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RADIOTRONICS

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Part 1

ULTRA LINEAR AMPLIFIERS

First article of a series by F. LANGFORD-SMITH

and A. R. CHESTERMAN

This first article gives a general introduction to the subject, with its history, some of its characteristics, and then an investigation into the effects of the tapping point on the power output and distortion. The effects of high resistive loads are also investigated.

1. Name

The name has been the subject of much controversy. "Tapped Transformer" and "Triode Tetrode" operation have been suggested in England, while "Partial Triode Operation" has been used in the Radiotron Designer's Handbook (Ref. 1). None of these seem to have taken on, so that we are left with the title "Ultra Linear", which will be used throughout this article in its abbreviated form, UL.

2. History

A claim has been made that the circuit was originated jointly by R. Lackey and R. R. Chilton of the Australian Radio College and distributed to students in the form of notes in 1933. Unfortunately, the early records were destroyed by fire, and no written description has been seen by the authors. If any one of our readers can produce the relevant documents, we would be happy to publish the fact.

The UL circuit (not, of course, under this name) was patented by the late A. D. Blumlein in 1937 (Ref. 2). It did not receive much publicity until 1951, when D. Hafler and H. I. Keroes (Ref. 3) published a fairly detailed description under their newly-coined appellation "Ultra Linear". Since then, it has attracted a good deal of attention and is now being widely used in place of pentode operation in high fidelity and other good quality amplifiers. Some of the many references are given at the end of this article. However, no satisfactory treatise on the subject has yet appeared with information sufficiently detailed to satisfy an amplifier designer. The present article is the first of a series to meet this need.

3. Description

A typical circuit diagram is shown in Fig. 1. It differs from pentode operation by the screens being connected to tapping points T, T, on the transformer primary. It is always advisable to fit screen suppressors R3 and R4 and usually also condensers C1 and C2 between the plates and the transformer end of the screen suppressors, to eliminate a form of instability. Typical values are 0.001 or 0.002 μF and 47 to 220 ohms. Grid stopper resistors (10K) are also desirable.

In this article, "pentode operation" is to be taken as including beam tetrode operation.

UL operation is a step between pentode and triode operation. When the tapping points are moved down to the B+ terminal, the valves operate as pentodes. When the two tapping points are moved to the plate ends of the windings, the valves operate as triodes; when the tapping points are in between, the operation is intermediate between triode and pentode operation. Any desired tapping points may be used — those closest to the B+ end give characteristics closely resembling pentodes and then as the tapping points are moved towards the plate ends the characteristics become more and more like triodes, until the extreme case is reached where full triode operation is obtained. **It is usual to refer to the tapping point as so many per cent. of the total impedance, and this practice will be followed in the present series of articles.** However, sometimes a tapping point is referred to as a percentage of the total number of turns. One may be converted to the other by using the relationship.

Percentage turns $= 10\sqrt{}$ *percentage impedance* (1)

For convenience, Table 1 has been calculated.

Table 1 — Tapping Point (from B+ end)

Percentage impedance	*Percentage turns*
0%	0% (pentode)
5%	22.4%
10%	31.6%
15%	38.7%
18.5%	43%
20%	44.7%
25%	50%
35%	59.2%
50%	70.7%
75%	86.6%
100%	100% (triode)

A complication with UL operation is that the screen voltage swings around the applied voltage. For example, with 250 volts applied, and a transformer tap of 20% impedance, the alternating screen voltage will be 44.7% of the alternating plate voltage (Table 1). If the plate load resistance is 5000 ohms (single-ended) and the power output is 5 watts, the r.m.s. plate voltage will be about 158 volts and the r.m.s. screen voltage will be about 70 volts.

The two most important effects of UL operation are on power output and total harmonic distortion. The power output with UL operation is always less than that with pentode operation and greater than that with triode operation, for constant applied voltages. As will be shown later, the maximum signal cathode current with UL is less than with pentode operation, and the cathode current efficiency is approximately the same, so that if the plate voltage is increased to give the same input power for both cases, then the output power will be the same for both UL and pentode.

4. Optimum bias and load resistance

Up to now all experimenters seem to have assumed that the load resistance and bias for UL would be the same as for pentode operation. A graphical approach indicated that the optimum load resistance would be different, so tests were carried out on type KT66 as a typical example.

5. Type KT66, 300 volt operation

Many measurements were made on type KT66 with 300 volt plate and screen supply, and those are summarised in Fig. 2. Curve 1, marked "Max. power output", shows power output against percentage tap, and each point is the condition of bias and load resistance giving maximum power output irrespective of distortion. Curve 2 shows the power output when the bias and load resistance are selected for minimum total harmonic distortion. On both these curves the load resistance and grid bias for each point are marked on the curves. Curves 3 and 4 give the THD for each of the two upper curves. It will be seen that the difference in power output between curves 1 and 2 is fairly small (less than 0.5 db) and in most cases it is only necessary to consider the minimum distortion curve (2). The following conclusions can be derived for type KT66, for constant plate and screen voltages.

(a) Lowest distortion occurs at about the 20% tap. It is deleterious to go beyond this point, on account of the reduction in power output and increase in distortion. At the 20% tap the power output is from 52% to 59% of the pentode maximum power, and the THD from 0.4% to 0.65%, depending on the bias and load resistance.

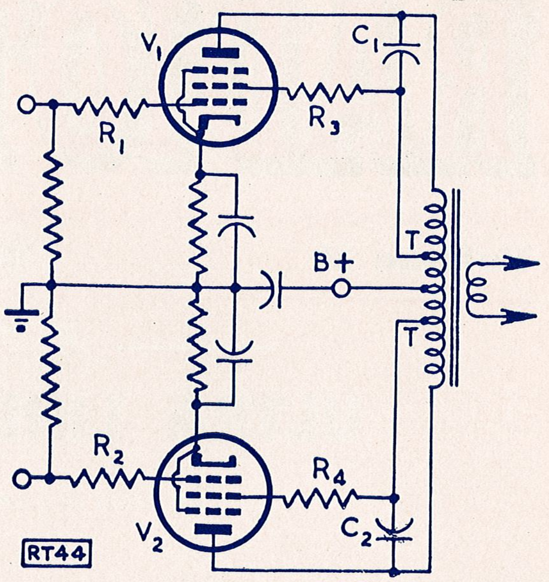


Fig. 1. Circuit diagram of a typical UL amplifier. (44.)

(b) The optimum tapping point for highest fidelity is between 17% and 20%, and it is not at all critical.

(c) The optimum tapping point for public address work is probably 5%. This gives from 73% to 78% of the pentode maximum power output, depending on the bias and load resistance, and from 0.5% to 2% THD. Of course, if the plate and screen voltages can be increased, it might be possible to use the 20% tap for P.A. with no loss of power output.

