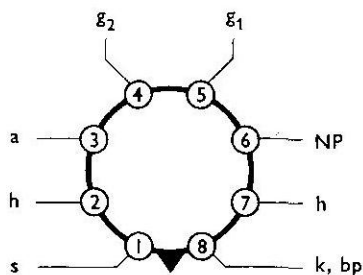


The KT88 has an absolute maximum anode dissipation rating of 42W and is designed for use in the output stage of an a.f. amplifier. Two valves in Class AB1 give a continuous output of up to 100W. The KT88 is also suitable for use as a series valve in a stabilised power supply.

The KT88 is a commercial version of the CV5220 and is similar to the 6550.

BASE CONNECTIONS AND VALVE DIMENSIONS



Base: Metal shell wafer octal

Bulb: Tubular

Max. overall length: 125mm

Max. seated length: 110mm

Max. diameter: 52mm

HEATER

V_h

6.3

V

I_h

1.6 (approx)

A

MAXIMUM RATINGS

	Absolute	Design Maximum	
V_a	800	800	V
V_{g2}	600	600	V
$V_{a,g2}$	600	600	V
$-V_{g1}$	200	200	V
p_a	42	35	W
p_{g2}	8	6	W
$p_a + g_2$	46	40	W
I_k	230	230	mA
V_{h-k}	250	200	V
T_{bulb}	250	250	°C
R_{g1-k} (cathode bias)			
$p_a + g_2 \leq 35W$		470	k Ω
$p_a + g_2 > 35W$		270	k Ω
R_{g1-k} (fixed bias)			
$p_a + g_2 \leq 35W$		220	k Ω
$p_a + g_2 > 35W$		100	k Ω

CAPACITANCES (Measured on a cold unscreened valve)

$c_{g1-a,g2}: 7.9 \text{ pF}$

$c_{g1-\text{all less } a,g2}: 9.3 \text{ pF}$

$c_{a,g2-\text{all less } g1}: 17 \text{ pF}$

THE M-O VALVE CO. LTD. • BROOK GREEN • LONDON • W.6

a subsidiary of

THE GENERAL ELECTRIC CO. LTD. OF ENGLAND

JUNE, 1961

CAPACITANCES (Measured on a cold unscreened valve)**Triode Connection** $c_{g1-a,g2}: 7.9\text{pF}$ $c_{g1-\text{all less } a,g2}: 9.3\text{pF}$ $c_{a,g2-\text{all less } g1}: 17\text{pF}$ **Tetrode Connection** $c_{g1-a}: 1.2\text{pF}$ $c_{g1-\text{all less } a}: 16\text{pF}$ $c_a-\text{all less } g1: 12\text{pF}$

CHARACTERISTICS

Tetrode Connected

V_a	250	V
V_{g2}	250	V
I_a	140	mA
I_{g2}	3 (approx)	mA
$-V_{g1}$	15 (approx)	V
g_m	11.5	mA/V
r_a	12	k Ω
μ_{g1-g2}	8	—

Triode Connected

$V_{a,g2}$	250	V
I_{a+g2}	143	mA
$-V_{g1}$	15 (approx)	V
g_m	12	mA/V
r_a	670	Ω
μ	8	—

TYPICAL OPERATION

Push-Pull. Class AB1. Cathode Bias. Tetrode Connection

$V_{a(b)}$	560	V
$V_{a(o)}$	521	V
V_{g2}	300	V
$I_{a(o)}$	2×64	mA
$I_{a(max \text{ sig})}$	2×73	mA
$I_{g2(o)}$	2×1.7	mA
$I_{g2(max \text{ sig})}$	2×9	mA
$R_{L(a-a)}$	9	k Ω
* R_k	2×460	Ω
$-V_{g1}$	30 (approx)	V
P_{out}	50	W
D_{tot}	3	%
†I.M.	11	%
$P_{a(o)}$	2×33	W
$P_{a(max \text{ sig})}$	2×12	W
$P_{g2(o)}$	2×0.5	W
$P_{g2(max \text{ sig})}$	2×2.7	W
$V_{in(g1-g1)(pk)}$	60	V

*It is essential to use two separate cathode bias resistors.

†Intermodulation distortion; measured using two input signals at 50 and 6000c/s (ratio of amplitudes 4:1).

Push-Pull. Class AB1. Fixed Bias. Tetrode Connection

$V_{a(b)}$	560	V
$V_{a(o)}$	552	V
V_{g2}	300	V
$I_{a(o)}$	2×60	mA
$I_{a(max \text{ sig})}$	2×145	mA
$I_{g2(o)}$	2×1.7	mA
$I_{g2(max \text{ sig})}$	2×15	mA
$R_{L(a-a)}$	4.5	k Ω
* $-V_{g1}$	34 (approx)	V
P_{out}	100	W

D_{tot}	2.5	%
†I.M.	10	%
$P_{a(o)}$	2×33	W
$P_{a(max sig)}$	2×28	W
$P_{g2(o)}$	2×0.5	W
$P_{g2(max sig)}$	2×4.5	W
$V_{in(g1-g1)(pk)}$	67	V

*It is essential to provide two separately adjustable bias voltage sources, having a voltage adjustment range of $\pm 25\%$.

†Intermodulation distortion; measured using two input signals at 50 and 6000c/s (ratio of amplitudes 4:1).

Push-Pull, Class AB1, Cathode Bias, Ultra-Linear Connection (40% Tapping Points)

$V_{a,g2(b)}$	500	375	V
$V_{a,g2(o)}$	436	328	V
$I_{a+g2(o)}$	2×87	2×87	mA
$I_{a+g2(max sig)}$	2×99	2×96	mA
$R_{L(a-a)}$	6	5	k Ω
* R_k	2×600	2×400	Ω
$-V_{g1}$	52 (approx)	35 (approx)	V
P_{out}	50	30	W
D_{tot}	1.5	1	%
†I.M.	4	3	%
$P_{a+g2(o)}$	2×38	2×28.5	W
$P_{a+g2(max sig)}$	2×17	2×16	W
$V_{in(g1-g1)(pk)}$	104	71	V
Z_{out}	4.8	4.5	k Ω

*It is essential to use two separate cathode bias resistors.

†Intermodulation distortion; measured using two input signals at 50 and 6000c/s (ratio of amplitudes 4:1).

Push-Pull, Class AB1, Fixed Bias, Ultra-Linear Connection (40% Tapping Points)

$V_{a,g2(b)}$	560	460	V
$V_{a,g2(o)}$	553	453	V
$I_{a+g2(o)}$	2×50	2×50	mA
$I_{a+g2(max sig)}$	2×157	2×140	mA
$R_{L(a-a)}$	4.5	4	k Ω
* $-V_{g1}$	75 (approx)	59 (approx)	V
P_{out}	100	70	W
D_{tot}	2	2	%
†I.M.	11	10	%
$P_{a+g2(o)}$	2×27.5	2×22.5	W
$P_{a+g2(max sig)}$	2×33	2×27	W
$V_{in(g1-g1)(pk)}$	140	114	V
Z_{out}	7	6.5	k Ω

*It is essential to provide two separately adjustable bias voltage sources, having a voltage adjustment range of $\pm 25\%$.

†Intermodulation distortion; measured using two input signals at 50 and 6000c/s (ratio of amplitudes 4:1).

Push-Pull, Class AB1, Cathode Bias, Triode Connection

$V_{a,g2(b)}$	400	485	V
$V_{a,g2(o)}$	349	422	V
$I_{a+g2(o)}$	2×76	2×94	mA
$I_{a+g2(max\ sig)}$	2×80	2×101	mA
$R_{L(a-a)}$	4	4	k Ω
$-V_{g1}$	40 (approx)	50 (approx)	V
P_{out}	17	31	W
D_{tot}	1.5	1.5	%
*I.M.	5.6	5.6	%
$p_{a+g2(o)}$	2×26.5	2×40	W
$p_{a+g2(max\ sig)}$	2×19	2×27	W
R_k	2×525	2×525	Ω
$V_{in(g1-g1)(pk)}$	78	114	V
Z_{out}	2	1.9	k Ω

*Intermodulation distortion; measured using two input signals at 50 and 6000c/s (ratio of amplitudes 4:1).

