The "Williamson Type" Amplifier Brought Up to Date

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Attention to detail in the construction of the Williamson-type amplifier, as well as in the choice of components and tube types, results in an amplifier with low noise level and a minimum of "bugs."

WHILE BUILDING a new "super" amplifier, it became necessary to provide an interim power amplifier for use with the pre-amplifier-equalizer unit to be described by the author next month.

The unit was to be rack mounted on a standard 19-inch assembly with a chassis 17 by 10½ inches. The power supply was to be integral with the amplifier with the provision for self-contained output-stage metering and plate-current balancing.

Electrically, it was required that the unit have a 16-ohm output; a calibrated input attenuator, a 600-ohm input or an unbalanced high impedance input of 100,000 ohms; a power output level of approximately 15 watts with negligible intermodulation distortion; a relatively flat power-frequency characteristic, a high output damping factor; a gain of 60 to 80 db, and a noise and hum level held to at least 80 db below a one-half watt nominal output level. Combined with these specifications was the requirement that the unit have excellent transient response not only when working into a resistive load but also under the condition of driving a speaker load. To cross-check the latter requirement, square-wave tests were to be made under both conditions of operation—resistive load and speaker—and these measurements were to be compared with the speaker output as sampled by a calibrated microphone.

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Preliminary Design

A number of circuits were investigated and checked. The basic Williamson design looked like a good starting place, and accordingly a rather comprehensive investigation was made of the various circuit literature published on this general type of circuit.

Initial tests soon indicated that four major sources of noise, distortion, and poor transient performance limited the optimum capabilities of the generally used circuit. The difficulties were found to be as follows:

1. The input stage was too noisy, had hum, and required careful selection of plate and coupling resistances in order to provide a balanced, "clean" output from the second half of the tube.
2. The driving power to the 807's was marginal at peak levels.
3. Typical coupling capacitor tolerances and variation of distributed capacitances tended to cause circuit unbalance at both high and low frequencies with attendant transient difficulties.
4. Composition resistors as normally used in the feedback circuit gave distortion from the frequently overlooked voltage co-efficient characteristics of the

