The "goodness" of an amplifier is not shown by its circuit diagram. Circuits have no inherent magic properties, but are merely the tools with which the designer seeks to achieve a certain result, and different designers—provided always that they have the same high standards in view—may achieve the same results by different means.

—D. T. N. Williamson [1]

High-Quality Circuits

Observations on Ultra-Linear, plus circuit features of three high-quality power amplifiers

By JOHN K. FRIEBORN

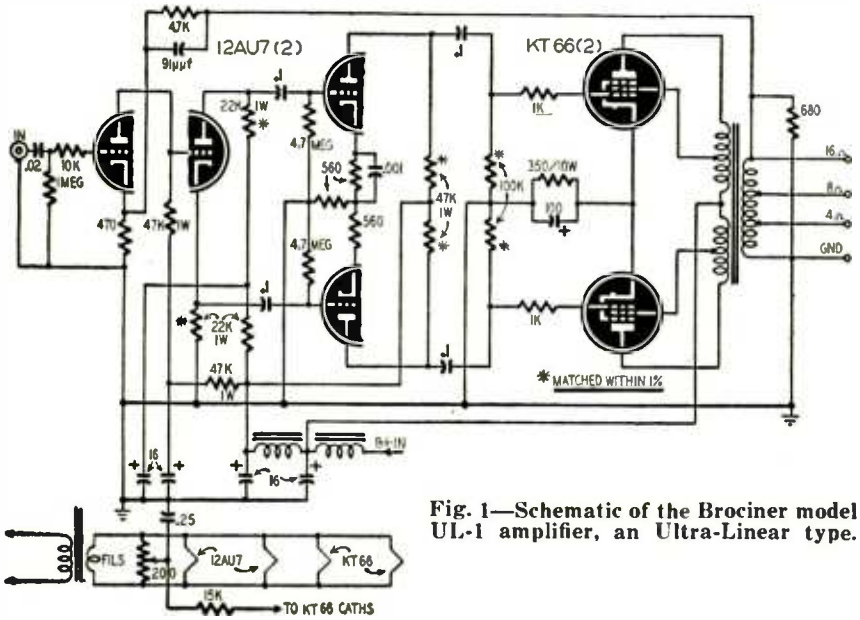


Fig. 1—Schematic of the Brociner model UL-1 amplifier, an Ultra-Linear type.

SINCE Williamson published the first description of his "High-Quality Audio Amplifier"[2], in 1947, other audio amplifier designers have had two apparent choices, "beating him or joining him." A popular compromise is to adopt his general circuit arrangement, but to replace the class-A triode output stage with another type giving higher efficiency. The Ultra-Linear version of the Williamson amplifier is the solution which recently has received the largest amount of publicity in this country. Amplifiers made by two American manufacturers utilize a type of output stage which is less well-known, but which Williamson himself regards as a more substantial improvement than the Ultra-Linear. Still another American amplifier uses a type of output stage which apparently can give results better than some of us expect of it.

Ultra-Linear

Where the original Williamson circuit uses triode-connected beam tetrodes in this output stage, the Ultra-Linear version has the screens connected to taps on the output transformer primary. A typical example of an Ultra-Linear Williamson is the Brociner model UL-1. (Fig. 1.) One explanation of the low distortion of this output circuit is that, since connecting the screens to the plate terminals of the transformer primary (the triode connection) produces a plate characteristic which is nonlinear in one direction and

connecting the screens to the E plus terminal of the transformer (the tetrode connection) produces a characteristic which is nonlinear in the other direction, screen connections to points somewhere between the center and the ends of the primary will produce approximate linearity[3]. (See Fig. 2)

Williamson points out[1] that the Ultra-Linear circuit is in effect a tetrode circuit with negative feedback from plates to screens and that the same improvement in linearity can be obtained with other circuits which give equivalent amounts of negative feedback. In fact, he remarks that equally good results can be obtained with an ordinary beam-tetrode output circuit by using sufficient feedback around the entire amplifier. The disadvantage of that arrangement is that sufficient over-all feedback to enable a tetrode output circuit to better the performance of the original triode Williamson may be difficult to obtain without instability. It can be done, as one of the amplifiers to be discussed in this article demonstrates. Inserting some feedback in the output stage makes it possible to reduce the distortion any specified amount with less over-all feedback.