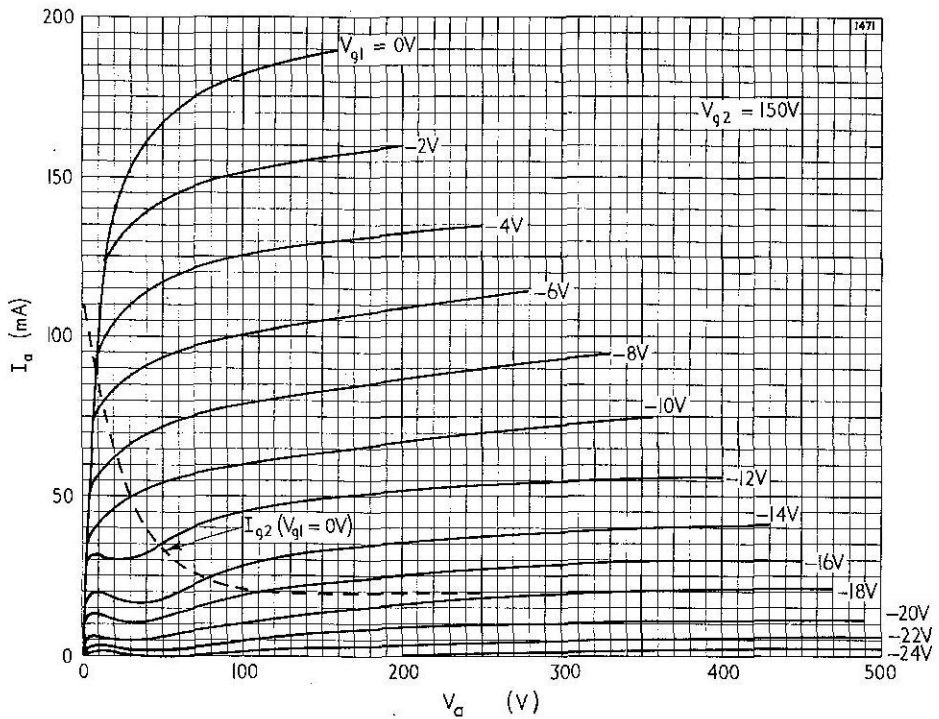
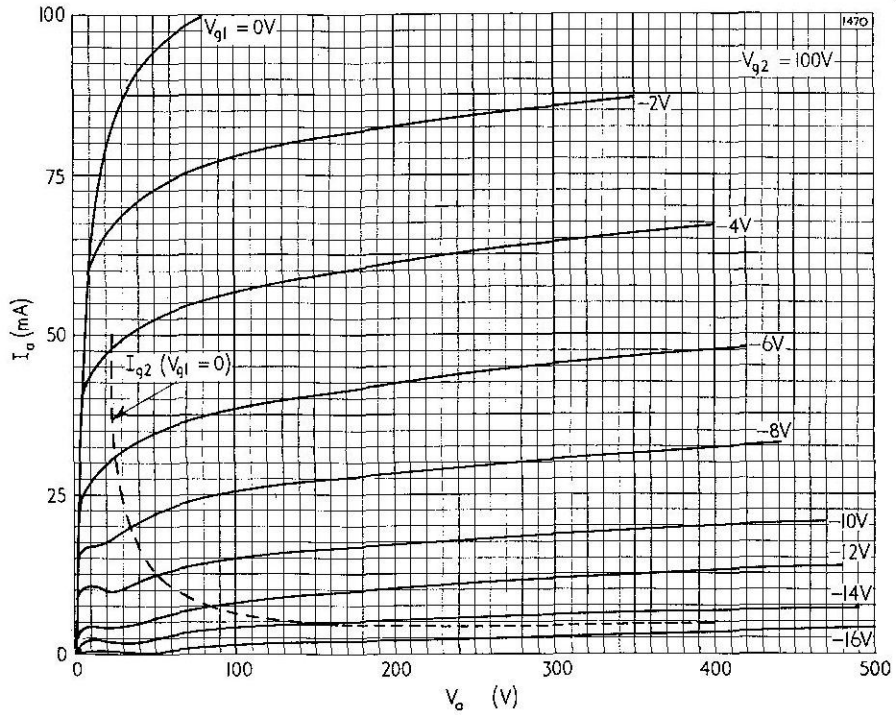
INSTALLATION

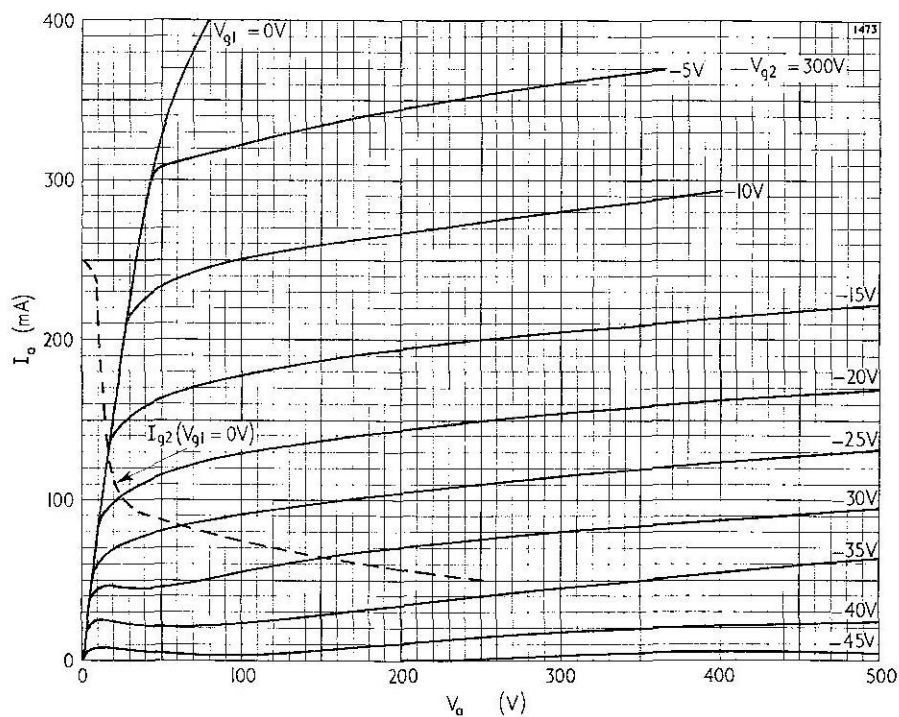
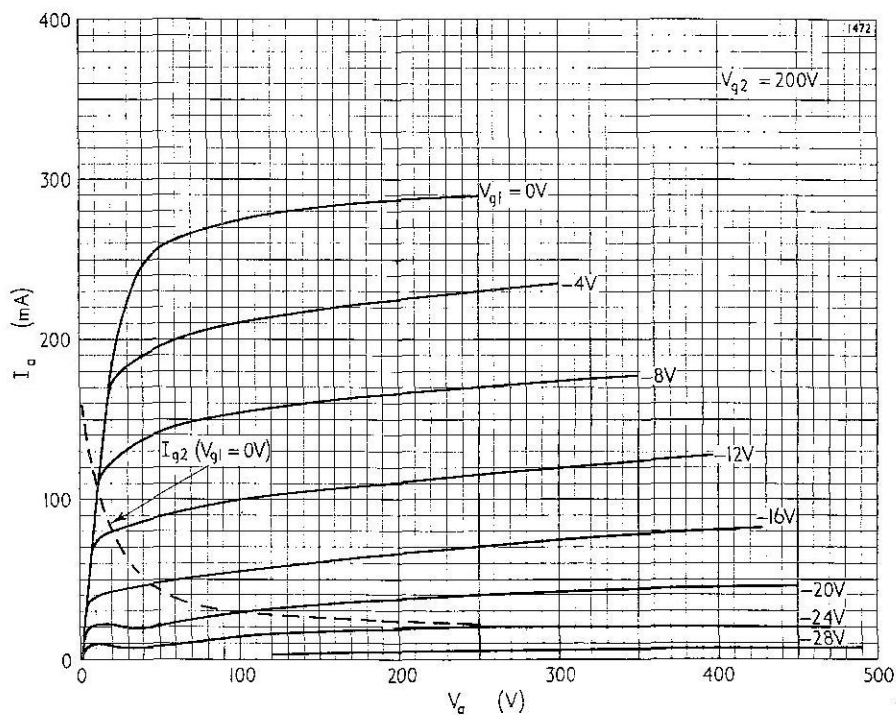
The valve may be mounted either vertically or horizontally.

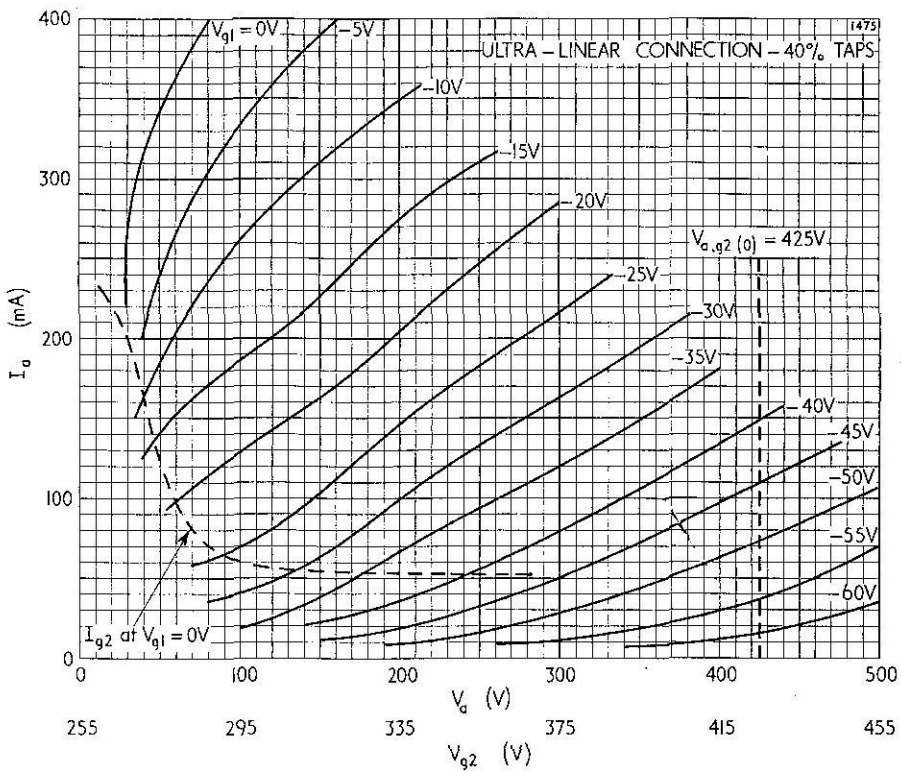
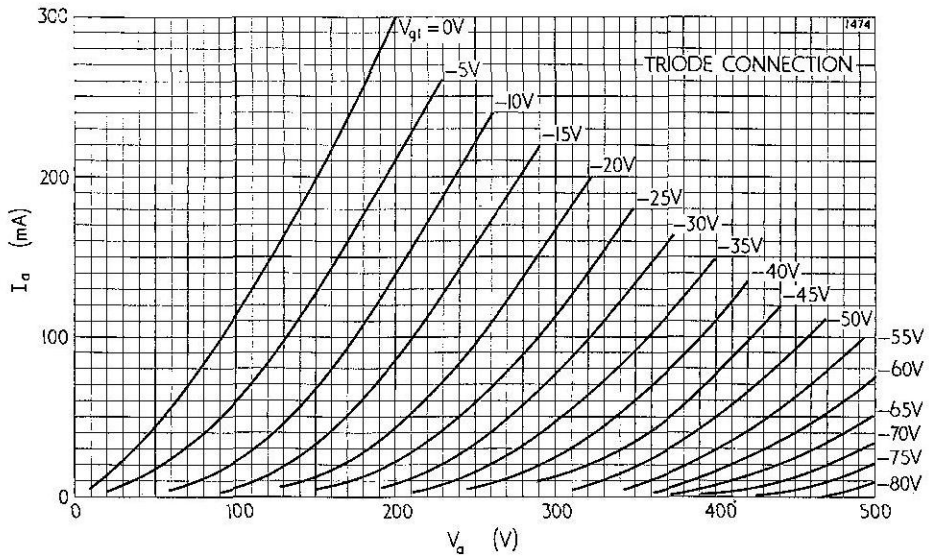
When a pair of valves is mounted vertically it is recommended that the centres of the valve sockets are not less than 4in. apart and that pins 4 and 8 of each valve are in line.

