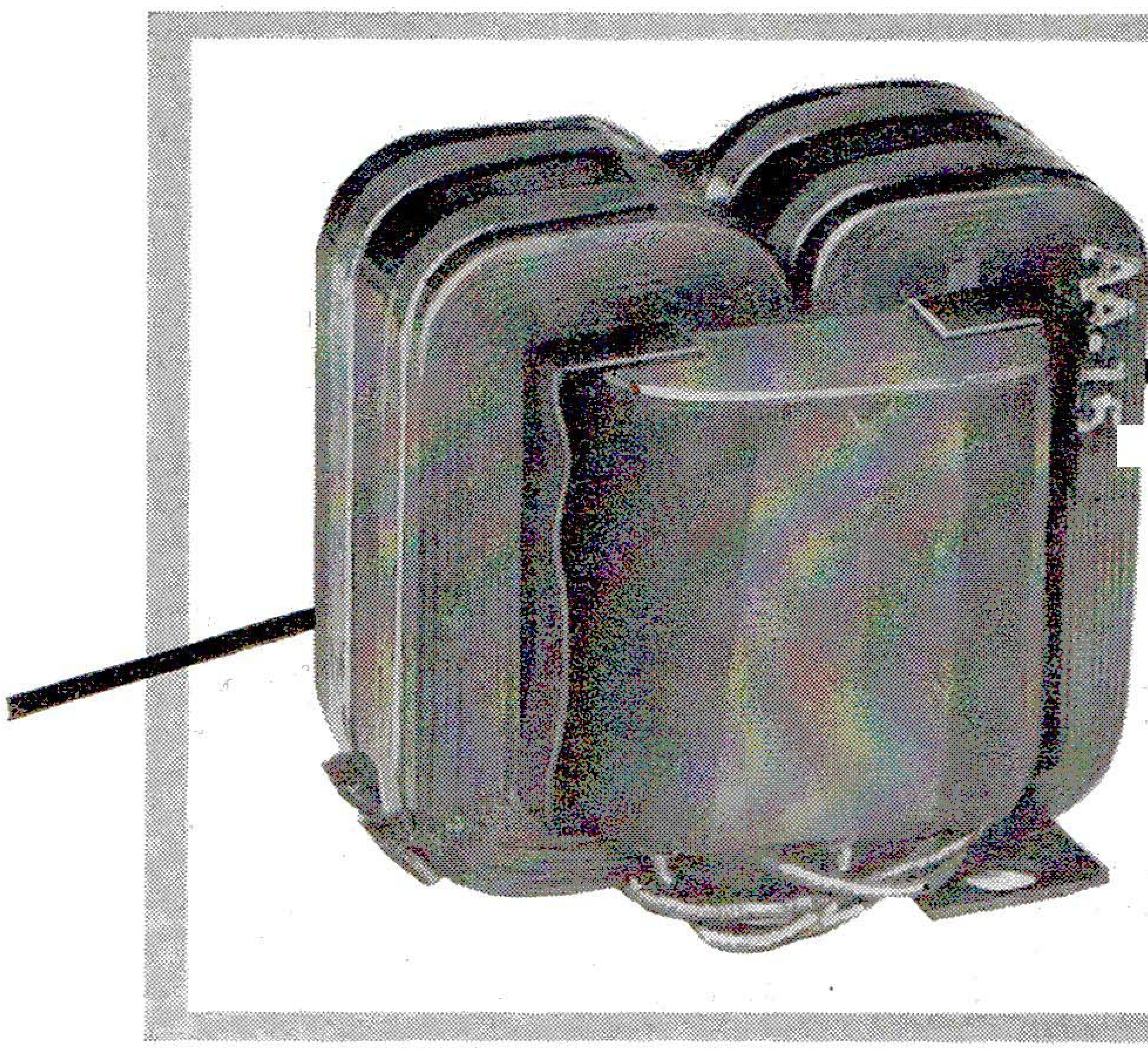
New Transformer Design for Power Amplifiers