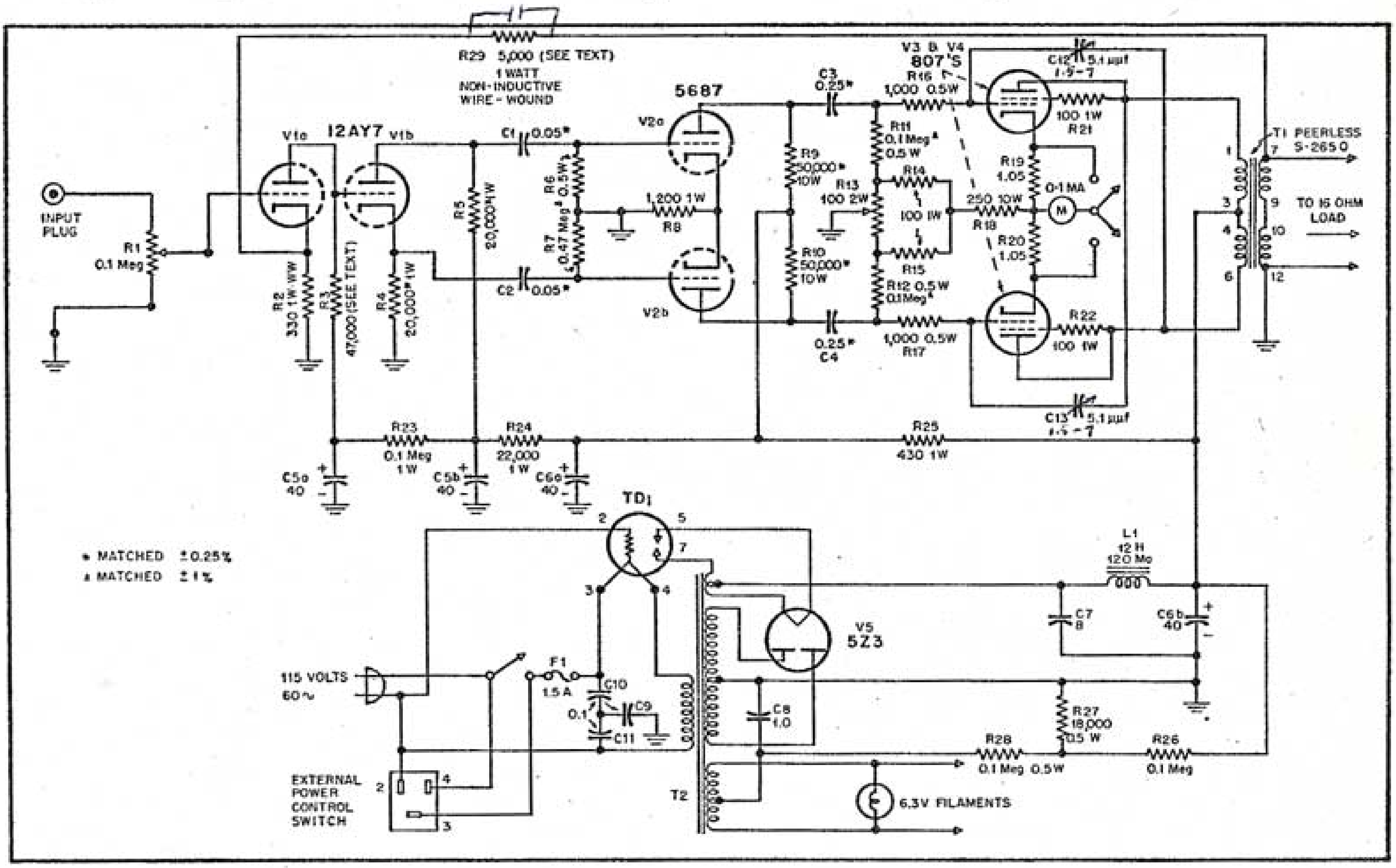
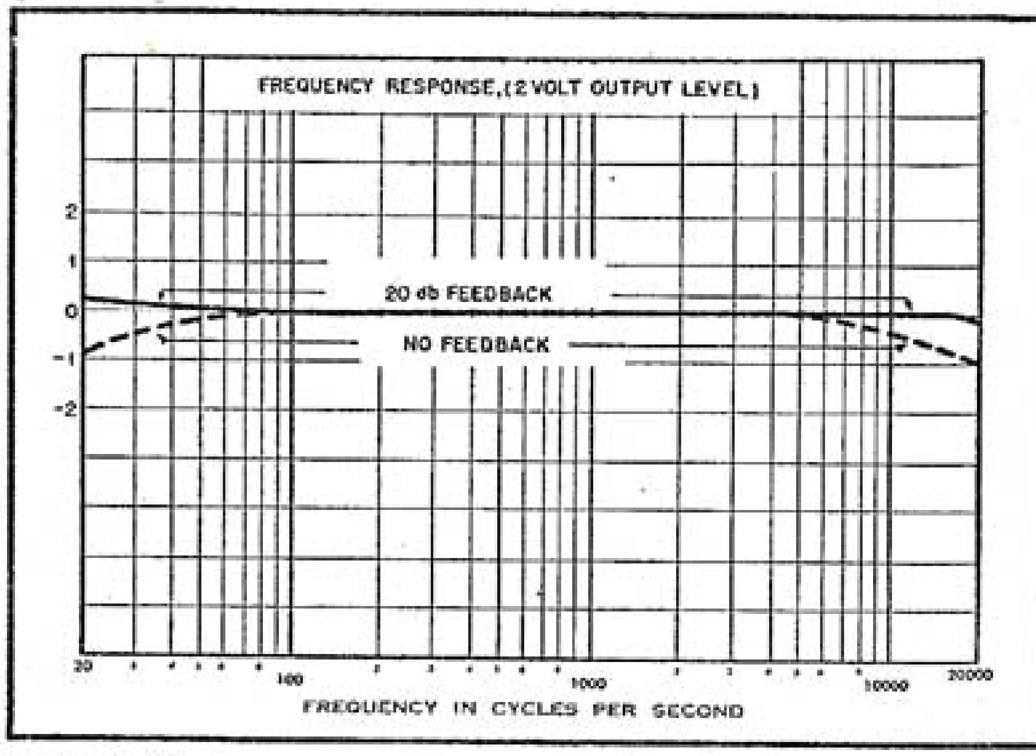


