Adapting the "Ultra-Linear" Williamson to 6550 Operation

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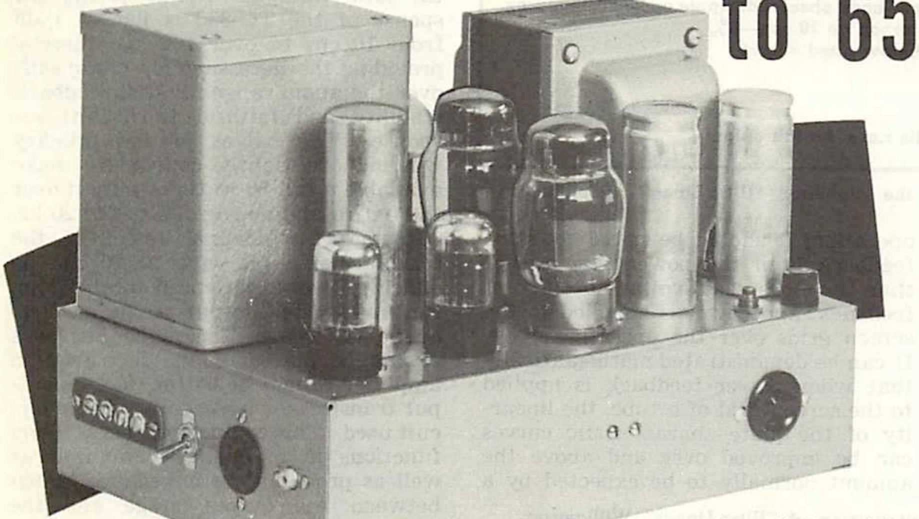


Over-all view of the "Ultra-Linear" amplifier that has been adapted for Tung-Sol 6550's.

A new high-power output tube, the 6550, will find many applications in converting present-day amplifiers and in new equipment. Up to 100 watts push-pull can be had.

SINCE its introduction many years ago, the *Williamson* amplifier has undergone a few design changes to further improve its performance. As originally described by Williamson, the amplifier was a 15-watt unit designed for low distortion, uniform output, and small phase shift over the entire audio range.[1] Since the original conception of the *Williamson* amplifier, American manufacturers have jumped on the bandwagon and today one will find many variations of the original circuit. Performancewise there is wide variation among the different units made in this country. One of the circuit improvements made by American manufacturers came with the application of "Ultra-Linear" operation to the output tubes, a mode of operation which doubled output power and further reduced distortion.[2] This amplifier has been widely accepted by audiophiles with the result that there are about twenty commercial amplifiers on the market today which incorporate this design feature.

The application of "Ultra-Linear" operation to the *Williamson*-type amplifier increased the output power to 30 watts using the same type of output tubes operating at the same voltages. When this circuit was first introduced it was immediately noted that the new combination provided better sound, even at the low volume levels which the original amplifier could handle. This phenomenon has resulted in a new evaluation of the power requirements of an amplifier as a part of an audio system and, in general, it has been observed that in amplifiers of analogous design, the unit of greatest capacity will sound best.

The attainment of high power in audio amplifiers has become relatively easy and inexpensive due to two factors, the increased efficiency of the "Ultra-Linear" output circuit and the introduction of new output tubes with greater power handling capabilities. One recently introduced tube, the *Tung-Sol* 6550, is particularly adaptable to output stages of the "Ultra-Linear" type and can be used to advantage in the "Ultra-Linear" *Williamson* circuit to provide an amplifier of 60-watt capacity having an intermodulation content at maximum output of 6/10th of one per-cent. This amplifier differs only in a small degree in dimensions and number of circuit elements from its predecessors, and many *Williamson*-type amplifiers can easily be modified to take advantage of the improved performance.

Amplifier Circuit

An examination of the circuit diagram reveals the basic *Williamson* circuitry of the first three stages. The first two, the input voltage amplifier and direct-coupled cathodyne phase inverter, are familiar and unchanged even with regard to tube type, the 6SN7. The driver stage also remains a 6SN7, with but one change. Individual cathode resistors have been added to provide a slight amount of local feedback in order to improve the loop feedback phase characteristics and increase the stability margin of the amplifier.

