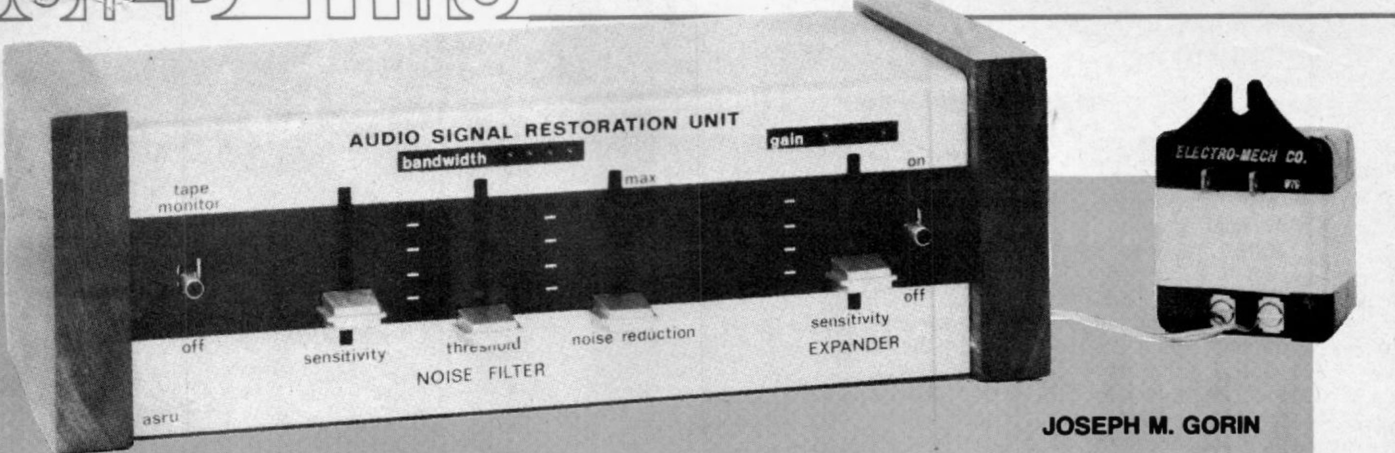


JOSEPH M. GORIN

HI-FI NOISE FILTER/Range Expander

Bring out the best in any recording with this combination noise filter/dynamic range expander.

THE ARTICLE, "NOISE REDUCTION TECHniques," that appeared in the January and February 1981 issues of **Radio-Electronics,** presented block diagrams of commercially available dynamic range expanders and noise filters. That two-part article showed how, by improving the dynamic range of even the best recorded musical signals, expanders and noise filters restore much of the emotional impact that is lost during the recording process. This two-part article will describe the operation and construction of a combination dynamic range expander/noise filter called the ASRU (*A*udio *S*ignal *R*estoration *U*nit).

This month, we will describe the basic operation of the ASRU and provide an in-depth description of how the expander portion of the circuitry works. Next month, we will discuss how the noise-filter circuitry of the ASRU works and provide the construction, installation, and operation details.

The expander—how it works

Like the expanders discussed in the January 1981 issue of **Radio-Electronics,** the expander section of the ASRU makes the low-level signals softer and the loud signals louder, thus providing improved realism and reduced noise. The expansion curve of the circuit is shown in Fig. 1. Note that the total change in gain is about 8.5 dB; the slope is very shallow. It requires over 40 dB of range to change from minimum to maximum gain, for an average expansion rate of about 1.2:1 (the ratio of output-level change to input-level change in dB). The curve shown provides expansion without unnatural side-effects.

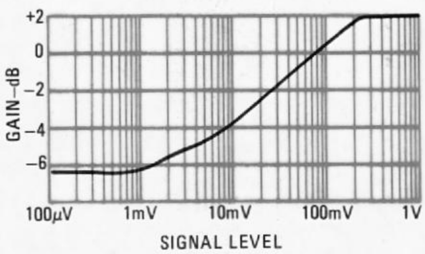


FIG. 1—EXPANSION CURVE of the ASRU shows a shallow slope.

A block diagram of the expander portion of the ASRU is shown in Fig. 2.

The first stage sums the right- and left-channel signals coming from the noise filter so that both channels can be controlled together, preventing the stereo image from changing due to variations in signal level in one channel or the other.

The control-voltage filter takes the output of the summing network and attentuates the high- and low-end frequencies to produce an audio signal that approximates the response of the human ear (see Fig. 3). That response is shown by the well-known Fletcher-Munson curves (Fig. 4) that depict the sensitivity of the ear for equal perceived loudness at different frequencies. Note that, at most levels, the ear is significantly more sensitive to midrange frequencies than to high- or low-end ones. In fact, due to the resonance of the ear canal, the ear is most sensitive to sounds in the 4-kHz range.

That midrange sensitivity accounts very strongly for our perception of the loudness of a sound and the control-voltage filter is designed to take advantage of that fact.

The attenuation of both ends of the audio spectrum tends to reduce the effects of noises such as turntable rumble and FM multiplex "hiss."

Furthermore, the steep roll-off at low frequencies prevents low-frequency signals from causing rapid and unnatural-sounding gain changes. That is beneficial because sudden changes in gain during the period of a signal can result in harmonic distortion—something we

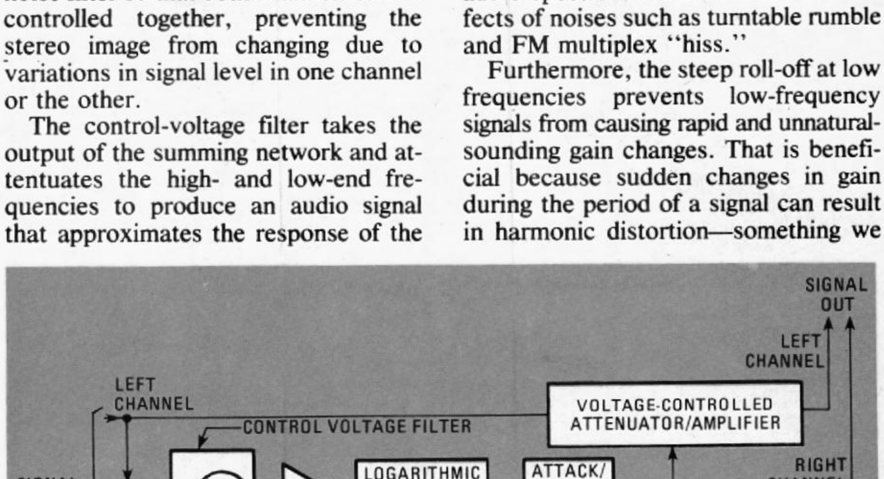


FIG. 2—BLOCK DIAGRAM of the expander portion of the ASRU. The first stage sums both channels to maintain stereo imaging.

R-E TESTS IT

LEN FELDMAN
CONTRIBUTING HI-FI EDITOR

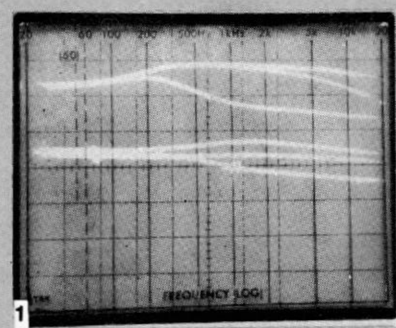
We tested a prototype of the Audio Signal Restoration Unit in our laboratory, using static signals as well as musical program material. As the author suggests, setting up the unit is a bit tricky. To some degree (unless the expander section is turned off altogether), there is some audible interaction between the various front-panel controls on the unit. We found that the best setting for the sensitivity control is such that medium or average loudness-level portions of the program source cause sequential extinguishing of the indicator LED's. The threshold control should be set so that in the absence of any signal, the lowest-level LED flashes only occasionally.

With the expander switch to the ON position, optimum setting of the expander-sensitivity control occurs when the right-hand LED flashes only intermittently. Of course, it is possible to use each section (noise reduction, dynamic filter and expander) as required, to suit program material, but we found that with the controls set as described above, we were able to improve reproduction of most program sources without having to make extensive readjustments every time we altered program material or content.

