

Build this super-deluxe 36 watter and say good-bye to power-amplifier troubles for years and years and years . . .

Perfectionist's Power Amplifier

by BEN ZALE

THERE is nothing quite like the quality of excitement generated by a new power amplifier. Others may talk of preamplifiers, speakers, enclosures, or what-have-you. But start discussing a new and improved power-amplifier circuit, and the ears of the true audiophile prick up, a fever flashes like lightning through his mind, and he is on his way to the parts distributor for the necessary components.

I experienced the same reaction recently when I came across a booklet¹ in which the Mullard 520 power-amplifier circuit is described. The specs of the new circuit were extremely impressive: 36

watts power output from 30 to 20,000 cps; frequency response within 1 db from 20 to 20,000 cps at 36 watts; 1M distortion, using 40 and 10,000 cps in a 4:1 ratio, a low 0.8% at 36 watts; hum and noise 89 db below 36 watts; and a damping factor of 50.

For me, however, the most exciting specification of all was the sensitivity: only 0.3-volt input for a full 36-watt power output! This extremely high sensitivity meant that the power amplifier, in normal use, would be driven at a tiny fraction of a volt. The reduction in the amount of drive signal needed for the power amplifier would enable me to use

my preamplifier at much lower operating levels, where distortion would be significantly diminished.

Aside from its excellent specifications, the circuit itself seemed simple and inviting from every point of view. It consists of a low-noise, high- μ pentode as a voltage amplifier feeding a dual-triode phase-inverter driver, which in turn drives two of the new EL34 power pentodes in an Ultra-Linear configuration.² Fig. 1 shows the completed amplifier, and Fig. 2 the under-chassis view.

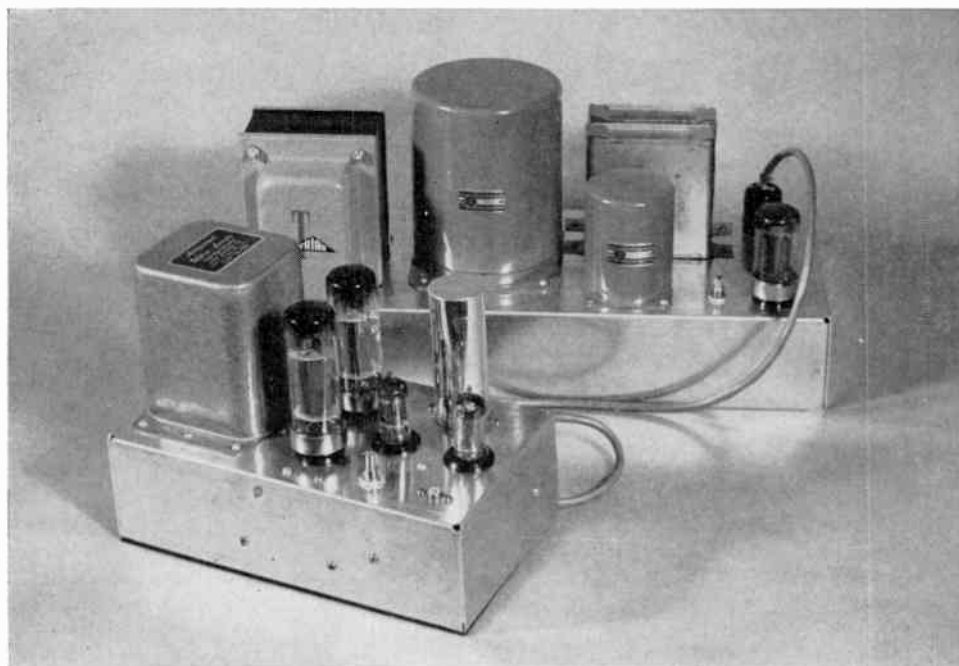
I had already used the internally shielded EF86 miniature-pentode voltage amplifier in my preamplifier circuit, and found it to be extremely low in noise and lacking in microphonics. Its high gain, combined with the low noise figure, made it an excellent choice for the voltage amplifier in the Mullard 520 circuit.

