MODULAR ACTIVE CROSSOVERS

By Erno Borbely and Jean-Claude Gaertner

The laws of physics are such that reproducing the entire audio frequency range with one transducer is practically impossible. We must, therefore, rely on filters to divide the audio spectrum into smaller ranges for loudspeakers. For cost reasons, most of these filters are passive. They allow us to get by with only one amplifier, and the whole setup seems very simple.

Calculating a passive filter is a difficult task for an amateur. Effectively, the loudspeaker's impedance varies considerably as a function of frequency, and this affects the results of the calculations. Utilization of networks that correct the impedance (and, more importantly, software like CALSOD and LEAP) facilitate these calculations.

Active filters, which require a separate amplifier for each band, are generally reserved for high-end speakers. Obviously, this costs more than a single amplifier, but the approach has several advantages: you can use loudspeakers with different characteristics; the amplifiers can be adapted to the particular frequency range they are supposed to reproduce; each speaker is driven directly from the amplifier's output with only a cable in between; filter element calculation is very simple and can be accomplished with textbook formulas.

A number of active filter structures are available, each having its own advantages and disadvantages. We chose a second-order structure called the Sallen-Key. The independence between the filter's low-pass (LP) and high-pass (HP) sections allows you to adapt the slope and cutoff frequency to suit your particular speaker. We will propose several filter applications for practical speaker systems.

All filter types theoretically can be implemented with the circuit proposed here, but only Bessels, Butterworths, and Linkwitz-Rileys are of interest for audio. The Bessel (also called Thomson) offers the best transient response. The overall slope around the cutoff frequency, however, is only about 4.5dB/octave, with the 6dB/octave slope per order achieved only several octaves beyond the cutoff frequency. The Butterworth offers

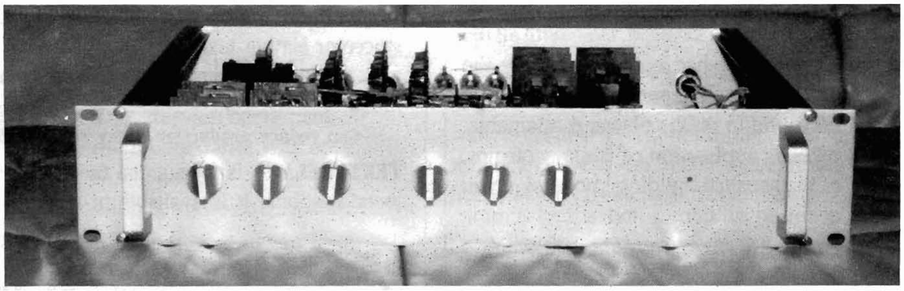

PHOTO 1: Front view of the crossover. We used an aluminum 2U 19′ Fisher box with an internal chassis.

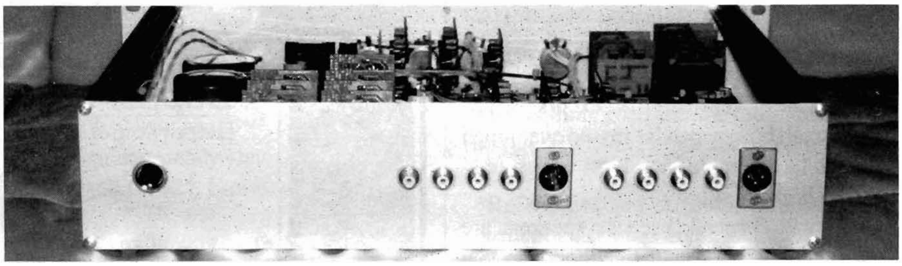

PHOTO 2: Rear view of the crossover. XLR is used for symmetrical, and Teflon® isolated cinch for asymmetrical input. Note that on this prototype we didn't mount the XLR plug that would be needed for symmetrical output.

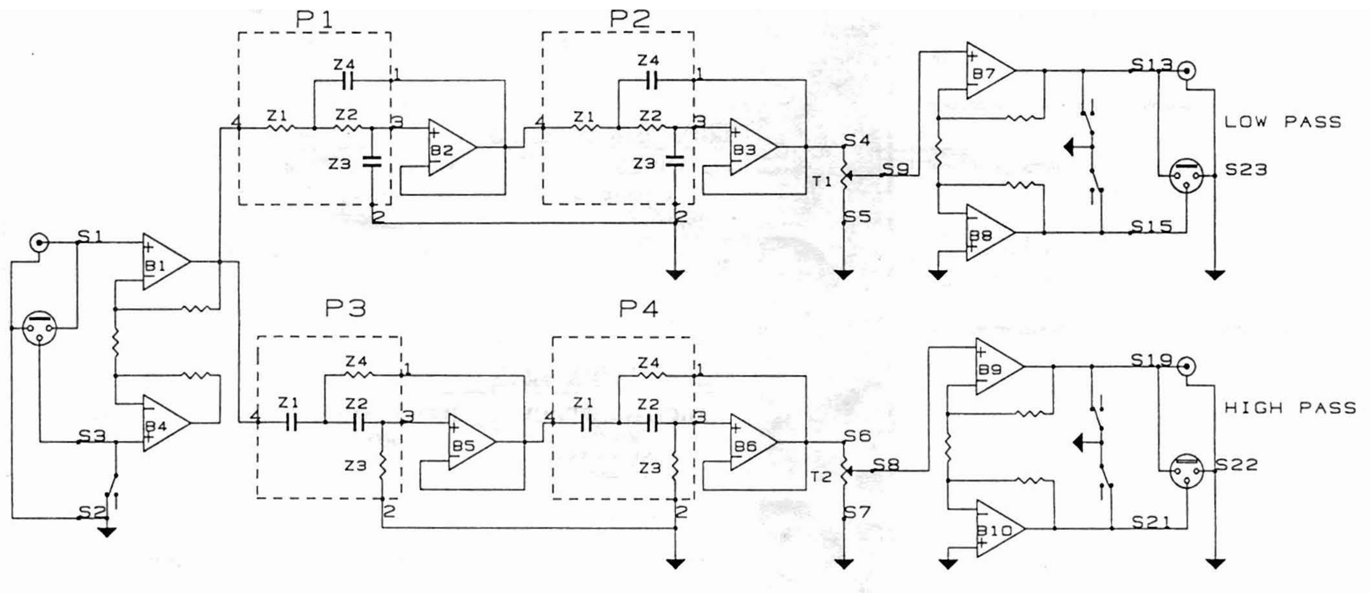

FIGURE 1: Two-way crossover block schematic. Power supply is ±24V. Switch on mute.

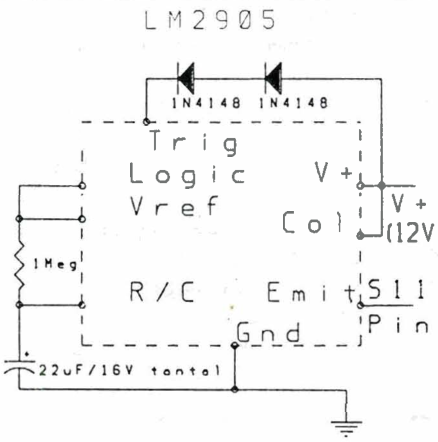

FIGURE 2: Switch-on delay schematic. The switch-on delay is R/C (about 22 seconds in this case).

