# "ULTRA LINEAR" AMPLIFIERS

*by F. Langford-Smith and A. R. Chesterman.*

This article treats 6V6-GT operation and makes a comparison between UL operation and the divided plate and cathode loading method used in the QUAD II and other amplifiers.

### 1. Type 6V6-GT UL operation.

Fig. 1A shows the power output versus tapping point for plate and screen 285 volts, and bias —19 volts, for selected values of load resistance. Fig. 1B shows the total harmonic distortion.

Figs. 2 and 3 show the same information for bias values of —21 and —22.5 volts. From these it appears that the 5% tap is the best all-round compromise, giving minimum distortion for —21 volts bias and 8000 ohms load resistance.

Fig. 4 shows the power output and distortion against grid bias. These confirm the impression given by the other figures, indicating a bias of —21 volts as optimum for power output and giving reasonably low distortion.

The load resistance of 8000 ohms plate-to-plate was selected as optimum, giving an output of 10.4 watts at 0.72% THD, even though an output of 11.2 watts was obtainable with a load resistance of 10,000 ohms. The reason for the choice is partly to make it less sensitive to increases in load resistance such as always occurs with a loudspeaker load, and partly to make the transformer simpler and with fewer primary turns.

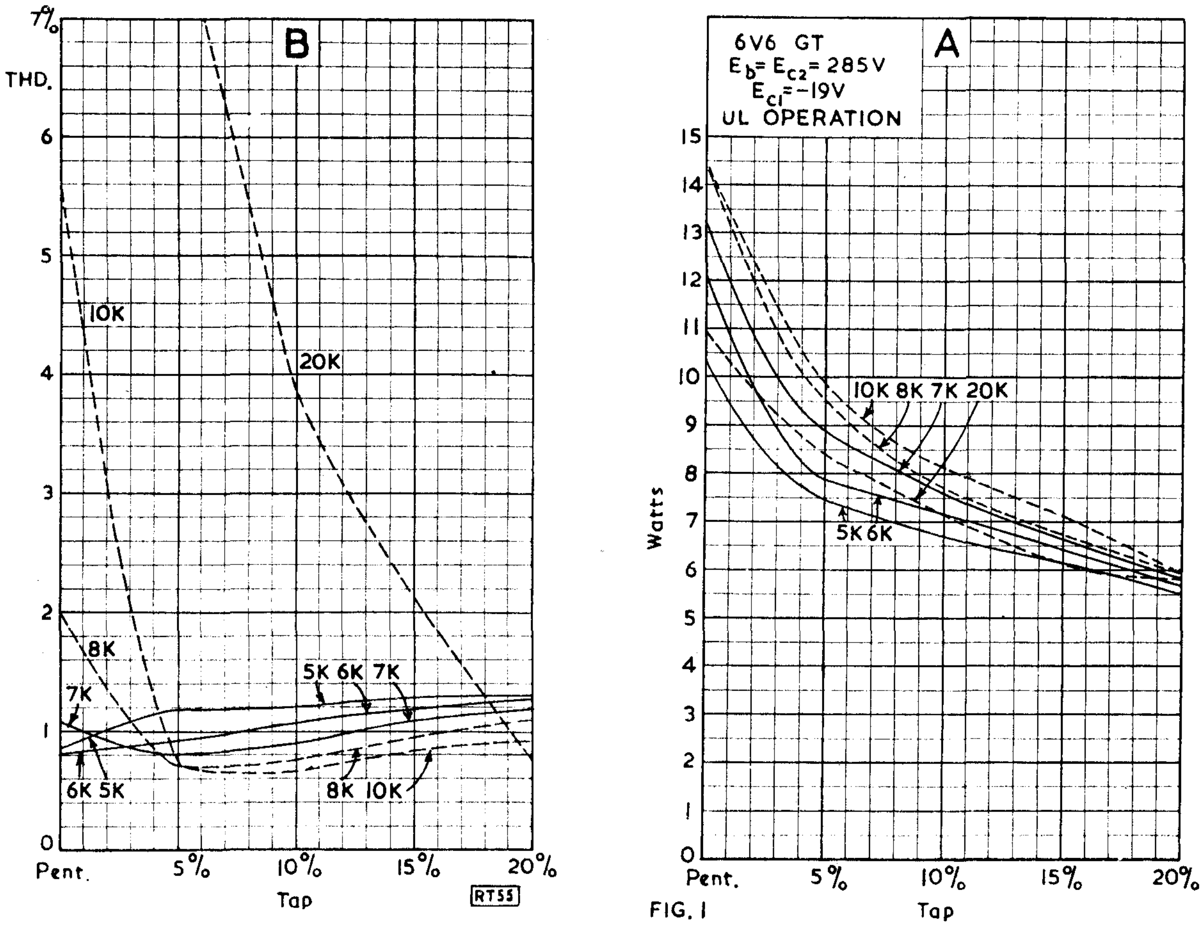


*Fig. 1. 6V6-GT push-pull UL operation,* $E_b = E_{c2} = 285V$, $E_{c1} = -19V$, *peak grid voltage equals bias; (A) Power output versus tap; (B) Total harmonic distortion versus tap (RT54).*

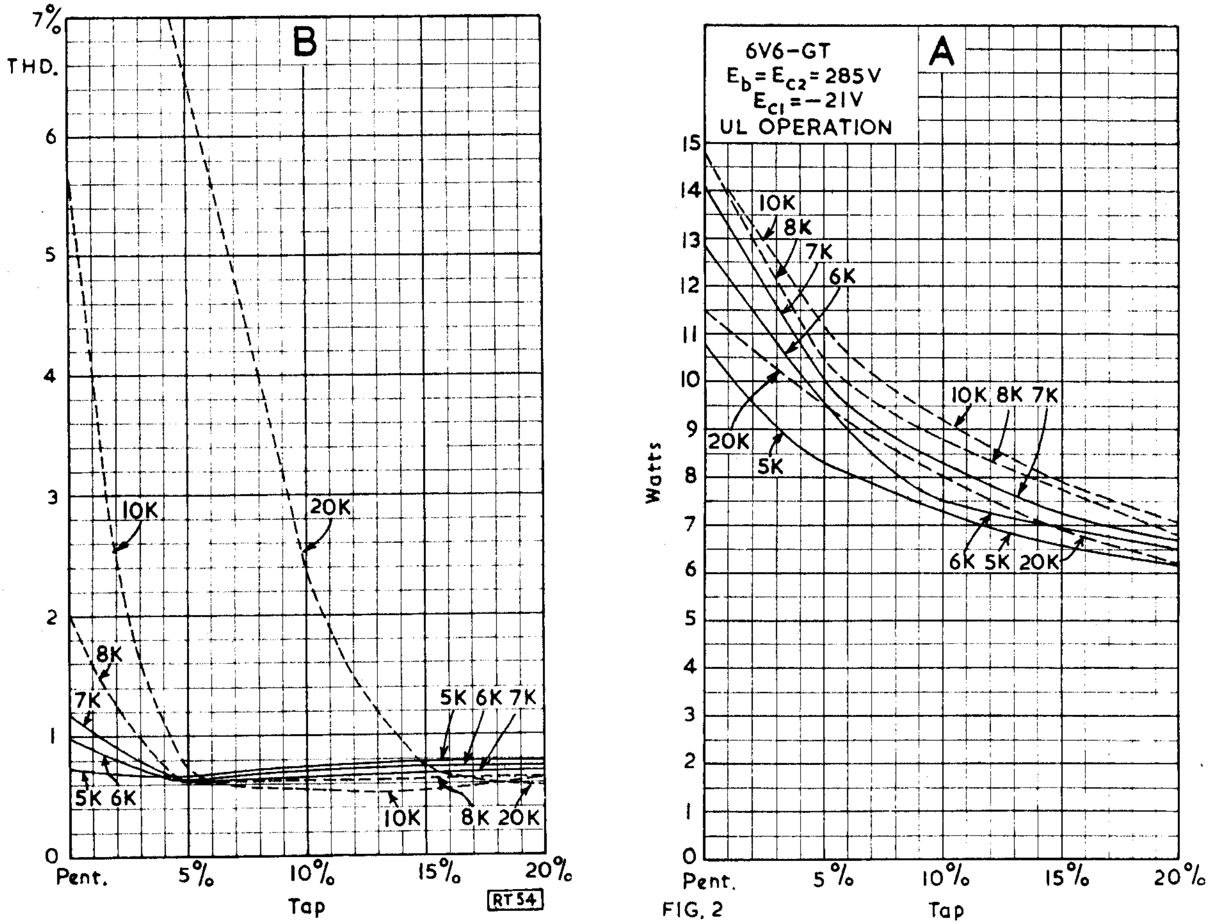


*Fig. 2. 6V6-GT push-pull UL operation,* $E_b = E_{c2} = 285V$, $E_{c1} = -21V$, *peak grid voltage equals bias; (A) Power output versus tap; (B) Total harmonic distortion versus tap (RT55).*

If high power output had been unimportant, a tapping point of 15% or 20% might have been selected to make the load resistance less critical for distortion. However, this distortion is less than that with pentode operation. The whole question of distortion with high impedance loads, such as occur with loudspeakers, will be treated in full detail in a later article in this series, and comparisons made between UL, triode and pentode operation.

