NEW APPROACH TO LINEAMPS AND DACS

By Erno Borbely

A friend of mine asked me the other day whether I could put together a simple lineamp for him. But, he said, it must have a crossover in it, because he has a subwoofer, and he does not want a separate box just for the crossover. I knew that he had a pair of small Magnepans and had just built a subwoofer box that he wished to try out. He thought 100Hz would be an appropriate crossover for the sub, and the slope should be 18dB per octave. Since I had the same Magnepans, I thought this was a good starting point.

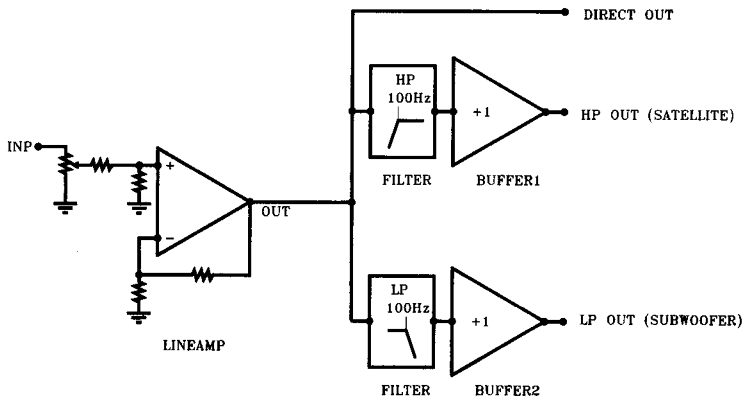

FIGURE 1: Comparison of combined lineamp and crossover and existing crossover design.

Some time ago, I designed a simple version of the crossover published in the 1/94 issue of *Speaker Builder*[1] that I thought might fill the bill. First I drew a block schematic of the combined lineamp/ crossover and then compared it to the existing crossover design: it was a perfect fit (*Fig. 1*). The input is the actual lineamp of the setup, and then it has two buffers with associated components for the crossover. But take a look at the building blocks before I explain how to use them as a combined lineamp/crossover.

TABLE 1

TYPICAL LINE-AMP SPECIFICATIONS

R1 = 100, R3 = 100k, R15 = R19 = 10k, C4 = 22pF
Open-loop gain: 48dB
Open-loop frequency response: –3dB at 20kHz
Open-loop THD: 0.05% at 10V/1kHz
Closed-loop gain: 6dB
Closed-loop frequency response: –3dB at 900kHz
Closed-loop THD: 0.0015% at 10V/1kHz
0.0022% at 10V/10kHz
Output impedance: approximately 30Ω
Rise/fall time: 200ns

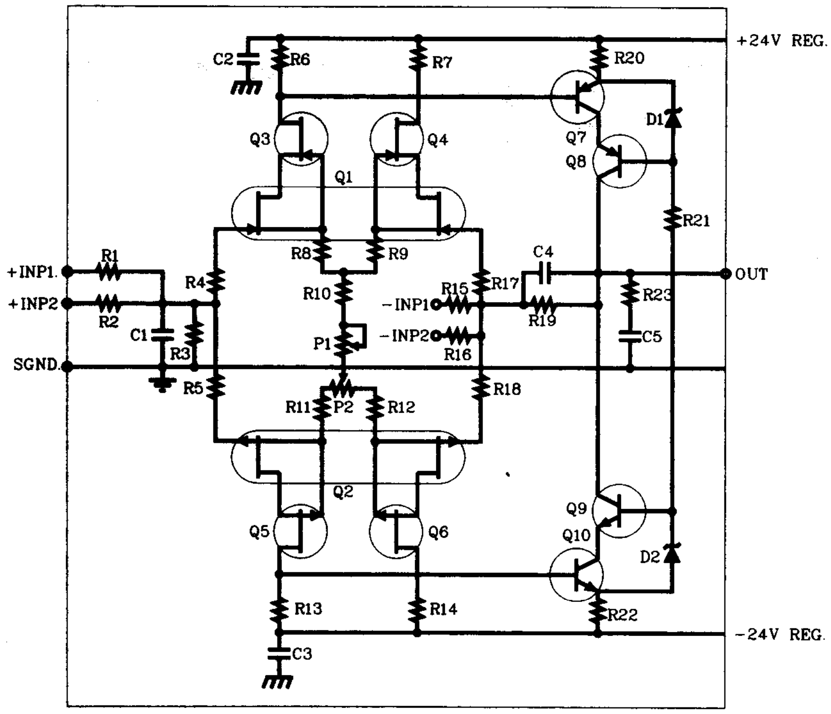

FIGURE 2: Class A, all-cascode op amp.

