ACTIVE PHASE-LINEAR CROSS-OVER NETWORK

The ideal cross-over network is free of phase-shift, resulting in optimum pulse performance and radiation pattern. Although the ideal is not yet within reach, the work of Stanley Lipshitz and John Vanderkooy enables it to be approached very closely.

The most serious problem with ordinary cross-over filters is best illustrated with reference to a two-way system. This consists of a low-pass and a high-pass filter. One of the properties of a low-pass section is that it causes a time-delay of the signal. A high-pass filter on the other hand causes an acceleration of the signal. These actions result in a number of complications at the cross-over point:

(a) the signals from the two sections partially cancel one another;
(b) the strongly varying phase shift between the two signals adversely affects the radiation efficiency of the overall system;
(c) the radiation pattern becomes frequency dependent.

Some years ago, Stanley Lipshitz and John Vanderkooy published a series of papers ([1, 2, 3]) that have laid the foundation of the so-called phase-linear cross-over network.

Basically, the phase-linear network uses a low-pass section that also provides a high-pass characteristic with the aid of a time-delay and subtraction circuit. True, the time-delay is not constant over the entire frequency range, but it varies only slowly; moreover, there are no phase differences between the two output signals, even near the cross-over frequency.

A block schematic of a two-way, as well as a three-way, system based on the work of Lipshitz and Vanderkooy is shown in Fig. 1. It should be emphasized that the time-delay is an essential facet of the design. There are filters that make use of the subtraction method only, but these do not exhibit phase linearity.

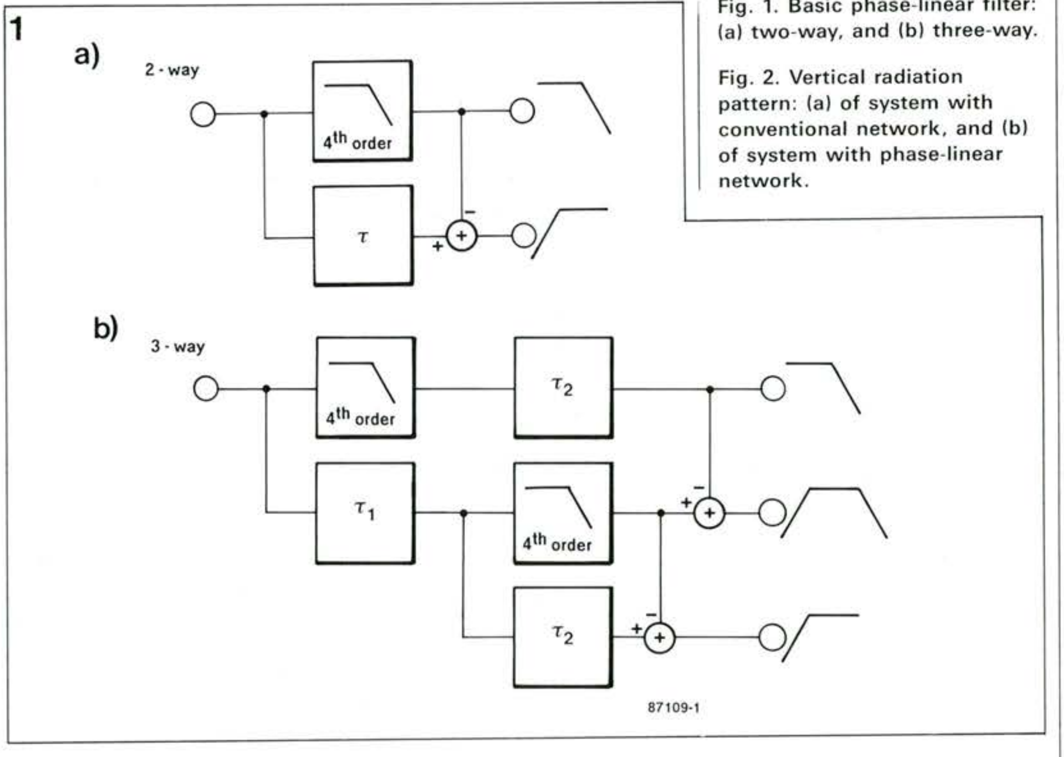

Fig. 1. Basic phase-linear filter: (a) two-way, and (b) three-way.

