

Ultra-Linear Operation of the Williamson Amplifier

DAVID HAFLER* and HERBERT I. KEROES†

The Famous "Williamson" can be improved simply by replacing the output transformer and making a few minor changes in other components. The results are well worth the effort and expense.

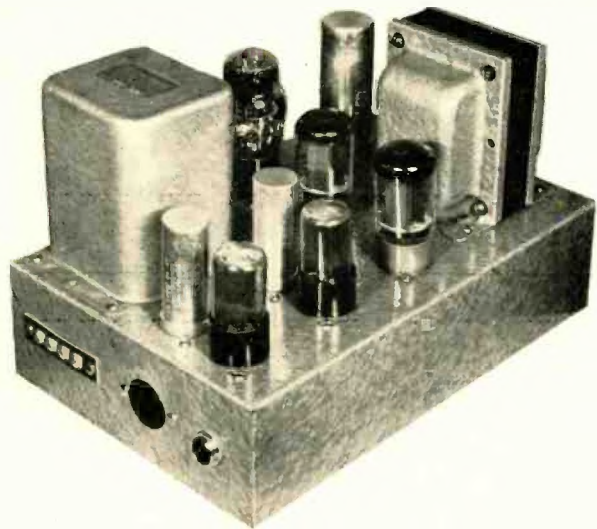
FROM THE TIME an article¹ appeared describing the principle of Ultra-Linear operation of power output tubes, considerable interest has been evidenced in the application of this new circuit improvement to the famous Williamson amplifier. The Williamson circuit has been publicized in several arrangements including at least one commercial one, and the configuration is undoubtedly the most popular high-quality audio circuit ever developed. For many people there is little necessity to attempt to improve this basic amplifier circuit. Its listening quality is excellent; it is easy to construct; and it provides top quality at a cost comparable with units which cannot measure up to its capabilities.

The one category in which the Williamson amplifier is significantly deficient is with regard to efficiency and power-output capabilities. Peak power output is less than 15 watts, and it takes a 450-volt supply at approximately 130 ma to achieve this power output. If this limitation can be overcome without deterioration of quality, a change in the original design is justified. If simultaneously it is possible to improve the amplifier both in measurable aspects and in listening quality, then a change is not only justifiable, it is mandatory.

It is difficult to improve on something which is really good. There are some audio enthusiasts who will scoff at the idea that the Williamson circuit can be improved. However, it has been five years since Mr. Williamson published his circuit; and in the course of five years, there is little which can maintain supremacy without change or renovation. When a basic circuit improvement—the Ultra-Linear output stage arrangement—came along, it was natural to see how it could fit in with the basic Williamson circuit.

The Ultra-Linear output stage is not a triode stage as is used with the Williamson circuit—nor is it a tetrode or pentode stage. It combines the advantages of both triode and tetrode by using an arrangement in which the

The authors' Ultra-Linear amplifier combined with the power supply on a single chassis.



screen grids of tetrodes are energized from a tap on the primary of the output transformer. This connection, on which patents are pending, modifies the operating characteristics of the tube. Proper location of the tap results in optimum input-output linearity simultaneously with efficient operation, power capabilities approximately double those of a triode connection, and low-impedance output such as is offered by triodes. In short, it permits better performance than either triode or tetrode connection of the tubes, and this is substantiated in comparative listening tests and distortion measurements.

The unique merits of the Ultra-Linear stage are particularly applicable to the Williamson circuit. The mating of the two seems to have been inevitable. The simple substitution of an output transformer with primary taps for Ultra-Linear operation and a few minor changes in circuitry, which will be discussed below, combined the basic circuits into an amplifier which practically everybody agrees is an improved version in all respects. Obviously, we must gain improvement if we substitute a more² linear output tube and use a transformer which exceeds the originator's stipulations for performance.

The original Ultra-Linear circuit utilizes a transformer, the Acrosound

TO-300, which was designed for use with tubes of the 6L6 type. Its 6600 ohms primary impedance therefore, is also correct for 5881's and 807's in the Ultra-Linear hook-up. In addition, KT-66's can be used without deterioration of quality as the slight mismatch is in a favorable direction with respect to distortion characteristics. Therefore, this transformer can be used with the tube types normally used in Williamson amplifiers without compromise of characteristics. It is of interest to note that the change in impedance to 6600 does not violate Mr. Williamson's design considerations. The modified tube characteristics of the Ultra-Linear connection require this impedance if we wish to preserve operating conditions similar to those of the original amplifier. In other words, the tubes are still matched for minimum distortion rather than for maximum power output. The transformer, therefore, can be placed in the circuit directly and the screens of the output tubes connected to the appropriate taps as shown in Fig. 1. This eliminates the two 100-ohm screen stopper resistors of the original circuit. The plate and screen leads of the transformer are color coded to avoid phasing difficulties.