(d) Whether adjusted for minimum distortion or for maximum power, UL with 15% to 20% tapping points gives lower THD and higher power output than triode operation — see Fig. 2.

(e) The optimum bias for maximum power output is greater for UL than for pentode operation. It increases from — 28 volts (pentode) to — 30 and — 34 volts (UL) and — 34 volts (triode) — see Fig. 2. These values of maximum power output are irrespective of distortion and would not be used in practice for pentode operation, since by allowing a slight reduction in power output there would be a considerable reduction in distortion. However, the condition for maximum power output can be used for UL operation, since the distortion is low.

(f) The optimum bias for minimum THD decreases from — 34V with pentode operation, to — 26V with all UL tappings and for triode operation.

(g) The optimum load resistance for maximum power output is greater for UL than for either pentode or triode operation, increasing from 6K (pentode) to 6K, 7K, and 8K (UL), and back to 5K and 6K (triode) — see Fig. 2.

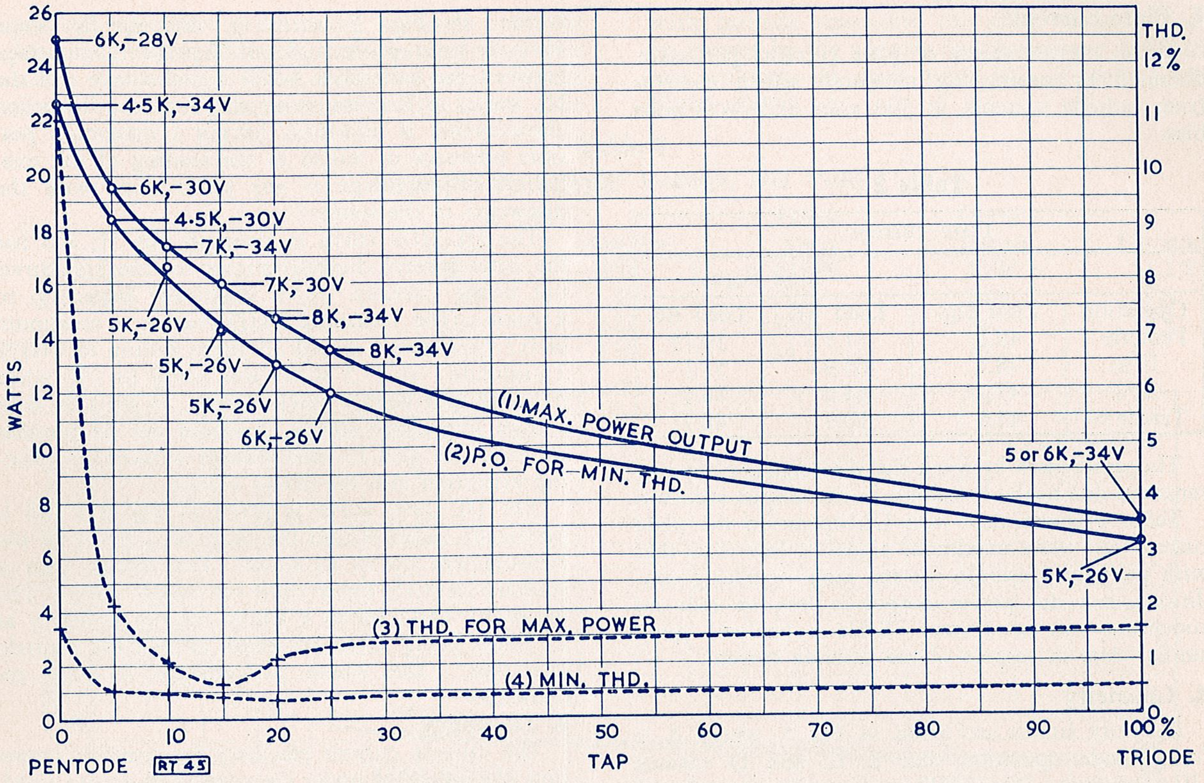


Fig. 2. Effect of tapping point on power output and total harmonic distortion. Type KT66's with E_b = E_{c2} = 300 V. Optimum bias and load resistance for each point. (RT45.)

(h) The optimum load resistance for minimum THD increases from 4.5K (pentode) to 5K for UL 10% to 20%, up to 6K at 25% tapping, and down to 5K for triode operation — see Fig. 2.

The detailed test results on which the curves of Fig. 2 were based are shown in Fig. 3. The effect of load resistance on power output is quite small over the range shown, but its effect on distortion is very marked. The effect of bias voltage is also more marked on distortion than on power output. Note that the minimum distortion point for pentode operation is quite critical, both on bias voltage and load resistance (although not shown in Fig. 3), whereas the 20% UL tapping gives almost constant distortion over the range of load resistances shown, for any bias voltage between —26 and —30 volts. This is a very valuable feature.

Note the surprising low distortion possible with pentode operation and a load of 4500 ohms—1.7% THD at —34 volt bias, but the operating point is rather critical.

The readings for distortion are only relative owing to the difficulties in reading a THD meter at very low levels, and the distortion in the signal voltage applied to the grids (up to 0.2%). There is necessarily some cancellation and accentuation of harmonics due to harmonic phase relationships between the input source and those produced in the amplifier. The Appendix gives the detailed conditions of testing.

6. Screen dissipation

The static screen dissipation will normally be slightly less than that for pentode operation, because of the increased bias. Since the screen makes some contribution to the total power output, the dynamic screen dissipation is not given by the screen input power. The maximum signal screen dissipation for identical operating conditions in each case, is highest for pentode operation, lowest for triode and UL is intermediate between the two. For this reason pentodes may sometimes be used with UL operation under conditions when pentode operation would cause the screen dissipation rating to be exceeded. The screen power relationships may be expressed:—

Screen dissipation = *screen input power* —

power output .... (2)

It is usually not convenient to measure the screen power output and, so long as the maximum signal screen input power is below the screen dissipation rating, the valve will be operating well within its ratings.

Fig. 4 shows the screen current plotted against tapping point for 300 volts and —30 volt bias. The lowest curve shows the zero signal current per valve, while the two upper curves show the maximum signal screen current for 5K and 8K load resistances. It will be seen that the 5% tap reduces the screen current to 57% and 55% respectively of the pentode value. Fig. 4 applies to a pair of typical valves, but wide tolerances occur in the screen currents drawn by all beam tetrode valves.

7. Plate current

Table 2 gives values of plate currents per valve, obtained by subtracting measured screen currents from cathode currents, at 300 volts and —28 volts bias.

