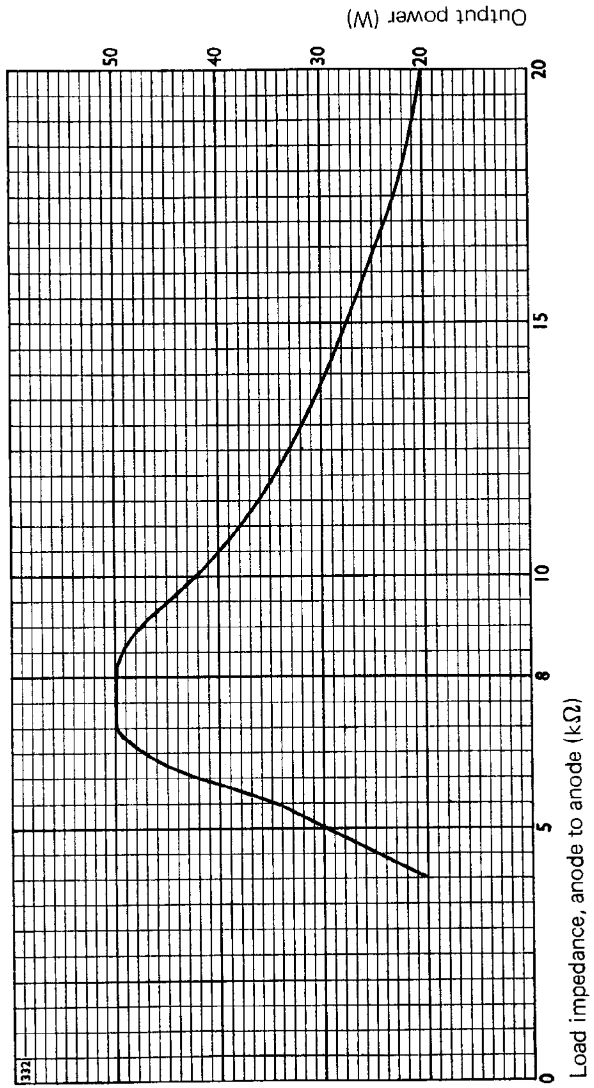
Fig. 8 OUTPUT POWER AND ANODE LOAD IN 50 W AMPLIFIER



Replaces 'KT66 Circuit Supplement'

GEC

AMPLIFIER CIRCUITS FOR KT66

This report describes some early work done on push-pull "ultra-linear" amplifiers using the KT66, with design details for two such circuits giving 30 and 50 W.

In ultra-linear operation, the screen grid of each KT66 is connected to a tapping point on the output transformer primary. This arrangement combines the advantages of both beam tetrode and triode operation in that the high output power of the tetrode is still obtainable but with the low distortion of the triode.

The tappings used were at 20% of each half-primary from the central ht connection, whereas 40% tappings are now commonly chosen. The difference in performance would be slight.

A 30 W ULTRA-LINEAR AMPLIFIER

The circuit is shown in fig. 1. The two KT66 valves are preceded by a pair of B65 (or 6SN7) double triode valves, one of which is used as a self-balancing phase inverter and the other as a push-pull voltage amplifier. Full output is given for an input of about 120 mV rms.

It has been found desirable to connect capacitors C13, C14 of 2000 pF across part of the output transformer in the interests of stability. Screen grid and control grid resistors R15, R16, R17 and R18 are included for the same reason.

The small capacitors C5, C6 serve to swamp stray capacitances in the phase inverter stage and ensure that a balanced output is obtained at the higher frequencies. Their value is not critical but they should be equal.

In order to obtain the full advantages of the ultra-linear circuit, an output transformer of high quality is required. That used in the design of this amplifier was made by Partridge Transformers Ltd., Ref. No. C1732. It has two equal secondaries in order to provide either a 4 Ω or 15 Ω output. Other details are:—

Leakage inductance	:	15 mH
Primary inductance	:	80 H
Ratio	:	22:1

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June 1977
Issue 1

Performance

The curves in figs. 2 and 3 show the performance in three kinds of operation at varying anode loads. Fig. 2 shows the ultra-linear performance at three different levels of distortion compared with the triode at full output. Fig. 3 shows the tetrode condition together with a comparative triode curve.

It will be seen that the ultra-linear circuit behaves quite differently from the tetrode. With the latter, full output is obtainable with a distortion which varies between 4% and 6% according to anode load. Except at the lower load impedances, the output for 1% and 2% distortion is only a small fraction of the maximum output.