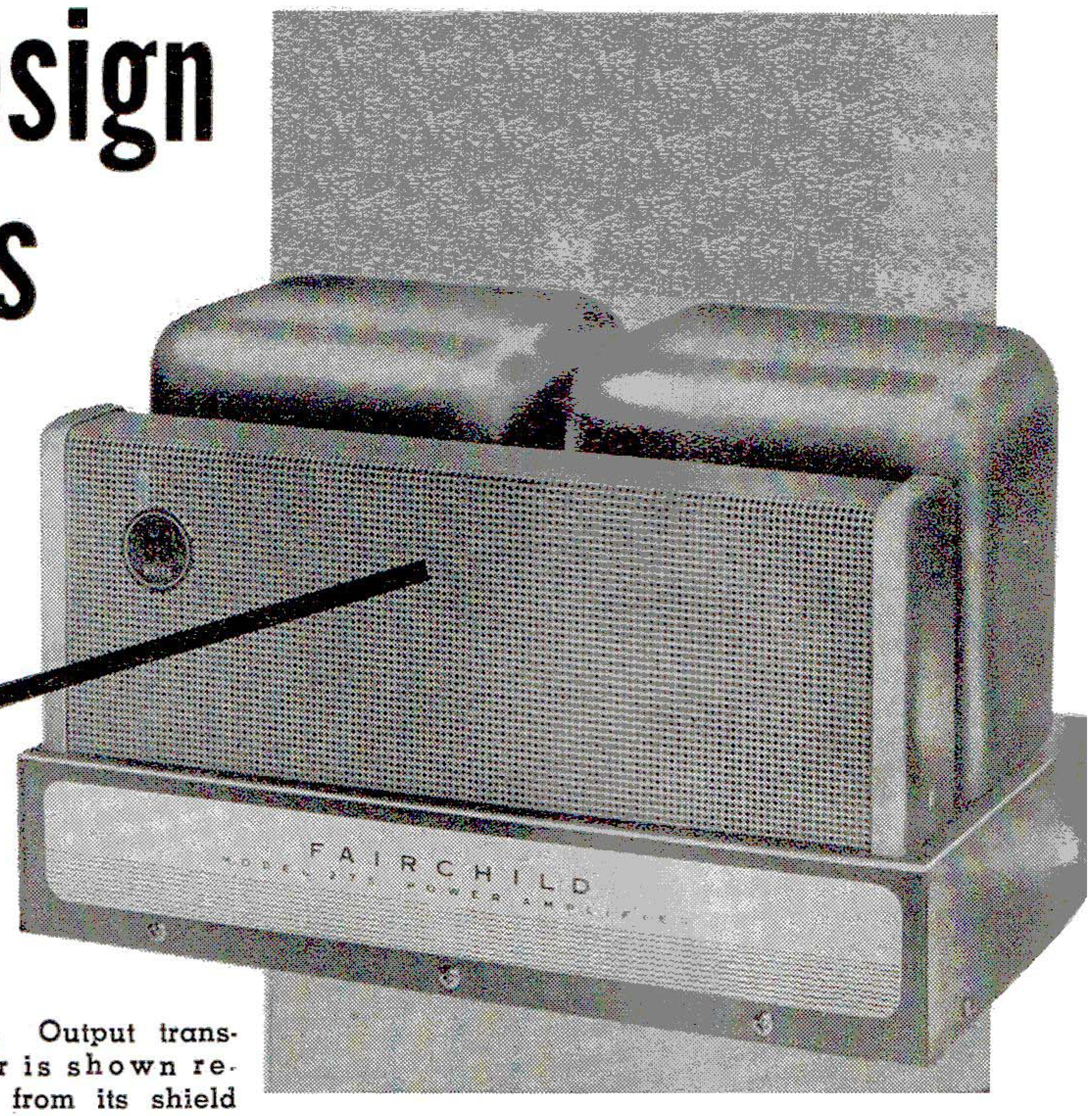


Fig. 1. Output transformer is shown removed from its shield can. This transformer is used in the Fairchild 275 amplifier shown.

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Grain-oriented iron strip core material in high quality output transformer packs high power into minimum space.

IT IS common knowledge among high-fidelity audio enthusiasts that when buying a power amplifier, it is best to look for the largest output transformer since it should provide the best low-frequency response. Today this is no longer necessarily true. For the last several years amplifier engineers have kept this popular conception in mind when designing power amplifiers. And advertising and sales departments have sometimes gone further; in some cases very large transformer "cans" have been employed to cover (hide) output transformers of very small size. That this notion regarding size of output transformer relative to high power is sometimes a fallacy is due to the increasing use today of *grain-oriented iron strip* as the core material of top quality output transformers. See Figs. 1 and 3.

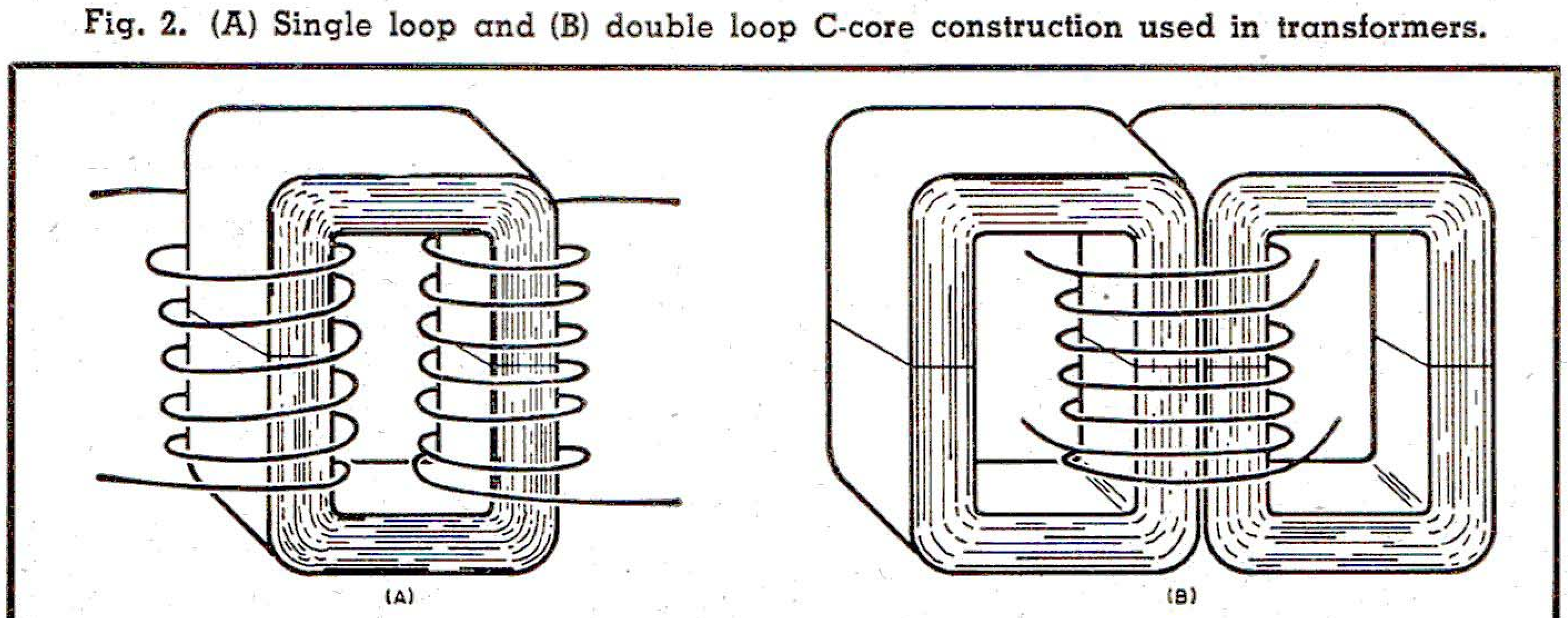
It is true that there is no substitute for a husky core of the highest possible saturation density, that is, one capable of the maximum number of flux lines per cubic inch. In other words, a big transformer may be good. But one whose core is of grain-oriented iron can be much better. It is important to bear in mind that larger cubic volume and/or greater maximum saturation density of core material relate only to the potential power delivery at the low-frequency end of the audio spectrum. Size is no help in getting good high-frequency response. That is controlled by several other factors.

