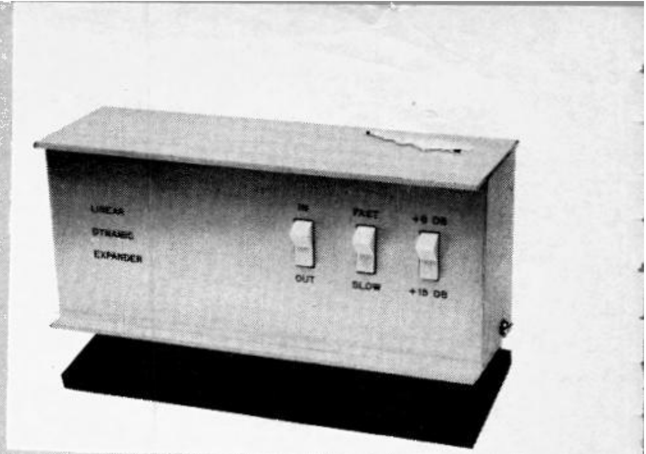
BUILD IC VOLUME EXPANDER



Improve apparent S/N ratio in your hi-fi system. Hot carrier diodes and IC's make it work

by KENNETH E. BUEGEL

THE MUSIC LOVER HAS NEVER HAD such an excellent range of equipment to choose from as he has today. Frequency response of the electronics extends far past the limits required and distortion levels are almost at the vanishing point. Signal to noise (S/N) ratios of 70 db or more are common. (At least on the specifications!)

These S/N ratios, however, start deteriorating as soon as the equipment performs its primary function—music reproduction. This is caused by the characteristics of the recorded medium. In tapes it is oxide irregularities which cause the familiar tape hiss. In records it is surface blemishes which continually increase through the useful life of the vinyl impression.

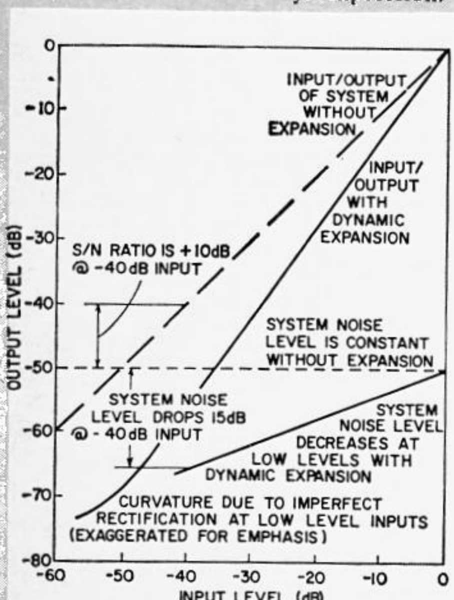


Fig. 1—Graph shows shift of input/output levels with linear expansion.

To alleviate these surface noises the recorded signal is artificially compressed when it is recorded. The loudness range experienced by the listener is thus decreased from what he hears at a live performance. In fact at least one major recording studio which claims to have reduced surface noise to new lows has only increased the compression until a solo violin has almost the same level as the full orchestra in a recording.

A device that would *linearly* expand the reproduced signal would more faithfully recreate the original performance. However, the effect of this expansion on the listener cannot be expressed only by electronic measurements of the signal.

In Fig. 1, the long dashed line shows the fixed linear relationship between input and output levels on an amplifying system without expansion. Note that at some low level near the −40 dB input point, the output signal is only 10 dB above the system output noise. (This noise is from the recording, tape or disc, and will be constant.) We hear the output signal, as it decreases from a high level to a low level, approaching a fixed background noise level.

The solid lines represent the performance of the same amplifying system with linear dynamic expansion included. With a +15 dB expansion characteristic added to our original 40 dB input range our output level now covers a 55 dB change. Even more important, the S/N ratio is *still* +10 dB at the lower input level.

If we had attempted to get this range of levels without expansion, our signal would have been 5 dB less than the noise level. Not easily depicted on a graph is the subjective response of the ear. Although the S/N ratio is still the same +10 dB at the −40 dB input point, the ear interprets this response as that from a system with much lower overall noise level, the same 15 dB that was added to the dynamic range.

When shopping for tape recorders we are continually faced with a S/N specification which, more or less truthfully, varies around 50 dB. Imagine what it would be like to see this read 65 dB. And this is precisely what it sounds like—with linear dynamic expansion.