Lineamp

The lineamp is a discrete all-cascode op amp, operating in Class A (*Fig. 2*). *Table 1* shows its typical specifications. As you will see later, it is actually a modified buffer, its input stage being converted to a fully complementary differential input. The input includes a dual monolithic low-noise JFET for DC stability, but otherwise uses the same devices as the buffer.

The input JFET cascodes operate at 2mA, which is set with P1. P2 adjusts the offset of the amplifier. The second stage, a bipolar cascode, operates at approximately 15mA, set by the first-stage current. D1 and D2 bias the cascode transistors Q8 and Q9 relative to the emitter voltage of Q7 and Q10. R21

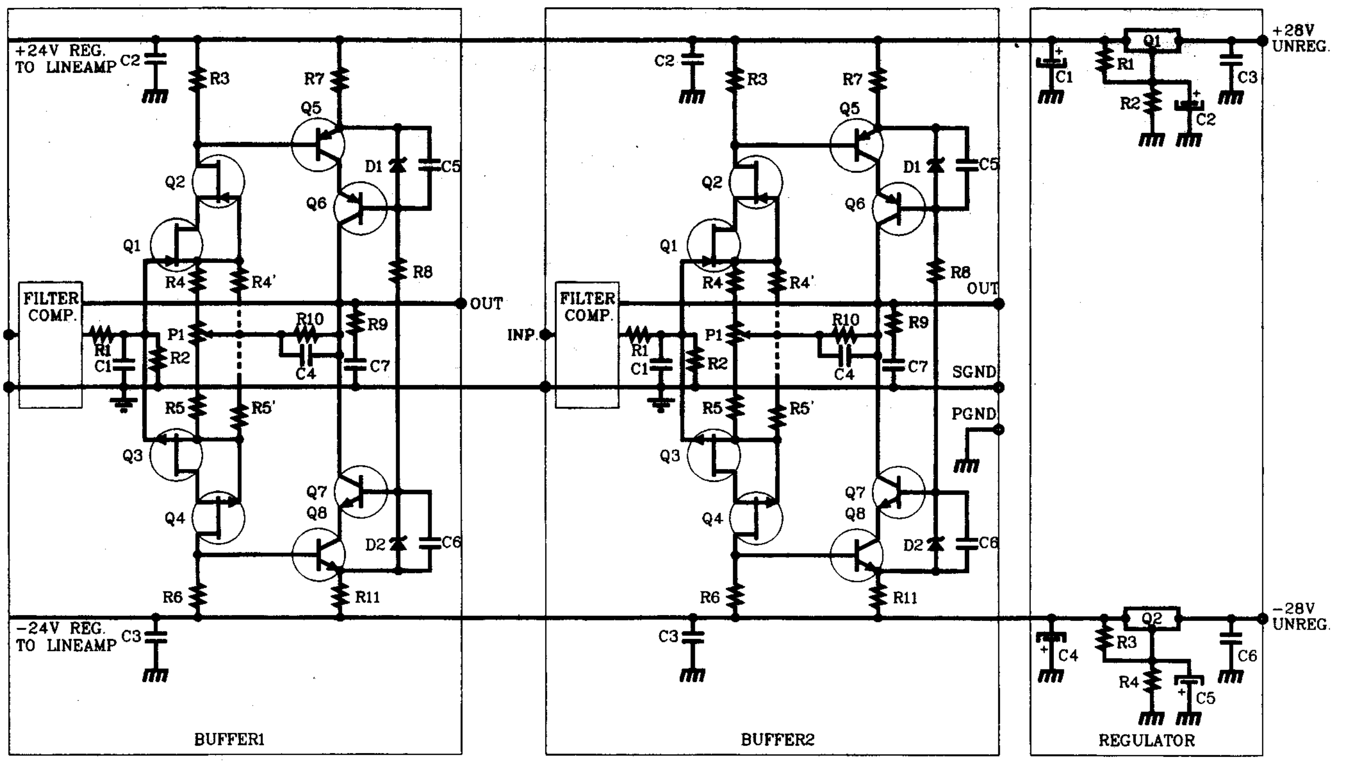

FIGURE 3: Filter buffers.

TABLE 2

TYPICAL FILTER-BUFFER SPECS

Open-loop gain: 47dB
Open-loop frequency response: –3dB at 110kHz
Open-loop THD: 0.05% at 2V
Closed-loop frequency response: –2dB at 1MHz
Closed-loop THD: 0.0015% at 6.5V/1kHz
0.0022% at 6.5V/10kHz
Output impedance: approximately 30Ω
Rise/fall time: <200ns

forces a current of about 1mA through the reference diodes.

