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STEREO IMAGE EXPANDER

Stereo sound shouldn't come from just between your two speakers. This easy-to-build stereo image expander can turn your whole listening room into a "sonic stage."

JOEL COHEN

THE BIGGEST PROBLEM WITH YOUR stereo system is probably in your head! If all the sound that came out of one speaker went into one ear, and all the sound that came out of the other speaker went into the other ear, you would perceive an astonishing sonic image. Unfortunately, your ears don't work that way — they both hear some sound from both speakers. That makes the sonic image — your perception of the stereo "stage" — considerably smaller and a lot less detailed than it could be.

While the basic components of a stereo sound-system are constantly being improved, their performance has reached the point where it is difficult to hear the difference between the new models and the old. The IR2200 stereo image expander, however, can enhance the performance of any stereo system, regardless of its age or cost, by processing the sound to bring out depth and dimension that is normally lost in reproduction.

Listening to stereo

The basic stereophonic process attempts to reproduce a detailed three-dimensional sound picture or image using two loudspeakers. In the analogous 3D-movie process the left image is kept out of the right eye, and vice versa, by polarized lenses and each eye sees only what was intended for it, producing in the brain a true 3-dimensional image. The sound of each stereo loudspeaker, though, is heard by both ears and the illusion of space and depth is muddied.

The major effect of that stereo crosscoupling is to limit the perception of the stereo image to the small area between your speakers. Time-delay circuits and some specially designed speakers can add ambience or a sense of spaciousness to the sound but they can never recover the major portion of the orginal image that is lost because of the stereo "double exposure."

The stereo image expander functions as the sonic equivalent of 3D's polarized glasses. It cancels most of the stereo crosscoupling, thus unfolding and refocusing the original sound picture to fill the space before you.

The image-limitation of the stereo playback-process is not a new problem invented to sell new equipment. It, and a process to correct it, were first described over 20 years ago. It is the technique (U.S. patent No. 4,308,423) used in the stereo image expander that is new and its design overcomes a number of the limitations of earlier equipment.

How we hear stereo

In a typical live listening-situation a listener hears all sounds at almost the same level in both ears. He uses the slight difference between the *first-arrival times*—the instants that the ears first perceive the sounds—of the sound at his left and right ears to pinpoint its source. That time difference is known as *interaural delay* and Fig. 1 shows an example for a sound source located 60° to the left of the listener.

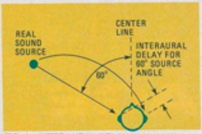

FIG. 1—INTERAURAL DELAY is what tells you what direction a sound is coming from.

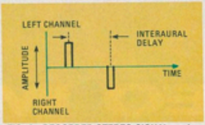

FIG. 2—RECORDED STEREO SIGNAL equivalent to Fig. 1. Left channel is shown above, right channel below.

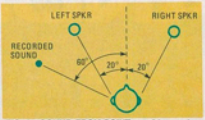

FIG. 3—SOUND FROM POINT outside speaker area will still appear to come from within it.

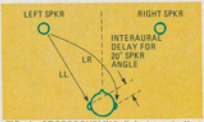

FIG. 4—CROSSCOUPLING (left-channel effect shown) feeds "false" stereo information to ears. "LL" is left signal heard from left ear; "LR" is left signal heard by right ear.

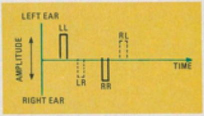

FIG. 5—HOW CROSSCOUPLED SIGNALS appear at listening position. Left-ear signal is above; right-ear signal below.

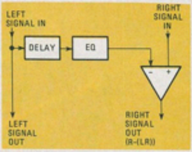

FIG. 6—BASIC CROSSTALK-CANCELLING circuit (one channel). "Right-signal out" is the right signal minus the "LR" compensation-signal.

No matter what stereo recording-technique is used, the two channels of a stereo playback-system contain signals whose time and amplitude relationships relate to the positions of the original sound-sources (Fig. 2). However, there is a basic problem in the reproduction of an accurate sonic image of a sound originating outside the space encompassed by the two speakers used in a typical stereo system. It was first described by Ben Bauer in a paper presented 20 years ago and is illustrated in Fig. 3. That problem is created by the crosscoupling of sound from the left speaker to the right ear and vice versa.

For example, a sound recorded from a source to the left of the left loudspeaker, as shown in Fig. 4, will not be accurately reproduced for the listener in normal stereo playback because the first sound to reach his *right* ear will be the crosscoupled sound from the *left* loudspeaker. (In the figure, "LL" represents the sound from the left source heard by the left ear; "LR" represents the sound from the left source heard by the *right* ear. We'll use "RR" and "RL" in a similar fashion.)

