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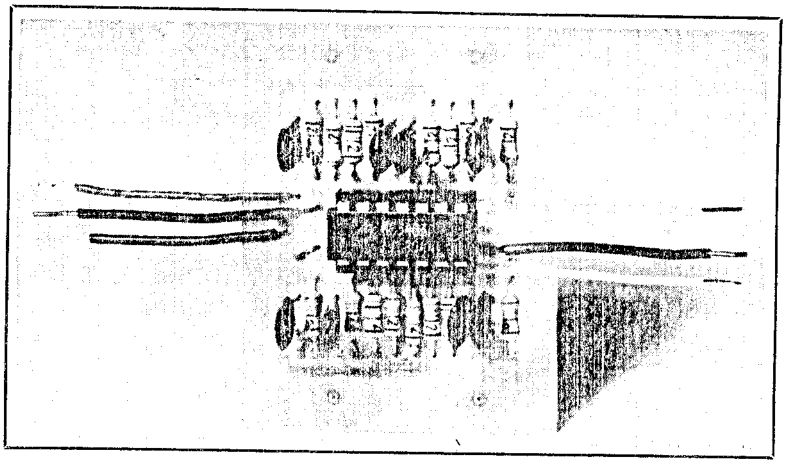
A Simple, Effective Receiving Aid



Enhance the intelligibility of phone or CW with this simple addition to your shack.

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Noise and interference often impair the intelligibility of signals received on the Amateur Radio bands. This article describes a novel audio-processing technique to enhance the intelligibility of signals corrupted by noise and interference. The circuitry required is inexpensive, easy to build and needs no alignment or adjustment, and can be used with any receiving equipment. The technique is effective when you are using either headphones or loudspeakers and when listening to Morse code or voice signals.

The general principle of the technique is shown in Fig 1. The audio output from the receiver, or transceiver, is split into two channels by the low- and high-pass filters. When you're listening with loudspeakers or stereo headphones, high-pitched sounds seem to originate from one direction, while low-pitched sounds seem to originate from the other. Middle-pitched sounds appear to come from a position directly in front of you. Placing the speakers at 45 degrees to the left and right of you achieves good results.

If several Morse code signals are crowded into the receiver's passband, each appears to be located in a different spatial position in relation to you. Consequently, your consciousness is provided a directional parameter, which enhances the ability to focus attention upon and, hence, to better comprehend any one of the signals. A received voice signal appears to originate from a position directly in front of you, but noise and interference near the edges of the passband appear to come from the left and right of the voice. This phenomenon renders the signal more intelligible. Broadband noise, either thermal or atmospheric, is perceived in a panorama and, although audible, is less distracting because your attention is focused on a signal that appears to originate from some particular direction.

Experiments with this technique on the high-frequency Amateur Radio bands have shown that although it is not a panacea, it improves the intelligibility of signals corrupted heavily by noise and interference. In addition, you can expect less fatigue during long periods of difficult reception, such as those experienced during contests on the 160-meter band.

Filter Parameters

Butterworth filters are the best choice for this application. The relative output power from a low-pass Butterworth filter can be expressed as

$$P_L = \frac{1}{1 + (f/f_c)^{2n}} = \frac{(f_c/f)^n}{(f_c/f)^n + (f/f_c)^n} \qquad \text{(Eq 1)}$$

where
f is the frequency
f_c is the cutoff frequency at half power
n is the number of poles

The relative output power from a high-pass Butterworth filter can similarly be expressed as

$$P_H = \frac{1}{1 + (f_c/f)^{2n}} = \frac{(f/f_c)^n}{(f/f_c)^n + (f_c/f)^n} \qquad \text{(Eq 2)}$$

If both the low- and high-pass filters are complementary, in the sense of having the same cutoff frequency and the same number of poles, Eqs. 1 and 2 reveal that the total output power is

$$P_T = P_L + P_H = 1 \qquad \text{(Eq 3)}$$

which is a constant, and independent of the frequency in question. Complementary Butterworth filters can split the audio band into a low-frequency channel and a high-frequency channel in such a way that the total spectrum of output power, from both channels, is exactly the same as the spectrum of input power. Thus, you would perceive exactly the same "tonal quality" whether the filters are switched in or out of the system. The direction from which a tone seems to originate depends on the ratio of the power at the output of one channel to