Several additional circuit changes have been found beneficial for optimum

* Acro Products Co., 369 Shurs Lane, Philadelphia 28, Penna.

† Hafler and Keroes. "An ultra-linear amplifier," *AUDIO ENGINEERING*, November 1951.

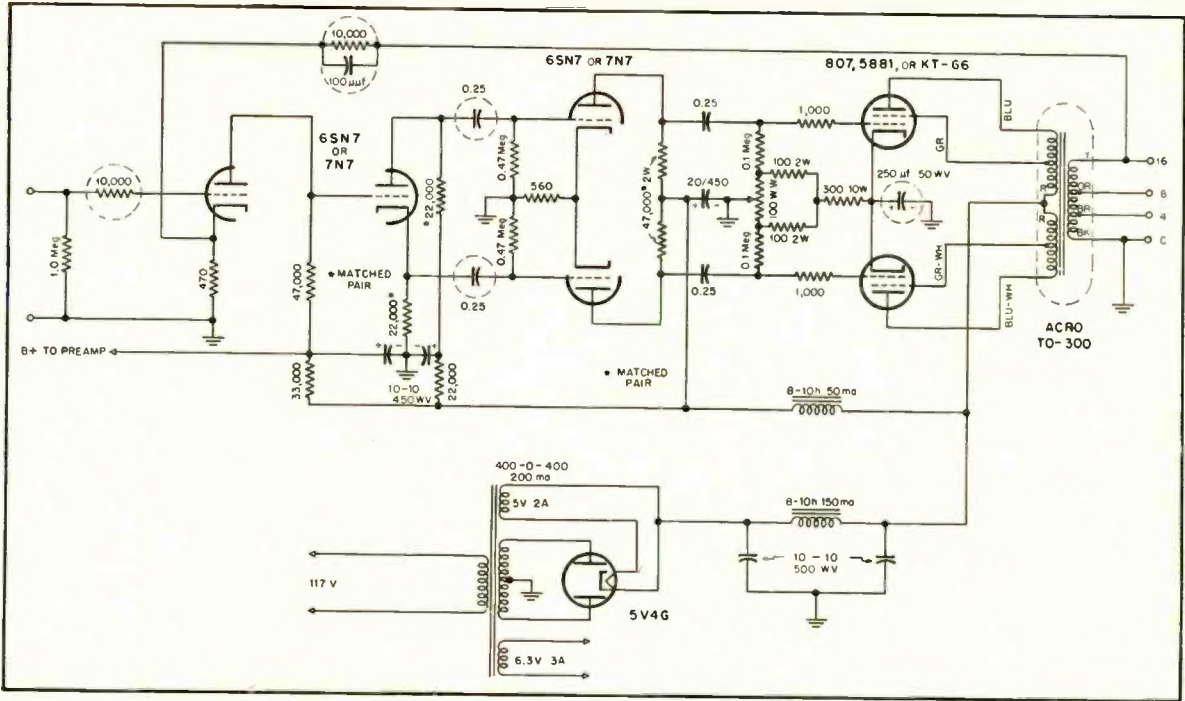


Fig. 1. Schematic of the Ultra-Linear Williamson amplifier. The components in dotted circles are those which are changed from the original circuit in making the conversion of an existing amplifier to Ultra-Linear operation.

performance. One of these is the change in value of the feedback resistor to 10,000 ohms in order to maintain 20 db of feedback. In the Ultra-Linear stage the gain of the stage is greater than for a triode stage. In addition, the change in primary impedance changes the proportion of voltage fed back. Thus the feedback is increased unless the feedback resistor is changed to compensate. The readjustment of this resistor to the desired value then permits the added gain of the Ultra-Linear output stage to increase the amplifier sensitivity. It can now be driven with a little over 1 volt as compared to almost 2 volts required for the original amplifier.

The feedback is taken from the 16-ohm tap regardless of the speaker connection. This tapped secondary arrangement is extremely convenient when shifting to speakers of different impedance as it does not require a change in the value of the feedback resistor. It is made possible by special transformer design (on which patents are pending) which permits equivalent response on

all taps of a tapped secondary winding.

The amplifier, as converted, now surpasses the original with respect to response, distortion, and transient characteristics. In addition, it was considered desirable to make certain other slight changes which primarily increase the stability under feedback conditions.

The low-frequency time constants of the original circuit's interstage coupling networks were the same for both such networks. This is not particularly desirable in a feedback amplifier since a given frequency loss is accompanied by maximum phase shift. Separation of the time constants permits less phase shift for the same frequency loss. In-

creasing one pair of coupling capacitors from .05 μf to .25 μf gives a five-to-one ratio of time constants for the two pairs of networks and increases the low-frequency stability margin at nominal increase in cost.

The insertion of a 10,000-ohm parasitic suppressor in the input grid and a 100-μf capacitor across the feedback resistor adds to the high-frequency stability margin and eliminates a slight ringing in the vicinity of 200 kc.