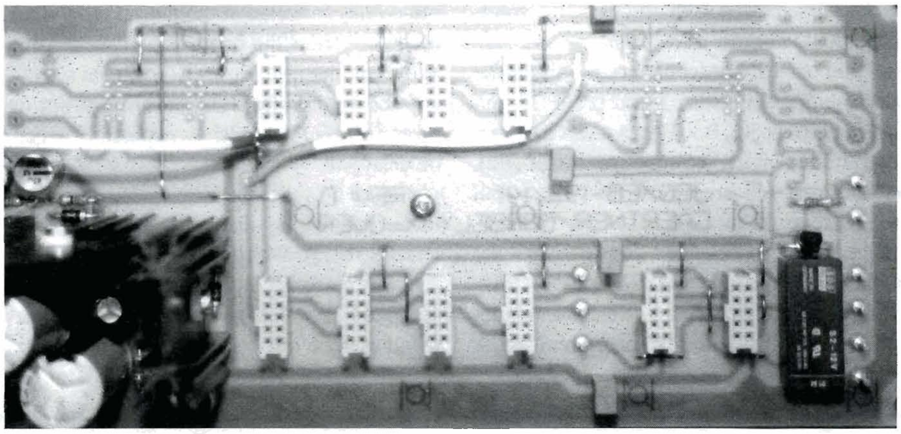

PHOTO 3: The three-way extension motherboard. Note the two shielded links: the first is to bring the buffered signal from the main two-way motherboard; the other is to link the high- and low-pass sections on the three-way extension motherboard.

ness, bandstop slope, and transient response. The Linkwitz-Riley, an even-order filter, combines all the qualities of the Butterworth with good phase response around the cutoff frequency.

CIRCUIT DESCRIPTION

The JC/EB-193/141 is a universal active filter designed for two- and three-way loudspeakers. It is implemented on a motherboard, with plug-in or solderable buffers and crossover networks. (Each motherboard serves one channel.) In the basic two-way mode, it provides a common input buffer, the LP and HP filter sections, and the output buffers. As a three-way extension board, it uses the filter sections and the output buffers. The filter slope is selectable in 6dB increments between 6 and 24dB. Input and output buffers can be configured for either single-ended or balanced operation.

Figure 1 is the block schematic for a two-way crossover. B1/B4 form a balanced-to-single converter and serve as a common input buffer for the filter sections. When used with single-ended sources, B4's input should be shorted to ground (S3 to S2). Alternatively, it can be removed from the board.

The crossover's LP section is formed with B2 and B3, with their networks P1 and P2. B5 and B6, with P3 and P4, form the HP section. As shown, each buffer and its associated network represents a basic second-order Sallen-Key filter; therefore, a second-order crossover

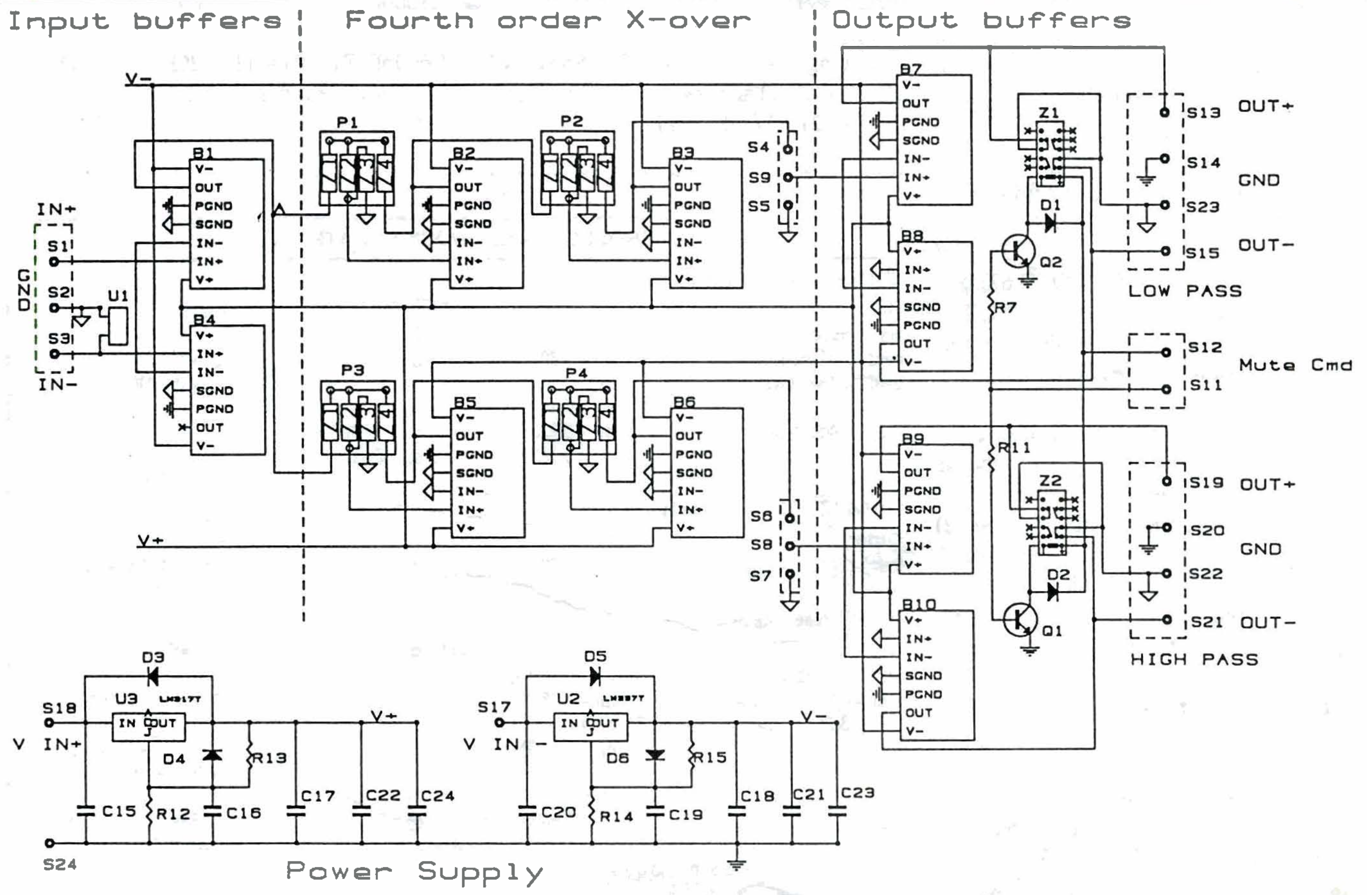

FIGURE 3: Two-way crossover schematic and wiring diagram.

can be implemented with only one buffer/network. A third-order filter requires one second- and one first-order network. This can be implemented with either P1/B2 or P3/B5, and Z2/Z3 of P2 or P4. B3 (B6) is needed only if you use the optional volume control P1 (P2). For a fourth-order crossover, you will need all four buffers and networks.

