Another Power Amplifier!

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Here's an amplifier that will loaf through the task of providing music throughout the house—and outdoors too. Also the distortion is extremely low.

The readers first reaction to this article on power amplifiers might very well be, as the title indicates, "Another power amplifier!" Still there are worth-while and interesting things to talk about with respect to vacuum-tube amplifiers. The amplifier described here and some of the design problems are just a bit unusual. In the first place, this is a very high-power amplifier in terms of the power levels which are usually used in high-fidelity systems. The amplifier itself is a relatively straightforward combination of well-tested audio circuits which have been presented in the literature over the years by various authors. This might well be the last of the vacuum-tube amplifiers as far as this writer is concerned. Perhaps a brief explanation of that last statement is in order.

For many years now it has been relatively easy to build essentially distortionless power amplifiers in the 50 or even 100-watt size. The only challenge has been to do it with fewer tubes, at smaller cost, and in the smallest possible space. It would seem that the next logical step would be to completely transistorize the power amplifier and thus make it even smaller and presumably more reliable. It is certainly a worthwhile goal—but it is also very difficult. In fact, at the present state of the transistor art it is very expensive to make relatively high-powered amplifiers with wide frequency response and low distortion.

In the case of the amplifier to be considered here, it was felt that the vacuum tube could be used with standard components to give the required design characteristics in the quickest time and with the least amount of effort. There was need for an amplifier which would deliver 100 to 150 watts under continuous duty sinusoidal output over the entire range from 20 cps to 20,000 cps. This requirement plus the inherent challenge presented by designing and constructing a really good high-power amplifier are the primary reasons for the existence of the amplifier design and design discussion which follows.

The final specifications which were set down for the amplifier are summarized as follows: Power output 120 watts continuous duty, frequency range 20 cps to 20,000 cps, 200 watts for short periods (5 minutes at a time), less than 2 per cent total harmonic distortion at 200 watts and less than 0.5 per cent at 100 watts (over the entire frequency range). These goals were attained in the amplier described here. More detailed performance characteristics are given at the end of this article.

This amplifier is of course much larger than would ever be required in even the largest home audio system contained in a single listening room. There are uses for such an amplifier in addition to those which led to its construction however. For example, it is very useful as a central amplifier for distributing music to an entire house and garden where a large number of individual speaker systems are to be driven. It is also valuable for high-quality commercial sound distribution systems which carry music as well as voice. Even at a 50-watt average

