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"ULTRA-LINEAR" OPERATION OF 6V6 TUBES



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One of the best designs in recent years covering an audio amplifier using 6V6 tubes. The author, in this case, has converted a Grommes unit to illustrate his design idea.

Fig. 1. The Grommes 100BA power amplifier after conversion to "Ultra-Linear" operation. See diagram of Fig. 4.

EVER since the introduction of "Ultra-Linear" circuitry,¹ there has been a steadily growing interest in amplifiers utilizing this type of output stage coupling. The basic arrangement has become popular in ardent audiophile circles and has also found commercial and industrial applications where extremely low distortion is required.

Essentially, the "Ultra-Linear" circuit is illustrated in Fig. 2. The screens of beam power output tubes are connected to taps on the primary of the output transformer; or if it is desired to operate the screens at a different a.c. potential than the plates, to a tertiary winding on the output transformer. Either arrangement requires a transformer with the correct ratio of screen load to plate load if optimum results are to be obtained, and a mismatch will lead to inefficiency and/or increased distortion.

The "Ultra-Linear" arrangement has been mistakenly referred to as a feedback circuit. This is not correct since negative feedback would produce a reduction in gain which does not occur with the "Ultra-Linear" circuit. It would be just as incorrect to refer to a triode as a tetrode with feedback as it is to analyze the "Ultra-Linear" circuit as a feedback circuit. Instead it must be considered as a new and different type of tube structure which is neither triode nor tetrode.

The circuit provides some of the advantages of both triodes and tetrodes, and it overcomes some of the disadvantages of each of these types. For example, it is more efficient and provides more power output than triodes. Its capabilities in this respect parallel the capabilities of tetrodes. However, it has low internal impedance, almost as low as triodes and about one-tenth that of tetrodes; this provides good

loudspeaker damping. Lastly, and most important of all, it has a more *linear* input-output relationship at most power levels than either triodes or tetrodes which means that its distortion is lower than other methods of operation. This alone justifies the use of the circuit in those cases where low distortion is the guiding criterion.

The "Ultra-Linear" circuit has achieved popularity in deluxe amplifier arrangements such as conversion of the Williamson circuit.² It has been widely used with tubes of the KT66, 807, and 5881 type for circuits in the 20 to 30 watt power bracket for circuits of truly outstanding characteristics suitable for the most critical usage. Naturally, 20 or 30 watts is a lot of power for living room use—just as 200 horsepower is a lot of power for a deluxe automobile. However, there are definite advantages to high powered amplifiers which are operated at a fraction of their potential output just as there are definite advantages to high powered cars which are run at a fraction of their capabilities.

Nevertheless, not all of us want, or can afford, 200 horsepower cars; and not all of us feel the need for, or wish to spend the money for, amplifiers of 20 or more watts power rating. Many audiophiles and music lovers are very happy with amplifiers in the 10 to 15 watt power bracket. The popularity of this range is demonstrated by the sales success of thousands of Williamson-type amplifiers as well as tens of thousands of lower cost amplifiers using 6V6 tubes providing 10 to 15 watts of power output. Undoubtedly, the greatest number of amplifiers in home use utilize the type 6V6 tube in one of several popular circuit arrangements, all of which have essentially similar performance characteristics.

The possibilities of using the "Ultra-

Linear" arrangement with 6V6 tubes in medium-powered amplifiers has been investigated carefully. It has been found that the tube is well suited for this mode of operation since its dynamic input-output characteristic can be linearized by proper selection of a tapping point for screen connection.

The characteristics of the 6V6 are not at all similar to the 6L6 family, and the connection arrangement which is optimum for 6V6's is quite different from that which can be used with the large tube types. As a tetrode, the 6V6 permits 10 to 15 watts of output depending on plate supply voltage and bias. These ratings are based on the point where clipping of a sine wave becomes visible—which happens when the grids start to go positive, and the driving source cannot furnish power to the tubes.