Coupling from plates to screens is only one way in which feedback can be produced in the output stage. Feedback voltage can be inserted between the grid and cathode and it would be more effective than feedback voltage inserted between the screen and cathode. Such an arrangement has been used in a British amplifier, the Acoustical[4], and in the two American amplifiers referred to above, the Bell model 2200 (Fig. 3) and the Bogen model DB20 (Fig. 4). It can be seen from the diagrams that the voltage across the feedback winding of the transformer actually varies both the cathode-to-grid voltage and the cathode-to-screen voltage (inverse feedback is applied to both the grids and the screens). Figures given by Williamson[1] indicate that this arrangement gives less distortion in the output stage alone than either the triode or the Ultra-Linear tetrode circuit. Specifications published by the manufacturers of both the Bell and the Bogen amplifiers indicate a harmonic distortion of 0.3% for an output of 20 watts. Variations of distortion in the Bogen model DB20 with power and with frequency are shown in the curves of Figs. 5 and 6, which were furnished by the manufacturer.

Bell model 2200

The Bell amplifier has a few notable variations on the conventional arrangement, aside from the output stage. The arrangement of two resistors and one capacitor in the cathode circuit of the first stage serves two purposes. First, the cathode resistor is partially bypassed, so that there is less feedback within this stage and greater over-all gain without feedback. For the same amount of over-all gain with feedback, the amount of feedback which can be used, and the reduction in over-all distortion, is greater. Second, since the negative feedback path is through the capacitor, less feedback results at low frequencies and the gain is increased to compensate for the low-frequency loss in the coupling capacitors.

The phase inverter in this amplifier is not direct-coupled, as it is in most variations of the Williamson amplifier. No 1% resistors are used in the push-pull stages, but other provisions are made to reduce the amount of unbalance. The push-pull voltage amplifier has an extra resistor, R1, common to the cathode circuits of both tubes. The usual cathode potentiometer for balancing the output stage tubes is used.

(The tube heater which is connected in the cathode circuit of the output stage belongs to the preamplifier. Each of the amplifiers described in this article, except the Brociner, includes a four-stage preamplifier, equalizer, and tone-control circuit, using two twin triodes. Only the main power amplifiers will be described in detail.)

Bogen model DB20

The Bogen amplifier has other unusual features in addition to the output stage design. It is particularly notable for its many uses of feedback. In addition to inverse current feedback in six of its eight stages, due to unbypassed cathode resistors, interstage negative feedback is used in the equalizer and in the tone-control circuit (not shown in Fig. 4). The power-amplifier section has not only the output-stage cathode feedback previously mentioned and over-all negative feedback, but also positive feedback between the cathodes of the last two stages.

This amplifier has the conventional direct-coupled phase inverter (V1-b). The plate voltage of V1-a and the grid voltage of V1-b are adjusted with R1 so that the distortion in the V1-b stage will be a minimum. Few critical components or adjustments are used. The phase inverter load resistors, R2 and R3, are matched by selection of pairs from ordinary production tolerance types. Other resistors are unselected. The common cathode resistor in the push-pull voltage amplifier stage improves the balance in that stage. The use of multiple feedback loops in the amplifier makes it possible to obtain the

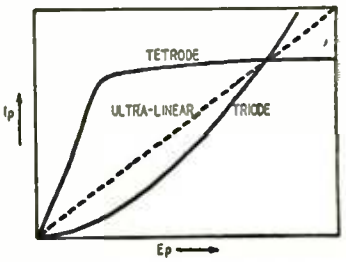


Fig. 2—Triode, tetrode and ultra-linear circuit plate characteristic curves.

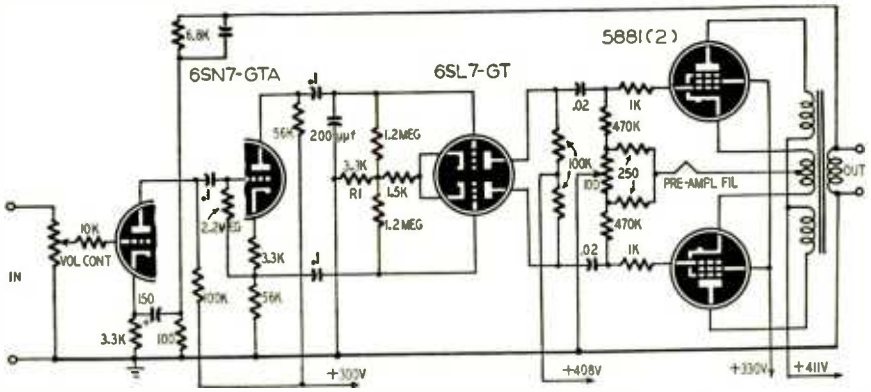


Fig. 3—The Bell model 2200 amplifier. Note that first stage is a.c. coupled.

