EB-108/435 ALL-JFET I/V converter, Filter and Buffer for DACs.

The EB-108/435 is a very high quality I/V converter/filter/output buffer, developed specifically for the **HB-DAC1704** DAC board (1), but can also be used with the **HagDac** DAC (2), the **RAKK DAC** (3) and other DAC boards. It can operate with current output DACs like the PCM1702, PCM1704, PCM1792/1794, AD1955, TDA154x, etc., but can also be used for DACs with voltage output, like the Wolfson 8740/8741 voltage DACs. Due to its excellent linearity and low noise it is equally suitable for all DAC systems.

Two sets of I/V converter/filter/output buffer are laid out on one dual board, size: 210 x 145mm. Power supply requirement is 100mA at +/- (18-24) V per channel. Independent power supply and regulator is recommended for the two channels. Only high quality components are used in the circuits: Nichicon FG, ELNA CERAFINE/SILMIC II, MICA and polystyrene caps, and VISHAY-Dale, PRP and Caddock resistors. The EB-108/435 is only available on teflon PCB.

The "analog" circuitry.
A block schematic of this "analog" part of the circuitry is shown in fig. 1.

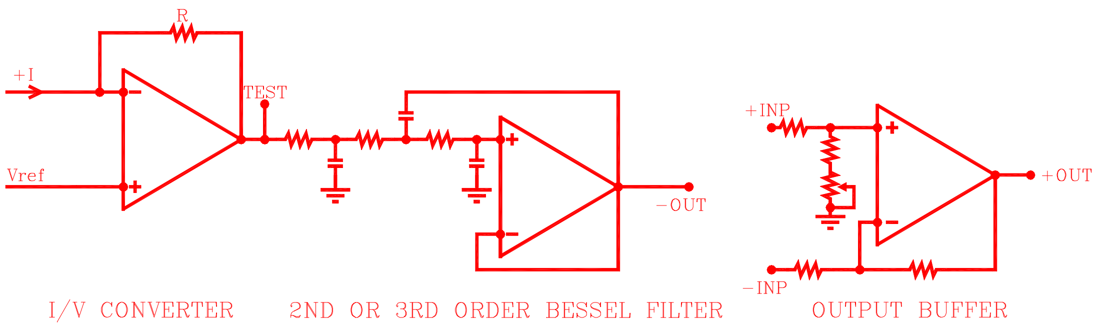


Fig. 1. The "analog" circuitry in a CD player.

The amplifier on the left-hand side is the I/V converter that converts the current output from the DAC to a voltage. The block in the middle is the filter, which is removing the digital noise that remains from the conversion process. Theoretically everything above 20 kHz should be "removed", and this is what the early CD players did with very steep "brick-wall" filters. These filters had a very undesirable transient response and combined with the opamp used the resulting sound was a very far cry from high-end.

With the present over-sampling systems there is no need for such steep filters and we can use less steep ones with much better transient response. The better CD players are using Bessel filters, with 2-5 poles. I have chosen a 2/3-pole one in this design. First of all this is easy to implement and secondly practical tests show that this is adequate for over-sampling systems.

The amplifier on the right hand side is an optional output buffer that can be used as a unity gain inverter, or a balanced-to-unbalanced converter. The output of the filter buffer is actually a negative output, since the I/V converter inverts the phase. The unity gain inverter restores the phase to "normal". Of course it also allows you to have a balanced output from your CD player, by taking the –OUT from the filter and the +OUT from the output buffer.

The gain-blocks shown in fig. 1 are usually IC opamps. There are a number of suitable ones for these functions, Analog Devices, National Semiconductor, TI/BB are offering good sounding opamps. Unfortunately a lot of the CD-players are still using older, less suitable ones, like the 5534 family devices and their derivatives.

But even if you use the best ones on the market, they cannot compete with discrete designs in my opinion. And certainly not with the ones made with our ALL-JFET/FET technology! Proven through the ALL-JFET/FET line amps and the ALL-JFET/FET power amps, the ALL-JFET/FET designs offer unprecedented resolution.