The cathode-coupled phase inverter (or long-tailed pair, as it is also called) made use of the ECC83, a dual triode corresponding to the 12AX7 but with guaranteed low noise and microphonics. The virtue of this phase inverter is its extreme simplicity of construction combined with its fine balancing qualities in supplying push-pull signals to the output tubes.³

EL34 (or 6CA7) power pentodes, now appearing in many new commercially manufactured amplifiers, are small and sturdy and are capable of delivering up to 100 watts in push-pull with 800 volts on the plates. This indicated operation well within maximum ratings in an Ultra-Linear circuit with only 440 volts on the plates and a 36-watt power output. It also suggested very low distortion.

The power supply (Fig. 3) was simple and straightforward as could be, consisting of a 200-ma transformer operating into a capacitor-input filter system, from which emerged 440 volts for the plates of the EL34 output tubes. Two decoupling stages followed, supplying power for the EF86 and ECC83 tubes. In essence, the same power supply as that in my UTC Williamson-type amplifier could have been used. Since the EL34's required about 40 ma more cur-

Fig. 1. This is the perfectionist's dream come true—our model of the power amplifier described by Mr. Zale, built solely from data contained in the article.



¹W. A. Ferguson, "Design for a 20-Watt High Quality Amplifier," *High Quality Sound Reproduction* (booklet of articles reprinted from *Wireless World*), Mullard Ltd., London, England. Available in the USA from International Electronics Corp., New York, N.Y. Also see: E. J. Porto, "High Fidelity Performance with Mullard's 520 Circuit," *Radio & Television News*, LV (Apr. 1956), pp. 66-68, 139.

²Herbert I. Keroes, *Theory and Operation of the Ultra-Linear Circuit*, monograph available from Keroes Enterprises, Philadelphia, Pa.

³Joseph Marshall, "The Grounded Ear," *AUDIOCRAFT*, I (Nov. 1955), p. 10. See also: Norman H. Crowhurst, "Designing Your Own Amplifier," *AUDIOCRAFT*, I (May 1956), pp. 21-23, 40-41.

are 5-watt units with 450-ohm ratings. But 5-watt wire-wound adjustable resistors of 500 ohms can be used to provide the exact 470-ohm value needed. The adjustment is made with an ohmmeter, thus providing a 1% tolerance range for all resistors in the circuit.

Coupling capacitors between the phase inverter and the power output tubes, in a push-pull circuit, should be matched if best results at the low end are to be obtained.⁵ Two of the proper value were selected, using a capacitance bridge, for use in the circuit. The other capacitors in the circuit included two ceramic types, two molded-paper types and a number of electrolytics. Instead of the 8- μ fd electrolytics called for in the parts list for decoupling, two 40- μ fd units were chosen, because use of the larger units helps to increase the margin of stability of a feedback amplifier.⁶ The filters used on either side of the filter choke are oil-filled units rated for a lifetime of use. The oil-filled input capacitor is to be preferred for a smoother ripple and the ability to withstand high peak starting voltages when the amplifier is switched on. Swift surges of starting current often wreak havoc with ordinary electrolytics when power supplies are operated at high voltages.

Finally, I came to the most important component consideration in the entire amplifier: my choice of output transformer. Here, the author of the article describing the Mullard 520 circuit was quite explicit on the need of a first-class unit: "The use of distributed load conditions does not modify the essential features of a first-class component — on the contrary, the output transformer may be a more critical component, since precise balance of primary windings must be maintained."⁷ Williamson also sees this

