

A Simplified Audio Amplifier

R. G. CHAPLICK*

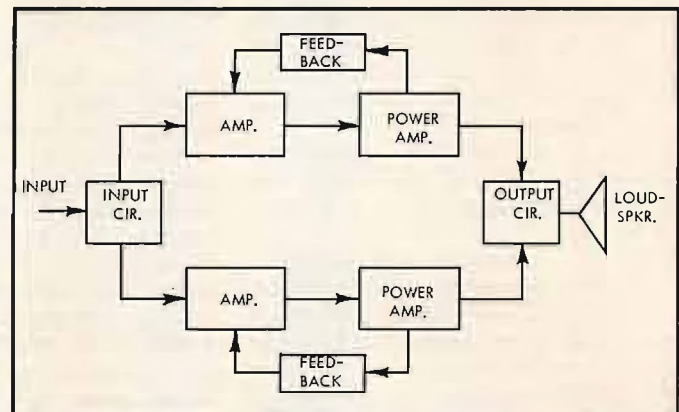
For the home constructor who wants reliability and permanence of performance, this return to time-tested engineering principles will be thoroughly appreciated. In addition to a simple and clearly presented design, the author throws in some excellent tips useful in everyday audio work.

RECENT DESCRIPTIONS and photographs in audio magazines indicate that there is a marked lack of simplicity in home audio systems. Operation of some systems can only be compared to the complexity of a guided missile count-down. The advantages of system simplicity were previously presented by the author,¹ and the application of simplicity to an amplifier unit will be discussed herein. The main benefit of simplification is improved reliability instead of the built-in obsolescence characteristic of present day American products—what one buys becomes obsolete between the store and home. A simplified amplifier having year-in, year-out dependability can be installed and forgotten.

Because countless amplifier circuits, ranging from small ten-watt units to the 100-watt laboratory units which are now popular, are available, readers undoubtedly will question the need for still another circuit. Unfortunately, designers of high fidelity amplifiers have not retained design features of professional broadcast equipment. These features, which help to improve reliability, have changed very little in the past decade. For example, broadcast amplifiers are of fixed design and do not need adjustment whereas nearly all high fidelity amplifiers require at least one adjustment for proper tube operation and a few require elaborate test equipment for this purpose. Many of the power supplies are over-elaborated beyond actual needs. Finally, the over-all gain of many preamplifier-amplifier combinations is too high. Current practice is to buy and to assemble a train of amplifiers with 30 to 50 db too much gain. Gain setting is then confined to the first 20 deg. of a rotary control, and the remaining 300 deg. is wasted. (This situation is somewhat analogous to those automobile engines which have 300 horsepower although only 100 are really needed.) Questions asked in audio magazines verify that too many people have the misconception that only the first 20 deg. should be used. Listeners should not be alarmed by the necessity for full rotation of the gain control.

* 10001 McKenney Avenue, Silver Spring, Md.

Fig. 1. Simplified block schematic of amplifier.



The reliability of an amplifier is improved by several methods. (1) Individual parts which have a known high reliability are used exclusively. (2) Reliability is inversely proportional to the number of parts. Therefore, by a simple decrease in the total number of parts the reliability can be increased. Although distortion is also inversely proportional to the number of parts, reduction of distortion will not be as startling as the improvement of reliability. (3) Design unity is built-in. That is, each chassis is complete in itself and is not dependent for power on any other chassis.

Critical Points

High fidelity enthusiasts probably will feel helpless with an amplifier without adjustments. However, a few disadvantages of adjustments are as follows. First, sliding contacts are notoriously unreliable, and elimination of them improves reliability. Second, assume that an amplifier has a potentiometer in the cathode circuit of the output tubes to balance the plate currents and to prevent saturation of the transformer core. How often is it balanced? Third, is this balance really critical? An extremely low percentage of distortion can be achieved by precise adjustment. Conversely, misadjustment of the same control results in high distortion. Moreover, a home amplifier is not a laboratory instrument and should not require readjustment or recalibration each time the power is turned on. Since small degrees of distortion can scarcely be heard

and large degrees are intolerable, a fixed, dependable, middle ground is preferred. Furthermore, the output transformer recommended herein has a permissible d.c. primary unbalance of 15 percent. In this manner audible distortion results chiefly from aging tubes which can be replaced.

An amplifier intended to reproduce music should reproduce the music as naturally as possible. Maximum naturalness depends upon a number of factors. The speaker system and the listening room acoustics have great influence, but a discussion of these items is out of place in this article. Noise in both the amplifier and the listening room should be at a minimum. Obviously, a noisy room is not the proper place in which to listen to music, but the amplifier should be designed to have low noise in order to produce a high signal-to-noise ratio.

