# A High-Quality AUDIO AMPLIFIER

Commercial version of the Williamson amplifier, the Radio Craftsmen Model 500.

By
**EDW. S. MILLER**
Chief Engr., The Radio Craftsmen, Inc.

***Complete data on a commercially built Williamson amplifier which uses special low-distortion tubes.***

ALTHOUGH the now-famous Williamson all-triode amplifier circuit, originally described in 1947, has been reproduced in the literature many times with various modifications, only recently has a complete amplifier based on this circuit been manufactured commercially. This chassis, known as the Craftsmen 500, was designed by *The Radio Craftsmen, Inc.,* Chicago. In the design, particular emphasis was placed on a unit that not only provided good operation over the range from 20 to 20,000 cps but also could be manufactured with consistent performance characteristics. Some of the many factors considered in this design are described.

### Circuit Modifications

The Williamson all-triode circuit, which includes a direct-coupled, split-load phase inverter feeding triode drivers and class A operated triode output tubes, is notable for its basic simplicity. Even without feedback, this amplifier provides the characteristics of an extremely high-fidelity amplifier.

It was found desirable to make modifications in the original circuit in order to obtain optimum performance and increase manufacturing margins to insure meeting specified characteristics on all units.

In one modification of the circuit, the center tap of the heater string is returned to the positive voltage appearing at the output tube cathodes. In this way the application of positive bias to the heater of the first 6SN7GTA reduces the flow of heater-cathode or heater-grid "hum" currents so that a hum and noise level of 90 db or more below rated output is maintained for the amplifier.

By referring to the schematic diagram (Fig. 2) it will be noted that the output tube cathode resistance has been split into two matched 400 ohm resistors connected at the cathodes with a removable link. Use of this linked resistor pair not only greatly simplifies the adjustment of the bias and balance of the power output tubes but also increases the accuracy of the operation with commonly available metering equipment. In making the adjustment, the link is temporarily opened while a voltmeter is connected between the two output-tube cathodes. $R_{16}$ is now adjusted for a zero reading on the meter. Now with the meter across either 400 ohm resistor, $R_{20}$ is adjusted for a 25 volt reading. The link is now replaced for normal operation. *Each* KT66 is now operating with the correct bias for exactly 62½ ma. plate current, which with 400 volts d.c. from plate to cathode, represents a plate dissipation of 25 watts.

Further modifications were also made to improve performance near the extremes of the operating range. They are described below.

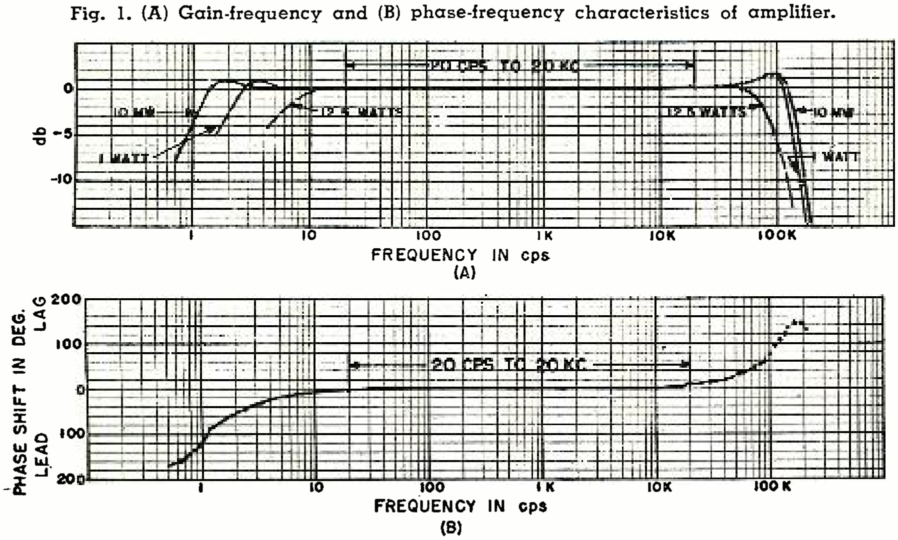
### KT66 Output Tube

The unusually low-distortion and excellent damping action obtained with this amplifier can be attributed to the use of class A operated triodes throughout the circuit along with the application of 20 db inverse feedback around the entire amplifier. For the output stage, beam tetrode type power output tubes are used connected as push-pull triodes and matched to 10,000 ohms plate-to-plate for a very low distortion class A operation. An additional advantage is obtained with the use of this type tube in that only a relatively low grid voltage is required to drive the tubes to full output; this amount of driving voltage is easily obtainable from a resistance-coupled 6SN7GTA.