If the same tubes are triode connected (by strapping the screen to the plate), power output, using the same criteria, is reduced to 2½ to 3½ watts. When the "Ultra-Linear" connection is used, the power output depends on the position of the screen taps. If a 50% tap is used, power is reduced to about one-half of the tetrode capability. If a greater than 50% tap is used, power is reduced toward the triode limitations. At a tapping point of about 24%, power output is within 90% of the tetrode condition, and distortion at all levels up to maximum is minimized. This point, therefore, has been selected as the optimum operating point for "Ultra-Linear" use.

It would be possible to take an even lower tapping point and obtain slightly more power output than the tetrode connection, but the distortion at low levels and the internal impedance both begin to increase as the tap is brought closer to the zero per-cent point which

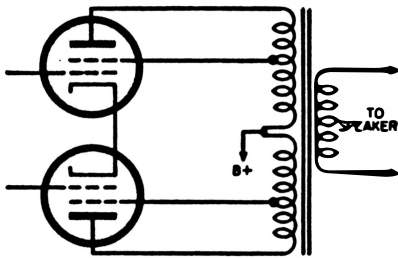


Fig. 2. Basic "Ultra-Linear" arrangement.

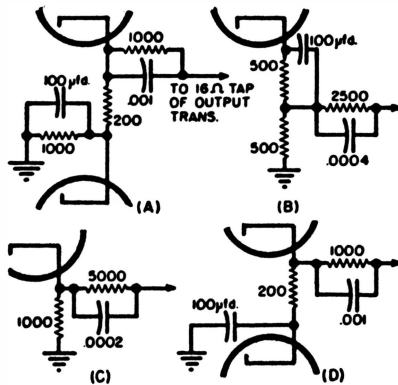


Fig. 3. Various feedback arrangements from voice coil of the output to the cathode of an early stage. See text for discussion.

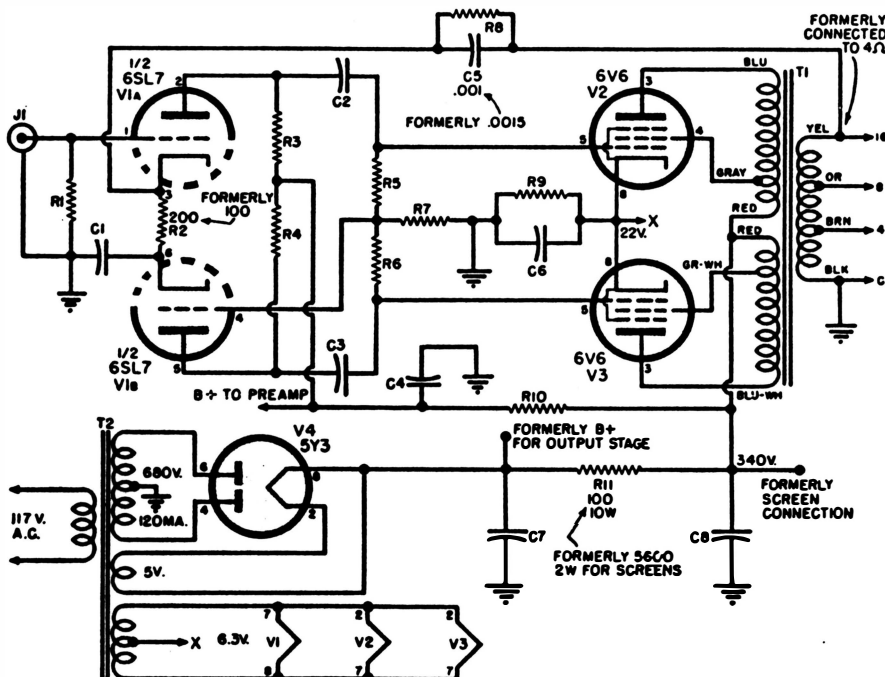
is coincident with conventional tetrode connection.

Thus the "Ultra-Linear" operating point has been set at a compromise level in which the factors of maxi-

imum power output, distortion at various levels, and internal impedance have all been weighed against each other. It must also be mentioned that listening tests at various tapping points with no feedback around the amplifier validate this selection of the tapping point. This was done without feedback on the assumption that the best amplifier without feedback would also be the best after the application of feedback. In these listening tests, the triodes fell behind because they could not handle the power (after all, 3 watts is insufficient for musical peaks), the tetrodes were somewhat screechy and boomy (too much internal impedance for satisfactory speaker damping), and the 24% point sounded natural and smooth even without connection of the amplifier feedback loop.