In addition, the dynamic range of the amplifier also should be high. That is, the amplifier should have enough power to reproduce any sudden high amplitude signal without clipping. Unfortunately, it is not always possible to predict whether the signal source will overdrive the amplifier. An ample reserve of power can be maintained easily by designing the system to drive the amplifier to half of its maximum power output with the average peak output signal from the preamplifier or control unit. Some automobile buffs may retaliate and say that half the power output is being thrown away. Such is not the case because a Hearing Contour Com-

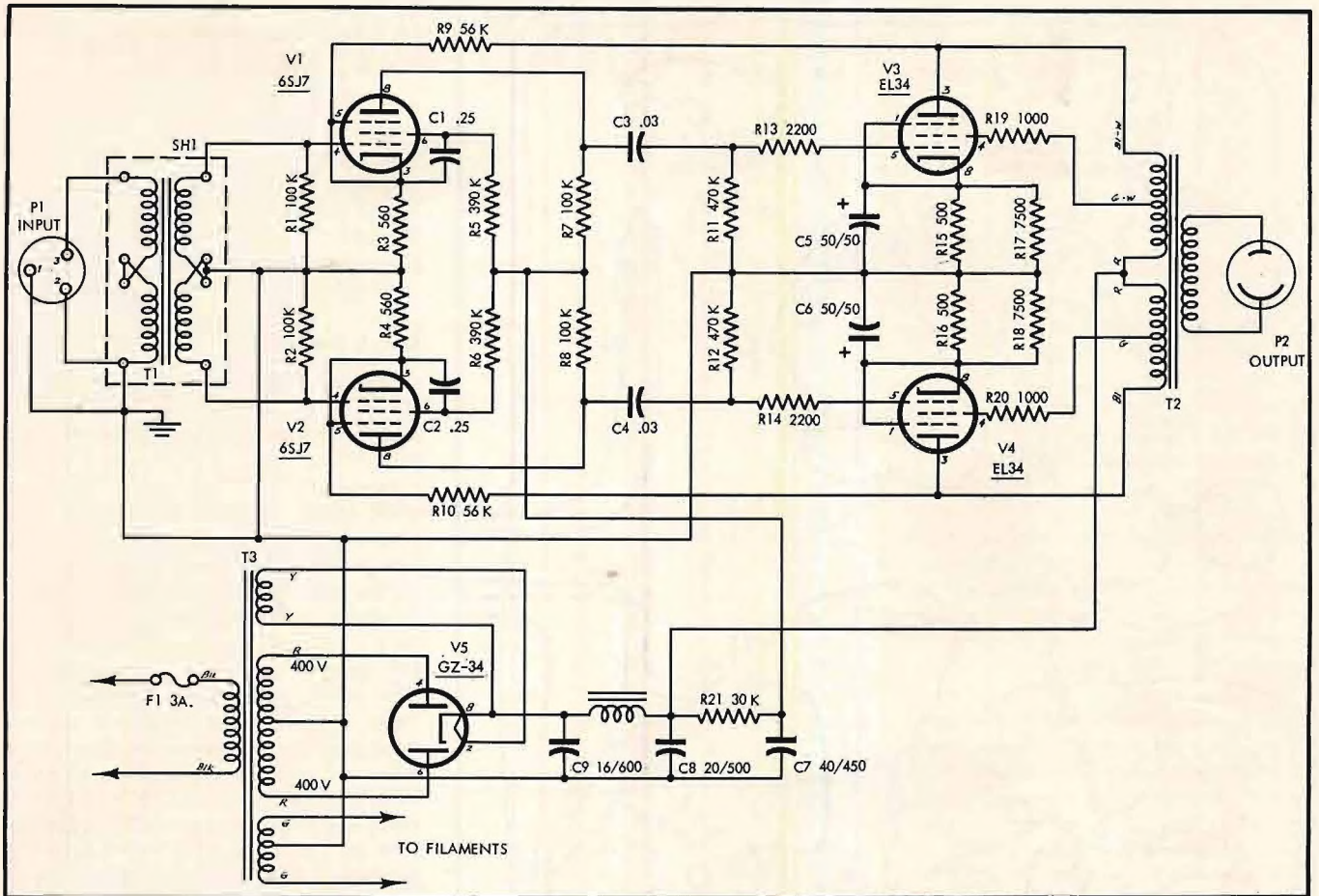


Fig. 2. Over-all schematic of the author's amplifier, which follows professional practice in design.

pensator in the control unit utilizes full output at low frequencies.

A properly designed amplifier does not require an elaborate and expensive power supply. A separate power supply to produce direct current for tube filaments is unnecessary in high-level circuits. Nor do filaments have to be biased above "ground" in such circuits.

Before a reader starts building an amplifier he should determine the needed

sensitivity. For example, the Mullard 520 amplifier² requires only 0.3 volts rms input to be driven to full output. On the other hand, one kit-type pre-amplifier has "Output to main amplifier, 0 to at least 2.5 volts rms from any normal program source." If this pre-amplifier-amplifier combination is used, a slight turn of the volume control can easily overdrive the amplifier. Obviously, more attention should be paid to the

input sensitivity.