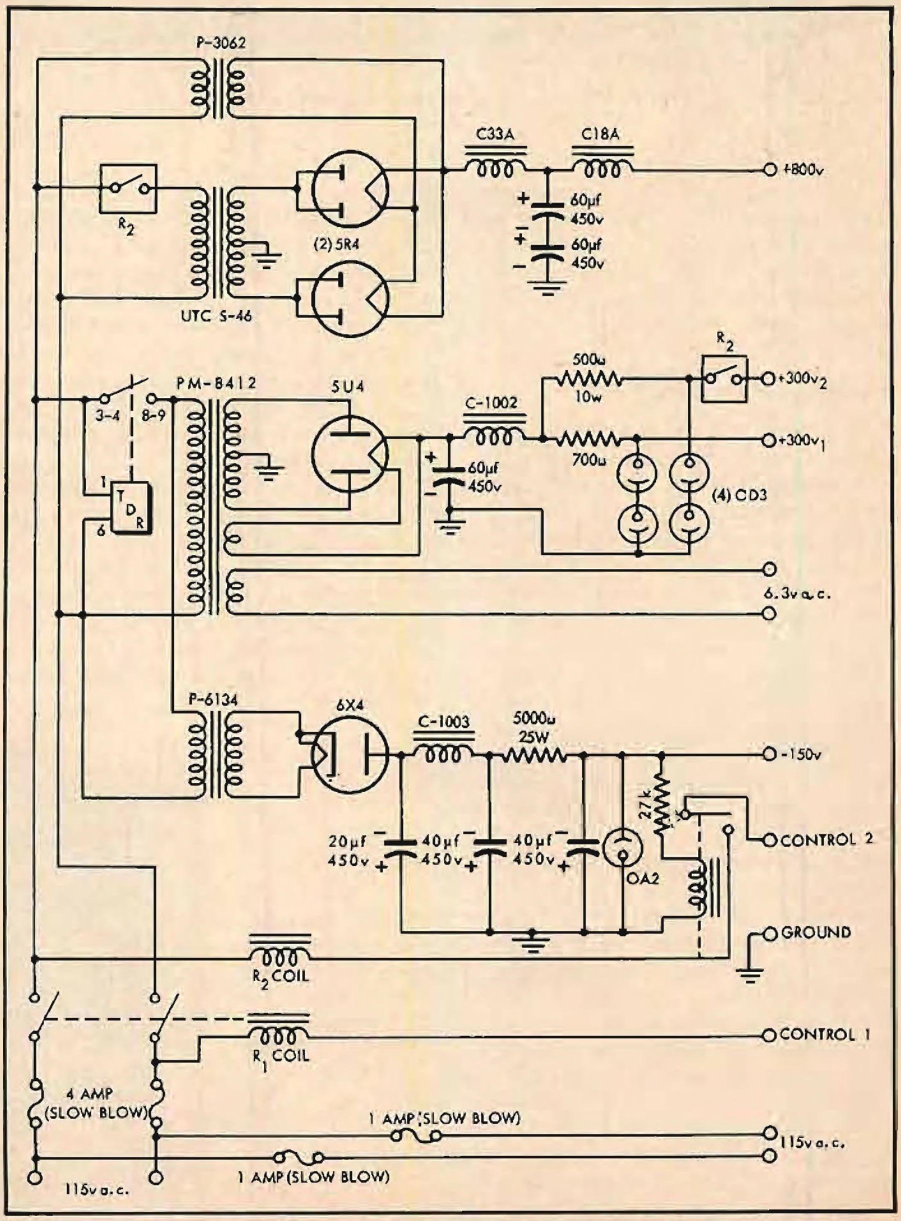

Fig. 1. Schematic diagram of the power supply.

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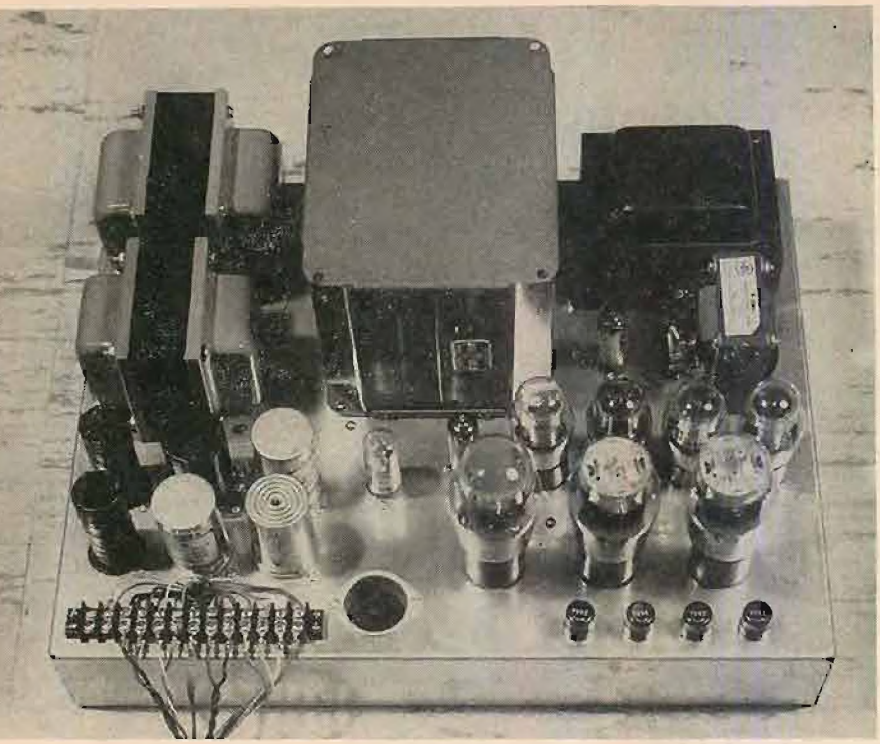

Fig. 2. Top view of the massive power supply.

level this amplifier is loafing along with plenty of reserve for the peaks. The peak output is 400 watts continuous wave or almost 600 watts on the instantaneous peak power basis described below.

