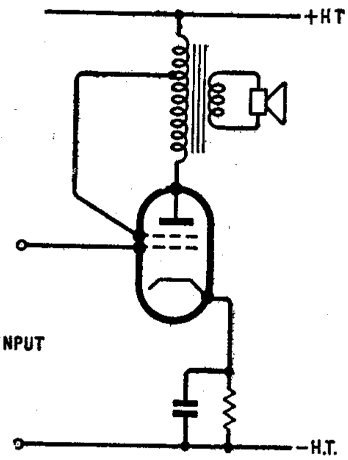
Tetrodes with Screen Feedback

FURTHER LIGHT ON THE SO-CALLED "ULTRA-LINEAR" CIRCUIT

AFTER a period of caution, amounting in some quarters to undisguised scepticism, the "ultra-linear" output stage[1, 2, 3, 4] is undoubtedly here to stay. It was unfortunate, though, that Hafler and Keroes in popularizing this circuit for audio amplifiers should have chosen a term which, if it means anything, suggests that the transfer characteristic has been bent "beyond the straight" and is therefore still curved!

Several alternative descriptions have been suggested, the most plausible being "triode-tetrode" operation. This hardly does justice to the circuit, since, although at the extreme limits of the screen tapping (Fig. 1) the valve is undoubtedly operating either as a triode or a tetrode, the intermediate tapping points do not give a progressive transition, so far as distortion is concerned, from one set of characteristics to the other. When the screen tapping point is properly adjusted the transfer characteristic is more nearly linear and distortion is less than that of either the tetrode *or the triode* connection. Obviously some factor is at work which is not present in either of the limiting conditions and "triode-tetrode" is misleadingly simple. If it is called the "UL" circuit the special nature of its performance is underlined, and we do not have to grit our teeth over that "beyond the linear."



TAPPING POINT (Measured from +h.t.)	
Impedance (%)	Turns (%)
0	0
5	22.4
10	31.6
15	38.8
20	44.7
25	50
30	54.8
50	70.8
100	100

Left: Fig. 1. Basic connections of UL output valve.

The UL nomenclature is, incidentally, adopted by F. Langford-Smith and A. R. Chesterman who have recently[5] carried out an exhaustive experimental investigation of the push-pull circuit (Fig. 2). The results of their measurements with KT66s are given in Fig. 3 and it will be noted that they have taken the trouble to adjust the load resistance and bias for the best performance at each tapping point. This ensures that the effects of screen feedback will not be modified or obscured by unfavourable operating conditions.

The curve for maximum power shows a clear minimum for a screen tapping of about 15%, and a similar though less pronounced minimum occurs at about 20% under minimum distortion conditions. Both these minima are of lower value than the distortion present under optimum triode conditions.

Any reduction in inherent distortion in the output stage reduces the degree of overall feedback required for a given amplifier performance and so increases the stability margin, but the improvement over triode performance by itself would seldom justify the expense of the extra primary tappings. The real advantage of UL operation is that triode performance in the matter of low inherent distortion is achieved with a power efficiency performance approaching that of a pentode. For a given audio-frequency power output and distortion level, smaller output valves and a less expensive power supply unit can be used with the UL circuit than would be necessary with triodes in the output stage.

For a given anode and screen supply voltage the available power output from a pair of valves in the UL circuit is always less than that given by the same valves operated as pentodes (tetrodes) (see Fig. 3), and the voltage gain is also less. It is sometimes argued that, provided the amplifier has a stability margin