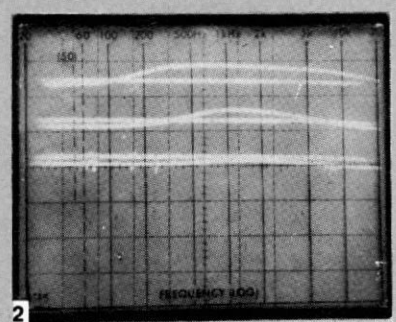
With the expander out of the circuit, and with the unit set for widest bandwidth (no dynamic filtering or noise reduction), overall frequency response of the unit measured flat within ±0.75 dB from 20 Hz to 20 kHz. The unit has essentially unity gain, but that may be varied by means of the input sensitivity control. With 0.5 volt input, we measured a signal-to-noise ratio of 90 dB, IHF "A"-weighted. With both the expander and the noise filter on, total harmonic distortion for a 1-kHz input signal at the 0.5-volt level measured 0.17%. With the expander turned fully off (the threshold control at its minimum position) but the noise filter on, distortion decreased to less than 0.1% for the same test signal.

A series of composite spectrum analyzer sweep photos for the expander/filter/noise-reduction unit is shown in Fig. 1. In both the upper and lower series of sweeps, the expander is on and degree of expansion is varied, as are the noise reduction and filtering action. Note that greater expansion occurs at the higher signal-level (upper traces) and that regardless of the level at which the tests were made, no expansion is evident at the low-bass frequencies.

Figure 2 shows the expander action alone (without any noise reduction or band-filtering action). With the expander turned off, response is flat from 20 Hz to 20 kHz; but with the expander turned on, the degree of expansion for louder passages, less for moderate passages and, in the lower traces, even a bit of downward expansion for quietest passages.



1
COMPOSITE spectrum-analyzer sweep photos for the ASRU.



2
SPECTRUM-ANALYZER sweep photos for the expander alone.

The Audio Signal Restoration Unit operates with very few side effects once it is properly adjusted. By not allowing expansion to take place at the bass frequencies, the designer has overcome some of the pumping and breathing effects common to other linear expanders. The 1.2:1 ratio of expansion is quite moderate, compared with some other commercially available expanders, but nevertheless is sufficient to add a measure of realism to most program material that has been compressed during recording.

As for the variable-bandwidth filters: if used to excess, they can create some undesirable audible effects; but it is possible to benefit from them without suffering such effects if adjustment of threshold and bandwidth is carefully done while listening to program material. We did not find the indicator LED's to be as helpful in setting up the unit as the author had suggested; but we did find that, with a little practice, we were able to use the "ASRU" with just about any component system that is equipped with an ordinary tape-out/tape-play monitor loop. The tape-monitor loop on the amplifier that is used to conect this unit is duplicated on the unit itself, so owners of cassette or open-reel tape decks need not worry about losing it.

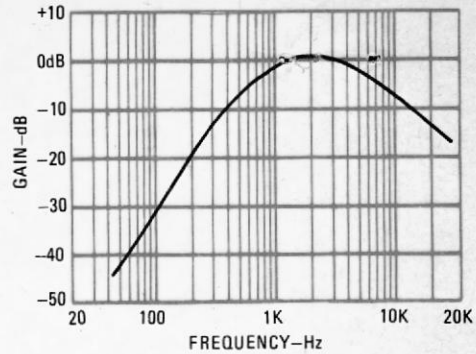


FIG. 3—FREQUENCY RESPONSE of control-voltage filter matches that of ear.

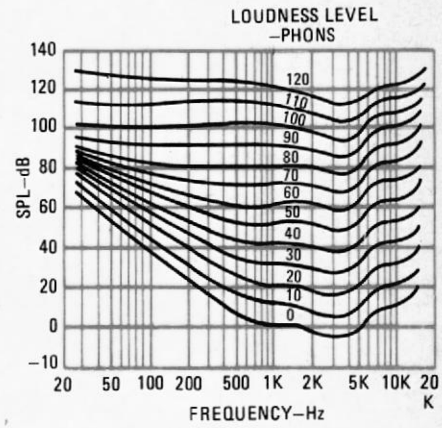


FIG. 4—FLETCHER-MUNSON curves show that the ear is most sensitive to midrange frequencies.

can do without.

The audio from the filter is passed through a precision full-wave rectifier that generates a current used to produce the control signal.

The logarithmic curve-shaping and attack/delay circuits convert that current into a control voltage that is approximately proportional to the logarithm of the current and that section of the expander provides attack and decay times that adjust themselves to the rate of change in signal strength.

Finally, the control voltage is supplied to the voltage-controlled attenuator/amplifier where it is used to modify the qualities of the original audio signal.

The ASRU's expander does not expand signals in the low-bass region as much as it does in others. There are two reasons for that.

First, consider Fig. 5-a, showing a warp or rumble (very-low-frequency) waveform along with a toneburst. As can be seen in Fig. 5-b, at the moment the toneburst is added, the level of the warp signal will increase because the expander will increase the gain and a "thump" will be evident, even though the warp noise alone was inaudible. Figure 5-c shows what happens when the ASRU is used—the "thump" doesn't occur because the action at very low frequencies is minimal.

Second, although the ear is relatively insensitive to very low frequencies—refer to the Fletcher-Munson curves in

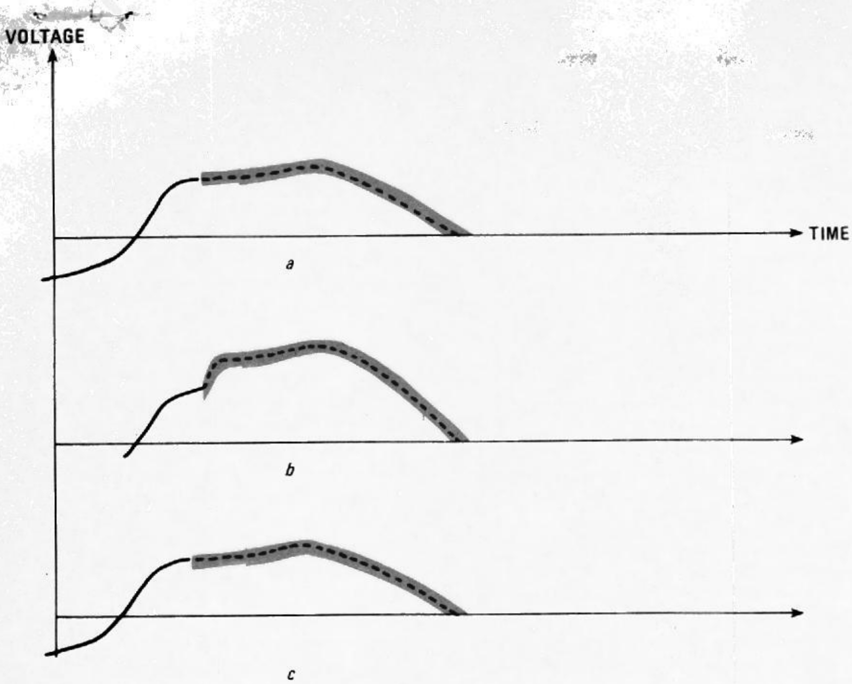


FIG. 5—WARP OR RUMBLE (thin line) with tone burst (thick line). The ASRU (c) eliminates thumps by not expanding such a signal.

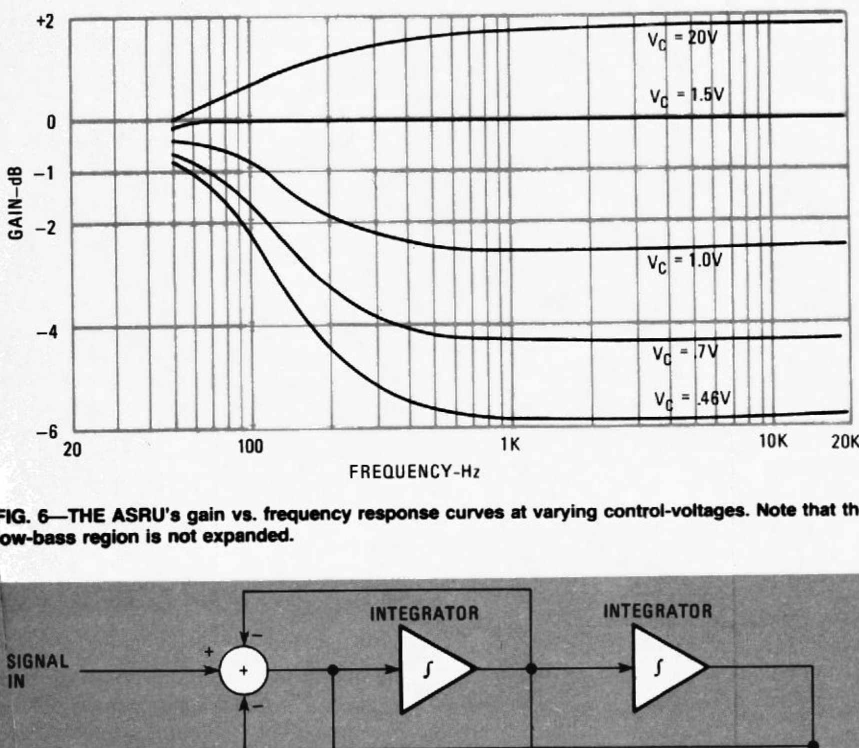


FIG. 6—THE ASRU's gain vs. frequency response curves at varying control-voltages. Note that the low-bass region is not expanded.