Fig. 1. Over-all schematic of the author's up-to-date version of the Williamson amplifier. Note use of tube types which differ from those originally chosen for use in the Musician's Amplifier—the most popular American version to date.



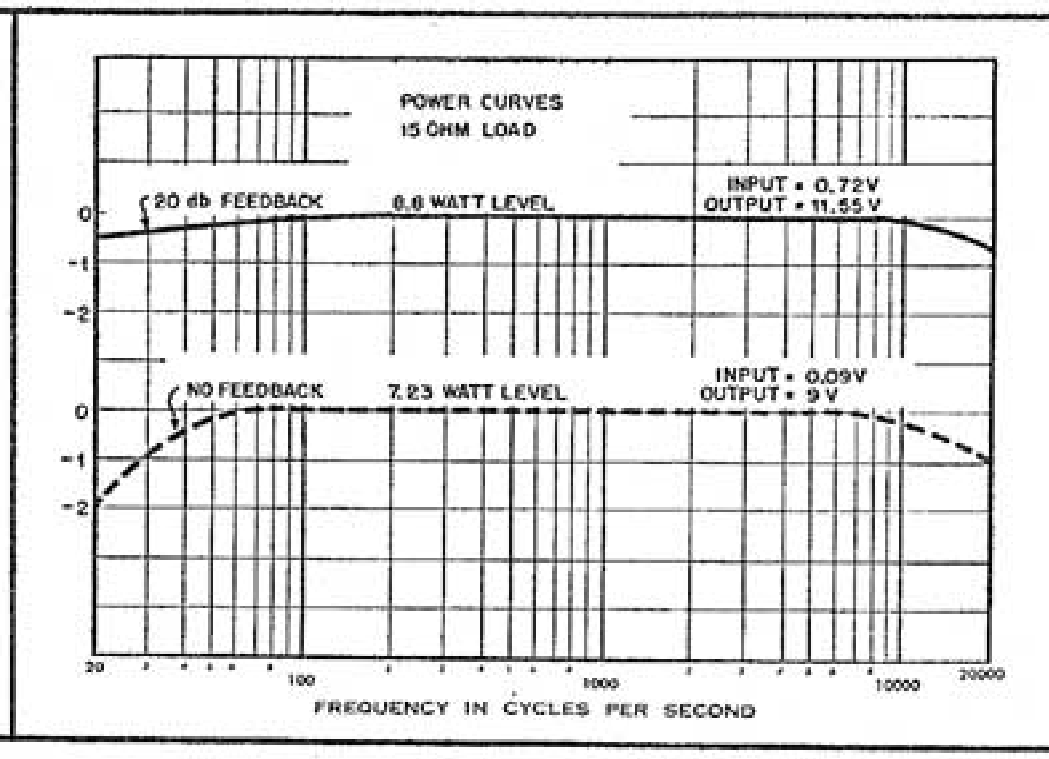


Fig. 2 (left). Frequency-response curves with and without feedback. Fig. 3 (right). Power output curves for 1 per cent distortion, with and without feedback.

units generally specified for use in this position.

It was also believed to be desirable to have a time delay provision so that plate voltage would not be applied to the system until after cathodes had reached a satisfactory operating temperature. Either an Edison or Amperite thermal relay tube would do the job in a satisfactory manner.

