BUILD THIS

Low Frequency Filter for your Hi-Fi

As your sound system gets better you can hear more—sometimes more than you want to. This simple, low-cost filter will get rid of rumble and acoustic feedback without affecting the quality of the audio.

By JOSEPH M. GORIN

IMPROVING AUDIO SYSTEMS ELECTRONically is what signal processors are all about: the LFF (*L*ow *F*requency *F*ilter) described here can improve the quality of reproduction from the low-frequency end of your sound system. The LFF helps eliminate three types of low-frequency problems: subaudible (too low in frequency to be heard) rumble, audible rumble, and acoustic feedback. By taking advantage of modern recording practices, and the characteristics of stereo discs, the LFF can filter out those annoyances without affecting the music.

Stereo recording conventions

A stereo phonograph record uses both walls of a groove to carry the right- and left-hand channel information. The continuously-changing positions of those walls relative to the position of the stylus of your cartridge cause it to move and to generate electrical signals which eventually are heard as sound. Figure 1-a shows the cross-section of a groove when only the right channel is modulated. Notice how the left wall remains stationary while the right wall moves. Also note that the stylus not only moves from side to side, but vertically, as well.

In the days before stereo, both walls moved together *horizontally*, as shown in Fig. 1-b. To permit stereo equipment to play monophonic recordings, a monophonic signal was defined as one having equal strength in both channels, causing the left wall to recede while the right wall advanced (and vice versa), moving the groove only horizontally.

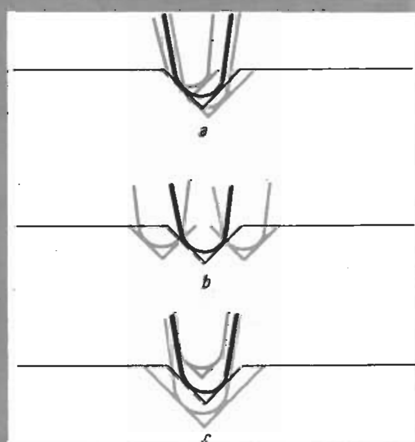

FIG. 1—CROSS SECTION OF a stylus in a record groove during right-channel, horizontal (mono), and vertical (out-of-phase) modulation.

Consider what would happen if the walls were to converge, as shown in Fig. 1-c. A large signal could easily make the groove disappear, or cause distortion when the contact point of the stylus changed as the groove got smaller. Fortunately, that can only happen with large out-of-phase signals, which, because phono pickups are velocity sensitive, tend to occur only at low frequencies.

When high-quality recording techniques—such as direct-to-disc—are used, long-wavelength, low-frequency signals occur only in-phase, since the microphones used are closely spaced in comparison with the wavelength of the sound. Large vertical excursions of the stylus will not take place under these conditions.

When multi-track recording is used, though, many signals having a multitude of phase relationships are mixed together. To eliminate the possibility of out-of-phase low-frequency signals finding their way onto a record produced using multi-track equipment, a circuit similar to that of the LFF is used to make the low frequencies monophonic (in-phase) and avoid that situation. Pure-vertical audio signals are not found on most records.

Vertical noise, though, is another matter. There are two kinds of low-frequency noise on a record—warp and rumble. All records, even the best, are warped to some degree. As the stylus tracks a warped record, it follows the vertical excursion of the warp and passes that on to your system. Much warp energy lies below audible frequencies and cannot be heard (al-

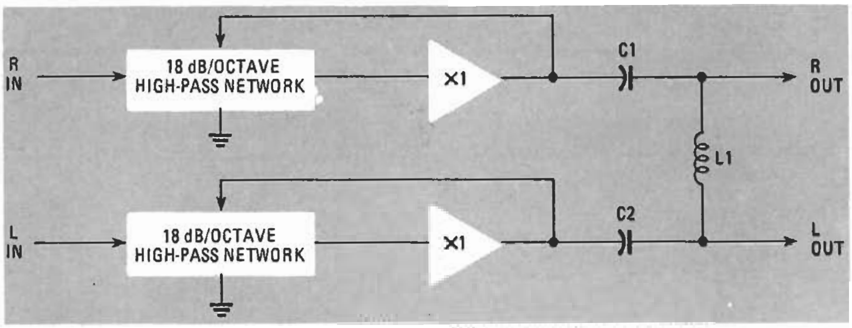

FIG. 2—THE L-C NETWORK in this block diagram shorts the left and right channels together at frequencies below 140 Hz, cancelling out-of-phase signals.