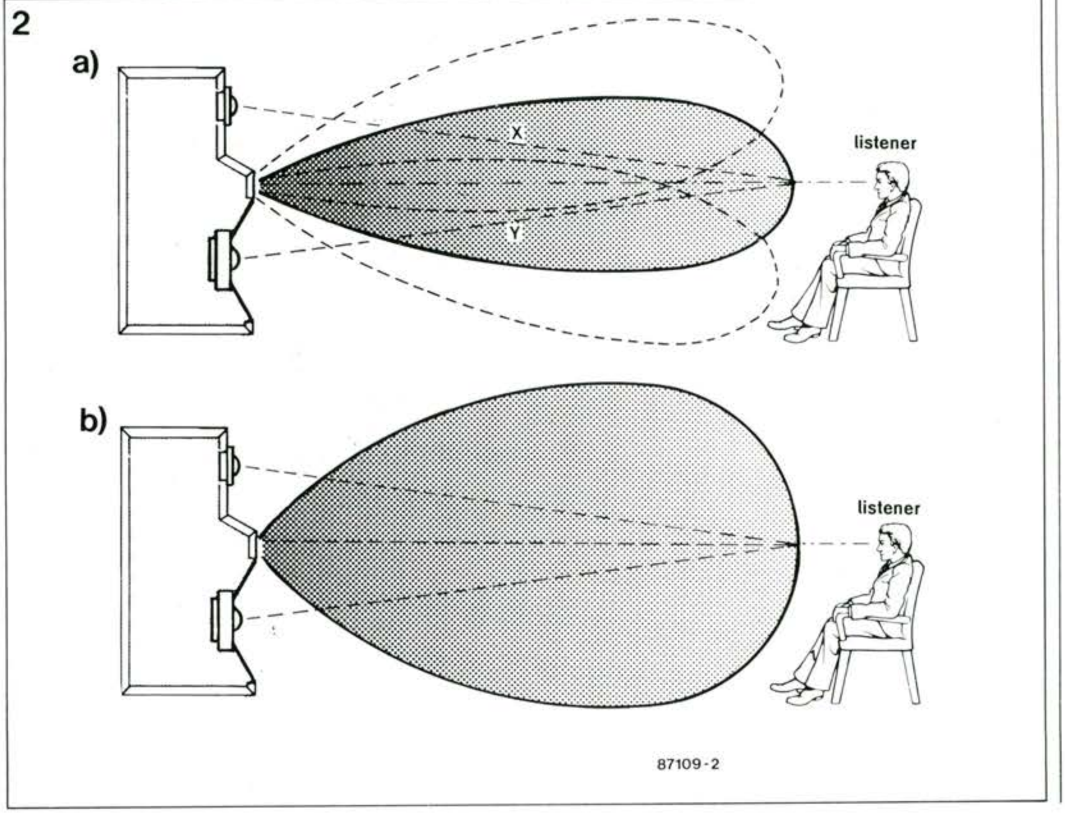

Fig. 2. Vertical radiation pattern: (a) of system with conventional network, and (b) of system with phase-linear network.