R19, C4, and R15 form the feedback network, which connects the output back to the inverting input of the lineamp. R23 and C5 are part of the buffer's stability network.

The lineamp is a linear, wideband, low-noise circuit. It is very flexible, and you can configure it in many different ways. It can operate as a unity-gain buffer, with both positive and negative inputs available. You can also use it for normal, single-input application with gain, both in noninverting mode (-INP1 grounded to SGND, input connected to +INP1) and inverting mode (+INP1 grounded to SGND, input connected to -INP1).

It can also process balanced signals, with the positive side of the balanced signal connected to the +INP1, and the negative side to the -INP1. Finally, you can use it to sum two channels into one signal for a common subwoofer, both in single-input mode (-INP1 grounded to SGND and the two channels connected to +INP1 and +INP2) and in balanced-input mode (the two channels connected to +INP1/-INP1 and +INP2/-INP2, respectively).

Filter Buffers

The buffers are probably familiar to some of you from the *Speaker Builder* article. These are low-noise, high-speed, unity-gain buffers, marked BUFFER1 and BUFFER2 (*Fig. 3*). *Table 2* shows the specifications. Each one is a two-stage circuit consisting of a JFET-cascode input stage and a bipolar-cascode second stage, both operating in pure Class A.

Due to the cascode-connected JFETs, which operate at 2mA drain current, the input stage has very low input capacitance and a high common-mode voltage swing. It is essential to match Q1 and Q3 to ±10% (or better) of IDSS (you can use either the "BL" or the "V" group) to get good linearity and low offset. The second stage operates at about 15mA, which is set up automatically when the current in the first stage is 2mA.

D1 and D2 bias the cascode transistors Q6 and Q7 relative to the emitter voltage of Q5 and Q8. R8 forces a current of around 1mA through the reference diodes. R10 and C4 connect the output back to the inverting input of the buffer, making the gain equal to 1. R9 and C7 are part of the buffer's stability network.

Although there is a 1M resistor (R2) at the input, it is not installed when you use the buffer as a filter, thus helping to increase the input impedance of the buffer so that it doesn't load the filter network. (R1 and C1 also represent a load, but only outside the audio range, and so do not influence the operation of the filter.)

The resistive components of the filter network accomplish the DC connection of the input, either connecting it to the output of the previous buffer or to ground. If you test the buffer without the filter network, you must provide a DC connection through R2. The output is derived directly from the collectors of Q6 and Q7; i.e., R9 is not in series with the output, which reduces the output impedance, thus improving the filters' accuracy.

In addition to the lineamp and the two buffers, two regulators are on the board, supplying it with ±24V. These are 317/337 three-terminal regulators—the simplest solution to on-board regu-

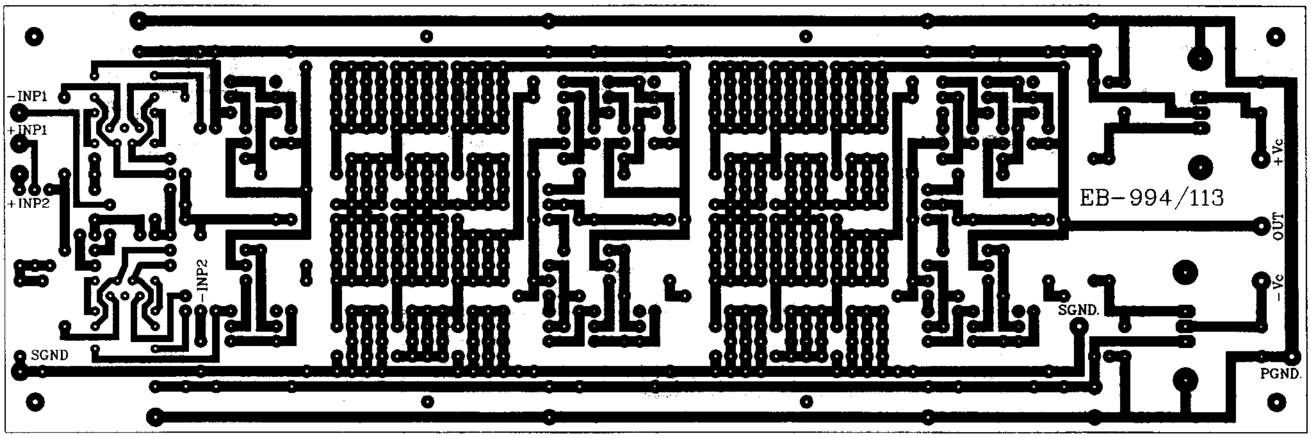

FIGURE 4: Lineamp and crossover layout (80%).