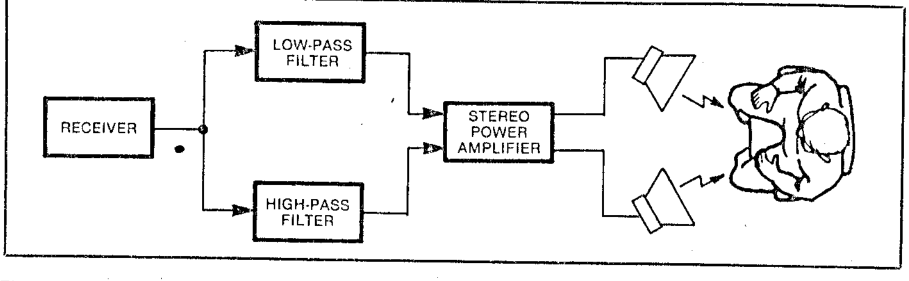

Fig 1—Illustration of the general principle.

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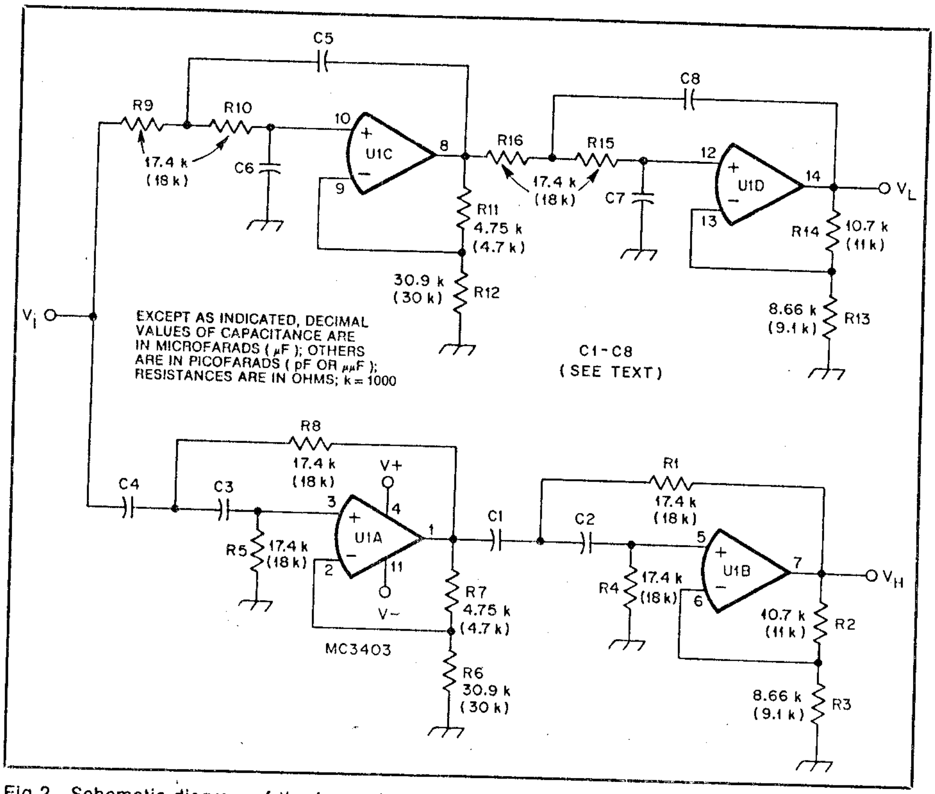

EXCEPT AS INDICATED, DECIMAL VALUES OF CAPACITANCE ARE IN MICROFARADS (μF); OTHERS ARE IN PICOFARADS (pF OR $\mu\mu$F); RESISTANCES ARE IN OHMS; k = 1000

Fig 2—Schematic diagram of the four-pole complementary Butterworth filters.