The single-to-balanced converter for the output is comprised of B7/B8 and B9/B10. They also serve as output buffers. For single-ended output, B8 and B10 can be omitted. A mute relay installed at the output will, when activated, short the output signal to ground. We recommend doing so in order to avoid DC thumps at the filter's output when powering up and down. *Figure 2* shows a possible switch-on delay.

Figure 3 is the two-way crossover's schematic and wiring diagram. The buffers are shown as blocks with pin assignments. Note that signal ground and power ground are completely separated, allowing you the flexibility of implementing your own grounding scheme. (You must, however, remember to connect the two grounds somewhere—either on the board or at the power supply.) The motherboard has built-in 317/337-type regulators, which you can omit when using off-the-board regulators. Q1 and Q2 are the relay drivers for the mute circuit. The mute relay, an SDS S2 12V, shorts the output of the buffers to ground. An instantaneous or delayed mute command is supplied to the board through Pins S11 and S12: S11 is the mute command pin (the relay is activated with a voltage higher than 2V);

CALCULATING THE CROSSOVER NETWORK

We wish to build a two-way crossover with a cutoff frequency of 2kHz, and will calculate all the values of the passive network.

$$F_C = \frac{1}{2 \times \pi \times R_0 \times C_0} \tag{1}$$

According to equation (1) we have:

$$2{,}000 = \frac{1}{2 \times 3.1416 \times R_0 \times C_0} \rightarrow R_0 \times C_0 = \frac{1}{6.2832 \times 2{,}000} = 7.95773 \times 10^{-5} \tag{2}$$

LOW-PASS SECTION

First-order:
We choose a value for C_0 = 5,600pF and according to (2) R_0 = 14,210Ω. So, we will use P1 (*Fig. 1*) and $Z_2 = R_0$ = 14,210Ω (13k + 1k21), $Z_3 = C_0$ = 5,600pF.

Second-order Butterworth:
Table A gives $m_1 = 0.7071$ $q_1 = 1.4142$. *Figure A2* gives $C_1 = m_1C_0$, $C_2 = q_1C_0$, so $C_2 = 2C_1$. We choose C_1 = 10nF, so C_2 = 20nF. $C_1 = m_1C_0 = 0.7071C_0$, so C_0 = 14.142nF and equation (2) gives R_0 = 5,627Ω (5k62). We will use P1 and $Z_1 = Z_2 = R_0$ = 5,620Ω, $Z_3 = C_1$ = 10nF, Z4 = C2 = 20nF (10nF+10nF).

Third-order Butterworth:
Table A gives $m_1 = 0.5$, $m_2 = 1$, $q_1 = 2$. *Figure A3* gives $C_1 = m_1C_0$, $C_3 = m_2C_0$, $C_2 = q_1C_0$. We can see that $C_2 = 2C_3 = 4C_1$. We choose C_2 = 20nF, C_3 = 10nF, C_1 = 5,000pF. $C_1 = m_1C_0$, so C_0 = 2,500pF and equation (2) gives R_0 = 7,957Ω. P1 and P2 will be needed. P1: $Z_1 = Z_2 = R_0$ = 7,960Ω (6k81+1k15), $Z_3 = C_1$ = 5,030pF (4,700pF+330pF), $Z_4 = C_2$ = 20nF (10nF+10nF). P2: $Z_2 = R_0$ = 7,960Ω (6k81+1k15), $Z_3 = C_3$ = 10nF.

Fourth-order Butterworth:
Table A gives $m_1 = 0.9238$, $m_2 = 0.3826$, $q_1 = 1.0823$, $q_2 = 2.6131$. *Figure A4* gives $C_1 = m_1C_0$, $C_3 = m_2C_0$, $C_2 = q_1C_0$, $C_4 = q_2C_0$. We choose C_4 = 22nF, so C_0 = 8.419nF and equation (2) gives R_0 = 9,452Ω, C_1 = 7.777nF, C_3 = 3.22nF, C_2 = 9.11nF. P1 and P2 will be needed. P1: $Z_1 = Z_2 = R_0$ = 9,452Ω (8k25+1k21), $Z_3 = C_1$ = 7.77nF(6.8nF+1nF), $Z_4 = C_2$ = 9.11nF (8.2nF+1nF). P2: $Z_1 = Z_2 = R_0$ = 9,452Ω (8k25+1k21), $Z_3 = C_3$ = 3.22nF (2.2nF+1nF), $Z_4 = C_4$ = 22nF.

Fourth-order Linkwitz-Riley:
Two second-order Butterworths in cascade. We have already calculated the values, so passive network P1 and P2 will be the same, as you can see in *Fig. A5*. P1: $Z_1 = Z_2 = R_0$ = 5,620Ω, $Z_3 = C_1$ = 10nF, $Z_4 = C_2$ = 20nF(10nF+10nF). P2: $Z_1 = Z_2 = R_0$ = 5,620Ω, $Z_3 = C_1$ = 10nF, $Z_4 = C_2$ = 20nF(10nF+10nF).

HIGH-PASS SECTION

First-order:
We choose a value for C_0 = 5,600pF and according to (2) R_0 = 14,210Ω. So we will use P3 (*Fig. 1*) and $Z_2 = C_0$ = 5,600pF $Z_3 = R_0$ = 14,210Ω (13k+1k21).

Second-order Butterworth:
Table A gives $m_1 = 0.7071$ $q_1 = 1.4142$. *Figure B2* gives $R_1 = R_0/m_1$, $R_2 = R_0/q_1$. We choose C_0 = 5,600pF, according to equation (2) R_0 = 14,210Ω, R_1 = 2,0096Ω, R_2 = 10,048Ω. We will use P3 (*Fig. 1*) and $Z_1 = Z_2 = C_0$ = 5,600pF, $Z_3 = R_1$ = 20k, $Z_4 = R_2$ = 10k.

Third-order Butterworth:
Table A gives $m_1 = 0.5$, $m_2 = 1$, $q_1 = 2$. *Fig. B3* gives $R_1 = R_0/m_1$, $R_3 = R_0/m_2$, $R_2 = R_0/q_1$. We choose C_0 = 6,800pF according to equation (2) R_0 = 11,702Ω, R_1 = 23,405Ω, $R_3 = R_0$ = 11,702Ω, R_2 = 5,851Ω. P3 and P4 will be needed (*Fig. 1*). P3: $Z_1 = Z_2 = C_0$ = 6,800pF, $Z_3 = R_1$ = 23,405Ω (22k1+1k3), $Z_4 = R_2$ = 5,851Ω (5k62+221). P4: $Z_2 = C_0$ = 5,600pF, $Z_3 = R_3$ = 11,702Ω (11k+681).