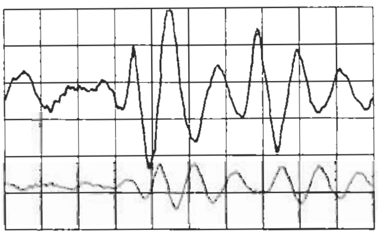

FIG. 3—SPECTRUM ANALYSIS of the "silent" groove of a record with considerable rumble. The upper curve is the input to the LFF, the lower curve is the output.

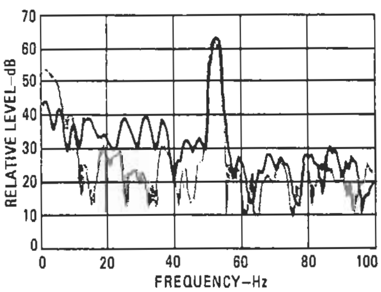

FIG. 4—THIS IS A spectrum analysis of the low-level, low-frequency introduction to a song. The upper curve is th' .nput to, the lower curve the output from, the LFF. Note how audio peak is unchanged by filter.

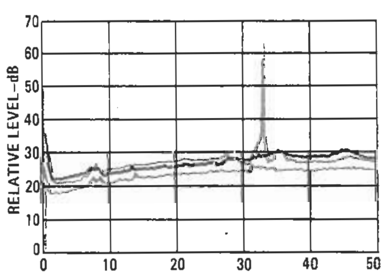

FIG. 5—FREQUENCY RESPONSE OF THE SYSTEM. Note how thoroughly the 30-dB peak (middle curve) is removed by the LFF (upper curve).

though it can affect your speakers), but many warps have an audible component as well.

All turntables have rumble. It usually results from noisy motor bearings and its vertical component is picked up by the stylus. However, with a good turntable, rumble is usually insignificant and is outweighed by the rumble cut into most records. That rumble exists because it is very hard to move the massive head of the cutting lathe across the master disc (known as the *lacquer*) when it is being prepared. The vertical component of the noise from the bearings in the lathe is transmitted to the cutting head, and to the lacquer. Eventually it winds up as part of your record.

Direct and indirect effects of noise

The direct consequence of the vertical modulation of the record groove that we have been discussing is low-frequency noise that detracts from the quality of the sound (and our enjoyment of it). This direct effect, however, is quite rare. It is noticeable only in high-end systems that are capable of reproducing the bottom octave of the audio spectrum.

The indirect effects arise from the larger-amplitude subaudible signals. They can cause vary large excursions of the speaker system's woofer. When the woofer's cone is displaced significantly, the sensitivity of the speaker changes. The result is intermodulation distortion caused by a mixing of the (normal) audio signal and the subaudible one. The effect is especially bothersome in high-efficiency and/or ported speaker-systems. In high-efficiency systems, the voice-coil/magnetic-field overlap drops quickly as the cone is displaced, causing significant intermodulation distortion. In a ported system, because of the reduced "air load" on the woofer, rumble components below the system's resonant frequency cause very large cone excursions, especially when compared to acoustic-suspension systems.

A second indirect effect is reduced power reserves in the power amplifier. That is because a significant portion of the amplifier's output capability is being used to reproduce the subaudible signal. If the amplifier is driven into clipping, further intermodulation distortion will be introduced.