Description of the Circuit

Turning first to a description of the circuit, we see in the power supply, *Fig.* 1, a relatively direct, though involved, circuit. There is a bit of complexity due to the need for provision to allow the output-tube filaments and the rectifier-tube filaments to warm up before the main power transformer is turned on. This delay is provided by a time delay relay which delays the turning on of both the 300 volt supply and the negative supply used for biasing the output tubes. Thus the filaments are allowed to warm up for a minimum of thirty seconds after the power switch is turned to the "on" or "standby" positions. Only after the negative supply has reached full voltage and the bias for the output tubes is supplied will the high voltage to the plates and the screens of the output tubes be turned on. The bias current through the plate relay operates a double pole relay which turns on the main high-voltage supply transformer and in addition connects the screen supply for the output tubes to the regulated 300-volt supply which is already in the standby condition. It is convenient to provide two power switches. One closes relay No. 1 which turns the bias supply and the 300-volt supply on. This is then the standby condition. The second switch is in series with the plate relay and thus can be used to override the turning on of the main power if desired. In cases where no long periods of standby operation are required, the second switch may be eliminated and the normal turn-on sequence will be followed each time the amplifier is turned on. The completed power supply is shown in *Fig.* 2 and *Fig.* 3. The chassis is made of aluminum and is a standard 13 × 17 × 3-in. in size. A large amount of filtering is used to keep the total hum in the amplifier to very low levels. In addition, a choke-input filter is required for the main plate supply because the power transformer is is used very near its maximum ratings at the continuous output rating of the amplifier. The main power transformer, UTC S-46, will deliver 300-ma continuously which is enough for 100-watts output. At the 200-watt level, however, the amplifier requires 500 ma. This transformer will supply this current for short periods without difficulty. If continuous operation at 200 watts is required, it would be necessary to use a somewhat larger power transformer.

The driver sections of the amplifier are supplied with 300 volts from a pair of regulators. Two VR-150 voltage regulators are used in series for the driver stages and a second pair similarily connected are used for the screen supply. There is a considerable variation of the screen current in the output tubes as the amplifier is driven from quiescent to full output and hence regulation is almost essential for the screen supply.

The negative supply should, of course, be regulated since the biasing of the output tubes is critical for long-term low-distortion operation. In the present amplifier a single OA2 is used for this purpose with the power supplied by one side of the 300-volt supply transformer through a separate rectifier tube. A separate filament transformer is necessary to avoid any heater-to-cathode voltage difficulties in the 6X4 rectifier.

The power amplifier schematic is shown in *Fig.* 4. Notice that the filament transformer for the output tubes is on this chassis to avoid running the high current required for the tubes through a long connecting cable. The total current required for the output tubes is 6.4 amperes. The filament power for the driver and input stages is taken from a separate transformer winding because it was at first thought necessary to bias the filaments at some d.c. potential with respect to ground. This later turned out to be unnecessary so that they may be connected to the same transformer which supplies the output tubes.

All components are standard. Notice

Fig. 3. Neat, cabled wiring as shown is best practice for the power-supply portion of any amplifier.