Fourth-order Butterworth:
Table 1 gives $m_1 = 0.9238$, $m_2 = 0.3826$, q_1

TABLE A

CROSSOVER NETWORK EQUATIONS

BUTTERWORTH (see note 1)

Order	m	q	equation
first (6dB/octave)	0	0	
second (12dB/octave)	$m_1 = 0.7071$	$q_1 = 1.4142$	$(p^2 + 1.4142p + 1)$
third (18dB/octave)	$m_1 = 0.5$	$q_1 = 2$	$(p^2 + p + 1)(p + 1)$
	$m_2 = 0.1$		
fourth (24dB/octave)	$m_1 = 0.9238$	$q_1 = 1.0823$	
	$m_1 = 0.3826$	$q_2 = 2.6131$	$(p^2 + 1.8477p + 1)$
			$(p^2 + 0.7653p + 1)$

LINKWITZ-RILEY (see note 1)

Order	m	q	equation
fourth (24dB/octave)	$m_1 = 0.7071$	$q_1 = 1.4142$	$(p^2 + 1.4142p + 1)$
			$(p^2 + 1.4142p + 1)$

BESSEL (see note 2)

Order	m	q	equation
first (6dB/octave)	0	0	
second (12dB/octave)	$m_1 = 0.6808$	$q_1 = 1.9077$	$(0.6180p^2 + 1.3616p + 1)$
third (18dB/octave)	$m_1 = 0.4998$	$q_1 = 1.9547$	
	$m_2 = 0.7560$		$(0.4771p^2 + 0.9996p + 1)$
			$(0.756p + 1)$
fourth (24dB/octave)	$m_1 = 0.3871$	$q_1 = 1.0048$	
	$m_1 = 0.6698$	$q_2 = 0.7298$	$(0.3889p^2 + 0.7742p + 1)$
			$(0.4889p^2 + 1.3396p + 1)$

Note 1: The coefficients in m and q are valid for low- and high-pass filters. All coefficients and equations are from the book *Filtre actif* by Paul Bildstein, Editions Radio, 9 rue Jacob 75006 Paris.

Note 2: For Bessel, the coefficients m and q are only valid for a low-pass filter (ibid., p. 54).

S12 is the power supply pin (+12V for the recommended relay).

Figure 4 is the block schematic for the three-way extension board; *Fig. 5* is the schematic and wiring diagram. The circuit consists of an LP (B2, B3) and an HP section (B5, B6), connected in cascade and forming a bandpass filter. The input signal is taken from the input buffer's output on the two-way filter board. The bandpass filter's output is converted to a balanced signal by B9 and B10. You can remove B10 from the board if the balanced output is not needed. Second- and third-order filters can be implemented as previously described.

We used ORCAD for all schematics and the new LAYO1 software for the PC board layouts. When we tested the laser printer check plot and the Gerber files, we found that the lines and pads appeared thinner on the check plot than on the screen. Both outputs, however, are usable. For the final prototypes, we used the Gerber output files with very good results. [*Note: LAYO1, an impressive package at an affordable price, is available from Old Colony Sound Lab—see the Availability Box.—Ed.*]

On the motherboard, the regulator heatsinks are grounded. Consequently, the latter must be insulated with mica or other insulator materials. The motherboard is configured as a two-way crossover (bold lines indicate the jumpers). This board is fully populated, with all four networks and all ten buffers installed. In many cases, you will be using fewer than the full complement. Except

$= 1.0823$, $q_2 = 2.6131$. *Figure B4* gives $R_1 = R_0/m_1$, $R_3 = R_0/m_2$, $R_2 = R_0/q_1$, $R_4 = R_0/q_2$. We choose $C_0 = 6{,}800$pF according to equation (2) $R_0 = 11{,}702\Omega$, $R_1 = 12{,}668\Omega$, $R_3 = 30{,}587\Omega$, $R_2 = 10{,}812\Omega$, $R_4 = 4{,}478\Omega$. P3 and P4 will be needed (*Fig. 1*). P3: $Z_1 = Z_2 = C_0 = 6{,}800$pF, $Z_3 = R_1 = 12{,}668\Omega$ (12k1+562), $Z_4 = R_2 = 10{,}812\Omega$ (10k+825). P4: $Z_1 = Z_2 = C_0 = 6{,}800$pF, $Z_3 = R_3 = 30{,}587\Omega$ (30k1+475), $Z_4 = R_4 = 4{,}478\Omega$ (4k32+150).

Fourth-order Linkwitz-Riley:
Two second-order Butterworths in cascade. We have already calculated the values, so the passive network P3 and P4 will be the same, as you can see in *Fig. B5*. P3: $Z_1 = Z_2 = C_0 = 5{,}600$pF, $Z_3 = R_1 = 20$k, $Z_4 = R_2 = 10$k. P4: $Z_1 = Z_2 = C_0 = 5{,}600$pF, $Z_3 = R_1 = 20$k, $Z_4 = R_2 = 10$k.

As another example, look at *Fig. 7*, which shows the actual response of one of the prototypes with a cutoff frequency of 140Hz.

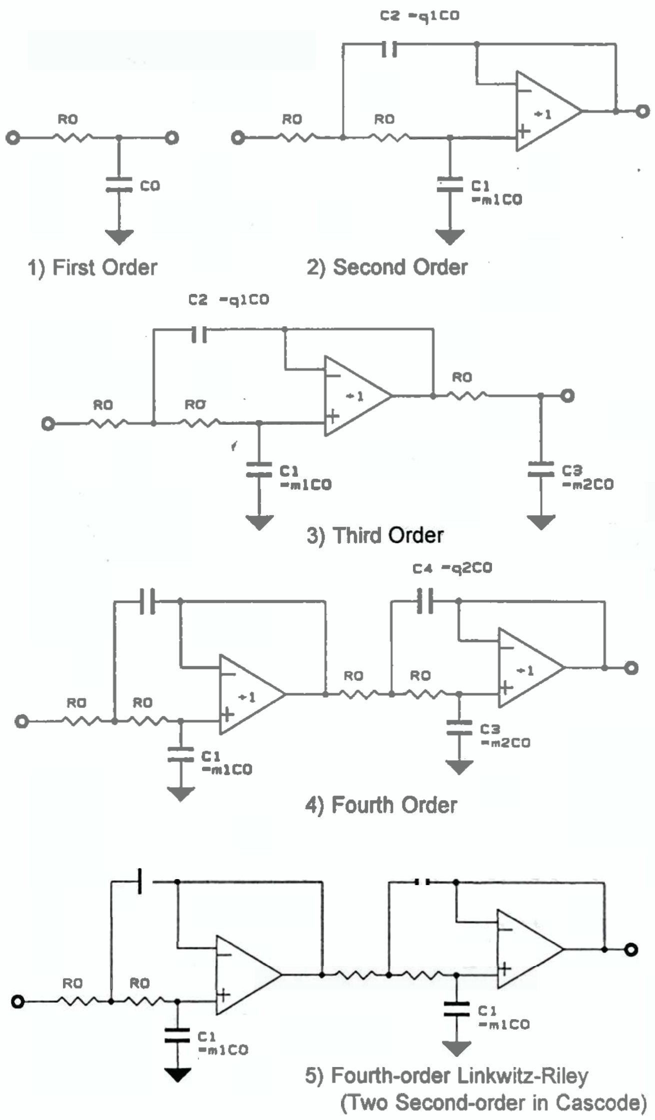

FIGURE A: Low-pass structure.