You can see from Fig. 5 that the sound from the left loudspeaker located 20° off center reaches the right ear before the sound from the right loudspeaker which would have identified the position of the recorded sound at 60° if cross coupling did not occur. In conventional stereo playback through loudspeakers, any sound that was recorded from a source outside the audio "stage" formed by the loudspeakers will still seem to come from somewhere on that stage. That is, the source of the 60° off-axis sound shown in Fig. 3 will appear to be the left-hand speaker—not to the left of the left-hand speaker, as it should be in that instance.

Immediately after determining the position of the sound source by comparing first-arrival times at both ears, the hearing mechanism begins to block out subsequent arrivals. Therefore, correct precedence is the primary key to stereo imaging. As long as the ears and brain can determine correctly when a sound has arrived, a good stereo image can be perceived.

Principles of stereo expansion

Over the years, by calculation and or measurement, the character of acoustic crosscoupling of first-arrival sounds has been well documented. While perfect cancellation of the entire crosscoupled sound must take into account a number of variations in listening-room characteristics, including the location of the listener, experimental and commercial equipment has been built over the past ten years that cancels that crosscoupling to a great degree.

PARTS LIST

All resistors ¼-watt, 5%, unless otherwise specified

R1, R6, R14, R16, R17—1000 ohms
R2, R4, R25, R26, R30, R31—100,000 ohms
R3, R5—47,000 ohms
R7, R15, R23, R24, R27-R29—20,000 ohms
R3, R5—47,000 ohms
R7, R15, R23, R24, R27-R29—20,000 ohms
R8—100,000 ohms, PC-mount potentiometer
R9, R13—4.7 ohms
R10, R20, R22, R34—4700 ohms
R11—100 ohms
R12—2000 ohms
R18, R19—10,000 ohms
R21—100,000 ohms, potentiometer, audio taper
R32, R33—390 ohms

Capacitors

C1, C2—470 µF, 35 volts, electrolytic
C3, C4, C6-C8, C12—0.1 µF, ceramic disc
C5—47 µF, 16 volts, electrolytic
C9, C17, C18—0.01 µF, axial ceramic or ceramic disc
C10, C13, C16—10 µF, 16 volts, electrolytic
C11—100 pF, axial ceramic or ceramic disc
C14—390 pF, axial ceramic or ceramic disc
C15—1500 pF, axial ceramic or ceramic disc

Semiconductors

IC1—LM340L15, 15-volt positive regulator
IC2—LM320L15, 15-volt negative regulator
IC3, IC4—MC4558 dual op-amp
IC5—CD4049 CMOS hex inverter
IC6—SAD512 or SAD1024 N-channel bucket-brigade device (Reticon. Also Radio Shack 276-1761.) (See text.)
Q1, Q2—2N2222, 2N3904 or similar
D1-D4—1N4002 or 1N4003
LED1—jumbo red LED
T1—35 volts, center-tapped, PC-mount (Dale PL-12-09 or similar)
S1-S3—pushbutton switch assembly: 3 DPDT or 1 DPDT, 2 4PDT (Schadow F-series or Centralab PB20-series)
J1-J8—RCA-type phono jack, right-angle PC-mount

Miscellaneous: PC board, IC sockets, enclosure, line cord, strain relief, hardware, etc.

The following are available from Sound Concepts, Inc., P.O. Box 135, Brookline, MA 02146: assembled and tested IR2200 stereo image expander, $169.00; kit of all parts (KIR-1), $95.00; PC board (KIR-2), $16.00; T1 (KIR-3), $7.50; all pots, knobs, switches and jacks (KIR-4), $12.50; all semiconductors and sockets for them (KIR-5), $19.00. Please add $2.00 for shipping and handling; MA residents add 5% sales tax. If at all possible give street address for UPS delivery. Please add 10% ($5.00 minimum) for parcel post outside continental U.S.A.

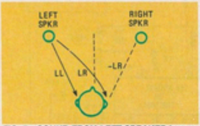

FIG. 7—SOUND FROM LEFT SPEAKER is cancelled at right ear by "−LR" signal.

