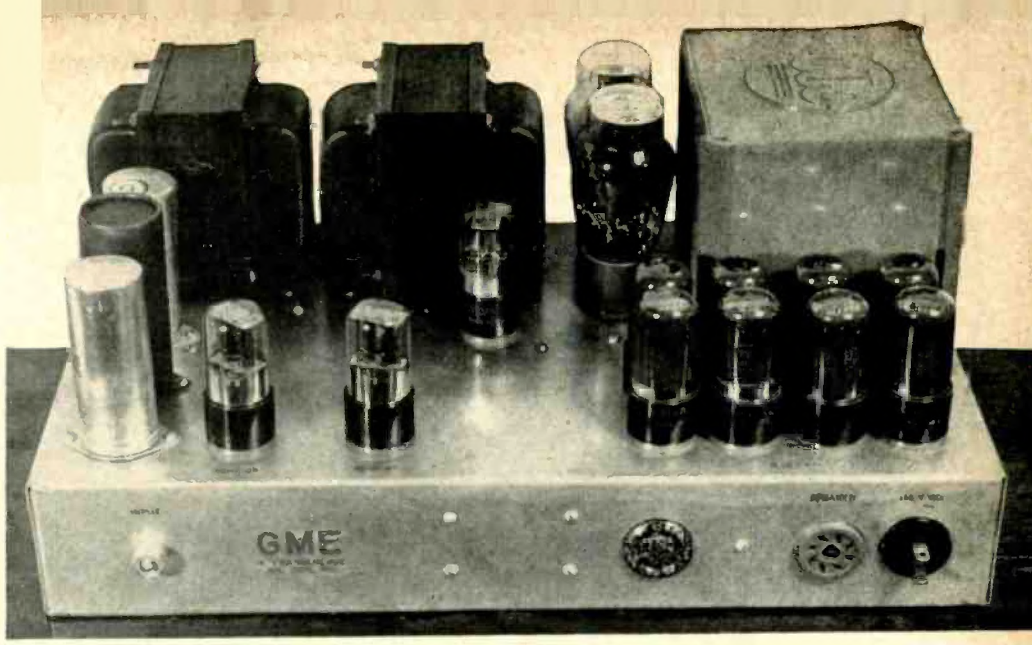

Fig. 1. Eight 6V6 tubes in push-pull-parallel cathode-follower output stage, and two paralleled power transformers give this amplifier an unusual appearance. Simple circuit arrangement provides maximum speaker damping.

A Practical Cathode-Follower Audio Amplifier

W. E. GILSON, M.D.,* and RUSSELL PAVLAT*

A design which provides high damping for the loudspeaker, resulting in excellent transient response.

SPEAKER damping is a comparatively neglected element in the discussion of high-quality amplifiers. Specifications usually state that the frequency response curve can best be drawn with a reliable straightedge, and that the percentage of distortion is negligible at a substantial number of BTU's output per second. The absolute flatness and freedom from distortion so obtained are largely of emotional value to the designer, as a slight variation at high output cannot be detected except by measurement, because the inner ear generates up to 50% harmonic distortion under that condition.[1] Such an amplifier may sound clean, or it may be quite "muddy," depending on the damping.

Such fine sounding specifications are usually accompanied by (sometimes accomplished by) the use of large amounts of inverse feedback. Thus fair damping is usually obtained, particularly if an excellent output transformer is used, or if the feedback is taken from the voice coil winding. Except in a very good transformer, there is regrettably little relation between the wave shapes of the voltages on the primary and secondary windings.

Although in comparable circumstances triodes sound somewhat cleaner than beam-power tubes to the writers, this is an uncertain subjective judgment. Many persons interested in audio reproduction will, when the proper stimulus is applied, inevitably state their dogma "Nothing can beat a pair of 2A3's." One amplifier on the market at present, with the modern equivalent of the 2A3, sounds definitely muddy, largely because of a lack of damping. No inverse feedback from the output winding is used, and the transformer is not of sufficiently high quality to provide close coupling between the tubes and the voice coil. Thus a good solid triode does not inevitably give clean reproduction. It can give very good results if used in a well designed amplifier.