When a pair of valves is mounted horizontally it is recommended that the centres of the valve sockets are not less than 4in. apart and that pins 4 and 8 of each valve are in the same vertical line.

Free air circulation around the valve is desirable.







INTRODUCTION

The KT88 may be used in pairs in either triode, pentode or ultra-linear push-pull circuits and this Supplement gives circuits and operating data for amplifiers giving outputs of 30 to 400 watts in various conditions of operation. The ultra-linear circuit is recommended for outputs up to 100W when the maximum output coupled with the lowest distortion is required and it is also used in the multiple-pair 400W amplifier described on page 20.

The curves in fig. 1 show the output and approximate distortion obtained from push-pull KT88 valves with various positions of the screen grid taps on the output transformer. At the left-hand side (0% taps) the valves are, of course, pentode-connected and on the right-hand side (100% taps) they are triode-connected. Generally speaking, the taps should be spaced at 20% to 50% of the turns on each half-primary from the centre, with 30% to 40% as the optimum. The dotted curve shows the reduction in output impedance obtained.

Either cathode bias or fixed bias may be used and the circuits show both types of operation. The former has the advantage of simplicity whereas the latter provides the normal maximum output of 100W from a pair of valves and higher efficiency.

The output power of the ultra-linear circuit is not less than that of the pentode at any given supply voltage and has the advantage that a low impedance screen supply is not required. The ultra-linear circuit does, in fact, show a rather higher efficiency in that a lower current is required from the power supply. For example, with fixed bias and a supply voltage of 460 an output of 65W is obtained with an anode current of 240mA in both the pentode and the ultra-linear arrangements but the pentode requires, in addition, a screen current of 35mA. Furthermore, it is desirable that the pentode screen supply be stabilised. The output impedance and distortion are both more favourable in the ultra-linear circuit, the former being 6.5k Ω in this example, compared with 50k Ω , and the distortion is almost entirely independent of load impedance above the rated value. Information on the effect of the positions of the screen taps upon the degree of intermodulation is given in the Appendix on page 26.

The triode connection is sometimes preferred when a moderate power output with low distortion is required. An output of up to 27W is obtainable with an h.t. supply of 485V and cathode bias and, even at lower voltages, the output is adequate for domestic amplifiers. The distortion will depend on the degree of matching between pairs but it is normal to obtain a distortion below 2% without negative feedback by the selection of two out of any three valves since this procedure, at worst, halves the normal variation in characteristics. Operating data will be found in the KT88 data sheet.

Due to the high mutual conductance of the KT88 some precautions have to be taken against parasitic oscillation whatever the circuit arrangement. Grid and screen series resistors of about 10k Ω and 270 Ω respectively, are recommended. In the ultra-linear circuit, resistance-capacitance networks may be found necessary between the anode and screen taps on the output transformer as shown in fig. 4. With some transformers they will not be needed and they become less necessary as the taps include a greater part of the primary due to the consequent reduction in leakage inductance.

Details are also given for Class B operation of triode-connected KT88 valves for an output of up to 150W. This type of operation is useful when a distortion higher than that given by the ultra-linear circuit can be tolerated.

When an output exceeding 150W is needed, the KT88 valve may be used in multiple pairs in parallel push-pull instead of a single pair of larger valves. One of the advantages of this method is the low cost of the power supply which is required to give an h.t. of only 550V. Another advantage is that a valve failure in the output stage merely reduces the available output power with a probable increase in distortion.

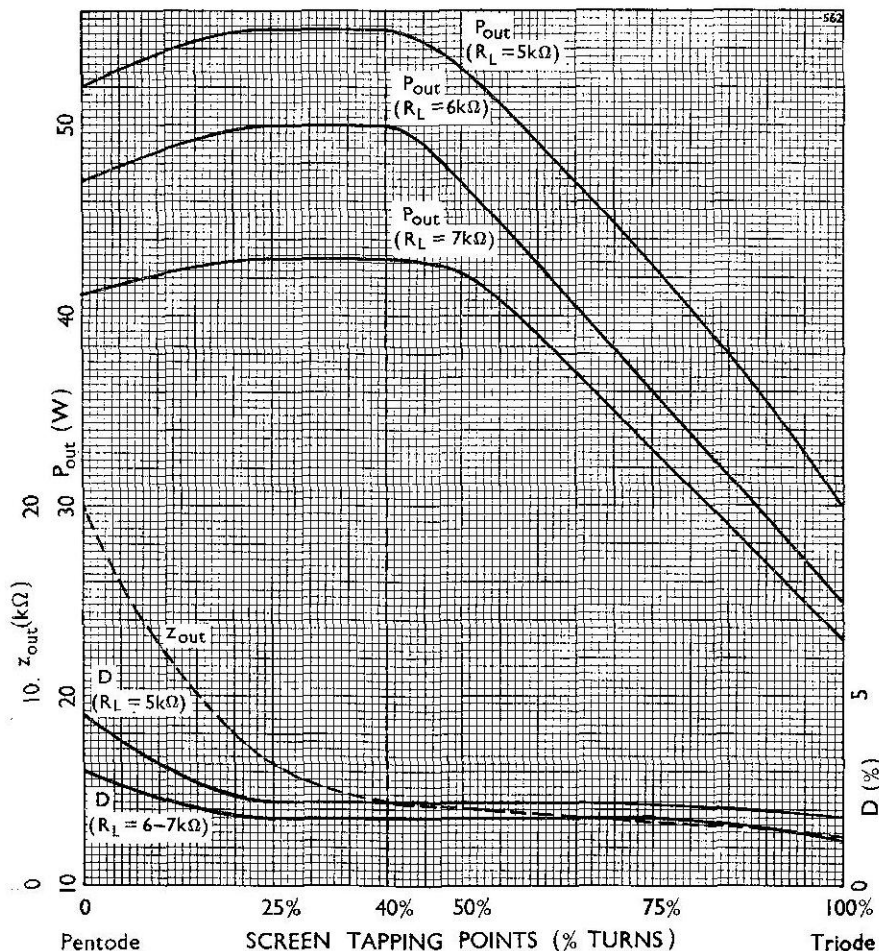


Fig. 1. Output power, distortion and output impedance of KT88 ultra-linear output stage at various positions of the screen taps from 0% to 100% of each half-primary from the centre tap.

Installation

The bulb temperature rating of 250°C must not be exceeded and any cabinet used must provide adequate ventilation. Under free air conditions this temperature is not reached at maximum ratings, but where a valve is enclosed the use of the temperature sensitive paint "Tempilaq" is recommended to check that adequate air circulation exists.

Although the KT88 may be mounted in any desired position it is recommended that, when valves are mounted horizontally, pins 4 and 8 should be in a vertical line as in fig. 2.

When two valves are mounted vertically, in the more usual manner, on a horizontal chassis, there is a slight advantage obtained if pins 4 and 8 of both valves are mounted in line, as in fig. 3. The coolest part of the bulbs then face each other whilst the hottest parts (nearest the anodes) are at right-angles.

*Obtainable from J. M. Steel & Co. Ltd., 36, Kingsway, London, W.C.2.

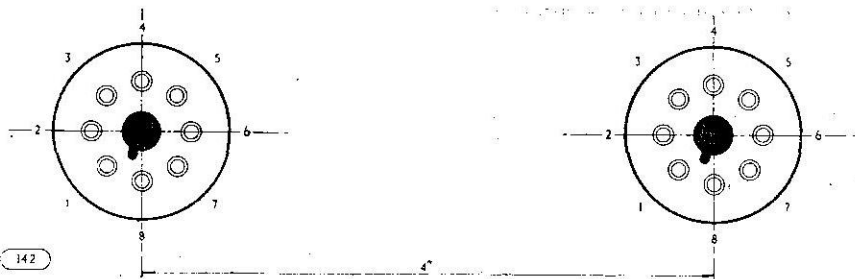


Fig. 2. Correct orientation and spacing of the valve sockets when the valves are mounted horizontally.