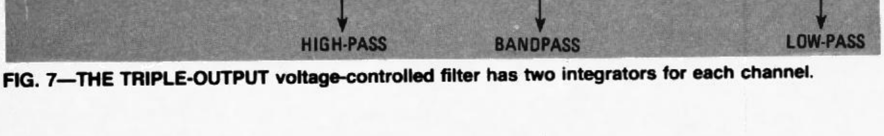


FIG. 7—THE TRIPLE-OUTPUT voltage-controlled filter has two integrators for each channel.

Fig. 4—once their level is above the threshold of hearing, a 2-dB increase appears as great as a 5-dB increase in the midrange area.

For both of those reasons, as well as to keep distortion to a minimum, the ASRU's expander does not expand the low-bass as much as it does the midrange. Figure 6 shows the ASRU's gain vs. frequency response at varying control-voltage levels. Note how well that matches the changes in gain sensitivity shown in Fig. 4.

The ASRU's shallow expansion-slope, midrange-emphasized control-signal and minimized low-bass expansion explain why it is so clean-sounding, while allowing 8.5 dB of effective expansion.

The noise filter—how it works

The heart of the noise-reduction system is a triple-output, voltage-controlled filter, the block diagram of which is shown in Fig. 7. It is a state-variable filter, which means that certain of its characteristics can be modified while others are maintained.

The integrators process the signal for use by later stages of the noise-reduction system (see Fig. 8). For sinewaves, the output is reduced by a factor of two (6 dB) for every octave increase in input frequency. By varying the gain or time-constant of those integrators, or the amount of feedback around them, the corner frequency (the frequency at which the amount of attenuation reaches 3 dB) can be changed without changing the shape of the filter.

Refer to Fig. 8 as we discuss the ASRU noise-reduction system.

If no signal is present, the control voltage sets the corner frequency of the triple-output filter to 1.2 kHz. Figure 9 shows the frequency response of each output of the triple-output filter with the corner frequency set at 1.2 kHz. The overall output of the noise filter is taken from the low-pass output via a buffer. Thus, with no input signal present, any noise will be greatly attenuated.

If a 5-kHz tone is suddenly applied to the input, it will appear unattenuated at the high-pass output and will be greatly attenuated at the low-pass and bandpass outputs. The AC-DC converter connected to the high-pass output will provide a strong signal that will rapidly pass through the attack/delay element and cause the control voltage to increase. As the control voltage increases, the corner frequency of the filter will also increase until it exceeds 5 kHz.

Soon there will be a stronger signal in the bandpass section than in the high-pass section. That is converted to DC and will be fed back and reduce the control voltage. In the case of a steady tone, that action will serve as a feedback loop that forces the bandwidth of the filter to "catch" the input frequency, allowing it to go through the low-pass filter to the output, while the noise above that frequency is filtered out.

Music, of course, is more than just simple tones. The ASRU noise filter will track the highest significant frequency of a complex signal. During a transient—a short, but intense, increase in high-frequency energy—the corner frequency will overshoot slightly. That is desirable, since transients mask noise very well.

If the signal is extremely strong,

PARTS LIST

All resistors ¼ watt, 5% unless otherwise specified

R1, R9, R10, R101, R109, R110, R221, R521,—100,000 ohms
R2-R5, R102-R105, R211, R213, R214, R305, R306, R309, R310, R405, R406, R409, R410, R519, R533, R535—10,000 ohms
R6, R106, R230, R507, R508, R520, R530—20,000 ohms
R7, R12, R107, R112—200 ohms
R8, R14, R15, R108, R114, R115, R205 R501, R502, R529—2200 ohms
R11, R111, R218—36,000 ohms
R13, R113, R201, R208, R209, R212, R215, R220, R222, R229, R513, R522, R528—4700 ohms
R16, R116, R202, R203, R210, R503—10,000 ohms, 30%, slide potentiometer, linear taper
R17, R117, R506, R537—3900 ohms
R204—2700 ohms
R206, R207—1.5 megohms
R216—68,000 ohms
R217, R509—3300 ohms
R219—820 ohms
R224, R307, R308, R312, R407, R408, R412, R514, R531, R532, R534—1000 ohms
R226, R516—270 ohms
R228—150 ohms
R231, R302, R303, R402, R403—270,000 ohms
R232, R304, R404—1200 ohms
R223, R510—6800 ohms
R225, R233, R313, R413, R504—560 ohms
R227, R527—120 ohms
R301, R401, R526, R536—1500 ohms
R311, R411, R525—12,000 ohms
R505—470,000 ohms
R511—910,000 ohms
R512, R515, R517—22,000 ohms
R518, R523—47,000 ohms
R524—47 ohms
R601—1.5 ohms

Capacitors

C1, C3, C5, C101, C103, C105, C201, C202, C204, C506—0.01 µF, 5% Mylar
C2, C6, C7, C102, C106, C107, C503, C504—3.3 µF, 35 volts, electrolytic
C4, C104, C205, C212-C214—0.022 µF, 10%, Mylar
C203—0.001 µF, 10%, Mylar
C206, C208—0.0033 µF, 10%, Mylar
C207, C209—680 pF ceramic disc
C210, C211, C301, C401—10 µF, 25 volts, electrolytic
C215, C505—1 µF, 35 volts, electrolytic
C216, C302, C307, C402, C407, C502—0.1 µF, 5%, Mylar
C303, C304, C403, C404, C501—100 pF, ceramic disc
C305, C306, C405, C406—22 µF, 16 volts, electroytic
C601, C602—1000 µF, 25 volts, electrolytic
C603-C607—0.1 µF, ceramic disc

Semiconductors

D201-D204, D206-D210, D501-D513, D515-D517—1N4148
D205—3.3-volt Zener
D514—4.7-volt Zener
D601-D604—1N4001
LED201-LED204, LED501, LED502—mini-LED (TL209 or equivalent)
Q201-Q203, Q501, Q502—2N3904
Q204-Q206—2N4250
IC1, IC2, IC4, IC7, IC9, IC10, IC11—RC4136 quad op-amp
IC3, IC6—4049 CMOS hex inverter
IC5, IC8—739 dual audio preamplifier
IC12, IC13—78L12A 12-volt positive voltage regulator
L201, L202—6.8 mH coil
T1—13.5 VAC, 350 mA, wall-plug transformer (Dormeyer PS14204 or equivalent)
J1-J4, J101-J104—RCA-type phono jacks
S1, S2—DPDT toggle or slide switch
Miscellaneous: 12-conductor ribbon cable, IC sockets, chassis and end panels, solder, wire, hardware, etc.

The following are available from Symmetric Sound Systems, 912 Knobcone Place, Loveland, CO 80537: Complete kit (ASRU) $110.00; PC boards (ASRU-PC), $18.00. Write for information on assembled units. No other parts or different combinations are available. End panels are unfinished. All prices include UPS shipping within U.S. Colorado residents add 3% tax.

EXPANDER-ONLY KIT

For those requiring only the expander portion of the ASRU, a kit, somewhat different from the one described here, is available from Symmetric Sound Systems. That kit, the EX-1, is priced at $60.00. A bare PC board, the SSS7, is also available for $11.00. See parts list for ordering information. A schematic, parts list, and a diagram for laying out your own EX-1 PC board can be obtained from the above company if a self-addressed, legal-size, stamped envelope (28 cents) is sent along with the request.