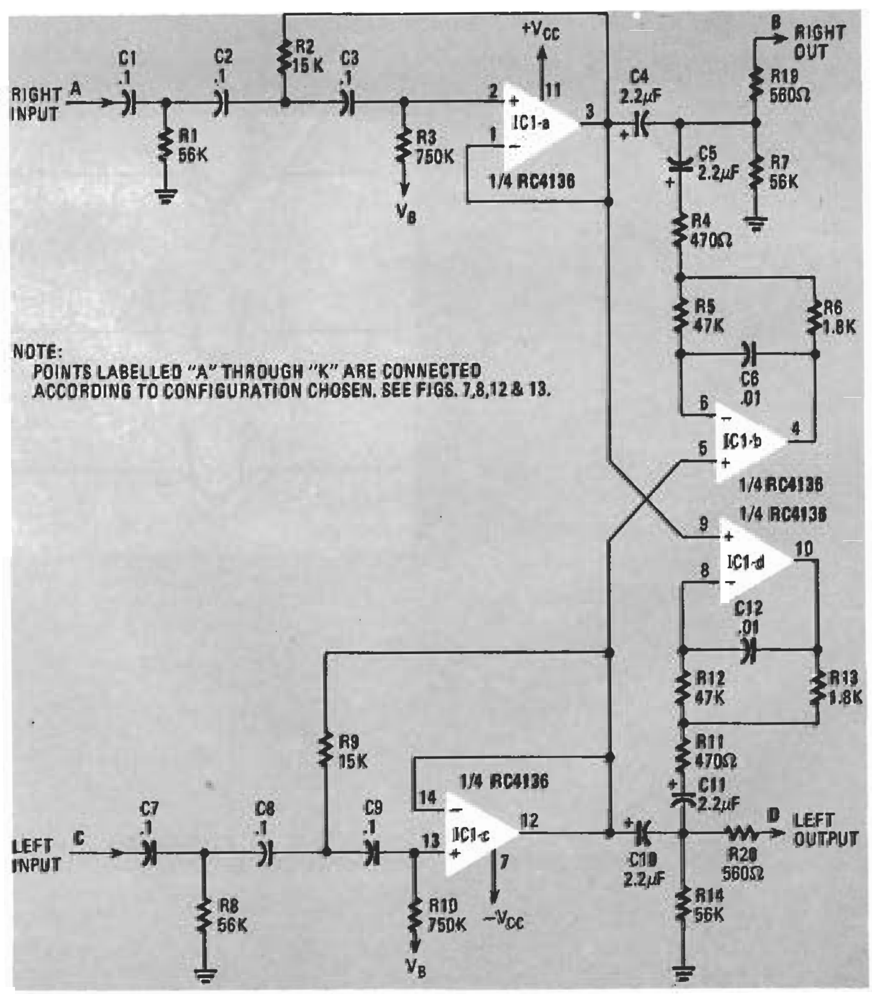

FIG. 6—THE KERNEL section of the LFF contains all of the filter circuitry. It can be installed in an existing piece of equipment, or used as part of a stand-alone unit.

PARTS LIST

Resistors ¼ watt, 5% unless otherwise noted
R1, R7, R8, R14—56,000 ohms
R2, R9—15,000 ohms
R3, R10—750,000 ohms
R4, R11—470 ohms
R5, R12—47,000 ohms
R6, R13—1800 ohms
R15-R17—220,000 ohms
R18—220 ohms
R19, R20—560 ohms

Capacitors
C1-C3, C7-C9—.1 µF, 5%, polyester film
C4, C5, C10, C11—2.2 µF, 10%, tantalum
C6, C12—.01 µF, 10%, polyester film
C13, C14, C17—.1 µF, 50 volts, ceramic disc
C15, C16—10 µF, 25 volts, aluminum electrolytic
C18—220 µF, 35 volts, aluminum electrolytic

Semiconductors
IC1—RC4136 quad op-amp
D1-D4—1N4002
J1-J8—chassis-mount phono jacks
S1-S8—DPDT miniature toggle switch
T1—wall plug transformer, 12-24 volts AC, 100 mA

Miscellaneous: PC board, chassis, hardwood end panels, hardware, wire, etc.