Table 2

Plate current			
		Max Signal	
Operation	Zero Sig.	Load 5K	Load 8K
Pentode	49.1	71.5	59.75
10%	48.1	63.9	57.3
20%	47.75	61.0	56.5
Triode	44.5	50.9	48.7

The differences between the zero signal plate currents are due to the resistance in the output inductor.

Table 2 shows that with UL operation the plate current rise with maximum signal is less than that with pentode operation for the same operating conditions, but the power output is less, so that no conclusion can be drawn. Table 3 (below) gives similar data in respect of the cathode current.

8. Linearity

Linearity curves are given in Fig. 5, where A is for pentode operation, and B, C, and D various UL conditions. The THD at the grids was reduced to 0.13% for Fig. 5 only. The linearity characteristics were measured using peak reading valve voltmeters for both grid and plate voltages, in order to get a true result*. The disadvantage of this procedure is that the power output indicated by the valve voltmeter is appreciably less than the actual power output when the THD exceeds about 1%. As a consequence, it has not been practicable to add the power output readings to the pentode linearity curve. The approximate power output may be calculated by multiplying the power indicated on the curve by a factor of 1.1 for 5% THD.

The pentode curves for maximum power output are given in Fig. 5A. Note the "shelf" in the distortion curve from about 15 to 19 watts output. The linearity curve deviates from the straight line about 2 watts power output, and the slope of the curve at maximum power output (input voltage 17.5 volts) is only 34% of that at low levels. This reduces the effective feedback at maximum power output.

The UL 5% curve is given in Fig. 5B. This is practically linear up to 2.5 watts and the deviation is distinctly less than for the pentode, although its shape is rather unusual. The THD curve reaches a maximum of 1% between 9 and 13 watts, then comes down to about 0.8% (minimum) at 18 watts before rising to 1.4% at zero grid.† Although this form of distortion characteristic is generally undesirable, the THD at any level is much below that for pentode operation. In the distortion curves of Fig. 5 there is undoubtedly some effect from in-phase and out-of-phase relationships between the harmonics in the signal source and the UL stage, so that the exact shape of the distortion characteristic is uncertain, having a maximum possible tolerance of ±0.26 in the reading of the total harmonic percentage at any point (i.e. twice the distortion in the source).

The UL 10% curve is given in Fig. 5C and has the same general characteristic as for the 5% curve, but better linearity. It is practically linear up to 4 watts. The measured THD reaches a maximum of 0.77% between 8 and 14 watts, falling to 0.68% (minimum) at 17.5 watts and rising to 1% when the peak grid voltage reaches zero. In practice, with a high impedance source, it would not be possible to drive the grid to zero voltage without introducing distortion into the driver voltage.

The UL 20% curve is given in Fig. 5D and is practically linear within the limit of accuracy of the measurement up to 15 watts. The voltage gain is constant at 7.15 times right up to 15 watts. The measured THD shows a steady rise up to 0.6% at 15 watts, being about one-tenth of that for pentode operation. The whole performance is quite remarkable.

9. Efficiency

The cathode current efficiency for pentode operation was measured under the conditions giving maximum power output. Three different conditions for UL operation were also measured, and are given in Table 3.

The pentode and the first UL condition given above are the respective conditions for maximum power output given in Fig. 2. The second UL condition is for the bias and load resistance which give maximum power output with pentode operation; it is therefore not optimum for power output or efficiency with UL operation. The third UL condition is intermediate between the other two UL conditions; it also is not optimum for power output or efficiency with UL operation.

Table 3 shows that, by selecting the UL condition giving maximum power output, the efficiency is 49.8% compared with 51.2% for the pentode. This is quite a remarkable performance, especially since the pentode output includes about 11% distortion, with the large third harmonic component giving an effective increase in the power output for a limited swing (Ref. 12). On the other hand the UL output had only about 1% total harmonic distortion, with a negligible effect on the power output.

Under the conditions for maximum power output in both cases, the efficiency with the 10% tap was slightly higher than for the 20% tap.

Thus UL operation, using conditions for maximum power output, will give nearly the same power output from a specified d.c. power input as will pentode operation. It merely requires somewhat higher plate voltage and somewhat less plate current than for pentode operation.

In addition, a specified valve, operating with constant d.c. input power, will give nearly the same power output with UL operation as it will with

† The zero grid line is where the peak input voltage is equal to the bias.

* An article on linearity characteristics will appear in a future issue.

pentode operation (each being operated under its own optimum conditions), and the total plate plus screen dissipation will be about the same. Hence, since the screen dissipation with UL is less than with pentode operation, the plate dissipation will be greater by the amount that the screen dissipation was reduced—in most cases this is only a very slight amount.

Table 3

Type KT66, Supply Voltage, 300 Volts

Condition		I_k (mA) no sig.	I_k (mA) max. sig.	Power input	Power output	Efficiency
Pentode	6K, —28V	105	165	48.8W	25W	51.2%
UL 20%	(1) 8K, —34V	60	99	29.6	14.8	49.8
	(2) 6K, —28V	108	122	36.4	14	38.5
	(3) 7K, —30V	88	116	34.5	14.2	41

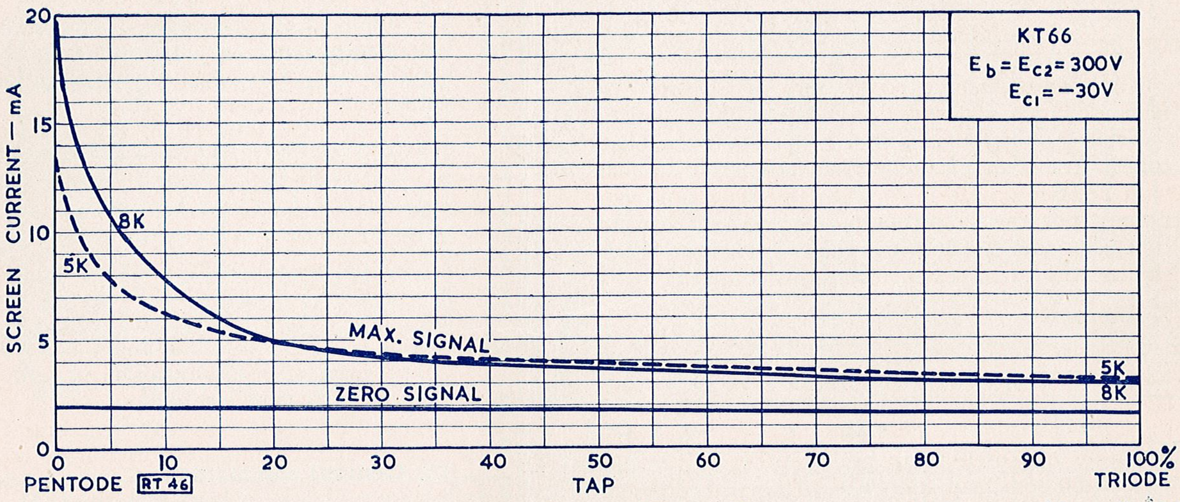


Fig. 4. Effect of tapping point on maximum signal screen current for a single valve, for load resistances of 8000 and 5000 ohms, and $E_b = E_{c2} = 300$ V. Zero signal screen current is also given. (RT46.)