When our transformer designers were given the project of designing the output transformer to be described here, they knew that cost was not a first consideration. The objective was to come up with an output transformer to transfer the greatest possible amount of undistorted power at all audio frequencies, especially in the bass region, from a push-pull tube load of 3400 ohms to the conventional voice-coil impedances.

Although complexity of amplifier circuit design had not been ruled out by the amplifier manufacturer, the best circuit turned out to be a conservative, straightforward design. It is based on three outstanding features: the "Ultra-Linear" (screen-tapped primary) output configuration, which provides maximum power efficiency with lowest distortion, (2) the new *Tung-Sol* 6550 tubes in push-pull for high power handling capacity (made to handle up to 100 watts, they run easy in this amplifier), and (3) a specially designed output transformer which provides some of the unique characteristics of this amplifier. The simplicity of this circuit lends ease to service or adjustment, in addition to lessening the probability of either being frequently necessary.

The bass response, linearity, and power capability of an output transformer depend (other things being equal) on the core material. Most output transformers consist of punched iron laminations stacked in thin layers forming a core around which the coil is wound. In general, heavier cores (thicker cross-sections) provide more power, especially at low audio frequencies. Another way of increasing the low-frequency power handling capability is through use of grain-oriented strip-wound core material. Two well-

Fig. 2. (A) Single loop and (B) double loop C-core construction used in transformers.



known brands of grain-oriented core materials are "Hypersil" and "Silectron."

This material is formed in prefabricated cores which are designated as "C-Cores" because of their shape. There are two types of "C-Core" transformer designs in general use for audio applications. The single core, which has two windings, is shown in Fig. 2A. A more useful shape for output circuitry is the double loop which is shown in Fig. 2B. This construction, see also Fig. 1, employs the greatest cubic volume of iron core relative to copper wire. It is a technique employed only in the most expensive output transformers. This particular method of building a transformer packs the maximum power handling capacity into the minimum space. Incidentally, construction of this sort results in a unit which weighs more per cubic inch of transformer volume than any other kind of output transformer.

The characteristics contributed by different kinds of core materials are graphically illustrated in Table 1 where the relative properties of cores using non-oriented iron in punched laminations and oriented material in strip-wound (C-type) cores are compared. This table shows that it is impossible to give a simple figure for the relative merit of these materials. In each case, the proportions determining the ratio of core to winding actually selected (third line in the Table) would be established by economic factors. Compared on a weight-for-weight basis, the new strip-wound cores win on all points. However, there are other factors which must be considered, such as cost and application, and except for these factors, all output transformers would use "C-Cores"!

The relative power rating figures in Table 1 need some explanation. From the figures it would appear that a transformer of comparable size and efficiency, using oriented material, would deliver ten times the power. While this is true, the principal advantage of grain-oriented material is in its ability to extend the frequency range downwards.

At the low-frequency end core saturation is the greatest problem. Thus it may be seen that there is no substitute for a husky core of the highest possible saturation density. It was found that by using the largest possible loops of oriented silicon steel strips in the double "C-Core" shape, the transformer would deliver 70 watts at below 20 cycles with extremely low distortion. This could not have been accomplished (with conventional circuitry) without a transformer many times larger, had punched laminations been used in the core.