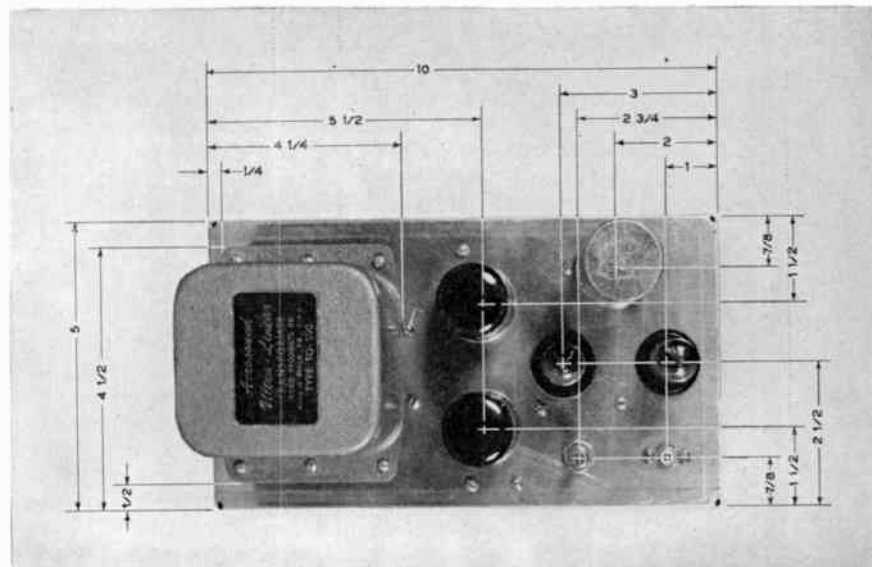


Fig. 5. Mounting guide for amplifier chassis; dimensions are expressed in inches.

component as a source of potential difficulty: "The constructor with limited facilities cannot be too strongly advised to keep to proved circuits which are inherently trouble-free. In particular, he should keep to designs requiring the minimum number of coupled circuits in the output transformer, since the possibility of pitfalls is greatest in this component and increases rapidly with the number of windings when all these must be closely coupled."⁸

It seemed quite clear at this point that only a reputable output transformer of the highest quality should be considered if the performance detailed in the specifications were to be obtained. The Acrosound TO-300 output transformer was chosen because the Mullard 520 is a tapped-screen circuit, and it seemed quite logical to suppose that the company responsible for the Ultra-Linear circuit and Ultra-Linear output transformer would produce an ideal component for this type of service. The unit itself is compact, makes use of grain-oriented

steel, and features a guarantee that AC primary balance is 1% or better.

Parts List

Resistors

- 2 1-megohm, 1/2-watt
- 1 4,700-ohm, 1/2-watt
- 3 2,200-ohm, 1/2-watt
- 1 100-ohm, 1/2-watt
- 1 100,000-ohm, 1/2-watt
- 1 390,000-ohm, 1/2-watt
- 1 82,000-ohm, 1/2-watt
- 1 270,000-ohm, 1/2-watt
- 2 180,000-ohm, 1/2-watt (matched)
- 2 470,000-ohm, 1/2-watt (matched)
- 2 470-ohm. Use 500-ohm 5-watt adjustable wire-wounds (see text)
- 1 680-ohm, 1/2-watt
- 1 7,500-ohm, 1/2-watt (critical value)
- 2 100,000-ohm, 1-watt
- 1 10,000-ohm, 1-watt
- 1 100-ohm wire-wound potentiometer
- 1 18,000-ohm, 1/2-watt

Capacitors

- 1 .05- μ fd, 400-volt
- 1 50- μ fd, 12-volt electrolytic
- 1 0.25- μ fd, 400-volt
- 2 40- μ fd, 500-volt electrolytic
- 2 0.5- μ fd, 400-volt (matched)
- 1 160- μ fd ceramic (for 16-ohm load)
- 2 50- μ fd, 50-volt electrolytic
- 2 8- μ fd, oil-filled, 600 working volts
- 1 0.1- μ fd, 400-volt
- 2 0.1- μ fd, 600-volt
- 1 1.5- to 7- μ fd trimmer

Other Parts

- 1 choke, 12 henries at 250 ma, UTC CG-102 or equivalent
- 1 choke, 75 henries at 50 ma, UTC CG-48C or equivalent
- 2 3-amp, slo-blo fuses
- 1 1/4-amp fuse
- 1 DPST switch
- 1 power transformer, 440 volts at 200 ma, UTC H-86 or equivalent
- 1 output transformer, 6,600 ohms plate-to-plate, 4-8-16-ohm secondary, Acrosound TO-300 or equivalent