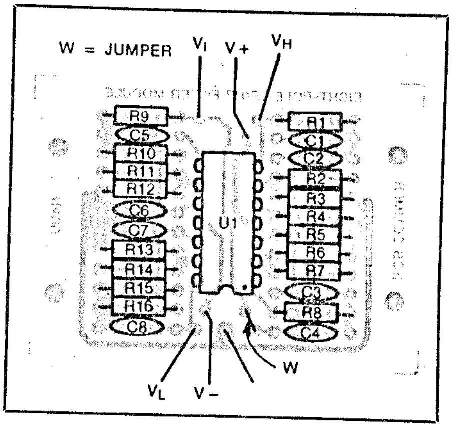

Fig 4—Parts-placement diagram for the four-pole complementary Butterworth filters.

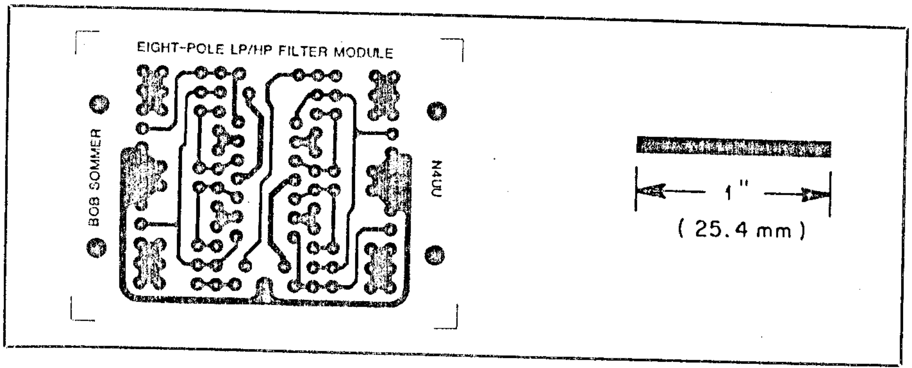

Fig 3—Full-size circuit-board etching pattern, shown from the foil side. Black areas represent unetched copper.

that of the other. Using Eqs. 1 and 2, this ratio can be expressed as

$$R = P_H/P_L = (f/f_c)^{2n} \qquad \text{(Eq 4)}$$

which, when converted to decibels (dB), becomes

$$R = 20n \log_{10} (f/f_c) \text{ dB} \qquad \text{(Eq 5)}$$

Consequently, complementary Butterworth filters provide a ratio of channel outputs with a constant slope of 20n dB per decade, or 6n dB per octave, across the entire audio spectrum. This characteristic causes the perceived origin of a tone to vary smoothly, at a rather uniform rate, from one direction to the other as the pitch of the tone is varied. When $f = f_c$, the two channel outputs are equal, $R = 1$ (0 dB), and the tone seems to originate in front of you.

Complementary Butterworth filters also provide a difference in phase at their outputs, which is fixed at 90n degrees. For you to perceive a distinct direction, it is essential that the two channel outputs be in phase, which is achieved when n is a multiple of four.

Experiments show that when the cutoff frequency is f_c = 900 Hz, voice signals appear to originate directly in front of you; and that n = 4 is the best choice for voice reception. The ratio of channel outputs varies at a rate of 24 dB per octave (Eq 5). This is low enough so that the various frequency components in the voice signal create the impression that the voice is directly in front of you and it is high enough to render the broadband noise in a panorama. In a typical SSB bandwidth of 2.4 kHz, the noise and interference at the band edges are 38 dB stronger in one channel than in the other, and seem to originate far to the left and right of the listener.

In receiving Morse code, many operators favor a frequency near 600 Hz. A cutoff frequency of f_c = 600 Hz is a good choice. In a typical CW bandwidth of 500 Hz, and with n = 4, noise and interference at the band edges are 14 dB stronger in one channel than in the other. Under these conditions, most signals appear to originate in front of you or moderately to the left or right. The Morse code operator will benefit from the use of eight-pole filters, particularly when using bandwidths of 250 Hz or less. With n = 8, the listener perceives signals within a crowded 500-Hz passband as a wide panorama, but senses only a moderate, but useful, panorama when the bandwidth is reduced to 250 Hz.