The core must not offer a reactive load for the tubes since this might cause high distortion. At the high-frequency end, two types of reactance are involved; leakage inductance and winding capacitance. Both must be kept as low as possible. Typical values

PROPERTY	NON-ORIENTED IRON PUNCHED LAMINATIONS	GRAIN-ORIENTED STRIP ("C-CORE")
Saturation Density (in gauss)	10,000	17,000
Specific Gravity	7.7	7.6
Ratio of Core to Winding (Weight—normal proportions)	1.7-2.5	.25- .5* .4 -1.0
Core Loss (per lb. at low frequency, 50 cps @ 10,000 gauss)	.63	.25[a] .34[b]
Core Loss (per lb. at medium frequency, 1 kc. @ 2500 gauss)	4.8	1.0[a] 2.0[b]
Maximum Density (relatively constant a.c. inductance)	5000 gauss	13,000 gauss
Inductance Factor (using same turns on core of same size)	1	3.5
Relative Loss Factor (assuming optimum efficiency on same core)	1	1.55
Relative Power Rating (using same size readjusted to optimum efficiency	1	10

Notes: *Applies for cores using a single "C" loop core and two windings. Other figure is for double-loop "C-Core" and one winding assembly.

(a) For strip wound core, strips .005" thick

(b) For strip wound core, strips .013" thick

Table 1. Comparison of transformer with punched laminations and grain-oriented strip.

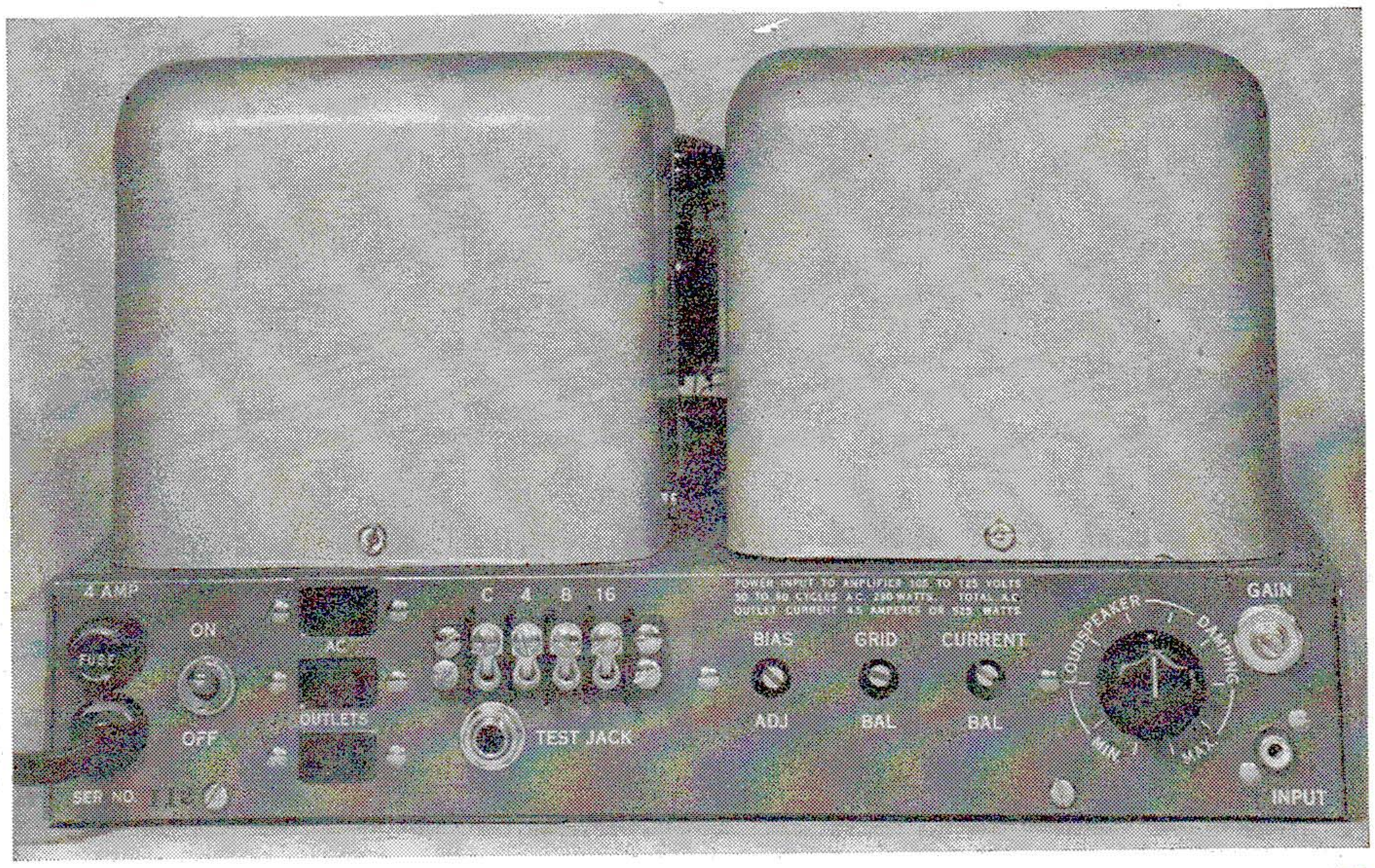
of leakage inductance across half the primary windings of this class of transformer must measure .004 henry or less! The correct proportions required to maintain low distortion output at high frequencies will depend on the loading condition of the tubes employed.