Use of the "Ultra-Linear" circuit involves utilization of an output transformer with the correctly placed taps. A special transformer, the *Acrosound TO-310*, has been designed specifically for this application; and its parameters were selected so that it would not limit the ultimate capabilities inherent in the circuit. For example, its bandwidth has been set at ± 1 db from 10 cps to 100 kc. so as to provide the low phase shift and good transient performance desired in the most critical applications. Similarly, its distortion characteristics complement those of the "Ultra-Linear" circuit and permit low distortion at both high and low levels from 20 cps to over 20 kc.

Fig. 4. The Grommes 100BA power amplifier converted to "Ultra-Linear" operation.



- R₁—470,000 ohm, 1/2 w. res.
- R₂—200 ohm, 1/2 w. res.
- R₃, R₄, R₆, R₇—220,000 ohm, 1/2 w. res.
- R₅—1000 ohm, 1/2 w. res.
- R₈—300 ohm, 10 w. wirewound res.
- R₁₀—5600 ohm, 1 w. res.
- R₁₁—100 ohm, 10 w. wirewound res.
- C₁—100 µfd., 15 v. elec. cond.
- C₂, C₃—1 µfd., 400 v. cond.
- C₄—10 µfd., 400 v. elec. cond.
- C₅—0.001 µfd. ceramic cond.
- C₆—40 µfd., 50 v. elec. cond.
- C₇, C₈—40/30 µfd., 450 v. elec. cond.
- T₁—Output trans. (*Acrosound TO-310*)
- T₂—Power trans. 340-0-340 v. @ 120 ma.; 5 v. @ 2 amps.; 6.3 v. c.t. @ 2 amps.
- J₁—Input jack
- V₁—6SL7 tube
- V₂, V₃—6V6 tube
- V₄—5Y3 tube

Circuit Considerations

There are many 6V6 circuits which have become popular, but by far the most commonly used is that in which a twin triode phase inverter is used to drive a pair of 6V6's; and feedback is carried from the output winding of the output transformer to the cathode of one of the triode sections. This basic configuration is simple, practical, economical, and adequate. The a.c. grid-to-grid voltage requirements of the 6V6 output stage are not stringent, and the phase inverter supplies ample drive without the need for an intermediate push-pull stage such as is used in the Williamson-type circuit. Since there are only two stages, the problems of utilizing feedback are simplified (as there is less phase shift in the circuit), and the designer can use less elaborate circuitry and components while preserving a satisfactory margin of stability.

Generally the phase inverter tube is a high mu triode such as the 6SL7 or 12AX7 in order to obtain as much gain as possible within the two stages. Actually, except for gain considerations, the specific type of inverter is of comparatively little consequence—circuit performance is determined almost completely by the mode of operation of the output tubes with respect to bias, supply voltage, and impedance match; the quality of the output transformer; and the proportion of feedback. The voltage amplifier stage contributes relatively little, as compared to the contribution of the output stage, to the over-all quality of the amplifier.

Conversion of these circuits to "Ultra-Linear" operation can be done by substituting an output transformer which has properly placed taps for connection to the 6V6 screens. Generally, this substitution will make an immediate decrease in distortion.

If the original amplifier used a screen dropping resistance, this is removed for "Ultra-Linear" operation; and the screens are connected to the tapping points on the primary of the output transformer. It is important to observe polarity and to connect the screen to the same primary side of the transformer as that from which the plate is energized. Otherwise an oscillatory condition will be provoked. Similarly, polarity must be observed between upper and lower output tubes, or the feedback from the secondary side of the transformer may be in the incorrect phase and cause regeneration.

When the screen resistor of the original circuit has been removed, the screen bypass condenser must also be disconnected. This can be readily put to good use by paralleling it across one of the filter condensers of the power supply for extra filtering and lowered power supply impedance.