You can have these benefits without throwing out your entire system and starting over. This project has been designed so that the device is placed between the preamplifier and power amplifier.

All expanders described in the literature to date have used a regen-

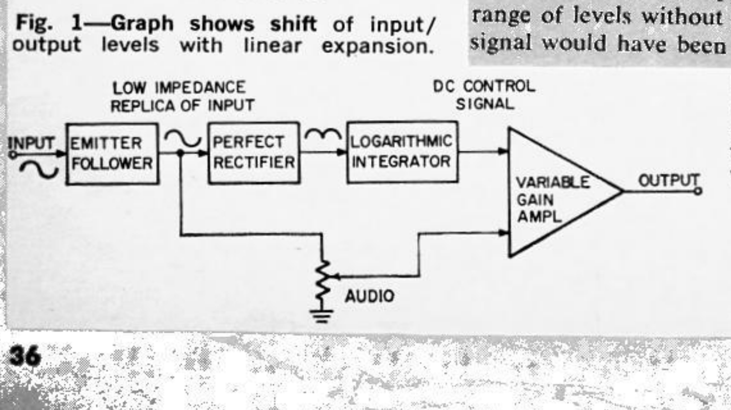


Fig. 2—Circuit of expander amplifier gain to vary directly with the input.

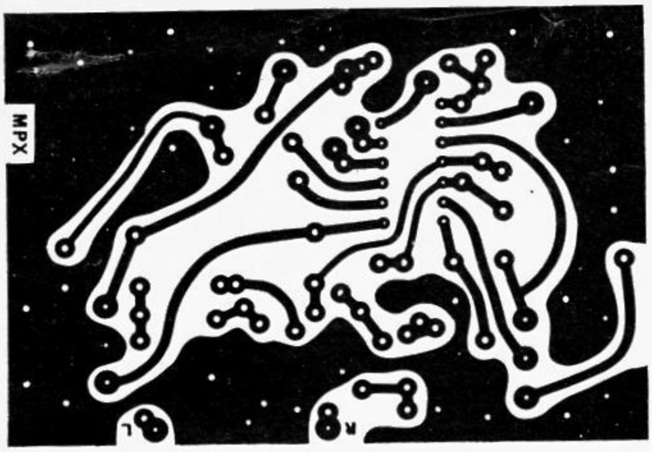
Expander specifications are:

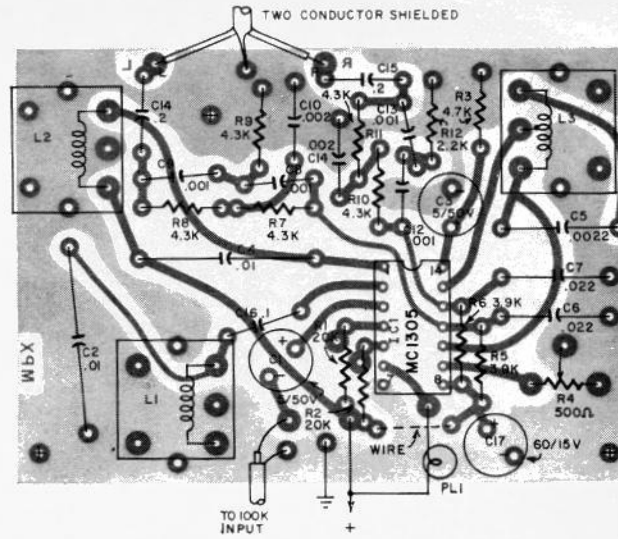
Nominal maximum input and output levels:	1V rms. (This may vary from 0.2V to 3.0V.)
IM and THD @ 1V rms output:	0.2% (Decreases at lower output levels)
Frequency response:	
−1 dB points	30 to 20,000 Hz
−6 dB points	20 to 40,000 Hz
Signal/Noise ratio	
@ .01V rms input	85 dB
@ 1V rms input	45 dB

Expansion Linearity:

@ +15 dB: less than ±0.5 dB deviation from straight line in any 10 dB segment between 0 to −50 dB input (0 d B = 1V rms).

@ +8 dB: less than ±0.3 dB deviation from straight line in any 10 dB segment between 0 to −50 input (0 d B = 1V rms).