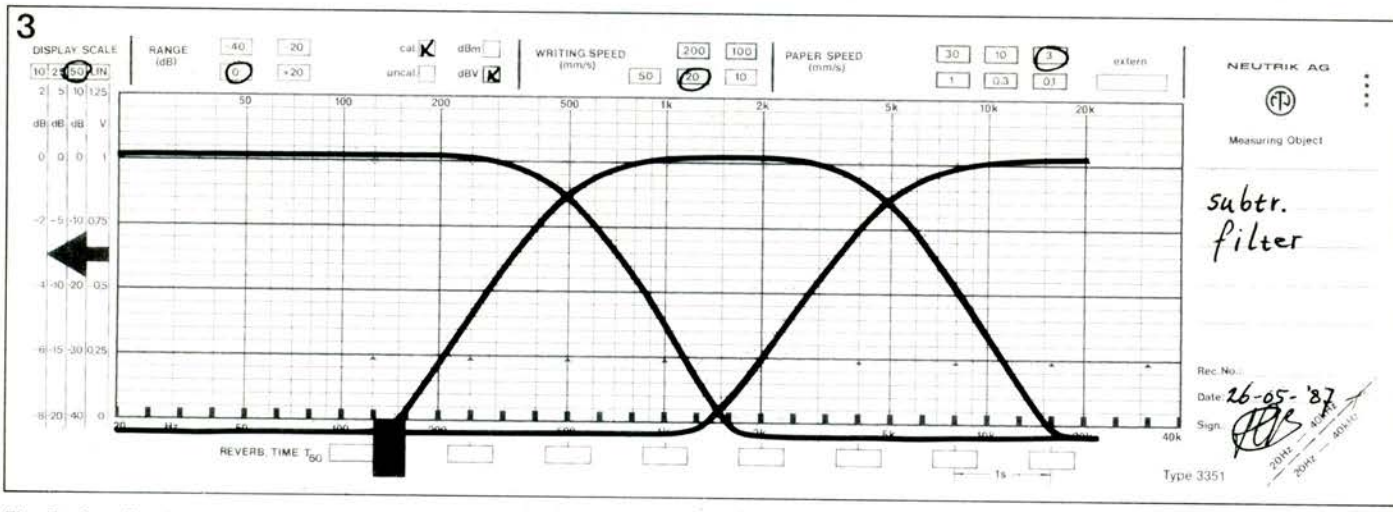

Fig. 3. Amplitude vs frequency characteristic of a three-way phase-linear network.

A customary fourth-order low-pass filter in the upper branch provides the normal low-pass performance. The delay, τ, is designed such that it has exactly the same phase behaviour as the low-pass section, and functions as an all-pass section. When then the output signal of the low-pass section is subtracted from the delayed signal, the result is a high-pass characteristic that has the same phase behaviour as that of the low-pass filter. Summing the two signals results in a perfectly straight line.

The set-up of a three-way system—see Fig. 1b—is a little more complicated, because an additional low-pass section has to be provided in the centre limb to obtain a band-pass characteristic for the middle frequency loudspeaker. This additional section must be compensated by a second delay, τ_2. Thus, in a three-way system, the τ_1 circuit simulates the time delay of the usual bass filter, while the τ_2 delay simulates the delay of the low-pass filter in the middle-frequency section.

The vertical radiation pattern (polar response) of a conventional loudspeaker system is shown in Fig. 2a. The dispersion is fairly small in the region where both speakers provide a signal. The spread also varies with frequency, which causes the lobe to either tilt or sag. The pattern of the phase-linear system in Fig. 2b shows that the lobe is much broader and points forward at all frequencies. In all this it is assumed that the acoustic centres of the loudspeakers lie on a vertical line, otherwise the pattern deteriorates.