The use of the 6AS7G appears to provide some improvement in damping. An experimental amplifier using this tube, constructed some time ago, sounded remarkably clean, considering that a poor output transformer was used. McProud[2] obtained an impedance of 7 2 ohms across the 16-ohm output winding, using the 6AS7G in a better amplifier with good components.

Considerably better damping can be obtained with a cathode follower amplifier. This type of audio output circuit has seldom been used, probably because of the high driving voltage required. The present circuit has been developed to provide adequate output with an economical source of distortion-free high driving voltage. The circuit appears slightly unconventional, but there is a definite reason for all of the departures from the usual. The amplifier is shown in *Figs.* 1 and 2.

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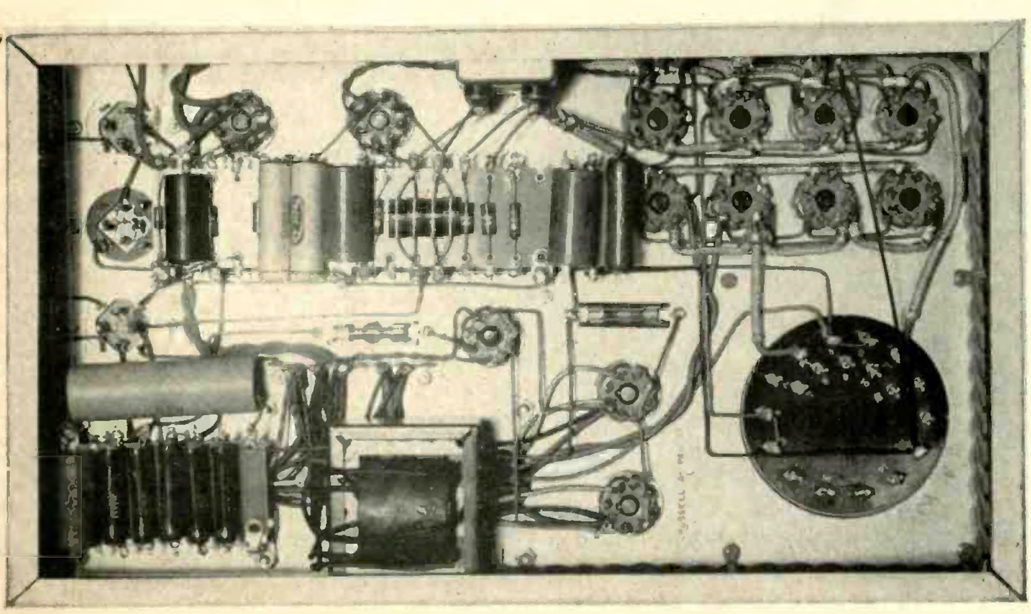
Fig. 2. Underside of amplifier chassis. Note clean, straightforward wiring layout.