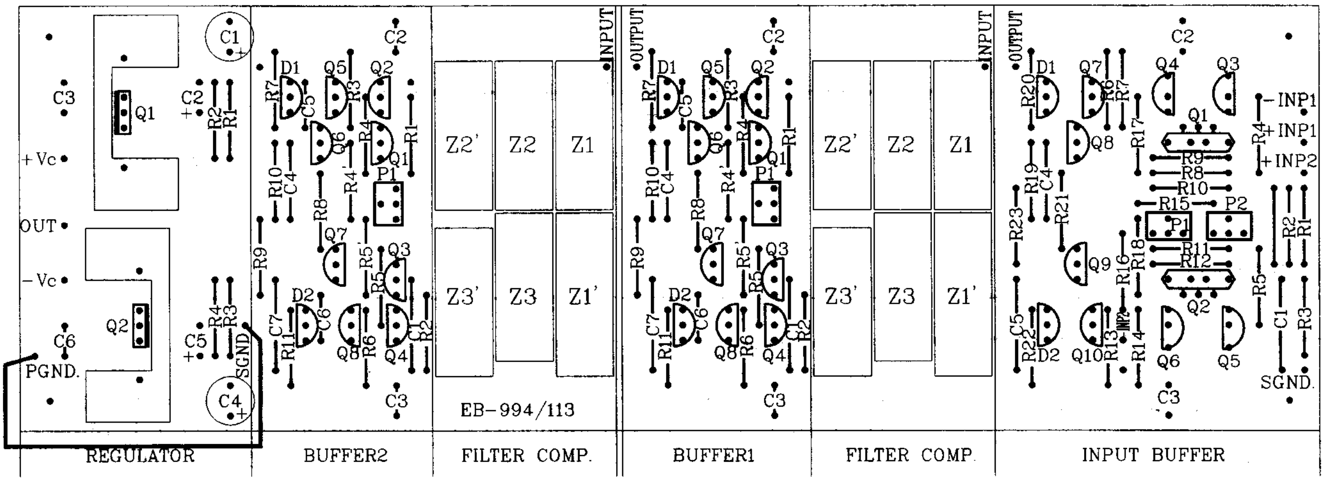

FIGURE 5: Lineamp and crossover stuffing guide (80%).

lation. If you are like me, you will probably use discrete regulation for your high-quality lineamp. In that case, leave out the regulators and bypass them with a jumper.

Filter Components

Figure 4 shows the board layout. Note the areas between the lineamp and the first buffer and between the two buffers; these are set aside for the filter components. Each buffer is laid out as a third-order filter, and the component area allows you to mount the six components for these (see stuffing guide in *Fig. 5*).

Naturally, you can also configure the buffers as first-order or second-order filters, in which case, some of the fields are not used. You can even implement fourth- or higher-order filters, but then you must connect the two buffers in cascade.

In addition, you can implement on the board all the usual audio-type filters, such as Butterworth, Bessel, and Linkwitz-Riley. For calculating first-order (6dB/octave), second-order (12dB/octave), or third-order (18dB/octave) Butterworth filters see *Figs. 6* and 7. The Linkwitz-Riley filters are two second-order Butterworth filters connected in cascade, so use the second-order calculation.[2]

If the calculation indicates nonstandard values, use two values of capacitors in parallel or two values of 1% resistors in parallel or in series. The capacitors should be high-quality film types (polystyrene or polypropylene), 5% or better, and the resistors 1% metal-film or tantalum.

Figures 6 and 7 also show the positioning of the filter components for the different orders of filters. You must short out unused series filter elements to make signal connections. For example, field Z1 is not used for second-order filters; it must be shorted to make connection to the next element.

A prototyping board (EB-994/115) is available for experimenting with different types and slopes of filters (*Fig. 8*). This plugs into the filter-component area of the board, essentially replacing the component area on the main board. When you use this board, there should be no filter components on the main board.

It is plugged in using double, gold-plated IC-socket-type pins, ensuring very good contact between the boards. However, take care when plugging the board in and out; it is easy to bend or break the pins. When you have found the right types and slopes for the filters, you can mount the components directly on the main board, thus avoiding the use of connectors in the signal path.

Combined Lineamp and Crossover

Fig. 9 shows a typical application for a combined lineamp/subwoofer crossover (*Photo 1* shows the PCBs). The crossover frequencies shown are 100Hz, but naturally you can choose others.