The output stage is coupled to the driver through a resistance capacity network which provides conventional *RC* coupling at signal frequencies and an attenuated direct coupling at subsonic frequencies. This again introduces an improved low-frequency phase characteristic which adds to the stability margin of the amplifier. The use of this combined *RC* and direct coupling is made possible by the choice of fixed bias operation of the output tubes whereby the required negative bias is obtained from a separate bias supply. The fixed bias supply consists of T_3, a 6.3 volt, 1 amp. filament transformer; a 50 ma. selenium rectifier SR_1; resistor R_{29}; and electrolytic capacitors, C_{12} and C_{13}.

In order to reduce hum to a minimum in preamplifiers that are to be powered from the main amplifier, a positive bias has been applied to the heater line through resistors R_{27}, R_{28}, and capacitor, C_8. If a separately powered preamplifier is to be used, this network can be eliminated, together with the hum balancing potentiometer R_{30}, and the centertap of the 6.3 volt winding on the power transformer T_2 can be grounded. "B plus" voltage for operation of the preamplifier can be taken either from point *X* or *Y* depending on the preamp to be used.

"Ultra-Linear" Output Stage

The "Ultra-Linear" type of output stage is characterized by output tubes of the tetrode type with the screens of the tubes connected to taps equally positioned about the centertap of the output transformer. The operation of the stage can most readily be understood by the following considerations: first, if the screen of an output tube is connected to the plate, the tube functions as a triode, and the plate characteristic curves are concave upward. Secondly, if the screen is connected to "B plus," the tube operates as a tetrode, and the plate characteristic curves are concave downward. If, however, the screen is connected to a tap on the primary of the output transformer, a type of operation is obtained midway between triode and tetrode. Depending upon the type of output tube used, the tap can be chosen to result in an almost linear set of plate

Power Output	60 watts @ 1000 cps; within ±.5 db of 1 kc. level @ 60 watts over range 20 cps to 30 kc.
Frequency Response	±1 db @ 1 watt, 2 cps to 220 kc.
Intermodulation Distortion (60 and 3000 cps mixed 4:1, equiv. sine-wave power)	10 watts—.07%; 20 watts—.10%; 30 watts—.15%; 40 watts—.25%; 50 watts—.40%; 60 watts—.60%
Square-Wave Response	Rise time on 20 kc.—2 microseconds; overshoot on 20 kc.—none observed; ripple on 20 kc.—approx. 1%; droop on 20 cps—5%
Hum and Noise	80 db below rated output
Nominal Feedback	20 db
Feedback Stability Margin	10 db
Damping Factor	15
Sensitivity	1.3 volts r.m.s. for full output

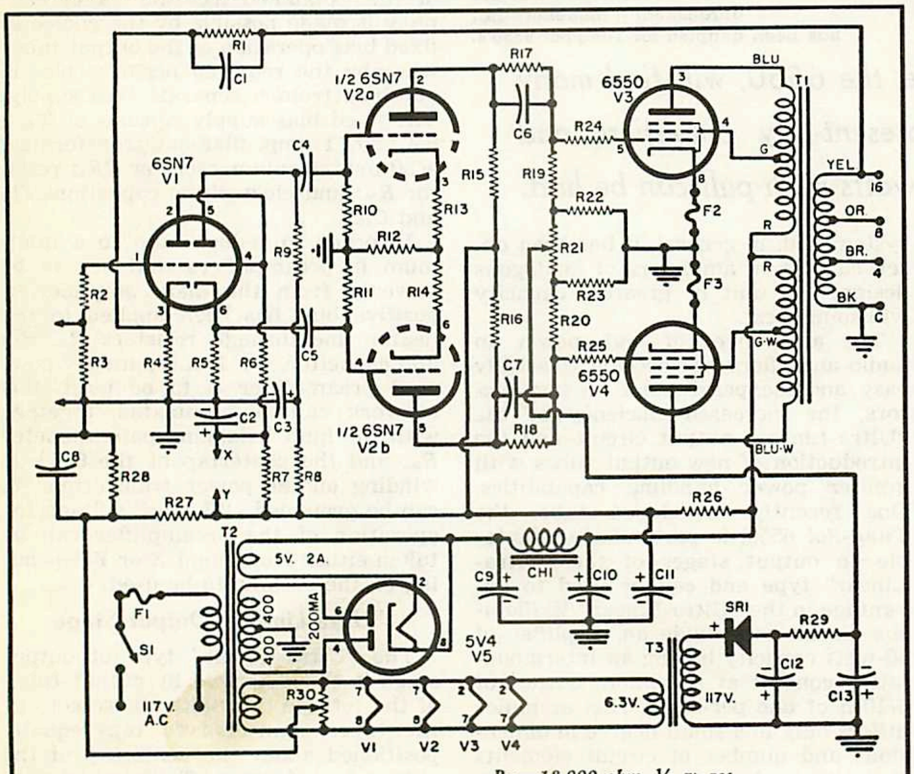
Table 1. Performance characteristics of the converted "Ultra-Linear" amplifier.