10. Negative feedback

The UL amplifier has internal negative voltage feedback which decreases the total harmonic distortion and reduces the output resistance and the gain, when compared with pentode operation. Each of these characteristics is intermediate between the values for triode and pentode operation.

However, the feedback cannot be treated as pure feedback, because it reduces the maximum power output and requires additional bias and higher load resistance for optimum operation.

The non-linearity known to exist in the screen characteristic is not the cause of these two phenomenon, which are fundamental, although it must have some effect on non-linear distortion. A further point in support of our conclusion is that the distortion with UL is not intermediate between pentode and triode, but is lower than either.

Measured values of the voltage gain are given below for KT66, $E_{bb} = E_{c2} = 300$ V, $E_{c1} = -30$ V and $R_L = 6000$ ohms.

Operation	Gain	Ratio
Pentode	10.2	1
5% tap	9.15	0.9
10% tap	8.6	0.84
20% tap	7.7	0.75

These values appear to check reasonably well with the gain reduction ratio derived from Williamson and Walker (Ref. 5) on the assumption that this can be treated as pure voltage feedback.

$$\text{Ratio} = \frac{1}{1 + \dfrac{X}{\mu_t} \cdot \dfrac{\mu R_L}{r_p + R_L}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

where ratio = 1 for pentode operation
X = fraction of output voltage fed back to screen
= percentage turns of tapping point ÷ 100
μ = pentode mu
μ_t = triode mu (screen connected to plate)
r_p = plate resistance of valve
and R_L = load resistance for single valve
= $\frac{1}{4}$ × load resistance plate-to-plate.

11. Overload characteristics and distortion

The overload characteristics as observed on an oscilloscope differ fundamentally from those of pentodes, although they bear some resemblance to those of pentodes with a high degree of feedback. Pentodes show slight flattening of the peak some distance before reaching maximum power output, the minimum visible being about 3 or 4%. UL amplifies without feedback show no visible deformation until

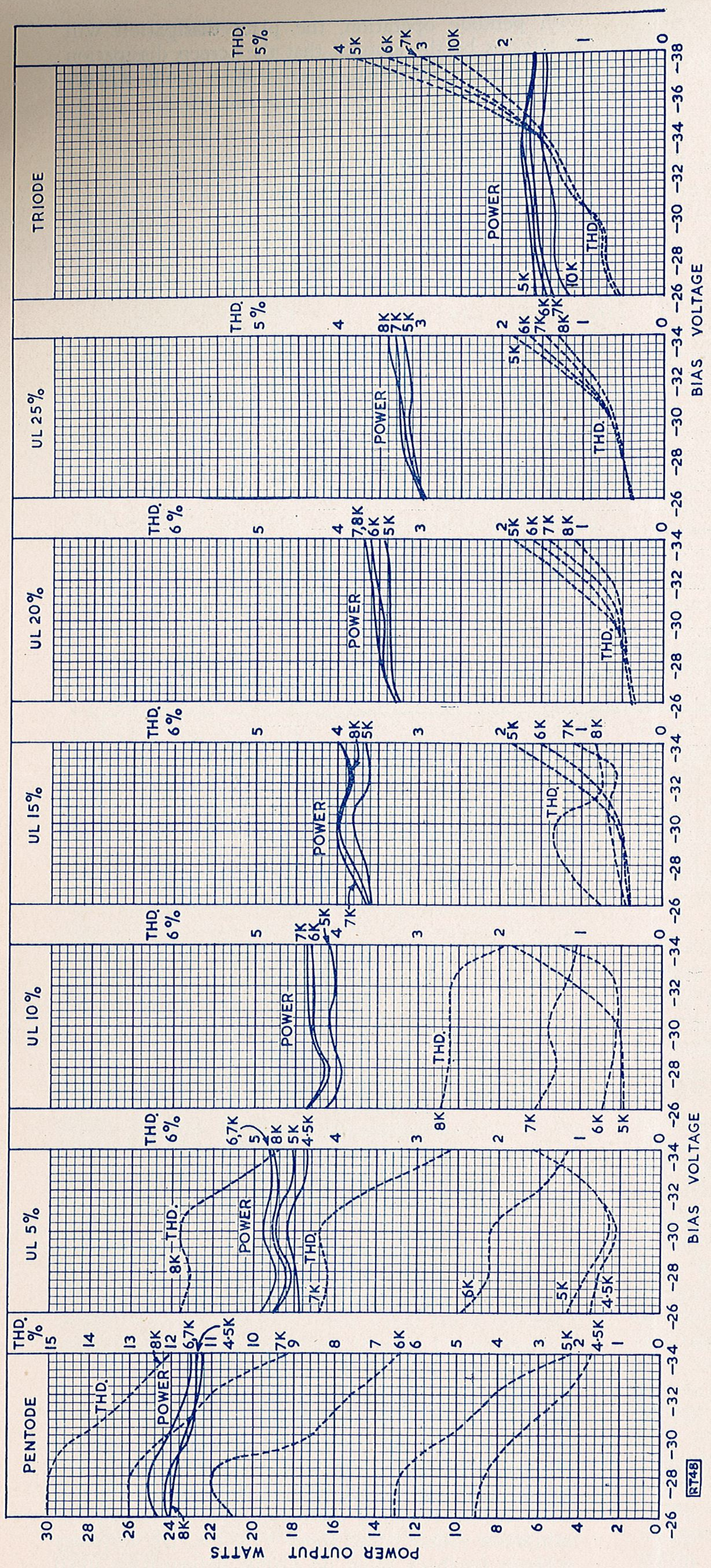


Fig. 3. Power output and total harmonic distortion versus grid bias voltage, for selected values of load resistance. (RT48.)

a "flat" appears at about 0.6%, and as the drive is increased this extends in a straight line chopping off the whole top of the peak.

This method is very much more sensitive as an indication of total harmonic distortion for UL than for pentode operation.

12. Characteristics deferred for a later article

(a) Input impedance (Miller Effect), see also Ref. 11.

(b) Output resistance. This is intermediate between pentode and triode operation.

(c) Non-linear distortion. Tests of IM distortion and measurement of individual harmonics to supplement total harmonic distortion as used in this article.

(d) The effects of a loudspeaker load. This may be simulated by a dummy load having a high impedance and a choice between 45° and zero phase angle, in addition to the normal purely resistive load.