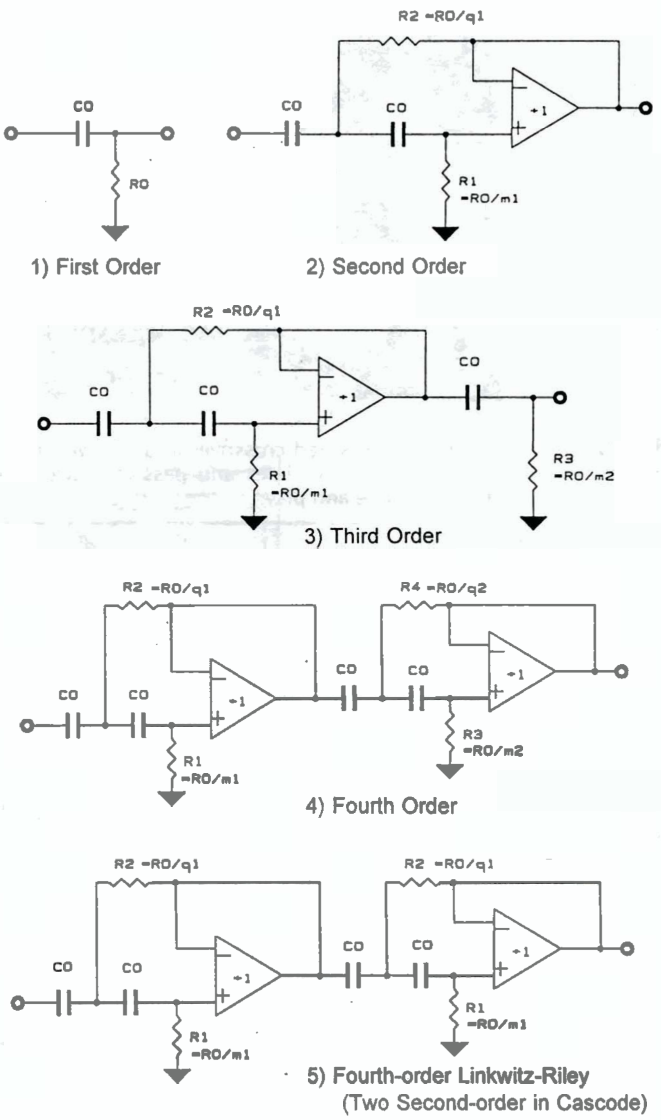

FIGURE B: High-pass structure.

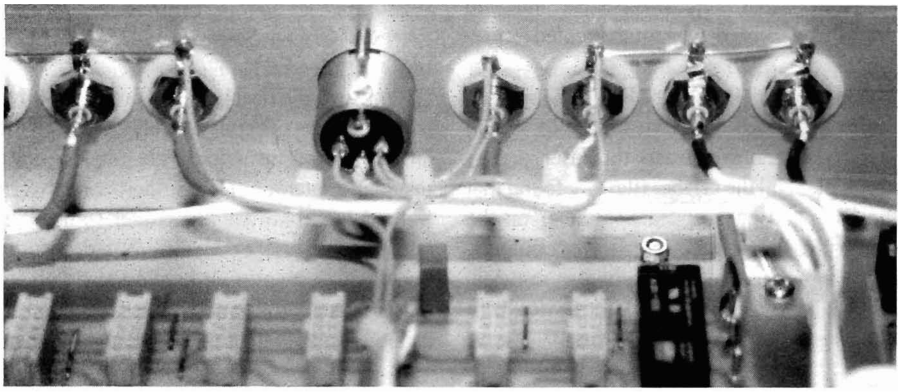

PHOTO 4: The rear panel. Note the way we made the ground connections; the ground input pin (the cinch on the right of the XLR) is connected to the signal ground on the motherboard. The three ground output pins are connected together and soldered to the star ground. Signal ground and power ground are connected at one position only for each channel. The best we found was to connect Pin S14 and S23.

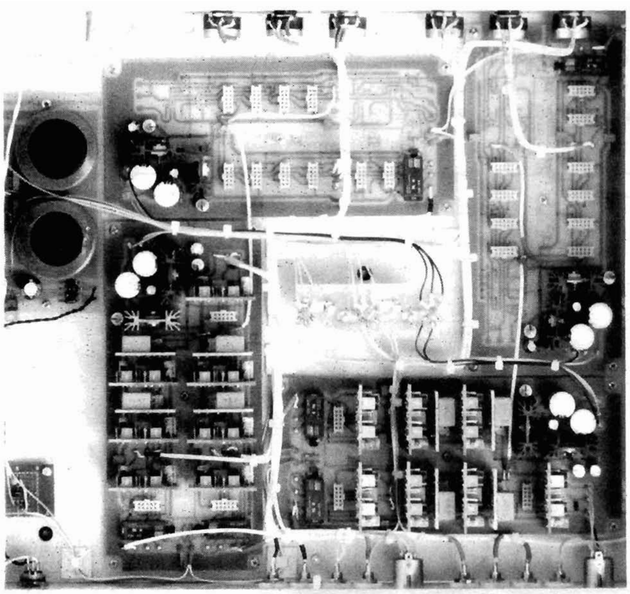

PHOTO 5: Top view of the measured crossover in a two-way asymmetrical input/output system, with the needed buffer modules and passive network. To go to three-way or symmetric, just plug in module and play.

for B4, B8, and B10, which are dedicated for balanced operation, you must always install a jumper between input and output for the missing unit. Otherwise, the next unit will not receive a signal. If you have installed connectors for each unit, but don't use all of them, you can install a wire jumper in the connector itself. [*Note: Board patterns and stuffing guides are available upon request. See the Availability Box for details.—Ed.*]

The volume control also needs bypassing if not used, as do the muting relays at the output. If you don't need the muting function, don't install them. The points marked X and Y on the stuffing guides indicate the location of the interconnection cable between the two motherboards (for a three-way system), which should be shielded. When the motherboard is used as a three-way extension board or bandpass filter, the optional volume control is connected to Pins S6, S7, and S8. Again, those units not used must be bypassed with a jumper.

The motherboard setup procedure is very simple. Simply check that regulators U2 and U3 are working. Apply a ±28V unregulated voltage to Pins S17, S18, and S24, and check the output voltages across filter capacitors C17 and C18. They should be close to ±24V. The buffers should be checked separately (see the BUF 124 setup procedure). Overall frequency response of the filter sections should be checked with buffers and networks installed.

UNITY-GAIN BUFFER

The heart of the crossover is the buffer, around which you build the filter sections. The schematic of the discrete BUF 124 is shown in *Fig. 6*. Originally developed as an input and tape buffer, it has been updated and optimized for filter operation. It features very low distortion and a rise-and-fall time of 200ns.

