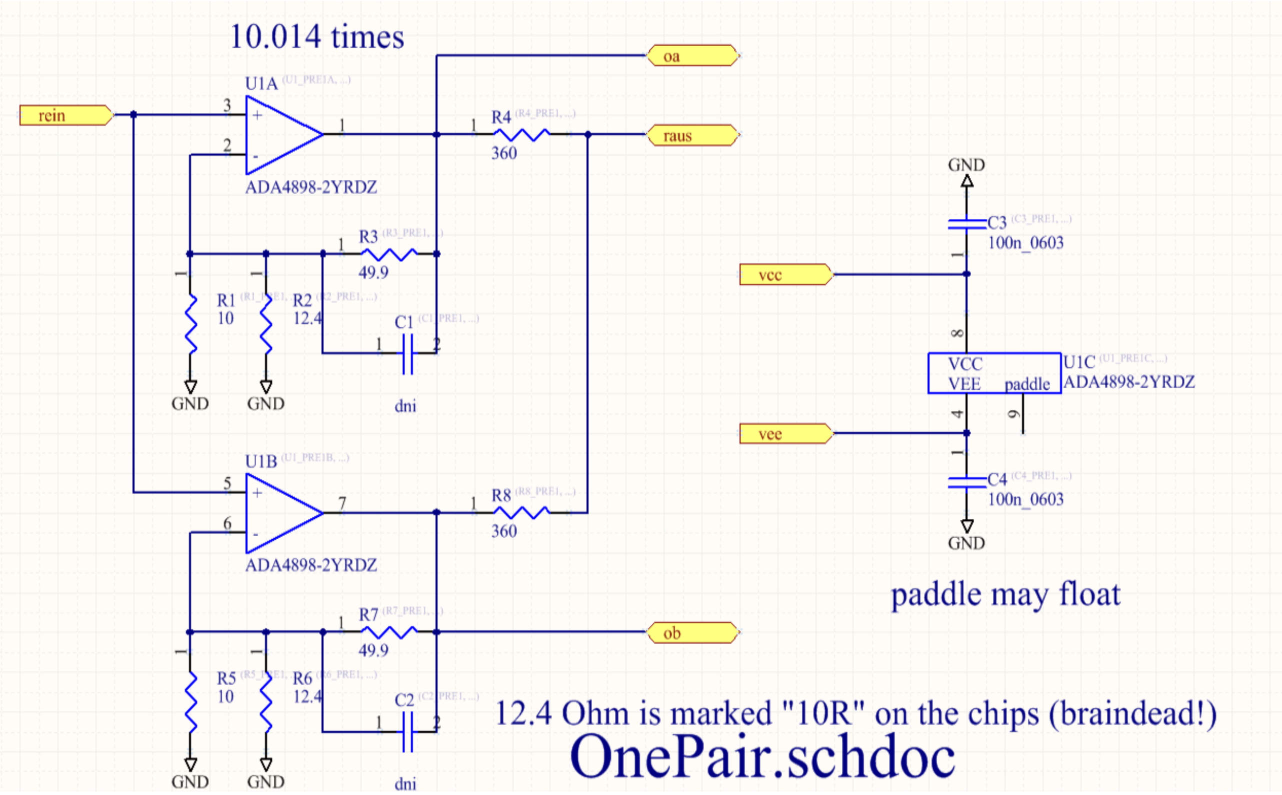
After the second stage is a dc block to keep the offsets small. A 1K / 47pF pole limits the upper corner freqency to 1.5 MHz. The 1K and the 10K bias resistor introduce a loss of 10/11, so the following stage must provide a voltage gain of 11 instead of 10 to make up for this. Since it is a noninverting op amp, we get convenient resistor values.

The last 20 dB stage works the same. The gain switch selects the appropriate amplifier outputs. The 20 dB position is directly fed by one of the 20 input amplifiers. Since there is no averaging in this case, voltage noise will be 0.9nV/sqrt Hz.