characteristic curves, and this mode of operation has been termed "Ultra-Linear." It has been determined experimentally that the best operating point for the 6550 is with the tap located at 40% of the primary turns.

"Ultra-Linear" operation of an output stage has sometimes been described as the application of negative feedback to the screen grids of the output tubes. If this concept is used to explain the operation, it should be noted that the feedback is of the power type rather than the more usual voltage or current feedback, and power is supplied to the screen grids over the operating cycle. It can be demonstrated mathematically that when power feedback is applied to the screen grid of a tube, the linearity of the plate characteristic curves can be improved over and above the amount normally to be expected by a consideration of voltage feedback only.[3]

The output transformer is an *Acrosound* TO-330. This transformer is ideally suited for the 6550 tubes, providing the correct impedance match for maximum power and lowest distortion, and primary taps located at 40% of the total winding. The frequency response of the TO-330 is flat ± 1 db from 10 cps to over 100 kc., thereby providing the necessary low phase shift over the audio range for best feedback stability and faithful transient response. The halves of the primary winding are tightly coupled to make available a full 60 watts of output over the entire audio range 20 cps to 20 kc. Although the nominal rating of the transformer is 50 watts at 20 cps, no difficulty was experienced in obtaining full undistorted output at the low frequency extreme. Too much emphasis cannot be placed on the fact that an amplifier cannot be better than its output transformer irrespective of the circuit used. This component serves many functions in a feedback amplifier as well as providing an impedance match between the output stage and the speaker. However, all of the necessary conditions can be met by a propitious choice of design and this unit can, in fact, be improved in certain performance categories, for example, bandwidth over and above the circuit with which it is associated.

Complete schematic diagram of the 60-watt version of "Ultra-Linear" Williamson.



R_1, R_3—10,000 ohm, ½ w. res.
R_2—1 megohm, ½ w. res.
R_4—470 ohm, ½ w. res.
R_5, R_9—22,000 ohm, 1 w. res. (matched ±1%)
R_6—47,000 ohm, 1 w. res.
R_7—33,000 ohm, 1 w. res.
R_8—22,000 ohm, 1 w. res.
R_{10}, R_{11}—470,000 ohm, ½ w. res.
R_{12}—470 ohm, ½ w. res.
R_{13}, R_{14}—220 ohm, ½ w. res.
R_{15}, R_{16}—47,000 ohm, 2 w. res. (matched ±1%)
R_{17}, R_{18}—470,000 ohm, ½ w. res. (matched ±1%)
R_{19}, R_{20}—47,000 ohm, ½ w. res. (matched ±1%)
R_{21}—10,000 ohm, linear taper pot
R_{22}, R_{23}, R_{27}—100,000 ohm, ½ w. res.
R_{24}, R_{25}—1000 ohm, ½ w. res.
R_{26}—2500 ohm, 5 w. res.
R_{28}—15,000 ohm, ½ w. res.
R_{29}—18,000 ohm, ½ w. res.
R_{30}—100 ohm wirewound pot
C_1—47 μμfd. ceramic capacitor
C_2-C_3-C_{11}—20/20/20 μfd., 450 v. elec. capacitor
C_4, C_5, C_6, C_7—.25 μfd., 600 v. capacitor
C_8—.1 μfd., 400 v. capacitor
C_9, C_{10}—10 μfd., 600 v. oil or elec. capacitor
C_{12}, C_{13}—20 μfd., 150 v. elec. capacitor
T_1—Output trans. (Acrosound TO-330, see text)
T_2—Power trans. 400-0-400 v. @ 200 ma.; 5 v. @ 2 amps.; 6.3 v. @ 5 amps.
T_3—Fil. trans., 6.3 v. @ 1 amp.
CH_1—4 hy., 200 ma. filter choke
S_1—S.p.s.t. switch
F_1—5 amp. line fuse
F_2, F_3—⅛ amp. cathode fuse
SR_1—50 ma. selenium rectifier
V_1, V_2—6SN7 tube
V_3, V_4—6550 tube (Tung-Sol)
V_5—5V4GA tube