Use the same-size printed circuit pattern above to make your decoder. Components specified will fit on the board. Component-side drawing on the right shows where to mount the parts. Some of the wiring to the unit is optional.

parts and drilled PC board is available. Please use the components listed, as the circuit board was laid out for them.

Construction of the project is simple, as is the alignment procedure. A 2.2 x 3.2-inch PC board provides enough component space without crowding. Recommended coils for this circuit are available only in a PC mounting style.

The best technique is to insert the IC and then add other parts outwards from the IC. *Don't* bend the leads on R4, IC1, or the transformers. After all parts are properly soldered, add the required external wires. If you do not plan to use audio muting or mono–stereo switching, wires are not connected to pins 4 and 5 of IC1.

Although a multiplex generator is the easiest alignment method, this unit can be aligned with a broadcast signal. Input level should be about 0.75 volt p–p to achieve maximum channel separation.

Each output should be connected to a 22K load to provide the proper terminating impedance to the Twin-T filters.

Connect an oscilloscope or ac vtvm to the junction of pin 1 and C4. Peak L1 and L2 for maximum 19 kHz as seen on the scope. This waveform should be about 1.6 volts p–p with a +15-volt supply. Move the scope probe to the junction of C5 and pin 4 of L3 and peak L3 for a maximum 38-kHz trace. This should be about 22 volts p–p. Caution: if you do not use a low-capacitance probe, the circuit may be slightly detuned when the probe is removed. This detuning will be slight and is corrected in the next step.

Connect the scope or vtvm to the *right* output and set up the generator for a *left-only* output. Set the wiper of R4 to midposition. Carefully peak L1, L2, and L3 for a *minimum* output on the *right* channel. Then set R4 for a minimum output.

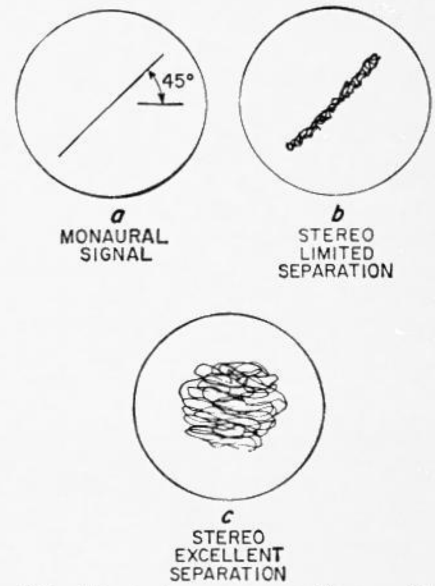
Now set the generator for a *right-only* output and read the output level on the right channel. Then set the generator to a *left-only* output. The difference in readings is the channel separation. It will not be as high as the figures given earlier since the residual reading also includes 19-kHz and 38-kHz components. An elaborate filter can remove these components for true separation readings, but the separation will not be increased.

FM station alignment

If you do not have access to a multiplex generator, connect the input to your tuner output. First peak L1, L2 and L3 for maximum output waveforms as described earlier. Connect the scope vertical input to the left output and the horizontal input to the right output. Tune to a monaural station and set the scope gains until the trace is a straight line at a 45° angle (Fig. 3-a).

Tune to a stereo broadcast and you will probably see something like Fig. 3-b. This indicates limited separation. Now, while watching the scope face, slowly tune L1, L2, L3, and R4 until you get a trace most like Fig. 3-c. If you can connect your amplifier to the adapter and also hear the output—preferably in headphones—so much the better.

Some stations have stereo programs which feature highly directional microphone pickup, this type of program material is the easiest to use for alignment. When the output looks like Fig. 3-c, you must identify the channels. It is possible to tune the unit so that the output labeled L is actually the right channel. Careful tests do not show any difference in separation or other specifications, however, so if you wind up with the channels interchanged, simply reverse them when you plug them into your preamp.



Figs. 3-a–c show scope patterns with vertical scope input to left output of the decoder and horizontal input connected to the decoder right output.

Most tube tuners will have more than 0.75 volt p–p output. This adapter will have decreased separation and increased distortion at higher input levels. The input impedance is around 20K so a 100K pot inserted in series with the input may be adjusted until the input is correct.