Specifications for a simplified amplifier are now easy to make:

1. The amplifier should be flat from 20 to 20,000 cps.
2. Distortion should be at a minimum.
3. The signal-to-noise ratio should be high.
4. The input sensitivity should be matched to the preamplifier output.
5. There should be no adjustments.
6. No high-voltage leads should be out-

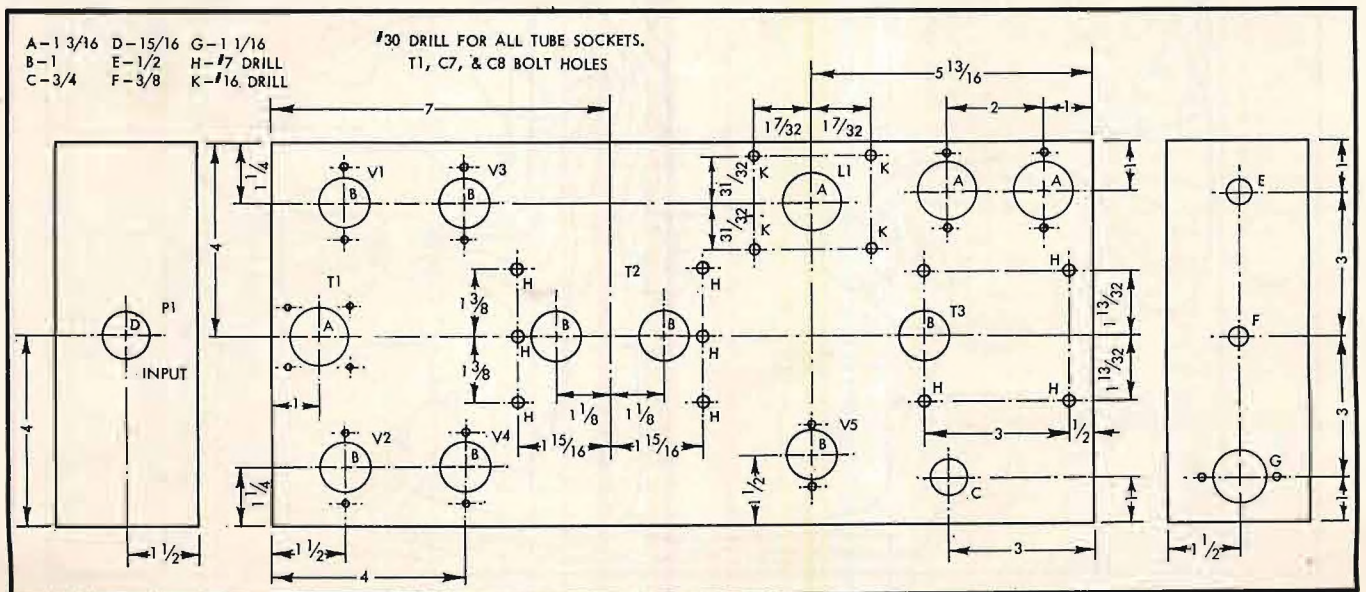


Fig. 3. Dimensional chassis layout for the amplifier.