The ALL-JFET I/V converter.

Fig. 2 shows the schematic of the discrete ALL-JFET I/V converter.

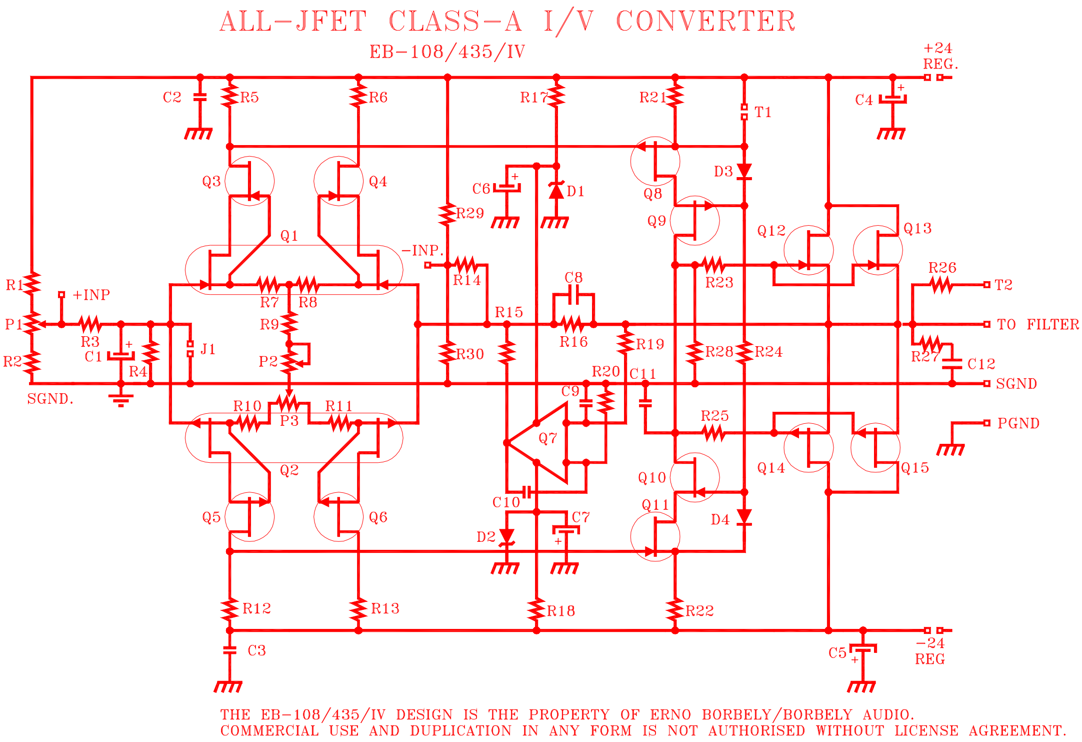


Fig. 2. The ALL-JFET I/V converter.

The I/V converter is a high quality, low-noise, discrete opamp. Q1 and Q2 are low-noise complementary dual JFETs. They are cascoded with single JFETs to reduce input capacitance and to improve linearity. The second stage is a complementary JFET cascode stage, operating at approx. 9mA. The output stage is a complementary JFET follower, here shown with two JFETs in parallel on both sides. The second pair is optional, for normal feedback and load impedances, i.e. >2k Ohm, they can be left out, but they are needed for the DACs with high current output, where the feedback resistor has a very low value. Q7 is a JFET-input opamp, which is sampling the output offset and corrects it to less than a couple of mV.

For current output DACs the output from the DAC is connected to the –INP of the converter, with R14 shorted. The feedback resistor R16 determines the conversion factor, i.e. the V_{out}/I_{in} ratio. If the DAC current is ±1.2mA, and you select R16=2k4, then the maximum output voltage will be $V_{out}=I_{in}$ x R16=5.7V peak-to-peak or 2V RMS. For DACs with higher current output R16 has to be reduced.