Note: The following are available from Symmetric Sound Systems, 912 Knobcone Place, Loveland, CO 80537. Complete kit, model LFF-1 with unfinished walnut end panels; $50.00 (Canada, $55.00 U.S. funds); model LFF-Kernel with R1-R20, C1-C12, IC1, PC board, and miscellaneous wire and hardware, $15.00; model LFF-PC printed-circuit board only, $7.00. All prices include UPS shipping in the U.S. on prepaid orders. Visa and M/C, add $1.00 handling and all shipping charges. U.S. mail, add $3.00 for the LFF-1 only. Colorado residents, add 3% sales tax.

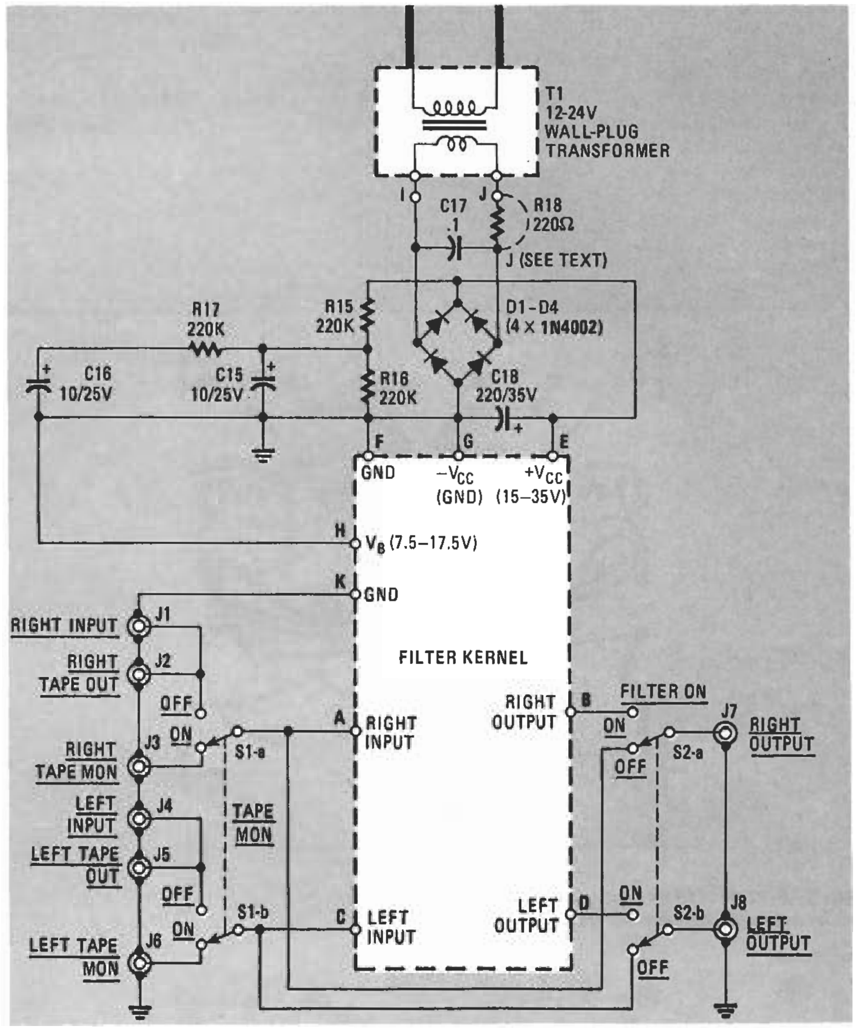

FIG. 7—FULL-WAVE BRIDGE POWER supply for a stand-alone LFF. The bias voltage (half the supply voltage) is connected to pin H of the kernel.