A practical network

In a practical network, it is not possible (at least with an ac-

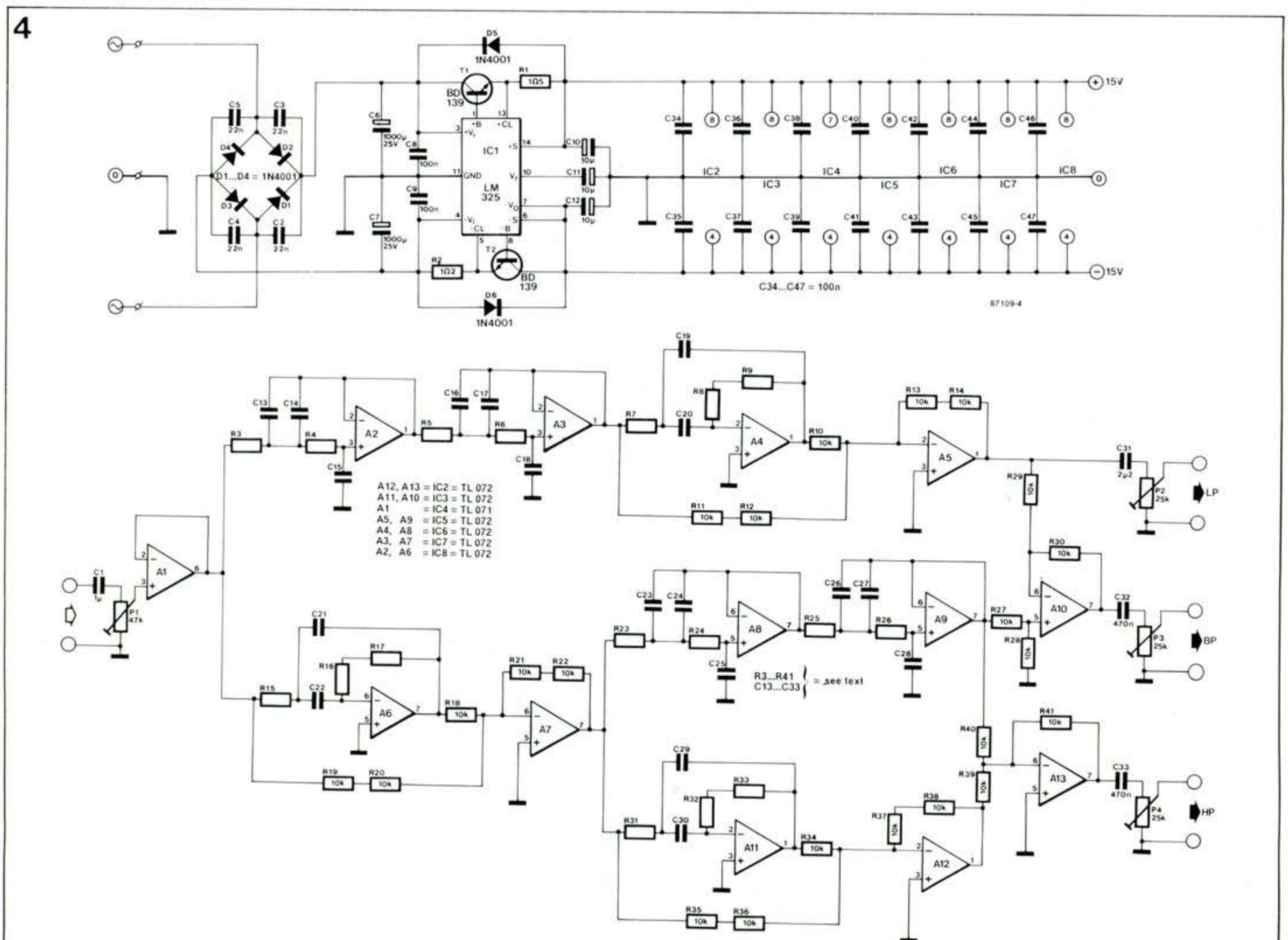

Fig. 4. Circuit diagram of the phase-linear network.

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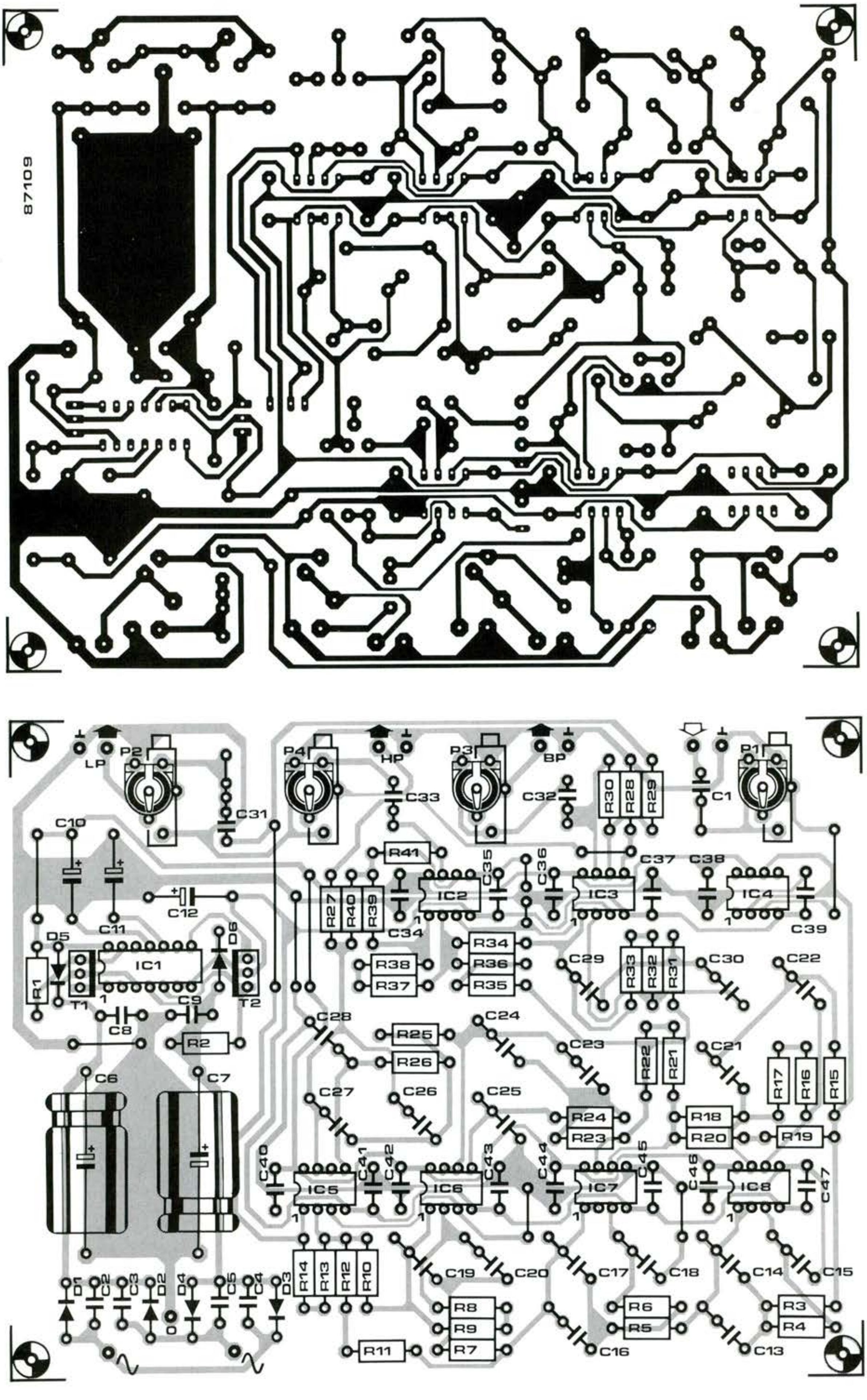