For DACs operating with symmetrical ± supply (PCM 1704, etc.) the + input of the I/V converter is grounded by jumper J1. When DACs with single supply are used the + input has to be biased at approx. ½ of the supply voltage. Some DACs have a Vref available which is generated by the DAC chip itself, and this can be connected to the +INP input on the I/V converter. If Vref is not available from the DAC then this has to be generated from the supply voltage of the I/V converter. The +INP is then adjusted by P1 for zero offset at test point T2.

Typical specs for the I/V converter, measured as a normal amplifier:

Open Loop gain:	76dB
Open Loop THD:	3V/1kHz: 0.05%
Closed Loop THD:	3V/1kHz: 0.0009%
Input impedance (-INP):	<0.3 Ohm
Rise time:	200nsec.

The ALL-JFET filter.

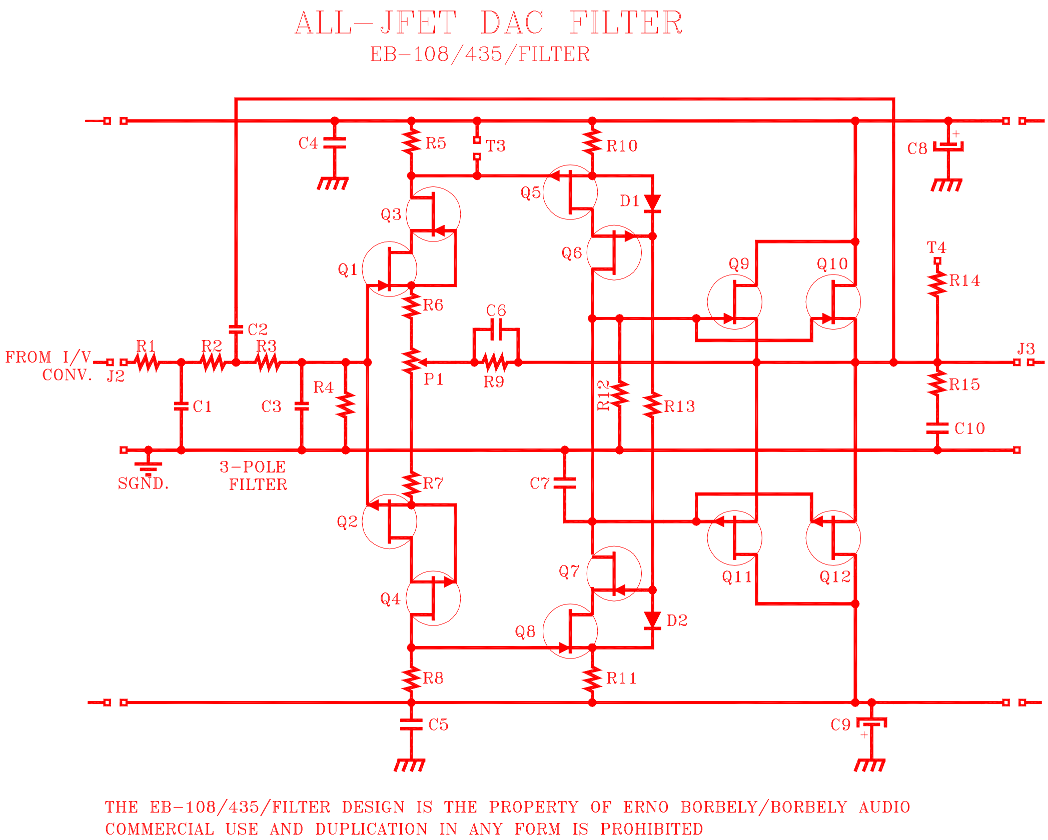


Fig. 3. The 3-pole BESSEL Filter.