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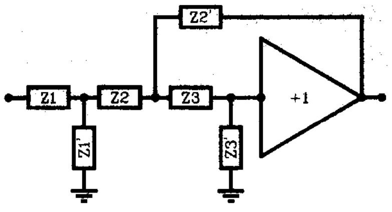
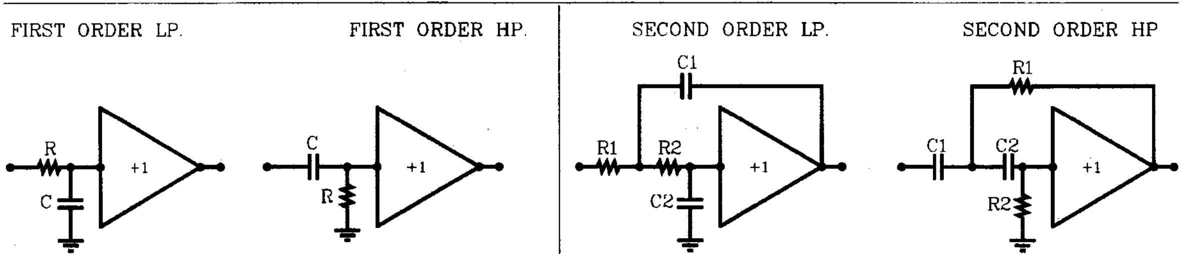


GENERAL FILTER LAYOUT
Component positioning on EB-994/113 board.



FIRST ORDER LP.

f=1kHz, R=10k

$C=\frac{1}{2\pi fR}=0.0159uF$

Pos.: R -> Z3
C -> Z3'

FIRST ORDER HP.

f=1kHz, C=0.022uF (22nF)

$R=\frac{1}{2\pi fC}=7.23k$

Pos.: C -> Z3
R -> Z3'

To scale both LP and HP:

f<1kHz: multiply C (or R) by $\frac{1000}{f}$

f>1kHz: divide C (or R) by: $\frac{f}{1000}$

SECOND ORDER LP.

f=1kHz, R1=R2=R=10k

$C1=1.41\frac{1}{2\pi fR}=0.02244uF$

$C2=0.707\frac{1}{2\pi fR}=0.01125uF$

Pos.: R1 -> Z2
R2 -> Z3
C1 -> Z2'
C2 -> Z3'

SECOND ORDER HP

f=1kHz, C1=C2=C=0.022uF (22nF)

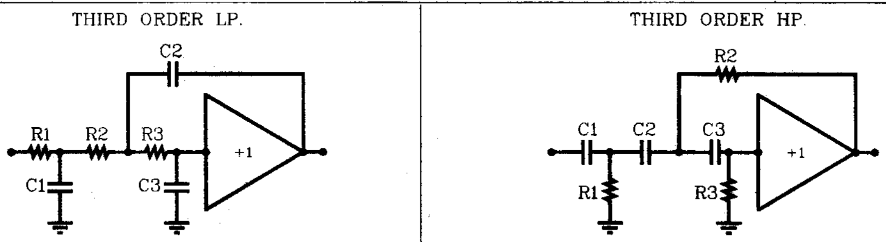
$R1=\frac{1}{1.41}\frac{1}{2\pi fC}=5.115k$

$R2=\frac{1}{0.707}\frac{1}{2\pi fC}=10.23k$

Pos.: C1 -> Z2
C2 -> Z3
R1 -> Z2'
R2 -> Z3'

To scale: same as first order filters.

FIGURE 6: Guide to calculating Butterworth first- and second-order filters—with component positioning.



THIRD ORDER LP.

f=1kHz, R1=R2=R3=R=10k

$C1=1.39\frac{1}{2\pi fR}=0.02212uF$

$C2=3.54\frac{1}{2\pi fR}=0.05634uF$

$C3=0.202\frac{1}{2\pi fR}=0.00321uF$

Pos.: R1 -> Z1
R2 -> Z2
R3 -> Z3
C1 -> Z1'
C2 -> Z2'
C3 -> Z3'

To scale both LP and HP:

f<1kHz: multiply C (or R) by $\frac{1000}{f}$

f>1kHz: divide C (or R) by: $\frac{f}{1000}$

THIRD ORDER HP.

f=1kHz, C1=C2=C3=C=0.022uF (22nF)

$R1=\frac{1}{1.39}\frac{1}{2\pi fC}=5.2k$

$R2=\frac{1}{3.54}\frac{1}{2\pi fC}=2.04k$

$R3=\frac{1}{0.202}\frac{1}{2\pi fC}=35.81k$

Pos. C1 -> Z1
C2 -> Z2
C3 -> Z3
R1 -> Z1'
R2 -> Z2'
R3 -> Z3'

FIGURE 7: Guide to calculating Butterworth third-order filters—with component positioning.

The lineamp gain is set by R15 and R19, with both equal to 10k; the gain is 6dB. This is probably all you need for listening to CDs. However, you can reduce R15 to achieve more gain.