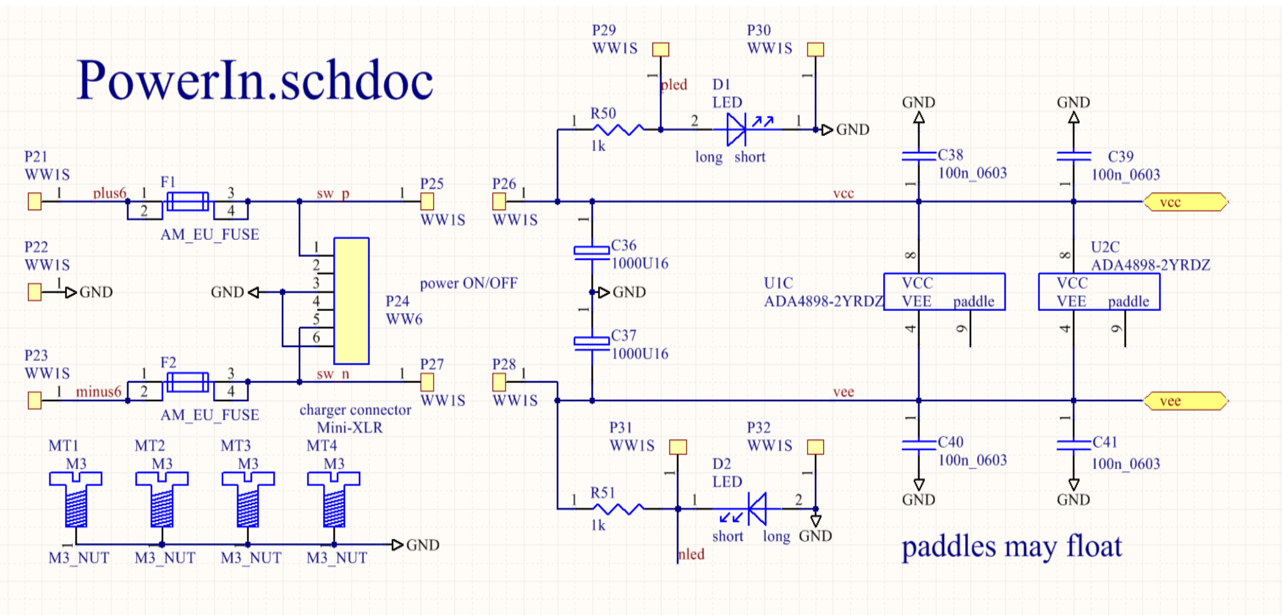
I would have liked a capacitor on the output of the preamp, but for a 50 Ohm output that would have been much to big. So I added another dc block and another low gain stage. This is either a *1.1 or a *2.2 amplifier that can provide a +6dB gain boost to keep the overall gain constant no matter if we use a 1MegOhm scope or a 50 Ohm spectrum analyzer as a load.

At the input of the last stage, the 1.5 MHz lowpass corner can be lowered to 1 KHz or 100 KHz to limit the noise bandwidth.


*10 = +20 dB
*10 = +20 dB
*10 = +20 dB
10Hz/0.1Hz switch
Gain = *10 = 20 dB
100KHz 1KHz 1.2 MHz
BW switch
Gain switch
+6dB boost switch
1 nV/sqrt Hz = 60R