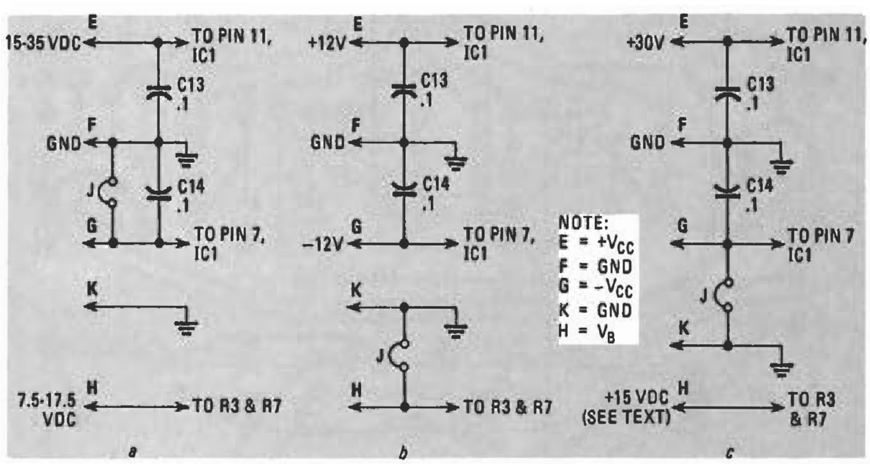

FIG. 8—HOW A POWER SUPPLY is connected to the kernel section of the LFF. Connections for a stand-alone unit are shown in ***a***. The LFF can also be built into an ASRU using the connections shown in ***b***, or a graphic equalizer using the connections shown in ***c***.

The obvious solution

There is a simple remedy for the problems just described—make the system monophonic at low frequencies and, for added protection, roll off its response below the range of normal hearing. This will have no effect on the program material—just on the noise. If the circuit is well-designed, it will not alter the stereo effect either, because a listener's perception of localization (imaging—the stereo effect) is based on frequencies much higher than the ones that will be filtered out. The LFF switches from stereo to mono at about 140 Hz, with a moderately rapid transition.

Figure 2 is a block diagram of the LFF. Both channels have 18-db/octave rapid-cutoff filters for subaudible signals below 15 Hz. The right and left channels are then combined by a network made up of C1, C2, and L1. At low frequencies, the impedance of the capacitors is large and that of the inductor is small, so that the two channels mix into one and out-of-phase signals cancel each other. At higher frequencies, the relative impedances reverse and the channels remain separate. The result is effective filtering of only the noise.

To get an idea of what the LFF does to subaudible noise, remove the grille cloth from one of your speakers and watch the cone of the woofer while switching from stereo to mono. You'll be able to *see* the rumble disappear.

TABLE 1

Crossover frequency:	140 Hz
Subaudible filter:	18 dB/octave below 20 Hz
Frequency response:	20Hz-20 kHz ±1 dB, both channels driven.
Differential rumble rejection:	20 dB @ 20 Hz
Separation:	25 dB above 1 kHz; 35 dB above 3 kHz
Rated output:	.5-volt RMS
Signal-to-noise ratio:	100 dB
Total harmonic distortion, 20 Hz – 20 kHz:	.02%
Maximum output:	Greater than 5-volts RMS; depends on power supply.

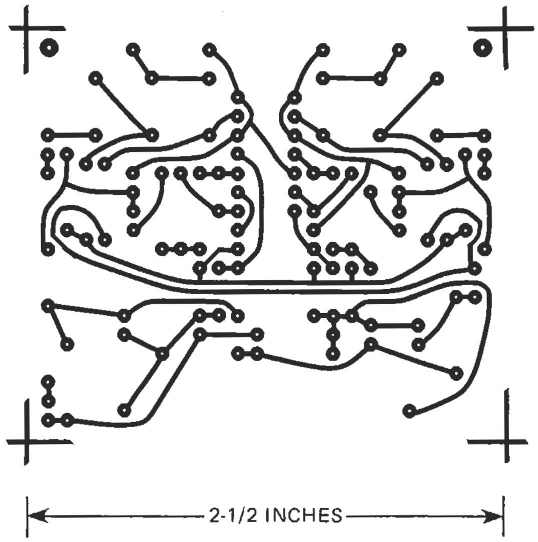

FIG. 9—FOIL PATTERN required for the small PC board is shown here full size.