The two filter buffers are operated at unity gain. The LP and HP outputs are therefore at the same audio level. If you need to adjust either output, you can install a volume control.

The buffers themselves can drive a fairly long cable, but if you use a volume control at the output—for example to regulate the level for the subwoofer—you must buffer it. The buffers are also available separately (EB-1190/124), with two on one board, and you can use them for this purpose.

Of course, you can also use the lineamp alone, since it has a direct output. This is useful if you have several systems and you wish to compare a full-range one with a satellite/sub combination.

ARS #123 →

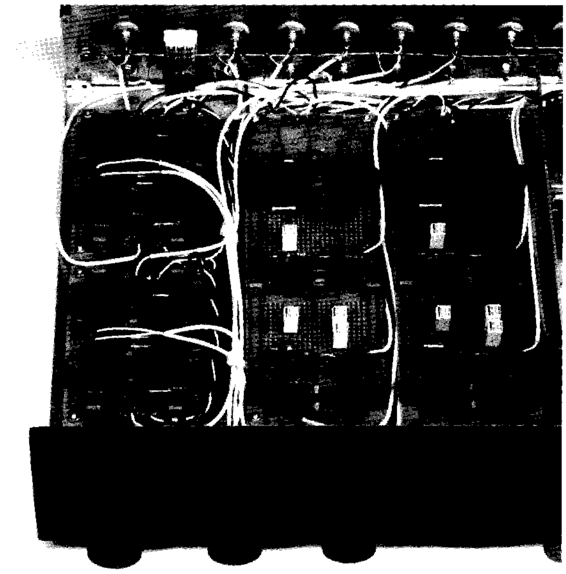


PHOTO 1: The two large PCBs are the lineamp/crossover combination, here shown without regulators. The boards on the left are two dual buffers, one set buffering the subwoofer output, the other the tape output.

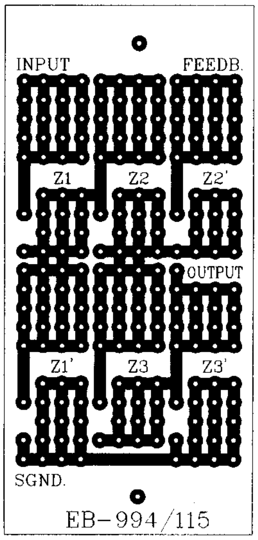


FIGURE 8: Layout for prototyping board (100%).

Digital-Analog Converter

The topology of the lineamp/ crossover combination is very much applicable as the analog part of an outboard DAC. You can use the lineamp as an I/V converter and configure the two buffers as an analog filter (*Fig. 10*).

You use the lineamp in the inverting mode. The input impedance of the inverting input (the summing point between R15 and R19) is approximately 18W, low enough so as not to affect the I/V process. Short out R15, so that you have access to this summing point.

The DAC current output is connected to -INP1. For appropriate gain, you must select R19, usually in the range of 2-3k. C4 will probably need some adjustment for best square-wave operation; 56pF is close to optimum. If you need de-emphasis, you can implement it with a capacitor and resistor across R19. Use a small relay for the switching.

Typically, analog filters in DACs are third-order Butterworth or Bessel. Butterworth will give you better

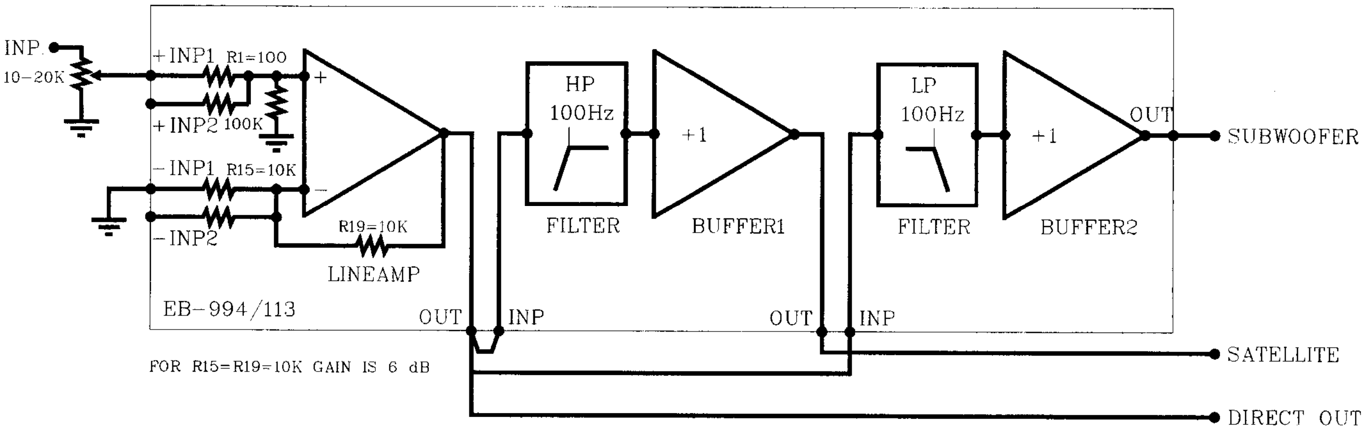


FIGURE 9: Combination of lineamp and crossover.

