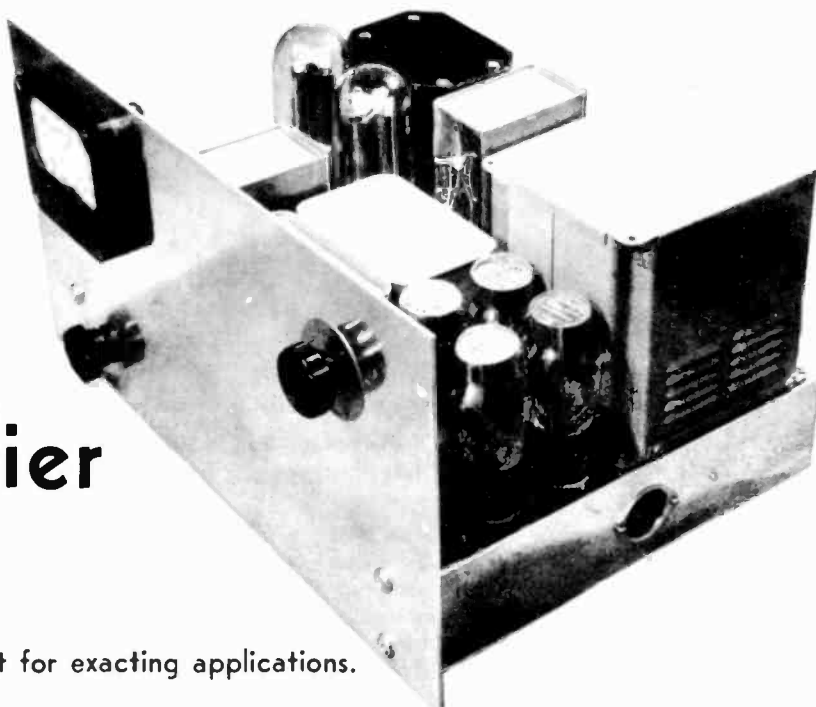


Three-quarter view of high-fidelity amplifier chassis.

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High-Power Triode Amplifier



The authors describe a high-quality audio unit for exacting applications.

AN AUDIO AMPLIFIER of high gain, high power, high stability, wide frequency range, low distortion and low noise content was required at the outset of a series of measurements of human hearing, loudspeaker performance, and recording fidelity. Because this unit was to be a link common to all the measurements, its characteristics had to exceed substantially the best expectations of the electro-mechanical equipment involved.

Calculation indicated that with loudspeakers of average efficiency peak powers of as much as 25 watts might be needed to attain the desired sound levels. A frequency range of 30 to 20,000 cycles within $\frac{1}{2}$ decibel would

exceed the requirements of measurement, but good voltage regulation of the output would have to accompany the response. Because the amplifier would be used at low as well as high output levels, internal noise would have to be kept below audibility compared to the zero vu level. It was anticipated that the measurements for which this equipment was constructed would take some weeks or months to complete, and since the data accumulated would be correlated, extraordinary stability would be a requirement in the amplifier. Finally, every reasonable precaution had to be taken against introducing distortion products in the amplifier, of whatever obscure

origin, which would offend the most sensitive listener.

