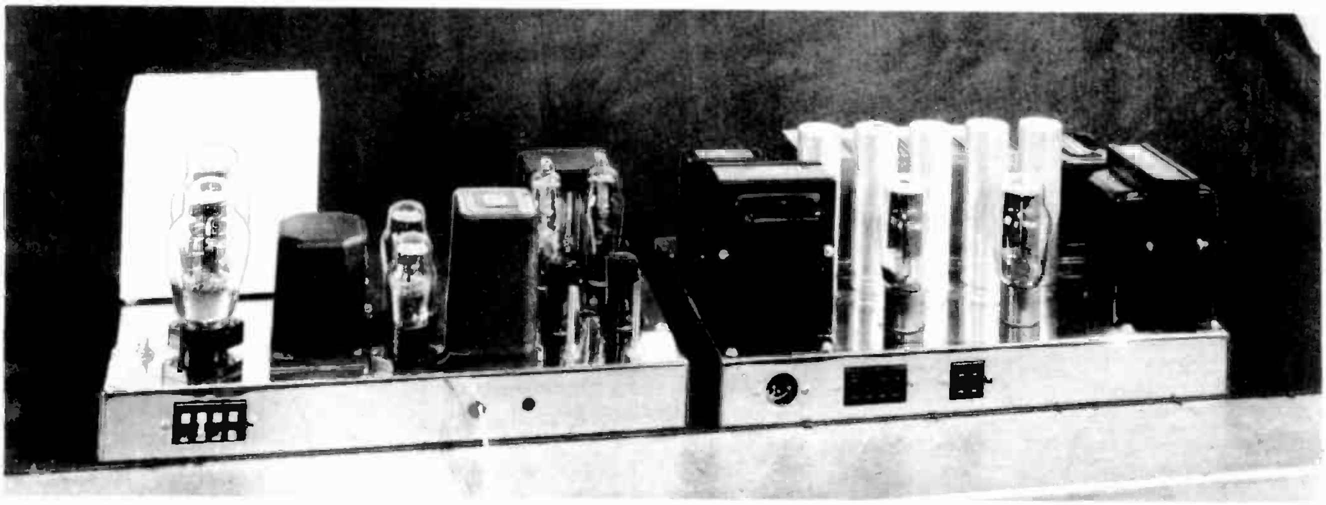

Fig. 1. The high-fidelity, high-quality amplifier and its power supply.

30-Watt High-Fidelity Audio Amplifier

CURTISS R. SCHAFER

A general-purpose medium-power amplifier of broadcast quality.

THE LOW-MU TRIODE AMPLIFIER enthusiasts are at it again, and in view of the impracticability of some of the designs that have been offered within the past few years, the author would like to point out a few fundamental requirements that must be met by a truly high fidelity amplifier which also can furnish sufficient power to "fill" a small auditorium, for loudspeaker testing, or for driving a wax or acetate cutter. These basic requirements are:

1. *Sufficient power output and gain.*[1,2]

2. *Low listening fatigue,* which is primarily insured by low intermodulation distortion.[3,4] The distortion products should result only from second and third harmonics instead of the higher order harmonics usually generated in beam-power tubes. Single-frequency harmonic analysis is useful only in determining some of the operating parameters of the tubes and transformers involved.

3. *Good transient response,* which results in a particularly clean-cut reproduction of speech. Whistling consonants are evidence of parasitic oscillations on peaks. The specific factors responsible for good transient response are (*a*) good high-frequency response, (*b*), low phase rotation,[5-8] (*c*), low internal impedance as seen by the loudspeaker or cutting head, and (*d*), low hysteresis distortion, especially at the higher frequencies, in any transformers that may be involved.

It should always be remembered that we are not dealing with sine waves in the reproduction of speech and music. This is important in the matter of phase rotation, for instance; two sine waves out of phase still add up to a sine wave, but two waveforms containing harmonics, and out of phase, add up to a new and different waveform which does not resemble either of the originals. Excessive phase shift in an amplifier sounds like high intermodulation distortion, and produces excessive listening fatigue.

4. *Good input vs. output linearity.* This demands that each voltage amplifier stage be capable of supplying several times the actual voltage required to drive the following stage.

5. *Reliability, ruggedness and ease of servicing,* both with regard to locating the faulty part and replacing it easily. This calls for the use of oil-filled or oil impregnated condensers, hermetically sealed transformers and chokes, resistors which do not get noisy with age and/or temperature variations, and tubes which are of simple design structurally, have their elements well braced, and do not have close grid-to-cathode spacing. Close element spacing offers the probabilities of high microphonism, grid emission and wide variations in electronic parameters with small variations in tube geometry. Glass envelope tubes usually have a lower gas content than metal envelope tubes. In addition, glass tubes are an aid to rapid servicing, as a bright spot on a cathode, a gassy rectifier, or an open filament are easily noticed.