Feedback Stability

In a feedback amplifier it is always desirable to maintain a maximum amount of feedback stability in order to assure complete stability under all conditions of output power level and output load. The degree of stability of a feedback amplifier is generally rated in terms of stability margin, meaning the amount of additional feedback in db that can be added before the amplifier becomes unstable and oscillates. This design figure is usually taken under conditions of rated resistive output load. However, loudspeakers are not constant resistance devices, but present to the amplifier an impedance containing a large reactive component over a good portion of their operating range. Moreover, in the band outside of the range of the speaker, the impedance may be almost completely reactive. It is desirable, therefore, to have a stability margin of 6 db or more to assure complete stability.

The stability characteristics of a feedback amplifier are associated with the bandwidth and phase shift characteristics of the amplifier circuit and output transformer, and there are several choices available to the designer to increase the stability of a given amplifier. First, bandwidth may be traded for stability. In this procedure loss networks are added to shape the amplifier response curve so that the response of the amplifier falls off by the amount of feedback plus the stability margin before the phase of the feedback voltage becomes regenerative. Secondly, gain within the useful band may be traded for stability. In this procedure local feedback may be added to stages within the amplifier in order to reduce their contribution to the phase shift. Thirdly, the bandwidth of the stages may be extended by the use of certain design techniques, and the phase shift correspondingly reduced.

The first method is subject to the criticism that it restricts the amplifier band reducing the rise time with regard to square wave response and, in this manner, affects the fidelity of transient reproduction. The first and third methods may be combined; the bandwidth increased and then loss networks added.

An appreciable increase in the bandwidth of the amplifier described has been achieved by the use of the TO-330 transformer. The response of the amplifier, with feedback, is flat to over 200 kc. An adequate stability margin of 10 db has been maintained by the use of methods two and three. A small amount of degeneration has been added to the driver stage by the inclusion of individual cathode resistors. The subsonic bandwidth has been extended and shaped by the addition of the 470,000 ohm coupling resistors R_{17} and R_{18}. With these added resistors the bias developed on the grids of the output tubes is partially dependent on the voltage developed at the plates of the driver tubes, and a plate current balancing control has been added to the output stage. The procedure of balancing plate current has been facilitated by individually fusing the output tube cathodes. To check plate current the fuse is removed. The fuse clip serves as a convenient tie point for the connection of a milliammeter.

Construction of the Amplifier

The amplifier can be constructed on a chassis 8" x 12" x 3". A careful arrangement of parts permits direct point-to-point wiring of the stages and a short, direct feedback connection between the output transformer and the first stage. The axiom for wiring amplifier stages is to have leads as short and direct as possible. It is desirable to twist filament leads; also leads to the power switch and preamp power connector. A neater job will usually result if filament, switch, and power supply circuits are wired first, then "B plus" circuits, then signal circuits less the coupling capacitors. The coupling capacitors are added last, and since these are generally large, they may be looped over the space from stage-to-stage. The coupling capacitors to the output stage can terminate on pin No. 6 of the 6550 sockets, since this pin is not a tube connection and can be used as a tie point.

Care should be taken when wiring the output transformer to see that the proper color coding is observed for the primary leads. Make certain that the tracer leads are connected to the output tube that is energized from the cathode of the phase inverter. If these leads are incorrectly connected the amplifier will motorboat when it is turned on. Correct phasing can be restored by either reversing the transformer leads or by reversing the connections of the coupling capacitors at the phase inverter section of the first tube.

The total cathode current per output tube will run about 75 ma. with a plate supply voltage of 425 volts and a grid bias voltage of minus 48 volts. If the cathode current differs considerably from this figure, it may be advisable to change the value of R_{20} until normal bias and plate current is obtained.

Conversion of Existing Amplifiers

It will occur to many that their *Williamsons* may be converted to take advantage of the increased power output offered by the 6550 tube by simply adding a few extra components and changing the output transformer. One precaution should be taken, however, against overloading the power transformer. The plate current drain of the output stage has been increased from the 100 ma. drain of the usual KT-66 tubes to 150 ma., and a power transformer that is operating close to maximum rating will not be able to supply the additional drain. Many power transformers will, however, be able to take it, and one should not rush to replace the transformer if it feels hot in service. A safe operating temperature for this component is 140 degrees F. which is an uncomfortable temperaature to the hand. However, if the power transformer ran at an uncomfortable temperature before conversion, it should be replaced.