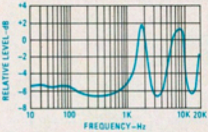

FIG. 8—MIXING OF MID-CHANNEL original and compensation signals can cause "comb effect" that distorts frequency response.

although not completely. Those systems derive a compensation signal from each channel which is the inverted analog of the crosscoupled signal, and then mix it into the opposite channel. A block diagram of such a system is shown in Fig. 6. To operate effectively, the playback system must be arranged so that the compensation signal meets the original crosscoupled signal in space just at the listener's ears (Fig. 7). That requires a fixed listening-position, which, for simplicity, is centrally located between the loudspeakers.

This type of crosscoupling cancellation uses the original signal—delayed by the interaural transit time and frequency-contoured to compensate for facial transmission and absorption characteristics—subtracted from the opposite channel.

Complete crosscoupling-cancellation, though, generates an unfortunate side effect. When the sound originates from directly between the speakers, the signals in each channel are identical in time and amplitude and the cancellation signals interfere seriously with the original ones, since the same signals are being delayed and then mixed back with themselves. That produces a combed frequency-response, shown in Fig. 8, that typically reduces the bass and upper-midrange levels and emphasizes the rest. The effect can be partially subdued by using equalization but, overall there is still a significant deterioration in fidelity in the critical central image-area where soloists are usually heard. At the same time, the cancellation signals do nothing to clarify the central sonic-image, since it would sound normal without any processing whatsoever.

How the stereo image expander works

The device described here uses an R−L (right-minus-left) difference component for generating the compensation signal. It is that signal, delayed and frequency-contoured, that is *added to the right channel* as shown in the block diagram in Fig. 9. That difference signal is also used to generate an L−R signal, which is added to the *left* channel. With a monophonic, or a centrally positioned stereo-source, there is no difference signal; nothing is added to either channel and the comb-effect is not apparent—and the tonal balance remains unaffected. As the sound source moves toward the right or left, the level of the compensation-signal increases accordingly.

At the extremes of the expanded stereo "sonic stage," a compensation-signal level about 6 dB below the main signal level is the optimum for a perfectly balanced stereo-signal source. In many (disc) recordings, though, the difference-signal level has been suppressed to reduce cutting and vertical-tracking problems. Increasing the level of the compensation or "image" signal increases the relative amount of difference-signal energy, effectively amplifying the sound in proportion to its angle off-center.

With the crosstalk minimized, the strongest difference-signals represent sounds at the left and right edges of the recording "stage" and now appear far to the outside of the loudspeaker positions. The IMAGE control can be thought of as an "edge-to-central area" balance control.

As a result of miking techniques, or the suppression of vertical-modulation components for the purposes of avoiding problems in record pressing, most records contain very little stereo information in the frequencies below 100 Hz and there is no substantial difference-signal to be processed below that frequency. As suggested earlier, however, record-warp and vertical-rumble signals from cutting lathes, turntables and non-uniform record surfaces that generate spurious low-frequency difference-signals may be present. For that reason, the image expander contains a 70-Hz high-pass filter in the difference-signal path.

Circuit description

A schematic of the stereo image expander is shown in Fig. 10. Its power

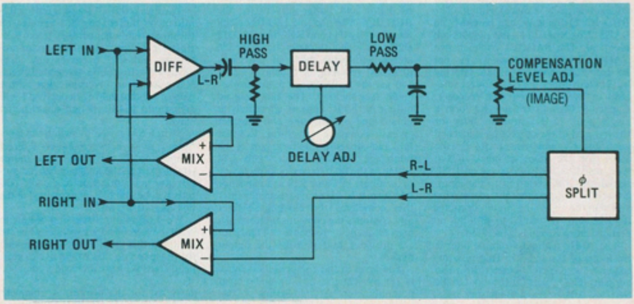

FIG. 9—BOTH CHANNEL-COMPENSATION signals are derived from original R−L signal by phase splitter.

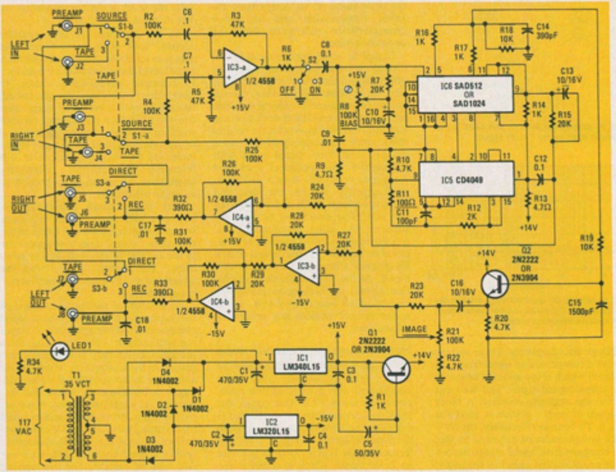

FIG. 10—BBD DEVICE, IC6, can be either SAD512 or SAD1024. See text for details.