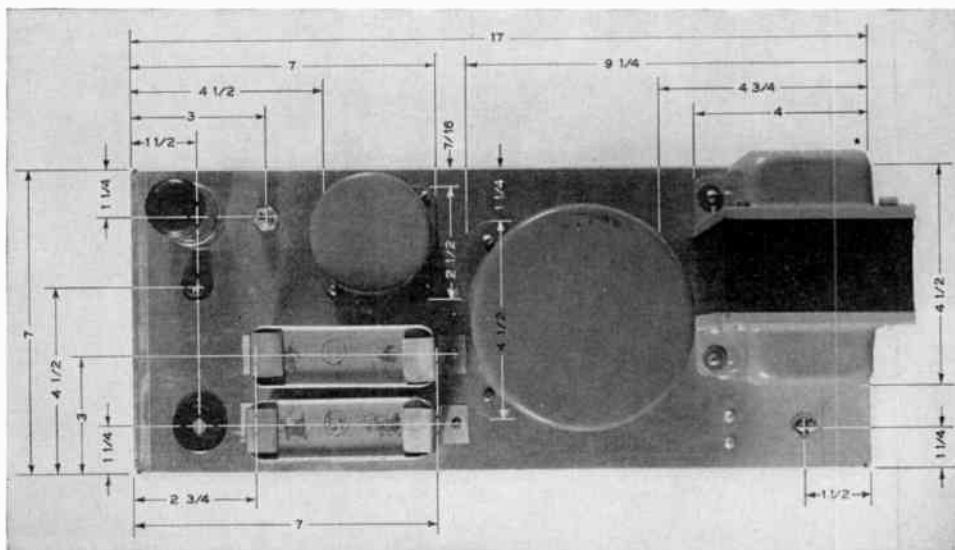
⁵Milton S. Kiver, "How to Improve Your Hi-Fi Amplifier," *Radio & Television News*, LIV (Sept. 1955), pp. 50-51, 128.

⁶M. V. Kiebert, "The 'Williamson Type' Amplifier Brought Up To Date," *Audio Engineering*, XXXVI (Aug. 1952), pp. 18-19, 35-36.

⁷Ferguson, *op. cit.*

⁸D. T. N. Williamson and P. J. Walker, "Amplifiers and Superlatives," *Wireless World*, LVII (Sept. 1952), pp. 357-361.

Fig. 6. Guide for mounting power-supply components. We used 17-inch chassis base.



- 1 EF86 tube
- 1 ECC83 tube
- 2 EL34 (matched pair)
- 1 GZ34 tube
- 1 Amphenol type 80-PC2F input connector (another type if preferred)
- Chassis, hardware, sockets

Construction

So much for choice of components. The rest was construction and care, to make sure that a top-drawer choice of components would not be rendered worthless by slipshod layout or craftsmanship.

It is good practice to avoid unnecessary difficulties in amplifier construction. A common annoyance in placing everything on a single chassis, including the power supply, is the danger of hum contamination. It's just as easy to use a separate chassis for the power supply, and to build the amplifier part of the circuit on another chassis. Two chassis are used, therefore, in this version of the amplifier. Placement photos are reproduced in Figs. 5 and 6.

The classical, professional approach is to lay out the circuit in a line, from one end of the chassis to the other, using a heavy ground bus connected to the chassis only at the input end, and with all circuit grounds connected to the bus in ascending order. The best approach in this case is the familiar T-formation, used by Sarser and Sprinkle in the layout of the "Musician's Amplifier."⁹

Wiring is point-to-point, with leads, especially plate and grid leads, kept as short as practicable. Wiring and parts layout are made as physically symmetrical as possible, in order to maintain circuit balance at the high end.¹⁰

The power supply chassis is laid out conveniently, since placement of parts is not critical.