Fig. 5. Printed circuit board of the phase-linear filter.

ceptable number of components) to simulate any phase behaviour with the aid of a delay circuit.

All-pass networks have some interesting properties:

(a) they cause a phase shift, but no signal attenuation over a given frequency range;
(b) the phase shift caused by them is twice as large as that caused by a filter of the same order.

From this, it is evident that the low-pass section should be an even-order type, i.e., second-, fourth- or sixth-order. In the present network fourth-order filters are used, since these give a sufficiently steep roll-off and do not unnecessarily complicate the circuit.

Like all fourth-order networks, the present consists of a cascade of two second-order filters. For the present purposes, these should be identical to ensure that the phase behaviour of the all-pass network will be the same as that of the filter.

It was found that the Linkwitz-Riley (Squared Butterworth) filter is eminently suitable for the present network, because it allows a fairly simple all-pass to be designed with only two opamps. The resulting circuit has exactly the same phase behaviour as a fourth-order Linkwitz low-pass filter. Note that the cross-over frequencies are −6 dB points (as in all Linkwitz filters), since there is no phase shift between the two channels. The relative amplitude vs frequency characteristic is given in Fig. 3, while the three photographs illustrate the typical performance of the network. The photographs show the output voltage at the low- and middle-frequency terminals (a) slightly below the cross-over point, (b) at the cross-over point, and (c) slightly above the cross-over point. No phase differences between the two signals are discernible anywhere.

Circuit description

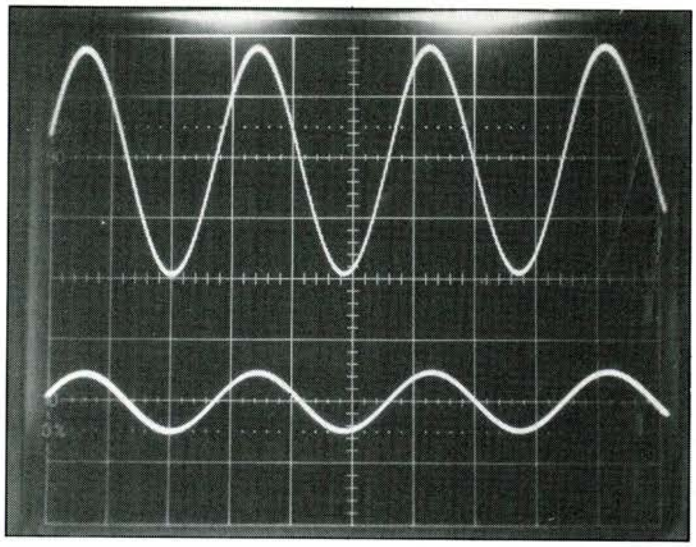
In the circuit diagram of Fig. 4, opamp A_1 is used as a buffer between the input signal and the filter proper. If necessary, the input signal may be attenuated by P_1; the total amplification of the network is unity.