(e) Effect of tolerances in the valve characteristics, especially screen current, on the optimum tapping point and other performance characteristics.

(f) Graphical examination of the composite characteristics with loadlines.

13. General comments

(a) Comparison with pentode operation.

The principal advantage of UL is that the distortion is so very much lower that the total circuit feedback can be less, leading to a higher stability margin or in many cases making possible the use of a cheaper output transformer for the same stability margin. Another important advantage is that the llnearity characteristic for the 20% tap is practically straight up to the grid current point, giving constant amplifier gain even without feedback. In this respect it appears to be as good as triode operation, and results in the full amount of feedback being applied at all levels. Pentodes suffer from drooping linearity characteristics and only have about one-third of the full amount of feedback at high levels where it is most wanted.

When compared on the basis of power output on a constant supply voltage (e.g. Fig. 2) UL operation shows a serious drop in maximum power output. This drop in power output occurs because, on the positive peak of the grid driving cycle, the screen voltage is reduced below that which would occur with the pentode operation, so that the maximum

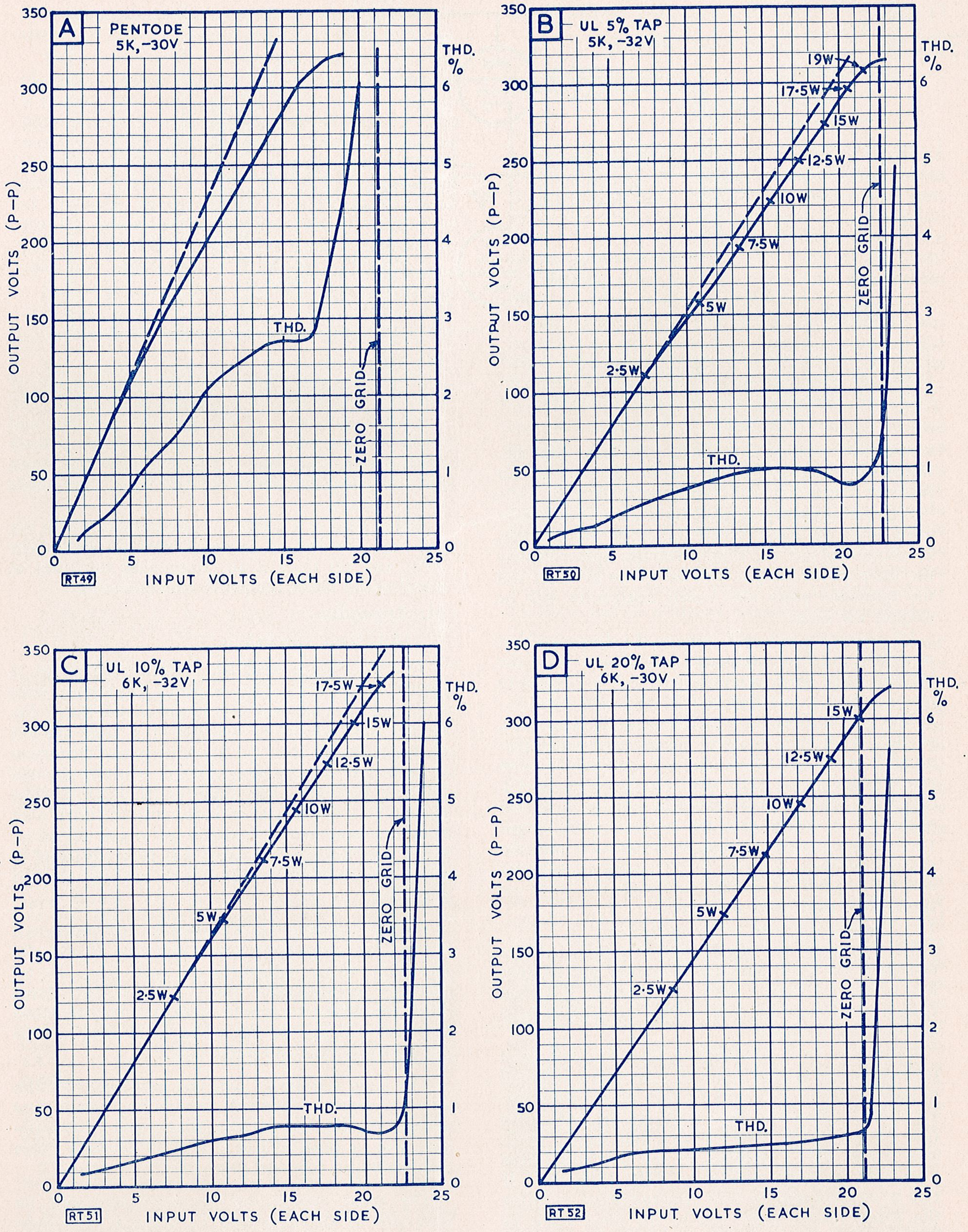


Fig. 5. Linearity curves, with total harmonic distortion, for KT66 with $E_b = E_{c2} = 300$ V:
A. Pentode $E_{c1} = -28V$, $R_L = 5000$ ohms (RT49).
B. UL 5%, $E_{c1} = -30V$, $R_L = 5000$ ohms (RT50).
C. UL 10%, $E_{c1} = -30V$, $R_L = 6000$ ohms (RT51).
D. UL 20%, $E_{c1} = -28V$, $R_L = 6000$ ohms (RT52).

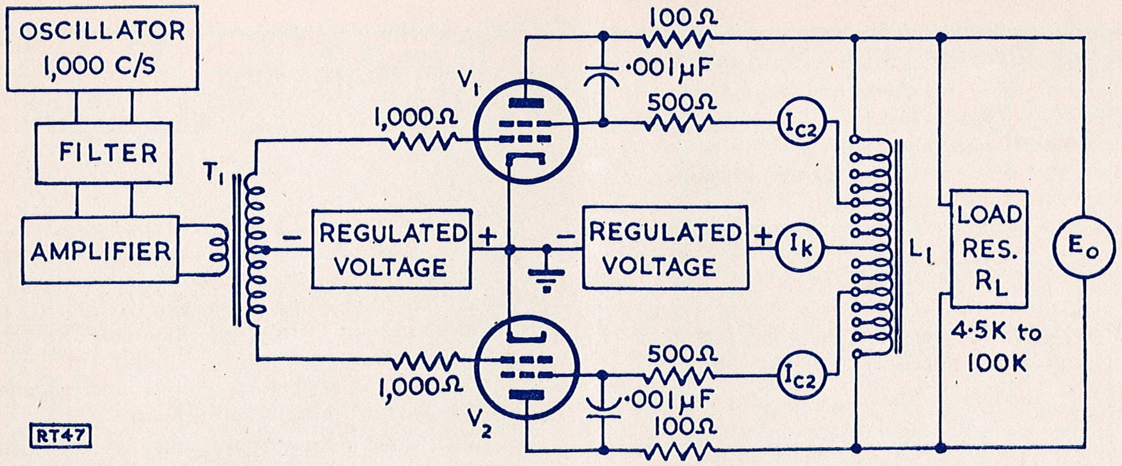


Fig. 6. Circuit used for deriving test results published in this article. (RT47.) Note that the 0.001 μF condensers are in different positions to those shown in Fig. 1.

signal plate current is reduced. However, the efficiency may be made to be almost the same as for pentode operation, and, circumstances and valve voltage ratings permitting, if the UL amplifier is supplied with the same power input as the pentode, by increasing the UL supply voltage, approximately the same power output will be given by both and the combined plate and screen dissipation will be roughly the same.