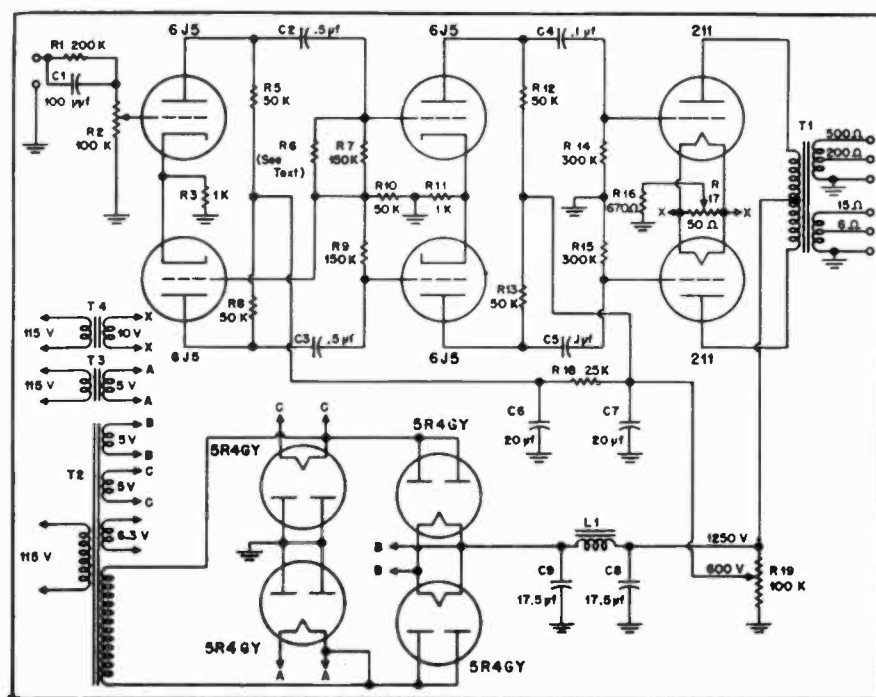
With these requirements in view, the long smooth curves of the larger triode power tubes looked attractive. An opportunity to evaluate the results to be had from the high costs usually associated with triode designs thus presented itself also.

Low Cost Components

Funds for the experiments were no more plentiful than usual, so the possibility of using low-cost war-surplus tubes was explored. The rather formidable 211 has for a long while been in copious supply at prices comparable to those of receiver types. Power supply requirements, always severe in triode

Fig. 1. Schematic of audio amplifier.

- R1—200,000 ohms, $\frac{1}{2}$ watt, carbon.
- R2—100,000-ohm wire-wound potentiometer.
- R3, R11—1000 ohms, 10 watts, wire-wound.
- R5, R8, R12, R13—50,000 ohms, 10 watts, wire-wound.
- R6—(see text).
- R7, R9—150,000 ohms, $\frac{1}{2}$ watt, carbon.
- R10—50,000 ohms, $\frac{1}{2}$ watt, carbon.
- R14, R15—300,000 ohms, $\frac{1}{2}$ watt, carbon.
- R16—1000 ohms, 50 watts, slider adjusted to 670 ohms.
- R17—50-ohm 4-watt potentiometer, wire-wound.
- R18—25,000 ohms, 10 watts, wire-wound.
- R19—100,000 ohms, 200 watts, with slider, wire-wound.
- C1—100 μ f, mica.
- C2, C3—0.5 μ f, 600 volts, oil-filled.
- C4, C5—0.1 μ f, 600 volts, oil-filled.
- C6, C7—20.0 μ f, 600 volts, oil-filled.
- C8, C9—17.5 μ f, 1500 volts, oil-filled.
- T1 U.T.C. PVM-3
- T2 U.T.C. S-43
- T3 U.T.C. S-54
- T4 U.T.C. S-62
- L1 U.T.C. S-31



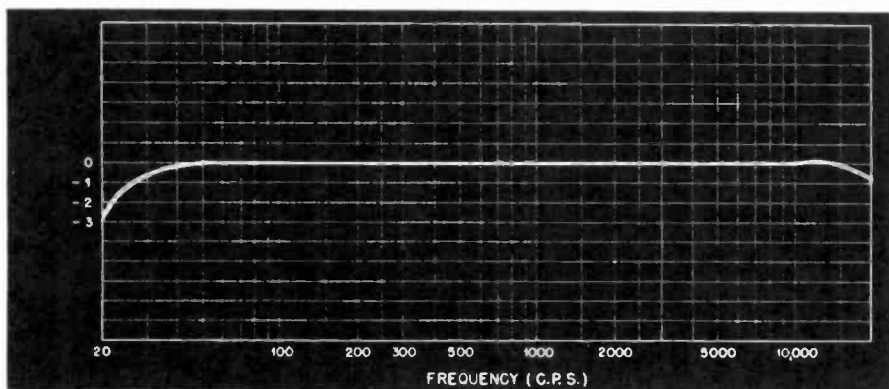


Fig. 2. Frequency response curve of audio amplifier at 30 watts output. Note that it is flat within less than one db from 30 to 20,000 cycles.