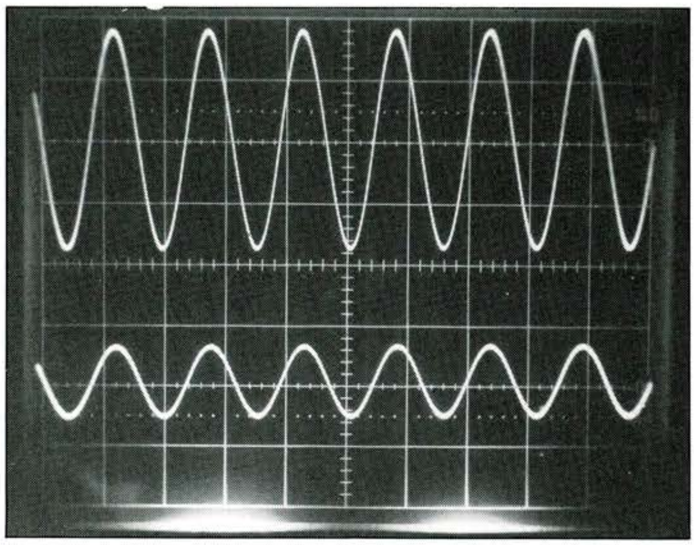
The low-pass filter is constructed around A_2 and A_3, while the associated all-pass filter is based on A_6 and A_7. The attenuation due to band-pass filter A_6 is compensated by A_7. The low-pass section for the middle frequencies consists of A_8 and A_9. Here, two identical all-pass filters are required, and these are formed by A_4-A_5 in the low section and by A_{11}-A_{12} in the high section. That completes the low-pass filter.

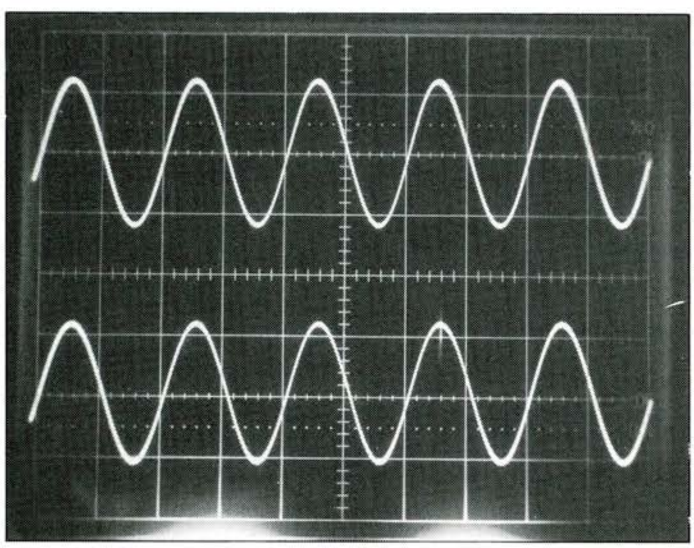
For the middle-frequency section, the output signal of A_5 must be subtracted from that of A_9, which is effected by A_{10}. Finally, the output signal of A_9 is subtracted once more from that of A_{12}, which is done by A_{13}. That completes the high-pass function.

The three outputs of the network are taken to preset potentiometers that enable matching each of them to the efficiency of the associated loudspeaker.

The quality of the power supply matches that of the cross-over network itself. Circuit IC_1 is a voltage regulator, which, in conjunction with two external series transistors, provides symmetrical output voltages. Diodes D_5 and D_6 ensure that the regulator is not damaged at switch-off.