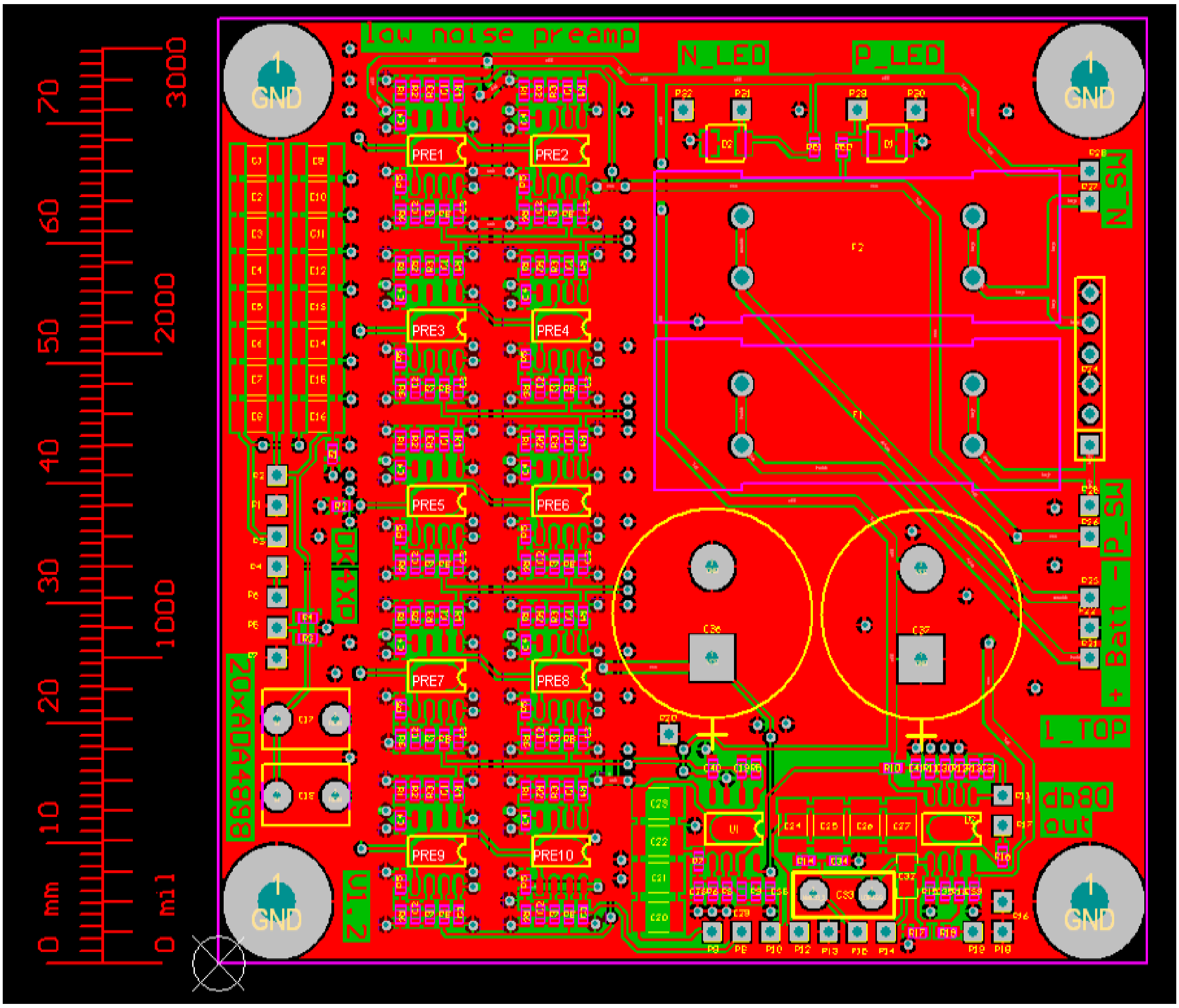
This amplifier pair exists 10 times in parallel. The output currents are summed by U1A in the root sheet. The output OB of amplifier pair number 10 also feeds the +20 dB position of the gain switch. The ROOMS-feature of the Altium Designer was used to draw the circuit and lay out the dual stage only once. The other 9 dual stages are just automatic copies.