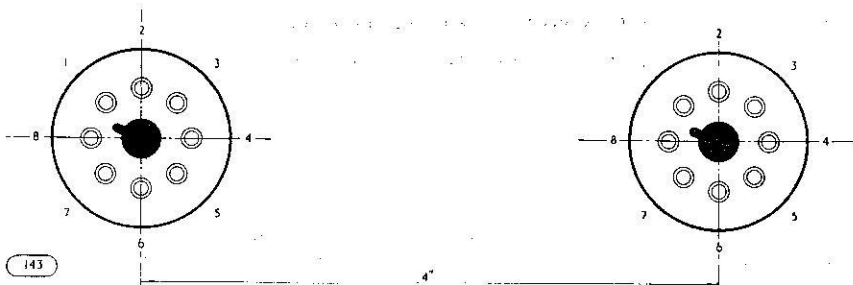


Fig. 3. Correct orientation and spacing of the valve sockets when the valves are mounted vertically.

Power Supply

The type of power supply required will depend on the operating conditions but a capacitance input filter circuit is satisfactory for the ultra-linear cathode bias amplifiers.

With fixed bias, the large change in anode current requires a low impedance power supply and an inductance input filter is essential. It is desirable for the smoothing capacitor to be of high value to prevent an instantaneous fall in voltage upon the occurrence of a transient. Satisfactory performance will be obtained with a single inductor and a capacitance of 50—150 μ F. Two 160 μ F, 450V electrolytic capacitors in series have been found very successful with the ultra-linear higher voltage working conditions.

The choice of a rectifier will depend on the power output required. The U52 or U54 are suitable for powers up to 50W, but for amplifiers designed to cover the range 50—100W, two U19 or two GXU50 rectifiers should be used.

A 30W ULTRA-LINEAR AMPLIFIER

With negative feedback, this amplifier (fig. 4) will give 32W output with about 0.25% distortion at an anode potential of 335V. The input signal to the first stage of the amplifier for full output is 500mV. Even when negative feedback is omitted the amplifier has only 1% distortion at 32W output and requires an input of 100mV. As the KT88 valves are conservatively run in this circuit they will have a long life.

Circuit Description

The output stage is preceded by a conventional double triode voltage amplifier V2 which is fed by a triode phase-splitter comprising one half of a further double triode V1. The first half of this valve is the input stage voltage amplifier, which is directly coupled to the phase-splitter. R8, in the cathode circuit of V2, reduces any signal unbalance in the phase-splitter and lowers intermodulation distortion.

Depending upon the particular characteristics of the output transformer, it may be necessary to prevent instability by connecting capacitors and resistors across part of each output transformer half-primary and "stopper" resistors in series with the grids and screens of the output stage. The curves of fig. 5 illustrate the performance of the output stage of this amplifier without feedback.

Continued on page 6.

COMPONENT VALUES FOR FIG. 4

30W ULTRA-LINEAR AMPLIFIER

G.E.C. VALVES

V1 B65/6SN7
V2 B65/6SN7
V3 KT88
V4 KT88
V5 U54

RESISTORS

(20%, 0.25W unless otherwise shown)

R1 1M Ω Log.
R2* 225 $\sqrt{\text{speech coil impedance}}$
R3 1k Ω
R4 22 Ω
R5 100k Ω
R6 15k Ω 0.5W
R7 15k Ω 0.5W } Matched to 5%
R8 4.7k Ω
R9 470k Ω 10%
R10 470k Ω 10%
R11 1k Ω
R12 1k Ω
R13 33k Ω 10% 1W
R14 33k Ω 10% 1W
R15 220k Ω
R16 220k Ω
R17 10k Ω
R18 10k Ω
R19 4.7k Ω 1W
R20 400 Ω 5% 5W
R21 400 Ω 5% 5W
R22 270 Ω 0.5W
R23 270 Ω 0.5W
R24 470-1500 Ω 0.5W
R25 470-1500 Ω 0.5W

*For 14db feedback.

CAPACITORS

C1 50 μ F 12V
C2 0.05 μ F
C3 0.05 μ F
C4 8 μ F 350V
C5 8 μ F 450V
C6 0.05 μ F
C7 0.05 μ F
C8 50 μ F 50V
C9 50 μ F 50V
C10 8 μ F 500V
C11 1000pF
C12 1000pF
C13 8 μ F 500V

MISCELLANEOUS

L1 10H 200mA
T1 35W Ultra-linear transformer
6k Ω anode-anode
†Primary Inductance : ≤ 50 H
Leakage inductances :
†Prim.—sec. : ≥ 10 mH
† $\frac{1}{2}$ prim.—UL tap : ≥ 10 mH
T2 Mains transformer
Secondaries :
375-0-375V 200mA
6.3V 5A CT
5V 3A

†With these values, R24, R25 and C11, C12 may be omitted.

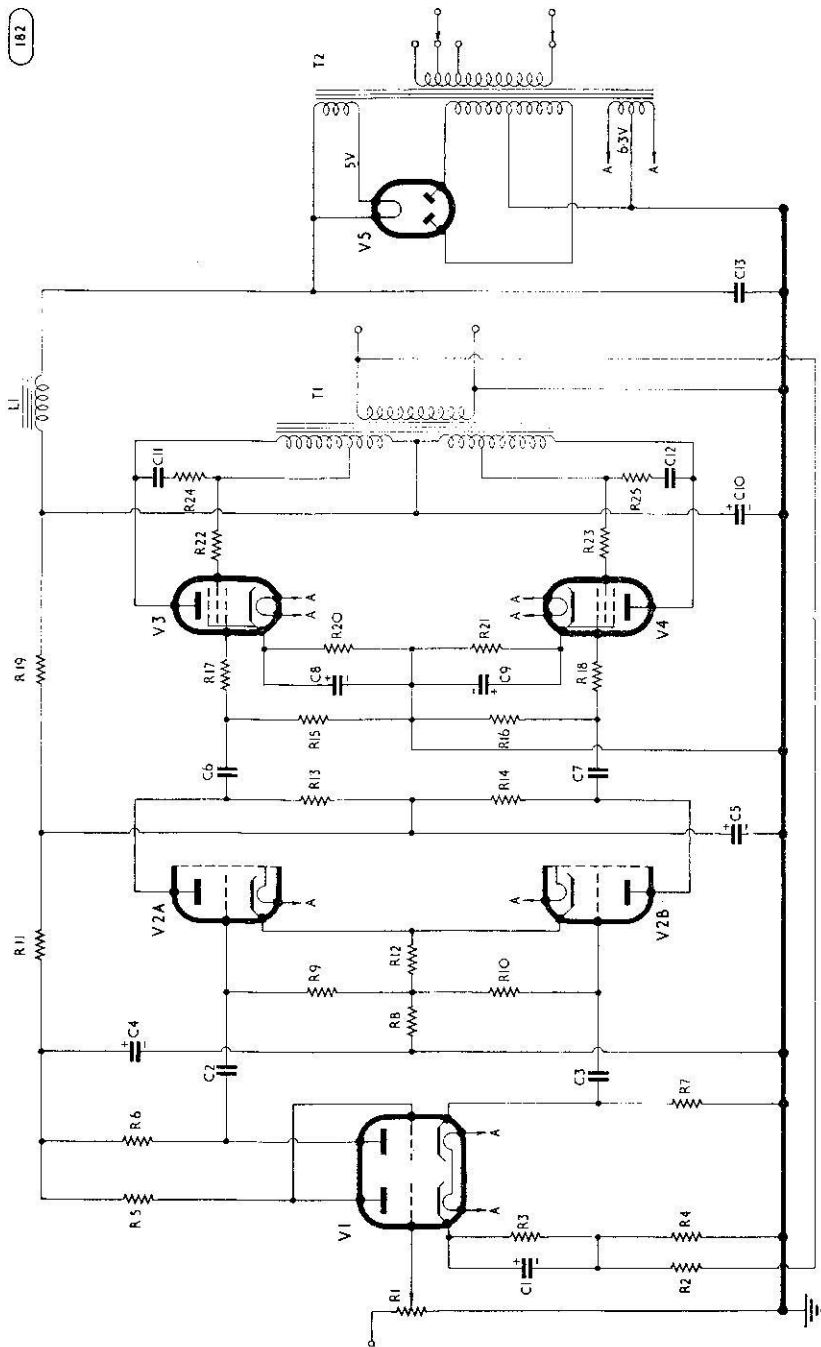


Fig. 4. Circuit diagram of the KT88 30W ultra-linear amplifier. The components list is given opposite.

The negative feedback network shown in fig. 4 provides 14db of feedback and this is adequate for all normal purposes. This value reduces the output impedance, distortion and sensitivity of the basic amplifier by a factor of 5.

Feedback from the output transformer secondary is introduced into the cathode circuit of the first stage via R2. Since the sensitivity of the amplifier without feedback is approximately 100mV, a feedback voltage of about 500mV is required for 14db feedback. As the voltage across the output transformer secondary for 32W is about 21.5 for a 15Ω load and about 11 for a load of 4Ω, the resistors R2 and R4 are chosen so that 500 mV will exist at their junction at full output. Assuming R4 to be 22Ω, R2 is given by $225 \sqrt{Z_o}$ (where Z_o =the loudspeaker impedance) and the nearest standard value may be used. If $Z_o=15\Omega$, R2 should be 1kΩ and if $Z_o=4\Omega$, R2 should be 470Ω.