Initial tests also disclosed that the use of 10- or 20-μf decoupling capacitors were inadequate at low frequencies if good transient characteristics were to be maintained down to 5 or 10 cps when a considerable amount of feedback was used. Accordingly, 40-μf units were used in this position, which then provided fairly good frequency and phase characteristics well down into the lower audio frequencies.

Study of the complete schematic, *Fig. 1*, will show the differences in detail from the standard design. In order to avoid the four major difficulties observed in basic Williamson circuits, all stages were carefully checked and tested as individual elements and the optimum configuration found prior to inclusion in the final assembly. Likewise, the entire amplifier was carefully tested and rechecked prior to inclusion of any feedback loops—that is, care was taken to assure a good triode design and performance even before feedback was incorporated in the final circuit. Tests indicated that this was a sound design procedure any way you listened to it—or looked at it on an oscilloscope.

First Stage Improvements

In order to circumvent the first listed difficulty—hum due to cathode-heater leakage, and noise arising in the first stage—it was necessary to take two corrective measures. First, a 12AY7 tube which was specifically designed for low-noise-level audio service, was used to replace the conventionally employed 6SN7 and care was taken to follow carefully the manufacturers' recommendation as to input grid resistance, heater connections, and voltage. By-passed and isolated heater bias was then employed with circuit parameters selected to provide minimum hum when an unbypassed first-stage cathode resistor was utilized as required when feedback is connected in at this point. Second, it was found that the 47,000-ohm plate-load resistor did, as would be expected, cause increased noise unless wire-wound or low noise level units were used.

With respect to noise level in the first-stage load resistor, a number of resistive elements were checked in order to secure a relative evaluation of each type and value. The following were tested:

1) ½ watt composition resistor
2) 1 watt composition resistor
3) 2 watt composition resistor
4) 1 watt deposited film resistor
5) 1 watt S.S. White low-noise-type resistor
6) 1 watt non-inductive, wire-wound resistor

The use of a 1-watt composition resistor in lieu of a ½-watt unit improved the noise level by approximately 3 db with a like improvement occurring when a 2-watt unit was substituted for the 1-watt unit. The 1-watt S.S. White unit was about 6 db better than the 2-watt composition resistor. The 1-watt deposited film resistor was slightly inferior to the S.S. White unit while the 1-watt non-inductive wire-wound resistor was about 6 db better than the 2-watt composition unit. Substitution of the 1-watt non-inductive wire-wound resistor for the generally specified ½ watt carbon unit thus provided about 12 db improvement in noise level, while the 12AY7 with a biased and properly by-passed heater circuit also cleans up the hum level by about 12 db and accordingly helps to meet the original design requirement.

Phase Splitter Improvements

Following the clean-up of the first stage, the inverter was investigated. Resistors matched to ±0.25 per cent were utilized. Both S. S. White units and 1- and 2-watt carbon units were checked as regards to noise level. As might be expected, however, the noise level was fixed by the first stage and no significant improvement was found when changing from one type of resistor to another. The relatively low resistance of these units, 20,000 ohms, minimizes the problems of high-frequency roll-off and asymmetrical phase characteristics sometimes found in this type of inverter circuit. The splitload, cathodyne circuit was found to be superior to all other circuits tested for possible use in this application.

The driver stage was next considered and a number of tube types were evaluated and tested for use in this position. Tubes tested and considered were the 6SN7, 6N7, 6K6's and 6V6's operated both as triodes and as pentodes, 6AG7's, 2C21, 6J6, 12AU7, and the 5687. It was soon evident that the 5687 was considerably superior to other driver configurations although pentode connected 6K6's were also excellent except for the fact that the considerable variation in tube characteristics between tubes required a careful balancing of tubes and a re-adjustment of the screen voltage each time a tube was changed. This was not the case with the 5687 (a dual triode) and accordingly this tube was selected as the driver. It is also obvious that the use of a single tube considerably simplifies the circuit layout and saves on both components and space.