UL operation not only reduces the distortion, but it makes the load resistance less critical over the limited range used in these tests. It is hoped to investigate this matter more fully at a later date.

The screen dissipation is less with UL operation, so that conditions of operation are sometimes permissible with UL which are not permissible with pentode operation. The only disadvantages of UL compared with pentode operation appear to be the slight loss in voltage gain, the reduced power output (unless the supply voltage is increased) and the slightly increased cost due to the tapped transformer and the stopper condensers (although the latter are sometimes used with pentodes).

(*b*) *Comparison with triode operation.*

UL operation has higher power output, greater efficiency, less total harmonic distortion and requires less driving voltage. When overloaded, it suffers from a particularly flat form of flat top even without any external feedback.

Operation on a loudspeaker load has not been covered by the present series of tests, but it is hoped to publish further results in the near future. However, a graphical check has been made on the only valve type for which UL characteristics were readily available (type 5881), leading to the conclusion that high load resistance will cause high distortion. If this is substantiated in later measurements, it leaves the triode output stage still as the ideal when its performance on a loudspeaker load (and not a fixed resistive load) is considered. However, this must be at the expense of larger power supply, and larger input voltage.

(*c*) *Operation.*

The point for minimum distortion is given, at least for type KT66, by a tapping point from 17% to 20% impedance, and the optimum grid bias and load resistance will both be greater than for pentode operation on the same supply voltage. Comments on increasing the screen voltage have been made in (a) above.

When used as a public address amplifier with the 5% tap, the loss in power output is only about 20%, and yet there is an outstanding reduction in non-linearity when compared with pentodes.

14. Appendix

14.1. Test conditions

The test circuit used for these measurements is shown in Fig. 6. The oscillator harmonics were reduced by a filter, and the amplifier non-linear distortion was reduced by the use of a large amount of feedback, so that the total harmonic distortion at each grid did not exceed 0.2% (0.13% for the linearity curves). The input transformer T_1 was made with a C core and an inductance of 100H, with a set-up ratio of 1:2 primary to whole of secondary. The leakage inductance was 16mH primary to whole of secondary, and 36mH primary to half secondary.

A tapped inductor I_1 was used in preference to a transformer, tapped at 5, 10, 15, 20, 25, 35, 50 and 75% of the impedance on each side. Its inductance plate-to-plate was 350H at low level, 500H at 240V 50 c/s, with leakage inductance from one half-winding to the other half 10mH. The d.c. resistance was 440 ohms total.

The large number of taps and switching facilities gave a tendency towards instability, which was avoided by the use of grid, screen and plate stoppers, and by capacitors of 0.001 μμF between plates and screens.

The input voltage was measured separately on each side of the secondary T_1, using a valve voltmeter, but the values were almost identical. An oscilloscope was connected in turn from each grid to earth and the side showing earliest signs of "flattening" was used as an indicator. The input was decreased until there was no visible deformation of a greatly enlarged waveform peak.

The output voltage, which was used for deriving the power output was measured with an Avo Model 8 rectifier type meter. This is the type of instrument commonly used in power output meters. This was checked for accuracy against a Western dynamometer type voltmeter. For pentode operation the error was between +2% and +3.5% from 100 to 240 volts, falling to zero from 270 to 300 volts. For UL operation the error was about +2% from 100 to 230 volts, zero at 250 volts, —1% at 270 volts, and zero again at 300 volts.

Before measuring distortion, the input and output voltmeters and the oscilloscope were disconnected, since they had an appreciable effect on the distortion.

The linearity tests were carried out with r.m.s. calibrated peak-reading valve voltmeters in both input and output circuits.

The supply voltage for the present series of tests was approximately 304 volts, giving very close to 300 volts between positive electrodes and cathodes.

15. References

1. Radiotron Designer's Handbook, 4th ed., p. 570.

2. Blumlein, A. D., British Patent No. 496,883 (5/6/1937). U.S. Patent No. 2,218,902 (22/10/1940).

3 Hafler, D., and H. I. Keroes, "An ultra-linear amplifier". Audio Eng. 35.11 (Nov., 1951), 15.

4. Hafler, D., and H. I. Keroes "Ultra-linear operation of the Williamson amplifier". Audio Eng. 36.6 (June, 1952), 26.

5. Williamson, D. T. N., and P. J. Walker, "Amplifiers and superlatives—an examination of American claims for improving linearity and efficiency", W.W. 58.9 (Sept., 1952), 357.

6. White, S., "The White Powtron Amplifier". Audio Eng. 37.11 (Nov., 1953), 32. Uses ultra-linear amplifiers, with 2 channels, 20 watts main amplifier, with frequency dividing network prior to both amplifiers. No distortion figures quoted. Employs mainly negative voltage feedback, but also small degree of negative current feedback; this is claimed to eliminate "power distortion" caused by variation in loudspeaker impedance.

7. Frieborn, J. K., "High quality circuits". Radio Electronics 24.9 (Sept., 1953). Includes Brociner UL-1 (ultra-linear), Bell 2200 (combined plate and cathode loaded), Bogen DB 20 (combined plate and cathode loaded with distortion curves), and Stromberg-Carlson AR-425 (pentodes with overall feedback—with distortion curves).

8. Marshall, J., "Junior Golden-Ear Amplier". Radio Electronics 24.11 (Nov., 1953), 55. Modified ultra-linear with push-pull 6V6.

9. Hafler, D., "Ultra-linear operation of 6V6 tubes". Radio and TV News, 51.6 (June, 1954), 43.

10. Ayres, W. R., "Audiology". Audio Eng. 37.5 (May 1953), 14, especially pp. 68-69 and Fig. 4.

11. Marshall, J., "Extending amplifier bandwith". Radio Electronics 24.10 (Oct. 1953), 40.

12. Radiotron Designer's Handbook, 4th ed., p. 564, second paragraph.

Applications Laboratory Report* Number 17

RADIOTRON 6BK8/Z729 ≡ EF86

LOW NOISE A.F. PREAMPLIFIER PENTODE

The Radiotron 6BK8/Z729 is a sharp cut-off a.f. pentode of medium transconductance and triode-mu in 9-pin miniature construction with noval base, which has been designed specifically for a.f. applications which are critical for hum, noise and microphony, and, in particular, for use in low level miscrophone and pick-up input and preamplifier stages of high gain audio amplifiers.