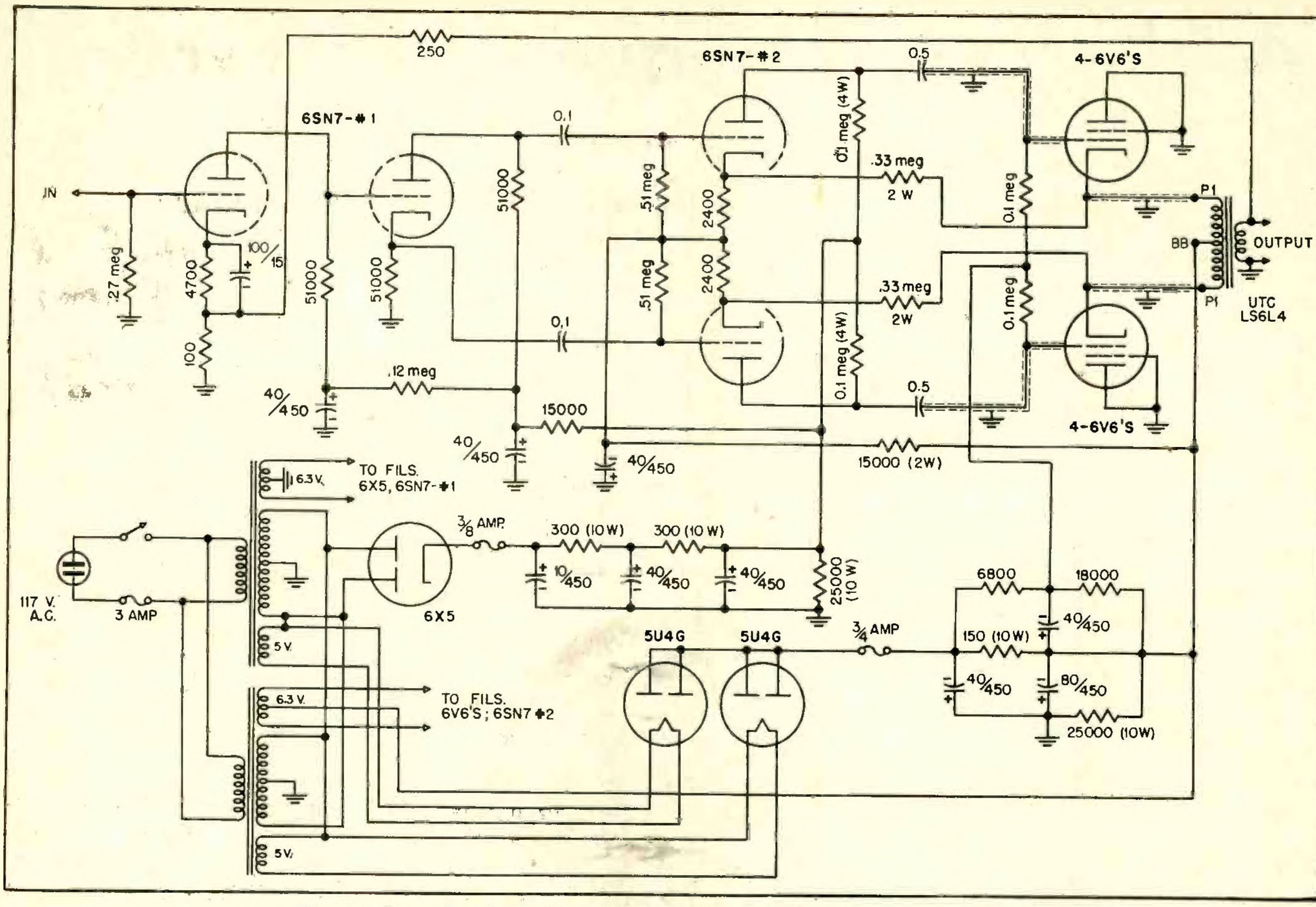


Fig. 3. Overall schematic of complete amplifier and power supply.