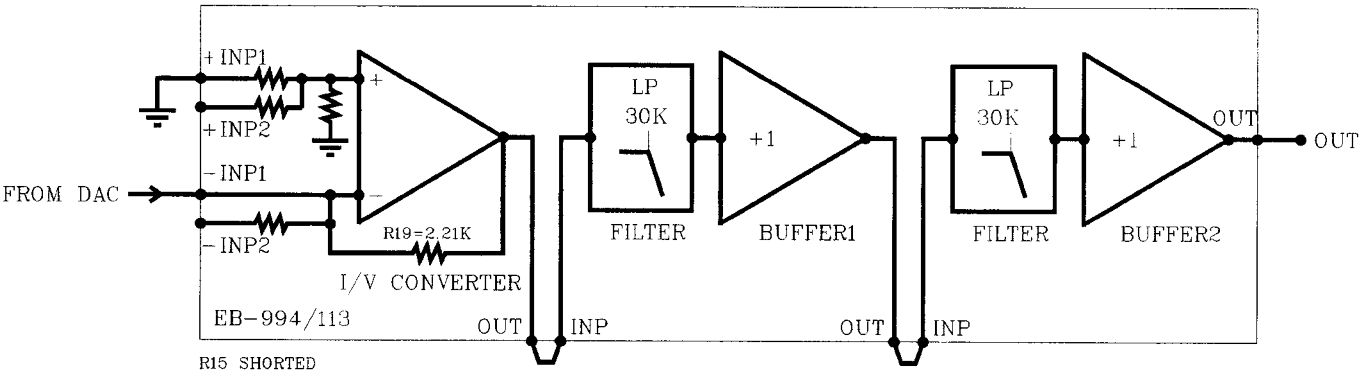


FIGURE 10: I/V converter and analog filter.

TABLE 3

EB-994/113 PARTS LIST

LINEAMP	
Resistors (All resistors 0.5W/1% metalfilm ROE MK-2 or equivalent)	
R1–3, R15, R16, R19	10k
R4, R5, R8, R9, R17, R18	100R
R6, R7, R13, R14	1.4k
R10	10R
R11, R12	75R
R20, R22	150R
R21	33.2k
R23	47R5
TRIMPOTS	
P1	200R Multiturn Cermet
P2	50R Multiturn Cermet
CAPACITORS	
C1	10pF, 100V, PS
C2, C3	0.1µF, 63V, ROE MKT 1826
C4	33pF, 100V PS
C5	560pF, 630V, PP
SEMICONDUCTORS	
Q1	2SK389BL/V
Q2	2SJ109BL/V
Q3, Q4	2SK246BL
Q5, Q6	2SJ103BL
Q7, Q8	2SA817A
Q9, Q10	2SC1627A
D1, D2	LM336Z-2.5
BUFFER1 AND BUFFER2	
RESISTORS	
R1, R10	1k
R2	1M (not used for filter)
R3, R6	1.4k
R4, R5	Adj for 2mA drain current
R4′, R5′	Adj for 2mA drain current
R7, R11	150R
R8	33.2k
R9	47R5
TRIMPOT	
P1	200R Multiturn Cermet
CAPACITORS	
C1	10pF, 100V, PS
C2, C3	0.1µF, 63V, ROE MKT 1826
C4	22pF, 100V, PS
C5, C6	0.1µF, 100V, ROE CER
C7	330pF, 630V, PP, PP
SEMICONDUCTORS	
Q1	2SK170BL (matched to 2SJ74BL)
Q2	2SK246BL
Q3	2SJ74BL
Q4	2SJ103BL
Q5, Q6	2SA817A
Q7, Q8	2SC1627A
D1, D2	LM336Z-2.5
REGULATOR	
RESISTORS	
R1, R3	121R
R2, R4	2.21k
CAPACITORS	
C1, C4	47µF, 63V, EKR
C2, C5	10µF, 35V, ROE TA
C3, C6	0.1µF, 63V, ROE MKT 1826
SEMICONDUCTORS	
Q1	LM317T
Q2	LM337T
MISCELLANEOUS	
PCB	EB-994/113
1mm solder pins	
Heatsink	SK 75-STS/TO-220, 25mm
Plug-in filter board (optional)	
PCB	EB-994/115
Eight sets of male and female pins for mounting on the mother board	

attenuation at the oversampling frequencies than Bessel, but Bessel filters are considered to sound better. The solution is to use a higher-order Bessel filter to get acceptable attenuation.