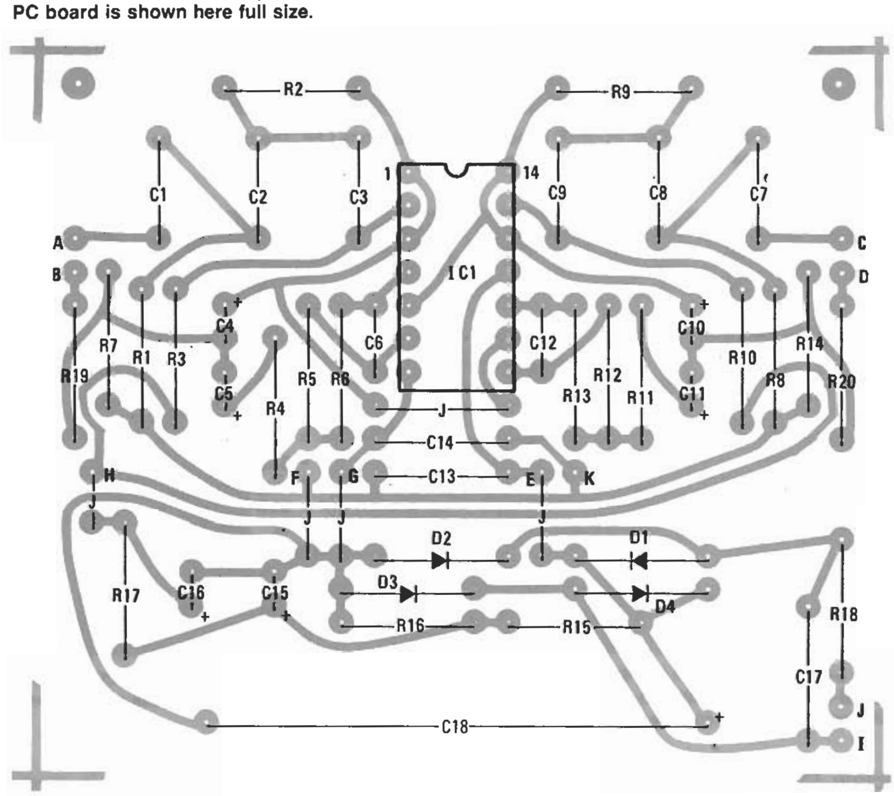

FIG.10—ALL PARTS except the wall-plug transformer, switches, and jacks are mounted on the PC board as shown.

Acoustic feedback

The LFF can also reduce the effects of acoustic feedback. Acoustic feedback is caused by sound from the speakers causing the pickup to vibrate. The vibrations are treated like a signal and are fed back to the amplifier. In serious cases, the system will "take off" and go into oscillation when the volume is turned up. Even when the sound level is well below the point where oscillation would take place, the feedback can cause aberrations in a system's frequency response that result in an "overhang" or "ringing" effect on bass transients and dull their impact and muddy the sound.

The main component is usually vertical and can be reduced by the LFF. You can simulate the effect of the filter by placing a record on your turntable—with the turntable turned off—and lowering the stylus onto the disc. Tap the base of the turntable with your finger as you increase the setting of your amplifier's volume control. Feedback should occur. If you put the amplifier in the "mono" mode, the feedback should disappear.

Performance

Figure 3 shows a spectrum analysis of the signal generated by a "silent" record groove that contains a significant amount of cutting-lathe-induced rumble. The upper curve is the signal input to the LFF and the lower one the output. The difference between the two is quite dramatic.

Figure 4 is another spectrum analysis showing the low-frequency, low-level, introduction to a song. The sound peak is reproduced equally well at both the input and the output; the noise that would normally be bothersome is greatly attenuated by the filter.

The frequency-response curves for a sound system are shown in Fig. 5. The lowest curve shows the results of a measurement made with the volume control turned down. The next higher curve (displaced for clarity) shows a 30-dB peak at the edge of oscillation. The narrowness of the peak implies that the system will ring for *seconds* after the end of the transient. The top curve shows the nearly complete removal of that peak by the LFF.

Table one lists the LFF's performance characteristics.