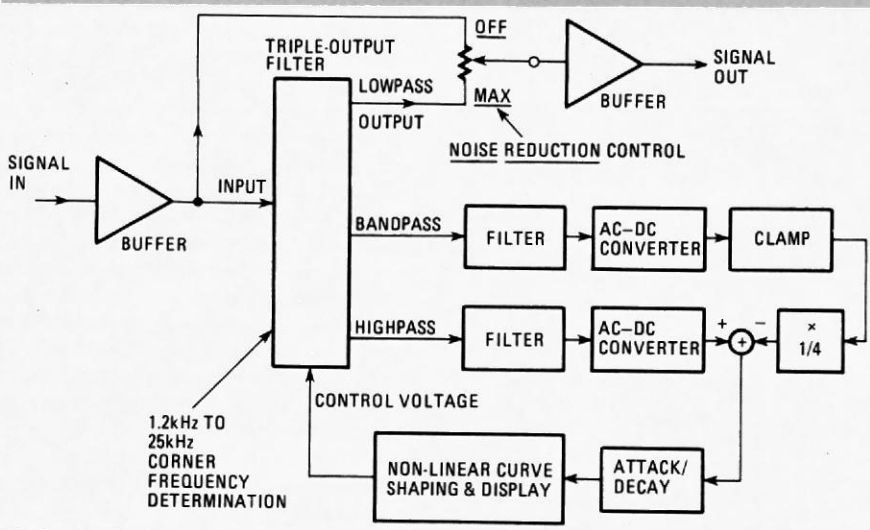


FIG. 8—BLOCK DIAGRAM of the ASRU's noise reduction system. If no signal is present, the corner frequency of the filter is set to 1.2 kHz.

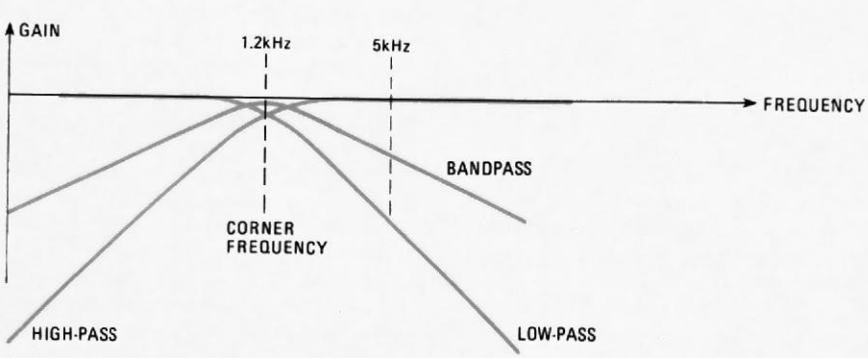


FIG. 9—THE TRIPLE-OUTPUT filter has low-pass, high-pass, and bandpass outputs. The scale here is log-log.

the clamp in the bandpass section will allow the bandwidth to extend all the way to 25 kHz. The attack/decay circuitry is designed so the bandwidth of the filter can be expanded rapidly, but takes longer to decrease than it did to increase. Because of the large amount of feedback used to control the bandwidth, that nonlinear response does not affect the steady-state (constant-level) response, but becomes very important in the case of transients.

As pointed out in the "Noise Reduction Techniques" article in the February 1981 **Radio-Electronics,** one of the advantages of a filter/expander combination is that each section can be adjusted to keep side-effects to a

continued on page 110

NOISE FILTER

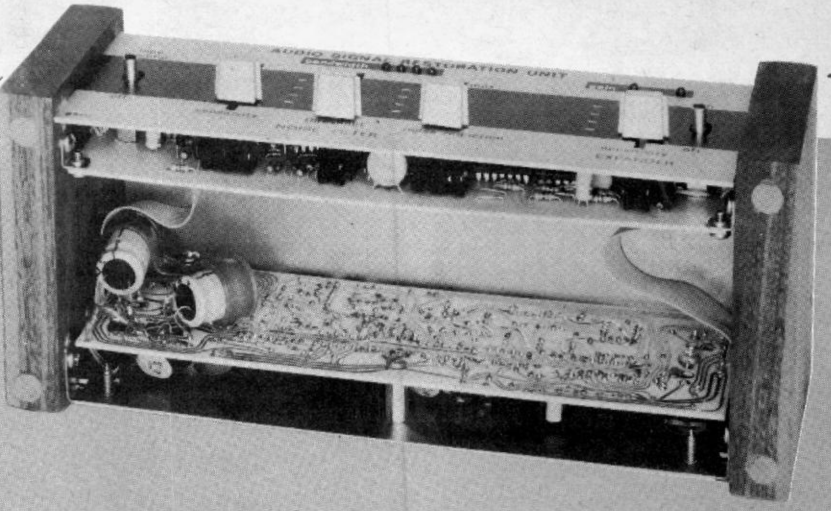
continued from page 44

minimum. A further advantage provided by multiple notch-filter techniques, is that the worst possible adjustment is limited to between 8 dB and 10 dB of attenuation. If a sliding cut-off filter were used, that might not be the limit and the error induced could be intolerable.

With the ASRU, the maximum permissible error can be set by the user and the possibility of obtaining an unnatural response—where a low-frequency band might be attenuated more than a higher-frequency one—is avoided. The noise-reduction control and the spectral-tracking concept with feedback are two features that make the operation of the ASRU so effective, yet free of side effects.

Next month, we will provide the circuit details for both the noise reduction and dynamic range expander portions of the ASRU. The construction details will also be given. **R-E**

BUILD THIS



HI-FI NOISE FILTER/Range Expander

Part 2—This month we'll look at the expander and noise reduction circuits in more detail and show you how to build the ASRU.

JOSEPH M. GORIN

IN THE FIRST PART OF THIS ARTICLE (March 1981 issue of **Radio-Electronics**) we discussed in general terms how the expander and noise-reduction sections of the ASRU (*A*udio *S*ignal *R*estoration *U*nit) work. We'll now cover those circuits in more detail.

Expander-circuit description

Figure 10 is a schematic of the right channel and control circuits of the expander portion of the ASRU. The signal is applied through R301 to IC6-a, a digital logic gate acting as a voltage-controlled resistor. Figure 11 shows the circuit of one of the six inverters that comprise the CD4049 IC and will help explain that unusual, but very effective and economical, circuit. The CD4049 CMOS hex inverter differs from most CMOS IC's because protection diode D_Z is intentionally omitted to allow driving the input from 10-volt logic signals while using a 5-volt power supply. In the ASRU, the "+" supply is connected to ground. That insures that the P-channel FET's, Q_A, are always off. That leaves us with Q_B active. As a result, we are left with six matched (see Fig. 11) N-Channel FET's because they are all fabricated on the same chip. The FET's are enhancement-mode devices, which means that after applying about 1.5-volts to the gate, the FET begins to turn on and the resistance between the source and drain decreases as the gate voltage is increased.

That causes IC6-a and R301 to form a voltage-controlled attenuator. The resistance of IC6-a varies between 55 and 90 ohms. At higher input levels, the gate voltage is reduced by the control circuits to reduce the attenuation. The output of the attenuator goes through C302 to operational amplifiers IC4 and IC5. Section IC6-f and its associated circuitry vary the amount of feedback around that op-amp combination and thus control the gain. Resistor R302 and capacitors C301 and C302, along with other parts in the feedback path, make sure that, at low audio frequencies, the signal does not go through the attenuators and is not expanded (see Fig. 6) of Part 1.

High attenuation in the early stages of the circuit reduces distortion by reducing signal levels, but makes noise a potential problem. The high gain and low noise required make the double op-amp combination (IC5-a and IC4-b) necessary. The front-end of that, op-amp IC5, is exceptionally quiet $(4/n\ V\ \sqrt{Hz})$ and is used as an input-differential pair of transistors.

Integrated circuit IC7-b serves to add 1.2 times the drain voltages onto the gates of IC6's FET's in a compensation scheme that further reduces distortion. The net result is an expansion block that is both quiet and undistorted. To derive the control signal, the two channels are summed by resistors R501 and R502. The gain of the control channel is varied with sensitivity control R503. Capacitors C506 and C502 reduce the low-frequency gain, and C501 rolls off the higher frequencies to obtain the curve shown in Fig. 3 of Part 1. The gain-stage of that filter is IC11-d. That IC and its associated components form a full-wave rectifier, such that the sum of the current through R509 and R510 is proportional to the absolute value of the filtered waveform. That makes the expansion polarity-independent so that all signals are expanded properly, regardless of their phase.