Design

With these elementary considerations in mind, we began the design of an amplifier. After a year of loudspeaker listening and testing with amplifiers rated at 10, 15, 20, 30, and 40 watts output, it was decided that an output of 30 watts with less than 5% total intermodulation distortion was required. We felt that this output should be obtained with triodes rather than beam power tubes: first, because the absence of a feedback loop would result in a simpler and more easily serviced amplifier; second, because the higher order harmonics generated by beam-power tubes (running up through the tenth) were considered undesirable, even though relatively low in amplitude. The value of distortion selected is so low that we felt we could ignore it when the amplifier is used in listening tests.

The output triodes were selected from a list of the following types: 50, 2A3, 6A3, 6B4G, 6A5G, 6AS7G, 3C33, RJ-563 and DRJ-564, and 300A. The first five of these belong to the same generic type, the 6A5G being a heater-

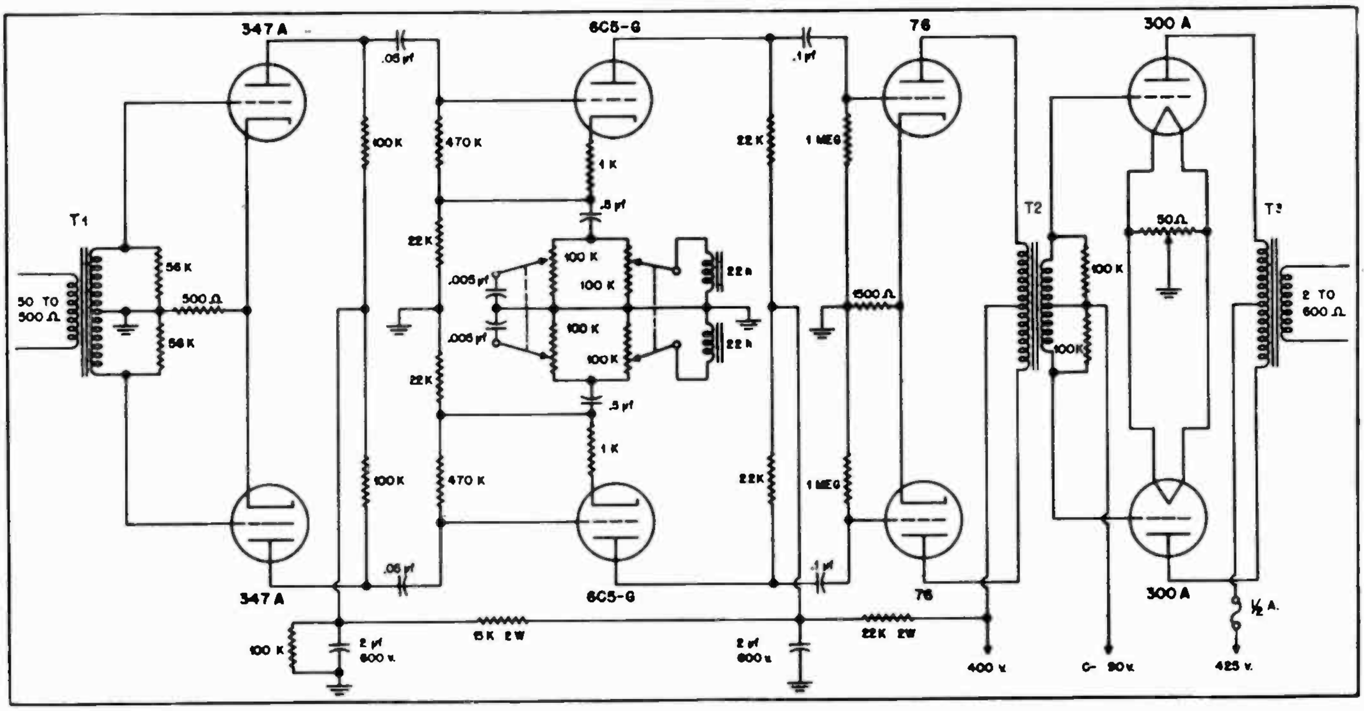

Fig. 2. Complete schematic of the 30-watt high-fidelity audio amplifier.

cathode type which is no longer available. The 2A3 is best of the four remaining in this group from the standpoint of hum. However, a 30-watt output from this type requires either (*a*), the use of four tubes in a push-pull parallel arrangement, which makes hum balancing difficult, or (*b*), the use of an automatic bias circuit for two tubes,[3] which we felt was undesirable from the point of view of tube aging in the bias circuit and the increased difficulty of servicing the bias circuit. In addition, we wished to operate our output tubes class A all the way, instead of going into AB operation at ten or fifteen watts. The 6AS7G was rejected because its maximum plate dissipation per section is only 13 watts, which is less than that of a 2A3 (15 watts), and also because its construction necessitates the use of self-bias.