In working with deposited-carbon resistors, it is wise to apply a minimum of heat to leads during soldering, since excessive heat will cause resistors of this type to change value. An excellent method of handling this problem is to attach some heat-conducting vehicle between the body of the resistor and the point where the resistor lead is being

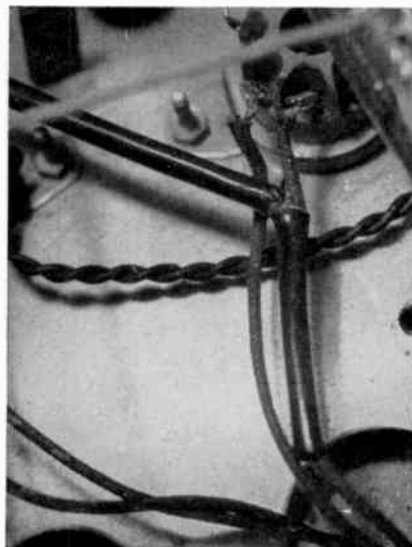


Fig. 7. "Glitch" circuit as used on original amplifier built by Mr. Zale.

soldered. The best tool I've yet come across for this purpose is one used by surgeons during operations, a surgical pliers called a hemostat. Alternatively, you can use alligator clips, needle-nose pliers, or any other handy device.

Use good-quality mica-filled sockets for best results. While RCA-type phono input sockets might be used, I prefer microphone connectors, since they are stronger and will not come apart, and make a better permanent connection.

A number of circuit changes were made on the recommendation of Herbert L. Keroes, of Acro Products Company. The changes were designed to optimize circuit values for this transformer, since the original circuit, as described in the Mullard booklet, made use of a Partridge output transformer.

It is true, in general, that the use of different output transformers will require the use of different types of networks or values of compensating resistors and capacitors for maximum stability and best transient response. This is because the frequency and phase characteristics of the circuit and transformer must be adjusted to complement each other for optimum results. The type of compensation worked out for this circuit, while somewhat unorthodox, produced excellent results, as seen in the oscillograms of square-wave response. There is very little overshoot and practically critical damping of the flat top of the wave. Moreover, the amplifier is stable on open and short-circuit output and over a wide range of capacitive loads, making it perfectly suitable for use with the new electrostatic speakers if desired.

The original circuit had a phase-shift network consisting of a 47- μ fd disc ceramic capacitor in series with a 4,700-ohm resistor strapped across the 100,000-ohm plate resistor of the EF86 tube. This circuit was eliminated in favor of a "glitch" circuit, made up of a very small capacitor in series with an 18,000-ohm resistor connected to the EF86 plate and one output tube plate,

the one to which the blue lead of the output transformer is connected. This capacitor may be a standard 1.5- to 7- μ fd trimmer set for best square-wave response, which should occur about midway in the range. A less easily duplicated, but equally effective capacitor was built into the amplifier described by paralleling within a spaghetti sheath about 1/2 in. of insulated hookup wire adjacent to the blue transformer lead (see Fig. 7 for detail).

The capacitor-resistor combination rolls off high-frequency response above 60 Kc gradually and smoothly. This approach is to be preferred, according to Mr. Keroes, over the more usual one of striving for a maximum flat bandwidth of 100 Kc and better, which usually results in a sharp cutoff at the upper end. In such an amplifier, there is generally less stability and considerable ringing on high-frequency square-waves.

Splitting the feed-back resistor into two sections (the original Mullard 520 circuit calls for a single 8,200-ohm resistor), with one section bridged by a compensating capacitor, contributed to improved stability. The 1,000-ohm stabilizing resistors connected in series with the output tube screens in the original circuit are not required with the TO-300 and were eliminated, since they would serve no useful purpose and would limit output power.

The capacitor used to bridge the feed-back resistor in the original circuit was a 220- μ fd unit. Recommended change is to 160 μ fd across the 7,500-ohm feed-back resistor only.

Here are the specifications I obtained for this version of the circuit: power output at 20 cps was 32 watts clean, with overload at 36.8 watts. This is notable in view of the fact that the Acrosound TO-300 is rated at 20 watts at 20 cps, and attests to the conservative specifications for this item. Clean power output at 1 Kc was 38.5 watts; at 20 Kc, 32.3 watts.