One last optional difference from Mr. Williamson's original circuit lies in the use of a bypass capacitor across the cathodes of the output stage. This has been found beneficial in both the Ultra-

Fig. 3. Square-wave performance at 20 cps (left) and at 50 kc (right).

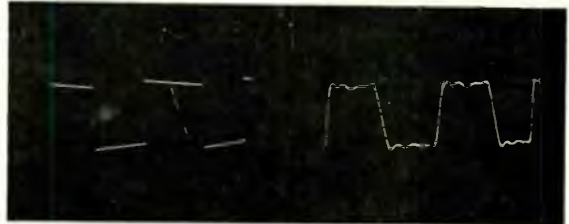
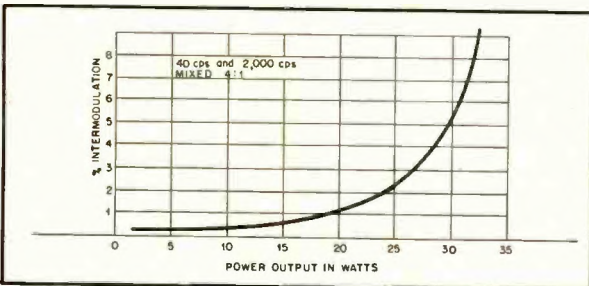


Fig. 2. Curve of intermodulation distortion vs. effective sine-wave-power output.



Linear conversion and in the triode Williamson² at high levels of operation as distortion at the overload point is diminished.

There are no changes required in the remaining stages nor in the power supply. Most of the publicized versions

[Continued on page 43]

² Keroes, H. I. "Building the Williamson amplifier," *Radio and Television News*, December 1950.

of the circuit utilize power transformers which furnish 400 volts at 200 ma. Since the drain of the circuit does not exceed 130 to 140 ma, the voltage obtained out of a capacitor input filter and 5V4 rectifier is about 450 volts. This is the correct value for the circuit as converted. Lower voltage will limit the power output capabilities.

Performance

Figure 2 shows intermodulation distortion versus power output. It can be seen that the power output of the circuit is effectively doubled over that of the original circuit for a given distortion. At low levels, around 1 watt, the IM hits such phenomenal values as .06 per cent. It is only 0.3 per cent at 13 watts. This curve is based on equivalent sine wave power in order to make it comparable with all the other published and advertised data on the Williamson circuit.³ The values graphed in Fig. 2 can be divided by 1.47 for those who wish to have direct comparability with the meter readings obtained on the intermodulation test equipment.

Figure 3 shows oscillograms of square-wave traces taken through the complete amplifier with repetition rates of 20 cps and 50 kc. Traces at intermediate frequencies approach theoretical perfection, and even such a rigorous test as the 50-kc wave shows up extremely well. The waveform has not "sined off," and the extent of ringing is less than that exhibited by the 5000-cps wave of many good quality amplifiers. These square-wave tests were made at a comparatively low level which makes the test even more rigorous. At low excitation levels, the inductance of an output transformer decreases, the phase shift increases and the tops of the square wave tilt. A high-level square wave will appear better than a low-level one at low frequencies. Similarly, high powers at high frequencies will clip any supersonic peaks in the response and improve the appearance of the square wave. The use of a high level of power can make a relatively poor amplifier appear better on square wave tests.

The frequency response of the converted amplifier is flat ± 1 db from less than 5 cps to 200 kc. Its phase shift reaches 3 deg. at 20 cps and at 20 kc, indicating symmetry of response with respect to the audio band.

The amplifier puts out 30 watts of power over a range greater than the audio spectrum. However, this type of power curve, as measured by response at high power levels, is not too meaningful. The important consideration is the amount of *undistorted* power available

³ Sarser and Sprinkle, "Musician's amplifier," AUDIO ENGINEERING, November 1949.

at various frequencies. The Ultra Linear Williamson arrangement puts out close to 25 watts at 20 cps and at 30 kc without clipping, attenuation, or other visual distortion of the waveform as viewed on a 'scope. By observing the transfer characteristic, it is possible to detect by eye harmonic distortion of less than 2 per cent. The power curve of the amplifier thus deviates from flat by less than 1 db over the range 20 cps to 30 kc.

As intimated above, the circuit has excellent listening qualities. This is a confirmation of the measurements. The additional power available shows up in cleaner and better articulated bass. The overall effect is of greater smoothness, more definition of detail in the sound, and better transient response. Ultra-Linear circuits seem to have a wider transient bandwidth—an audible benefit which is not readily susceptible to measurement. The combined effect of the Williamson circuit configuration—a wide-band, low-distortion arrangement—plus an output stage of decreased distortion and higher power capability, a stage which exceeds the original specification and operating parameters, must be heard to be appreciated.