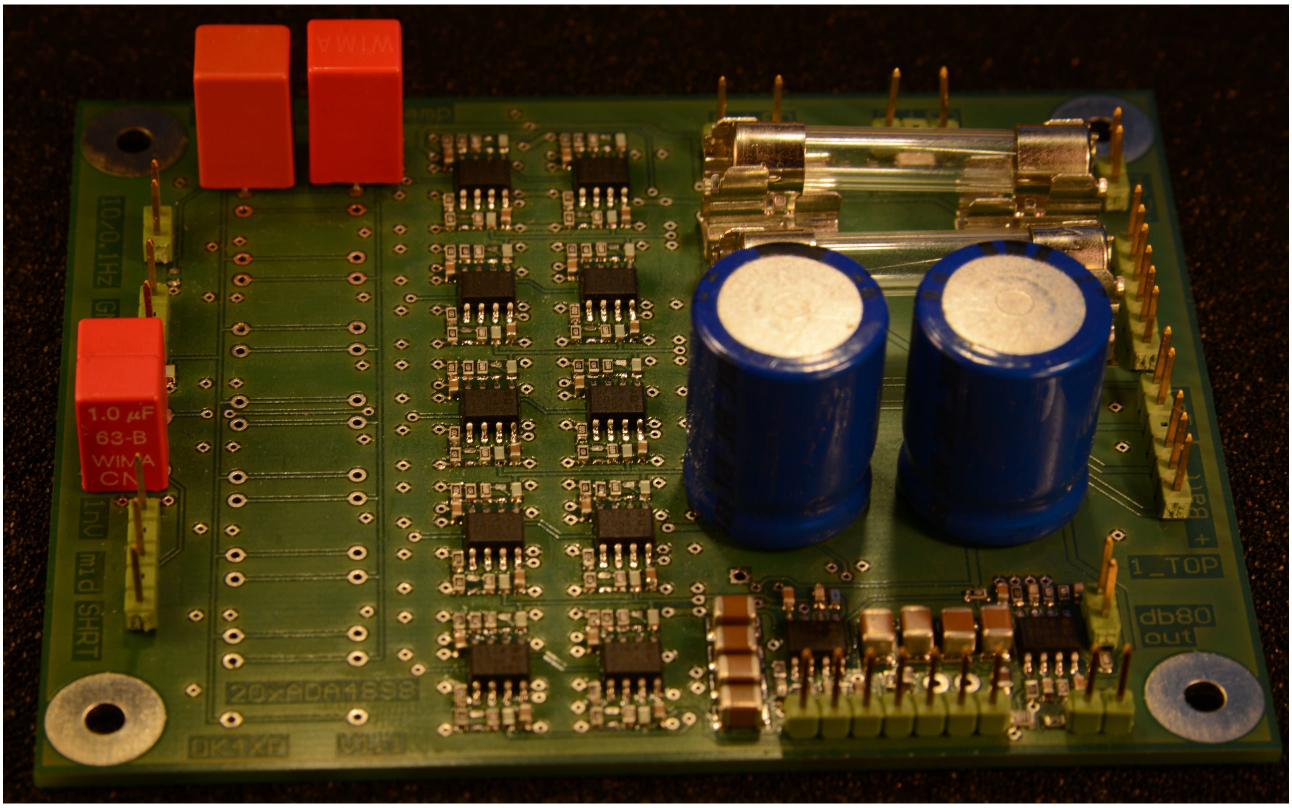
The amplifier is normally fed by 2 pairs of 5 NiMH cells. There are fuses where the accumulator voltage enters the board because the batteries can deliver a lot of current when shorted.

The batteries can be charged via a Mini XLR connector. One could also operate the amplifier via remote power, but that might result in noise loops. It is also possible to use a higher supply voltage, limited only by the op amp and capacitor specs. Note that the amplifier then may produce output voltages that are lethal to the 50 Ohm input of some delicate spectrum analyzers and you may have to solder the thermal pads of the op amps.