supply delivers regulated ±15 volts for all the IC's except IC5 and IC6, which make up the delay line. An additionally filtered +14-volts is used for them to minimize the noise in the SAD512 BBD (*B*ucket *B*rigade *D*evice) circuit. The BBD IC, incidentaly, can be either an SAD512 *or* SAD1024—the pinouts are identical. The SAD1024 contains two SAD512's, and one of them will just not be used. The input signals are selected by S1 from either the main source (preamp or receiver) or a tape recorder. Capacitor C6 and resistor R2 form a single pole, 16-Hz, subsonic filter for the left part of the correction signal and capacitor C7 and resistor R4 do the same for the right channel. IC3-a, with resistors R2-R5, derives an R−L signal at −6 dB referred to the input. Switch S2 (ON/OFF) either passes that signal to the rest of the circuit, or routes it to ground. If routed to ground, no compensation signal is generated.

The 70-Hz high-pass rumble filter is made up of C8 and R7. That resistor, together with potentiometer R8, also supplies the DC bias for the input to the SAD512 BBD. An anti-aliasing high-frequency (15 kHz) filter is formed by C9 and R6. Resistors R9 and R13, and capacitor C12 RF-isolate the rest of the circuit from noise that may be generated by the clocking circuitry.

Five out of six sections of the CD4049 inverter operate as the clock oscillator and buffer drivers for the BBD, IC6. The nominal 1.8-MHz clock rate is set by C11 and R12. The SAD512 shifts the signal through one of its 256 stages with each cycle of the clock (0.55 μs) resulting in a delay time of 140 μs, the optimum for a 40° speaker angle (see below). The time-delayed output of the IC appears alternately at pins 5 and 6; tying the two together gives a complete waveform. Resistor R18 and capacitor C14 form part of the interstage coupling-circuit, with C14 acting as the first-stage clock-frequency noise filter. Resistor R19 and capacitor C15 form a 10-kHz high-frequency filter that completes the clock-noise filter and contours the compensation signal's high-frequency response. Transistor Q2 provides buffering for the output mixers.

The level of the compensation signal is set by R21 (IMAGE), an audio-taper potentiometer. At mid-setting it sets that level to about −6 dB with respect to the input signals. At settings above that point it adds a boost of up to 10 dB for stereo-deficient source material. The control can also attenuate the compensation signal for that rare material that exhibits "a hole in the middle."

The delayed R−L signal is fed via R24 into mixer/buffer stage IC4-a along with the direct right-channel signal from R25. Resistor R32 provides short-circuit protection and C17 bypasses any stray clock-noise to ground. Integrated circuit IC3-b forms an inverting stage with a gain of −1 that delivers a delayed L−R signal into IC4-b, the left mixer/buffer stage.

Switch S3 is used to switch the tape-output jacks between either a direct connection to the main signal-source (DIRECT) or to the image-enhanced output (REC). The function of the REC outputs will be completely explained in the next part of this article.

We'll begin our discussion of how to build the stereo image expander when we continue this article. In the meantime, for those of you that would like to get a head start, we have included a complete parts list for the project. A complete kit, as well as an assembled-and-tested version, is also available—see the Parts List for ordering information. **R-E**

STEREO IMAGE EXPANDER

Add an extra dimension to your recorded music with this Stereo Image Expander. Build it and hear what you've been missing.

JOEL COHEN

Part 2 IN THE FIRST PART OF this article, we looked at the theory behind the Stereo Image Expander. This time we'll apply what we've learned and build our own.

Assembly

A foil pattern for the expander PC-board is shown in Fig. 11, and a parts placement diagram in Fig. 12. Figure 13 will also help you in completing the board. Some of the instructions here pertain specifically to the parts supplied with the kit available from the supplier indicated in the Parts List, but may also be applicable to you if you're building from scratch.

Pin 1 of each IC is indicated by an indented dot and all but IC5 are mounted with pin 1 facing towards the rear of the board. The bucket-brigade device, IC6, is subject to damage from static charge—it's a good idea to be sure that you are grounded before handling it. The use of IC sockets is recommended.

The BBD, incidentally, can be either an SAD512 *or* SAD1024—the pinouts are identical. The SAD1024 contains two SAD512's, and one of them will simply not be used.