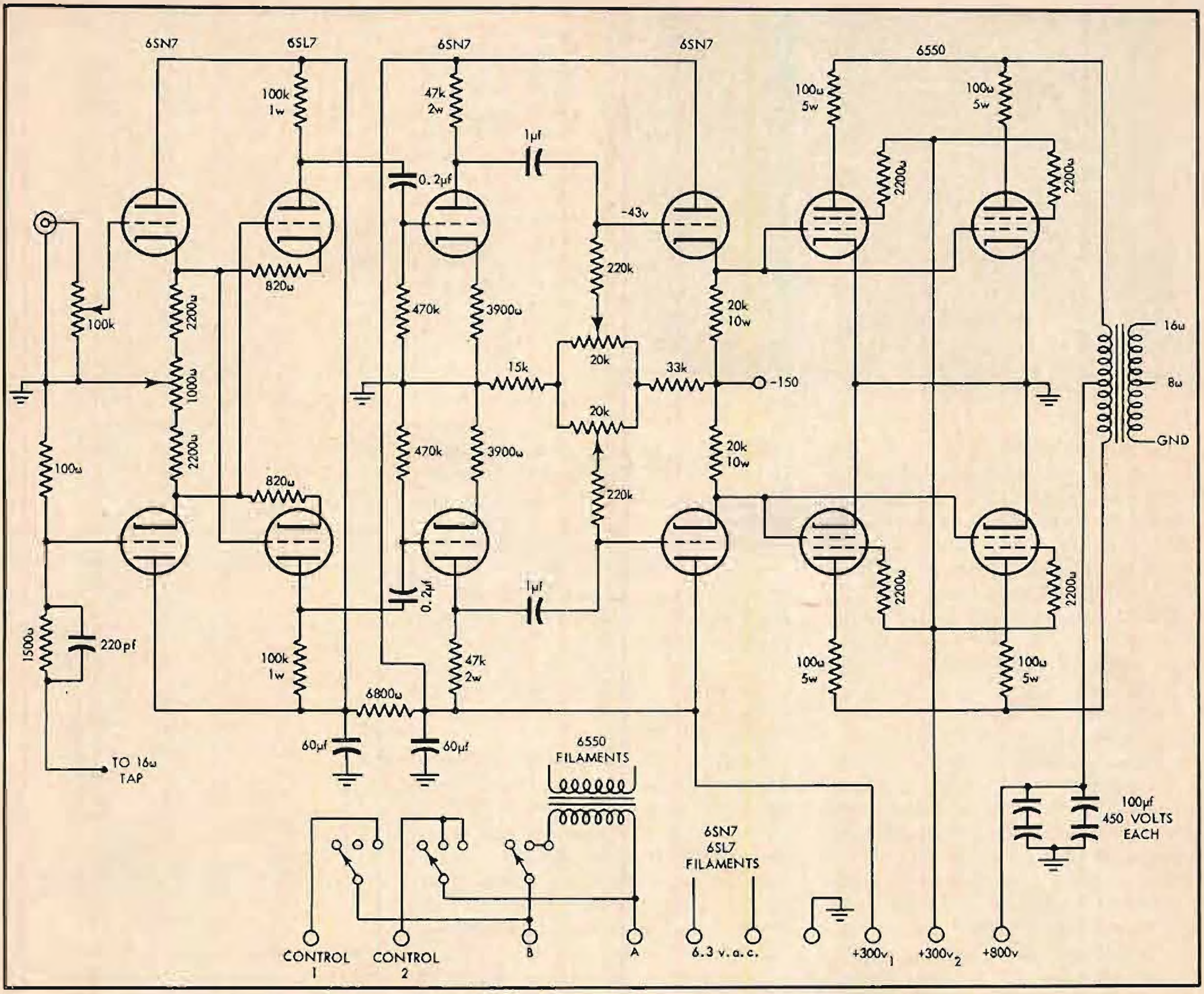

Fig. 4. Schematic diagram of the power amplifier

that there are only four capacitors in the entire amplifier. The high value coupling capacitors are physically quite large unless the "metallized" type is chosen. These may be seen in the photograph of the underside of the amplifier shown in *Fig.* 5. Straight point-to-point wiring is used throughout the amplifier. Good sturdy hook-up wire going from point-to-point and covered with spaghetti will hold its shape and give a neat and permanent job. Several capacitors which were added after the amplifier was completed can be seen on the underside also. These would be more conveniently mounted on the top. They should be protected from the direct radiation from the output tubes, however, since excess heat may be harmful to them. A pair of 20,000-ohm potentiometers are used to adjust the bias on the output tubes to an optimum value. A 1,000-ohm resistor is used for balancing the drive. Adjustment is best achieved by means of distortion measurements, but it is not very critical. Particular care should be taken with the output-transformer leads since they are at high potential and have 1200-volt peak-to-peak signals appearing on them at full output.