Fig. 3 shows the 3-pole filter/buffer. The filter buffer is a high quality, low-noise, very fast discrete opamp. The input stage is a complementary cascode JFET circuit. The second stage is a complementary JFET cascode stage, operating at approx. 10mA. The output stage is a complementary JFET follower, here shown with two complementary JFETs in parallel. The second pair is optional, for normal feedback and load impedances, i.e. >2k Ohm, they can be left out. Since the buffer is working with unity gain, there is no need for a servo circuit.

Normally the filter is -0.1dB at 20kHz and is -3dB at 55kHz. With 192kHz DACs the -3dB can be increased to 100kHz or 150kHz. Also, some newer DACs do not require 3-pole filters, a 2-pole is sufficient. A 2nd order 100 kHz or 150 kHz Bessel filter can be implemented as follows:

100kHz:
R1 = shorted
C1 = removed
R2 = R3 = 4k75
C2 = 300 pF (150 || 150 pF)
C3 = 220 pF

150kHz:
R1 = shorted
C1 = removed
R2 = R3 = 4k75
C2 = 200 pF (100 || 100 pF)
C3 = 150 pF

Typical specs for the filter buffer:

O.L. gain:	48dB
O.L. THD:	3V/1kHz: 0.05%
C.L. THD:	3V/1kHz: 0.001%
Rise time:	<200nsec.
Minimum load:	2k

The ALL-JFET output buffer.

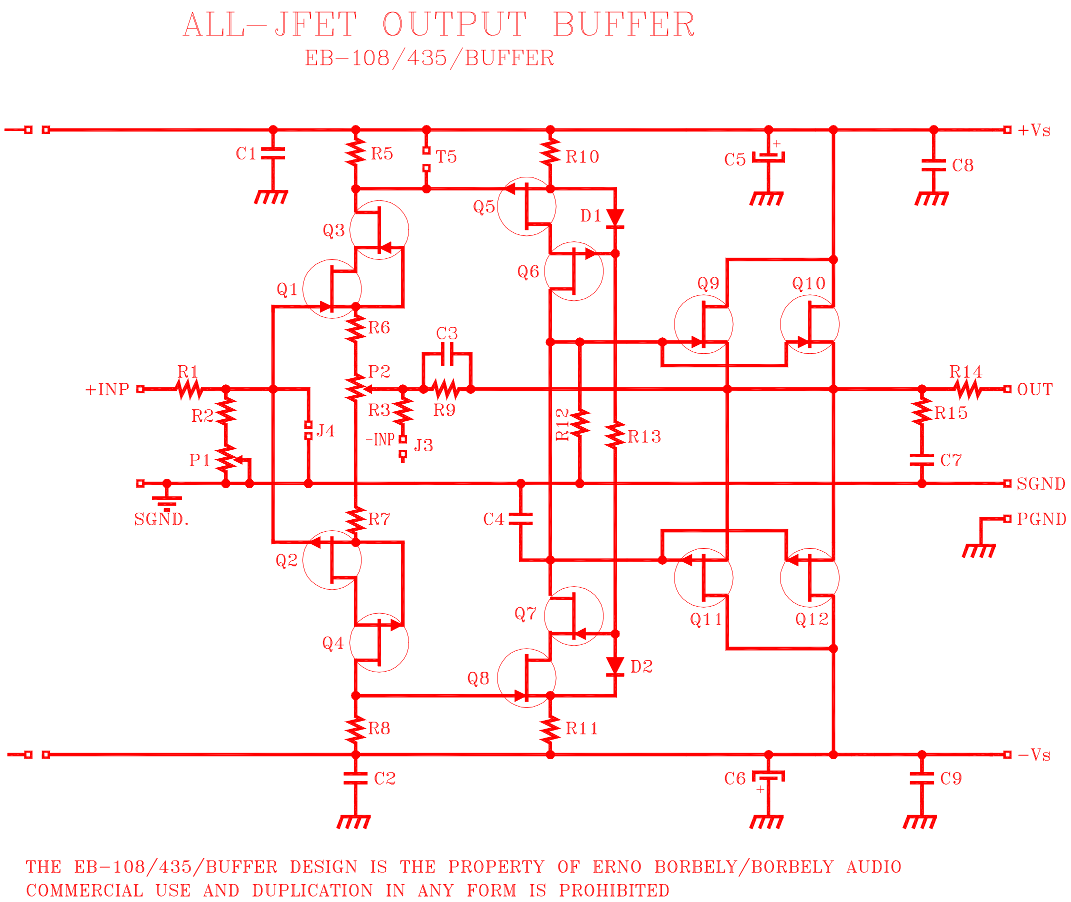


Fig. 4. The output buffer.