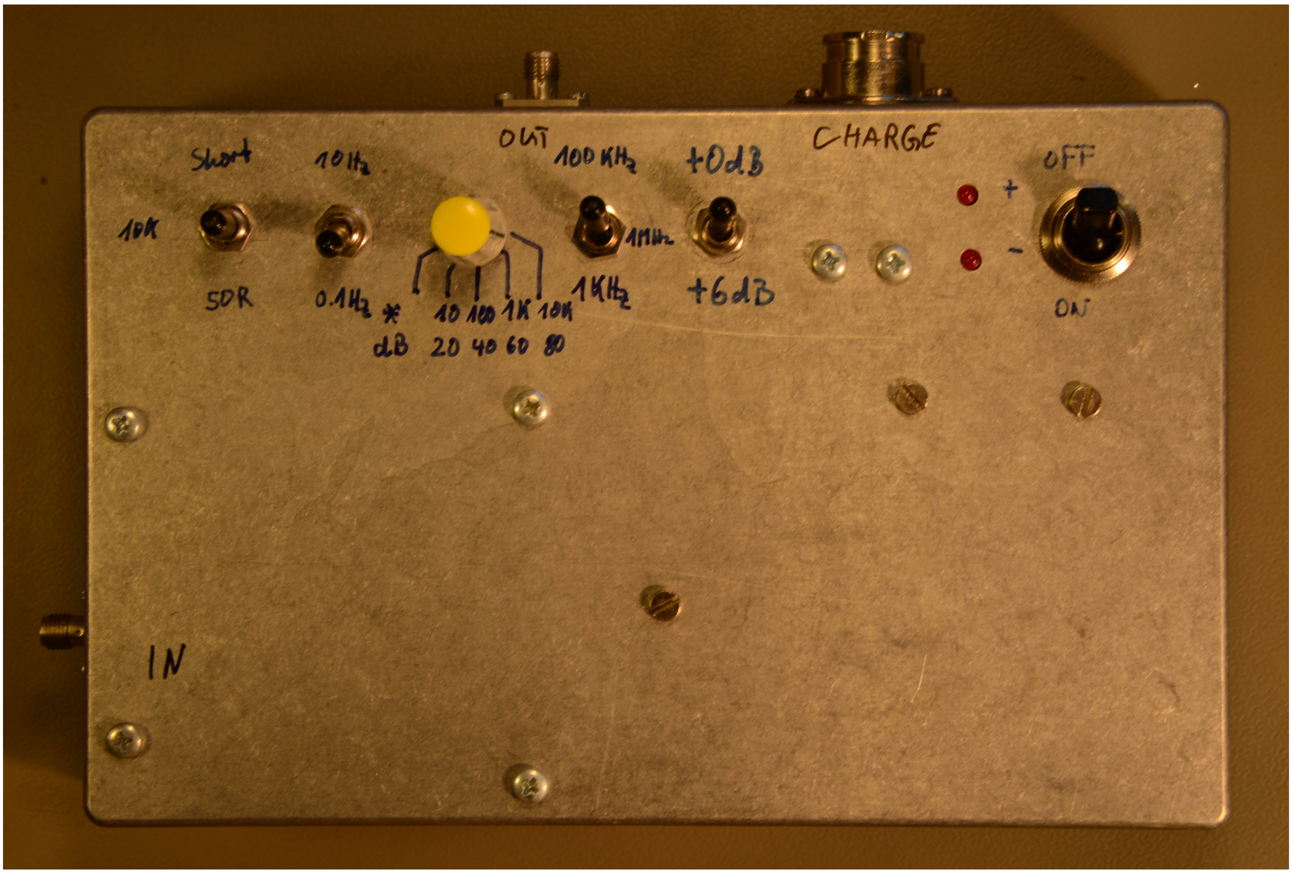
Layout, V1.2



The board is 2 layers, plated through. The bottom layer contains no parts and very few jumpers. It is almost all ground.



The board, Version 1.1   Yes, I skimped on the input coupling capacitors.



Version 1.0, completed

Parts:

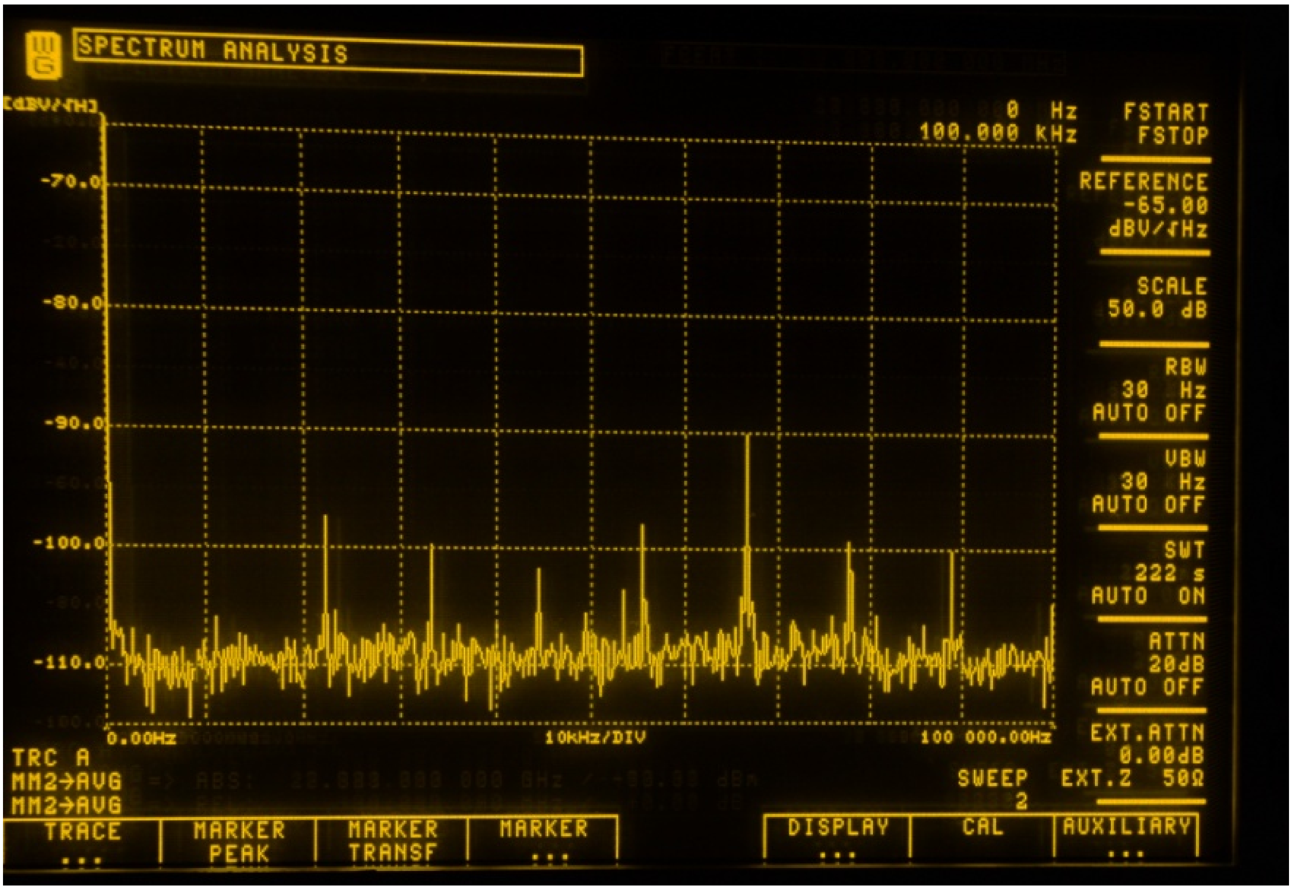
All resistors are Susumu 0603 thin film 0.5%.
On the very first board I used 16 pcs. ceramic 10u 50V 1210 X7R as input coupling capacitors without noting any drawbacks such as vibration sensitivity or unwanted currents. Version 1.1 used 10uF Mylar foil capacitors but getting them in an acceptable size is really hard, so Version 1.2 returned to the ceramics. The real thing would be Polypropylene, and those capacitors are about the size of the entire board.

All parts, except the board, fuse holders and some foil capacitors are available at Digi-Key.