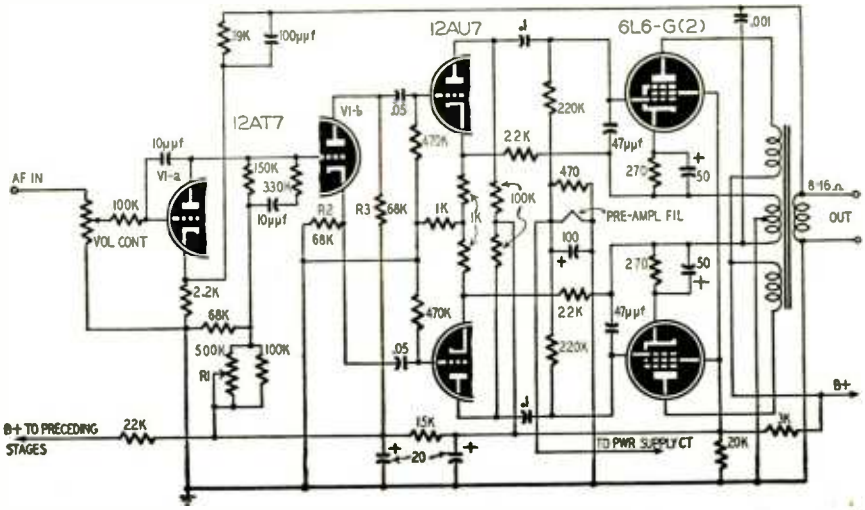


Fig. 4—The Bogen DB20 amplifier uses both positive and negative feedback.

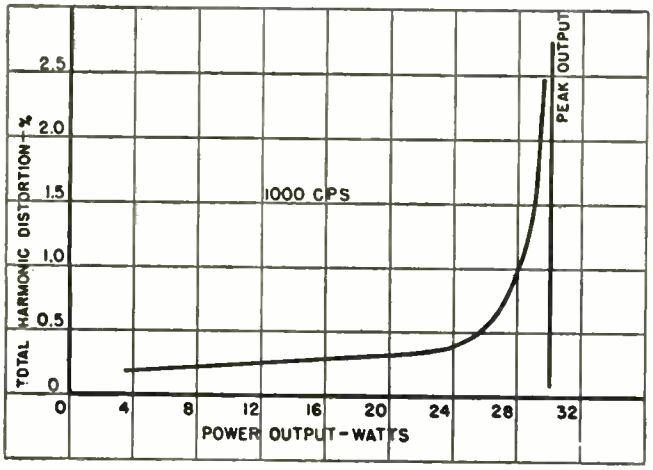


Fig. 5—A graph showing the variation in harmonic distortion at various power output levels in the Bogen model DB20.