Be sure to observe the polarities of the electrolytic capacitors and diodes. Note that regulators IC1 and IC2 are mounted with their center leads bent back toward the curved part of the package, while the transistors they resemble have their center leads bent slightly forward, toward the flat sides of the packages. Don't forget the two jumpers shown in the parts placement diagram.

The transformer must be installed with pins 1 and 2 toward the rear of the board. Bend the two mounting tabs away from the transformer and solder them to the foil side of the board. If you are using the phono jacks provided by the supplier shown in the Part List, cut off the plastic tabs at their rear corners before attaching them and be sure they are firmly seated parallel to the board before soldering. The switch bodies must be spaced .093-inch above the top of the board if the cabinet supplied with the kit is used. If the switches do not have shoulders on their mounting pins, use three plastic spacers over the pins at the front of S3 and the rear of S1 and S2. Be sure the switches and IMAGE control are seated parallel to the board so they will fit into the holes in the chassis.

To mount the LED, bend its leads at a 90° angle while holding it towards you with the anode lead on your right. Solder it in so that the bend is ½-inch above the top of the board. Install the completed board in its enclosure, and attach the line cord. Be careful of stray strands of wire, especially near the grounded board-mounting screw at the rear corner.

Alignment

Only one adjustment is required; the BBD bias which is set by R7. There is about a 2-volt window for signals to pass through the BBD and the bias is set for the center of that range so that the maximum peak-to-peak signal can pass through without clipping. There is enough headroom in the design of the expander to allow for individual IC variations if the bias is simply set to +3.5 volts.

If you want to "fine tune" the expander, apply about 1.5-volts RMS at 1 kHz to just the left input and observe the waveform present at jumper J1. If the bias is too high, the top of the sinewave will be clipped; if it's too low, the bottom will be clipped. At the optimum setting the waveform will be just slightly clipped at both top and bottom.

Rooms and loudspeakers

While most of us would find it difficult to tell the difference between one amplifier and another by ear, we all know that different speaker-systems have different qualities and that the sound from a particular system can vary depending on where it is located in a room. Most of the sound energy reaching our ears comes not