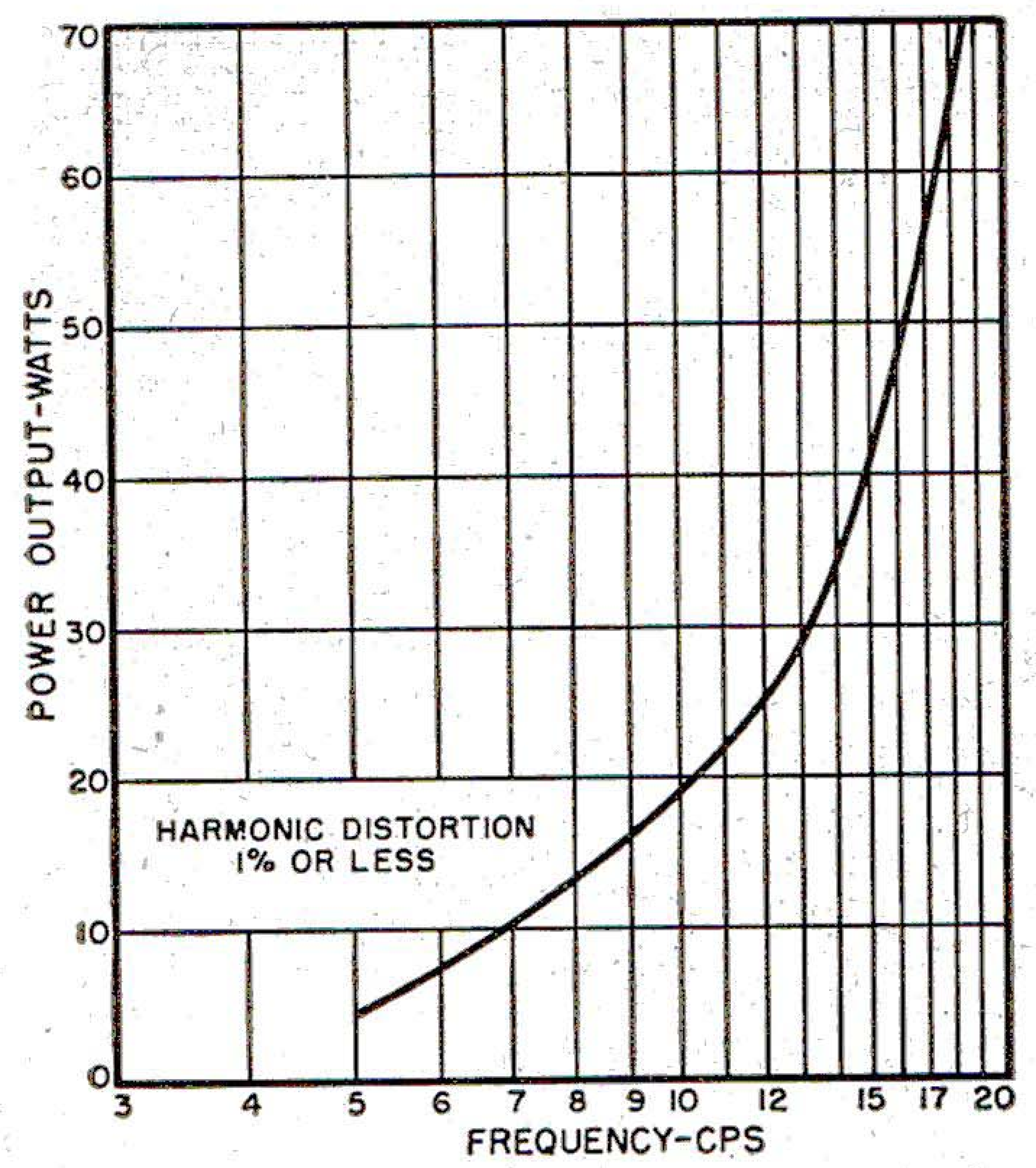
This company decided that although the use of grain-oriented "C-Core" strip for an output transformer is more expensive than would have been an even much larger core of regular transformer punched laminations, *Fairchild's* requirements in regard to low-frequency power delivery to the voice coil from the 6550 tubes called for the use of a double-loop "C-Core" if the transformer was to be kept to any sort of practical size to fit onto a chassis for home use. Even with this extraordinarily efficient core material, the transformer is physically as large as any transformer of ordinary laminated core material in current production for this sort of amplifier.

The transformer manufacturer produced several sample transformers, first adjusting the primary inductance to produce a plate-to-plate load of 3400 ohms, then altering the gauge of the coil wire. Testing sample transformers indicated the correct size wire to allow just enough d.c. voltage loss from the "B plus" supply. One of the little-known, but important, details of audio transformer design is the extremely complicated interleaving of the coil windings. Windings next to the core have much smaller diameter (and consequently less wire length) than windings farther outside. The windings are, therefore, divided into numerous sections and alternated, interleaved, to help equalize the resistance in each half of the primary as well as the leakage inductance and distributed capacitance.

At the present writing there are a number of high-quality power amplifiers, in addition to the *Fairchild* Model 275 to be described, that use the grain-oriented "C-Core" strip material in their output transformers. Among such units are the *Marantz* 40-watt model, the *Fairchild* Model 255 (25

Fig. 3. Rear view of amplifier showing power (left) and output (right) transformers.