The BUF 124 two-stage circuit consists of a JFET-cascode input stage and a bipolar-cascode second stage—both pure Class A. Due to the cascode-connected JFETs, which operate at 2mA drain current, the input stage features very low input capacitance and high

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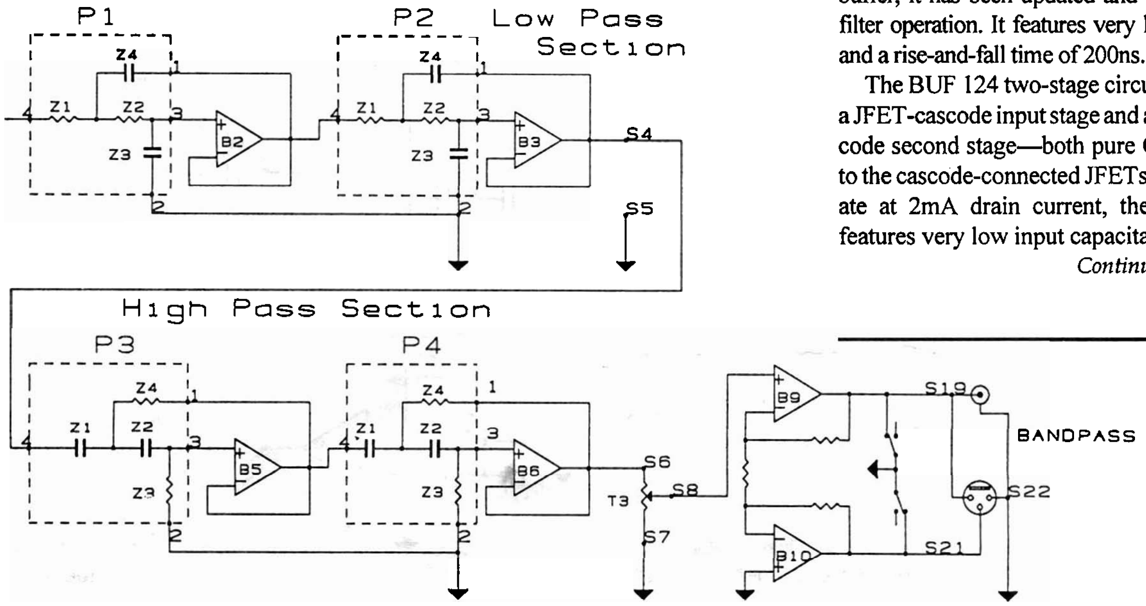
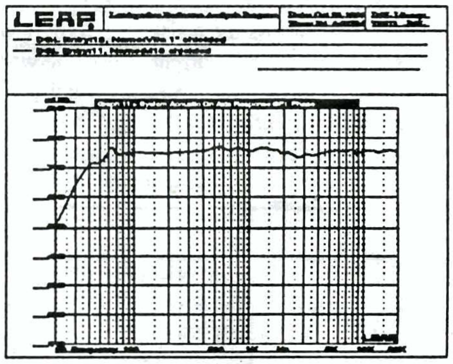


FIGURE 4: Three-way extension board block schematic. Power supply is ±24V. Switch on mute.

THE CENTER OF IT ALL

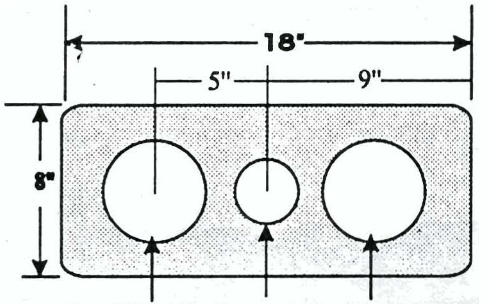
The center channel, often thought of as responsible for only reproducing dialogue, is actually responsible for reproducing about two thirds of the total acoustic energy of a typical movie. Much of the film's music track and a great deal of the sound effects originate from the center channel. This leaves the front, main channel mostly responsible for augmenting the center channel's foundation with far left and right information; and this leaves the rear channel responsible for spatial ambience. This being the case, the center channel must be well designed and constructed with high quality components, and when done well, it should have a similar tonal balance to that of the front, main speakers. We at A&S Speakers following these guidelines, have developed a top quality center speaker. Vifa components, among the most respected and widely used in the high-end market, are used in our center speaker as well as all of our A/V satellite speakers. This insures excellent quality and tonal consistency in our A/V packages.

THE CENTER CHANNEL



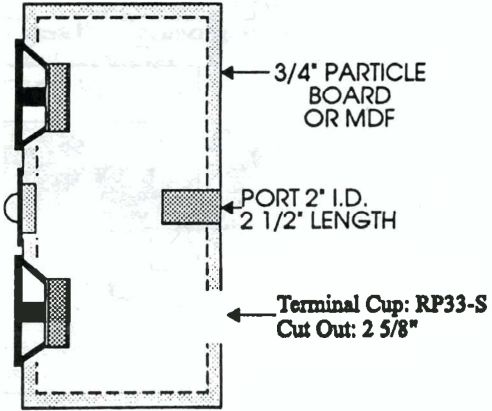
TECHNICAL SPECIFICATIONS

Frequency response: 55 Hz - 20kHz +/-3db
Sensitivity: 88 db
Nominal Impedance: 8 ohm
Thermal power capability: 100 watts RMS
Crossover frequency: 2800 Hz



FRONT VIEW

Price: $217.00 assembled ea.
$197.00 kit ea.
$115.00 w/o cabinet ea.



TOP VIEW
INSIDE SECTION

A&S speakers

3170 23rd Street; San Francisco, CA 94110
Telephone: (415) 641-4573 Fax: (415) 648-5306

Reader Service #31

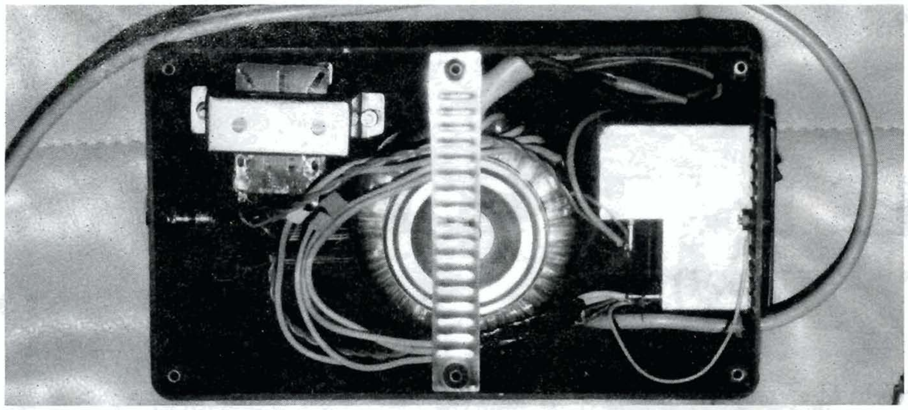


PHOTO 6: External power supply box with a conventional transformer (top left) for the relays and a toroidal transformer for the buffers. We used an AC filter, seen in the right of the photo.

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common-mode voltage swing. Q1 and Q3 must be matched to ±10% of I_{DSS} (either the "BL" or the "V" group can be used).