Circuit description

Schematics for the LFF are shown in Figs. 6 and 7. Figure 6 shows the main circuitry, or "kernel," suitable for installation in existing equipment. A power supply and other circuitry needed to construct a stand-alone unit are shown in Fig. 7. Figure 8 shows power-supply connections to the kernel. Use the connections shown in Fig. 8-a for a stand-alone unit and those shown in Figs. 8-b and 8-c for use as part of another piece of equipment. Those connections will be discussed in more detail later in this article.

The subaudible-noise filter is made up of R1-R3, C1-C3, and IC1-a. The use of three R-C pairs allows a steep 18-dB/octave rolloff; the controlled amount

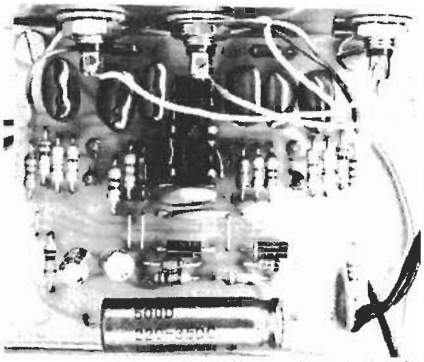

FIG. 11—THIS IS HOW the PC board should look when all components are in place on the board.

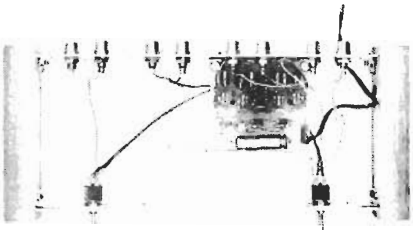

FIG. 12—AN UNDERSIDE VIEW of the LFF stand-alone unit. The kernel board can also be installed inside a piece of existing equipment.

of positive feedback through R2 helps keep the response of the device very flat down to 20 Hz.

Capacitors C4-C6, resistors R4-R6 and IC1-b perform the functions of C1, C2, and L1 shown in the block diagram in Fig. 2. Capacitor C4 is the diagram's C1, and C5 is the diagram's C2. The inductance represented by L1 is supplied by R5, R6, C6, and IC1-b in a circuit configuration known as a *gyrator*. It simulates an inductor with a value of L = 1/R5 × R6 × C6 between pin 12 of IC1-c and the junction of resistors R4-R6, with a resistance equal to (R5 × R6)/(R5 + R6) across the inductance. That configuration offers an inductance of 1.2 henries without the typical problems of saturation, poor tolerance, hum pickup, and high cost. The resistance of the inductor, together with that of R4 in series with it, damps the L-C resonant circuit to prevent ringing.

Construction

Figures 9 and 10 are the foil pattern and parts-placement diagram for the LFF. The kernel (on the upper part of the board) is attached to the power supply on the bottom part by jumpers to the holes marked "H," "F," "G," and "E."

Assembly is quite simple. To build a stand-alone unit, refer to Figs. 10 and 11 and mount all the components on the board. Install the finished board in a plain enclosure and wire it to the jacks, switches, and wall-plug transformer as shown in the schematics. Any wall-plug transformer with an output of 12-24 volts AC can be used—short out R18 if the transformer supplies 18 volts or less. Be careful to observe the polarities of the electrolytic capacitors and the diodes, and to position the IC correctly. The completed unit is shown in Fig. 12.

The LFF can be connected to any sound system with a TAPE MONITOR switch. Connect the LFF's inputs to TAPE RECORD or TAPE OUT on your amplifier and its outputs to TAPE PLAY or TAPE MONITOR. Anything that had been connected to these jacks can now be connected to the corresponding jacks on the LFF, maintaining your sound system's full capability and flexibility.

Installation in existing equipment

The LFF is such a simple circuit that the overhead of a chassis, end-panels, power supply and switches begins to look ridiculous. The board can easily be installed in existing equipment; the graphic equalizer and ASRU noise-reduction units, which were presented in **Radio-Electronics** in May 1978 and March-April 1981 respectively, will be used as examples.

A dual-supply connection is shown in Fig. 13, which uses the ASRU as an example. The bias voltage, V_B, is connected to ground and op-amp IC1 uses the ±12-volt supplies. Figure 8-b shows the connections to points "E," "F," "G," "H," and "K."