Measurements

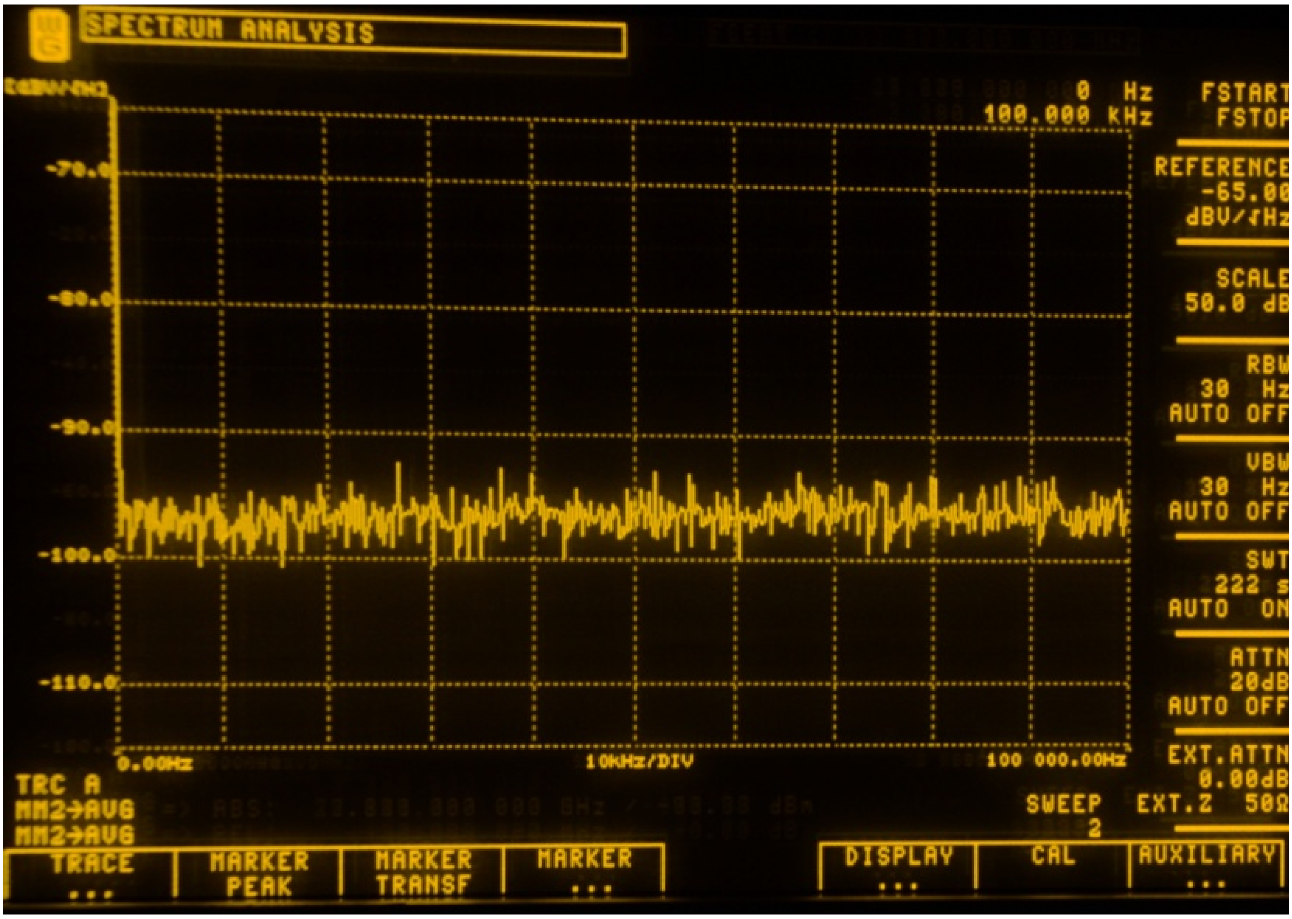
W&G SNA-33 spectrum analyzer, 20 Hz-26GHz, downto 1 Hz resolution

556/dsc3609: input shorted



The peaks are lab noise, especially the energy-saving lamp on the bench.

dsc3610: input terminated with 50 Ohms = 0.909 nV/sqrt Hz thermal noise at room temperature.



During the first measurements the noise reference resistor was 50 Ohms = 0.909 nV/sqrt Hz; its thermal noise ist abt. 13 dB louder than the amplifier input shorted, so the equivalent input voltage noise is 13 dB below 0.909 nV/sqrt Hz or about 200 pV/sqrt Hz.

I did change the resistor to 60 Ohms in the meantime since that equals 1nV/sqrt Hz pretty exactly.

History

V1.0	2013 Aug 16	Initial release
V1.1	2015 Jan 8	added logarithmic noise plot on page 1