The only other changes which need be made involve the feedback resistor and feedback compensating condenser which shunts this resistor (or in some circuits bypasses it to ground). The ratio of series resistor to shunt re-

sistor in the feedback path determines both the total gain in the circuit and the proportion of feedback. For example, with a 6SL7 phase inverter and feedback from the 16-ohm tap of the *Acrosound* TO-310 transformer, the power amplifier will have 17 db of feedback and require a maximum input signal of 3 volts to drive it to full output when the ratio of feedback to cathode resistance is 5 to 1. If the ratio is changed to 7.5 to 1, the amplifier will be driven with a 2 volt input, but the feedback is cut down by 3 to 4 decibels. Similarly, a 12AX7 has about 50% more gain than a 6SL7. If this tube is used with a 7.5 to 1 ratio of resistance, the amplifier can be driven to full output with 2 volts of signal while still maintaining 17 db of feedback. In the original construction, it is recommended that the 12AX7 be used so as to obtain this increased sensitivity. However, in converting an existing amplifier, the constructor can leave the 6SL7 tube in the circuit and can adjust for the required sensitivity by varying the feedback resistor. If necessary, he can sacrifice a portion of the feedback in order to maintain sufficient gain for the pre-amplifier stages which are being used.

In many commercial amplifiers, the power amplifier section must be sufficiently sensitive to be driven by 1 volt of input because of the relatively low gain of the earlier stages. If this is the case, it is necessary to diminish the feedback (by increasing the feedback resistor). However, the most modern preamp designs are intended to supply about a two volt input such as is found on Williamson-type amplifiers. Any of these preamps will handle the converted 6V6 amplifier and still permit 14 or more db of feedback. This is sufficient feedback to reduce distortion, hum, noise, and internal impedance to low values suitable for top quality applications. Thus the more common front-end arrangements will serve with the "Ultra-Linear" 6V6 amplifier while preserving an adequate proportion of feedback. When the 12AX7 is used, the designer has an additional 3 or 4 db of latitude in his choice of gain *versus* proportion of feedback.

In some amplifiers which are of the public-address type rather than the high-fidelity type, inadequate feedback is used which is limited to 6 db or less. Conversion of these amplifiers with the increased feedback which results from a 5 to 1 resistor proportion will produce insufficient gain. In those cases, there must be either a sacrifice of feedback or the addition of more gain in the early stages. However, in these amplifiers the original quality is generally so poor that the substitution of the "Ultra-Linear" output arrangement will make a decided improvement in performance even if only 6 db of feedback is used. The *relative* improvement in a low grade amplifier is even greater than is achieved by converting a fairly good amplifier which has a high proportion of feedback.

When feedback in excess of 12 db

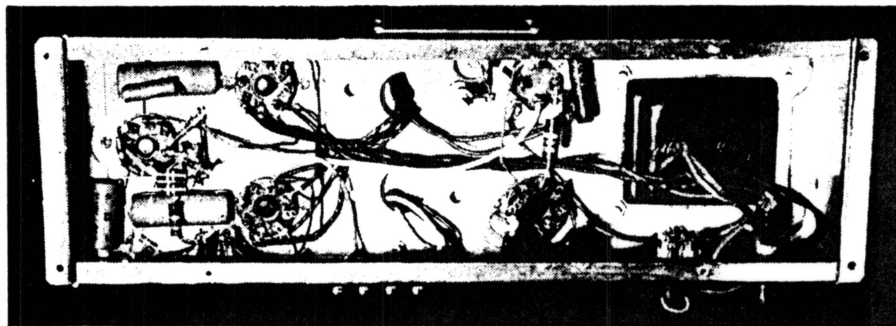


Fig. 5. Bottom view of converted Grommes amplifier showing new output transformer.

is used, there is some possibility that the amplifier response will peak in the ultrasonic region even though the response without feedback is flat over a very wide range. This peaking can be eliminated with a consequent improvement in transient response, by adding a network to change the phase of the feedback voltage in the peaking region. One simple arrangement is to add a small condenser across the feedback resistor. A suitable condenser value in the type of circuit under discussion is one which makes the product of the feedback resistor in ohms and the condenser in microfarads equal to unity. Several typical circuits using a 5 to 1 resistor proportion are illustrated in Fig. 3. In these arrangements, the feedback connection is brought to the cathode or pair of cathodes of the phase inverter stage. All of the arrangements have the same proportion of feedback and the identical phase correction.