Four-Pole Filters

Fig 2 shows a circuit diagram for a pair of four-pole complementary Butterworth filters. The voltages V_i, V_L and V_H refer to the input signal, the low-pass filtered output, and the high-pass filtered output, respectively. The supply voltages, V+ and V−, can range between ±6 and ±15 volts, and the quiescent current is nominally 3 mA. I use the MC3403 quad op amp because I've found it to be totally free of crossover distortion. The LM324 and MC4741 are readily available, inexpensive and interchangeable. Using 0.01-μF capacitors will provide f_c = 900 Hz for use with voice; 0.015-μF capacitors will provide f_c = 600 Hz for use with Morse code.

The precise value of the capacitors is not important, but it is important that all eight be matched closely. If a capacitance meter is not available, an easy alternative is to build a simple astable multivibrator, using a 555 timing circuit and note the frequency of oscillation as various capacitors are connected (see accompanying sidebar). Polyester film capacitors, with a 10% tolerance, are inexpensive when purchased in lots of 100; and one such lot will yield several sets of eight closely matched capacitors. Fig 2 shows two sets of resistor

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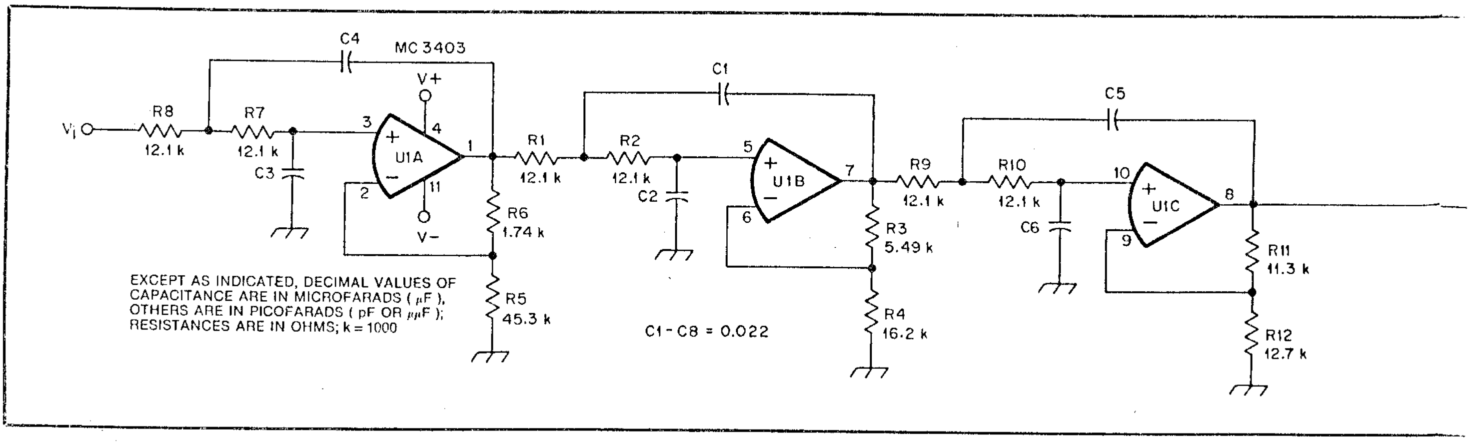

Fig 5—Schematic diagram of the eight-pole low-pass Butterworth filter.