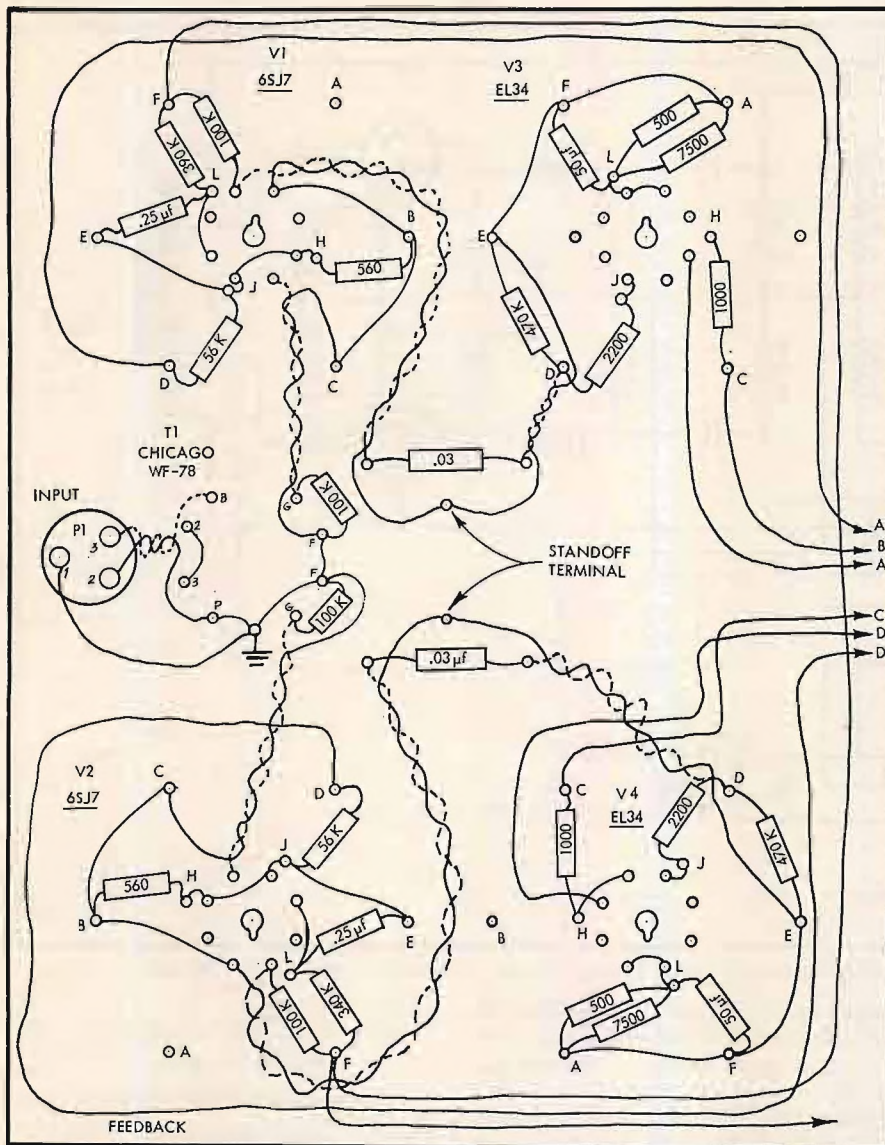


Fig. 4. Wiring diagram for Vector sockets used in both amplifier stages.

side the chassis. With proper part orientation the amplifier and its power supply can be on a single chassis.

7. For home use the peak power output should be about 30 watts.

Discussions of these specifications with an audio consultant lead to the amplifier block diagram shown in Fig. 1, and the complete schematic in Fig. 2. Essentially, the amplifier consists of three main circuits: output, input, and feedback.

Circuit Description

Output Circuit. The output circuit of the Mullard 520 amplifier² is used to take advantage of the high power output.

Input Circuit. The input circuit consists of the necessary amplifier and phase-splitter stages to drive the output circuit. Much has been written recently on the subject of phase splitting. Unfortunately for the high fidelity field, a very simple device, an input transformer, has been avoided for phase splitting. The input transformer probably has fallen into disrepute because it will not pass a perfect square wave. The author does not listen to square waves, since other methods of testing steady and transient response are available and the lack of square corners is of little importance. High-quality musical reproduction is the primary object of this amplifier.

After reading about phase splitters the author finds no scientific and only two non-technical disadvantages of input transformers. The disadvantages cited most often are cost and space required. The Chicago Standard transformer

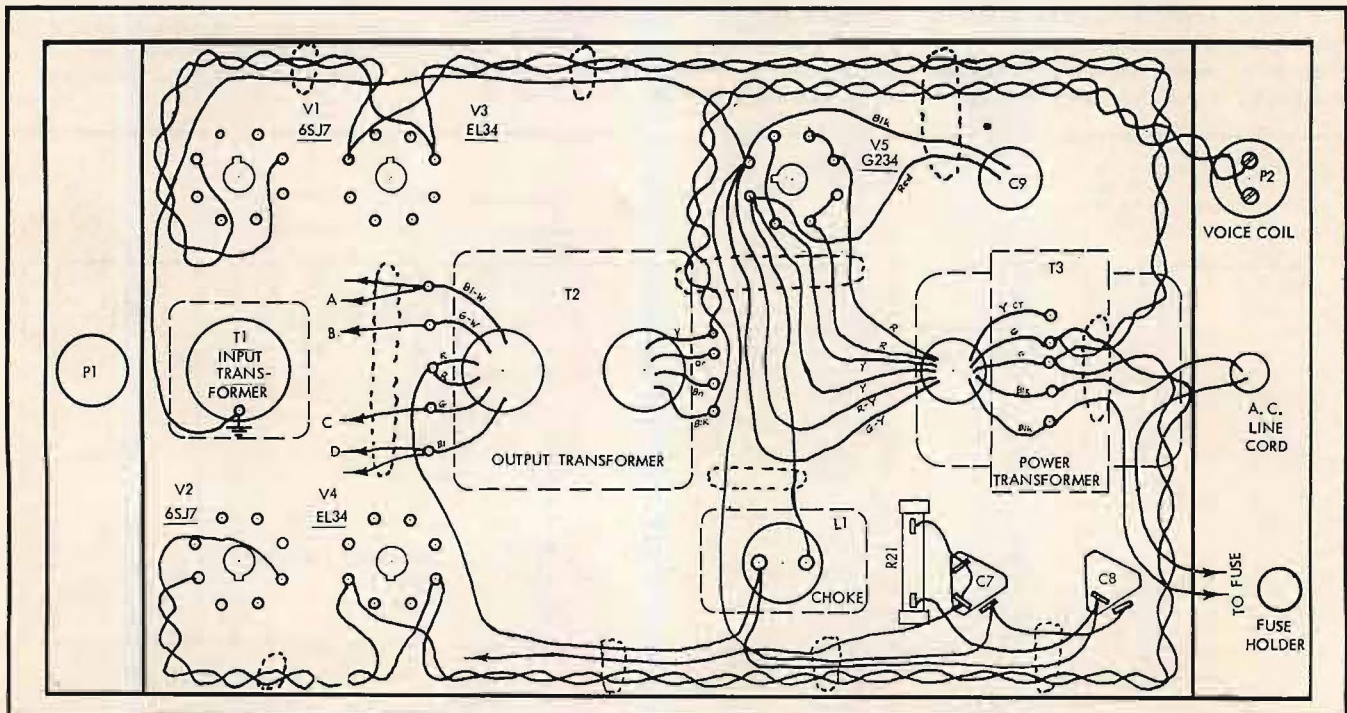


Fig. 5. Wiring diagram for interconnection of main chassis parts with amplifier sockets.