Various tube types have been used for this stage and the resulting operating performance of some typical tubes are given in tabular form for the convenience of the reader. The higher power output and adequate ratings, as shown in the chart, confirmed the choice of the KT66 for the output stage as used in the original design.

In any feedback amplifier, one of the

Fig. 1. (A) Gain-frequency and (B) phase-frequency characteristics of amplifier.



most important measurements of the amplifier's performance is its margin of stability. In order to eliminate variations in amplifier performance throughout its operating frequency range, this margin must be as great as possible for the amount of inverse feedback being used. Of course, the most important component determining this margin of stability is the output transformer. Out of numerous transformer designs tested, the design finally selected had interleaved windings, 120 hy. primary inductance, 25 mhy. leakage inductance, and full power output from 10 to 50,000 cps. The other circuit components determining the degree of stability margin are investigated by considering first the low frequency range operation, and then operation through the higher frequencies.

### Low Frequency Operation

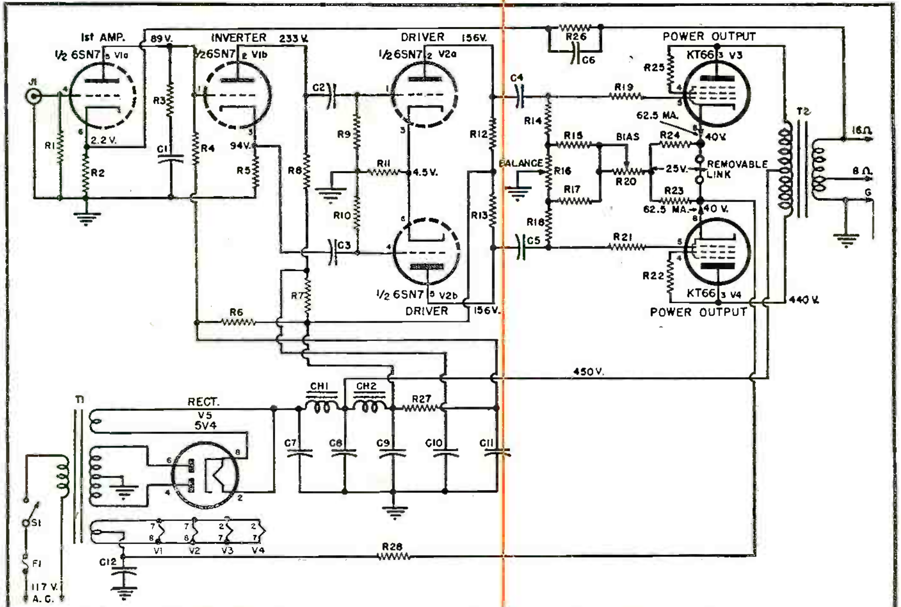
Because of the unusually flat gain characteristic and low phase shift required throughout the frequency range of 20 to 20,000 cps. the amplifier operation necessarily should be checked over the entire range of ½ cps to 2 mc. to insure conservative stability margins.

Components determining the low frequency performance are, besides the transformer primary inductance, the four interstage coupling condensers and their associated grid input resistances, and the power supply filtering or decoupling components. The power supply component values do not appreciably affect the amplifier operation in any frequency range except for a 20° phase correction furnished by $R_{27}$, $C_{11}$ and $R_7$, $C_{10}$ at 2 cps.

The greatest stability margin in any feedback amplifier design is obtained by staggering the time-constants of the interstage coupling networks. Thus, improved low frequency stability was accomplished by altering the values of these interstage coupling components from those found in the original design: $R_9$, $C_2$ and $R_{10}$, $C_3$ in the schematic each has the same time constant of 0.2 sec., $R_{14}$, $C_4 = R_{18}$, $C_5 = .01$ sec., and $L_p$ (120 hy.)/$R_p$ (2500 ohms in parallel with 10,000 ohms = 2000 ohms) = .06 sec. The first amplifier stage, being d.c. coupled, is not a factor to be considered because of its infinite time constant.

Low frequency performance is further complicated by the fact that the primary inductance, $L_p$, is not constant but varies with both signal level and d.c. saturation, according to the characteristics of the transformer core. In order to minimize this effect, the transformer was designed with a large core utilizing high-permeability laminations, stacked to provide a higher than normal air gap. The result of these precautions was a considerable increase in the margin of stability throughout the low-frequency range as compared to previous designs based on the Williamson circuit.