The currents in R509 and R510 and a bias current through R511 are converted by IC11-b, R512-R514, and D503-D505 to a voltage that is approximately proportional to the logarithm of the current. It is the non-linear impedance of the resistor-diode network that forms the gradual slope shown in Fig. 2 of Part 1. A rapid upward change in signal level causes D507 and D508 to turn on, and C504 and C505 can be rapidly charged. A slower rise will turn on only D507, so that C505 is charged more slowly through R517; that dual-mode reduces distortion for steady-state signals. For falling signal amplitudes, C504 and C505 must discharge slowly through R515 and R517.

The voltage on C505 is amplified by IC11-a. If the control voltage (IC11, pin 3) is below 4 volts, D515 is off and the signal is attenuated by R525-R527, to control FET gate-voltage deriver IC7-d. Figure 12 shows a block diagram of the gate-voltage deriver. Varying either the input voltage or drain current (I_D) will cause the op-amp to change the FET gate-voltage so that $V_{IN} = I_D \times R_{FET}$. In that case, increasing signal levels will increase V_{IN} and thus R_{FET}. Since IC7-d drives the gates of both IC6-a and b, their resistances will track its output.

In summary, increased signal levels will increase the control voltage, and thus the resistance of IC6-a, reducing the attenuation. As the control voltage gets even higher, diode D515 turns on, and the increasing current from R525 flows into the drain of IC6-c. That

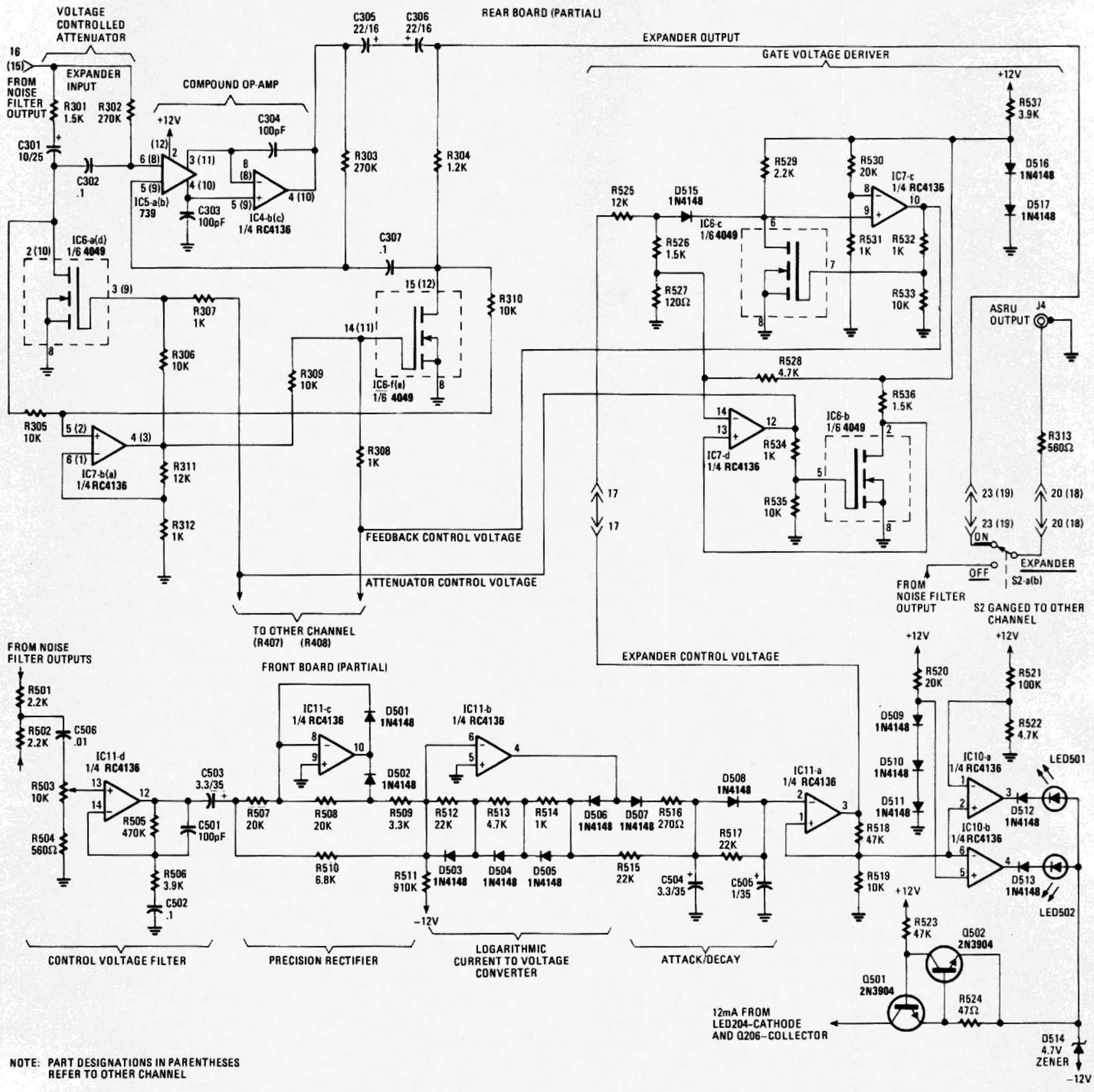


FIG. 10—RIGHT CHANNEL and control circuits of the expander portion. To find left-channel part numbers, add 100 to right-channel part numbers.

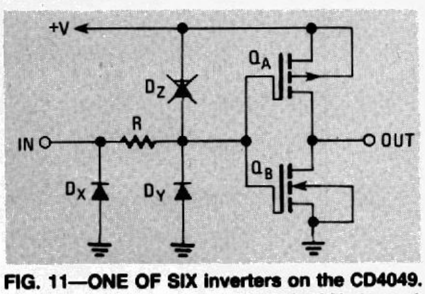


FIG. 11—ONE OF SIX inverters on the CD4049. Only the Q_B sections—six matched N-channel FET's—are used in the ASRU.

causes the IC7-c gate-voltage deriver to reduce the resistance of IC6-c and IC6-f, increasing the gain of the op-amp combination, IC4-IC5.

The op-amps driving LED501 (−6 dB) and LED502 (+1 dB) are used as comparators and absorb the current from Q501 through their respective LED's if the gain is either less than −6 dB or more than +1 dB. Transistors Q501 and 502 act as a constant 12 mA current source that is used for the display of the noise filter part of the ASRU. Zener diode D514 makes sure that the current source can still operate when both LED501 and LED502 are off.

Even the power supply (Fig. 13) is unusual. To maintain the exceptional signal-to-noise ratio desirable in a noise-reduction accessory, without requiring extensive magnetic shielding or coaxial wiring, the transformer is of the wall-plug type, and is physically separate from the ASRU. This type of transformer has a single, untapped secondary. To get both plus- and minus-12-volt

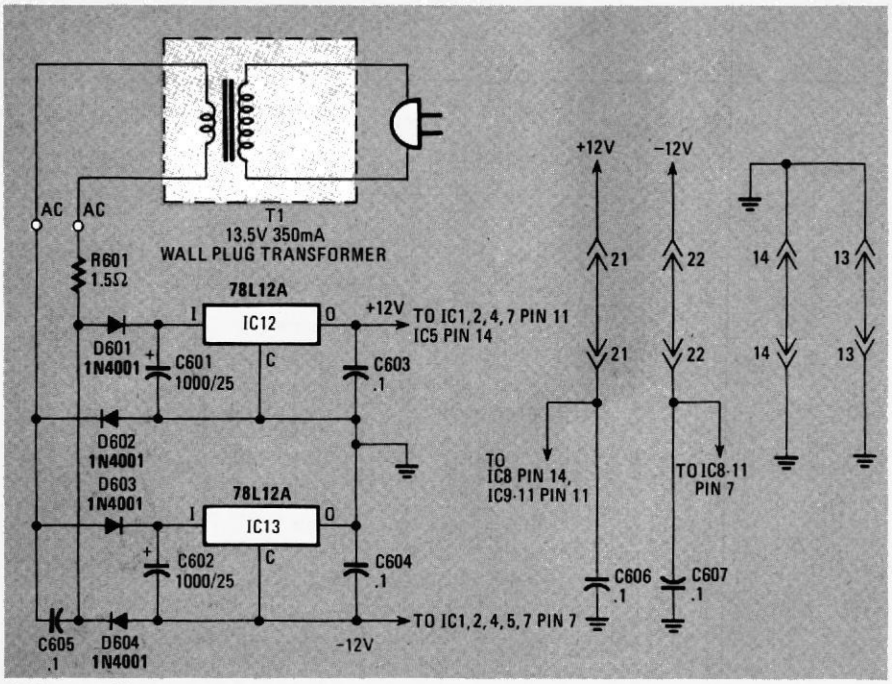


FIG. 13—POWER SUPPLY of the ASRU uses a separate wall-plug transformer, eliminating a potential source of hum.