The output buffer is also a very high quality discrete opamp, using only JFETs. Since the I/V converter inverts the phase in active converter mode, the output of the filter buffer is –OUT. The output buffer restores the correct phase to +OUT. Naturally, the two outputs being out of phase you have a balanced output from the DAC.

When used as a unity gain inverter the +INP has to be grounded (Jumper J4), and the output of the filter is connected to the –INP, through jumper J3.

Application options.

The EB-108/435 can be used with dual and single supply DACs. Fig. 4 shows the application for a dual supply DAC, like the BB PCM-1704. Since the DC output of the PCM-1704 is zero Volt with no signal, the +INP of the I/V converter is grounded. The output buffer is connected in inverting mode, producing the +OUT. A balanced output is available from the output of the filter (-OUT) and the output buffer (+OUT). This application works very well and sounds very good with the **HB-DAC1704** DAC board from BORBELY AUDIO (1) and also with Jim Hagerman's **HagDac** (2).

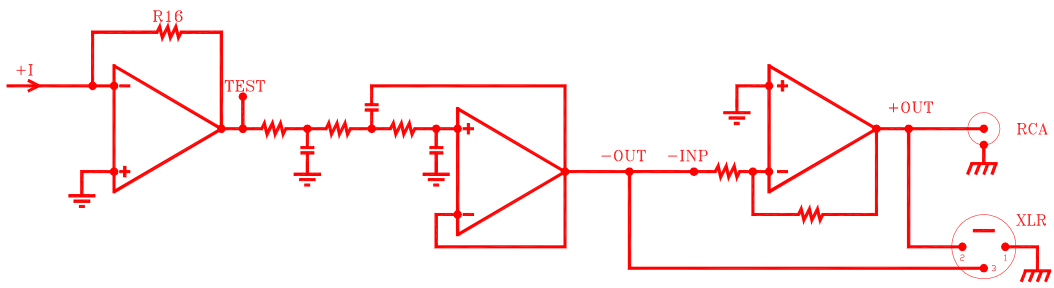


Fig. 4. Application of EB-108/435 for dual supply DACs.

Dual supply DACs can easily be used with passive I/V conversion, see fig. 5. The I/V converter is used as a non-inverting amp with gain. The conversion is done with a resistor, shown as R4 at the +INP. Normally R4 cannot be chosen arbitrarily, because of the protection diodes at the current outputs, consult the appropriate DAC datasheet. Typically R4=100 Ohm, which will produce a voltage of I x R4 at the +input. With 2mA p-p current available from the DAC, this voltage will be 200mV p-p, or ~70mVRMS. If a standard 2VRMS is needed at the RCA output, then the amp has to have a gain of 28x or 30dB. R16/R14 has to be selected to provide this 30dB gain. The XLR balanced output will provide 6dB more output than the RCA.

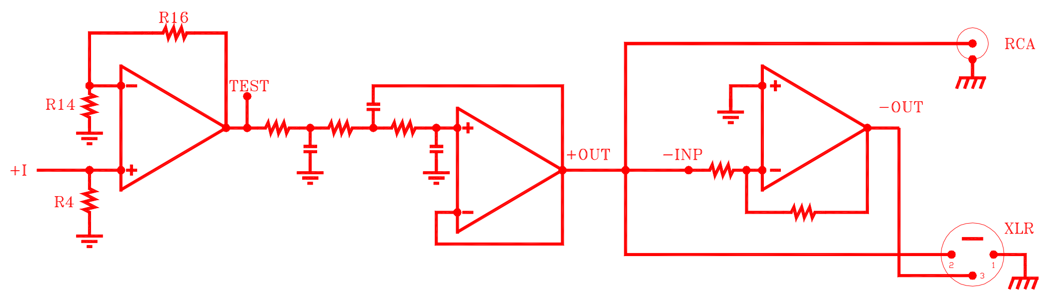


Fig. 5. Passive I/V conversion with dual supply DACs.