The operating conditions for the output stage of the amplifier of fig. 4 are given in Table I.

TABLE I
30W ULTRA-LINEAR AMPLIFIER
Operating Conditions

(Fig. 4)

$V_{a(b)}$	375	V
$V_{a,g2}$	335	V
$I_{a+g2(o)}$	2×80	mA
$I_{a+g2(max \text{ sig})}$	2×85	mA
$P_{a+g2(o)}$	2×27	W
$P_{a+g2(max \text{ sig})}$	2×12	W
R_k	2×400	Ω
V_g (approx)	-32	V
P_{out}	30	W
$R_{L(a-a)}$	5	kΩ
Z_{out}	1	kΩ
D	0.25	%
$V_{in(rms)}$ (approx) (to first stage)	500	mV

If negative feedback is omitted, the last three values are as follows :

Z_{out}	4.5	kΩ
D	1	%
$V_{in(rms)}$ (approx) (to first stage)	100	mV

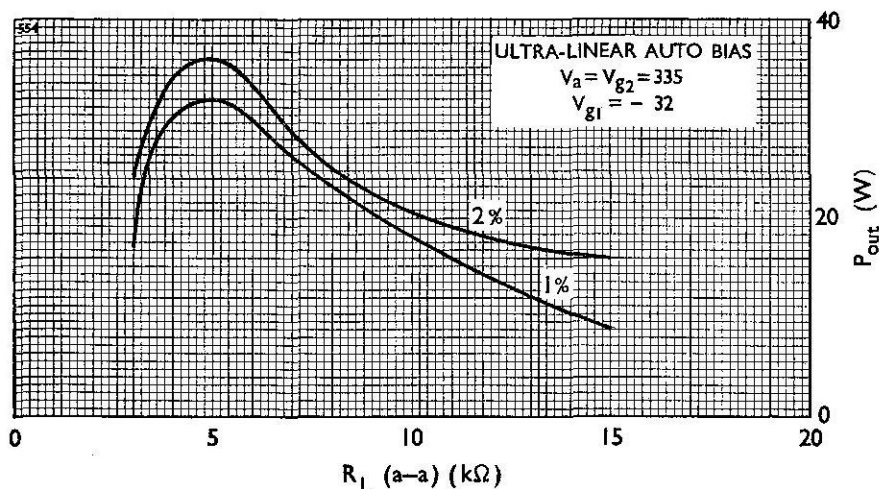


Fig. 5. Performance of the KT88 30W ultra-linear amplifier of fig. 4.

A 50W ULTRA-LINEAR AMPLIFIER

This section describes the use of the KT88 in a design for an ultra-linear amplifier with cathode bias giving 50W output at 0.2% distortion.

Circuit Description

The circuit of the complete amplifier is given in fig. 6. The design is similar to that of the 30W amplifier except for the type of input stage and the inclusion of the networks consisting of C6, R10 and C7, R11 between the first two stages. These networks reduce the amount of overshoot and consequent "ringing" in the output transformer.

The first double triode, V1, is arranged as a self-balancing floating paraphase phase inverter which feeds V2, the following push-pull voltage amplifier. Potentiometer R22 allows the signal input to the output stage to be adjusted for output stage dynamic balance.

The power supply incorporates a thermistor in the h.t. output line in order to reduce the surge from the directly heated rectifier while the remaining valves are warming up. The performance of this amplifier is illustrated in fig. 7 and the output stage operating data are given in Table II.

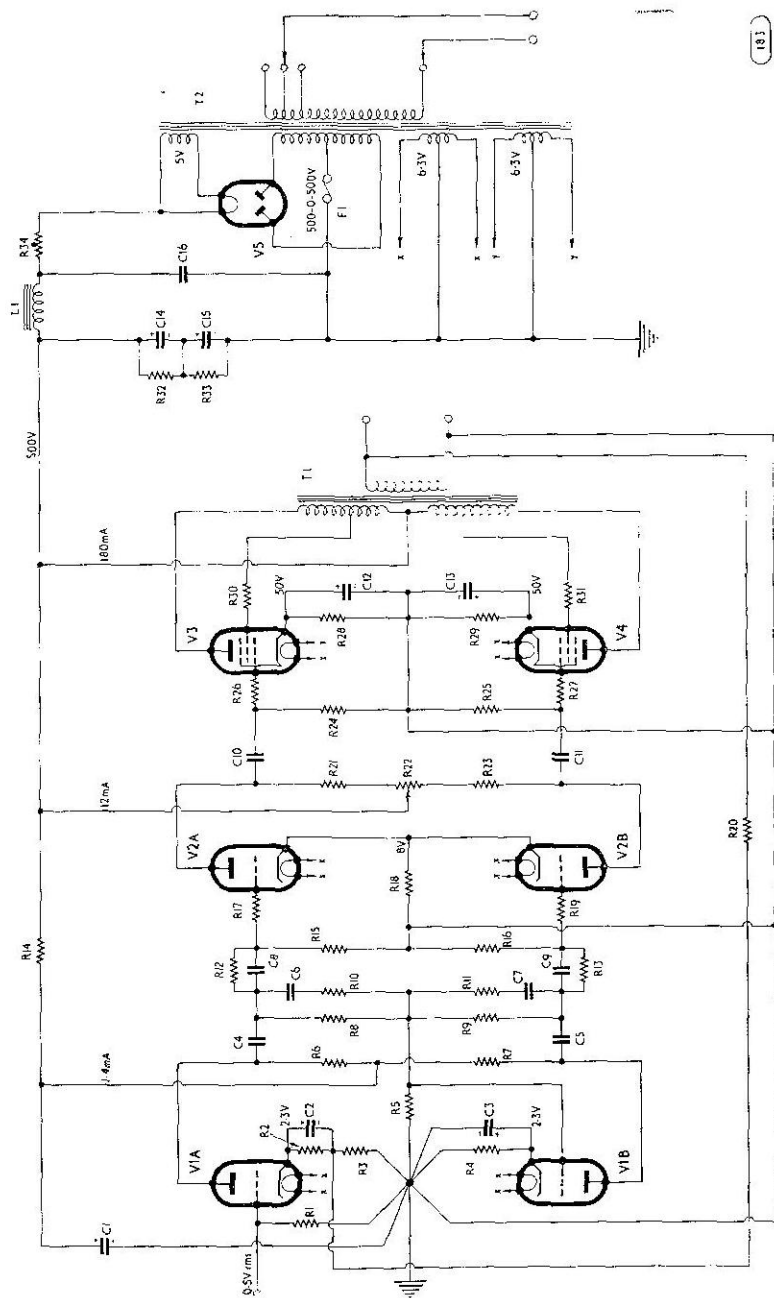


Fig. 6. Circuit diagram of the KT88 50W ultra-linear amplifier.

COMPONENT VALUES FOR FIG. 6**50W ULTRA-LINEAR AMPLIFIER****G.E.C. VALVES**

V1 B339/12AX7
 V2 B329/12AU7
 V3 KT88
 V4 KT88
 V5 U52/5U4

R27 10k Ω
 R28 525 Ω 5% 6W
 R29 525 Ω 5% 6W
 R30 100 Ω
 R31 100 Ω

RESISTORS

(20%, 0.5W unless otherwise shown)

R1 1M Ω
 R2 3.3k Ω
 R3 100 Ω
 R4 3.3k Ω
 R5 1M Ω
 R6 220k Ω 10%
 R7 220k Ω 10%
 R8 1M Ω
 R9 1M Ω
 R10 10k Ω
 R11 10k Ω
 R12 4.7M Ω
 R13 4.7M Ω
 R14 100k Ω
 R15 470k Ω
 R16 470k Ω
 R17 10k Ω
 R18 680 Ω
 R19 10k Ω
 R20 4.7k Ω
 R21 33k Ω 2W
 *R22 25k Ω 4W
 R23 33k Ω 2W
 R24 220k Ω
 R25 220k Ω
 R26 10k Ω

*Optional potentiometer for dynamically balancing the output stage. If omitted, R21 and R23 should be 47k Ω , 2%, 2W.

CAPACITORS

C1 8 μ F 500V
 C2 50 μ F 12V
 C3 50 μ F 12V
 C4 0.25 μ F
 C5 0.25 μ F
 C6 470pF
 C7 470pF
 C8 0.005 μ F
 C9 0.005 μ F
 C10 0.5 μ F
 C11 0.5 μ F
 C12 50 μ F 100V
 C13 50 μ F 100V
 C14 24 μ F 350V
 C15 24 μ F 350V
 C16 4 μ F 750V
 C17 8 μ F 500V

MISCELLANEOUS

L1 5H 250mA
 T1 50W Ultra-linear transformer
 5k Ω anode-anode
 Primary inductance : $\geq$ 30H
 Leakage inductances :
 Prim.—sec. : $\geq$ 10mH
 $\frac{1}{2}$ prim.—UL tap : $\geq$ 10mH
 T2 Mains transformer
 Secondaries :
 500—0—500V 250mA
 6.3V 5A CT
 6.3V 1—2A CT
 5V 3A
 F1 1A delayed fuse

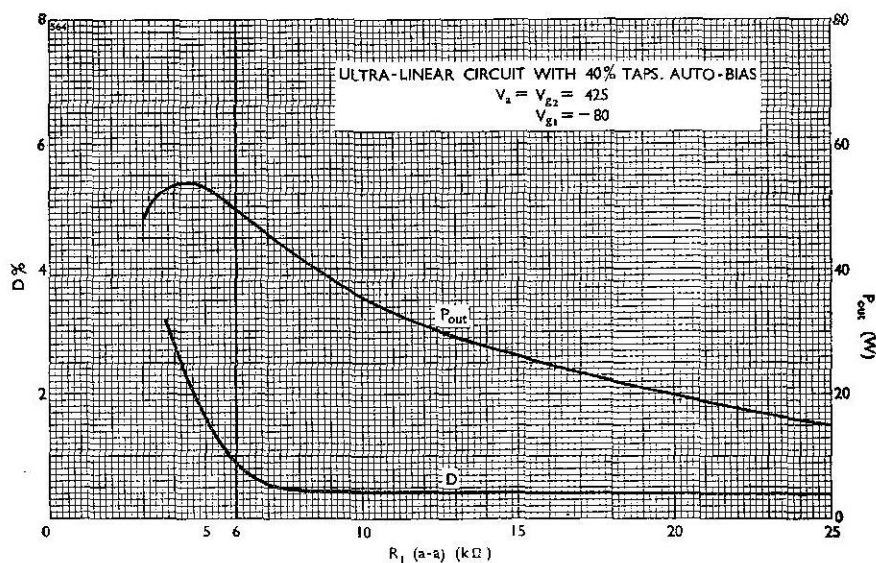


Fig. 7. Performance of the KT88 50W ultra-linear amplifier of fig. 6.