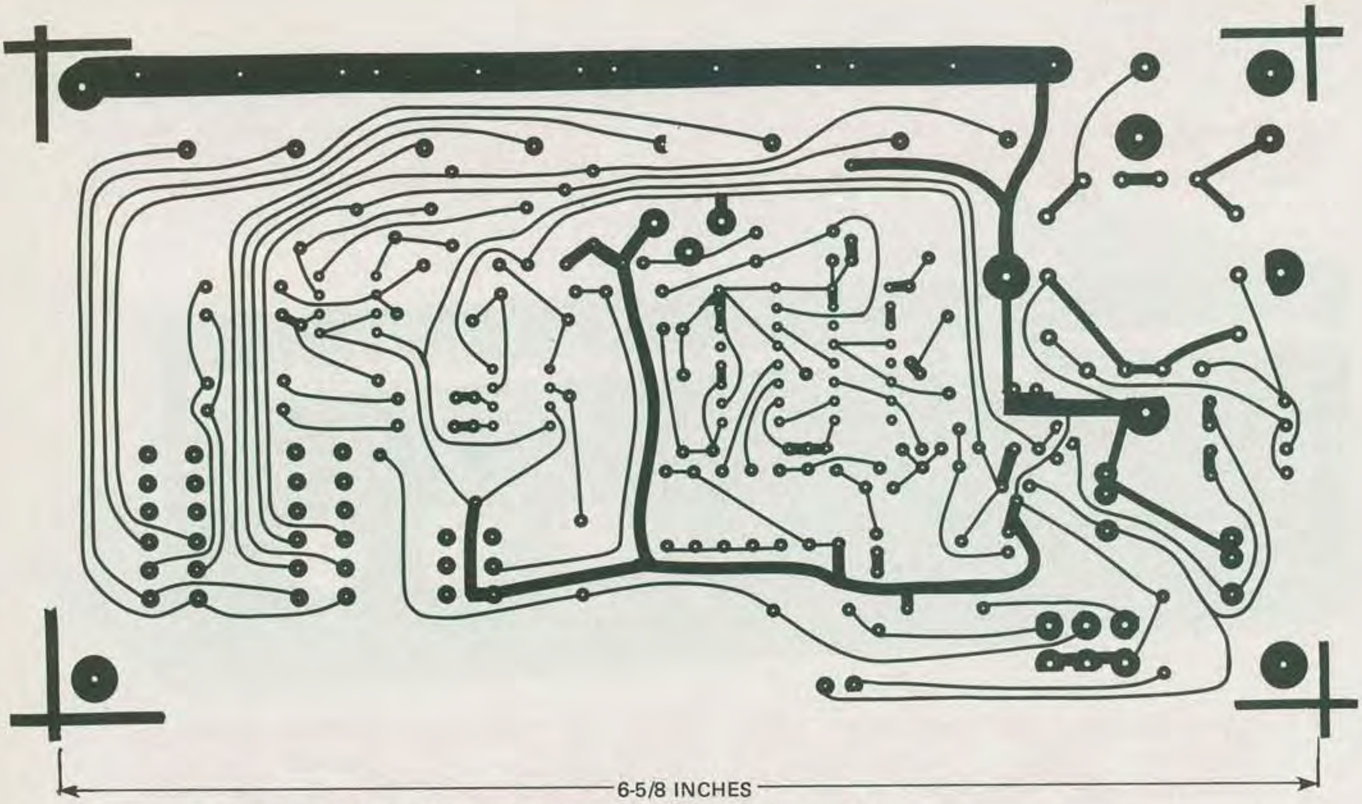

FIG. 11—STEREO IMAGE EXPANDER is constructed on single-sided PC board. The use of IC sockets is recommended.

directly from the speakers, but from secondary reflections of the sound from the walls, floor, and ceiling. The frequency response of that sound energy is shaped by the absorption characteristics of the surface it reflects from. The stereo image, however, is formed entirely by the first-arrival sound traveling directly from the loudspeakers to our ears.

Several conditions are needed for a good stereo image, and they are the same whether that image is expanded or not. First, the listening position must be the same distance from each speaker so that each ear hears its own speaker first. It is also helpful to point the speakers in toward the listening position. Second, the first-arrival sound from the speakers should precede the arrival of the first *reflected* sound by as long a time as practical, with one or two milliseconds being the minimum. That usually requires that the speakers be two feet or more from any wall or large piece of furniture and no more than 10 or 12 feet from the listening position. Third, the two speakers should be separated by an angle of 40°; that is, an imaginery line drawn to each speaker should form a 20° angle with one drawn from the listener to a point directly between them. That means that the distance between the centers of the two speakers should be 7/10 of the distance from each speaker to the listening position. Fourth, the speakers must be connected in phase. The easiest way to test that once they are positioned is to tune in some FM interstation hiss or a monophonic program. If the speakers are in phase the sound will appear to come from a point directly between them. If they are out of phase, it will seem to come from the sides, or from each speaker individually. If the apparent source is diffuse, the speakers should be repositioned as described above and again checked for phasing.

Finally, the speakers themselves must produce a sharp coherent wavefront.

PARTS LIST

All resistors ¼-watt, 5%, unless otherwise specified

R1, R6, R14, R16, R17—1000 ohms
R2, R4, R25, R26, R30, R31—100,000 ohms
R3, R5—47,000 ohms
R7, R15, R23, R24, R27-R29—20,000 ohms
R3, R5—47,000 ohms
R7, R15, R23, R24, R27-R29—20,000 ohms
R8—100,000 ohms, PC-mount potentiometer
R9, R13—4.7 ohms
R10, R20, R22, R34—4700 ohms
R11—100 ohms
R12—2000 ohms
R18, R19—10,000 ohms
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R32, R33—390 ohms

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C5—47 μF, 16 volts, electrolytic
C9, C17, C18—0.01 μF, axial ceramic or ceramic disc
C10, C13, C16—10 μF, 16 volts, electrolytic
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D1-D4—1N4002 or 1N4003
LED1—jumbo red LED
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S1-S3—pushbutton switch assembly: 3 DPDT or 1 DPDT, 2 4PDT (Schadow F-series or Centralab PB20-series)
J1-J8—RCA-type phono jack, right-angle PC-mount

Miscellaneous: PC board, IC sockets, enclosure, line cord, strain relief, hardware, etc.

