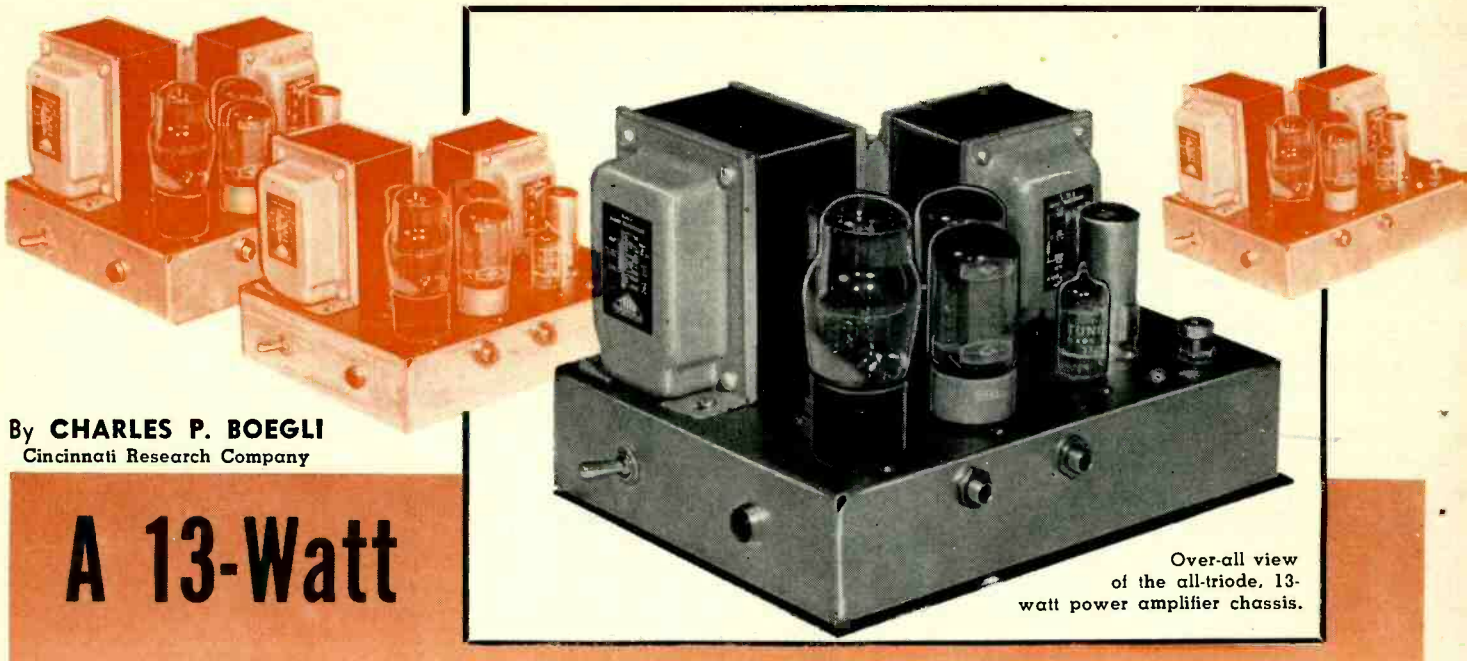

Over-all view of the all-triode, 13-watt power amplifier chassis.

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A 13-Watt All-Triode "Infinite Feedback" Amplifier

Construction details on a well-designed, all-triode unit which is right size for the average home audio system.

IN ONE of the author's previous articles[1] he described a 35-watt amplifier with a novel combination of features, namely 100% negative feedback around the output transformer and the output and driver stages, together with sufficient positive feedback around the driver stage to cause it to oscillate in the absence of the negative feedback. That article presented the mathematical basis of the design and showed that the arrangement can lead to a very stable amplifier having extremely low distortion and approximately zero output impedance. These principles were applied to the design of an amplifier using class-A push-pull 300B tubes in the output stage and the unit was found to develop 37 watts at 2% (r.m.s. sum) IM distortion, or 35 watts at a distortion limit of 1%.

Two features of this amplifier make it somewhat unsuited for average home use. The output power of 37 watts is far in excess of that required in most homes, and the low input impedance of the amplifier necessitates a special final stage in the preamplifier with which it is to be used. Need seems to exist for a smaller amplifier which, while retaining the same circuit features, will have a maximum output on the order of ten watts, sufficient for home systems utilizing all but the most inefficient speaker systems. That the input impedance should be sufficiently high to permit the use of most available preamplifiers is a further requirement.