Parts list

Resistors:

R_1;R_2 = 1K5J
R_3 to R_9; R_{15} to R_{17}; R_{23} to R_{26}; R_{31} to R_{33} = 22K5F
R_{10} to R_{14}; R_{18} to R_{22}; R_{27} to R_{30}; R_{34} to R_{41} = 10KF
P_1 = 47KJ cermet preset
P_2 to P_4 = 25KJ cermet preset

Capacitors:

C_1 = 1μ0 plastic film
C_2 to C_5 = 22n ceramic
C_6;C_7 = 1000μ; 25 V electrolytic
C_8;C_9;C_{34} to C_{47} = 100n ceramic
C_{10} to C_{12} = 10μ; 25 V electrolytic
C_{13} to C_{18};C_{21};C_{22} = 10n; 2.5% polypropylene
C_{19};C_{20};C_{23} to C_{30} = 1n0; 2.5% polypropylene
C_{31} = 2μ2 plastic film
C_{32};C_{33} = 470n plastic film

Miscellaneous:

PCB Type 87109 (readers who wish to make their own PCB may order the relevant drawings free of charge on the Order Form on page 69).

NOTE: Many components may be available from
Audiokits Precision Components
6 Mill Close
Borrowash
DERBY DE7 3GU
Telephone: (0332) 674929

Semiconductors:

D_1 to D_6 = 1N4001
T_1 = BD139, T_2
T_2 = BD140
IC_1 = LM325
IC_2;IC_3;IC_5 to IC_8 = TL072; NE5532; LF353; LM833, OP215
IC_4 = TL071; NE5534; LF356; OP27; OP15

Construction

The network is most conveniently constructed on the ready-made PCB Type 87109 shown in Fig. 5. The values of the components given in the parts list pertain to cross-over frequencies of 500 Hz and 5,000 Hz. Different frequencies may be calculated with the aid of the Linkwitz formulas in Ref. 4.

In several places, capacitors are shown in parallel and resistors in series: this is done to enable the use of as many components of the same value as possible. As usual, the choice of capacitors is determined mainly by their loss factor and cost, which normally results in plastic film types.

It should be noted that each PCB has its own regulator IC: this is convenient where the network is fitted in the loudspeaker enclosure.

The impedance at the network outputs, depending on the position of the presets, has a maximum value of 12 kilohm. Since this may be on the high side for certain output stages, the value of the presets may be reduced to 5 kilohm, which results in a maximum output impedance of 2.5 kilohm. Where this is done, the value of C_{31} should be increased to 4µ7. A useful rule of thumb is that the input impedance of the output stage must be at least ten times as large as the output impedance of the network.

The PCB may be used to construct a two-way network, in which case the following components are omitted: IC_2; IC_5; IC_6; R_7 to R_{14}; R_{23} to R_{26}; R_{31} to R_{41}; C_{19}; C_{20}; C_{23} to C_{30}; C_{33}; P_4. Furthermore, a wire link should be fitted between pin 1 of A_3 and another between pin 7 of A_7 and C_{32}.

References

1. S. Lipshitz & J. Vanderkooy, *A Family of Linear-Phase Cross-over Networks of High Slope Derived by Time Delay* (*Journal of the Audio Engineering Society*, Jan. & Feb. 1983).

2. S. Lipshitz and J. Vanderkooy, *Is Phase Linearization of Loudspeaker Cross-over Networks Possible by Time Off-set and Equalization?* (*JAES*, Dec. 1984)

3. S. Lipshitz and J. Vanderkooy, *Use of Frequency Overlap and Equalization to Produce High-slope Linear-phase Loudspeaker Cross-over Networks*, (*JAES*, March 1985)

4. *Linkwitz Filters, Elektor Electronics*, April 1987

90 TWO-TONE RF TEST OSCILLATOR

This test oscillator is useful to ensure optimum operation of RF amplifier stages designed to work on the short-wave bands. Based on two crystal oscillators, it provides considerable output power (10 to 100 mW) to enable measuring intermodulation characteristics of high level and RF power stages. The quartz crystals used here not only serve as the frequency determining elements (2...20 MHz), but also as output filters to prevent one generated signal being lost in the other oscillator. With this in mind, tapped inductors L_1 and L_2 ensure freedom of mutual interference when the oscillator is used for frequencies higher than 10 MHz. Both inductors are wound as 12 turns of enamelled copper wire with a centre tap, on either a small balun or a suitably rated core with an air gap. Outputs of equal amplitude can be obtained by adjusting P_1.

The test oscillator consumes about 250 mA from a 60 V supply. This means that both transistors should be fitted with a heat-sink, and that chokes L_3 and L_4 should be capable of carrying about 150 mA. *B*