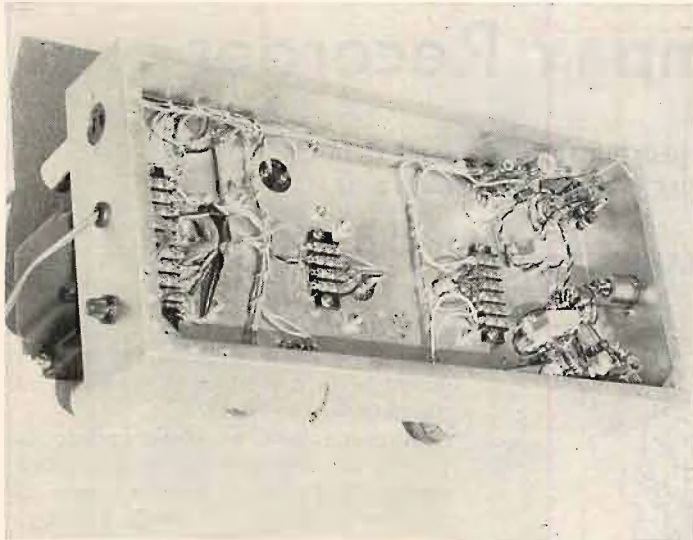


Fig. 6. Underside view of complete amplifier chassis.

(WF-28) suggested herein has base dimensions of $1\frac{1}{2} \times 1\frac{1}{2}$ inches. This area is no greater than that required for a 6SN7 or even a 12AU7. Therefore this argument is no longer valid. High-quality transformers are expensive (WF-28 is \$10.70), and manufacturers of amplifiers can use this as an excuse for not employing the transformer. Now consider the phase splitter in a Williamson-type amplifier. If low-noise resistors are used, the cost of the stage is six to seven dollars. On the other hand, if the builder adds six more dollars for the transformer and its shield he makes substantial gains in performance. Furthermore, in an audio system whose over-all cost can approach eight hundred dollars the sacrifice of quality for a few dollars is hardly justifiable.

The input transformer enables this amplifier to be separated a very long distance from the preamplifier or control unit without being subject to switching transients or r.f. pickup. The transformer has a higher inherent stability than a tube phase splitter, and it is balanced at all frequencies. In a tube phase splitter the resistance-capacitance characteristics of the plate and the cathode circuits are not equal at all frequencies. Therefore, compensation is necessary to overcome this deficiency. The main advantage of a precise center-tapped input transformer is that it provides a fixed, balanced, input amplifier, and controls or adjustments for this purpose are unnecessary.

Feedback. Three types of feedback are employed, and in order of importance they are:

- (A) Primary voltage feedback from the plates of V_3 and V_4 to the cathodes of V_1 and V_2 .
- (B) Feedback in the output stage itself via the screen grids of V_3 and V_4 .
- (C) Subsidiary current feedback caused by the unbypassed cathode resistors of V_1 and V_2 .

Feedback (B) is adequately described in reference (2). Hence, no explanation is needed in this article.

Feedback (A) and (C) comprise a form of Duerdoth's multiple feedback, and the two feedback voltages must be added together to determine the performance.



Fig. 7. Arrangement of Vector sockets for amplifier stages.

The performance, however, will be determined primarily by (A). The subsidiary feedback increases the stability by reducing the slope of the βA characteristic over a wide range of very low and very high frequencies. Readers

should consult reference (3) for a more detailed and technical explanation of this feedback.

Transient response is improved with this type of feedback. Most amplifiers have feedback from the secondary of the output transformer to the cathode circuit of the input tube. The leakage reactance of the output transformer will create phase shift and delay. Thus, the transformer holds up the feedback information, and the transient response is not as good as it could be. The feedback circuit contains no reactive elements and results in low phase shift and feedback delay and improved transient response. For a general discussion of transient response, reference (4) is recommended.

Construction

Figure 3 shows the dimensions for drilling and punching almost all the holes in the chassis. Some holes, e.g. tube socket screw holes, are best located with the socket itself and are therefore omitted. An aluminum chassis must not be used because it is inadequate to support the weight of the transformers. A steel chassis is stronger, provides electromagnetic shielding, and is worked almost as easily as an aluminum one. Pilot holes for chassis punches are made with the following technique. An "egg-beater" hand drill is used with a succession of small drills to obtain a $3/16$ " diameter hole. Then a $1/4$ " and a $3/8$ " diameter drill are clamped in a carpenter's brace and used in succession to produce the pilot hole for the punch. When all holes are drilled, punched, and deburred, the chassis and the bottom plate are washed thoroughly with a detergent to remove all grease and oil. After they are rinsed and dried, the chassis and bottom plate are sprayed with clear plastic.