With two buffers, each laid out as a third-order filter, you can implement Bessel filters up to sixth order. In practical filter design, you would probably settle on a fifth order. Also, to avoid too much attenuation under 20 kHz, you should choose the 3dB point further away from 20kHz, say at 35 or 40kHz. A well-designed fifth-order Bessel filter with a 3dB point at 40kHz will give you over 70dB attenuation around 350kHz.[3]

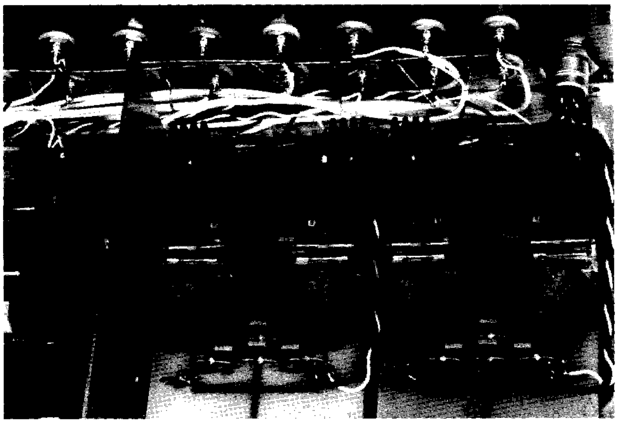


PHOTO 2: The wideband, low-noise regulators use AD797 op amps and MOSFET outputs. The outboard transformer is connected through a Lemo 3B connector (upper right corner).

Power Supply

As I indicated before, the layout allows you to use three-terminal regulators on the PC board (*Photo 2*). If you use these, then all you need is a transformer with 2 × 24V AC for each channel, a rectifier bridge, and a couple of large electrolytics (I recommend 10,000µF/40V). However, according to Walt Jung's excellent series of articles on high-performance regulators,[4] these are not suitable for high-quality audio. I recommend, therefore, that you use one of the circuits Walt published in his articles. As an alternative, Borbely Audio offers high-quality, low-noise, wideband regulators.

Setup Procedure

I recommend that you start the assembly of the crossover with the regulators. Connect ±28V unregulated voltage to the board and test the regulators. Then install BUFFER2, BUFFER1, and the input buffer, testing each separately. Inputs should be shorted during DC measurements or adjustments.

With BUFFER1 and BUFFER2, short the signal ground (SGND) to the power-supply ground (PGND) at the output. Set P1 to mid-position. Connect a voltmeter across R3 (or R6) and measure the voltage drop. It should be 2.8–3V. If the voltage drop is less than 2.8V, install R4′ and R5′. If the voltage is more than 3V, install R4 and R5.

The values of R4, R5, R4′, and R5′ depend on the IDSS of Q1 and Q3, and some experimentation is necessary to determine the right values. The EB-994/113 Kit is sold with matched devices, and the appropriate values of R4, R5, R4′, and R5′ are included.

Next, connect a DC millivoltmeter to the output of the buffer and adjust the offset to 0V with P1. If you have complete audio instrumentation in your workshop, perform the usual gain, frequency response, noise, total harmonic distortion (THD), and intermodulation distortion (IM) measurements.

With the lineamp, connect the +INP1 and -INP1 pins to signal ground. Connect a voltmeter across R6 (or R13) and measure the voltage drop. Adjust the voltage across R6 to 2.8V with P1. Connect the voltmeter to the output and check the offset. Adjust the offset to 0V with P2. Again, carry out the usual audio measurements if you have audio instrumentation. ■

The EB-994/113 and EB-994/115 designs are the intellectual property of Erno Borbely/Borbely Audio. The design can be licensed to OEM customers for Kit and factory-wired production. Contact Borbely Audio (Angerstr. 9, 86836 Obermeitingen, Germany, 49/8232/903616, Fax 49/8232/903618, EBorbely@aol.com) for details. Erno Borbely/Borbely Audio reserves the right to improve and otherwise alter any specification supplied in this document, or any documentation supplied hereafter.

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3. Jean-Claude Gaertner, private communication.
4. Walter G. Jung, "Regulators for High-Performance Audio, Part 1," *The Audio Amateur*, 1/95.