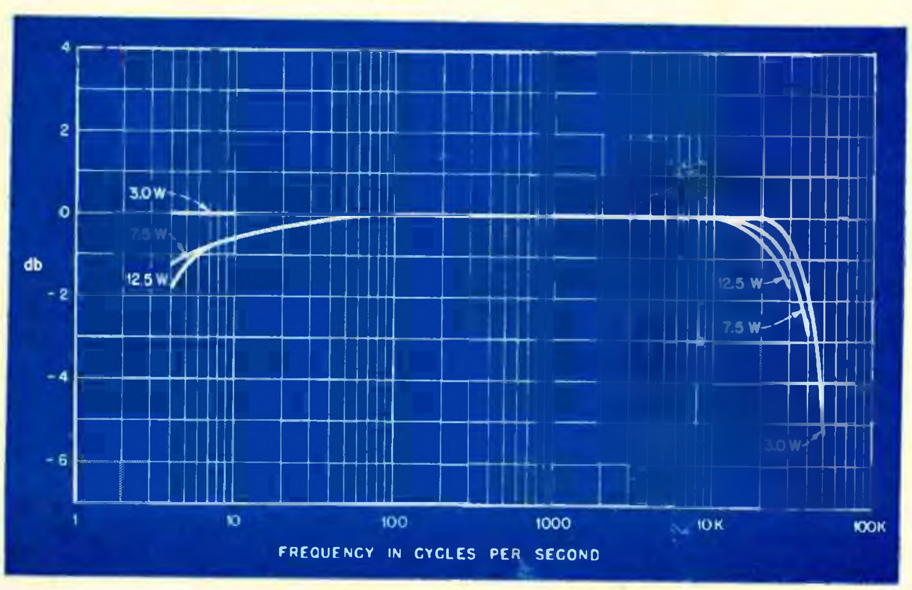
Driving Voltage

The driving voltage is obtained by using a resistance coupled 6SN7 with a plate supply voltage of 700, and a plate voltage of 300. The cathode follower output requires high current at low voltage, and the preamplifier stages require low current at low voltage. To fulfill these requirements, two SNC transformers are used with their high-voltage secondaries in parallel. The combination is then rated at 350 volts each side of the center tap, at 300 ma. Two 5-volt and two 6.3-volt windings are also available. One of the 6.3-volt windings, with its center tap connected to ground, is used for the heaters of the early amplifier stages and for the 6X5GT rectifier, which supplies 350 volts above ground at low power for these stages. The two 5-volt windings are used for the two 5U4G rectifiers, which are connected in the reverse of the usual manner to provide 350 volts below ground at high power, for the output stage. There is a total difference of 700 volts, across which the driver stage is operated. The remaining 6.3-volt winding, which has its center tap connected to minus 350, supplies the heaters of the driver and output stages.

The bias for the final stage is obtained from the pulsating d-c voltage drop across the 150-ohm filter resistor, which voltage would otherwise be wasted. This is voltage-divided and filtered and gives a 25-volt negative bias which is highly stable.

In order to obtain peak output, it is necessary to make the driver and cathode follower circuit slightly more sensitive, as the limitation lies in the phase-inverter output. Approximately 5 per cent regenerative feedback is added from cathode to cathode, increasing peak output and noticeably reducing peak overall distortion. This changes the output impedance imperceptibly because of the large amount of overall degenerative feedback. The regenerative circuit may be omitted if desired.

Fig. 4. Frequency response curves at different output levels. Note that range extends from 4 cps to well over 30 kc.



Early models of this amplifier manifested a variety of motorboating. Because of the low impedance of the output stage, and its consequent control of the power supply voltage, in-phase motorboating is likely to occur due to the push-pull tubes acting as if they were in parallel. The first model using this circuit had the lower ends of the 2400-ohm driver bias resistors connected directly to minus 350. Motorboating occurred even with only the drivers and output tubes plugged in. This can be explained by regarding the minus 350 as the reference point, with ground moving up and down in voltage, depending on the drain by the output stage on the power supply. Ground is coupled to the grids of the drivers through various capacitors and resistors. A negative pulse on the grids of the drivers will cause the grids of the output tubes to become less negative, causing greater drain on the power supply. Ground and the grids of the driver will thus become more negative, and motorboating results. This interesting but undesired phenomenon was eliminated by inserting a 15,000-ohm resistor between the 2400-ohm bias resistors and minus 350, and connecting a 40-μf capacitor from the junction to ground. As it is now connected, when ground moves up and down both the grids and cathodes move with it, and the output is practically zero.