The selected condition gives 71% of the output obtainable with the same valves as pentodes under the same conditions except that the bias is the published value (—19 volts).

The curves and other data are for operation in the conventional way with the peak signal voltage equal to the bias ("zero grid"). Of course, in any practical amplifier, it is not possible to drive to zero grid without grid current and consequent distortion, and the consequent reduction in effective power output applies to all types of operation. The output resistance under these conditions without external feedback is 15,400 ohms plate-to-plate. With the 20% tapping, this figure would become 9,600 ohms.

*Conditions for fixed bias* (values are both valves):

| | |
|---|---|
| Supply voltage (plate to cathode) ... | 285 volts |
| Bias voltage ..................... | —21 volts |
| Load resistance (P-P) ............. | 8000 ohms |
| Cathode current: zero signal ....... | 58 mA |
| max. signal ....... | 85 mA |
| Power output ..................... | 9.8 watts |
| Total harmonic distortion .......... | 0.8 % |
| Total input power (based on cathode current), max. signal ............ | 24.2 watts |
| Efficiency (based on cathode current). | 40.5 % |

(Compare this with the tetrode efficiency 46.5 %)

*Conditions for cathode bias* (values are for both valves):

| | |
|---|---|
| Supply voltage ................... | 306 volts |
| Cathode bias resistor (each valve)* .. | 430 ohms |
| Plate to cathode voltage (max. signal) | 285 volts |
| Grid bias (max. signal) ........... | 20.2 volts |
| Load resistance (P-P) ............. | 8000 ohms |
| Cathode current: zero signal ....... | 83 mA |
| max. signal ....... | 94 mA |
| Plate current: zero signal ......... | 75.4 mA |
| max. signal ......... | 82.8 mA |
| Screen current: zero signal ......... | 7.6 mA |
| max. signal ......... | 11.2 mA |
| Power output ..................... | 9.6 watts |
| Total harmonic distortion .......... | 0.98 % |
| Total input power (based on cathode current), max. signal ............ | 26.8 watts |
| Cathode current efficiency .......... | 36 % |

* With each cathode resistor adequately bypassed. Alternatively a common cathode resistor of 220 ohms could be used.