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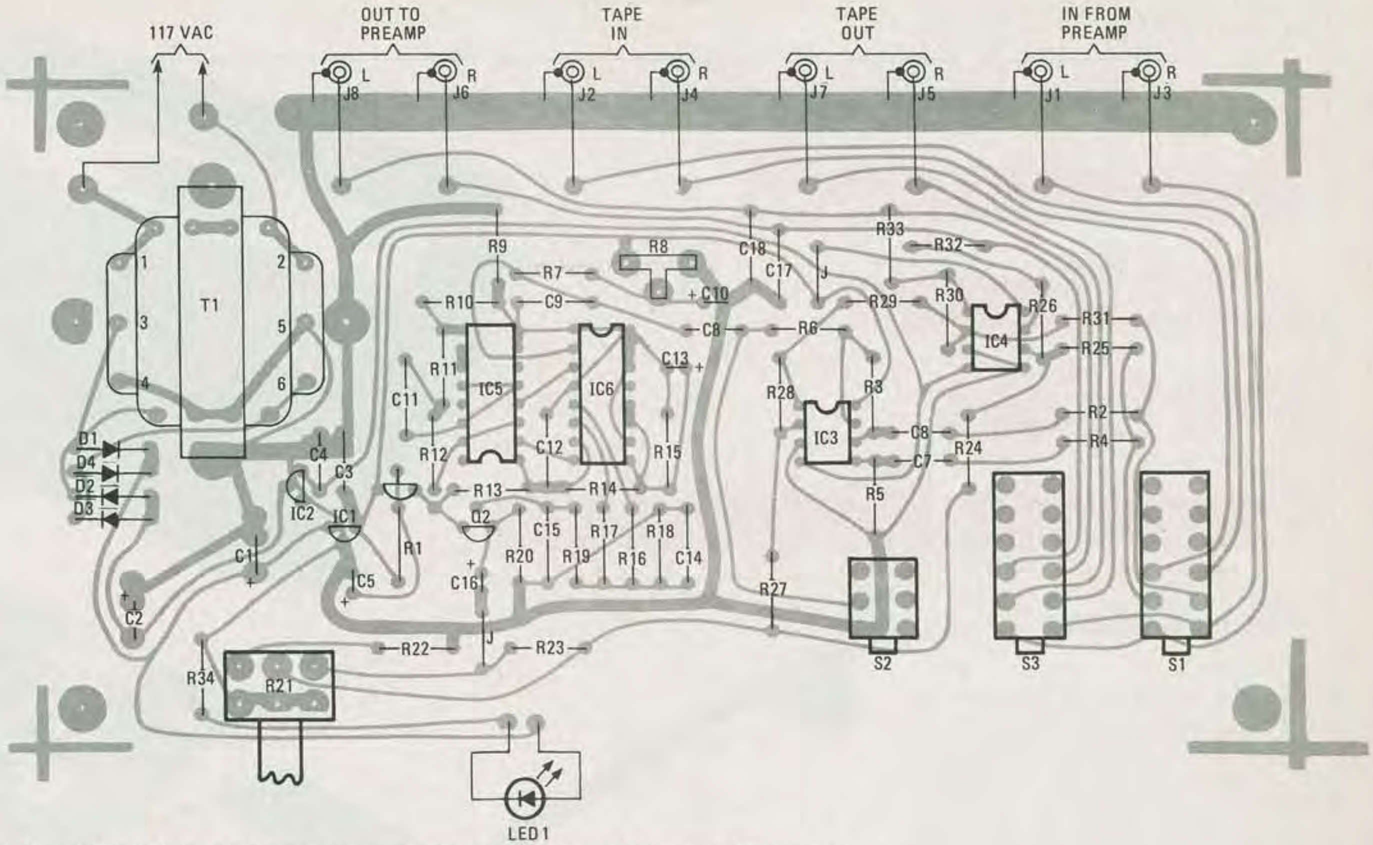

FIG. 12—PROVISION IS MADE for mounting right-angle input and output jacks directly on board.

Two- and three-way speaker systems with a single in-line vertical array of drivers usually work best. Omnidirectional speakers, or those with multiple drivers covering the same frequency range, cannot create as sharply focused an image.

You can actually check all this out before trying an image enhancer. Using a mono signal to get a tightly focused single sound-source located between the speakers is the best and easiest way to judge the imaging capability of your speakers in your listening room. Once you are set up correctly, you will probably be impressed with how much better your stereo system sounds—even without expansion.

Installation and use

The stereo image expander is intended to be connected in the tape-monitor loop of your preamplifier or receiver. Provision is made in the expander for connecting a tape recorder. The recorder can be used in the normal manner when the preamp's tape-monitor switch is on and S1 of the expander is in the TAPE position. Image-enhanced tapes that can be played back *without* the expander can be made when S3 is in the REC position. You should never have S1 and S3 pushed in at the same time since that effectively connects the recorder's output back to its input.