Speaker Damping

The primary purpose in the design of the amplifier was to achieve unusually good damping. This has been carried to such an extent that the limiting factor is the d-c resistance of the output winding, less than one ohm. The cleanness of reproduction obtained is definitely noticeable. A good demonstration is side 4 of Columbia's "Young Person's Guide to the Orchestra", which has excellent low notes as well as the crack of a whip near the end of the record. The extreme low frequencies are more naturally reproduced because of the added control of the voice coil. There is no muddiness. Another test of the damping, somewhat analogous to definition in a camera lens, is the separation of rapidly rolled drumbeats.

It is usually suggested that the output of a tweeter be reduced by means of a resistor network, because it is higher in efficiency than a woofer. In listening tests it has been found tentatively that the introduction of a resistance in series with a good compression type tweeter reduces its sharpness and clarity, making it sound like an ordinary cone type tweeter. It is thus suggested that other methods might be tried, such as multiple tweeters spreading the sound more widely, for example.

The amplifier is used primarily in our "Gilson", a radio-phonograph combination using a Jensen 18-inch theatre speaker with two Jensen tweeters. Passably good reproduction can be obtained, however, even with a 15-inch

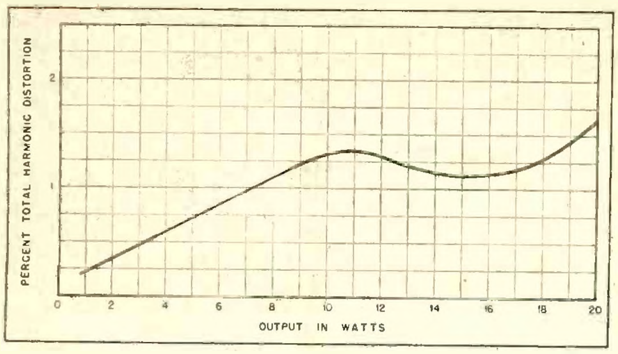


Fig. 5. Total harmonic distortion vs output at 50 cps.

speaker designed for home use, because of the control of the voice coil.

The frequency response is shown in *Fig.* 4, the total harmonic distortion in *Fig.* 5. The deviations shown cannot be detected by the ear.

Figure 6 shows oscillograms taken from the 16-ohm voice coil of a 15-inch speaker. The response to a square wave at 200 cps is shown at (A), at 5000 cps at (B).

The effect of damping is demonstrated at (C) and (D). A 0.5-volt d-c pulse is applied to the input, producing a transient, the shape of which depends on a number of factors. (C)

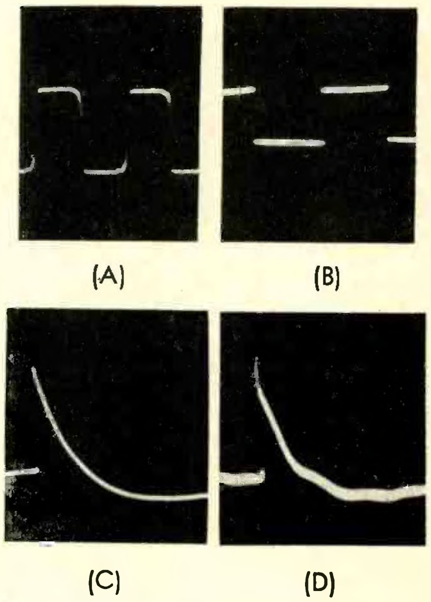


Fig. 6. Oscillograms of output for various input signals: (A) 200-cps square wave; (B) 5000-cps square wave; (C) 0.5-volt d-c pulse at input, speaker connected normally; (D) same signal as at (C), but with 10-ohm resistor in series with voice coil. Last two oscillograms show effect of damping.

shows the lack of overshoot and smooth exponential return as the coupling capacitors discharge. At (D), a 10-ohm resistor has been connected in series with the 16-ohm voice coil. The potentials produced by the marked overshoot and continued vibration of the voice coil can clearly be seen.

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