Frequency response was flat from 20 to 20,000 cps, being down 1/2 db at 20 Kc, 3/4 db at 50 Kc, 1 db at 60 Kc, 6 db at 100 Kc, and 10 db at 200 Kc, all at 36 watts. The rolloff at the high end was clean and gradual. Square-wave response was excellent even at 20 Kc, with

Continued on page 46

⁹David Sarser and Melvin C. Sprinkle, "Musician's Amplifier," *Audio Engineering*, XXXIII, (Nov. 1949), pp. 11-13, 53-55. See also: Glen Southworth, "Chassis Layout and Wiring," *AUDIOCRAFT*, I (Dec. 1955), pp. 21-23, 43.

¹⁰Kiver, *op. cit.*

Fig. 8. Curve showing intermodulation distortion with respect to power output.

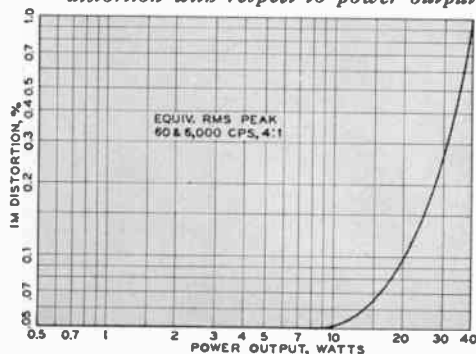
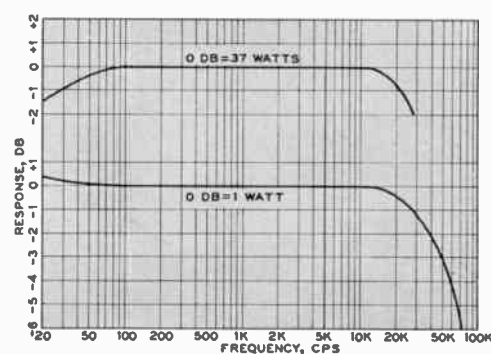


Fig. 9. Power response (top curve) and frequency response of model built here.



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Continued from page 19

a practical minimum of high-frequency ripple.

Hum and noise measured 85 db below 36 watts. Changing the input tube to another EF86 improved this figure to 86.5 db below 36 watts. (This was before the installation of the hum balancing network including positive bias, with which the hum and noise level has been further improved to measure more than 90 db down at 36 watts.) The British version measured 89 db below 36 watts. It was felt that an optimum choice, by selection of input tube, would have given an even better figure. Also, the line voltage, during measurement, tended to run low, thereby reducing my figures somewhat. At any rate, my measurements equalled those of the original version.

Intermodulation using 60 and 3,000 cps in 4:1 ratio, was 0.55% at 34.5 watts and 0.75% at 35.4 watts. With 60 and 7,000 cps, IM read 0.8% at 36.3 watts, which was somewhat better than the original version. Sensitivity was measured at 300 millivolts input for full 36-watt power output, and the damping factor was measured at better than 50.

A higher line voltage at the time the measurements were taken might have served to improve the figures significantly. As it is, they justified the assertions of the designers of the Mullard 520 circuit completely. Such differences as did occur were more than likely the result of differences in test equipment and measurement setups, and line voltage at time of testing. A more carefully matched pair of output tubes would also have provided improved IM figures.

The changes that have been made in this version of the Mullard circuit are small, but in my opinion are important and fully justified. In stability and square-wave response I believe the amplifier equals or exceeds the performance of anything available at this date. I would like to express my sincere thanks to Herbert I. Keroes, of the Acro Products Company, for his many suggestions and his personal interest and help; and to E. J. Porto, International Electronics Corporation, for his kindness in reviewing this article and for clarification of points of material interest.

AUDIOCRAFT Test Results

We encountered very little difficulty in building our unit. We followed Mr. Zale's instructions closely, and found that they are comprehensive and complete in almost every detail. For the sake of building ease we chose to order the 17-inch chassis base for the power supply, and heartily recommend this approach to anyone for whom space is not a problem.