In the ultra-linear arrangement, almost full output is obtained at 2% distortion and very little increase is obtained if this is permitted to rise to 3%. The output for 1% distortion is about 50% of the maximum.

It will be seen that, for most values of anode load impedance, the ultra-linear circuit produces only half the distortion of the triode for equivalent outputs and is capable also of giving double the output for the same order of distortion.

The output impedance of the ultra-linear circuit is considerably lower than that of the tetrode arrangement, though higher than the triode's. Measurements made at 20 W output with the optimum anode load of 7 kΩ show that the ultra-linear and tetrode circuits have impedances of 9 kΩ and 35 kΩ respectively. A comparable measurement on the triode circuit gave 3.5 kΩ. The ultra-linear circuit has, therefore, an impedance similar to the anode-anode load impedance of 7 kΩ, whereas the tetrode impedance is very much higher. The ultra-linear circuit can exert a considerable damping factor, a valuable asset with a loudspeaker load.

The frequency response of the complete amplifier of fig. 1 shows a loss of 1.5 db at 20 Hz and 25 kHz.

Operating Conditions

In all three kinds of operation discussed, the dc anode and screen voltages were equal, at 400 V relative to the cathode, for the sake of easy comparison. However, it should be noted that the KT66, as a tetrode, is not normally used with 400 V applied to both anode and screen because the screen dissipation would be excessive at sustained full output, although operation would be satisfactory with normal speech and music signals.

Fig. 7 CURRENT, DISSIPATION AND DISTORTION IN 50 W AMPLIFIER

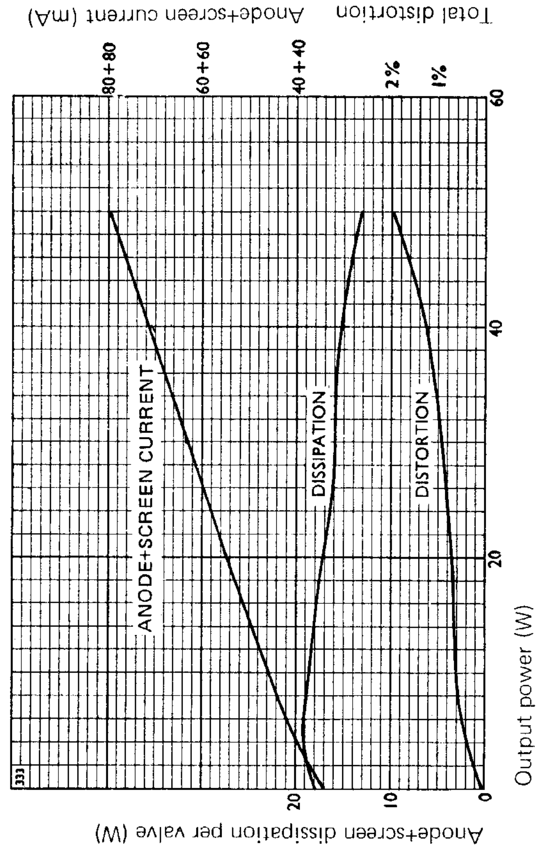
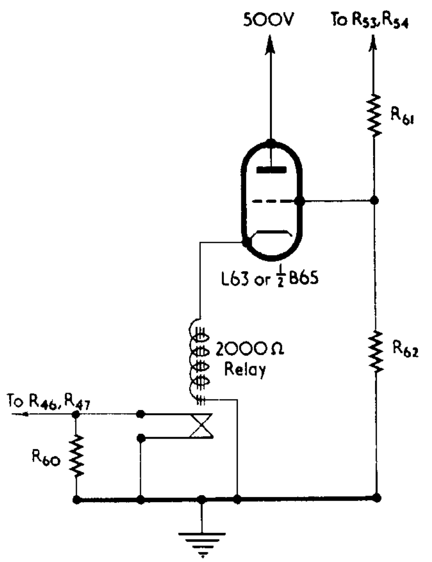


Fig. 6 BIAS FAILURE PROTECTION



This circuit may be added to the 50 W amplifier to protect the KT66 valves in the event of bias failure. The resistor R60, normally short-circuited by the relay, provides an emergency cathode bias. R61 and R62 replace R52.