With good design and layout and provided performance is not affected by factors external to the valve, the inherently good low level characteristics which have been achieved in the design and manufacture of the 6BK8/Z729 permit satisfactory operation of this valve as a resistance-capacitance coupled pentode amplifier, with a.c. heater excitation, in the input stage of low level high gain equipments, such as broadcast studio and tape recorder amplifiers, without sacrificing overall noise performance. In typical equipments, with proper care and suitable design, hum and noise voltages, referred to the control grid, of the order of 1.5 μV for hum and 2 μV for valve noise (hiss) for a bandwidth of 15 Kc/s, can be achieved without undue difficulty.

The internal electrode structure is completely shielded, the internal shielding being connected to base pins 2 and 7 which should be earthed to the chassis. For most applications, the internal shielding is entirely adequate and the use of an external shield-can unnecessary. In applications, however, in which minimum attainable noise levels are required external shielding of the stem section of the valve may be necessary. In such cases, a shield-can register or collar attached to the socket and earthed to the chassis, as a rule, provides adequate shielding.

Because of special precautions taken in the design to reduce the capacitance coupling between the control grid and the heater to a minimum, the total hum voltage referred to the control grid, under typical resistance coupled amplifier conditions, does not exceed 1.5 μV when either side of the heater is earthed. Optimum and lower values of hum voltage may be achieved, where warranted, by the use of an a.c. earth connected to a centre-tapped resistor wired across the heater pins at the valve socket and by biassing the cathode negatively with respect to the heater sufficiently to cut off any residual heater-cathode emission present. A most convenient, simple and inexpensive arrangement for this purpose consists of two 50 ohm resistors connected in series across the heater, with a 0.25 μF capacitor connected from the junction of the two resistors to ground or chassis. The heater-cathode bias is then readily provided by connecting the junction of the two resistors to a point on a high

* Contributed by the Applications Laboratory, Valve Works, Ashfield.

resistance voltage divider, approximately 15 volts positive with respect to the chassis or ground. In order to achieve the minimum hum levels attainable in this way, it is essential to use only a valve socket of good quality and design, having low capacitance and very high leakage resistance between the control grid and heater contacts particularly. Care must also be taken with the socket wiring and that the centre shield is earthed.

In general, for most applications, the microphony characteristics of the 6BK8/Z729 are of a sufficiently low level that the use of a special anti-vibration, anti-shock type of socket mounting is unnecessary, even under relatively severe vibration and microphony conditions, such as occur for example in most portable tape recorder equipments, in which the valve is subject to motor vibration and microphony due to close proximity to the loudspeaker which often is operated at a relatively high level. Under extreme conditions, however, some degree of isolation may be necessary depending on the performance requirements.

Radiotron 6BK8/Z729 is now included in the Radiotron range and is currently available from stock.

Tentative ratings, characteristics and pentode resistance-capacitance coupled amplifier data are set out hereunder. It is hoped to publish triode characteristics and triode resistance-capacitance coupled conditions in a subsequent issue of Radiotronics.

Tentative Maximum Ratings and Characteristics General Data

Electrical:

Heater for Unipotential Cathode:

Voltage	6.3	ac or dc volts
Current	0.2	amp.

Direct Interelectrode Capacitances: °

Pentode Connection:

Grid No. 1 to Plate	0.025	$\mu\mu$F.
Input	4.0	$\mu\mu$F.
Output	5.5	$\mu\mu$F.
Grid No. 1 to Heater	0.0025	$\mu\mu$F.

° With no external shield.

Mechanical:

Mounting Position	Any
Maximum Overall Length	$3\frac{3}{16}''$
Maximum Seated Length	$1\frac{15}{16}''$
Maximum Diameter	$\frac{7}{8}''$
Bulb	T-6-$\frac{1}{2}$

Base: Small Button Noval 9-Pin (JETEC No. E9-1)

BOTTOM VIEW

Base Connections:

Pin 1—Grid No. 2
Pin 2, 7—Internal Shield
Pin 3—Cathode
Pin 4—Heater
Pin 5—Heater
Pin 6—Plate
Pin 7—Internal Shield
Pin 8—Grid No. 3
Pin 9—Grid No. 1

AMPLIFIER — Class A_1
Pentode Connection

Maximum Ratings, Design-Centre Values:

Plate Voltage	300	max. volts
Grid No. 2 [Screen] Voltage	200	max. volts
Grid No. 2 Supply Voltage	300	max. volts
Grid No. 2 Input	0.2	max. watt.
Plate Dissipation	1.0	max. watt.
Cathode Current	6.0	max. mA
Grid No. 1 (Control-Grid) Voltage:		
Negative Bias Value	50	max. volts
Positive Bias Value	0	max. volts
Peak Heater-Cathode Voltage:		
Heater negative with respect to cathode	150	max. volts
Heater positive with respect to cathode	100	max. volts

Characteristics:

Plate Voltage	250	volts
Grid No. 3 (Suppressor): Connected to cathode at socket.		
Grid No. 2 Voltage	140	volts
Grid No. 1 Voltage	−2.0	volts
Plate Resistance	2.0	megohms
Transconductance	1850	umhos
Plate Current	3.0	mA
Grid No. 2 Current	0.6	mA.

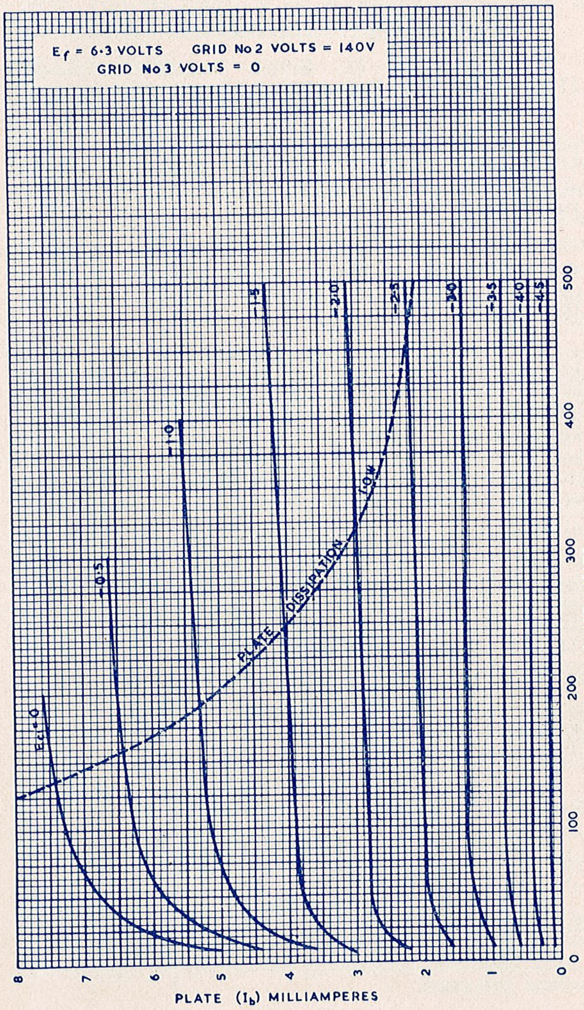


Plate Family Characteristics.