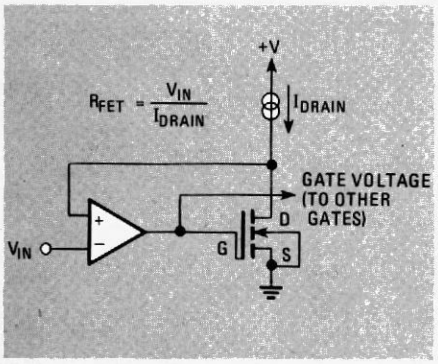


FIG. 12—GATE-VOLTAGE DERIVER, IC7-d, is used to control gain of op-amps IC4 and IC5.

supplies using economical positive voltage regulators, the circuit operates as follows. On positive half-cycles of the transformer output, C601 is charged up through D601 and D602. A standard IC regulator, IC12, is used. On negative half-cycles D603 and D604 charge up C602, which powers regulator IC13, except in this case, the regulator's output is grounded, and the terminal that is normally grounded supplies −12-volts.

Noise-reduction circuit description

The noise-reduction-section schematic is shown in Fig. 14. One of the variable integrators is formed by resistor R6, IC2-a, C1, R8 and IC3-b. With just R6 as an input resistor, and C1 as a feedback capacitor, IC2-a would be a fixed-gain integrator. The attenuator—consisting of R8 and IC3-b—in the feedback loop allows the gain to that integrator to be varied.

Capacitor C2 provides AC coupling to prevent DC errors (such as voltage-offsets) from causing "thumps" when the resistance of IC3-b changes. Resistor R7 provides bandwith compensation for the op-amp.

Capacitor C3 and resistor R9 do two things: They filter the control signal to keep it from acting too quickly and also feed back drain voltage to the gate of this section of the IC to cancel some of the FET's distortion.

The summing network (see Fig. 7 in Part 1) is made up of IC1-b and R2-R5. The reason there are two "−" inputs and one "+" input is because the design of the integrators causes the signal to be inverted. The input impedance is kept high by using IC1-a as an input buffer. The output buffer, IC10-d, acts to keep the output impedance low. Resistor R16 is used to vary the amount of noise reduction.

The highpass and bandpass signals are added by R14 and R114, and by R15 and R115, respectively. Two 19-kHz filters to remove any residual pilot tone from FM multiplex signals—preventing interference with the action of the noise filter—are made up of C201 and L201, and C204 and L202.

It is important that strong fundamental tones below 1 kHz and non-musical signals above 25 kHz not be allowed to affect the control-voltage-determining circuits. High sensitivity, though, is necessary to allow the filter to respond to low-level, high-frequency signals such as those produced by triangles (the percussion instrument that goes "ding"). The A739—IC8—provides that high sensitivity at a very low noise figure.

That IC is run in an *open loop* configuration (without feedback) at the frequencies where most musical activity takes place. Resistors R206 and R207, and capacitors C210 and C211 provide feedback to control the biasing of the op-amp and to roll off the low-frequency gain. Resistors R204 and R205 reduce the open-loop gain, and capacitors C206-C209, along with C203, roll off the high-frequency gain. Low-frequency gain is also rolled-off by C202, C205, C212 and C213.

Capacitors C212 and C213 also couple the highpass and bandpass signals into precision rectifiers IC9-b and IC9-c. The combined gain of those two IC's is about 2000. By obtaining that gain through two stages—IC8, whose output is a current, and IC9 (together with R208 and R209), that changes that current to a voltage—it is possible to get a gain with rectification that is normally very difficult to obtain due to stray capacitive feedback.

The weighted-difference blocks (Fig. 8, Part 1) are made from resistors R212-R214. they subtract, rather than add, because IC9-c is a *positive*-output rectifier, while IC9-b has a *negative* output. The bandpass channel is clamped by diode D205 that turns on at about three volts, allowing the energy in the highpass section to push the bandwidth all the way out at high levels. The action of the bandpass channel is slowed by C214. That helps cause filter corner-frequency overshoot during transients.

The fast-attack/slow-decay circuit consists of IC9-d and its associated components. The attack time is 4 mS; the decay time 80 mS. Low-impedance drive for the exponential curve-shaping and display network, R224-R228 and Q204-Q206, is provided by IC9-a. When low-level control voltages are present at C216, all the transistors are off, and the resistors act as a simple voltage divider.

As the voltage at the capacitor increases to a few tenths of a volt, Q202 turns off, Q201 turns on, and LED201 goes out. At higher voltages, Q204 turns on, and LED202 goes out. Since the base-emitter voltage of Q204 cannot be much greater than 0.6 volt, R224 is eliminated from the voltage divider, increasing its output dramatically. In turn, Q205 and Q206 turn on with the same effect. As the voltage on R228 approaches 1.2 volts, D210 and Q203 turn on and clamp the voltage at C216 in a feedback path to prevent driving the voltage-controlled filter too hard. Thus, until the limit is reached, attenuation constantly declines exponentially.

The voltage on R228 is offset slightly by R230 so that, even with no input signal, the filter bandwidth can never go below 1.2 kHz. As was explained previously, IC4-a, IC3-c and IC3-d, together with their associated parts, form a gate-voltage deriving circuit.