To adjust the DC offset at the output, P1 = 200Ω. R4/R5 and R'4/R'5 are connected in series and in parallel with P1, respectively, and are used to set the current in the input stage to 2mA. You can check the current by connecting a DVM across R3 (or R6) and measuring the voltage drop across the resistor, which at 2mA is 2.8V. If the drain current is higher than 2mA (i.e., the voltage drop is >2.8V), you must connect R4 and R5 in the circuit to reduce it. If it is less than 2mA, connect R'4 and R'5 in parallel with P1 to increase the current.

The second stage operates at approximately 15mA. When the input stage is operating at 2mA, this current is set up automatically to the correct value. D1 and D2 are used to bias the cascode transistors Q6 and Q7 relative to the emitter voltage of Q5 and Q8. R8 forces a current of approximately 1mA through the reference diodes.

R10, R16, and C4 form the buffer's feedback network. In unity-gain application (i.e., when the buffer is used as a filter), R16 is not connected to ground. It is used only when the buffer is connected as a balanced-to-single or single-to-balanced converter. In balanced operation, the gain of the input and output buffer is higher than unity. R9 and C6 form the amplifier's output network, isolating the buffer from capacitive loads. Since it works in pure Class A, the buffer is virtually short-circuit proof—you can short its output with a relay for muting purposes.

The buffer is connected to the motherboard through a 10-pin gold-plated connector. You can solder it to the motherboard or install a mating connector on the board and plug it in. [*Note: The BUF 124 is available as a kit. See the Availability Box.—Ed.*]

BUFFER SETUP PROCEDURE

Test each buffer module separately, if possible, before installing it on the motherboard. This simplifies measurements, adjustments, and any necessary component changes. If you have access to a scope, connect it to the buffer's output and check for radio frequency (RF) oscillations. 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. Inputs should be shorted under DC measurements/adjustments.

Before testing, set P1 to mid-position. Short signal ground to power supply ground

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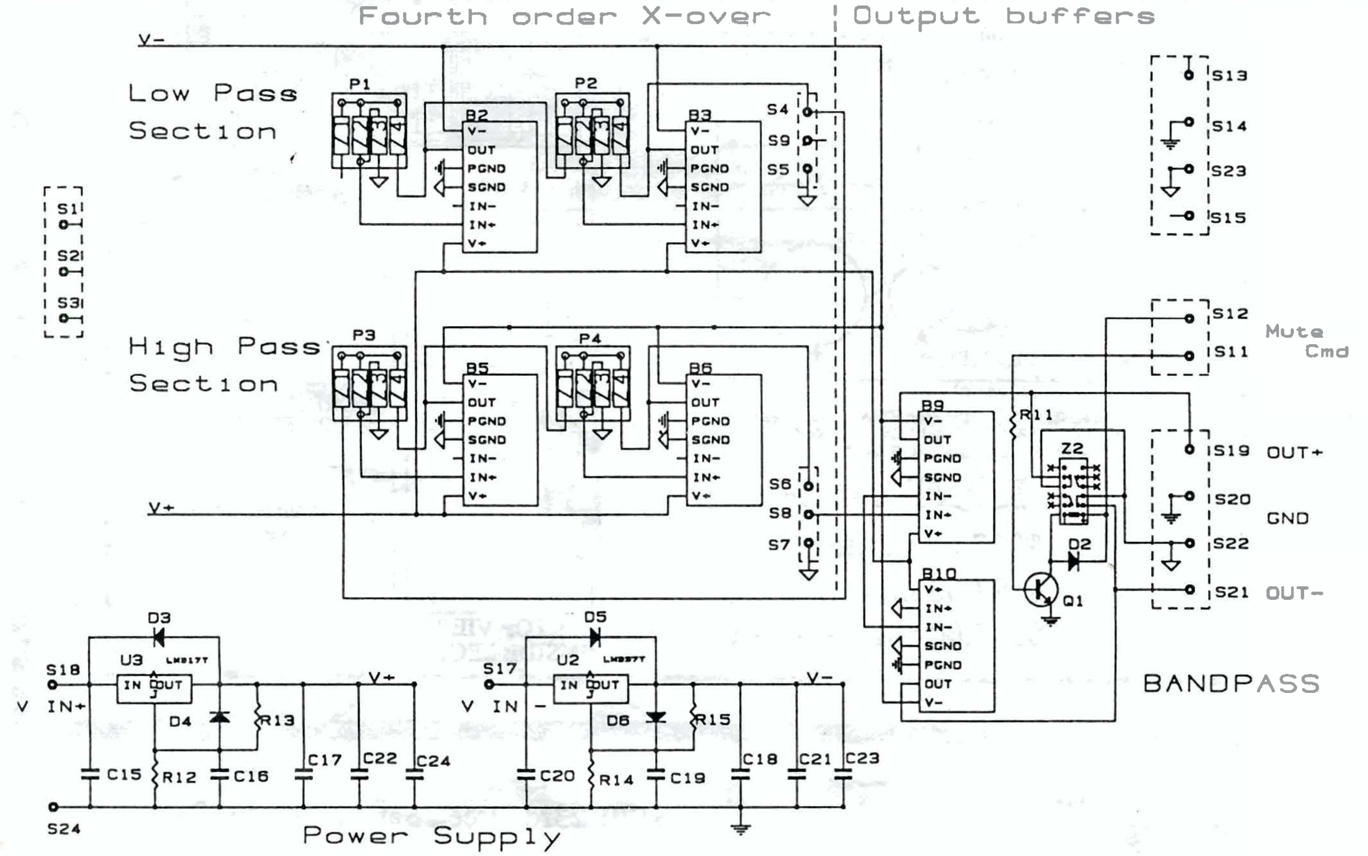
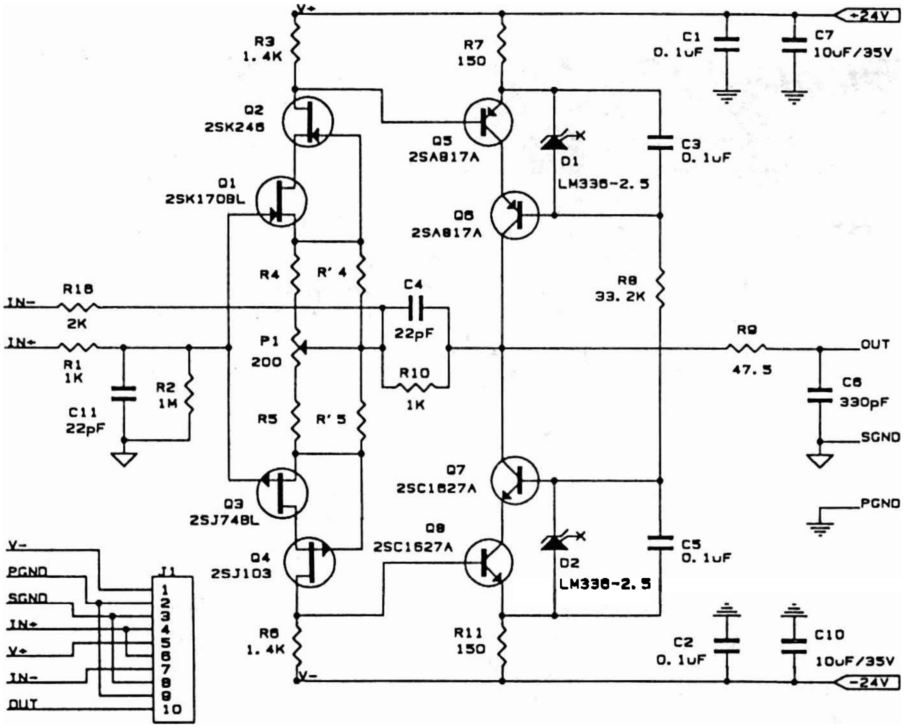


FIGURE 5: Three-way extension board schematic and wiring diagram.