On the high end of the operating frequency range, the transformer characteristics again are the most important




$R_1$, $R_9$, $R_{10}$—470,000 ohm, ½ w. res.
$R_2$—470 ohm, 1 w. wirewound res.
$R_3$—2700 ohm, ½ w. res.
$R_4$—47,000 ohm, 1 w. res.
$R_5$, $R_7$, $R_8$, $R_{28}$—22,000 ohm, 1 w. res.
$R_6$, $R_{27}$—33,000 ohm, 1 w. res.
$R_{11}$—390 ohm, ½ w. res.
$R_{12}$, $R_{13}$—47,000 ohm, 2 w. res.
$R_{14}$, $R_{18}$—100,000 ohm, ½ w. res.
$R_{15}$, $R_{17}$—100 ohm, 1 w. res.
$R_{16}$, $R_{20}$—100 ohm, 2 w. wirewound pot
$R_{19}$, $R_{21}$—1000 ohm, ½ w. res.
$R_{22}$, $R_{25}$—100 ohm, ½ w. res.
$R_{23}$, $R_{24}$—400 ohm, 5 w. wirewound res. ± 2%
$R_{26}$—4700 ohm, ½ w. res.
$C_1$—560 µµfd. mica cond.
$C_2$, $C_3$—.5 µfd., 600 v. cond.
$C_4$, $C_5$—.1 µfd., 600 v. cond.
$C_6$—68 µµfd. mica cond.
$C_7$—4 µfd., 600 v. oil-filled cond.
$C_8$, $C_9$, $C_{10}$, $C_{11}$—40/40/8/8 µfd., 600 v. elec. cond.
$C_{12}$—.25 µfd., 200 v. cond.
$J_1$—Input jack
$S_1$—S.p.s.t. toggle sw.
$F_1$—117 v., 3 amp. line fuse
$T_1$—Power trans. 425-0-425 v. @ 150 ma.; 5 v. @ 2 amps.; 6.3 v. @ 3 amps.
$T_2$—Output trans. 10,000 ohms plate-to-plate to voice coil, 15 w. minimum
$CH_1$—4 hy., 150 ma. filter choke
$CH_2$—30 hy., 150 ma. filter choke
$V_1$, $V_2$—6SN7 tube
$V_3$, $V_4$—KT66 tube
$V_5$—5V4 tube

Fig. 2. Schematic diagram of amplifier. The KT66's specified on diagram are British tubes and may be difficult to obtain locally. Suitable substitutes are given below.

factors in determining the stability margins. Considerable care was used in selecting the transformer from numerous high-fidelity designs, considering both stability and frequency range.

Analysis of the circuit operation for this range is not as simple as at low frequencies. Although the 25 mhy. leakage inductance of the output transformer determines the frequency above which the amplifier gain begins to fall, the many, seldom-measured interwinding capacities and leakage inductances (*Continued on page* 95)

Comparative ratings and operation of popular tubes used in the Williamson circuit.

| | KT66 | 5881 | 6L6 | 1614 | 6AR6 | 807 |
|---|---|---|---|---|---|---|
| Description | British tube with ratings higher than 6L6 and different characteristics | Tung-Sol improved 6L6 with higher ratings | | Single-ended 807 but lower ratings | Radar power tube | Transmitting tube requiring plate cap |
| Socket Arrangement | Single-ended like 6L6 | Single-ended like 6L6 | Single-ended | Single-ended like 6L6 | Single-ended but different | Plate cap |
| Manufacturers' Ratings: Plate Voltage (max.) | 400 v. | 400 v. | 270 v. (screen rating) | 375 v. | 300 v. (screen rating) | 400 v. |
| Plate Dissipation (max.) | 25 w. | 26 w. | 19 w. (Triode | 19 w. Ratings | 21 w. controversial) | 25 w. |
| G. O. L. Output† | 10 w. | 8 w. | 8 w.* | 8 w.* | 10 w.* | 8 w. |

*Voltage and dissipation ratings inadequate for commercial dependability.
†G. O. L. (grid overload) is level where grids just begin to draw current. With resistance coupling, distortion increases markedly beyond this point.
Above readings are as operated in Williamson circuit: 400 v. plate; 25 w. dissipation; 10,000 p.p. load.

Los Angeles to expedite distribution of the company's "Elmenco" line. Carl Drillick is in charge of the new West Coast operation . . . **TEL-O-TUBE CORPORATION OF AMERICA** has purchased the entire equipment and inventory of **VIDEO INDUSTRY PRODUCTS COMPANY** of Paterson, N. J., manufacturers of TV and CR tube test equipment and electronic instruments. The firm will be operated as the electronic division of the parent firm at 159-161 Marshall St., Paterson.