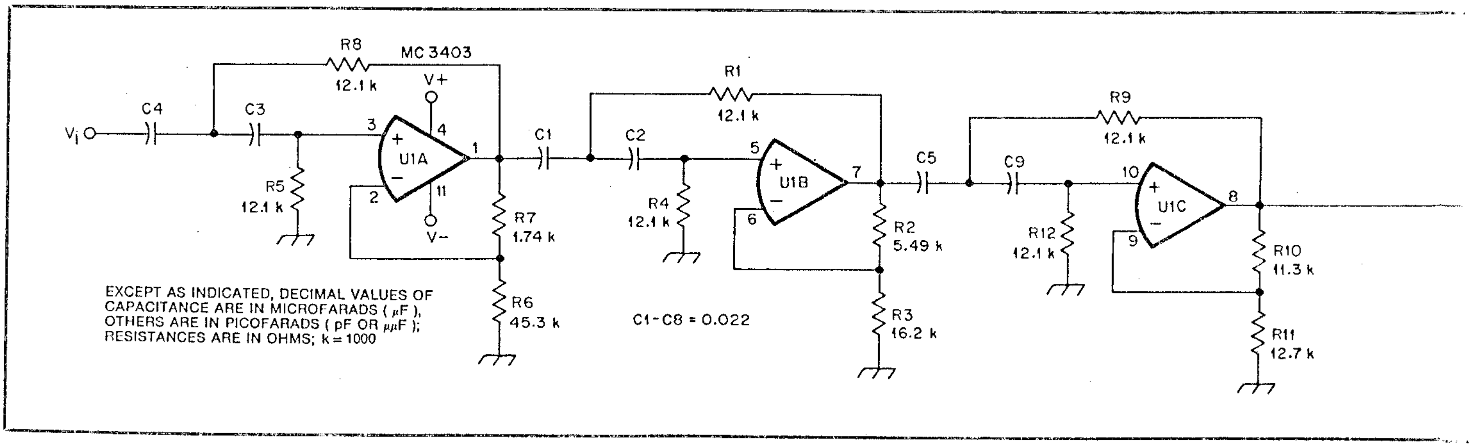

Fig 6—Schematic diagram of the eight-pole high-pass Butterworth filter.

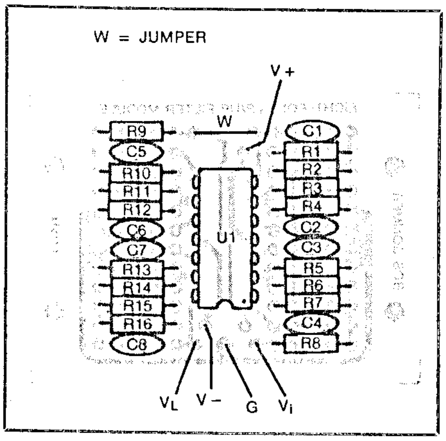

Fig 7—Parts-placement diagram for the eight-pole low-pass Butterworth filter.

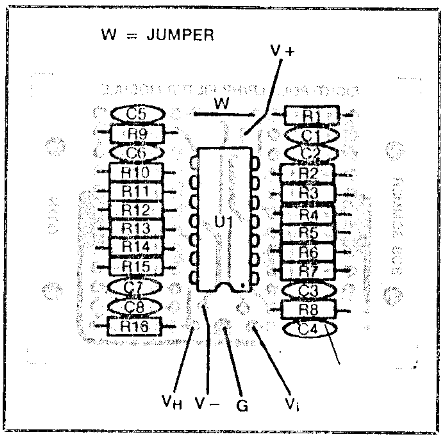

Fig 8—Parts-placement diagram for the eight-pole high-pass Butterworth filter.

values; those for resistors with a 1% tolerance, and those (in parentheses) for resistors with a 5% tolerance. These four-pole filters will work well using components with 5% tolerances, but the use of components with a closer tolerance will ensure a more accurate matching of the gain and phase of the two channel outputs.

Fig 3 shows a pattern for etching a circuit board for these filters, and Fig 4 shows the parts placement. The hole spacing will accommodate the 100-V polyester film capacitors and either 1/8-W, 1% resistors, or 1/4-W, 5% resistors. The input to the filter, V_i, can be taken from the receiver audio jack for either headphones or a remote speaker. The filter outputs, V_L and V_H, should be capacitively coupled to either high-impedance stereo headphones (at least 100 ohms), or to a stereo power amplifier and loudspeakers. Use large coupling capacitors, such as 47 μF, to ensure phase matching of the two channels at lower audio frequencies.

Eight-Pole Filters

Eight-pole filters provide a wider spreading of the signals, which is preferable for Morse code. Figs 5 and 6 show circuit diagrams of complementary low- and high-pass Butterworth filters. Resistors of 1% tolerance should be used in the construction of these filters, and all 16 capacitors, as a group, should be matched to within 1%. Two circuit boards, in accordance with Fig 3, are required: one for the low-pass filter, and one for the high-pass filter. The circuit boards have extra pads to accommodate either a resistor or a capacitor in certain positions, depending on which circuit is being built. Figs 7 and 8 show parts placement for the low- and high-pass filters, respectively.