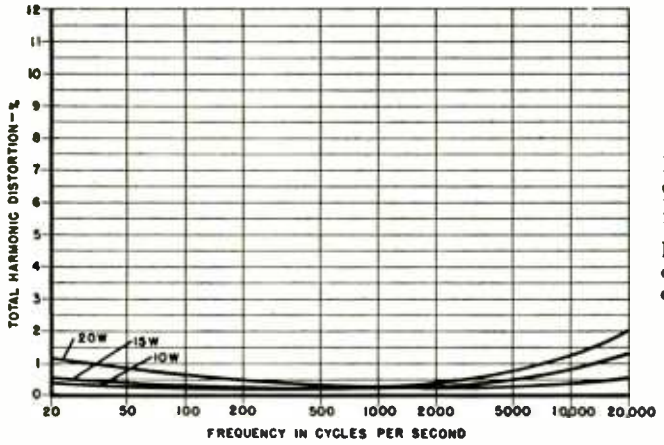
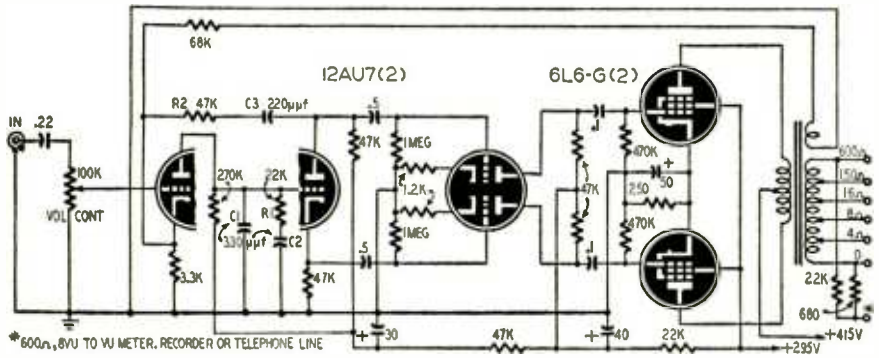
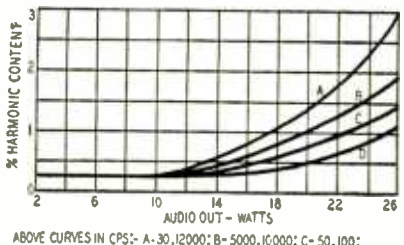


Fig. 6—Harmonic distortion in the DB20 at the 10-, 15-, and 20-watt levels for frequencies up to 20 kilocycles.





ABOVE CURVES IN CPS:- A-30,12000; B-5000,10000; C-50,100; D-400,1000

Fig. 7 (above)—The Stromberg-Carlson AR-425 amplifier in the schematic has a sensitivity of 2 volts input for full rated output. Fig. 8 (left)—A graph of the harmonic distortion variation in the AR-425 amplifier at different frequencies as well as power output levels.

specified level of distortion without critical balancing of the output stage.

Stromberg-Carlson model AR-425

The power-amplifier section of Stromberg-Carlson model AR-425 custom amplifier is shown in Fig. 7. A direct-coupled phase inverter circuit is used, but the push-pull voltage-amplifier stage does not have a common cathode resistor and close-tolerance resistors are not used for balancing. A simple beam tetrode power stage is used in this amplifier, with no intrastage feedback, yet the harmonic distortion at 20 watts output is approximately the same as in the other amplifiers described in this article, according to curves furnished by the manufacturer (Fig. 8). Using frequencies of 60 cycles and 7 kilocycles in a 4 to 1 voltage ratio, this amplifier develops only 0.7% intermodulation distortion at 15 watts output. Using 40 cycles and 7 kc, the intermodulation distortion is 1.2% at 15 watts. When making power runs to determine the percentage of intermodulation distortion, the 15-watt complex waveform measured by the distortion meter is equivalent to 23.5 watts of sine-wave signal having the same peak value as the resulting signal produced by intermodulation within the audio amplifier.

The low distortion is accounted for partly by the large amount of over-all negative feedback used. To overcome the resulting tendency to oscillation at high frequencies, the gain of the first two stages at high frequencies is reduced by two separate means.

The output of the first stage is shunted by a combination of two capacitors and one resistor, C1, C2, and R1, so that the effective load impedance at high frequencies is reduced. Also, negative feedback at high frequencies is provided between the plate of the second stage and the cathode of the first, through C3 and R2.

All four of the amplifiers discussed in this article have damping factors of around 15, compared with 30 for classical triode versions of the Williamson. That is, the various tetrode versions have an output impedance of about one-fifteenth the speaker voice-coil impedance, against one-thirtieth for the triode circuit. Williamson points out[1] that the effective damping resistance is the sum of the amplifier output resistance and the speaker voice-coil resistance. The tetrode circuits therefore have total damping resistances, not twice as great as the triode circuit, but only about 3% greater. END

References

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[2] "Design for a high-quality amplifier," D. T. N. Williamson. *Wireless World*, April, 1947, p. 118, and May, 1947, p. 161.
[3] "An ultralinear amplifier," D. Hafler and H. I. Keroes, *Audio Engineering*, November, 1951, p. 15.
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