At full output, a voltage of 475 V rms is present across the primary of the output transformer. The KT66 anodes therefore swing 400 ± 340 V, i.e. 60 to 740 V. The two screen grids have the same dc potential but the ac voltage is one-fifth of the anode swing. They therefore operate between 335 and 465 V.

Comparison of Operating Conditions (Pair of Valves)

	Triode	Tetrode*	Ultra-Linear	
$V_{a(b)}$	450	450	450	V
V_a	400	400	400	V
V_{g2}	400	400*	400	V
I_{a+g2}	125	125	125	mA
$I_{g2\,(o)}$	5	5	5	mA
I_{a+g2} (max sig)	135	155	145	mA
I_{g2} (max sig)	8	24*	15	mA
R_k (per valve)	560	560	560	Ω
V_k (app)	36	36	36	V
$p_{in\,(o)}$	50	50	50	W
p_{in} (max sig)	54	62	58	W
P_{out}	15	32	32	W
η	28	52	55	%
D (max sig)	2	$\ngtr$ 6	2	%
$R_{L\,(a-a)}$	6	7	7	kΩ
Z_{out}	3.5	35	9	kΩ
$V_{in\,(g1-g1)\,(rms)}$	52	42	56	V
Relative P_{out} for given V_{in}	x1	x5	x2.5	
	0	+7	+4	dB

*Suitable for intermittent operation only, owing to excessive screen dissipation at full output. When continuous full output is required, use the operating condition : V_a = 400 V, V_{g2} = 300 V.

Addition of Negative Feedback

Negative feedback may be added to the circuit of fig. 1 when an improved performance is required. It is suggested that 14 dB feedback is adequate for all normal purposes, although this may be increased if necessary. The application of 14 dB feedback will reduce the output impedance, distortion and overall sensitivity by a factor of five. This will provide an amplifier having the following characteristics:–

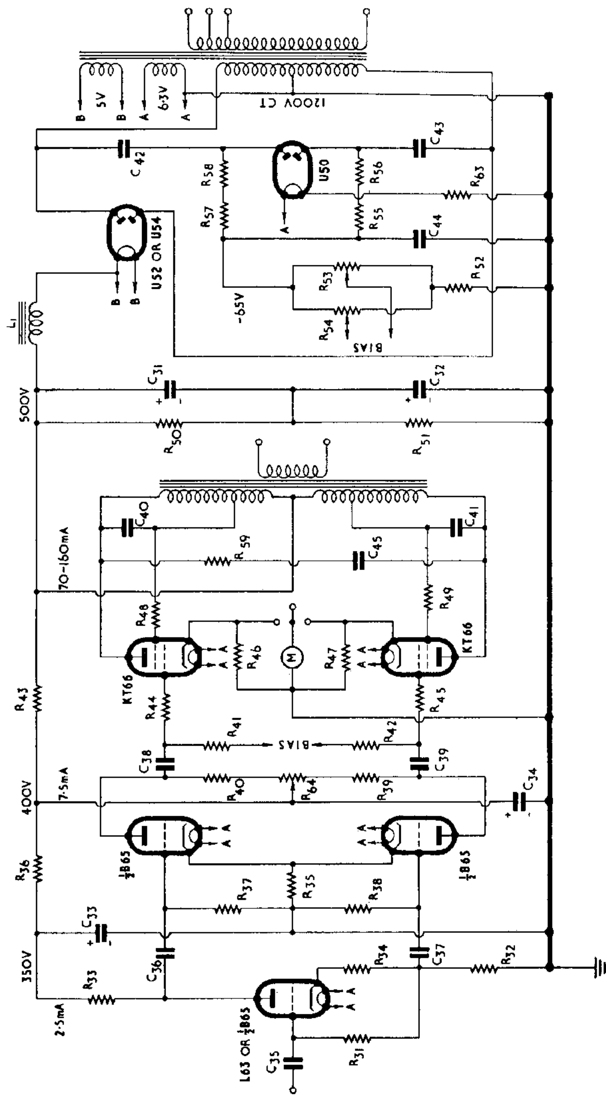
Input for full output	:	600 mV rms
Output impedance	:	1.8 kΩ
Distortion	:	0.5 %
Damping factor	:	4

The method is shown in fig. 4, the feedback voltage being introduced into the cathode circuit of the first valve. The bias resistor R22 (shown as R2 in fig. 1) is connected in the cathode circuit of one triode only. A further bias resistor and capacitor, R23, C23, are provided and feedback is applied across R24 from the secondary of the output transformer via R25.