Attenuators

The four-pole filters have a gain of about 8 dB, while the eight-pole filters have a gain of about 17 dB. To maintain a constant sound level as the filters are switched in and out, each channel should have a gain of 3 dB. Consequently, the four-pole filter output should be attenuated by about 5 dB, and the eight-pole filter should be attenuated by about 14 dB. Fig 9 shows a circuit for ap-

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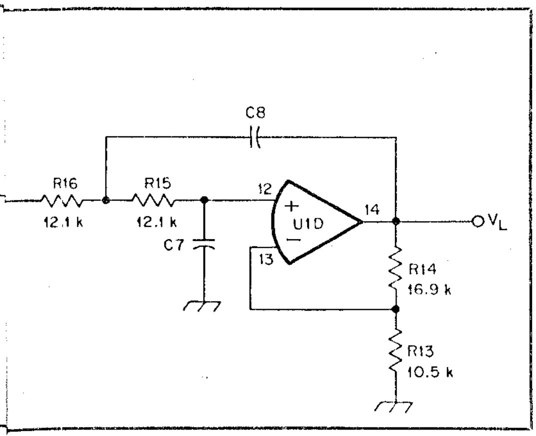

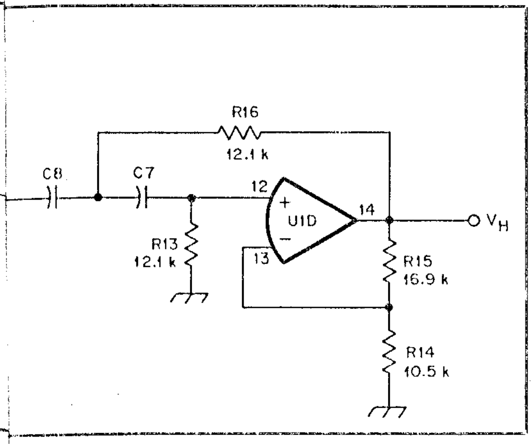

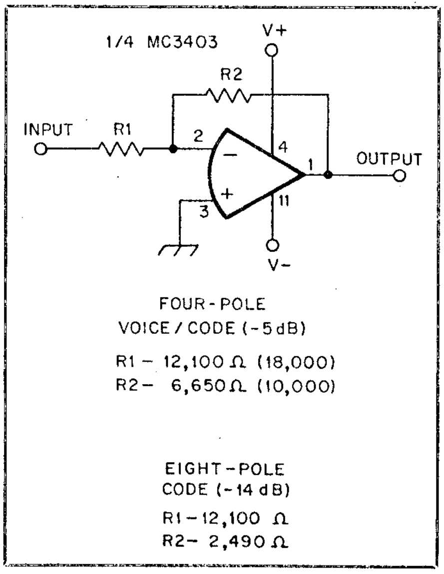

Fig 9—Schematic diagram of attenuators.

propriate attenuators, with resistance values. The parenthetical values for the four-pole filter are for 5% resistors. A single IC will accommodate up to four attenuators, and you can obtain the appropriate pin numbers from Figs 2, 5 or 6. Attenuators should be used—they are easily built and inexpensive, and permit the inherent wide dynamic range of the filters to be used to better advantage.

Refinements

Fig 10 shows an implementation of this audio-processing technique, together with some embellishments. The four-pole filters with f_c = 900 Hz, or the eight-pole filters with f_c = 600 Hz, can be selected by switch S1 for voice or code reception, while the filters can be included or bypassed with switch S2. The low- or high-frequency channels can be interchanged with switch S3 to reverse the direction of the panorama. Users with a frequency-selective hearing loss might prefer one position over the other. An 8.2-ohm resistor is included to terminate the receiver audio output stage.

When loudspeakers are used, they must be properly phased, as is the case with any high-fidelity stereo system, and identical speakers should be used to ensure the proper balance between channels.