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**LLOYD A. HAMMARLUND**, president of the *Hammarlund Mfg. Co., Inc.* recently celebrated his thirty-fifth anniversary with the communications firm.

He has been with the company continuously since 1916, except for two years' leave for service in the Army during World War I. He has worked in every department of the company, taking over as president ten years ago.

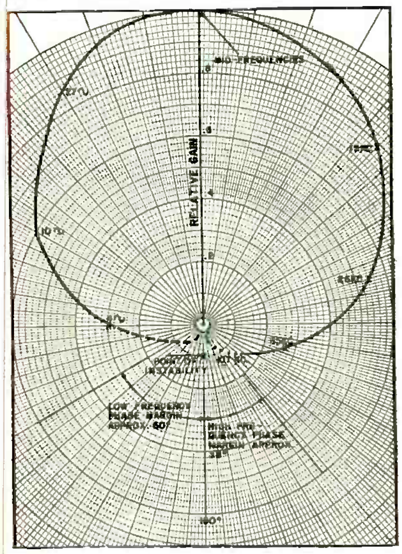
The company was started in 1910 by Mr. Hammarlund's father, Oscar, and has grown steadily until it is now occupying 100,000 square feet at two locations in New York City. —30—

**Audio Amplifier**

*(Continued from page 39)*

are often more important in determining the exact margin of stability. Two phase-correcting networks have been utilized to improve this margin—$R_3$ and $C_1$ shunting the first amplifier plate and $C_6$ bypassing the feedback resistor. The resulting mode of high-frequency operation is further influenced by the load; and especially in the case of capacitive loads, the gain and phase characteristics must be watched for tendencies toward instability.

Fig. 3. The "Nyquist diagram." Measurements were made with the corrective network and without feedback. See text for full details.



The quickest analysis of an amplifier's operation with respect to its stability is accomplished by plotting the gain and phase response *without feedback* at all frequencies on a polar diagram. The resulting chart (see Fig. 3) is known as a Nyquist Diagram. The graphical measurement of the margin of stability then appears as the distance from the curve to a −20 db point (the amount of inverse feedback) at 180° phase shift. Oscillations would occur with the application of this amount of feedback, if the curve were to enclose this point. As shown in the graph (Fig. 3), both the low and high frequency stability margins are unusually wide.

### Speaker Damping

One extremely important characteristic, resulting from the use of a triode output stage along with a large degree of inverse feedback, is a very low output source impedance. In the case of the *Craftsmen* 500 amplifier, this impedance, as seen by a speaker connected to the 16 ohm tap, is only 0.5 ohm. The amplifier can, therefore, be considered to have a 16/0.5 or 32:1 damping factor. Of even greater importance is the fact that this impedance is maintained near this value (see Fig. 4) throughout the audio range. The usefulness of such excellent speaker damping at very low frequencies has been readily demonstrated in reducing speaker "muddiness" and "one-note-boom." At higher frequencies, the effect of damping transient distortions in the speaker is often conveyed to the listener as a fresh sensation of clarity in reproduction.

### Distortion

As can be seen by referring to the distortion *vs* power output diagram, both the harmonic and intermodulation distortions are remarkably low in this amplifier. At one watt, the intermodulation distortion (measured with 40 and 12,000 cps:4/1) is below 0.04%,

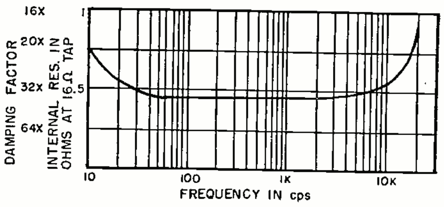



Fig. 4. Graph showing the output source impedance-frequency characteristic of unit.

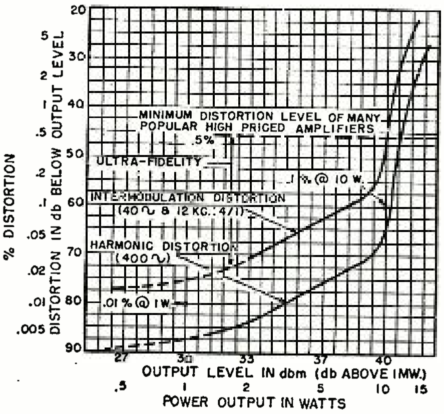



Fig. 5. Harmonic and intermodulation distortion vs power output of unit.

while the harmonic distortion is even less than 0.01%.

Because these very low magnitudes of distortion are maintained throughout the audio range, this amplifier has been described as being not only a high-fidelity amplifier but also capable of *ultra-fidelity*.

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Under chassis view of the Craftsmen 500 amplifier using the Williamson principle.