The bias voltage at the grids of the output tubes will be about −43 volts. The driver stage is capable of about 140 volts peak-to-peak drive and will thus drive the output stage slightly into the grid conduction region at full output. This will not cause trouble however, since the grids are cathode driven and there is no recovery time involved for bias changes which would normally take place if the output tubes were capacitor coupled to the driver stage. The output clips smoothly and there is no measurable recovery time from even extreme overload. Recovery time from ten times overdrive to one tenth maximum output is less than one cycle at 20,000 cps. Absolutely no signs of high-frequency oscillation or low-frequency instability are present under any signal conditions.

The regulation of the high-voltage supply will have a rather interesting effect on the maximum power output capabilities. The power available for steady-state operation is not as high as it is for sudden short impulses or bursts of sinusoidal signal. Thus one finds that there are different ratings possible for a power amplifier, depending upon the test procedure used. To clarify this problem, consider the following situation. Using the present amplifier as an example, we find that the power supply voltage is 800 volts with no signal, or with a very small signal, but that it drops to 600 volts at the 200-watt level. This drop in voltage does not occur immediately. If the capacitors which are used to filter the plate supply are very large as they are in this amplifier, it will take as long as 1/10 second to drop if full power is suddenly called for. Since the maximum power output possible depends on the plate voltage supply we find that the amplifier will supply considerably more than the steady-state power for a few cycles of applied signal even at low frequencies. The steady-state power in this case is 200-watts rms. This

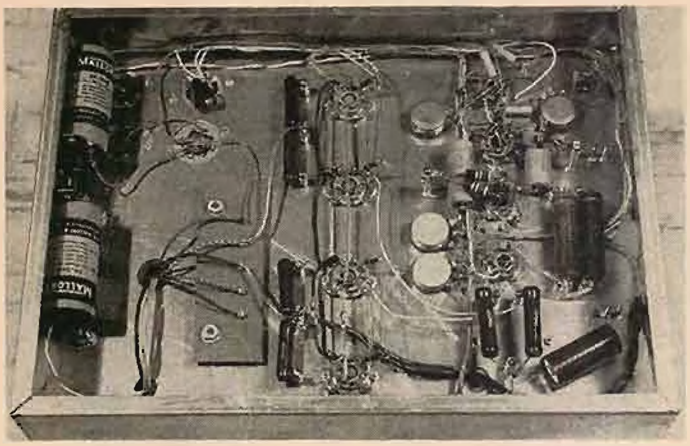

Fig. 5. Bottom view of the amplifier, in contrast to the power supply, shows the diligent use of point-to-point wiring for all signal carrying connections. Note that all components are rigidly fastened down rather than supported on thin leads.

means that the peak power is 400 watts for a steady sinusoidal signal. However, if only a short burst of sinusoidal signal is applied it is possible to obtain almost $(800/600)^2$ times this power, or about 700 watts. This latter figure might be called the instantaneous peak power.

Now it would be folly to try to rate all amplifiers according to the suggestions discussed above. Manufacturers have difficulty enough with the present sets of advertising claims. It is interesting to note, however, that a rating on the instantaneons peak power available is not completely ridiculous. (At least one manufacturer uses this rating technique.) If we consider normal music for example, we find that the ratio of the average to peak power required for undistorted reproduction is in the neighborhood of 10 to 20. This means simply that the loudest tones during a given interval which is not too long will require a 10 or 20 watt amplifier if the average level is 1 watt. The system is thus required to pass high power peaks for only very brief instants and can spend most of the time recovering from these peaks. All of this consideration would tend to indicate that any amplifier would perform slightly better under music or noise conditions than it does when sinusoidal signals are used to test it.