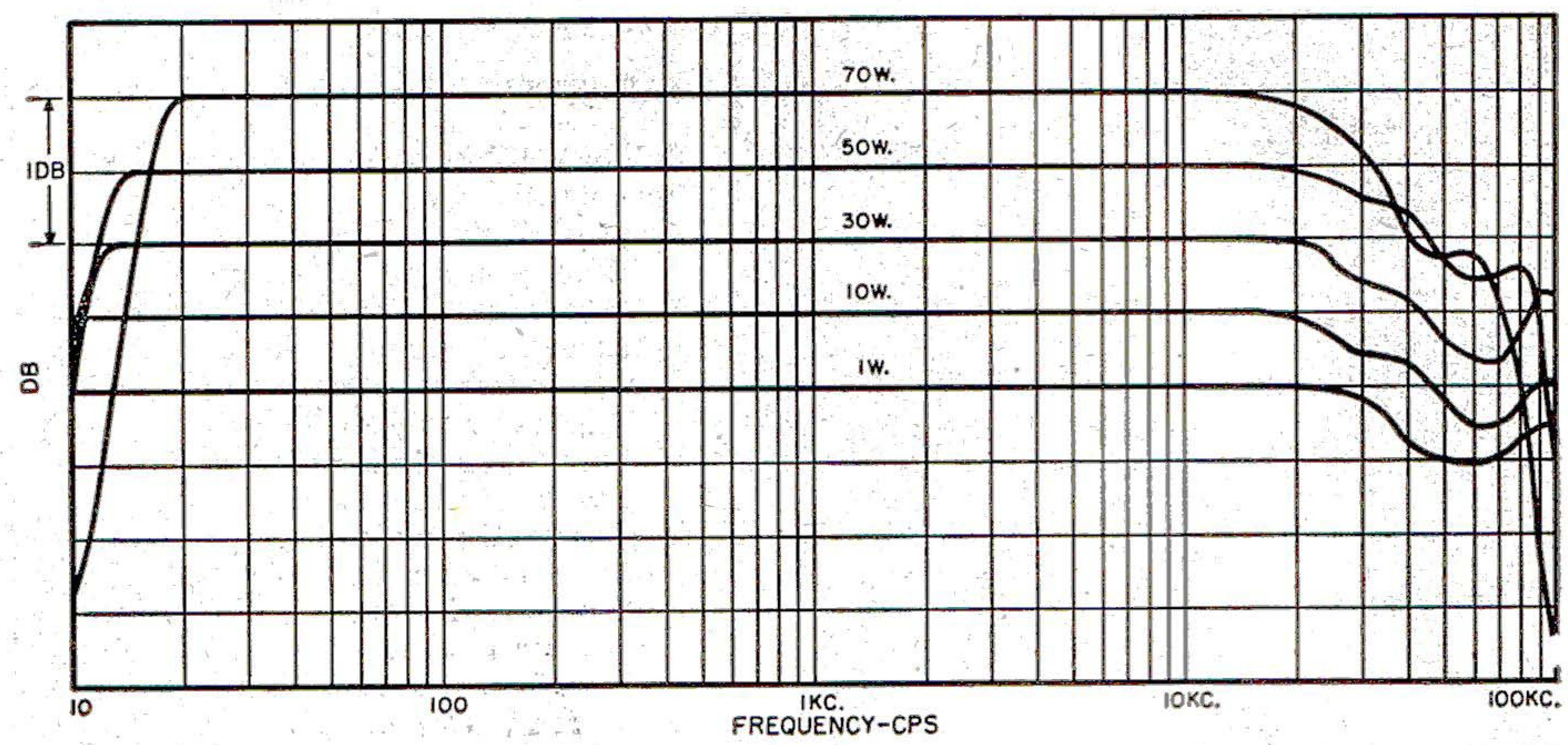


Fig. 4. Power response curves of amplifier at levels from 1 watt to 70 watts. Note that a full power of 50 watts is available down to 15 cps.

Fig. 5. Output at very low frequencies for 1 per-cent (or less) distortion.

watts), *Acro* (kit amplifiers), the *Dynakit, Interelectronics* 40-watt unit, and *Sonotone*. The future will almost certainly see increasing use of grain-oriented iron as output transformer requirements continue to become more stringent, particularly with reference to low-frequency power.

The Amplifier

The Model 275 high power amplifier was designed around this special audio output transformer to provide full power from below 20 to above 20,000 cps. Each stage of the amplifier has conditions of operation well within tube specifications. Three class A triodes precede the output stage, which employs the new *Tung-Sol* 6550 beam tetrode power tubes. Since these tubes are built to produce 100 watts of audio power they run easily at the 75 watts continuous which this amplifier produces. See Fig. 6.

Three types of feedback are employed, not including local feedback at voltage amplifier cathodes. They are (1) conventional negative voltage feedback from the 16-ohm tap of the transformer secondary, (2) negative current feedback, used in the variable damping circuit, and (3) screen grid feedback, through the employment of primary taps on the output transformer for "Ultra Linear" operation of the 6550 tubes. These three types of feedback combine to produce the low IM distortion figures of under 0.5% at 65 watts with any combination of test frequencies. At levels of 10 to 35 watts the distortion figures are so low as to be incapable of being read accurately on standard measuring equipment.