We used an electric hand drill for pilot holes for our chassis punches, and

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for screw mounting holes. Every component of the amplifier can be mounted with round holes—even the transformers and oil-filled capacitors—which makes the mechanical construction extremely simple.

We did not choose to follow Mr. Zale's method of making the "glitch" circuit since we felt the average home constructor could more readily duplicate results by using the 1.5- to 7-microfarad trimmer capacitor. To mount our trimmer, we enlarged the hole in a mounting lug to accommodate the adjustment screw, attached the trimmer, and mounted the lug on the side of the chassis so that the screw would be accessible from underneath the chassis for adjustment. Nor did we use a pair of GZ34's in the power supply, since one is more than adequate.

We also added a 100-ohm potentiometer between the cathodes of the output tubes (Points A and C, Fig. 4) and connected the arm to ground (Point B, Fig. 4), readjusting the cathode resistors to 420 ohms each. Although precise adjustment of the 500-ohm adjustable resistors for minimum distortion can achieve the same effect, the job is tricky, since tightening the adjustment screw without changing its position (and thus its resistance) is difficult. The potentiometer makes precise balancing simple.



because it can be adjusted easily while the amplifier is in operation, while testing for current balance or minimum IM

When assembly was completed it was necessary to balance the output stage and adjust the filament balance for minimum hum. To guarantee the validity of our test results, we used the amplifier in our own system for a while before checking its performance.

When checks finally were made, the results proved the durability of Mr. Zale's design. The use of low-noise resistors throughout the circuit, and the extreme filtering in the power supply, produced a signal-to-noise ratio in our unit of 93 db!

Just as fine were the figures for intermodulation distortion, Fig. 8. Using 60 and 6,000 cps in a four-to-one ratio, our unit measured below the residual of the meter up to about 15 watts, rose slowly to 0.5% at 35 watts, and reached the

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Continued from preceding page

1% point at 38 watts. These figures follow very closely those obtained by Mr. Zale, further confirming the reliability of the circuit when 1% components are used.

Although our unit did appear to roll off beyond 20,000 cps a bit faster than Mr. Zale's, Fig. 9, we attributed this fact to stray wiring capacitances introduced by the slight changes we made in parts placement and component layout. The differences are minute, and do not degrade the audible performance of the amplifier in the slightest.

Low-frequency stability was excellent, and high-frequency square waves closely approximated those photographed by Mr. Zale, (Figs. 10, 11, and 12).

Although this is a rather expensive amplifier (it cost us about \$110 to

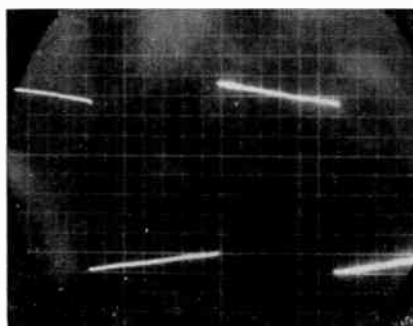


Fig. 10. Response to 30-cps square wave.

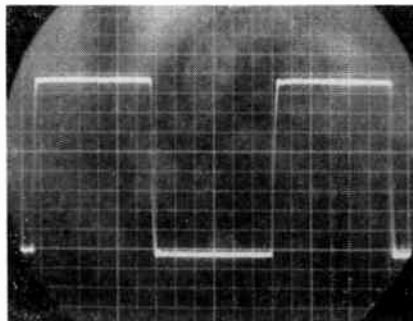


Fig. 11. Response to 3-kc square wave.

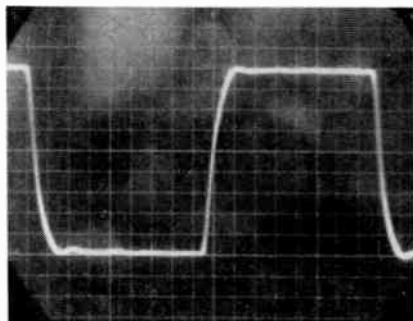


Fig. 12. Response to 11-kc square wave.

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