TABLE II

50W ULTRA-LINEAR AMPLIFIER

Operating Conditions

(Fig. 6)

$V_{a(b)}$	500	V
$V_{a,g2}$	425	V
$I_{a+g2(o)}$	2×87	mA
$I_{a+g2(max\ sig)}$	2×100	mA
$P_{a+g2(o)}$	2×40	W
$P_{a+g2(max\ sig)}$	2×18	W
R_k	2×525	Ω
V_g (approx)	-50	V
* P_{out}	50	W
$R_{L(a-a)}$	5	k Ω
* D	0.2	%
$V_{in(rms)}$ (to first stage)	500	mV

*These figures refer to an average pair.

A 100W FIXED BIAS ULTRA-LINEAR AMPLIFIER

The circuit of this amplifier is given in fig. 8 and it provides 100W output at 5% distortion with an h.t. potential of 560V. The performance is shown graphically in fig. 9 and Table III gives the operating conditions for the output stage.

With fixed bias, the large change in anode current necessitates a low impedance power supply and, with normal rectifier circuits, an inductance-input smoothing filter is essential. The smoothing capacitor should be of high value to prevent an instantaneous fall in h.t. potential upon the occurrence of a transient signal. Satisfactory performance will be obtained with a single inductor and a capacitance of 50–150 μ F. The circuit diagram shows two 160 μ F 450V electrolytic capacitors in series as an economical method of obtaining the required capacitance.

Reducing the h.t. potential to 460V, the load impedance to 4k Ω and the grid bias to –65V results in an amplifier giving 65W output. The performance of this version is shown in fig. 10 and the appropriate operating data are included in Table III.

Protection Against Bias Failure

Should the bias supply fail, the KT88 anode currents would increase excessively and it is recommended that some device be incorporated for protecting the output valves in the event of bias failure. The arrangement illustrated in fig. 11 inserts a suitable resistor into the output stage cathode circuit which will enable the amplifier to function temporarily at half maximum output.

A triode, which could be one half of a double triode used also in the first stage of the amplifier, is connected in series with a relay across the main h.t. supply. The relay contacts are normally closed and short-circuit the emergency cathode resistor R1. The triode is held at cut-off by the connection of its grid to the bias supply at a point about 50V negative to earth. Should the bias fail, the grid of the triode will rise to earth potential and current will flow through the triode. This energises the relay, the contacts of which will open and bring into circuit the cathode bias resistor.

TABLE III
100W ULTRA-LINEAR AMPLIFIER
Operating Conditions

(Fig. 8)

$V_{a(b)}$	460	560	V
$V_{a,g2}$	450	550	V
$I_{a+g2(o)}$	2×50	2×50	mA
$I_{a+g2(max\ sig)}$	2×120	2×150	mA
$P_{a+g2(o)}$	2×25	2×30	W
$P_{a+g2(max\ sig)}$	2×20	2×33	W
$*V_{g1}$	–65	–80	V
P_{out}	65	100	W
$R_{L(a-a)}$	4	4.5	k Ω
z_{out}	6.5	6.5	k Ω
$\dagger D$	3–6	3–6	%
$V_{in(rms)}$ (to first stage)	1 to 1.5	1 to 1.5	mV

*A bias voltage range of at least $\pm 25\%$ is recommended.

$\dagger$ The distortion will vary according to the degree of matching by R11.

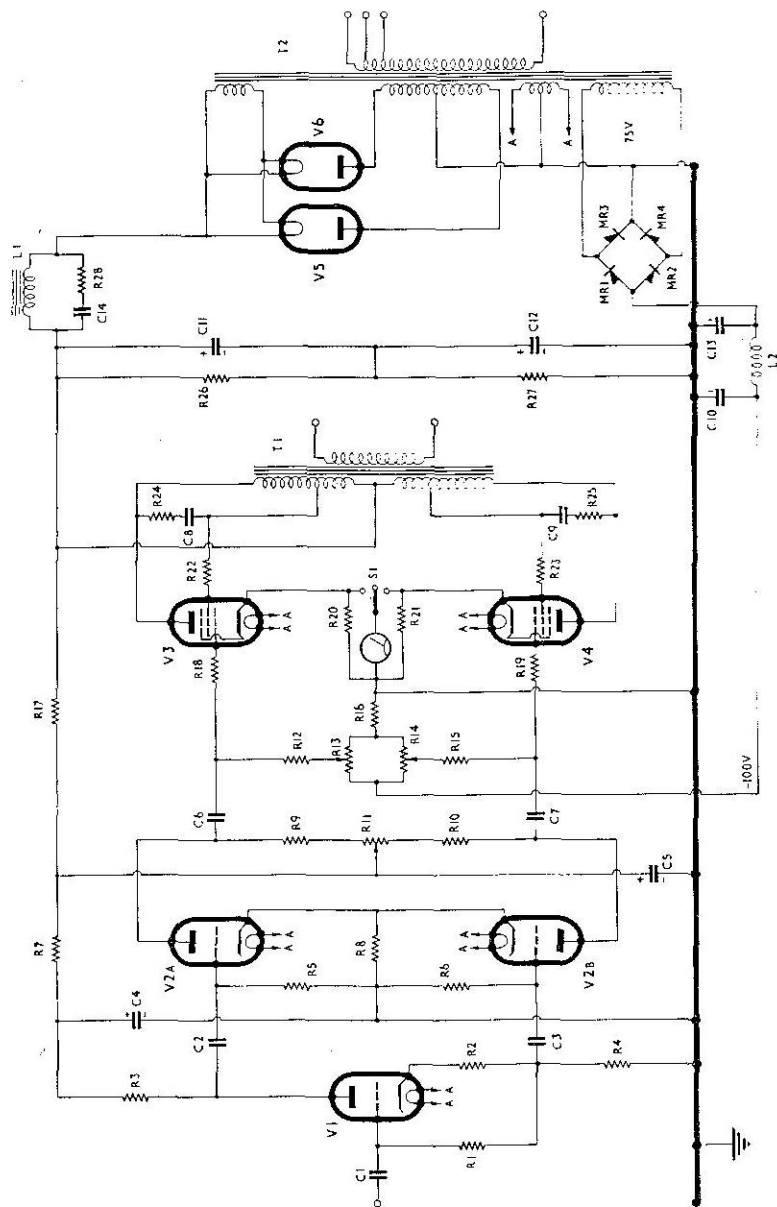


Fig. 8. Circuit diagram of the KT88 100W fixed bias ultra-linear amplifier. R26 and R27 equalise the voltages across C11 and C12, the series-connected smoothing capacitors. C14 and R28 prevent the build-up of high voltage transients across L1.

COMPONENT VALUES FOR FIG. 8**100W FIXED BIAS AMPLIFIER****G.E.C. VALVES**

V1 L63/6J5
 V2 B65/6SN7
 V3 KT88
 V4 KT88
 V5 } U19 (or GXU50 with delay)
 V6 }

RESISTORS

(20%, 0.25W unless otherwise shown)

R1 1M Ω
 R2 1.5k Ω
 R3 33k Ω 1W } matched to 5%
 R4 33k Ω 1W }
 R5 470k Ω 10%
 R6 470k Ω 10%
 R7 33k Ω 1W
 R8 1k Ω
 R9 33k Ω 10% 1W
 R10 10k Ω
 R11 33k Ω 10% 1W
 R12 100k Ω 10% 0.5W
 R13 20k Ω w.w. preset
 R14 20k Ω w.w. preset
 R15 100k Ω 10% 0.5W
 R16 10k Ω 10% 1W
 R17 4.7k Ω 1W
 R18 5.6k Ω
 R19 5.6k Ω
 R20 } Meter shunts
 R21 }
 R22 270 Ω 0.5W
 R23 270 Ω 0.5W
 R24 470-1500 Ω 0.5W
 R25 470-1500 Ω 0.5W
 R26 100k Ω 10% 1W
 R27 100k Ω 10% 1W
 R28 10k Ω 0.5W

CAPACITORS

C1 0.01 μ F
 C2 0.05 μ F
 C3 0.05 μ F
 C4 8 μ F 350V
 C5 8 μ F 450V
 C6 0.1 μ F
 C7 0.1 μ F
 C8 1000pF
 C9 1000pF
 C10 8 μ F 250V
 C11 160 μ F 450V } each 100+60
 C12 160 μ F 450V } dual
 C13 8 μ F 250V
 C14 0.01 μ F 750V