designs, at first made it appear an uneconomic choice, but a reasonable solution was found. The wide demand among radio amateurs for power equipment in this range has resulted in quantity production of the required transformers at tolerable cost. High-voltage condensers were available through war surplus. And a bridge rectifier was feasible with the low-priced 5R4GY rectifier tube, with its comfortable 250 ma current rating, and 2100 inverse peak voltage capability. The problem appeared surmountable if costly interstage transformers could be avoided.

So the 211 was tentatively selected, and in the interest of reducing drive requirements, insuring stability of operation, and eliminating the necessity of a fixed-bias supply, pure class A connection was proposed.

The availability of very high plate-

supply voltages suggested the possible use of ordinary receiver triodes in conventional resistance-coupled circuits. The calculations revealed that this would be the most critical section of the amplifier, but with 600 volts at the high-potential end of the 6J5 plate resistors these tubes, operating at nearly full rated dissipation in push-pull, would drive the 211s just beyond the requirements.

The medium- μ driver triodes dictated the use of another stage of voltage gain, which could conveniently use the same tube type. Phase inversion was removed to the input stage so that degeneration in the drivers' cathode resistor would tend to remove any unbalance in a.f. grid-to-ground voltage remaining after inversion. The 6 decibels of gain added by making the input a push-pull stage was also desirable. The need for high stability with

high gain demanded a tube inverter of unusual characteristics. The cathode-loaded inverter was rejected, despite its stability, because of the possibility of cathode-filament hum, a considerable hazard where relatively high gain follows inversion. Gain requirements ruled against the cathode inverter too. The ordinary voltage-divider type was eliminated by its necessity for constant readjustment with tube aging. The stability and gain of the conventional floating-paraphase inverter were attractive, but its never-quite-perfect balance was a disadvantage. In the end a modification of the latter type proved satisfactory: the load on the input tube was varied by shunting $R7$ with $R6$, of varying values above a megohm, until a virtually perfect balance of a.f. to the driver grids was obtained. The floating-paraphase action maintained the balance over long periods of use.

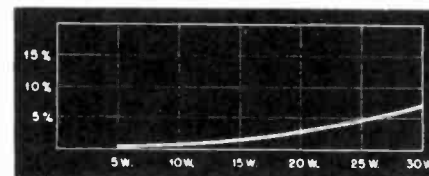


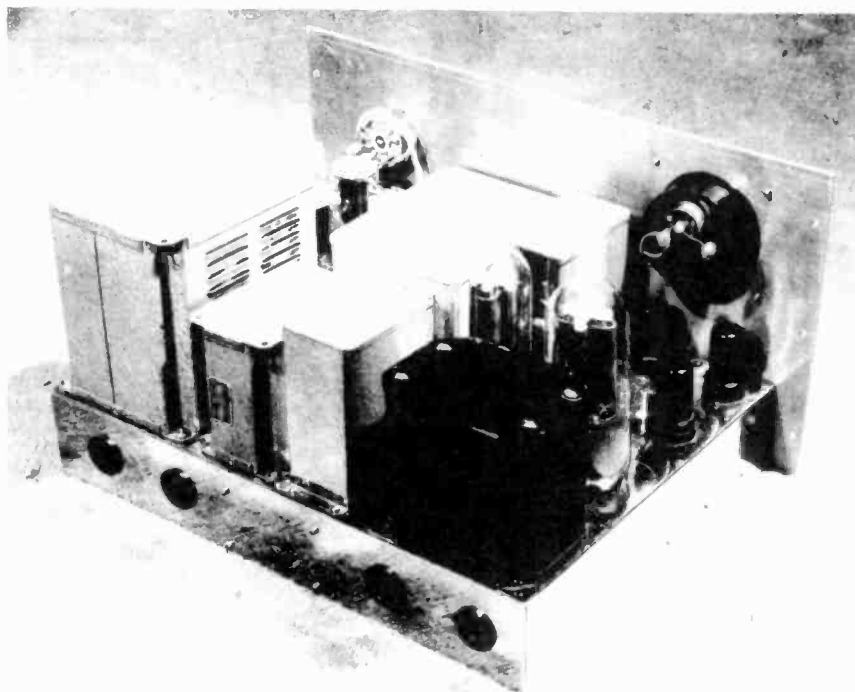
Fig. 3. Intermodulation distortion vs. power output.