Fig. 8. Top view of completed amplifier.

Anyone who desires to duplicate this amplifier is urged not to substitute parts. Each part is chosen with respect to size, tolerance, and proved reliability. Before being soldered into the circuit, each resistor and capacitor should be checked with an ohmmeter to ascertain that the part is "good." Inspection of parts before assembly provides reliability by eliminating the butchery that results from parts replacement. Low-noise resistors can be used if desired but are not necessary since the circuits are designed to function at an extremely low noise level with ordinary resistors. The Mullard 520 output circuit specifies a 470-ohm, 5-watt resistor in the cathode circuit of each EL-34. Unfortunately, such a resistor is not commercially available. This value is obtained by paralleling a 500-ohm, 5-watt resistor with a 7500-ohm, 1/2-watt resistor.

Wiring

Figures 4 and 5 show the method for wiring the amplifier. These diagrams should be studied carefully before any actual wiring is done. Note that in Fig. 4 the parts are shown as though the Vector turrets were exploded. The letters *A* to *L* refer to the letters on the turret. Assembly on the turret sockets is made before installation in the chassis. Hold the resistors and capacitors on the turret to ascertain that the parts fit properly. On V_1 and V_2 turrets the resistors are mounted first and against the turret body. C_2 and C_3 can then be mounted. On V_3 and V_4 the 500-ohm resistors are mounted away from the other parts because of the heat generated. R_{11} and R_{12} can be mounted across the end of the turret. Figure 7 is a close-up photograph showing the turret assemblies. The resistor and capacitor leads do not have to be wrapped around the terminals since good solder (60% tin, 40% lead) has adequate strength to support these parts. When the soldering is being done, use alligator clips to conduct heat away from the parts. The use of a high wattage soldering gun is forbidden. For most audio purposes a 35-watt soldering tool is adequate and is faster than the gun. The Wall 18 soldering tool with a production-type tip is highly recommended.

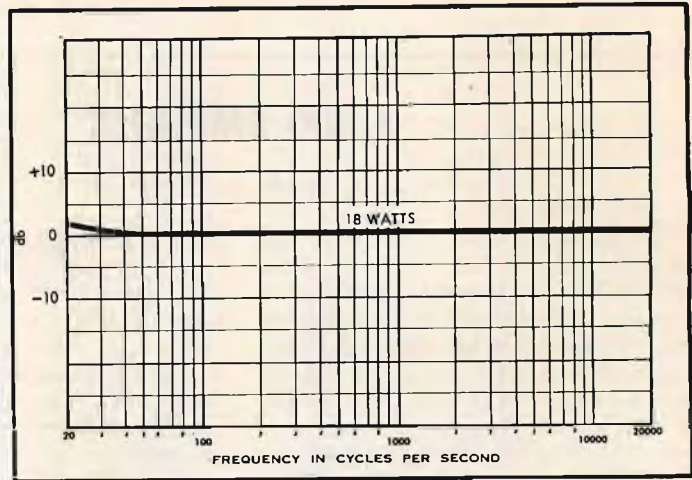
After the turret assemblies are complete, mount them on the top of the chassis. This top-of-the-chassis technique, which provides ample working room, offers the greatest accessibility and ease of wiring. The "U" nuts make the turrets very easy to mount. Wire the

turret sockets completely as shown in Fig. 4 with the recommended hookup wire. Use twisted pairs of color-coded wires and solder them at the turret terminals only. The color code facilitates tracing and locating the end of a particular wire. Do not twist a pair of wires by grabbing one end and twisting the other. Cut two pieces of wire to the proper length and clamp one end of each together in a vise. Then twist each wire clockwise with the fingers. Simultaneously move the wrists about each other counterclockwise. The twisted pair will be neat, tight, and symmetrical. The wires should be long enough so that, after groups of wires have been laced, there will be no strain on the soldered joint.

When the wiring of the turrets is finished, inspect all soldered joints before removing the turrets from the top of the chassis and remounting them inside. Now install the transformers, capacitors, and other hardware. Use 10-32 machine screws to fasten the transformers to the chassis. Mount the output transformer as shown in Fig. 5. Minimum hum will be induced by the power transformer if it is properly oriented. Mount capacitors C_7 and C_8 by means of the phenolic wafers in order to insulate the cans from the chassis.

Three barrier terminal strips are needed. The Cinch-Jones type 240 is recommended but seems to be unavailable from usual sources. The type 140 "W-140" solder terminals is the best substitute. One strip is needed under the power transformer, and the number of terminals will be determined by the number and length of the power transformer leads. If the proper leads are long enough to reach the socket of V_5 as shown in Fig. 5, then only a five-terminal strip is needed for the 6.3-volt winding, the primary leads, and a convenient point for getting the center tap of the 5-volt winding out of the way. Before being soldered, these center-tap leads should be well scraped and tinned. If the transformer leads are too short to reach the rectifier tube socket then enough terminals to accommodate these leads will be needed. A four-terminal strip is required for the output leads of the T_2 . Cut the leads and solder them to the terminals. The output impedance is easily changed by moving one wire to the proper terminal. If the primary leads of T_2 are long enough, the plate and screen leads can be soldered directly to the turrets. In this case only one chassis terminal for the high-voltage center tap is needed. If the primary

Fig. 9. Frequency response of amplifier at half-power output.



leads have been cut too short, then a five-terminal strip is necessary. *Figures 6 and 7* show how terminal strips are used in the prototype amplifier.