MISCELLANEOUS

L1 5H 325mA
 L2 20H 10mA
 T1 100W Ultra-linear transformer
 4.5k Ω anode-anode (100W)
 4k Ω anode-anode (65W)
 Primary inductance : $\leq$ 40H
Leakage inductances :
 Prim.—sec. : $\geq$ 6mH
 $\frac{1}{2}$ prim.—UL tap : $\geq$ 6mH
 T2 Mains transformer
 Secondaries :
 700—0—700V 325mA
 6.3V 5A CT
 5V 7A
 75V 10mA (bias)
 S1 1-pole 3-way
 MR1 }
 MR2 } 75V 10mA
 MR3 }
 MR4 }

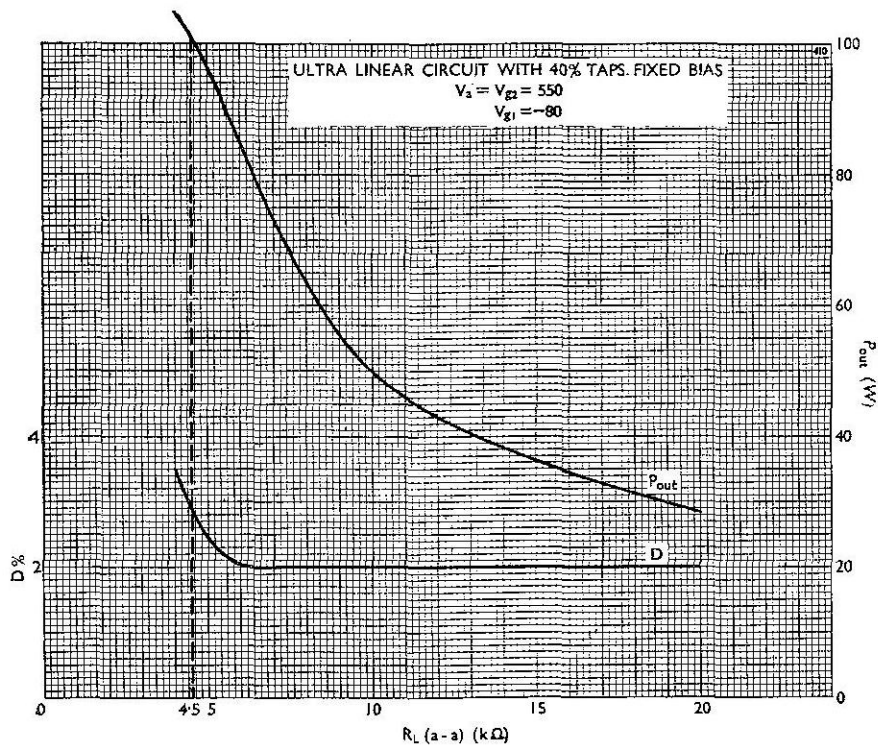


Fig. 9. Performance of the KT88 100W amplifier of fig. 8.

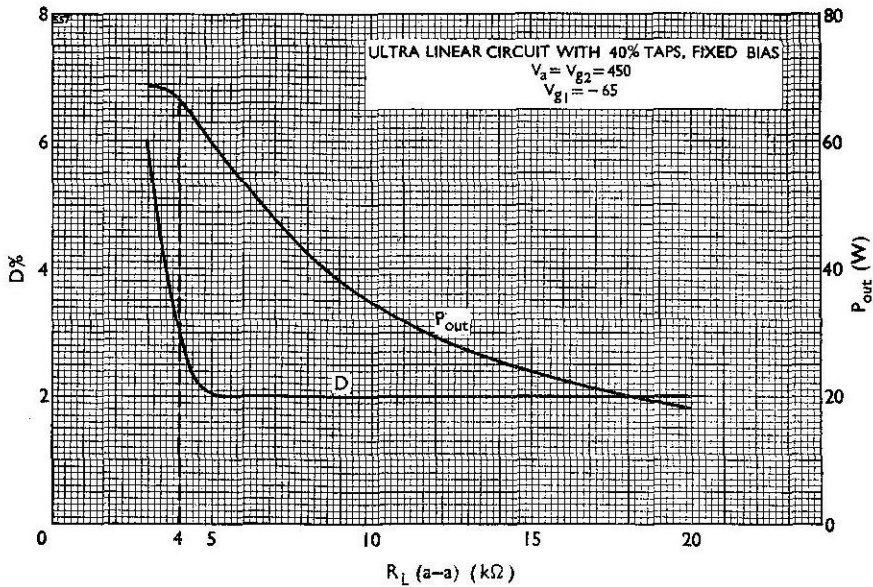


Fig. 10. The modified characteristics of the amplifier in fig. 8 when it is arranged for 65W maximum output (see Table III).

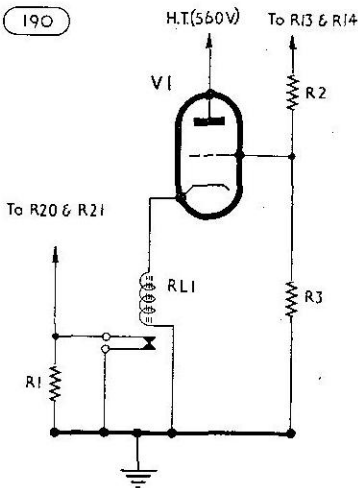


Fig. 11. Bias failure protection for the KT88 fixed bias amplifier. R2 is connected to the positive (earthly) junction of R13 and R14 in fig. 8. R2 and R3 take the place of R16 in the amplifier. The earth connection to the meter in fig. 8 is broken and the meter (and R20, R21) taken to R1. Component values: V1: G.E.C. L63/6J5; R1: 330Ω 10% 5W; R2: 6.8kΩ 10% 0.5W; R3: 15kΩ 10% 0.5W; RL1: 20kΩ.

A 150W CLASS B AMPLIFIER

Two KT88 valves, triode-connected in Class B, may be used when maximum output for intermittent (ICAS*) operation is required. It is permissible to use a higher anode voltage than is usual, and an output up to 150W is obtained.

This type of operation is satisfactory when a distortion higher than that obtained with the ultra-linear circuit, may be tolerated. (A typical use would be in a speech modulator for a transmitter).

Circuit Description

The circuit is shown in fig. 12. In this circuit, the screen and control grids are connected via resistors R18 and R19 forming, in effect, a high impedance triode. Both grids are driven into the positive region from a driver stage capable of providing 180 + 180V r.m.s., the current drawn by the control grids being limited by R18 and R19.

Successful operation is almost entirely dependent upon the design of the driver stage. This should have a low impedance, so as to ensure minimum distortion in the output stage.

Satisfactory results can be obtained by using a resistance loaded pentode stage. The load resistors R16 and R17 in fig. 12 also serve to reduce the 750V line to 450V for the pentode anodes. This method of supply prevents the line voltage from rising excessively during the quiescent periods, when the output stage passes no more than 15-20mA.

Continued on page 18.

COMPONENT VALUES FOR FIG. 12

CLASS B 150W AMPLIFIER

G.E.C. VALVES

V1	L63
V2	KT66
V3	KT66
V4	KT88
V5	KT88
V6	} U52, U54, GU50 or GXU50
V7	
V8	
V9	

R14	100k Ω	10%	1W w.w.
R15	100k Ω	10%	1W w.w.
R16	5k Ω	5%	20W w.w.
R17	5k Ω	5%	20W w.w.
R18	22-100k Ω	1W	
R19	22-100k Ω	1W	
R20	100k Ω	10%	1W
R21	100k Ω	10%	1W
R22	10k Ω		

RESISTORS

(20%, 0.25W unless otherwise shown)

R1	470k Ω
R2	1k Ω
R3	33k Ω
R4	33k Ω
R5	220k Ω
R6	220k Ω
R7	10k Ω
R8	10k Ω
R9	22k Ω 1W
R10	600k Ω 5% 3W w.w.
R11	600k Ω 5% 3W w.w.
R12	220k Ω
R13	220k Ω

CAPACITORS

C1	0.01 μ F
C2	0.05 μ F
C3	0.05 μ F
C4	8 μ F
C5	25 μ F
C6	25 μ F
C7	32 μ F
C8	32 μ F
C9	0.5 μ F
C10	0.5 μ F
C11	0.01 μ F
C12	0.01 μ F
C13	160 μ F
C14	160 μ F
C15	0.01 μ F
C16	160 μ F

*ICAS : Intermittent commercial and amateur service.