The final refinement in the circuit was the addition of a short time constant filter in the input, calculated to counteract the high-frequency losses within the amplifier due to distributed shunt capacitances. High-frequency losses due to Miller effect, often experienced in high-impedance triode grid circuits, were held to a minimum by the 100,000-ohm value assigned the input potentiometer. This value likewise reduced the chances of frequency discrimination from RC effects, prominent in many higher-impedance input designs.

Again in the interest of low noise level and high stability, wire-wound resistors were used in all d.c.-carrying circuits, and oil-filled capacitors were used throughout. If a suitable quality of oil condenser is used for coupling, d.c. leakages will remain even after long use at values lower than those found in new paper condensers, keeping the grids essentially at ground potential, with attendant long-time circuit stability. In the presence of heavy a.c. fields the shielding afforded by the can construction is probably a considerable advantage too.

The photographs show how the entire unit was mounted on a single standard rack chassis. The controls illustrated

As shown, the amplifier is built on a standard rack chassis.



on the front panel are for gain and monitoring level.

It should be noted that potentially lethal voltages exist on the underside of the chassis. No high-voltage contacts are brought to the top. The equipment is mounted so that no access can be had to the underside without first disconnecting the power.

Tests

The intermodulation curve of Fig. 3 was taken with the Pickering analyzer, using input frequencies of 100 and 7000 cycles at 10 decibels difference in level. Total harmonic distortion analysis gave reading of $\frac{1}{3}$ to $\frac{1}{4}$ the numerical values of the IMD figures, at corresponding powers.

The frequency-response curve of Fig. 2 is a power line, based on 30 watts, and is therefore of significance at much more than usual operating levels. The low-frequency drop is attributed to output-transformer core-saturation.

Noise level was measured with a

shielded 100,000 ohm resistor across the input terminals, with the gain control wide open. Further amplification of the output was required to distinguish its character audibly. It was the usual random hiss superimposed upon a lower level of hum. The absolute level of noise at the output under these conditions was -52 dbm, or nearly 96 decibels below the nominal 30-watt level.

Effective internal impedance at the 15-ohm tap is 6 ohms.

Thirty watts of output was reached with about 0.1 volt drive, giving a nominal 85 db maximum gain.

Although all the tests indicated that the amplifier was suitable for its purposes, the final judgement would have to be that of prolonged listening by critical people. The nature of the distortions which offend a "golden ear" still defies analysis, but whatever their causes these offenses had to be excluded from the present amplifier if it were to be useful. The operation was ap-

parently a success, for the equipment was later used with laboratory-produced transducers capable of accurate reproduction of sounds in the 20,000 cycle area without pain to the perhaps hypercritical listening of the speaker-creators. Prolonged use has confirmed the original opinion that the amplifier is contributing no unpleasantness. Its low internal impedance is audibly an effective damp on oscillatory excursions of bass speakers employed with it.

For all of the excellent characteristics obtained here, no fuel is meant to be added to the fire of academic argument over triodes and beam tubes. The high-frequency equipment mentioned above has been used with beam amplifiers employing ample feedback with no decrease in listening satisfaction. It is believed that the requirements met by the present amplifier could have been reached equally well, and at lower cost, with beam tetrodes using generous feedback.