The RJ-563 and DRJ-564 are Westinghouse types, and either would be an excellent choice except for their relatively high cost ($15 and $25 net, each). The RJ-563 has a mu of 3.8, a plate resistance of 800 ohms, and a maximum plate dissipation of 60 watts. The DRJ-564 has a mu of 3.8, a plate resistance of 400 ohms, and a maximum plate dissipation of 100 watts (maximum plate current 400 ma).

A single 3C33 compares very favorably with a pair of 2A3s, except that it is easier to drive, having a mu of 11. Its maximum plate dissipation is 15 watts per section, it has a heater-type cathode, and a peak cathode current rating of 500 ma per section. Again the drawback is one of price, which gives a very low watts-per-dollar ratio.

We finally selected the Western Electric 300A (or 300B) as the tube we wanted. It has a mu of 3.8, a plate resistance of 700 ohms, a maximum plate dissipation of 40 watts, and a power output of 17.8 watts as a single-tube class A amplifier, with the second and third harmonics down 21 and 30 db respectively.[9] In a push-pull stage the second would be almost completely cancelled out, of course. The single plate assembly, as opposed to the dual plate assembly of the current production of 2A3s, makes hum very easy to balance out, and the very good uniformity of characteristics makes it unnecessary to balance the plate currents by means of a bias adjustment for each tube.

The output transformer selected gave excellent wave form at forty watts output, particularly at the ends of the range we wished to cover, 20 cps and 20 kc.[10] It provides a plate-to-plate load impedance of 4000 ohms into secondary loads ranging from 2 to 600 ohms. We had early decided on designing an amplifier that would give full power output (not down 1 or 2 db) at thirty cycles, because we wished to use organ transcriptions in some of our listening, and we were surprised at the number of output transformers whose waveform became very bad at 30 cycles, and also above 10 kc.

The grid-to-grid driving voltage required for the 300As is 180 volts peak, which is easily supplied by a pair of 76s in push-pull operating into a

300A and 300B Vacuum Tubes

Filament voltage	5.0 volts
Nominal filament current	1.2 amperes
Amplification factor	3.8
Plate Resistance	700 ohms
Grid-plate transconductance	5500 micromhos
Maximum plate voltage	450 volts
Maximum plate dissipation	40 watts
Typical operation, Class A single tube amplifier:	
Plate voltage	450 volts
Grid bias	97 volts
Plate current	80 ma
Load resistance	2000 ohms
Power output	17.8 watts
Second harmonic	21 db down
Third harmonic	30 db down

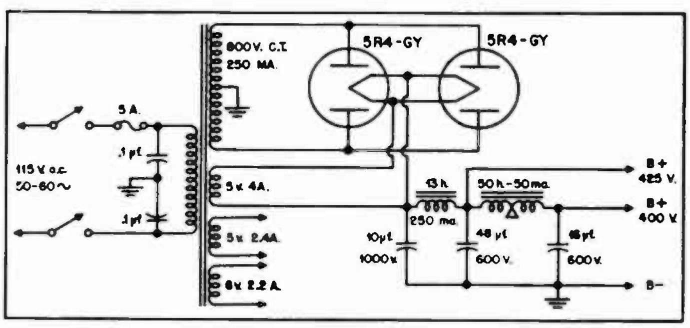

Fig. 3. Schematic of the power supply.

mumetal cored interstage transformer, of the author's own design, with a stepup ratio of 1:2. The UTC LS-22 could just as well be used here. The 76 tube will handle almost 50% more driving voltage than the 6J5 or 6C5.

The amplifier is push-pull all the way; second harmonic distortion is pretty well down, and less plate supply filtering is required than for single-ended stages. The first stage uses Western Electric 347As, which generate very low values of hum, microphonics and fluctuation noise.[11] The 1603 triode connected is an acceptable substitute.