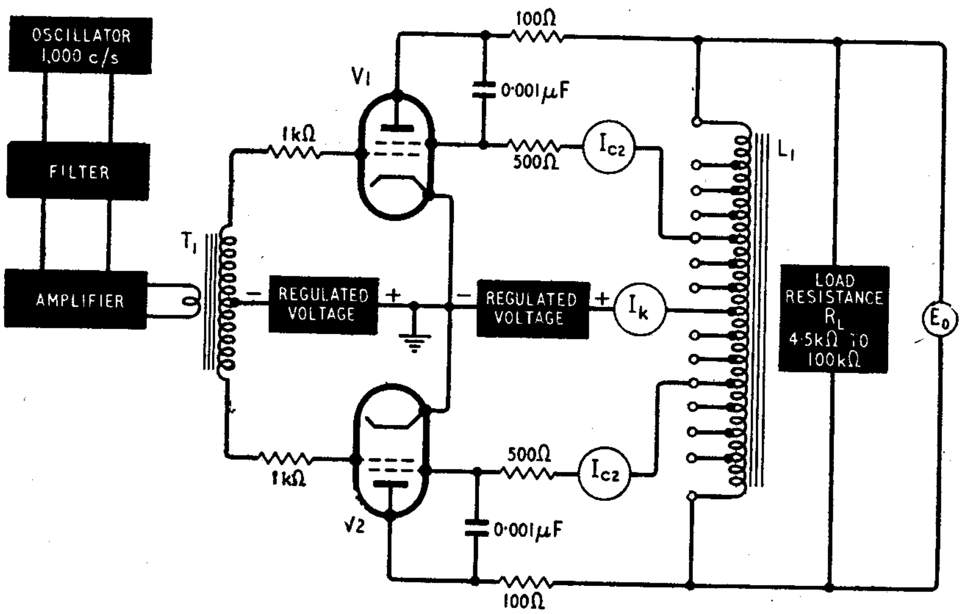


Fig. 2. Circuit used by Langford-Smith and Chesterman as a basis for measurements of power output and distortion given in Fig. 3.

capable of accepting the higher overall feedback necessary to reduce distortion, the same results will be obtained by using normal pentode operation. Langford-Smith points out[3] that the voltage gain characteristic of a pentode stage (Fig. 4 (a)) is far from linear compared with the UL circuit, and that with pentodes the feed back near full power output will be reduced—just where it is most wanted. It is also stated that since the maximum-signal cathode current is less with UL than with pentode operation and the cathode current efficiencies are approximately the same, it should be possible to increase the anode voltage to bring the UL power output up to the pentode level.

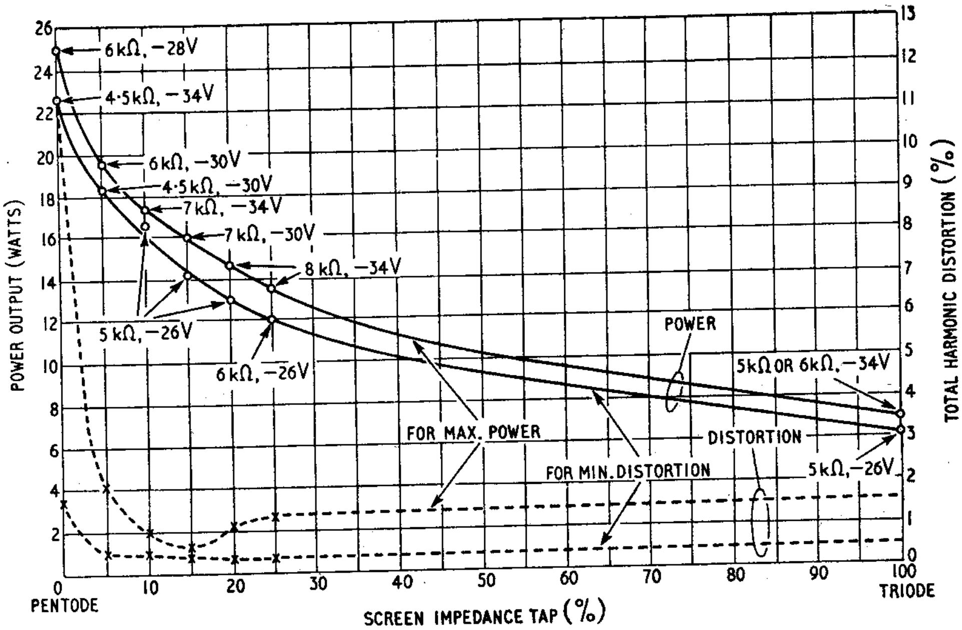


Fig. 3. Variation of total harmonic distortion and maximum power (peak input=grid bias) with screen tapping. Load and bias adjusted for optimum performance at each measured point using a pair of KT66 valves with 300V anode and screen supply.