After going through the preceding studies, a preliminary circuit was set up on an experimental chassis, and frequency and phase characteristics were run with the feedback loop left open. It was soon noted that rather peculiar things were happening at low frequencies. ±20-per cent coupling capacitors had been used (without actually checking to see what they were) while the grid coupling resistors had been held to ±10 per cent. The coupling capacitors were then tested and found to have a wide capacitance spread. As soon as matched units were employed, the sides of the push-pull circuits maintained balance and the frequency and phase characteristics smoothed out the way theory said they should.

The use of cross-neutralization or phase correction in the output stage materially helped to extend and smooth out the high-frequency end of the spectrum but again, watch out for balanced capa-

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citors and a symmetrical circuit layout which is most important in this part of the circuit because this is one of the limiting points in the high-frequency end of the spectrum.

At this point, the amplifier, even without feedback, "listened" good and would appear to satisfy even the most discriminating user. In order to find out what was available, a series of characteristics were measured. The frequency response, gain, noise level, mid-range output impedance and power characteristics were measured.

With something already good to work with and an available 20 db of gain to utilize, the feedback loop was closed. Initial steady-state measurements were made and it looked as though the arithmetic were right. It being early in the morning and we being anxious to test the listening quality of this new unit, the

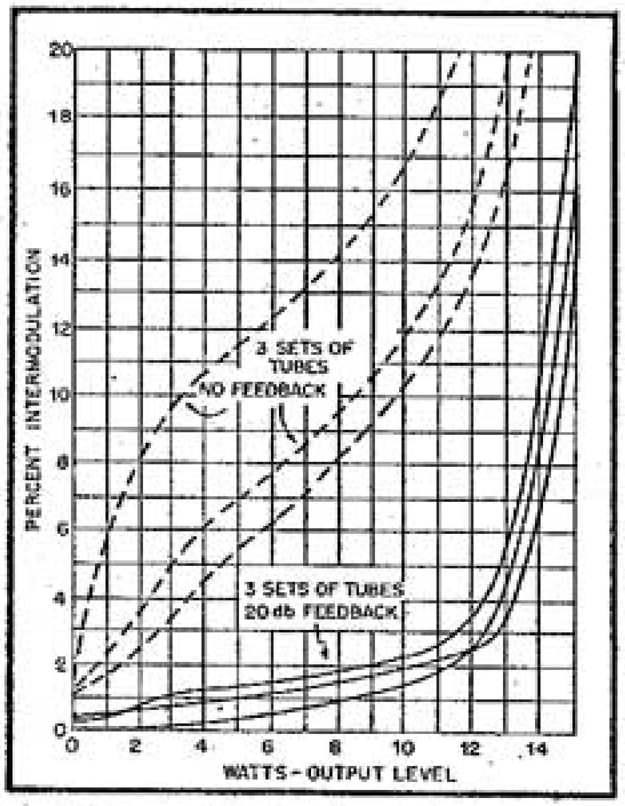

Fig. 4. Intermodulation distortion curves, with and without feedback, taken with three sets of tubes in each condition.

system was set up and a test tape of known excellence fed into the system. And was it terrible!

Additional tests were now made. The feedback loop was opened, and a square-wave generator was fed into the amplifier. The transient performance looked good under this condition of operation. The feedback loop was closed, the circuit again checked and curves and bumps appeared where and when they shouldn't. The input cathode resistor was a ½-watt carbon unit as was the feedback resistor—so remembering a bit about voltage coefficients of composition resistors, 2-watt carbon units were substituted for the ½-watt units and an immediate improvement was noted. The transient performance, however, did not completely clean up until these two resistors were replaced by non-inductive 1-watt wire-wound units. The performance of the amplifier was now remeasured and is compared—with and without feedback—in *Figs.* 2, 3, and 4.