An interesting feature of this IC is its 8–22-volt supply specification. If the adapter is aligned at 15 volts and the supply voltage decreased, separation stays almost unchanged. This is not true if the adapter is aligned at a lower voltage which is then increased. In no event should the supply exceed +22 volts. Operation at +15 volts is highly recommended, since no performance characteristic was improved at higher voltages. As the supply voltage is not critical, a relatively inexpensive Zener diode with capacitor filtering will provide very stable operation. **R-E** erative technique—the amplifier output signal has been used to determine its own input signal. While this type of device actually can increase the dynamic range, it is far from linear.

Assembly has been simplified and the only equipment needed to calibrate the unit is a dc voltmeter or scope, an audio generator and an ac vtvm, or scope. The design of several earlier models has been thoroughly evaluated and this version reflects the stress placed on performance as well as ease of calibration.

How it works

All signals used in the expander are derived from the input signal (see Fig. 2). The input signal is applied to the high input impedance of an emitter follower. The follower output is applied to a pot, used to adjust the audio level applied to the variable-gain amplifier. The total follower output is applied to a "perfect" rectifier which rectifies signals lower than 1 mV rms. This full-wave rectified signal is then integrated into a dc voltage. The dc voltage varies as the logarithm of the input signal. (Remember that the gain of an amplifier is expressed in decibels according to the formula:

$$\text{dB gain} = 20 \log \frac{e_{out}}{e_{in}}$$

This dc control signal is applied to the control element in the variable-gain amplifier so the gain of the amplifier varies directly with the input signal. Thus, as the signal input increases, the dc control signal rises and the output of the variable gain amplifier corresponds to:

$$e_{out} = e_{in} + K \log e_{in}$$

The schematic, Fig. 3 shows how we get these functions. IC1 is the "perfect" rectifier. Since D1 and D2 are inside the feedback loop of the op amp, the diode threshold voltage is

PARTS LIST

*T1—26.8VCT fil trans., Triad F90X or equiv.
RECT 1—1A, 50V bridge rectifier
C18, C19—250 μF 25V elecrolytic, Mallory MTV250DN25 or equiv.
C20, C21—500 μF, 15V electrolytic, Mallory MTV500 DN15
D5, D6—1W, 15V, 5% Zener diodes
R28, R29—½W, 220Ω, 5%
R30, R31—½W, 33Ω, 5%
PC board—PS-1, Transitek

Expansion Channel (for stereo, 2 of each are required)

All resistors are ¼W, 5%
R1, R2—220,000 ohms
R3—470 ohms
R4—2500 ohms, ¼W trimmer, CTS type X201R252B or equiv.
R5, R7, R9—20,000 ohms
R6—3600 ohms
R8—1800 ohms
R10, R23—10,000 ohms
R11, R20, R27—1500 ohms
R12, R15, R17—560 ohms
R13—1000 ohms, ¼W trimmer, CTS type X201R102B or equiv.
R14, R16—75,000 ohms
R18, R19—2200 ohms
R21, R25—180 ohms
R22—220 ohms
R24—100,000 ohms
R26—6800 ohms
C1—150 μF, 15V electrolytic, Mallory MTV150CK15 or equiv.
C2—0.1 μF, 10V ceramic, Centralab UK-10-104 or equiv.
C3—25 μF, 35V electrolytic, Mallory MTV25CB35 or equiv.
C4—68 pF ceramic
C5, C9, C14—22 pF ceramic
C6, C13—470 pF ceramic
C7—100 μF, 15V electrolytic, Mallory MTA100E15
C8—50 μF, 15V electrolytic, Mallory MTV60CB15
C10—.0012 μF ceramic
C11—500 μF, 6V electrolytic, Mallory MTV 500DJ6 or equiv.
C12—0.2 μF, 10V ceramic, Centralab UK10-204 or equiv.
C15—220 pF ceramic
C16, C17—0.1 μF, 20V ceramic, Centralab UK20-104 or equiv.
D1, D2—IN4154, G-E
*D3, D4—Hot carrier diodes, HP5082-2800
Q1—2N3391, G-E
*IC1, IC2, IC3—709 C Operational Amplifier
*S1, S2, S3—4pdt custom rocker switch
*PC Board—EXP-3
*Items available from Transitek; D3, D4 $1.25; IC1, IC2, IC3 $2.65; S1, S2, S3 $1.40; PC Board EXP-3 $2.75; Board PS1 (pwr), $1.00; PS1-K (pwr supply board with all components but T1), $7.00; EXP-3K (all items for 1 expansion channel), $26.00; Two EXP-3K's, $48.00
Transitek Co.
P.O. Box 98205
Des Moines, Washington 98016