Since the basic sensitivity of the amplifier is approximately 120 mV for full output, a feedback voltage of about 500 mV is required for 14 dB negative feedback. The output voltage is 21.5 for Z_o = 15 Ω and 11 for Z_o = 4 Ω; therefore, the two resistors R24, R25 are chosen so that 500 mV will exist at their junction at full output.

Assuming that R24 has a value of 22 Ω, the value of R25 is given by $225\sqrt{Z_o}$ and the nearest standard values may be used. For Z_o = 15 or 4 Ω, resistors of 1 kΩ or 470 Ω are satisfactory.

Fig. 5 A 50 W ULTRA-LINEAR AMPLIFIER
See Pages 11 and 12 for Component Values



R52 (see fig. 6)	22 kΩ	1 W	10%
R53	20 kΩ	w.w.	
R54	20 kΩ	w.w.	
R55	220 kΩ	1 W	10%
R56	220 kΩ	1 W	10%
R57	220 kΩ	1 W	10%
R58	220 kΩ	1 W	10%
R59	220 kΩ	1 W	10%
R60 (see fig. 6)	330 Ω	5 W w.w.	10%
R61 (see fig. 6)	6.6 kΩ	0.5 W	10%
R62	15 kΩ	0.5 W	10%
R63	0.65 Ω	5 W	
R64	20 kΩ		

CAPACITORS

C1	0.01 μF	350 V	
C2	50 μF	12 V	Electrolytic
C3	0.1 μF	500 V	
C4	0.1 μF	500 V	
C5	100 pF	250 V	
C6	100 pF	250 V	
C7	8 μF	450 V	Electrolytic
C8	8 μF	450 V	Electrolytic
C9	0.02 μF	500 V	
C10	0.02 μF	500 V	
C11	50 μF	50 V	Electrolytic
C12	50 μF	50 V	Electrolytic
C13	2000 pF	500 V	
C14	2000 pF	500 V	
C15	8 μF	450 V	Electrolytic
C16	8 μF	450 V	Electrolytic
C21	0.01 μF	350 V	
C22	50 μF	12 V	Electrolytic
C23	50 μF	12 V	Electrolytic
C31	160 μF	450 V	Electrolytic
C32	160 μF	450 V	
C33	8 μF	450 V	
C34	8 μF	450 V	
C35	0.01 μF	350 V	
C36	0.01 μF	500 V	
C37	0.01 μF	500 V	
C38	0.05 μF	750 V	
C39	0.05 μF	750 V	
C40	0.001 μF	300 V AC	
C41	0.001 μF	300 V AC	
C42	0.025 μF	600 V AC	
C43	0.025 μF	600 V AC	
C44	4 μF	200 V	
C45	0.001 μF	440 V AC	