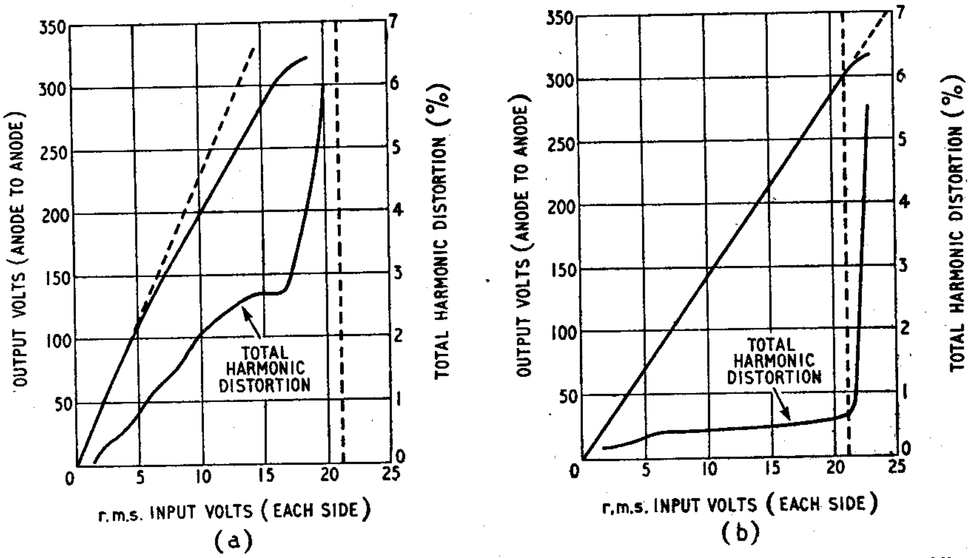


Fig. 4. Voltage transfer characteristics of KT66s, (a) as tetrodes, (b) under 20% tap UL conditions. The vertical dotted line indicates the level at which peak input equals the grid bias.

In the test circuit (Fig. 2) used by Langford-Smith and Chesterman it will be seen that anti-parasitic measures have been liberally applied and the authors mention a tendency towards instability which is attributed to the multiplicity of tappings and their associated switches. This tendency to instability in the UL circuit must not be overlooked. It is closely related to the design of the output transformer and is discussed in detail elsewhere in this issue.

"Mechanism" of the UL Circuit.—Although the circuit behaves, so far as reduction of gain and output impedance are concerned[3], according to the known laws of feedback circuits and shows a smooth transition from the pentode to the triode condition, the conventional feedback formulæ fail to account for the dip in the distortion curve at a critical screen tapping point (which varies from valve to valve).

It has been suggested that non-linearity in the screen/anode characteristic may offset curvature of the control grid characteristic, but this cannot be easily checked as the screen characteristics of power output valves are not usually included in the makers' literature. But is this basically the right explanation? If the screen curvature is sufficient to cancel the grid curvature at comparatively low levels of feedback (5% in the case of the 6V6) why does it not predominate and cause more than the observed distortion as the screen feedback approaches 100% (triode)?

An alternative and more plausible hypothesis recently published[6], takes into account the non-linearity resulting from multiplicative mixing when feedback is applied to an electrode other than the input grid. It is known that non-linearity can be introduced into an otherwise linear valve characteristic by applying feedback to the suppressor grid. This form of distortion will be present also when the screen characteristic is itself linear. It is shown mathematically that feedback can be critically adjusted to cancel a particular harmonic (in practice the third) and that as all even harmonics are already cancelled by push-pull operation the residue must consist of higher-order odd harmonics. The analysis has not been extended to these higher harmonics, and although individually they are of amplitudes approaching the experimental threshold of measurement, it is by no means certain that they may not have been increased by the same process which reduced the much stronger third harmonic. In practice, judging from the subjective quality from UL amplifiers we have heard, this effect, if present, is negligibly small; but it would repay investigation (assuming that distortion measurements of sufficient precision are forthcoming) if only to throw more light on the fundamental processes of UL operation.

Acknowledgment. Figs. 2, 3 and 4 are based on Figs. 6, 2 and 5 respectively of *Radiotronics* (Australia), Vol. 20, No. 5, May, 1955.

References

[1] A. D. Blumlein. British patent No. 496,883 (1937).

[2] "An Ultra-linear Amplifier," by D. Hafler and H. I. Keroes; *Audio Engineering*, November 1951.

[3] "Amplifiers and Superlatives," by D. T. N. Williamson and P. J. Walker, *Wireless World*, September 1952.

[4] Correspondence: Graham Woodville, *Wireless World*, November 1954; P. J. Walker, N. F. Butler, *Wireless World*, December 1954.

[5] "Ultra linear Amplifiers," by F. Langford-Smith and A. R. Chesterman, *Radiotronics*, May, June, July, 1955.

[6] Editorial (W.T.C.), *Wireless Engineer*, August 1955.

"D.C. Stability of Transistor Circuits"

THE author of this article in the April, 1955, issue asks us to point out that the base current in the example (left-hand column, p. 167) should be calculated from equation (3) on p. 164 and not from equation (8) as shown. The numerical error is, however, small and the value of R_B is increased from 12,500 to 13,000 ohms and the stability factor S from 17 to 17.5.