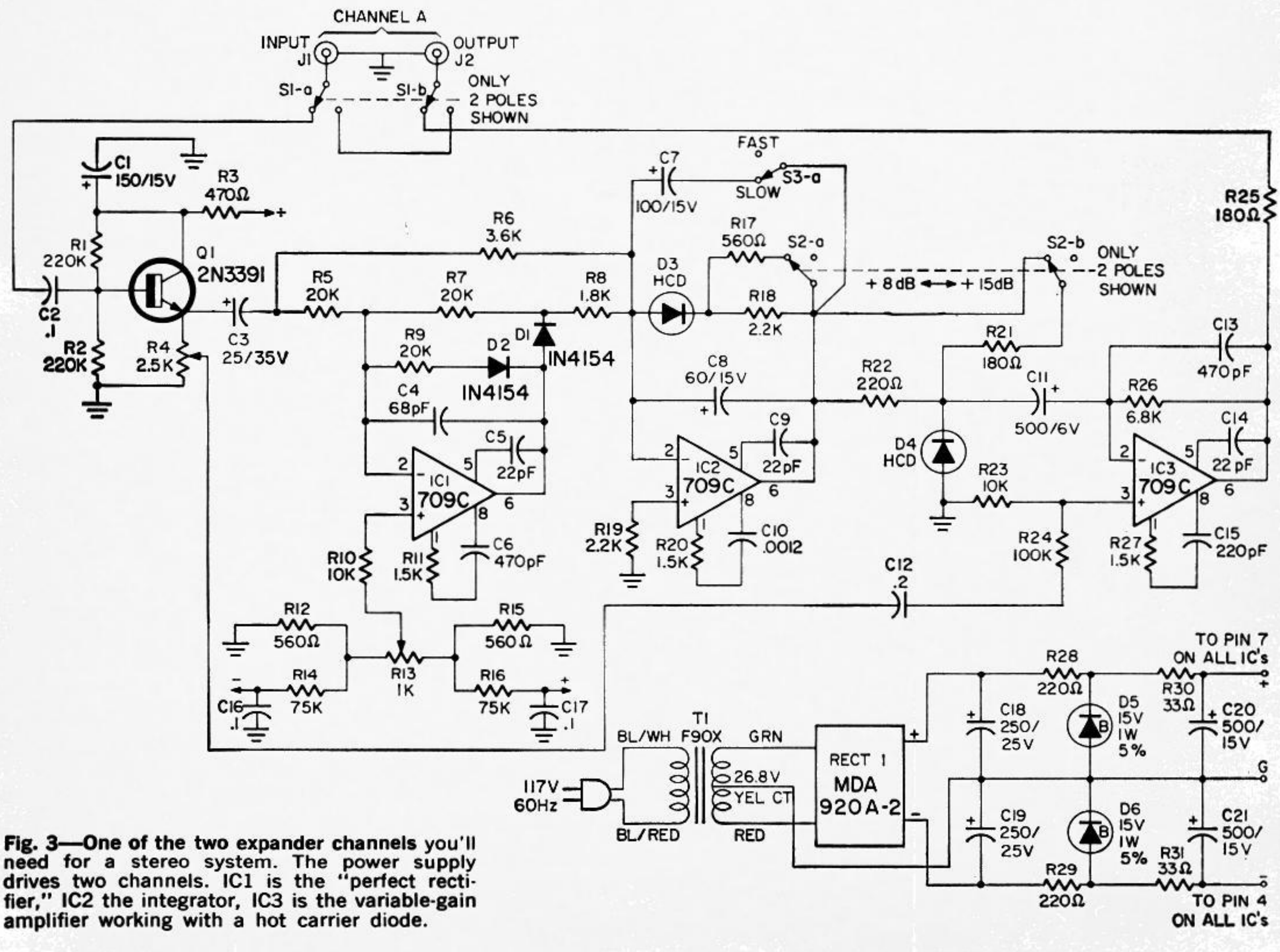


Fig. 3—One of the two expander channels you'll need for a stereo system. The power supply drives two channels. IC1 is the "perfect rectifier," IC2 the integrator, IC3 is the variable-gain amplifier working with a hot carrier diode.

reduced by the open loop gain of the amplifier—typically 7,000 to 15,000. Capacitor C8, in the feedback loop of IC2, integrates the rectified signal. The value of C7 and C8 determines low-frequency distortion. If the time constant chosen is extremely short, the expander tends to increase gain on the positive and negative peaks of a low-frequency input signal.