Fig. 1 A 30 W ULTRA-LINEAR AMPLIFIER
See Pages 11 and 12 for Component Values

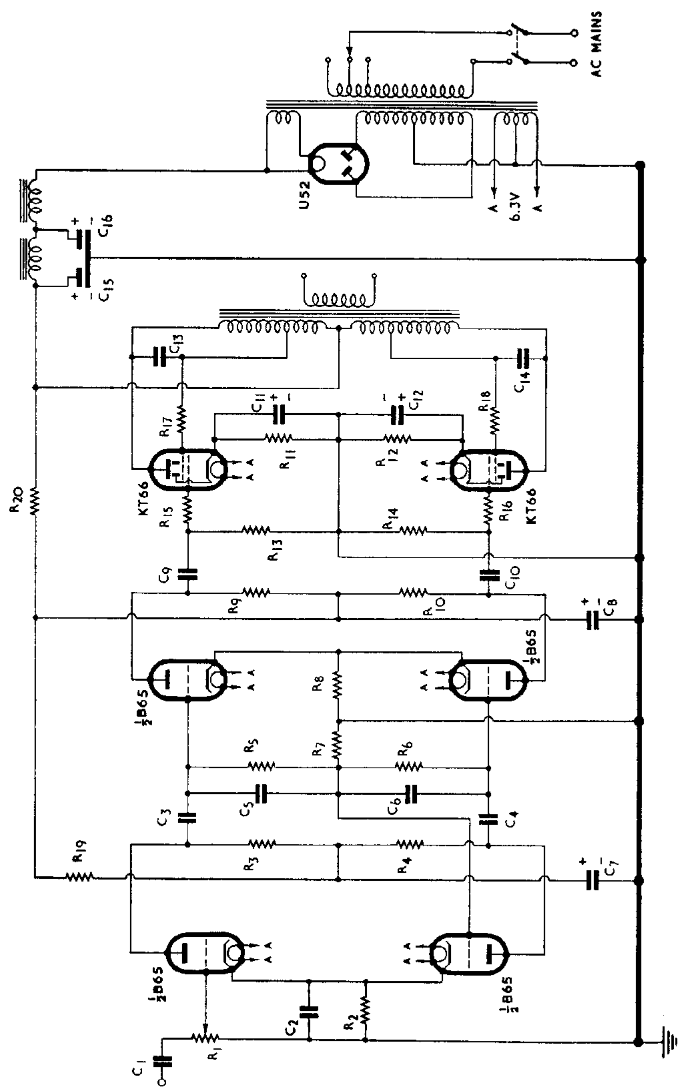
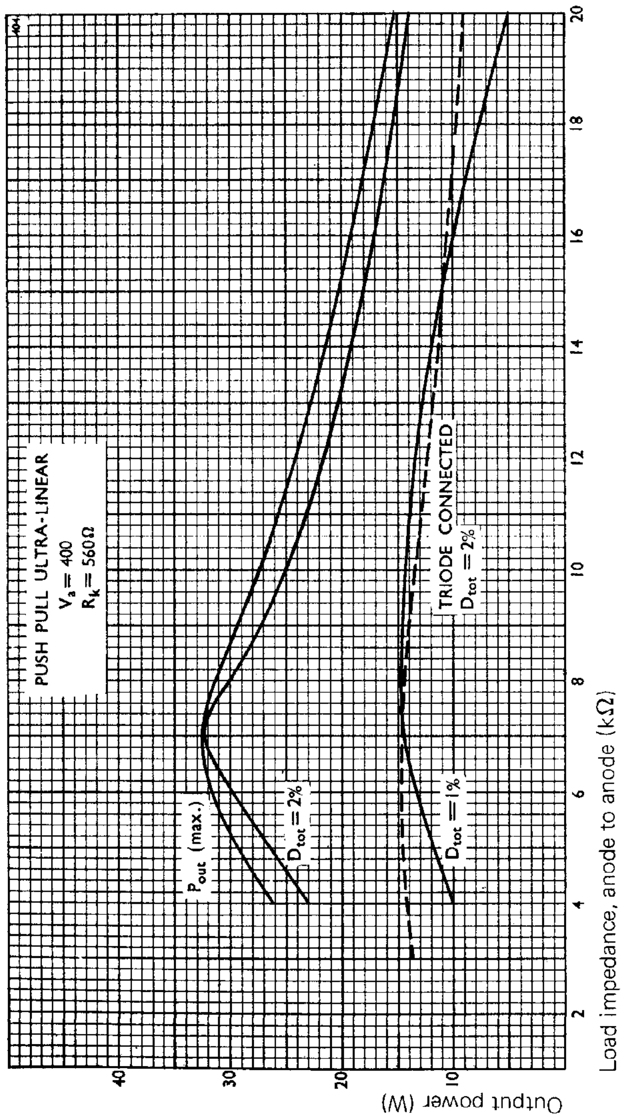


Fig. 2 A COMPARISON OF ULTRA-LINEAR WITH TRIODE OPERATION



COMPONENT VALUES

RESISTORS
(0.25 W, 20% unless otherwise shown)

R1	500 kΩ		
R2	750 Ω		
R3	33 kΩ	1 W	10%
R4	33 kΩ	1 W	10%
R5	270 kΩ } matched to 5%		
R6	270 kΩ }		
R7	270 kΩ		10%
R8	750 Ω		10%
R9	33 kΩ	1 W	10%
R10	33 kΩ	1 W	10%
R11	560 Ω	5 W w.w.	5%
R12	560 Ω	5 W w.w.	5%
R13	270 kΩ		10%
R14	270 kΩ		10%
R15	10 kΩ		
R16	10 kΩ		
R17	220 Ω		
R18	220 Ω		
R19	10 kΩ	0.5 W	
R20	5.6 kΩ	1 W	
R21	500 kΩ		
R22	1.5 kΩ		
R23	1.5 kΩ		
R24 }	see p. 4		
R25 }			
R31	1 MΩ		
R32	33 kΩ	0.5 W } matched to	5%
R33	33 kΩ	0.5 W }	
R34	1.5 kΩ		
R35	1 kΩ		
R36	22 kΩ	0.5 W	
R37	1 MΩ		
R38	1 MΩ		
R39	47 kΩ	1 W	10%
R40	47 kΩ	1 W	10%
R41	150 kΩ		10%
R42	150 kΩ		10%
R43	10 kΩ	1 W	10%
R44	10 kΩ		
R45	10 kΩ		
R46 } Meter shunts	10 Ω		
R47 }	10 Ω		
R48	100 Ω		
R49	100 Ω		
R50	100 kΩ	1 W	10%
R51	100 kΩ	1 W	10%