Fig 6 shows the application of EB-108/435 for single supply DACs, like the Philips TDA154x series. The current output of the single supply DACs is sitting at approx. ½ of the DAC's supply voltage, i.e. ~2.5V for 5V DACs. If you connect the current output of such DACs to the –INP of the I/V converter with the +INP grounded, the output of the I/V converter will be -2.5V. In order to eliminate the DC offset from the I/V output the +input has to be biased up to approx. ½ the DAC's DC output.

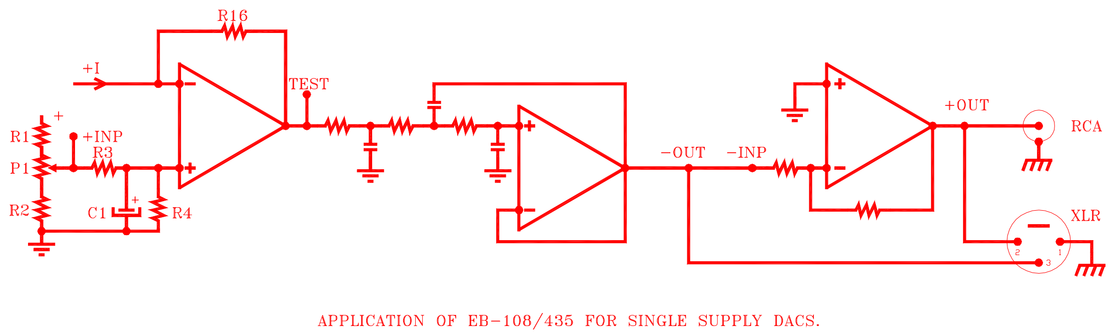


Fig. 6. Application of EB-108/435 for single supply DACs.

If a reference voltage is available from the DAC, then the voltage divider R1/P1/R2 is not needed. Connect the reference voltage from the DAC to +INP on the board. R3/R4 has to be selected so that the output offset is zero. Consult the appropriate datasheet for the R3/R4 values. If a reference voltage is not available, then install R1/P1/R2 and adjust P1 for zero offset at the I/V output.

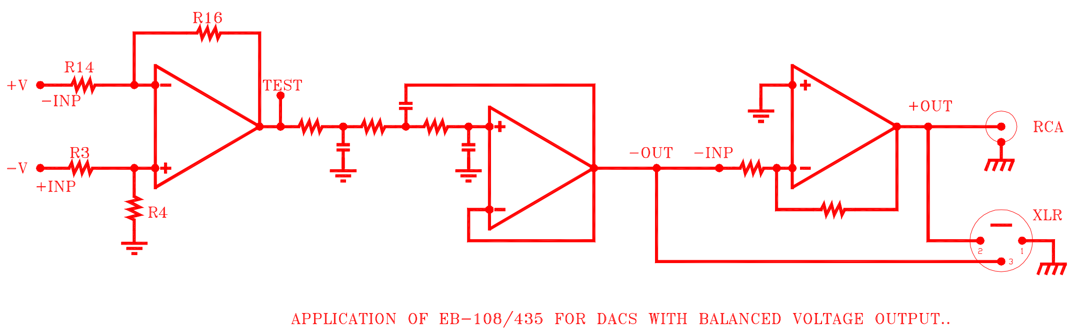


Fig. 7. Application of EB-108/435 for single supply balanced current output DACs with passive conversion and balanced voltage output DACs.