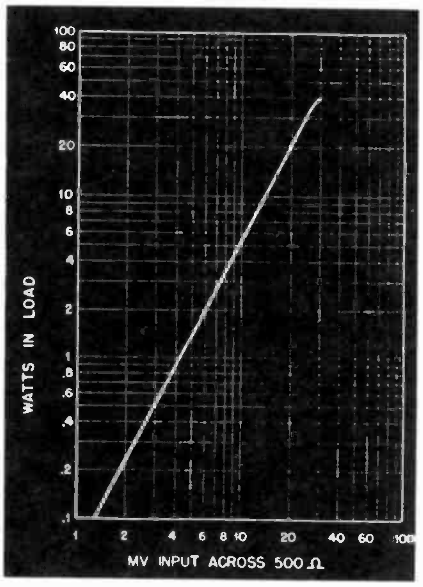

Fig. 4. Voltage sensitivity graph.

A variation of the Thordarson degenerative tone control circuit is used, because it will (*a*) handle a fairly high value of input signal, (*b*) give a 1:1 voltage "gain" even in the flat response position, and (*c*) introduce no measurable harmonic distortion of its own. Here again, 1603s triode connected may be used in place of the 6C5Gs.

Two 45-volt batteries, Burgess 5308 or equivalent, were selected as being the most reliable and economical source of bias voltage. No current is drawn from them, and from previous experience the author has found that they are good for about two years before their voltage begins to drop at all. The power supply circuit is conventional throughout. The 5R4GY was selected for rectifier service because its voltage ratings are high, it is economical of filament power, and electrolysis at its lead-in wires proceeds at a much slower rate than it does in the 5Z3 or 5U4-G. No electrolytics are used.

Figure 1 is a photograph of the amplifier, with its power supply chassis at the right. Eight-prong Jones plugs and sockets are used for inter-connecting the two, with a four prong Jones plug for the speaker. A four-prong socket is also provided on the power supply chassis so that heater and plate supply power may be taken for a pre-amplifier or tuner. The 10 μf 1000-volt input filter is made up of the five 2-μf 1000-volt cylindrical cans on the power-supply chassis. The output transformer is at the left rear of the amplifier chassis, and the cast case holding the two bass tone control chokes is between the 76s and the 6C5s. Metal 6C5s were used at the time the picture was taken, but 6C5-Gs are used in their places now. The two dual 100,000-ohm tone control potentiometers are Mallory, Type LL.

The 347As are shown at the right rear, just this side of the input transformer.

Figure 2 is a schematic of the amplifier, and *Fig*. 3 of the power supply. *Figure* 4 shows the voltage sensitivity and excellent linearity of the amplifier, and *Fig*. 5 shows the intermodulation distortion as read on an Altec Lansing intermodulation analyzer. The frequencies used were 40 cps and 12 kc. Total hum and noise are 75 db below maximum rated output. With the tone controls in the "flat" position, the frequency response at 30 watts output is uniform within 2 db from 30 cps to 25 kc, with almost all of this variation taking place above 15 kc. The tone controls provide a maximum of 8 db boost at 50 cps and 10 db boost at 8 kc. No bass or treble attenuation is provided, as it has been the author's experience that such attenuation is rarely if ever used.

Listening tests, comparing this amplifier with 15, 30 and 40-watt amplifiers of well-known manufacturers, have confirmed the low distortion and excellent transient response of this design.

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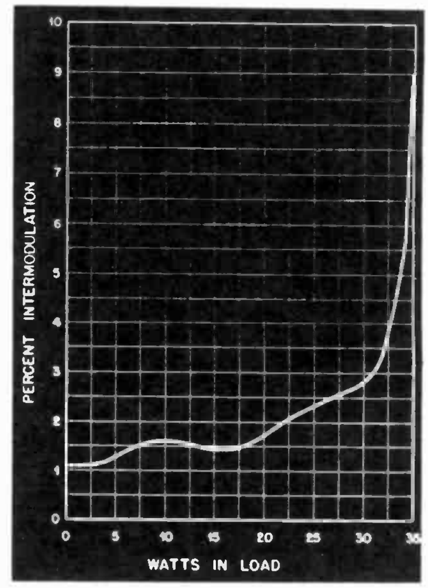

Fig. 5. Intermodulation distortion at various levels.

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POSSIBLE TRANSFORMER SUBSTITUTIONS

	Input	Interstage	Output	Power	1st Choke	2nd Choke
ADC	215A	215D	315E			
Freed			F-1967			
Langevin			300A			
Peerless	K-251-Q	G-212-Q			C-455-A	
Triad	HS-4	HS-27	HS-94			
UTC	LS-12	LS-22	LS-6L4	S-43	S-31	S-27