With the final version of the improved and up-to-date Williamson unit connected into the complete system, it appears as though this new amplifier may become more than the "interim" amplifier that it started out to be.

At this point attention is invited to *Fig.* 4 which presents the IM tests on the circuits both before and after closing of the feedback loop. In each case a family of curves has been presented. These families of curves represent measurements made with eight 807's, four of which were new, two of which had over 1000 hours of operation, and two of which had over 3000 hours of operation in a voltage regulator. The best curves in each case resulted from optimum tube selection, the poorest curves were made with the poorest combination of tubes.

Tests with various combinations of 12AY7's and 5687's indicated that the IM was negligibly influenced by these stages but rather was almost entirely determined by the characteristics of the particular type 807 tubes used in the output stage.

Past experience has indicated that all too often the proud parent of a circuit presents the brain child in Sunday-go-to-meeting clothes rather than in the day-to-day attire and environment of run-of-the-mill tubes which are generally the only ones normally available to the average experimenter or the unsuspecting public. In this instance it is believed that a representative and fair evaluation of the circuit has been made.

Construction

Care was taken in construction to avoid circulating ground currents and accordingly, an electrical connection is made to the chassis at only the one point next to the input. Twisted and capacitively shielded filament leads and as balanced and symmetrical physical and electrical layout as possible with this circuit further simplifies wiring and assembly while keeping capacitances as they should be.

PARTS LIST

C_1, C_2	.05 µf, 600-v. paper, matched ± ¼%
C_3, C_4	0.25 µf, 600-v. paper, matched ± ¼%
C_5, C_6	40-40/450-v. electrolytic
C_7	8 µf, 600-v. oil filled
C_8	1.0 µf, 400-v. paper
C_9, C_{10}, C_{11}	0.1 µf, 600-v. paper
C_{12}, C_{13}	5.1 µµf, 600-v. mica
L_1	12-H, 120-ma filter choke
M_1	1-ma meter, 100-ohm resistance
R_1	0.1 meg audio taper pot
R_2	330 ohms, 1 watt, wire-wound, non-inductive
R_3	47,000 ohms, 1 watt, wire-wound, non-inductive
R_4, R_5	20,000 ohms, 1-watt, wire-wound, non-inductive, matched ± ¼%
R_6, R_7	0.47 meg, ½-watt, matched ± ¼%
R_8	1200 ohms, 1-watt, composition
R_9, R_{10}	50,000 ohms, 10-watt, wirewound, matched ± ¼%
R_{11}, R_{12}	0.1 meg, ½-watt, composition, matched 1%
R_{13}	100 ohms, 2-watt pot, wirewound, linear
$R_{14}, R_{15}, R_{21}, R_{22}$	100 ohms, 1-watt, composition
R_{16}, R_{17}	1000 ohms, ½-watt, composition
R_{18}	250 ohms, 10-watt, wire-wound
R_{19}, R_{20}	1.05 ohms, wirewound shunt for meter
R_{23}, R_{26}, R_{28}	0.1 meg, 1-watt, composition
R_{24}	22,000 ohms, 1-watt, composition
R_{25}	430 ohms, 1-watt, composition
R_{27}	18,000 ohms, ½-watt, composition
R_{29}	5000 ohms, 1-watt, wire-wound, non-inductive
T_1	Output transformer, 10,000 ohms plate-to-plate/4-8-16 ohm secondary Peerless S-265Q (Similar transformers of other makes are: Acro—TO-290; Triad—HSM-89 or S-48A; UTC—LS-6L1. Suitable results should be obtained, although author has not made measurements with these types.)
USED PARTRIDGE CFB/0/0.95 10 KΩ PRIMARY	
T_2	Power transformer—400-0-400 v. at 200 ma; 5 v. at 3 a.; 6.3 v. at 6 a.
TD_1	Amperite thermal time-delay switch
V_1	12AY7
V_2	5687 (Tung-Sol)
V_3, V_4	807
V_5	5U4G (or 5V4G)