Circuit Conversion

These conversion considerations are exemplified in the conversion of the *Grommes* 100BA amplifier, Fig. 1, the circuit of which is shown converted in Fig. 4. This amplifier is typical of many which come both with and without preamps in the \$40 to \$60 price bracket. Both former values and converted ones are indicated on the schematic. There are only three electronic parts changes in addition to the new output transformer.

Physically, it takes only two additional holes for mounting the output transformer—the remaining holes line up without alteration. The transformer fits rather snugly but inasmuch as it contributes no heating, its proximity to other parts causes no difficulty.

Any power supply which is satisfactory for the original circuit is also suitable for the "Ultra-Linear" con-

version since the "Ultra-Linear" circuit is less critical as to supply regulation than the tetrode circuit. In the *Grommes* 100BA no filter choke is used, and the converted circuit works just as well without one although a single 100 ohm resistor was added in converting in order to reduce the hum voltage.

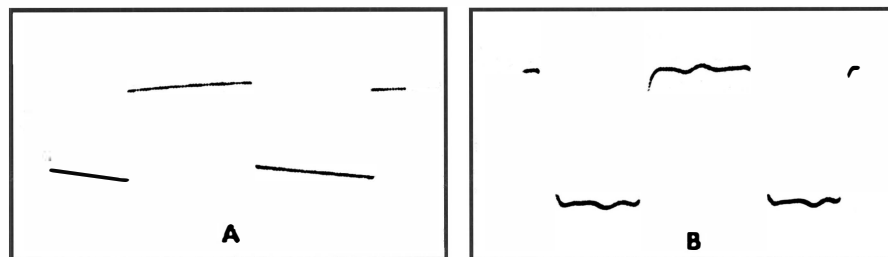
The converted amplifier has extraordinary specifications for its size and price. In fact its specs read amazingly like those of a conventional triode Williamson amplifier. Frequency response is flat $\pm .5$ db from 20 cps to over 100 kc. at a 1 watt level. (By increasing the size of the cathode condenser of the 6SL7 the low end response can be made flat to below 5 cps.) At 10 watts, response is flat ± 1 db from 20 cps to over 60 kc., and clean waveform is preserved from 20 cps to 30 kc. even at this high a level.

The transient response as evaluated by square waves is shown in Fig. 6. There is a minimum of transient distortion and phase shift at these two extremes of the audio band.

Intermodulation distortion is extremely low. It runs about .1% at 1 watt, rises to .4% at 8 watts, and to .5% at 10 watts. It is still below 1% at 11 watts. These tests were made with 40 and 7000 cps mixed 4 to 1 and are based on equivalent sine-wave output. This is the conventional method of rating which is used for practically all commercial amplifier equipment.

The quality of a low cost 6V6 amplifier is normally not up to the top high-fidelity standards which have been set by the Williamson-type amplifiers produced in recent years. However, it is now possible, by using the "Ultra-Linear" circuit arrangement and a top quality output transformer, to convert these run-of-the-mill amplifiers into ones whose quality is comparable with the best obtainable in the

Fig. 6. Square-wave performance (A) at 20 cps and (B) at 20 kc. See text for details.



10 to 15 watt power range. For many people this power range is ample for all home requirements.

Careful listening tests have borne out the justification for the "Ultra-Linear" conversion. Particularly in the low frequency range there is substantial improvement. The solidness and clarity of the heavy bass passages is a revelation when one contrasts old and new amplifiers. The silkiness and smoothness of the treble range also stand out in a side-by-side comparison. In short, the improvement in measured characteristics is confirmed and substantiated by a corresponding improvement in listenability.

REFERENCES

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2. _____: "Improving the Williamson Amplifier", *RADIO & TELEVISION NEWS, February 1953*