Capacitors C_3 and C_4 are mounted vertically by means of small angles made of thin sheet metal. Standoff terminals are employed as junction points for the "ground" lead. *Figure 7* shows this arrangement. The wiring can be completed at this point. Observe the wiring of the chassis input connector. The highest numbered terminal (3) is the signal-carrying lead.

The next lowest number (2) is the signal-return lead. The lowest number (1) is the shield which is not connected to the chassis of the preamplifier. Readers will find the assembly of the input connector (Cannon XL-3-12) to the Belden 8412 cable a distinct pleasure in comparison to the standard phono connector. One suggestion is necessary. After $\frac{3}{4}$ " of the outer covering has been removed, unravel the shield and twist it into a single lead. When twisting, however, orient the lead so that the three leads will fit into the soldering pots without one lead having to be twisted around another. This symmetry will become obvious.

Note the wiring of the rectifier tube socket. Should the recommended rectifier tube (GZ-34) fail, any 5-volt rectifier tube with an octal base can be used temporarily. Lace the wires of the output and power transformers so the wires with a high potential will not be too

close to the chassis. The twisted pairs of wires carrying the signals should be short but not so short that the wires will be strained.

Each soldered joint should be examined carefully. Check the filament and plate circuits for "shorts" to the chassis. If the amplifier passes a mechanical and electrical inspection, the wires can be laced as shown in *Figs. 5, 6, and 7*, thus completing the amplifier. *Figure 8* is a photograph of the external arrangement.

Performance

The performance of the finished amplifier is very satisfactory. *Figure 9* shows the frequency response at 18 watts output (average peak output). Maximum output is 36 watts allowing a margin of 3 db. The gains without and with feedback are 65.4 and 44 db respectively. Thus 21.4 db of feedback is applied. The measured internal generator impedance is 4.4 ohms which with a 16-ohm load provides a damping factor as 3.64. Background noise is nearly unmeasurable: 63.7 db below the average peak output of 18 watts. (Neither harmonic and intermodulation distortion nor the square-wave response has been measured for lack of test equipment.) The input sensitivity is 2.2 volts rms for 18 watts output.

This amplifier is installed in an audio system consisting of an ESL Concert cartridge, a Heath WA-P2 preamplifier, a JBL D130 low-frequency speaker,

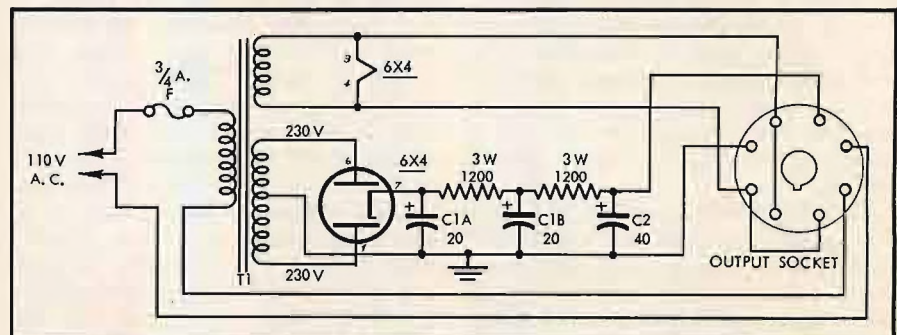


Fig. 10. Schematic of power supply for Heath WA-P2 preamplifier.

an Electro-Voice T-35 high-frequency speaker, and a JBL C34 enclosure. The results of musical production are very gratifying. The sound can only be described as extremely clean and natural. Certain passages of music masked by the previous amplifier are now revealed for the first time. These improvements more than compensate for the expense of construction. Readers who want a reliable, long-life, wide-range amplifier are urged to duplicate this unit.

Warning. The rectifier and output tubes produce an amazing amount of heat. This amplifier should not be placed in a small enclosed space unless adequate ventilation is provided. If possible, ventilation openings should be made to provide a "chimney" type of air circulation over the amplifier.