These objectives have been accomplished in the circuit to be described here. At the same time, because every part of the circuit has been designed with a view toward economy of construction, the new amplifier can be made at a cost somewhat less than comparable *Williamson* units. That no sacrifice in performance has been made to economy should be strongly emphasized; nevertheless, the final circuit does not contain a single unnecessary component.

Design

The circuit diagram of the complete amplifier is shown in Fig. 1. For the output stage, tubes of the class including 1614, 5881, KT-66, and 350B were selected. Not only are such tubes widely available but their characteristics are so similar that they may be used interchangeably with no modification of the remainder of the circuit. All of them have a maximum plate dissipation on the order of 26 watts when connected as triodes (with the exception of the 350B, for which the dissipation is 34 watts). The greatest power is developed by operating them near their maximum ratings. A control is incorporated into the stage for balancing the plate currents of the output tubes, but this adjustment has a very small effect on hum level.

The output transformer is a *Triad* S-35A, a reasonably-priced component of exceptional characteristics. In this circuit the full output power of 13 watts is available from less than 16 to over 30,000 cps. The entire circuit has been designed around this transformer; preliminary calculations[2] seem to indicate that a wider frequency response is of no benefit whatever in audio amplifiers. As in the earlier 35-watt amplifier, the secondary of the output transformer is connected in balanced fashion, with the 0 and 16-ohm taps attached to the 16-ohm speaker and the 4-ohm tap grounded through the driver bias resistor paralleled with a small bypass capacitor. The speaker lines are at a small positive d.c. potential and must not be grounded to the chassis in any manner.

Various output stages were tested in the experimental work, including straight pentode and "Ultra-Linear" arrangements. Both these circuits increased the available power output to about 18 watts. Both appeared to have the common property that while the distortion level was quite low if the amplifier was connected to a load of the correct impedance, it rose objectionably as the load impedance was reduced below the correct value. This tendency was not observed with the triode connection; a reduced load resistance lowered the maximum power output but the distortion at lower levels increased only slightly. The "Ultra-Linear" output stage requires an output transformer considerably more expensive than the one indicated in this article and the nominal increase of output power does not seem to warrant this extra cost.

The output stage is thus quite conventional; the bypass capacitor across the cathode resistor common to the output tubes has been eliminated in the interest of economy with no measureable adverse effect upon performance.

A neon bulb shunting the grids of the output tubes limits the input voltage and prevents destruction of the tubes in the event the speaker leads are accidentally shorted together. (Shorting the speaker leads together effectively removes the negative feedback and permits the drivers to oscillate.) Tubes like the 5881 are considerably more resistant to this type of abuse than the 300B's used in the larger amplifier but they are nonetheless ruined in less than a minute by shorting the speaker lines in the absence of the neon-bulb limiter.

The push-pull driver is a single 12AU7, around which sufficient positive feedback is fed to produce oscillation in the absence of the negative feedback. The cathodes of the 12AU7 are connected directly to the secondary of the output transformer, providing 100% negative feedback, preventing oscillation of the drivers, and indeed, resulting in an extremely stable amplifier. Output tubes of the heater-cathode type bring up several problems not encountered with the filament type used in the larger amplifier. When early models of the present unit were turned on, the driver tubes heated up much more rapidly than the output tubes and oscillation occurred for a few moments, until the output tubes "caught up." This oscillation was heard as a loud "whoop" in the speaker —frightening to many listeners. A great deal of work went into the design of the positive-feedback loop to eliminate this effect, and it never occurs in the latest circuit.

The input stage, which is also the inverter, is a dual triode with a large common cathode resistor. Signal is fed into one grid and the other grid is grounded through a capacitor. The outputs from the two plates are very closely balanced and have practically identical internal resistances. The circuit is well balanced and, except for the grid connections, completely symmetrical. 60-cps hum created by the large heater-to-cathode voltage, and 120-cps hum from the power supply appears in-phase at the two plates and is canceled at the transformer. Also, because it is quite degenerative, the input stage introduces a negligible amount of distortion.

Modification for push-pull input is easily made, and consists of reconnecting the first stage so that the two inputs are fed to the two grids. This means that for push-pull input the grid shown grounded in the circuit diagram is removed from ground and connected to the other side of the input. A dual gain control is then required.