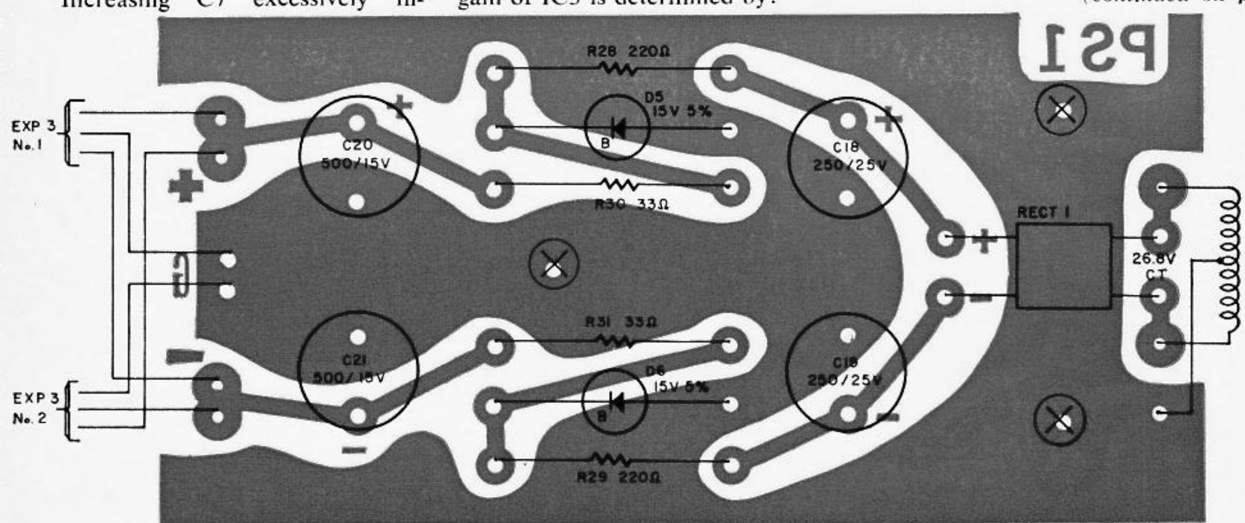
Increasing C7 excessively increases the time constant and causes a noticeable "pumping" action on the volume. However, unless you are a devotee of large pipe organs, for most music the fast position of S3 is best. D3 and R18, in another feedback loop of IC2, provide a modified logarithmic dc feedback. Diode D3 is a hot carrier diode with a much lower threshold voltage than ordinary diodes. The ac gain of IC3 is determined by:

$$\text{gain} = \frac{Z_F + Z_R}{Z_R}$$

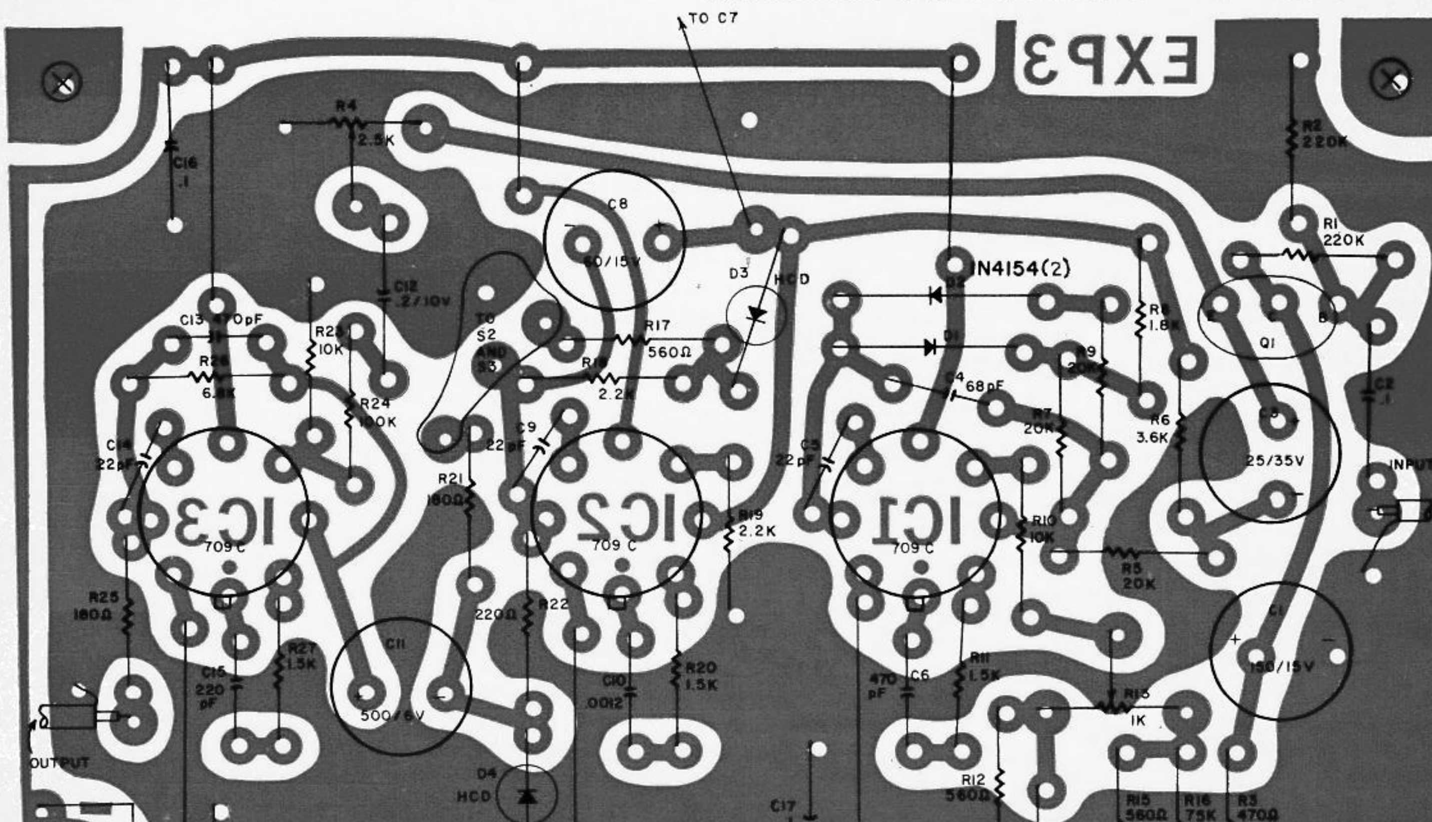
where Z_R is the impedance of C11 and D4 and Z_F = 6.8k. Capacitor C11 is large so its impedance, even at low frequencies, is much lower than the impedance of D4. Thus the gain of IC3 becomes:

$$\frac{Z_F + R_{D4}}{R_{D4}}$$

(continued on page 39)



Use the component placement above to build the power supply for a stereo unit. One expander channel board is below. **Mount components** on the expander like this. Use low-wattage iron to solder in the IC's, or install IC sockets for 709's.



The modified dc control signal of IC2 varies the current through D4 and thus the dynamic resistance of D4. Since C11 isolates the dc output of IC2, IC3 operates with a dc gain of unity and the output can never have a dc voltage of more than 5 mV. Resistor R13 sets the dc voltage applied to D3 and D4 so even without an audio input signal these diodes do not operate at extremely low current levels where their dc resistances could show wide variations from unit to unit. As a result the low-cost hot-carrier diodes provide nearly ideal results for the circuit.

The power supply is a full-wave center-tapped bridge rectifier providing ± 15 volts to the operational amplifiers. Although the op amps do not require extremely low ripple supplies, the base supply of Q1 is sensitive to ripple and the additional filtering provided by C1 and R3 reduces the remaining ripple to negligible values.

Switch S1 either connects the expander or completely removes it from the system. Switch S2 selects either a +8 or a +15 dB expansion range, and S3 selects the fast or slow time constant.