The phase inverter-driver is one half of a 12AV7 with about 300 volts on the plate. The driving voltages for the grids of the 6550 output tubes are taken from the plate and the cathode of this split-load phase inverter. Matched-pair resistors are used here

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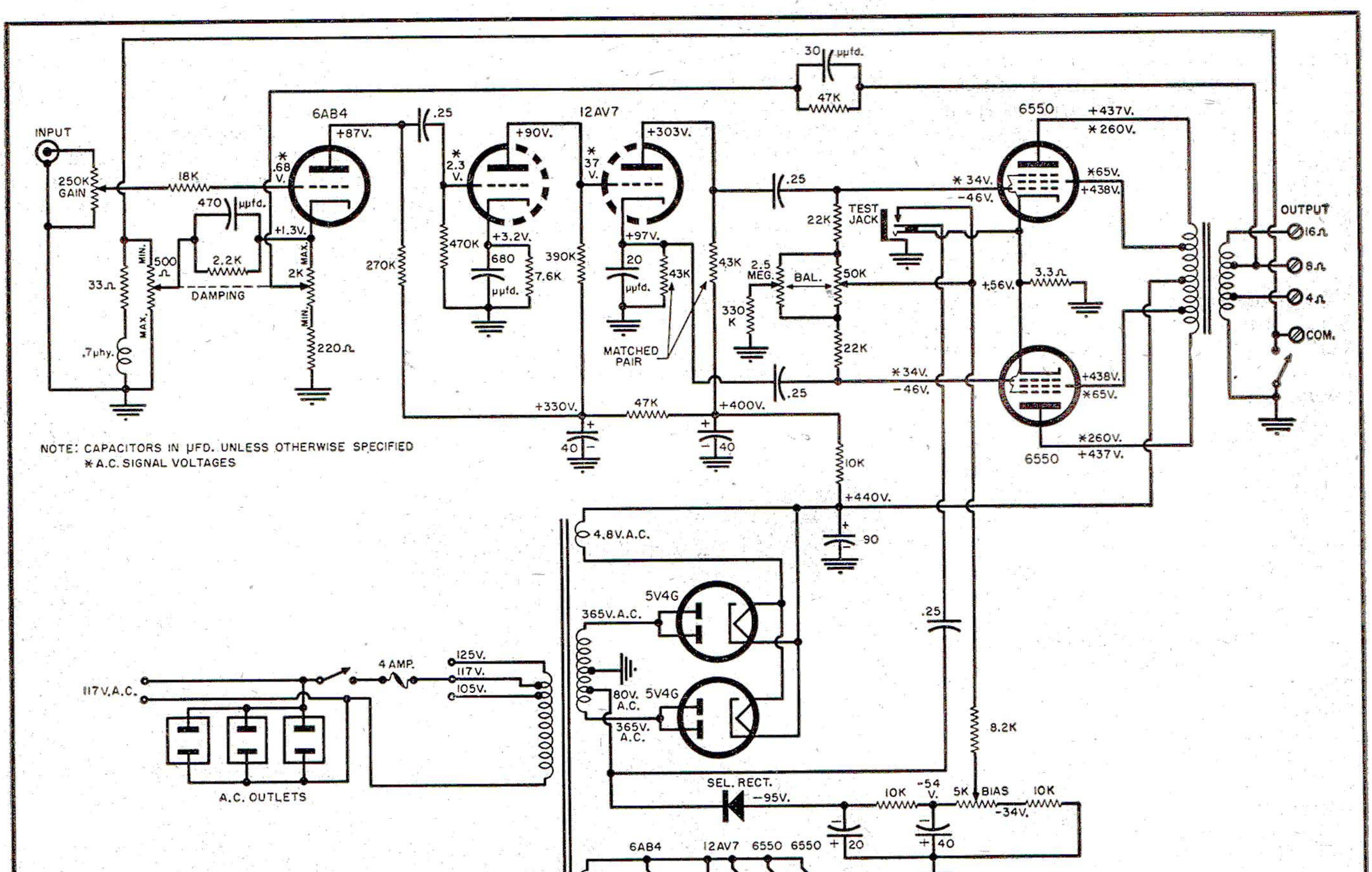

Fig. 6. Schematic of amplifier showing extreme simplicity and straightforward design.

Fairchild Amplifier

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to provide equal signals to the following grids. The cross-coupled phase inverter was rejected because its high-frequency response does not nearly match its low-frequency performance, and it is extremely complicated, non self-balancing, and liable to age out of adjustment. The split-load phase inverter is subject to none of these liabilities, and it provides the smallest amount of phase shift at both ends of the frequency spectrum. It has inherently low distortion due, in large part, to the local (current) feedback that occurs across the large cathode resistor which is an integral part of this circuit.

With the exception of the negative current feedback connection in the first stage, the voltage amplifiers are quite conventional. The circuit constants were selected to give more than adequate gain without sacrificing the very wide bandpass essential for good transient response.

The power transformer is equipped with three taps: 117 volts, 100-105 volts, and 125 volts, eliminating the necessity for a voltage regulator in high or low voltage areas. Thus the rated output of the amplifier is not altered by substantial variations in line voltage.

Another feature which will interest many audiophiles is the provision for variable damping. By means of an exclusive damping control, the stability of the amplifier does not change when the damping factor is changed. Similarly the frequency response distortion and gain remain unchanged. The damping factor is continuously adjustable from .1 to 10. This gives a source resistance at the output terminals which is adjustable from .4 ohm to 160 ohms and on the 16 ohm tap alone from 1.6 to 160 ohms.