During the experimental work on early versions of this amplifier, changing the input tube was found to have a profound effect on the distortion. The resistances inserted between the 12AX7 plates and the driver grids overcome this tendency and allow replacement of the 12AX7 with no special precautions as to selection. They also permit this tube to be lightly loaded while at the same time a comparatively low resistance is presented to the 12AU7 grids, improving the high-frequency response. A grounded tube shield will eliminate any tendency of the first stage to pick up hum, but the shield has been found unnecessary in most cases.

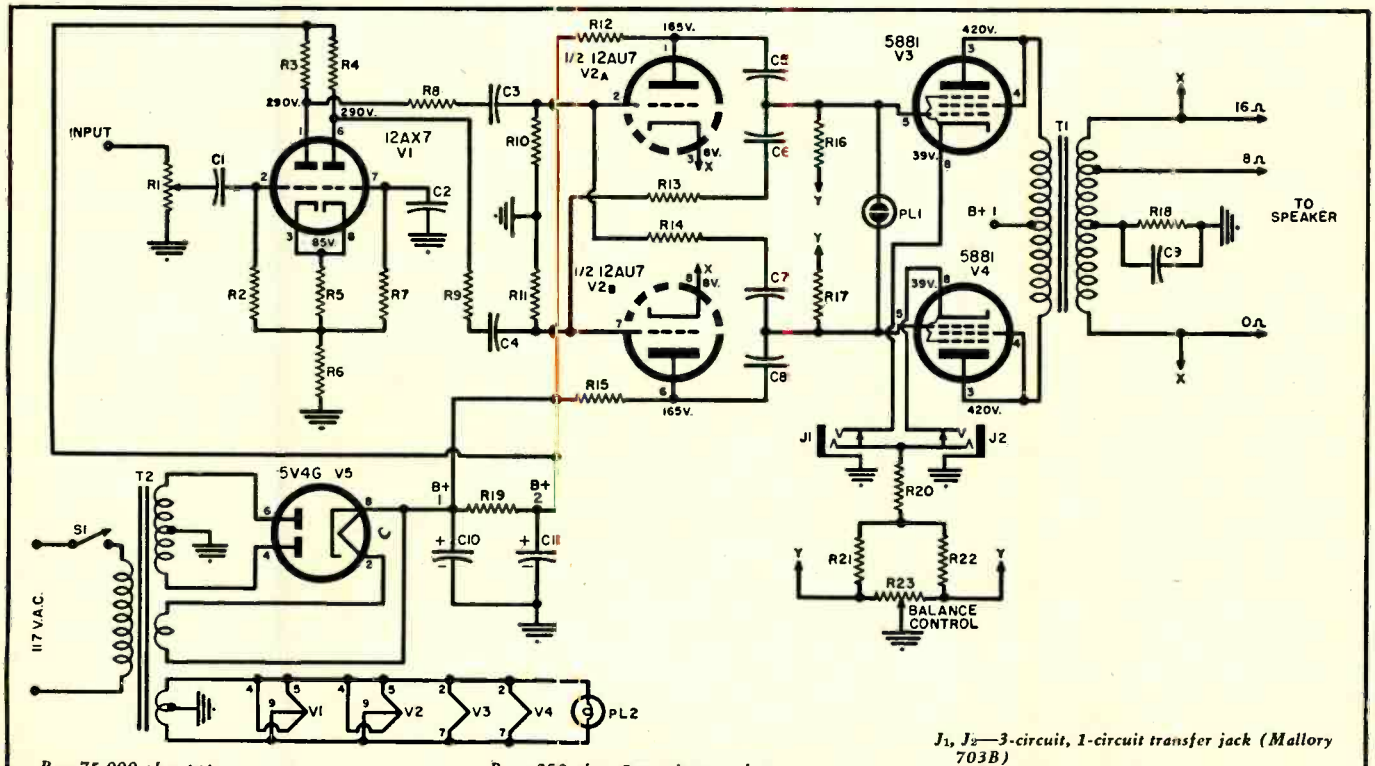
A 75,000-ohm potentiometer is employed as a gain control in the amplifier's input. This resistance is not too low for the great majority of preamplifiers if they have an output capacitor no smaller than 0.25 μfd. The use of a gain control larger than 100,000 ohms may result in an increase in hum and a loss of high frequencies at certain settings, since the input capacitance of the inverter stage is appreciable.