Figure 14 shows how the LFF can be installed in an equalizer with a single-ended power supply. The connections for that arrangement are shown in Fig. 8-c. In that example, V_B (+15 volts) can be obtained from the equalizer. In other circuits, where no V_B exists or can be located, R15-R17, C15, and C16 can be used to derive V_B from V_{CC}. It is important that the LFF be connected *ahead of* the equalizer, since mismatches in the low-frequency band settings of an equalizer produce phase shifts that can reduce the effectiveness of the filter.

There you have it—a simple, inexpensive circuit to help wipe out warps, rumble, and the howl and muddiness caused by acoustic feedback; it is equally effective as a stand-alone unit, or when incorporated into an existing piece of equipment. **R-E**

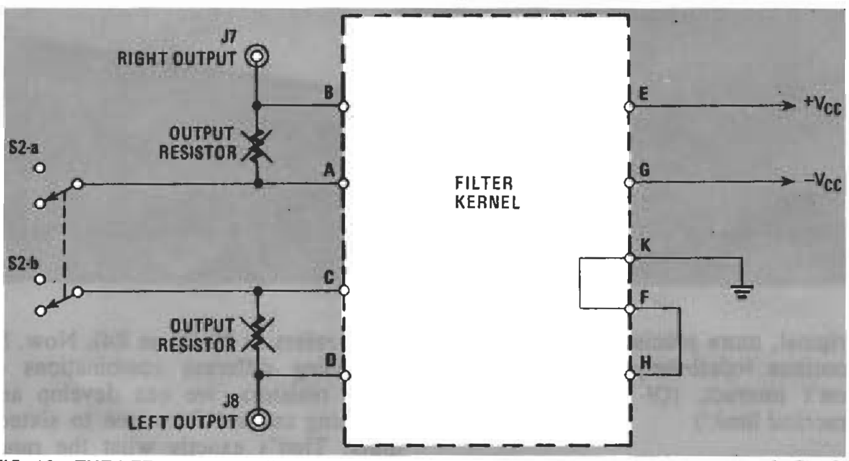

FIG. 13—THE LFF can be installed in an ASRU using the connections shown above and in Fig. 8-b. It that is done, the power-supply circuit is not required.

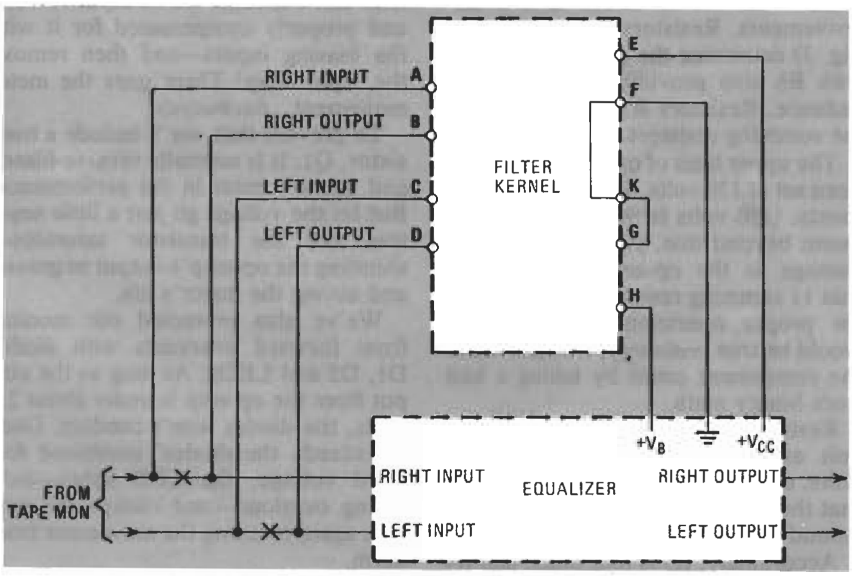

FIG. 14—IF THE LFF IS INSTALLED in a graphic equalizer, be sure to connect the LFF ahead of the equalizer.