Control-circuit gain is varied by R202 and R203. That sensitivity control

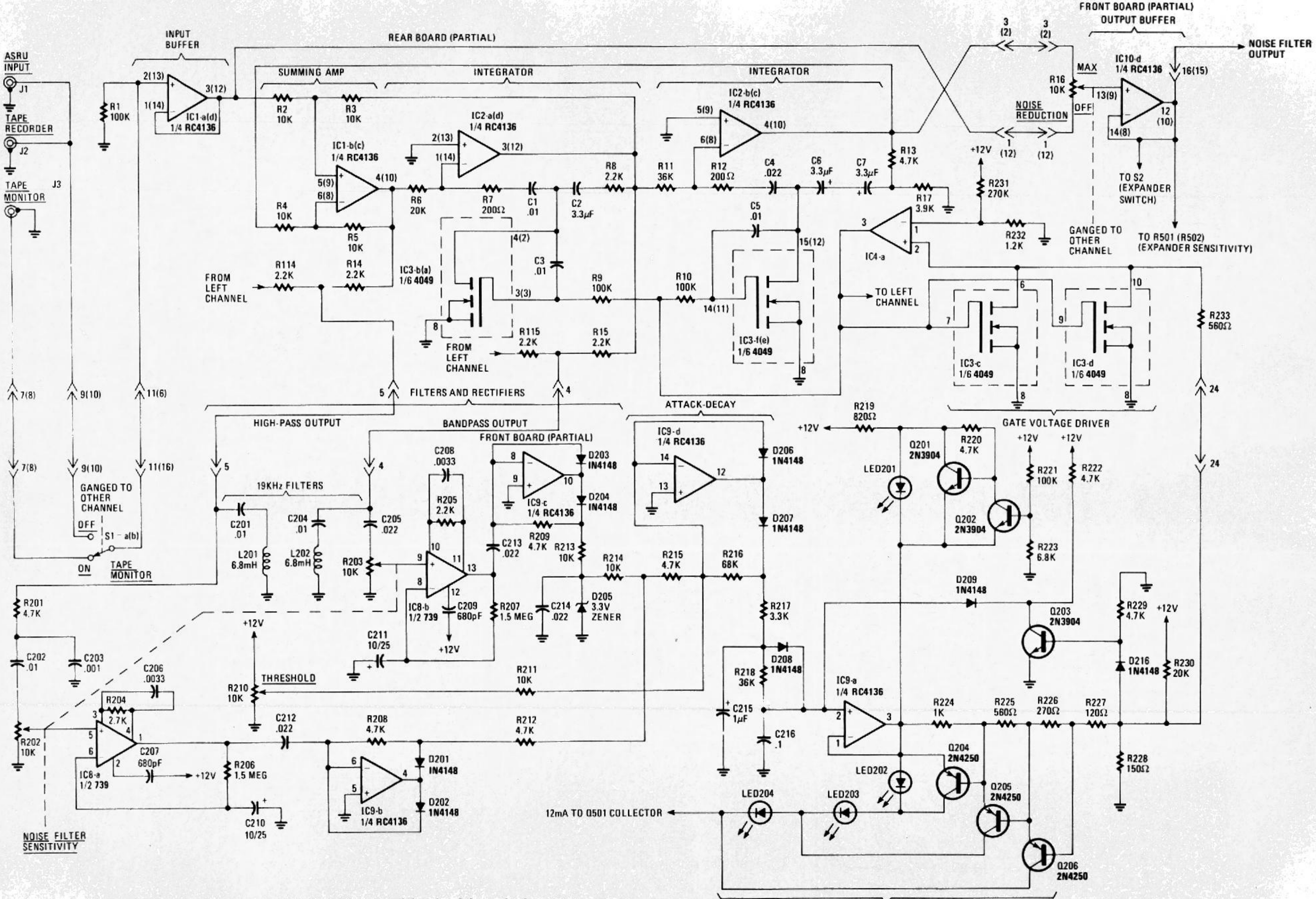


FIG. 14—NOISE REDUCTION portion of the ASRU. Note that part of the circuit is on the front PC board and part is on the rear board.

determines the ASRU's response to transients. Resistor R210, the THRESHOLD control, supplies a bias current to the attack/decay circuit; if there is enough noise to change the 1.2-kHz quiescent corner frequency, that current can keep that from happening.

Construction

Because of the complexity of this project, the use of PC boards is recommended. A single foil pattern, Fig. 15, can be etched on one piece of copper-clad material that can then be cut in two to provide both the front and rear single-sided ASRU boards.

mended. Install those first, followed, in sequence, by the resistors, diodes, capacitors, transistors, and other components. Make sure that all 24 jumpers (12 on each board) are accounted for.

In the prototype (Fig. 18), the LED's were mounted in a 16-pin IC socket that had been cut in half, lengthwise. That allowed them to protrude far enough forward to reach the holes in the front panel.

The front and the rear boards are mounted back to back. Use two short pieces of 12-conductor ribbon cable to connect the two boards by means of the holes located at the ends of the boards.

tubes until you need them. Before handling them ground both yourself and the PC board to discharge any static electricity that may be present.

The two power-supply capacitors, C601 and C602, are mounted on the back (foil side) of the rear board and secured with plastic cable clamps. The clamps are attached through a spacer to the hole between jacks J1 and J6.

Make sure, of course, that every polarized component is correctly oriented.

The two PC boards are supported by wooden end-panels and a metal cover may be added for appearance's sake and to protect the boards. Since the power transformer is of the wall-plug type and is isolated by distance from the ASRU, hum is not a problem.

Installation

Like most other signal processors, the ASRU is connected to a receiver or amplifier using the tape-monitor loop. Its input is connected to the TAPE RECORDER or TAPE OUTPUT jacks, and the output to the TAPE MONITOR, TAPE PLAY or TAPE IN jacks.

Used that way, the TAPE MONITOR switch can be used to bypass the ASRU or to bring it into the circuit. (The EXPANDER and NOISE REDUCTION controls, if turned to the OFF position, will also take the ASRU out of the circuit, and the TAPE MONITOR switch can always be left in the ON position.)

A tape deck can be connected to the ASRU just as it had been connected to your receiver or amplifier before the ASRU took over that unit's tape-monitor jacks.

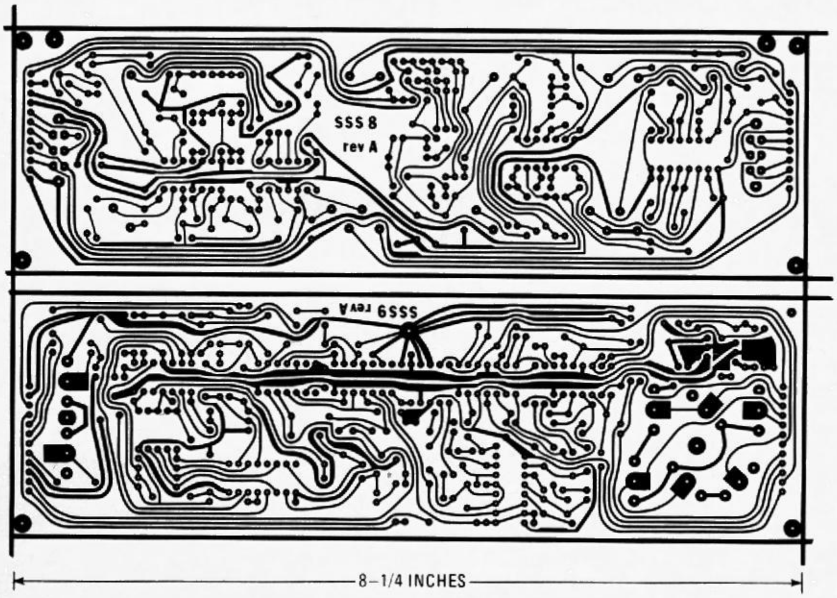


FIG. 15—FOIL PATTERN for the front and rear PC boards. Both patterns can be etched on a single copper-clad board (as shown) if you wish.

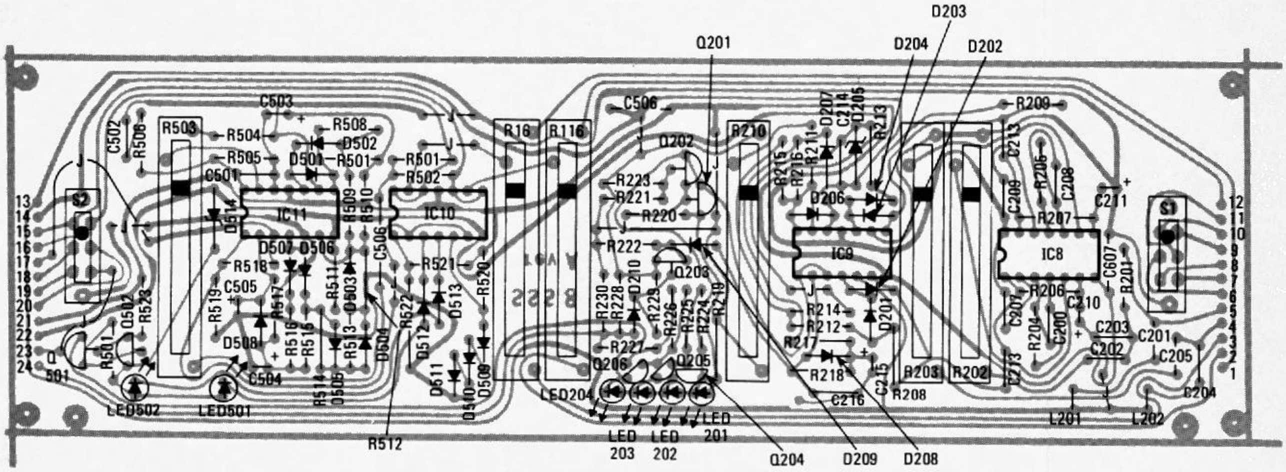


FIG. 16—PARTS PLACEMENT guide for the front PC board. The use of IC sockets is recommended.

Parts-placement diagrams for the front and rear boards are shown in Figs. 16 and 17. Use those, together with Fig. 18, to help you in stuffing the boards.

The use of IC sockets is recom-

Hole 1 on the rear board is connected to hole 1 on the front board, hole 2 to hole 2, etc.