Because of the symmetry of the amplifier, the power supply can use a minimum of filtering without increasing the hum level. The large amount of feedback in the amplifier helps keep the hum level quite low even with unbalanced output tubes, although badly unbalanced tubes decrease the stability at low frequencies and in extreme cases can cause motorboating.

Construction

The entire amplifier and power supply can be mounted on a 7 by 9 by 2-

Fig. 1. Schematic of 13-watt amplifier. Parts should not be substituted in construction.



R_1—75,000 ohm pot
R_2, R_7—1 megohm, ½ w. res.
R_3, R_4, R_{12}, R_{15}—100,000 ohm, ½ w. res.
R_5—680 ohm, ½ w. res.
R_6—40,000 ohm, ½ w. low-noise-type res.
R_8, R_9, R_{10}, R_{11}—120,000 ohm, ½ w. res. ±5%
R_{13}, R_{14}—1 megohm, ½ w. res. ±5%
R_{16}, R_{17}—330,000 ohm, ½ w. res.
R_{18}—1500 ohm, ½ w. res.
R_{19}—15,000 ohm, 5 w. wirewound res.
R_{20}—250 ohm, 5 w. wirewound res.
R_{21}, R_{22}—100 ohm, 1 w. res.
R_{23}—50 ohm wirewound pot
C_1, C_6, C_7, C_9—.01 μfd., 400 v. capacitor
C_2—.05 μfd., 400 v. capacitor
C_3, C_4, C_5, C_8—.1 μfd., 400 v. capacitor
C_{10}-C_{11}—40/40 μfd., 475 v. elec. capacitor
S_1—S.p.s.t. switch
PL_1—NE-2 neon lamp
PL_2—6.3 v. pilot lamp
J_1, J_2—3-circuit, 1-circuit transfer jack (Mallory 703B)
T_1—Output trans., 5000 ohms c.t. to 4-8-16 ohm v.c. (Triad S-35A)
T_2—Power trans. 350-0-350 v. @ 160 ma.; 5 v. @ 3 amps.; 6.3 v. c.t. @ 5 amps. (Triad R-16A)
V_1—12AX7 tube (with shield)
V_2—12AU7 tube
V_3, V_4—5881 tube (1614, KT-66, or 350B could be substituted)
V_5—5V4G tube

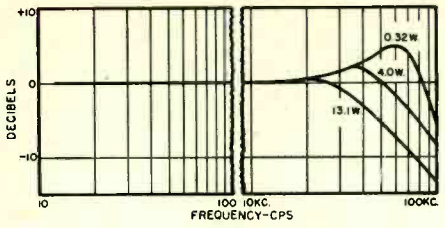


Fig. 2. Frequency response of the 13-watt "infinite feedback" amplifier. See text.

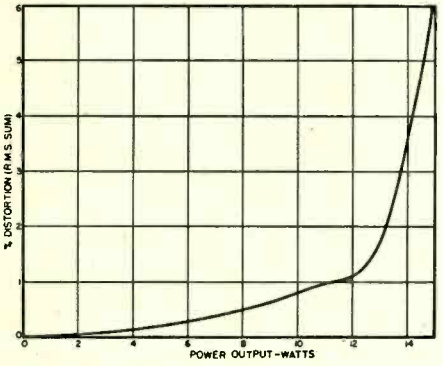


Fig. 3. Intermodulation distortion of the amplifier. 60 and 7000 cps, 4 to 1 ratio.

inch chassis if the layout is done carefully. The necessary compactness is achieved by mounting components directly on the output-tube sockets while using a terminal strip for the first two stages. The photographs show the completed amplifier and an underchassis view which clearly illustrates how the terminal strip is mounted. The terminal strip should be assembled by attaching the resistors first, followed by the capacitors.

Coupling capacitors of the highest quality should be used in constructing the amplifier. The writer has made over a dozen units, and in every case where excessive hum or distortion was encountered the trouble could be traced to a leaky capacitor which was throwing the two halves of the amplifier out of balance. Except for the few 5% resistors indicated on the diagram, no precision or specially selected or matched components are required to assure satisfactory performance.

The constructor must be cautioned not to change the values of any components in the circuit or to use tubes other than those specified. Changes very often have an unexpected result; for instance, decreasing the size of the coupling capacitors between the input and driver stages actually causes a rise in the bass response and may lead to motorboating.