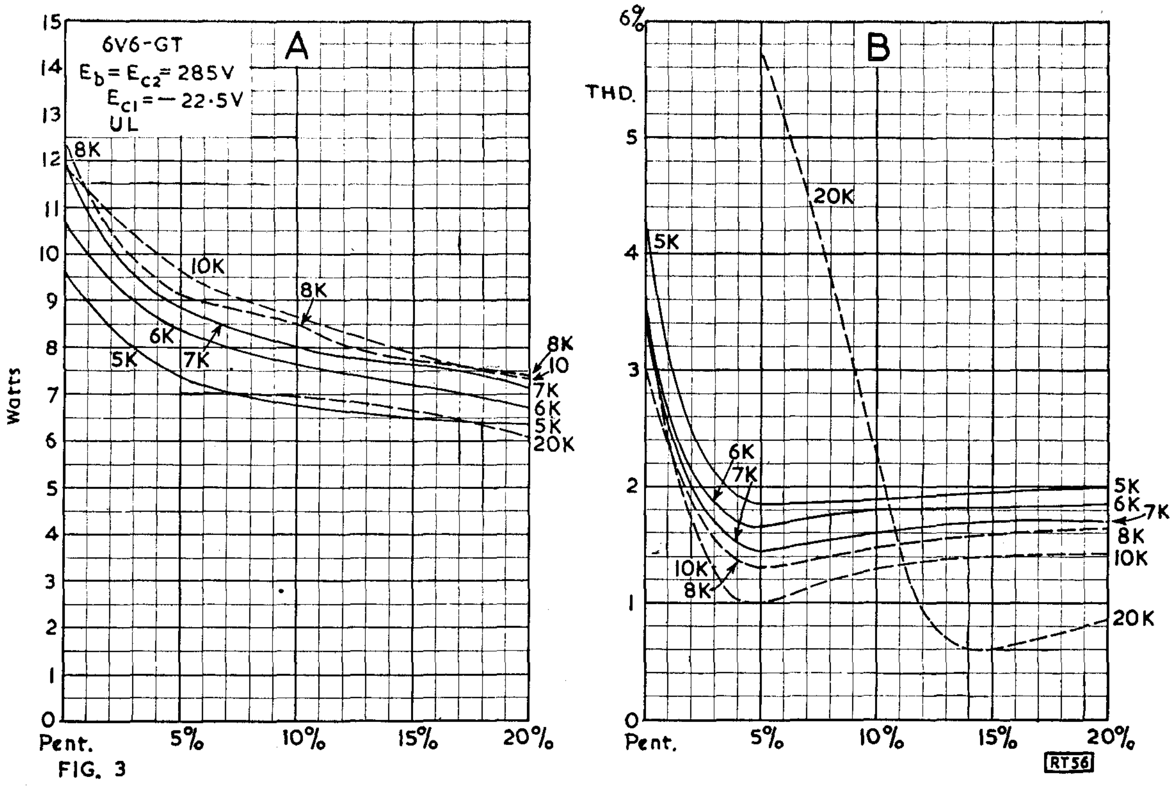


*Fig. 3. 6V6-GT push-pull UL operation, $E_b = E_{c2} = 285V$, $E_{c1} = -22.5V$, peak grid voltage equals bias; (A) Power output versus tap; (B) Total harmonic distortion versus tap (RT56).*