The anode supply is provided with an inductance filter L1, C31, C32. Because of the large variation in current with input signal the effective capacitance of C31, C32 has been made 80 μF. The working voltage is excessive for a single electrolytic and C31, C32 are, therefore, connected in series to give a rated voltage of 900. This single section filter provides a substantially ripple-free anode current. If a lower capacitance were used in place of C31, C32, an additional filter section would be required to reduce the ripple to a reasonable value, and the lower capacitance would be incapable of supplying the peak current required by a transient input signal.

At lower anode voltages the following results are obtainable. No circuit modifications are needed, the bias supply being a function of the anode voltage.

DC voltage	350	425	V
Quiescent current	25 + 25	30 + 30	mA
Max signal current	55 + 55	65 + 65	mA
Power output	20	30	W
Anode to anode load	8	8	kΩ

The value of the components C40, C41, C45 and R59 will depend to some extent on the output transformer, R59 and C45 are optional and are used to suppress ringing. The most satisfactory method of selecting the value of these four components is by the use of a square wave generator, but an audio oscillator extending to, say, 50 kHz may be used to detect a peak in the supersonic region. C40 and C41 may be unnecessary with some types of transformer.

With the transformer used, the values shown gave a fall in output of 3 dB at 18–20 kHz with a load resistance of 15 Ω.

Protection Against Bias Failure

In common with other amplifiers which derive the bias potential from a separate supply instead of a cathode resistor, the 50 W amplifier is rendered inoperative should the bias supply fail. Furthermore, the KT66 anode current would rise to an excessive value. The U50 is run at a very low anode current, a few milliamperes, and will, of course, have a long life.

A simple device which permits the amplifier to function with cathode bias in case of failure of the bias supply is shown in fig. 6. A triode, which could be one half of a B65 substituted for the L63 in the first stage, is connected in series with a relay across the 500 V supply. The grid is taken to the bias supply. Normally the anode current is cut off and the relay short-circuits the resistor R60 connected in the cathode circuit of the KT66 valves. Should the bias fail, the relay will be energised, the relay contacts will open and the bias resistor R60 will allow the amplifier to function at about half maximum output.