Figs. 2 and 3 show the frequency response into a 16-ohm resistive load and the r.m.s. sum intermodulation distortion at various output levels. An input of 0.5 volt is sufficient to drive the amplifier to full output. The unit shows an output resistance of approximately zero ohms over the range of audible frequencies, which forces the most refractory speaker to behave docilely. Although the response is quite flat listeners are often impressed with what seems to be greater bass response than that attainable with other flat amplifiers, and this can be attributed to the high damping factor (by the usual definition, the damping factor is infinite). The improvement is especially noticeable with woofers of low efficiency.

The amplifier is very stable and shows no tendency to motorboat or, unless overdriven, to oscillate at any frequency or output level. A capacitance of 0.1 μfd. shunted across the speaker terminals does not cause any oscillation or other evidence of instability; this is far in excess of the capacitance presented by any speaker system. The entire amplifier can be wired in a few hours' time and no special precautions as far as lead dress, shielding, or bus bar ground are necessary if the layout of the experimental model is followed. The noise level of several chassis with the inputs shorted varied somewhat with the tubes used but a value greater than 2 mv. = 77 db below 13 watts was never encountered. In all the experimental amplifiers built by the author ground connections were made to any convenient chassis point.

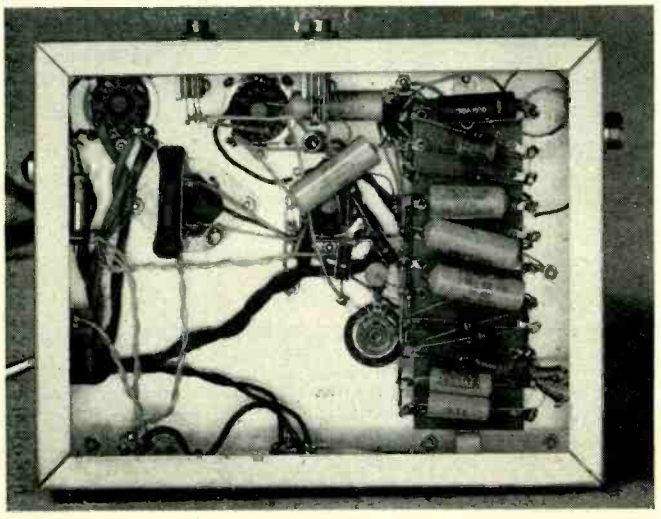
Summary

Since the appearance of the article describing the 35-watt unit several commercial amplifiers have been developed featuring "variable damping factor." The articles describing these amplifiers [3, 4] draw various conclusions as to the damping factor desirable for results of the highest quality.

If, instead of the 1-megohm fixed positive-feedback resistors in the amplifier described here, a dual potentiometer was employed, the output resistance of the amplifier can be controlled within small limits. When the amount of positive feedback is reduced the output resistance increases up to a maximum corresponding to a damping factor of 4; if the amount of positive feedback is increased the output resistance becomes negative. As the latter occurs, however, the stability of the amplifier becomes much worse, and a damping factor of —1.0 can certainly not be obtained.

When the positive feedback is varied in either direction from the optimum (sufficient to make the driver oscillate in the absence of negative feedback) the distortion of the amplifier at a given ouptut level increases. The increase is gradual while the positive feedback is being lowered. On the other hand it rises rapidly as the positive feedback is increased beyond the optimum value. For this reason, the use of such a control to obtain negative damping factors is not to be encouraged. *No circuit has yet been devised* which will, at the same time, produce a large negative damping factor and low amplifier distortion[5]. This objection does not apply, of course, to amplifiers in which a control is provided to vary the output resistance between positive limits.

An amplifier of the type described here, unfortunately, will not make a five-dollar speaker in a cardboard box perform like a two-hundred dollar assembly in a folded horn. It will try, of course, and sometimes the effort becomes so strenuous that oscillation occurs. Such oscillations have been touched off by overloading the amplifier during efforts to obtain resounding bass from tiny speaker enclosures. Given the amplifier, the remedy in such cases lies in either of two directions: a better speaker system should be installed or a filter should be inserted before the amplifier to remove the low frequencies which the system cannot reproduce anyway. Used in conjunction with a speaker of comparable quality, the amplifier is capable of results which have, to date, been thoroughly pleasing to well over a hundred persons and displeasing to only two or three.



Under chassis view of the 13-watt amplifier. Layout and lead dress is non-critical but use of terminal strip simplifies construction.

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