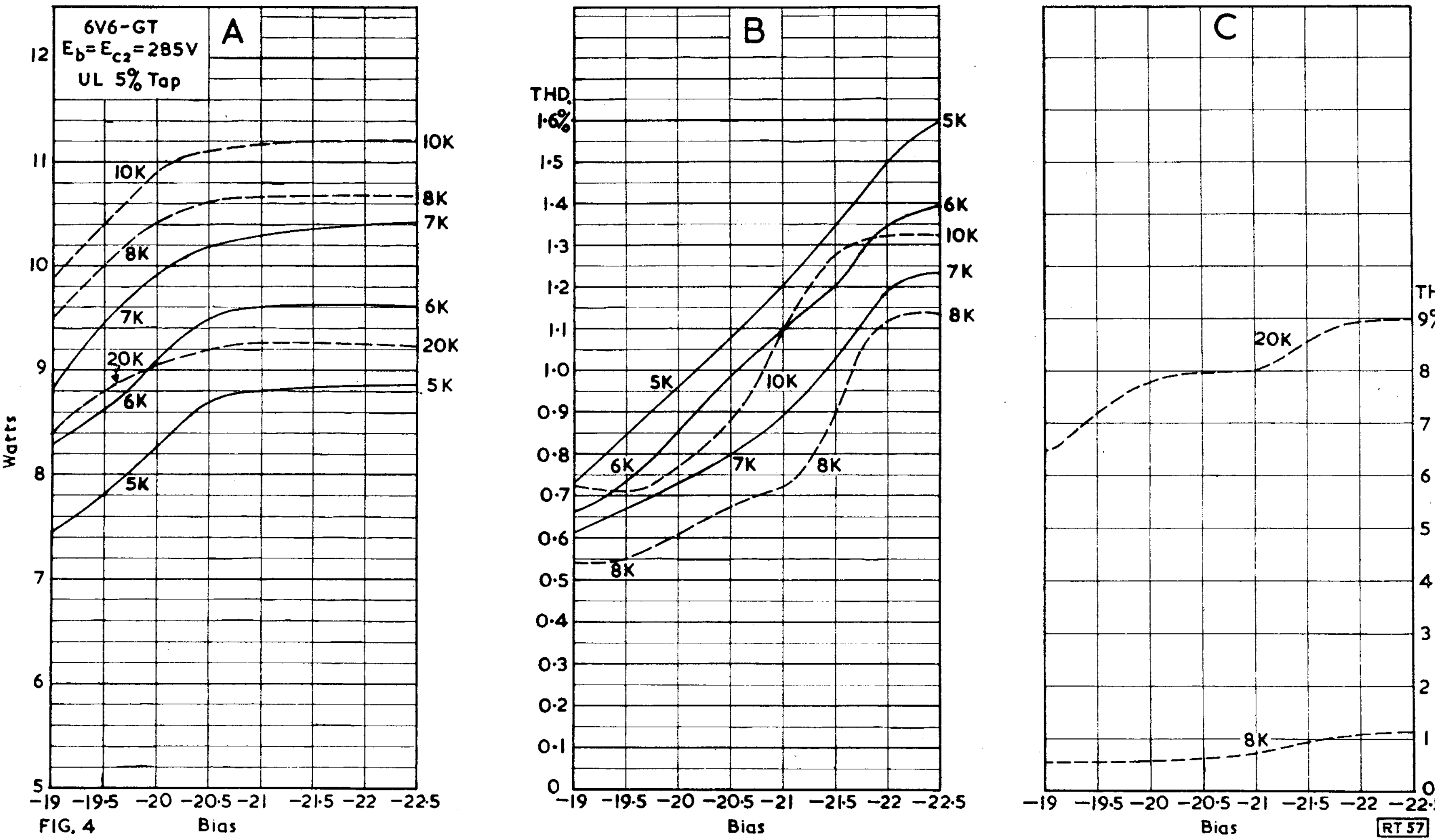


*Fig. 4. 6V6-GT push-pull UL operation, $E_b = E_{c2} =$ 285V, tap 5%, peak grid voltage equals bias: (A) Power output versus bias; (B) Total harmonicdistortion versus bias; (C) Total harmonic distortion versus bias for 20,000 ohm load, with 8,000 ohmload for comparison. Note that THD scales in B and C differ (RT57).*

## 2. Comparison between UL and divided plate and cathode loading.

Divided plate and cathode loading is used in the QUAD II and other amplifiers (Ref. 1 and 2). The transformer half-primary is in two sections, part connected from cathode to earth and part from plate to B+, while the screen is bypassed to earth. It is obvious that there will be an a.c. voltage between screens and cathodes in the same way as the UL amplifier — in fact, it can be kept to the same value if desired. Thus divided loading operation has a performance in some ways similar to that of the UL operation. The principal difference is that divided loading has additional negative voltage feedback in the cathode-grid circuit.

For equivalent results with divided loading the cathode winding should have the same proportion of the total impedance as for UL operation. For example, with type KT66 this impedance ratio should be about 20%. In effect, the transformers will differ only in that the winding for the former is broken at the tapping point.

The choice between UL and divided loading will be influenced by the reduced gain with the latter. In most other respects the two methods are quite similar, and results for one apply very closely to the other.

The measured impedance ratio in the QUAD II amplifier is 3.5%, which is considerably less than the optimum (20%) found in our tests of type KT66. It seems likely that the preceding stage gain is insufficient to permit optimum operation of the output stage, but this will be checked later by direct measurement.

It is hoped to publish, at some future date, test results using a special output transformer permitting divided loads with a choice of several impedance ratios.

† Radiotronics, May, 1955.

## 3. Comments on UL operation.

The UL amplifier is quite distinctive, neither a pentode nor a triode, but with its own marked characteristics. Its power output is definitely less than that of a pentode, as is clearly shown for type KT66 by Fig. 2 of Part 1 of this series†. This effect has often been obscured by the choice of conditions to give optimum performance for UL operation and then, without any other change except the connection of the screens on the transformer, measuring the power output for pentode operation. As shown in the earlier article, this would not give optimum pentode operation, so that the comparison is not a fair one. This remark applies particularly to the curve published by Hafler and Keroes.

Secondly, the reduction in distortion with UL operation is much greater than the reduction in gain. Taking Figs. 5A and B from Part 1 of this article, which are both for 5000 ohm loads, the ratio of gains from pentode to UL 5% operation is approximately 1.48 times (from the slopes of the tangents to the linearity characteristics). On the other hand the ratio of total harmonic distortion varies from approximately 1.4 times at low levels, to over 3.3 times at 18 watts, for the same power output in both cases. The same effect holds under all conditions which we have measured, for type 6V6-GT as well as KT66.

Thirdly, the optimum load resistance for UL operation, in all cases so far tested by us, is greater than that for pentode operation.

Fourthly, the shape of the plate characteristics of the valve is distinctly different from those of either triodes or pentodes.

These points all indicate that UL operation is distinctly different from either triode or pentode operation, and should be regarded as a separate phenomenon.

### References.


1. W. N. Williamson and P. J. Walker, "Amplifiers and Superlatives", W.W. 58.9 (Sept., 1952), 357.
2. P. J. Walker (letter), "Ultra-linear Operation", W.W. 60.12 (Dec., 1954), 593.