Fig. 3 A COMPARISON OF TETRODE WITH TRIODE OPERATION

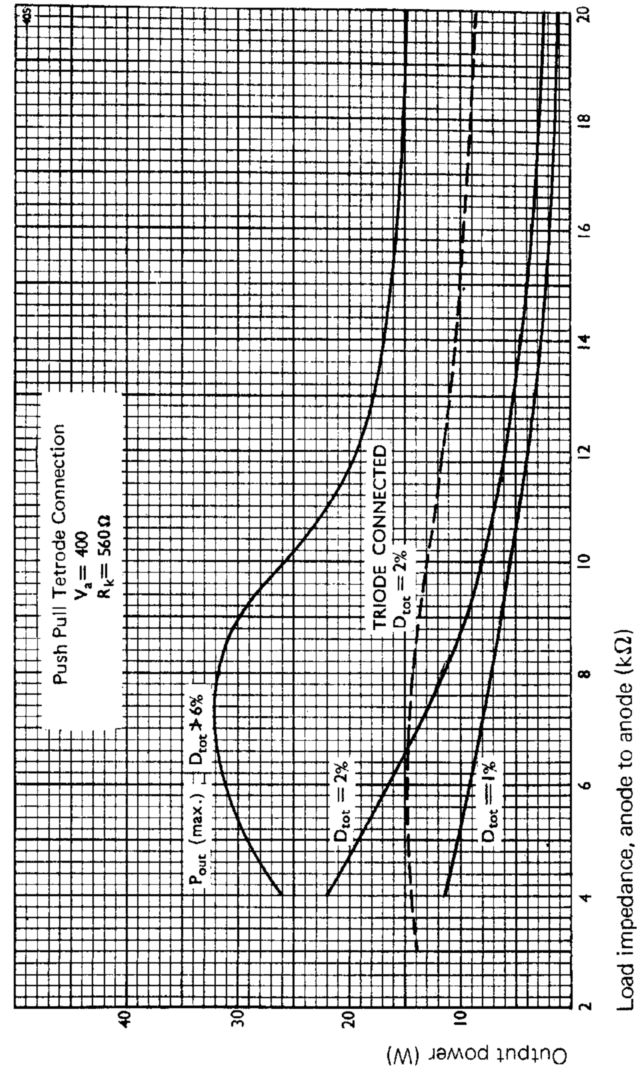
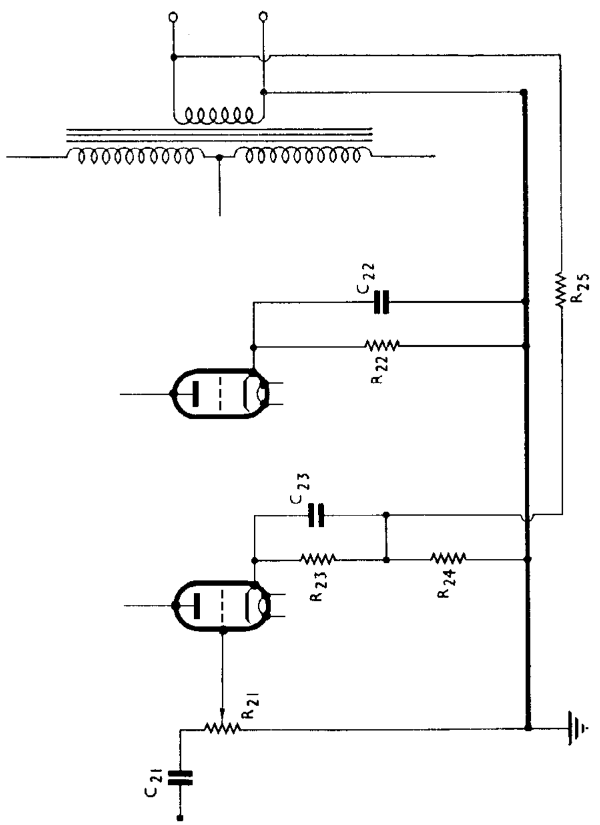


Fig. 4 THE ADDITION OF NEGATIVE FEEDBACK TO THE AMPLIFIER OF Fig. 1
See Pages 11 and 12 for Component Values



A 50 W ULTRA-LINEAR AMPLIFIER

When the maximum output is required from a pair of KT66 valves they may be used with fixed bias in the ultra-linear circuit. The operating conditions are given below and the recommended circuit is shown in fig. 5.

Operating Conditions (Pair of Valves)	Quiescent	Max Signal	
$V_{a,g2}$	525	500	V
I_{a+g2}	70	160	mA
V_{g1}	−57.5	−57.5	V
†$R_{L(a-a)}$	–	8	kΩ
P_{out}	–	50	W
*D	–	2	%
P_{a+g2} (per valve)	18	15	W
Z_{out}	–	6	kΩ
$V_{in\ (g1-g1)\ (rms)}$	–	90	V
V_{in} (to amplifier in fig. 5)	–	2.5	V

†An output transformer having a ratio of 6:1 would be suitable for 105 V output, 225 Ω.

*The distortion will vary from 1% to 3% with different valves. The performance is displayed graphically in figs. 7 and 8.

Circuit Notes

The two KT66 valves are set to a similar quiescent current, which may be between 30 and 40 mA, using the meter M and the meter shunts R46, R47. A negative bias voltage range of 50 to 65 V is provided by the controls R53, R54. A quiescent current below 30 mA will increase the distortion.

The bias voltage is derived from a U50 connected to the 600-0-600 V transformer via the capacitors C42, C43. The resistors R55, R56, R57, R58, not only smooth the supply in conjunction with C44 but also reduce the voltage to the appropriate value. The resistors R52 to R58, associated with the bias supply, are generously rated to maintain a stable voltage.

R64 is adjusted, at about 90% of full output, to give equal cathode currents in the two output valves. It is capable of compensating for inequality of output from the driver stage and also for variations between the two output valves. When the two cathode currents are equal the distortion is at a minimum.