Appendix 1—POWER SUPPLY FOR PRE-AMPLIFIER

This amplifier is intended for use with the Heath WA-P2 preamplifier. In accordance with the arguments for simplicity, unity, and unit independence the construction of a separate power supply for

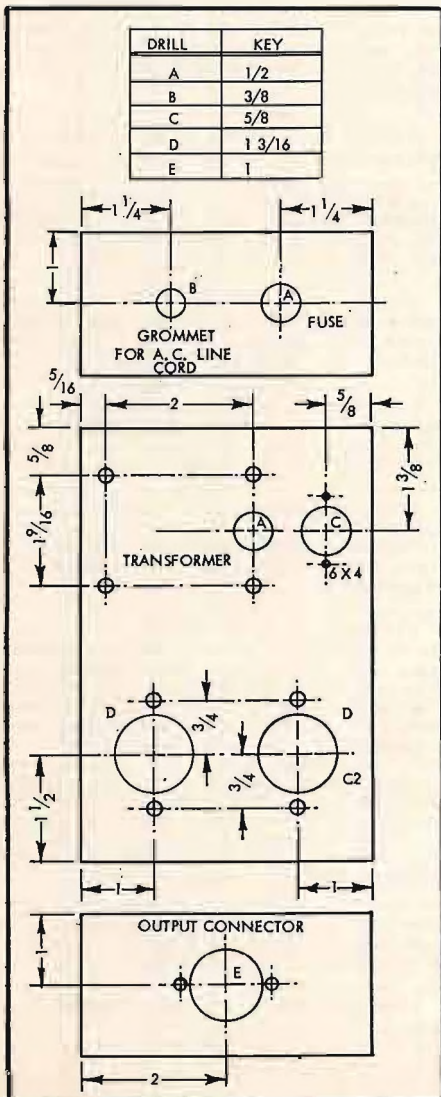


Fig. 11. Chassis layout for preamplifier power supply.

the preamplifier is necessary. The circuit for this unit is shown in Fig. 10, and the chassis layout is given in Fig. 11. The circuit being conventional, no discussion is needed. The center tap of the 6.3-volt winding is not grounded because of the hum balance potentiometer in the preamplifier. If the center tap consists of two wires, the ends must be scraped, soldered together, and covered with insulating tape. Otherwise, the 6.3-volt winding will be open.

REFERENCES

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- 2 E. J. Porto, "High fidelity performance with Mullard's 520 circuit." *Radio and Television News*, April, 1956.
- 3 F. Langford-Smith, "Radiotron Designers Handbook." Fourth Edition.
- 4 G. F. Cooper, "Transients in feedback amplifiers." *AUDIO*, March, 1958.

AMPLIFIER PARTS LIST

- C_1, C_2 0.25 μf , 600 volts, paper
- C_3, C_4 .03 μf , 600 volts, mica (Sangamo Type A)
- C_5, C_6 50 μf , 50 volts, electrolytic
- C_7 20-20 μf , 450 volts, electrolytic
- C_8 20 μf , 500 volts, electrolytic
- C_9 16 μf , 600 volts, electrolytic
- J_1 Input connector, Cannon XL-3-12
- J_2 Output connector, Hubbell 7468
- L_1 Filter choke, 7 Hy, 200 ma, 140 ohms (Kenyon T-152)
- P_1 Input chassis plug, Cannon XL-3-13
- P_2 Output chassis plug, Hubbell 7468
- R_1, R_2 100 k ohms, 1/2 watt, 5%
- R_3, R_4 560 ohms, 1/2 watt, 5%
- R_5, R_6 390 k ohms, 1 watt, 5%
- R_7, R_8 100 k ohms, 1 watt, 5%
- R_9, R_{10} 56 k ohms, 2 watts, 5%
- R_{11}, R_{12} 470 k ohms, 1/2 watt, 10%
- R_{13}, R_{14} 2200 ohms, 1/2 watt, 10%
- R_{15}, R_{16} 500 ohms, 10 watts, 10% (Ohmite "Brown Devil")
- R_{17}, R_{18} 7500 ohms, 1/2 watt, 5%
- R_{19}, R_{20} 1000 ohms, 1/2 watt, 10%
- R_{21} 30 k ohms, 10 watts, 5% (Ohmite "Brown Devil")
- SH_1 Transformer shield (UTC A-33)
- T_1 Interstage transformer (Chicago WF-28)
- T_2 Output transformer (Acrosound TO-300)
- T_3 Power transformer (Stancor PC-8412)
- V_1, V_2 6SJ7
- V_3, V_4 EL34/6CA5
- V_5 GZ 34

Miscellaneous

- 4 Turret sockets (Vector 10-O-9T)
- 1 Octal socket (Amphenol 168-015)
- 1 Fuseholder (Littelfuse 342008)
- 1 3-amp. fuse (Littelfuse 3AG)
- 1 Power cord (Belden 1749K)
- 1 8 x 17 x 3 steel chassis
- 1 8 x 17 bottom plate
- 1 Grommet for 3/8-in. hole
- 8 U-nuts (Vector 440-U)
- 3 Barrier-type terminal strips (see text)

PREAMP POWER SUPPLY PARTS LIST

- C_1, C_2 20-20 μf , 450 volts, electrolytic
- R_1, R_2 1200 ohms, 3 watts, wire-wound
- T_1 Power transformer (Stancor PC-8418)

Miscellaneous

- 1 Fuseholder (Littelfuse 342008)
- 1 ¼-amp fuse (Littelfuse 3AG)
- 1 6X4 tube
- 1 Miniature socket (Amphenol 147-925)
- 1 Octal socket (Amphenol 168-015)
- 1 4 × 6 × 2 chassis
- 1 4 × 6 bottom plate
- 1 Line cord (Belden 1749K) **Æ**