Now let's build one

The device built for this article is in an extruded aluminum cabinet. The only parts mounted to the front cabinet panel are the switches. The power transformer, power supply pc board, and two expander pc boards are arranged along the rear cover plate. Other arrangements are possible for mounting the parts used to construct a dynamic expander.

Use the circuit boards as templates to determine the locations of the mounting holes. The easiest method of construction is to first place all the resistors on the boards in the positions shown on the component layout sheets, then the ceramic capacitors, next IC1 through IC3 and Q1, and finally the upright electrolytic capacitors. Add the external wiring to the expander boards before mounting them with ¼-inch spacers.

The length of the shielded leads to S1, S2, and S3 may be 6-feet long, thus allowing the switches to be placed on an existing panel with the expander itself tucked away in some hidden corner. Use of a 1/16-inch tiplet in a small 37½-watt soldering iron is recommended. A larger tip may be used in soldering leads to the ground foil. Note that each expander board has its own ground return to the power supply. Arrange your board mountings so you have access to R4 and R13 for the calibration adjustments. No switch is used in the power supply line since most systems provide switched ac line outlets.

Calibration techniques

Follow these steps in sequence to calibrate the expander.

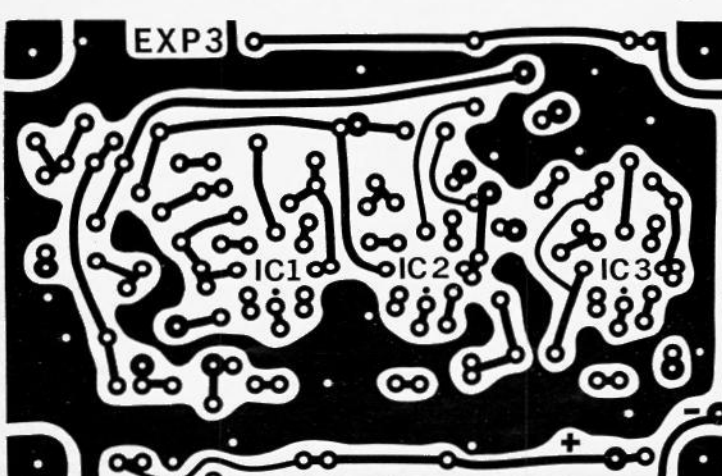
1. Check the outputs of the power supply. These should read plus and minus 15 volts $\pm 5\%$.
2. Apply a short to J1 on both channels. Set S1 to the expander IN position and S2 to +15 dB. Set S3 to the FAST position.
3. Adjust R13 in each channel until a dc voltmeter or scope reads −0.2V at the output of IC2. (This voltage at pin 6 may be read most easily at one of the contacts of S2-a.) Adjust slowly, this is an integrator!
4. Apply a 1 kHz, 1V rms signal to J1 on both channels and adjust R4 on each channel until the outputs read 1V rms.
5. Reduce the input to 0.01V rms and measure the output on each channel. One channel will probably have slightly higher output than the other. Readjust R13 on the lowest channel until its output is the same as the highest channel.
6. Repeat steps 4 and step 5.

When calibration is complete the unit is ready to use. If your preamp output is low impedance, as virtually all preamps are, you may run 20 feet of shielded cable between its output and J1 on each channel. 40 feet of cable may be used between J2 and the power amplifier.

Expansion ratios can be adjusted by varying the values of R17, R18, R21, and R22. These particular values have been chosen so that the output level does not change significantly when switching S2.

The pot connected between the IC2 outputs on each channel is of doubtful use. When it is used it forces the channel with the lowest input signal to operate at the gain of the loudest channel—which brings up the noise level of the lower channel. Since noise reduction is one significant advantage of linear expansion, this type of connection can only defeat its purpose.

Listeners report that the music in the expanded system sounds more like a live performance, although the rustling of programs is absent! The most convincing demonstration is to play a favorite tape or record with the expander in the circuit, then to remove the expander and play the same music again. In just the few minutes you have listened to the music without the noise background your ears will become accustomed. Without expansion you will immediately notice the noise which appears during softer passages. The difference is similar to going back to black and white after watching color television. **R-E**



ACTUAL-SIZE PRINTED CIRCUIT PATTERNS

Here's how the PC patterns look from the copper side. Reproduce them photographically to build your dynamic expander. You'll need two of the expander boards (left) for stereo, but only one power supply (below). Parts placement for the boards is on the preceding page.