Fig. 7 shows the application of the EB-108/435 for single supply balanced current output DACs with passive conversion like the **RAKK DAC** using the PCM-1794 (3) and balanced DACs with voltage output, like the Wolfson 8740/8741. The I/V converter is used as a balanced-to-unbalanced converter. The single supply DACs have a DC offset at the output. Using equal resistor ratios on both inputs (R16/R14 and R4/R3) normally eliminates the DC offset. (Remember that the input impedance on the –INP is not equal R14!!) Lets assume –V=+V=2.5V. The DC voltage at the +input is 1/2x 2.5=1.25V. Due to the feedback the DC voltage at the –input is also 1.25V. This results in zero Volt at the I/V output.

The EB-108/435 can also be used for balanced current output DACs using two PCM-1704. Both I/V converters, filters and output buffers have to be used on the dual EB-108/435 board for a balanced channel. i.e. two dual boards are needed for stereo. Fig. 8 shows one channel of a balanced circuit. For dual supply DACs like the PCM-1704, the +inputs of the I/V converters are connected to ground.

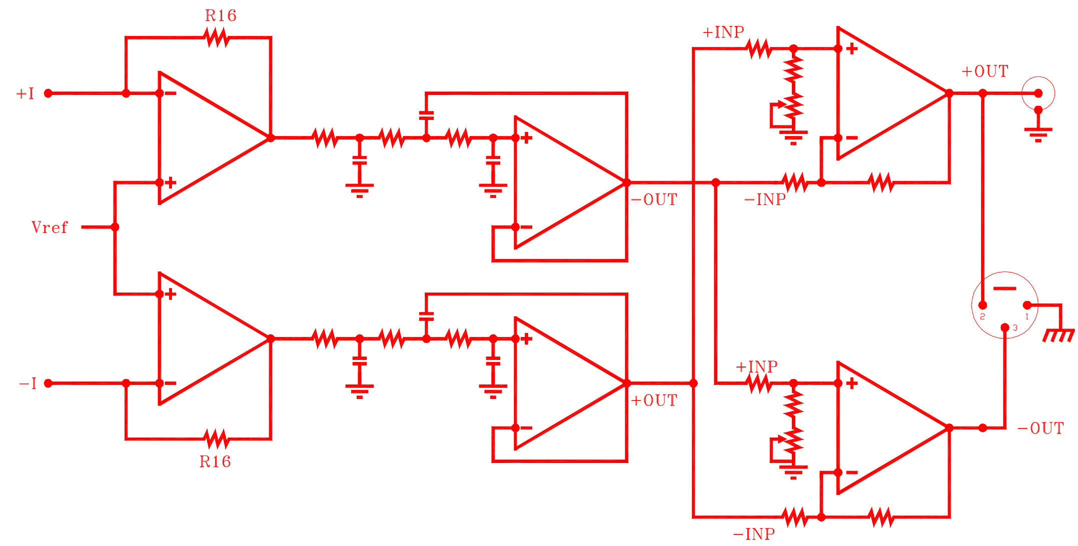
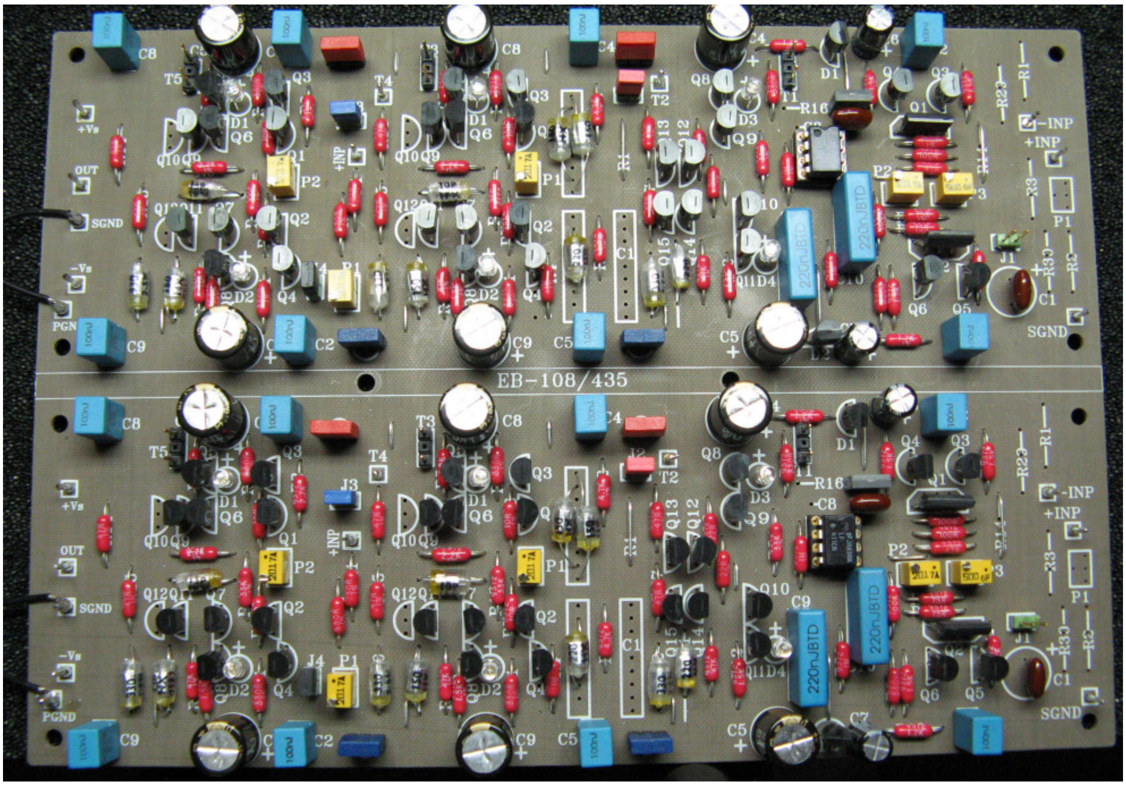