Q1, Q2 MATCHED IDSS

R4, R'4, R5, R'5 SEE TEXT

SGND: Signal Ground

PGND: Power Ground

FIGURE 6: BUF-124 schematic.

TABLE 1

BUF 124 PARTS LIST

PART	DESCRIPTION
Resistors	
R1	1k*
R2	1M
R3, 6	1.4k
R4, 5	Select for I_D = 2mA
R4′, 5′	Select for I_D = 2mA
R7, 11	150
R8	33.2k
R9	47.5
R16	2k (For balanced operation)
Trimpot	
P1	200 multiturn cermet
Capacitors	
C	22p/630V PP, MICA, COG
C1,2,3,5	0.1μ/63V WIMA MKS-2
C4	22p/630V PP, MICA, COG
C6	330p/630V PP
C7, 10	10μF/35V TA
Semiconductors	
Q1	2SK170BL**
Q2	2SK246
Q3	2SJ74BL**
Q4	2SJ103
Q5, 6	2SA817A
Q7, 8	2SC1627A
D1, 2	LM336Z-2.5

Miscellaneous

10-pin connector, 3M type number: 2510-5002

BUF 124 PC board

*All resistors 0.5W/1% metal film, Resista MK-2 or equivalent.

**Q1 and Q3 are matched to 10% of I_{DSS}.

Continued from page 26

at the output. Connect ±24V regulated supply to the module and perform the following measurements/adjustments:

1. Connect a voltmeter across R3 (or R6) and measure the voltage drop. It should be 2.8–3V. If it is less than 2.8V, install R4′ and R5′. If the voltage is more than 3V, install R4 and R5. (The resistor values depend upon the I_{DSS} of Q1 and Q3. Some experimentation will be necessary to determine the correct values.) The BUF 124 kit is sold with matched/marked Q1/Q3, which makes selecting the right resistor values easy.
2. Connect a millivoltmeter to the amplifier's output, and, with P1, adjust the offset to 0V.

CROSSOVER NETWORKS

The crossover networks are mounted on plug-in PC boards. Separate PC boards are available for the low- and high-pass networks. The crossover networks are connected to the motherboard through the same kind of connectors as the buffers. For calculation of the crossover network, refer to the sidebar "Calculating the Crossover Network." ⯈

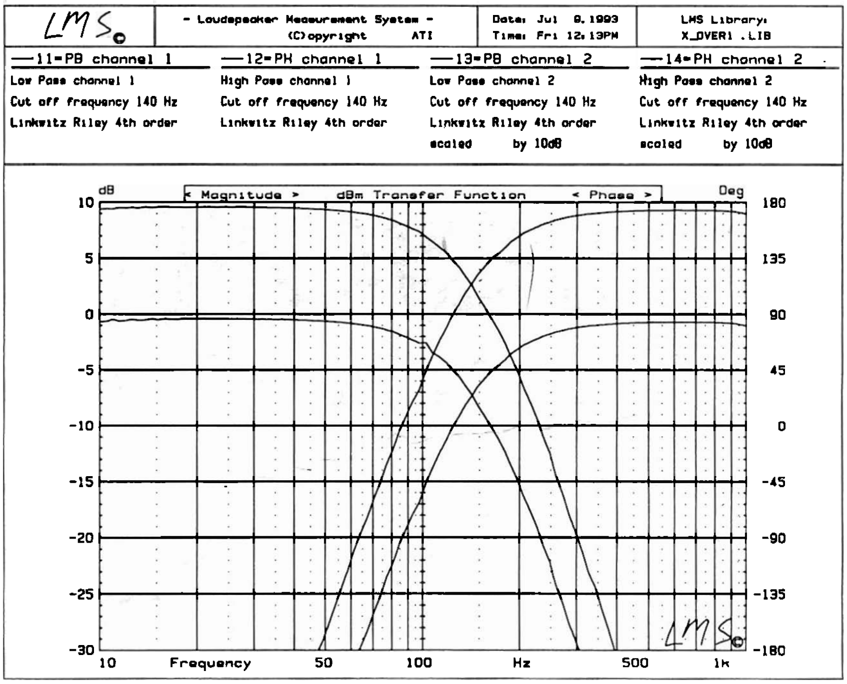


FIGURE 7: Response of the crossover populated as a two-way system. The cutoff frequency is 140Hz in a fourth-order Linkwitz-Riley mode. Only one value of capacitor and two for the resistors was needed: 0.1μF/160V WIMA MKP2; 7.5k and 15k 1% metal film resistors.

TABLE 2

TWO-WAY MOTHERBOARD PARTS LIST

PART	DESCRIPTION
Resistors	
R7, 11	47k
R12, 14	2,210
R13, 15	121
Capacitors	
C15, 20	1,000µF/35V radial
C16–19	47µF/35V radial
C21–24	0.1µF/100V WIMA MKS02
Semiconductors	
Q1, 2	BC337 or equivalent
U2	M337 TO220
U3	LM317 TO220
D1–6	1N4007 or equivalent
Miscellaneous	
B1–5	
B6–10	
P1–4	10-connector 3M ref. 8510-4500
Z1, 2	SDS Relay S2-12V
Heatsink	Schaffner ref. WA 337-25, 4 or 38, 1
U1	2-pin removable jumper

TABLE 3

THREE-WAY MOTHERBOARD PARTS LIST

PART	DESCRIPTION
Resistors	
R11	47k
R12, 14	2,210
R13, 15	121
Capacitors	
C15, 20	1,000µF/35V radial
C16–19	47µF/35V radial
C21–24	0.1µF/100V WIMA MKS02
Semiconductors	
Q1	BC337 or equivalent
U2	LM337 TO220
U3	LM317 TO220
D2–6	1N4007 or equivalent
Miscellaneous	
B2–6, 9, 10	
P1–4	10-connector 3M ref. 8510-4500
Z2	SDS Relay S2-12V
Heatsink	Schaffner ref. WA 337-25, 4 or 38, 1

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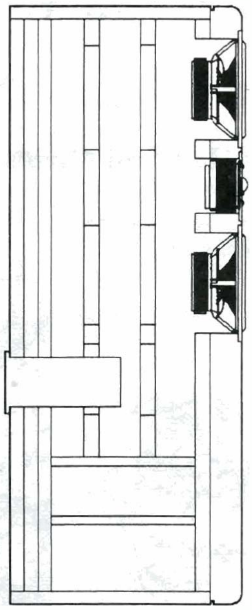
POWER



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