The recorder-output jacks from your receiver or preamp should be connected to the INPUT FROM PREAMP jacks, J1 and J3, on the expander and the OUTPUT TO PREAMP jacks, J6 and J8, to your tape-input or tape-monitor jacks. The expander's TAPE OUTPUT jacks, J5 and J7, are connected to the line-input jacks on the recorder and its line-output jacks connected back to the TAPE INPUT jacks, J2 and J4, on the expander.

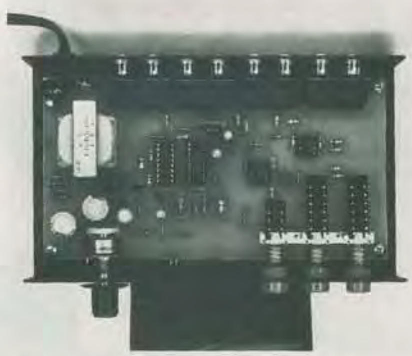

FIG. 13—NOTE HOW LED is mounted *above* the board, not flush with it. All components including transformer and switches, are soldered to board.

If you are using two tape-loops and two recorders, place the expander in loop 2. To play unenhanced tapes through the expander, use the tape-monitor switch corresponding to the loop the recorder is in. With S1 in the TAPE position, the signal comes directly from the recorder connected to the expander, and in the SOURCE position the signal is supplied by the receiver or preamp. If the expander is in loop 2 and you want to listen to the recorder in loop 1, either engage both tape monitor switches or—if you have them—the TAPE MONITOR 2 and DUB 1 TO 2 switches on the preamp or receiver.

If you have other signal processors in your system the expander should be the last one in the chain so that there is a minimum loss of phase integrity. If, for example, you already have an equalizer in your tape loop with a recorder plugged into it, plug the expander into the equalizer's tape jacks and the recorder into the expander's tape jacks. The expander can also be connected to the external-processor loop or between the preamp and power amp if you don't wish to use it for recording.

Listening

Before you make a critical evaluation of the stereo image expander's capabilities, make sure your system is set up as described earlier. Start with a record or tape of a good live or concert hall performance, preferably of a large orchestral work so you have a realistic frame of reference. (Most of the recent Telarc records have excellent imaging.) You may want to turn up the image level slightly with some other records, particularly those that were originally recorded using multiple-mike techniques and whose

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stereo effect comes primarily from the studio's mixer-board. You can "A/B" the effect with the ON/OFF switch.

The majority of studio recordings are made from a mix of simultaneous "dry" sources and create an artificial image based on intensity differences between channels rather than on time and phase information. Even so, most of them will open up and sound more spacious—the speakers will become "transparent." Some recordings will do fascinating—and frequently spectacular—things when turned loose by the expander. Try any of Pink Floyd's or Tomita's releases to really put the expander through its paces.

Background reading

The first mention of loudspeaker crosscoupling and its effects appeared in a paper given by B.B. Bauer to the AES in 1961. A detailed exploration of the problem, a solution and test results appear in an article entitled:

"Head related two channel stereophony with loudspeaker reproduction" by P. Damaske, pp. 1109 to 1115 of the *Journal of the Acoustic Society of America,* Vol. 50, No. 4, Part 2, 1972 **R-E**

STEREO IMAGE EXPANDER

I am surprised that the two-part article, "Stereo Image Expander," by Joel Cohen (**Radio-Electronics,** June and September 1982) has not generated more comment in your letters department.

I decided to build the image expander, and am I ever glad! Over the years, I have tried to put as little between my ears and the source music as possible, concentrating on obtaining the best speaker systems that I could afford.

Without doubt, next to good speakers, the stereo image expander is the most important component in my system; the improvment in detail and clarity, the general sense of "being there" is just *awesome!* I have used the image expander with Infinity *Monitor IIa's* and with Sander's *Electrostatics,* with excellent results. Naturally, the sonic effect is most realistic with the *Electrostatics*. I can wholeheartedly recommend Mr. Cohen's device to any serious music listener.

One word of caution: In the article, Mr. Cohen explains the importance of carefully determining the optimum speaker placement for best stereo image, even without his device. That very important step must *not* be skipped over if the full potential of the stereo image expander is to be realized.

Thank you for an outstanding construction project and a fine magazine, and don't let the anti-computer people scare you off! I built the Mark 8 successfully in 1974 and enjoy the broad spectrum of your projects.

PAUL FARR
Olivenhain, CA