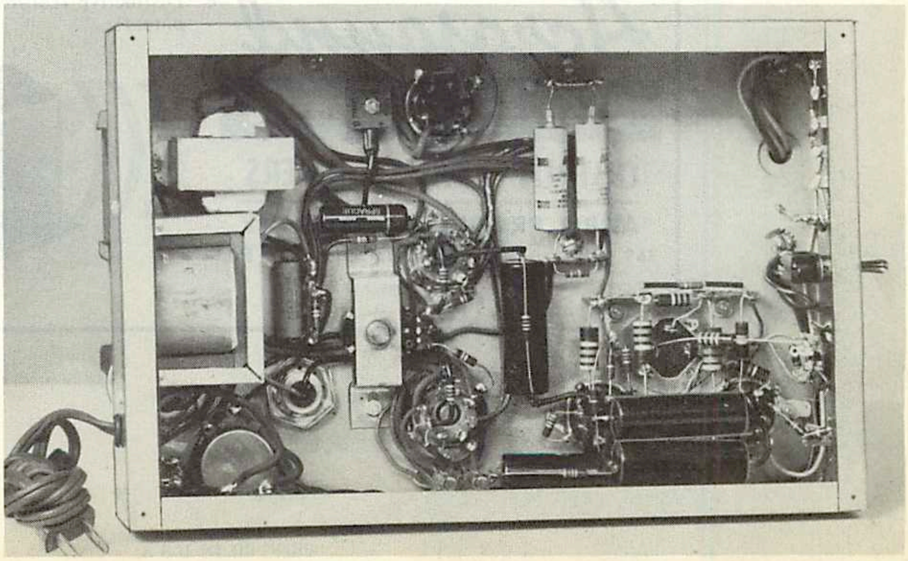
Performance

The measured performance figures of the amplifier are given in Table 1. The frequency response at low output levels is flat from 2 cps to 220 kc. Maximum power of 60 watts is delivered at all frequencies between 20 cps and 30 kc. The square wave response at 20 cps shows 5% droop, and at 20 kc. the square wave is clean with no overshoot and a rise time of 2 microseconds. The intermodulation figures are particularly good, being only 0.15% at 30 watts and 0.6% at 60 watts, for a combination frequency of 60 and 3000 cps, mixed 4:1.

Much has been written about amplifier testing and on the interpretation of test results. However, the deeper one goes into the field of amplifier design, the more apparent it becomes that the best test instrument is the human ear with music supplying the signal source. Unfortunately, the ear cannot supply a numerical rating of merit, but only a comparison of "better" or "not as good." The amplifier described in this article has been subjected to comparative listening tests with both the older "Ultra-Linear" *Williamson* using KT-66's and with other good amplifiers. Listeners were generally agreed that this amplifier had many points of superiority.

The relative importance of the power amplifier in a high-fidelity system has always been a controversial subject. There are those who maintain that a low power amplifier of 5 watts or so is adequate for good reproduction and qualify this by the indisputable statement that the average sound power required for good room volume is no greater than this figure. Others state that a moderately good power amplifier is a much more perfect device than other elements of the reproducing system, in particular phono pickups and speakers. Both of these schools of thought fail to recognize some basic facts relating to requirements imposed upon the power amplifier. In the first case, although average room volume may require only a few watts, peak powers may exceed the average by 10 times or more, and it is the fidelity with which these peaks are reproduced that contribute to the feeling of presence. With regard to the second point, it is true that there is still room for improvement in pickups and speakers, however, any additional contribution to intermodulation distortion in the

Underchassis view of amplifier. Note the point-to-point wiring of circuit.



power amplifier makes itself felt by the generation of new combination tones which further change the identity of a musical instrument, and produce the effect of blurring the sound. This latter effect can be easily demonstrated in a comparison test by playing a poor recording with lots of surface noise. The noise will be there in each instance, but will be much less objectionable with an amplifier of lower distortion. Finally, one must recognize that a condition of interaction exists between the speaker and the power amplifier. A high power amplifier of low and constant internal impedance exerts better control over the speaker characteristics at high peak powers.

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