When we use a sinusoidal signal to test an amplifier which is designed to handle music, we are in fact using a signal which is as much unlike music as possible. The reason for using sinusoids, of course, is that it is easy to do and easy to obtain consistant and relatively interpretable results.

This effect became of interest in the present amplifier design because it is somewhat more exaggerated in this amplifier than in a normal low-power amplifier. If the voltage regulation on the power supply were perfect this effect would not appear and the steady-state peak power would be the same as the instantaneous peak power. This would be an ideal situation which can be achieved in low-power amplifiers rather easily by means of electronic regulation. In the case of a 600-volt 500-ma supply, the added complexity of electronic regulation becomes almost prohibitive.

The filtering shown in this design consists of 4 capacitors of 100 μf each connected in series-parallel to give an effective value of 100 μf at 900 volts maximum voltage. The choke-input filter with a swinging choke at the cathodes of the rectifiers gives as good regulation as one can expect for a simple rectifier-filter combination.

As far as the steady-state output of this amplifier is concerned, it will deliver 100-watts continuously. That is, for hours or even days at a time. It will deliver 200 watts for periods of a few minutes. Periods longer than ten minutes have not been tried. But the output tubes and power transformer warm up considerably after this time.

The distortion for the amplifier for several output levels is shown in *Fig. 7*. The distortion at high outputs is easily measurable and is found to lie at about the level anticipated in the specifications. At low outputs the distortion is below about 0.2 per cent and is impossible to measure with the equipment available to the author. It is in fact very difficult to measure distortion levels below 0.2 per cent because of the residual distortion in even the very best oscillators. Special filters are required for more accurate measurements and these can usually be made only at single frequencies. The noise output of the amplifier, which includes thermal noise and hum, is less than 500 μv at the 16-ohm tap of the output transformer. This is negligible and may be attributed to the very heavy filtering in the power supply and the high voltage on the output tubes.

In conclusion, it is fair to say that the amplifier described here has been found to be a very reliable power source when driven by an oscillator for variable frequency applications as well as a very fine power amplifier for high-fidelity applications where extreme output is required. For the serious amateur it is a very useful addition to his stock of electronic tools. Æ

Fig. 6. Top view of the amplifier.

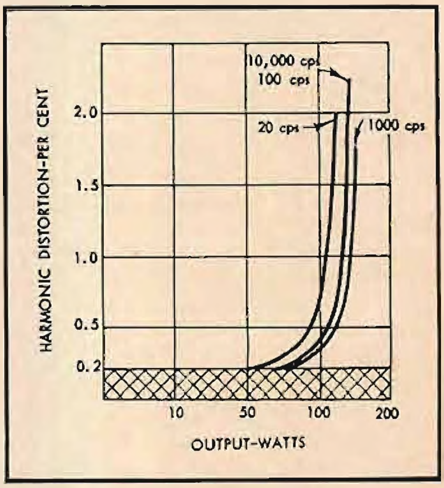

Fig. 7. Total harmonic distortion for several frequencies.

PARTS LIST

In addition to the standard parts which are shown in the schematic diagram, the following list gives the specifications for the transformers and filter chokes which may be replaced by equivalent types:

Output transformer		
Dynaco	A-450	
Power transformers		
UTC	S-46	2000-0-2000 volts, 300 ma
Triad	F-21 A	6.3 volts, 10 amp
Stancor	PM 8412	400-0-400 volts, 200 ma; 5 volts, 3 amp; 6.3 volts, 5 amp
Stancor	P 6134	6.3 volts, 1.2 amp
Filter Chokes		
Stancor	C 1002	15 henry, 75 ma
Stancor	C 1003	16 henry, 50 ma
Triad	C 33A	300 ma, 5/25 henry (swinging)
Triad	C 18A	300 ma, 8 henry
Relays		
Potter and Brumfield, Type M LB-5		10,000-volt plate relay
Potter and Brumfield, Type KA11AY		110 volt d.p.d.t.
Potter and Brumfield, Type KL11A		110 volt d.p.d.t.
Amperite	115NO30T	time delay relay