For triode ratings & amplifier conditions, see May '57 issue, P.68.

Application Data

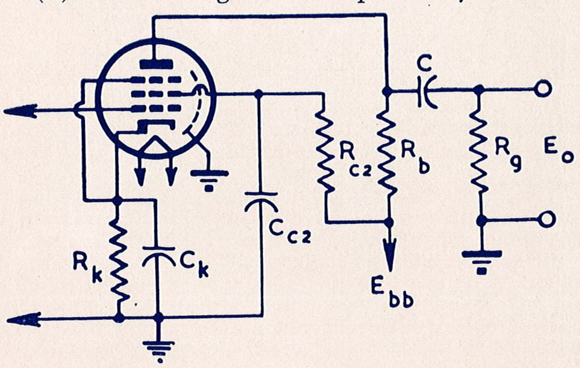
Operation as Resistance-Capacitance Coupled Pentode Amplifier.

Typical Operating Conditions*: Pentode Connection.

E_{bb} Volts	R_b MΩ	R_g MΩ	R_{c2} MΩ	R_k Ω	V.G. $E_o = 10V.$ r.m.s.	Ttl. Harmonic Distortion % $E_o = 10V.$ r.m.s.	$E_o = 33V.$ r.m.s.
150	0.1	0.1	0.18	1500	68	0.9	—
	0.1	0.22	0.18	1600	85	0.7	—
	0.1	0.47	0.18	1600	102	0.4	—
	0.22	0.22	0.56	3000	95	1.6	—
	0.22	0.47	0.56	3000	128	1.1	—
	0.22	1.0	0.56	3300	151	0.9	—
	0.47	0.47	1.0	8200	116	1.5	—
	0.47	1.0	1.2	7500	159	1.4	—
	0.47	2.2	1.5	6800	204	1.1	—
200	0.1	0.1	0.22	1200	74	0.5	—
	0.1	0.22	0.33	1000	99	0.3	—
	0.1	0.47	0.33	1100	114	0.1	—
	0.22	0.22	0.68	2200	115	0.9	—
	0.22	0.47	0.68	2200	151	0.5	—
	0.22	1.0	0.68	2400	175	0.5	—
	0.47	0.47	1.2	6200	143	1.1	—
	0.47	1.0	1.5	5100	217	0.7	—
	0.47	2.2	1.8	4700	256	0.7	—
250	0.1	0.1	0.27	1000	79	0.4	2.2
	0.1	0.22	0.33	820	103	0.1	1.3
	0.1	0.47	0.33	910	123	0.1	0.9
	0.22	0.22	0.68	2000	120	0.6	3.8
	0.22	0.47	0.82	1800	167	0.2	2.4
	0.22	1.0	0.82	2000	200	0.2	1.8
	0.47	0.47	1.5	4300	176	0.8	4.1
	0.47	1.0	1.8	3600	250	0.4	3.4
	0.47	2.2	2.2	3900	294	0.4	2.3
300	0.1	0.1	0.33	680	80	0.4	1.5
	0.1	0.22	0.39	750	107	0.3	0.8
	0.1	0.47	0.39	750	128	0.2	0.5
	0.22	0.22	0.82	1500	137	0.3	1.9
	0.22	0.47	0.82	1600	182	0.2	1.6
	0.22	1.0	1.0	1500	222	0.2	0.8
	0.47	0.47	1.8	2700	208	0.5	3.5
	0.47	1.0	1.8	3300	270	0.3	3.2
	0.47	2.2	2.2	3300	333	0.4	1.5

*** Explanatory Notes.**

(a) Circuit Diagram — Component Symbols.



(b) Component tolerances — In accordance with current practice, operating conditions have been determined, using only preferred values of resistance of R_b, R_{c2} and R_k within the following tolerance ranges, R_b 20%, R_{c2} 10%, R_k 5%, R_g 20%. Consequently, the conditions tabulated are not always optimum with respect to harmonic distortion, and improved distortion values may in certain cases be obtained by exact adjustment of the particular conditions using non-preferred values for R_k and R_{c2}.

(c) In all cases, a value of R_k has been chosen such that the effective control grid negative bias is not less than 1.6 volts, plus the peak value of the signal voltage, to ensure negligible grid damping of the input circuit.

(d) Grid No. 3 (suppressor) should be connected to cathode at the valve socket.

(e) Voltage gain (V.G.) and Total Harmonic Distortion were measured at a frequency (1000 c/s.), at which the attenuations due to the capacitor C coupling R_b to the following grid resistor, R_g, and incomplete bypassing of R_{c2} and R_k by C_{c2} and C_k respectively are negligible.

The results tabulated were obtained using a valve having the nominal published characteristics. Slight departures from these values can be expected with the normal variations in characteristics, which occur from valve to valve.

(f) For the conditions tabulated, the valve noise (hiss) voltage, referred to the control grid, is normally lowest for the highest R_b values (lowest cathode current conditions) and is substantially independent of E_{bb}. Typical limiting measured values which include the normal variations from valve to valve for the values of R_b and conditions tabulated, for a bandwidth of 15 Kc/s., are as follows:—

R_b	Valve Noise Voltage (Referred to Control Grid) — 15 Kc/s. Bandwidth.
0.1 megohm	2.3 — 5.0 μV
0.22 megohm	2.0 — 4.0 μV
0.47 megohm	1.0 — 3.0 μV

(g) The tabulated conditions have been selected mainly on the bias of the best practical compromise for minimum distortion and acceptable gain for the two output voltages of 10 and 33 volts r.m.s. and do not represent the optimum conditions for minimum valve noise. The noise voltages obtained under these conditions should, however, be adequate for most low level applications, since they are of similar order to the thermal noise levels of typical low level input circuits connected to the control grid of the first preamplifier valve.

The New A.W.A. Low Noise A.F. Preamplifier 6BK8 / Z729

Editor .... D. Cunliffe-Jones
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