Fig. 8. Professional I/V converter and filter with high CMRR balanced output.

The added advantage of using the EB-108/435 for this application is the availability of the two output buffers. These can be wired up as balanced-to-unbalanced converters for both phases. Both of the buffers also have CMRR trim capabilities, creating high CMRR balanced outputs, which is considered very important in professional applications. An unbalanced RCA output with high CMRR is also available as an additional benefit.

Regulator and power supply for EB-108/435.

The EB-108/435 needs approx. 100mA at +/-(18-24)V per channel. Recommended regulators are the ALL-FET EB- 208/418 dual series regulator or the EB-906/255 dual shunt regulator. Appropriate power supplies are the EB-108/291 dual PS with 4-pole Jensen capacitors or the EB-906/275 low ESR power supply.



The EB-108/435 teflon PCB with PRP resistors and ELNA capacitors. Configured for parallel coupled PCM-1704s in active conversion.

References.

1. BORBELY AUDIO: HB-DAC1704 Ver. 1.01 DAC board with AES, SPDIF and USB or I2S inputs, using 4 PCM-1704 DAC chips for balanced or parallel operation.
http://www.borbelyaudio.com/pics/HB_DAC1704_V1_01b.pdf

2. **Hagerman Technology**, www.hagtech.com/hagdac.html.
HagDac DAC card custom modified for Borbely Audio

3. **K&K Audio**. http://www.kandkaudio.com/digitalaudio.html
RAKK DAC Mark II Digital-to-Analog Converter.

Acknowledgements.

My sincere thanks to Miklós Kiss of Whiteful Audio, www.whiteful.ini.hu (Online DIY - magazine in Hungarian and English) for designing test boards for balanced PCM-1704 and balanced PCM-1794 DACs, which not just served as test jigs, but also perform as my best-sounding outboard DACs.

Also thanks to Jim Hagerman of **Hagerman Technology** for supplying his HagDac card custom modified for operating the PCM-1704 in active conversion mode.