Be particularly careful when installing IC3 and IC6—they're static-sensitive. Keep them in their protective foam or

Operation

It takes some effort to learn how to set up and use the ASRU properly at first. Things become easier with practice, though. The LED's give you an idea of what's happening in the system, and the controls are not very critical (because of the spectral-tracking loop

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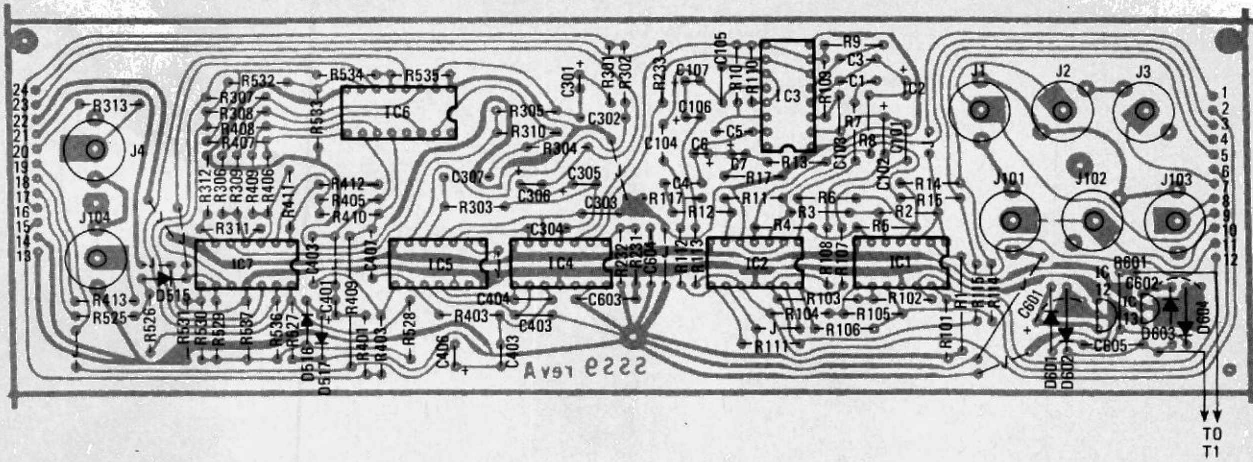


FIG. 17—PARTS PLACEMENT guide for the rear PC board. Capacitors C601 and 602 are mounted on the *foil* side of the board.

noise filter and shallow-slope expander) once they are set for your system.

The noise-filter sensitivity should be adjusted so that there is an adequate change in bandwidth during musical transients. That is the most difficult part; you should experiment by watching the display and listening carefully with the NOISE REDUCTION control at its maximum setting and the THRESHOLD control at its minimum setting. If you set the sensitivity too high, you will hear noise come and go during "unspectacular" musical passages—a sign that the ASRU is working too hard.

If the sensitivity is set too low, you'll hear normal signals being rolled off too much. Don't be fooled by the *apparent* lack of treble—it's there, but people who habitually listen to recorded music often feel it's reduced when listening to a system with noise reduction.

It's possible to set the sensitivity of

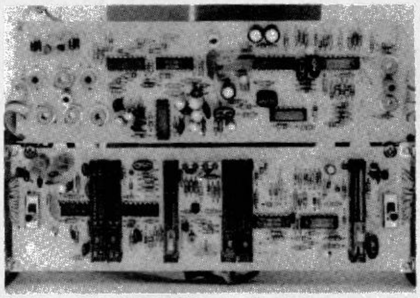


FIG. 18—COMPONENT SIDE of the front and rear PC boards. The two boards are connected by 12-conductor ribbon cable.

the unit high enough to make the noise in the signal cause the bandwidth to open up too easily. If that happens, advance the THRESHOLD control until, during a silent passage, the lowest LED of the display flickers occasionally.

The NOISE REDUCTION control setting is largely a matter of personal taste. Start with it turned about three-quarters of the way up, and listen carefully when the bandwidth is reduced.

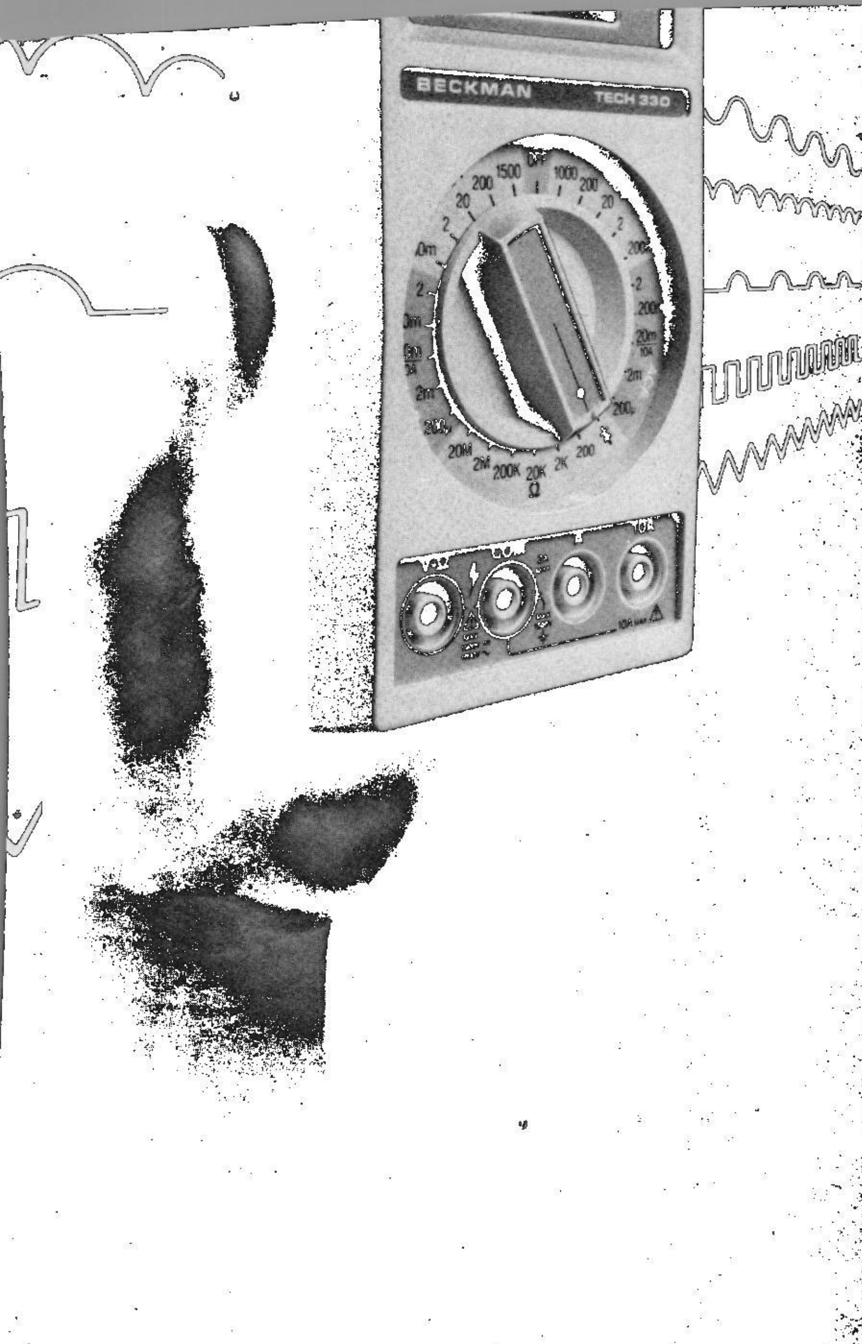
The expander's SENSITIVITY control should be set so that the right-hand (highest) LED flickers during peaks.

After everything has been adjusted, you may still have to reset the expander's sensitivity from time to time for use with different sources (e.g., if the tuner's output level is higher than the phono's). The THRESHOLD setting may also have to be changed, depending on the amount of noise in your program material. For very noisy material, reduce the noise-filter sensitivity and increase the noise reduction to maximum.

You now have a top-notch signal processor that will greatly enhance your listening pleasure. Use it well!

Acknowledgement

The concept of the spectral-tracking loop for noise reduction was invented by Fred Ives of Hewlett-Packard Company while at MIT. Pat Bosshart of MIT also worked on the concept and introduced it to me. **R-E**



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Measurement Comparison Chart			
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Full Wave Rectified Sine Wave	0.298V	0.707V	0.707V
Half Wave Rectified Sine Wave	0.382V	0.500V	0.500V
Square Wave	1.110V	1.000V	1.000V
Triangular Sawtooth Wave	0.545V	0.577V	0.577V

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