Specifications

Frequency response (+0 —.5 db) is 20 to 20,000 cps at any level to 70 watts. The unit's sensitivity is less than .7 volt r.m.s. required for the rated output as against a 1 volt minimum output delivered by most signal sources.

Figs. 4 and 5 show the response of the amplifier. Fig. 5 is especially interesting in that it shows the very low frequency performance. According to Fig. 7, a power output of about 65 watts is available at under 0.5% IM distortion, while about 75 watts is available at 1.5% IM distortion. Square wave performance of the amplifier is shown in Fig. 8.

The input impedance is 250,000 ohms which matches all modern signal sources whether or not cathode follower output is employed. Output impedances of 4, 8, and 16 ohms are provided.

Hum and noise are better than 90 db below rated output (less than 1 mv. on the 16-ohm tap). Six controls are provided for this amplifier: "on-off," gain, dynamic balance adjust, static plate-current balance adjust, damping factor adjust, and bias adjustment of the output stage plus test jack. There are six tubes: a 6AB4, a 12AV7, two 6550's and two 5V4G's. The unit draws 290 watts and will operate over a voltage range of 105-125 volts at either 50 or 60 cycles.

The entire amplifier is housed in a beige and gold cabinet which has been styled by *Raymond Loewy Associates* to match the *Fairchild* preamplifier-equalizer and other of the company's power amplifiers. It is quite heavy, weighing 32 lbs. Over-all dimensions are 8¾" x 13" x 7" high. The audiophile net price is $213.00. —30—

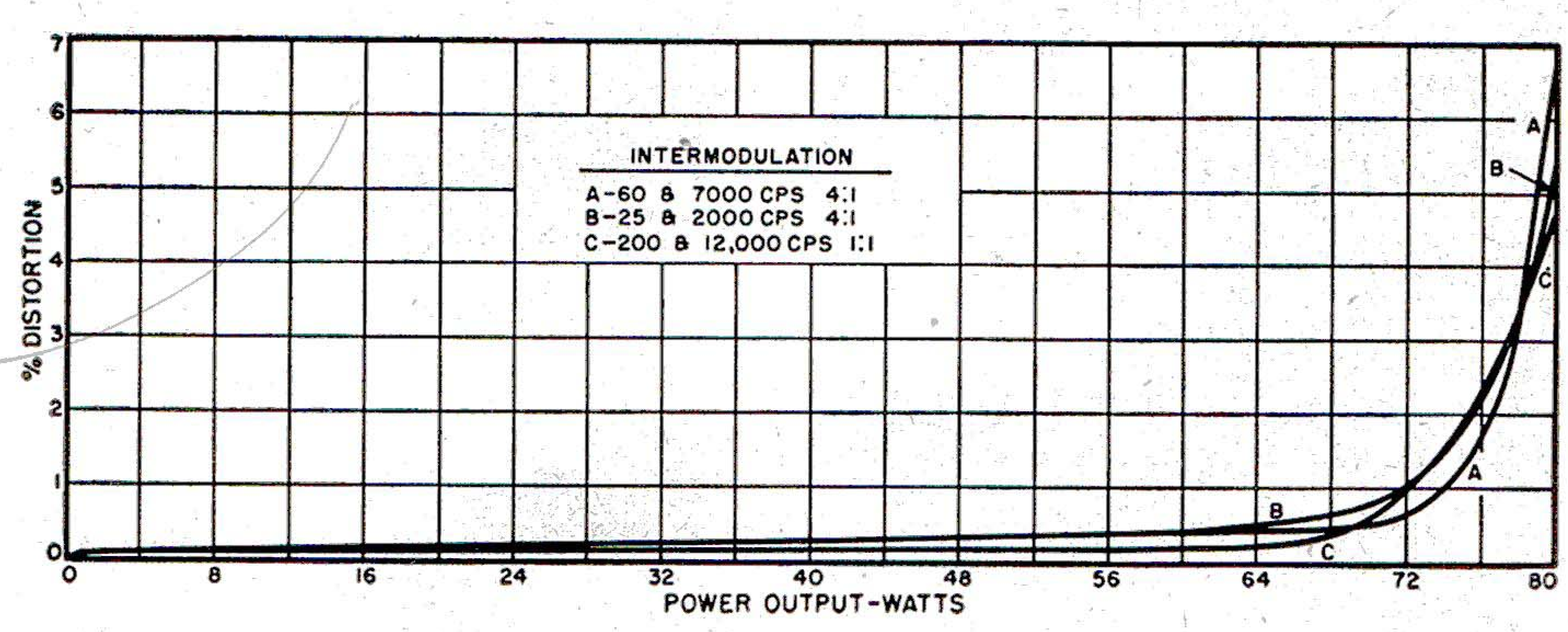

Fig. 7. IM distortion of amplifier at three different input signal mixtures.

Fig. 8. Response of amplifier with 6 kc. square wave input. (A) was taken at 70 watts output, while (B) was at a 40-watt output level. Variable damping has been used in both cases to eliminate a bare trace of ringing visible in (C), which was also taken at 40 watts output with variable damping at minimum.