Miscellaneous

The use of this technique is protected by U.S. Patent No. 4,434,508, with the author as inventor and American Systems Corporation as assignee. Amateur Radio operators are encouraged to build these circuits for their own use, but manufacturers are cautioned that all rights under the patent code will be enforced. [It should be noted that this article and patent describe a technique where the number of poles, (n), is a multiple of four. This approach maintains the outputs in phase. A parallel, independent development occurred in approximately the same time frame at ARRL HQ, resulting in a design using three-pole Butterworth filters. This project was reported and published in *The 1981 Radio Amateur's Handbook,* pp 8-50 to 8-52. This ARRL development is in the public domain.—Ed.]

Circuit boards and limited quantities of resistors and capacitors are available from the author and American Systems Corporation. For price and other information, contact them at: 7535 Little River Tpke, Annandale, VA 22003.

Acknowledgments

I wish to thank N. Perriello for preparing Figs 1, 4, 7 and 8, and Dr. Francis A. Burkle-Young for editing the manuscript.

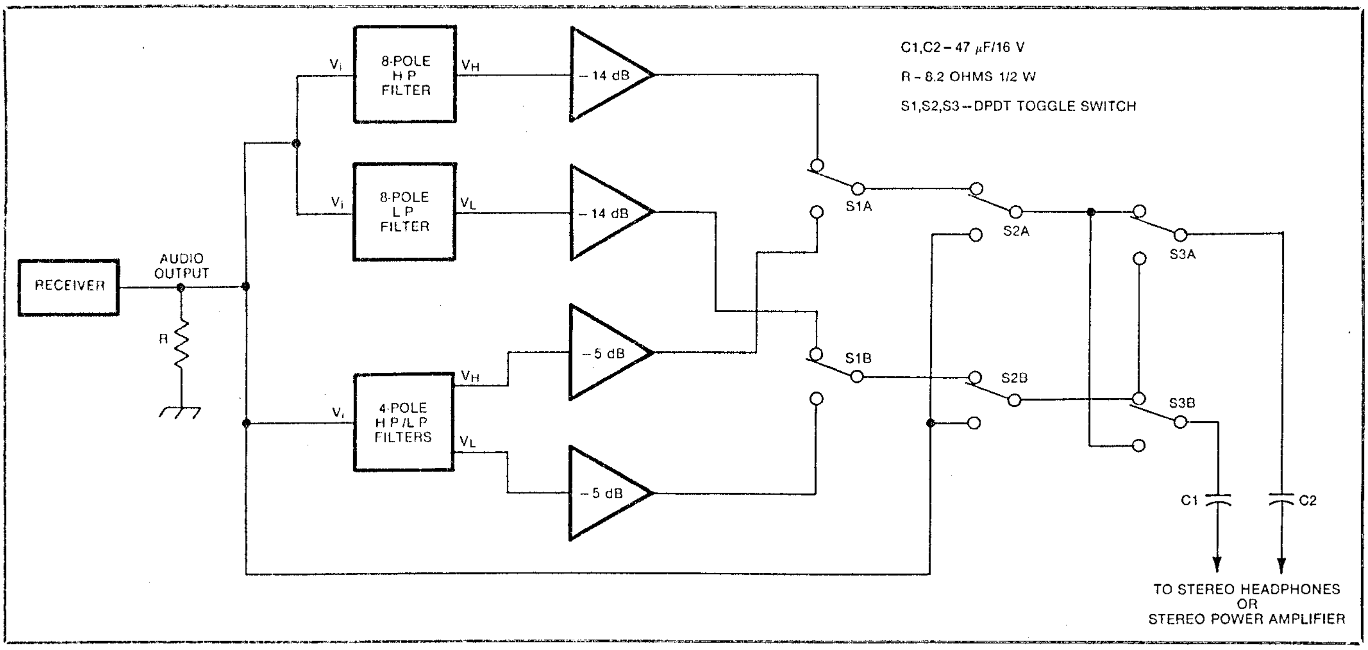

Fig 10—Block diagram of a total system with flexible switching provisions.