Dates for Your *Wireless World* Diary

INDIVIDUAL announcements have already been made of the dates of some of this year's exhibitions, but for the convenience of readers we give below a list of the principal shows in 1956.

Television Society Exhibition — **March 6-8**
Royal Hotel, Woburn Place, London, W.C.1.

Components Show (R.E.C.M.F.) — **April 10-12**
Grosvenor House, Park Lane, London, W.1.

British Industries Fair — **April 23-May 4**
(Electrical Section), Olympia, London, W.14.

Association of Public Address Engineers Exhibition — **April 25 & 26**
Conway Hall, Red Lion Square, Holborn, London, W.C.1.

Mechanical Handling Exhibition — **May 9-19**
Earls Court, London, S.W.5.

Physical Society Exhibition — **May 14-17**
Royal Horticultural Society Halls, Westminster, London, S.W.1.

British Sound Recording Association Exhibition — **May 26 & 27**
Waldorf Hotel, Aldwych, London, W.C.2.

Institution of Electronics Exhibition — **July 12-18**
College of Technology, Manchester.

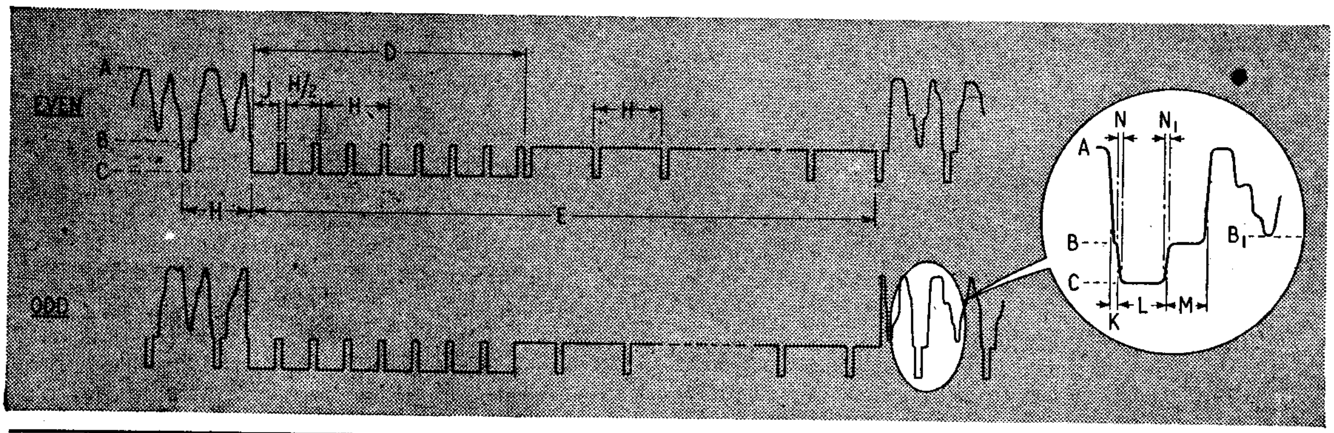
National Radio Show — **Aug. 22-Sept. 1**
Earls Court, London, S.W.5.

Farnborough Air Show (S.B.A.C.) — **Sept. 3-10**
Farnborough, Hants.

Television Waveform

ONE or two minor changes have been introduced in the British television waveform since the publication three years ago (August, 1952, issue) of the operating details of the various world systems (405, 525, 625 and 819 lines). To bring up to date the published information, the amended drawing of the 405-line waveform and the relevant tabular matter are reproduced below.

The first change is in the black level (B_1) which has been lifted by 5 per cent of peak white amplitude. What was previously known as black level (30% of peak carrier) is now called the suppression level (B). The second change, made a few months ago, was the lengthening of the pre-sync. suppression period, or front porch, (K) by 0.5 μsec.



A	(peak white)	100%	H	(line period [μ sec.])	98.7
B	(suppression level)	30%±3%	J	(frame pulse duration [μ sec.])	40±2
B_1	(black level)	35%±3%	K	(front porch [μ sec.])	1.5−2
C	(sync. level)	0−3%	L	(line pulse duration [μ sec.])	8−10
D	(vert. sync. pulses)	4 lines	M	(back porch [μ sec.])	6−9
E	(frame suppression period)	14 lines (1.4 msec.)	N	(rise time [μ sec.])	$\ngtr$0.25
			N_1	[μ sec.]	$\ngtr$0.25