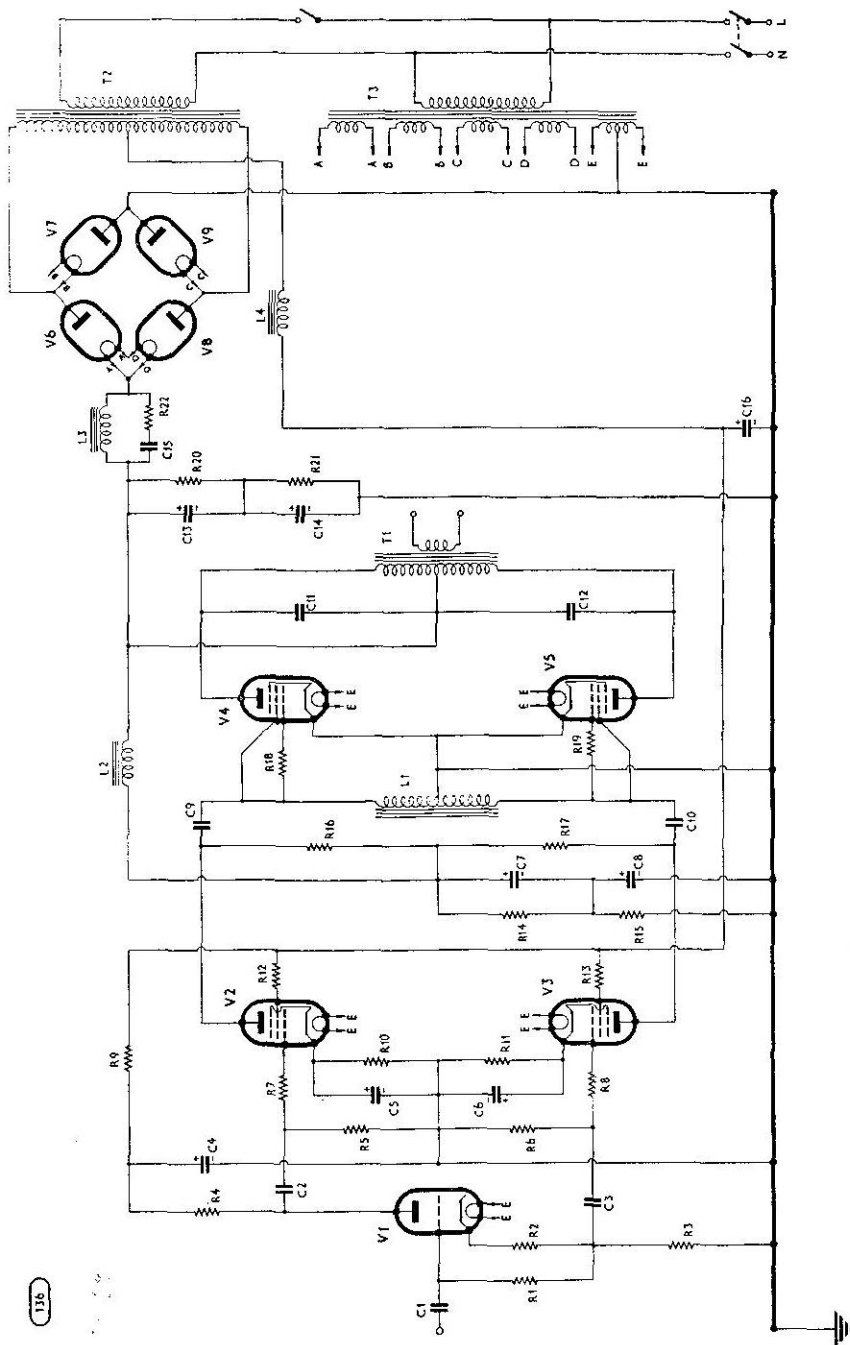


Fig. 12. Circuit diagram of the 150W Class B amplifier.

An inductance L_1 is used in place of grid return resistors as the output stage grids draw some 30mA at full output. The characteristics of L_1 are not critical. It should have a d.c. resistance not exceeding 500 Ω , an inductance of about 20H and a centre tap. A small output transformer, with the secondary left unused, is satisfactory.

A bridge-connected rectifier system fed by a transformer giving 900V r.m.s. provides the anode supply to both the output and driver stages. A centre tap on this transformer enables half the d.c. anode voltage to be obtained for the driver screens and the previous stage(s). The electrolytic capacitors C13, C14 and C16 are of high value in order to absorb the large fluctuations of anode current (from about 120 to 400mA). The series connection of C13 and C14 permits a voltage up to 900. Suitable rectifiers are : GU50, GXU50, U52 or U54.

Table IV gives the operating conditions for the amplifier and fig. 13 illustrates its performance.

TABLE IV
CLASS B 150W AMPLIFIER
ICAS RATING
Operating Conditions

(Fig. 12)

Output Stage

$V_{a(o)}$	850	V
$V_{a(max\ sig)}$	750	V
$V_{g2(rms)}$	60	V
$I_{a(o)}$	2×10	mA
$I_{a(max\ sig)}$	2×140	mA
I_{g1+g2}	30	mA
P_{out}	150	W
$R_{L(a-a)}$	6	k Ω
z_{out}	25	k Ω
D	6 to 8	%
p_{dr} (approx)	7	W
$V_{in(g-g)(rms)}$	360	V
z_{in}	18	k Ω

Driver Stage

$V_{a(o)}$	500	V
$V_{a(max\ sig)}$	400	V
$V_{g2(o)}$	375	V
$V_{g2(max\ sig)}$	325	V
$I_{a(o)}$	2×50	mA
$I_{a(max\ sig)}$	2×55	mA
$I_{g2(o)}$	2×2	mA
$I_{g2(max\ sig)}$	2×7	mA
$V_{in(g-g)(rms)}$	40	V

The above conditions are suitable for normal speech applications only. For other purposes, $R_{L(a-a)}$ should be increased to 7.5k Ω . At $V_a=600V$ an output of approximately 100W is given.

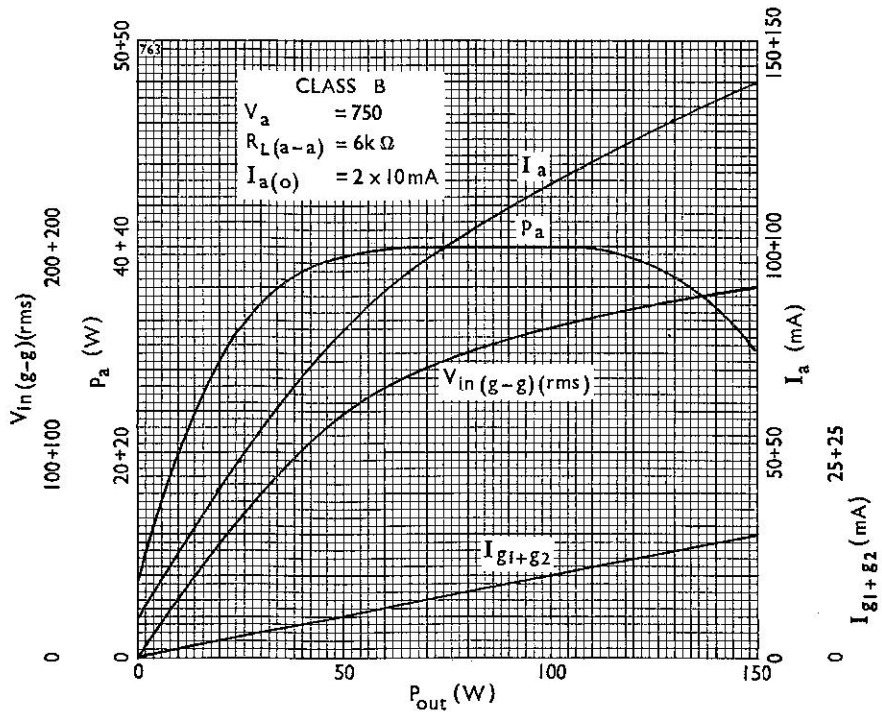


Fig. 13. Performance of the 150W Class B amplifier of fig. 12.

MULTIPLE-PAIR PUSH-PULL AMPLIFIERS

The circuit diagram of fig. 14 illustrates the use of ten valves in a fixed bias ultra-linear output stage and this arrangement gives 400W output. More or less than five pairs of valves can be used, depending upon the output power required.

A single control is used for grid bias adjustment and this simplifies the amplifier at the expense of somewhat higher distortion and lower output.

Continued on page 22.

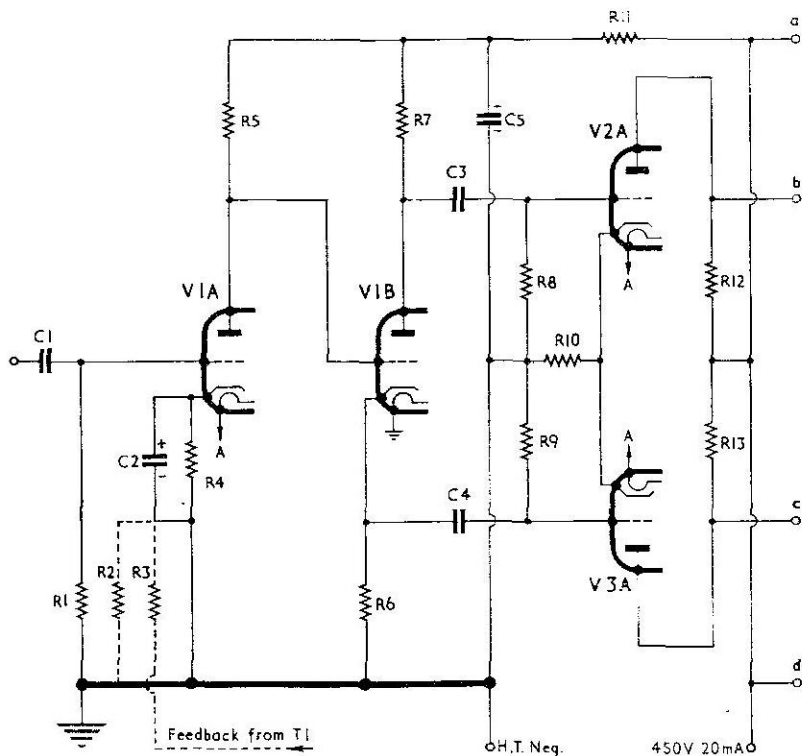
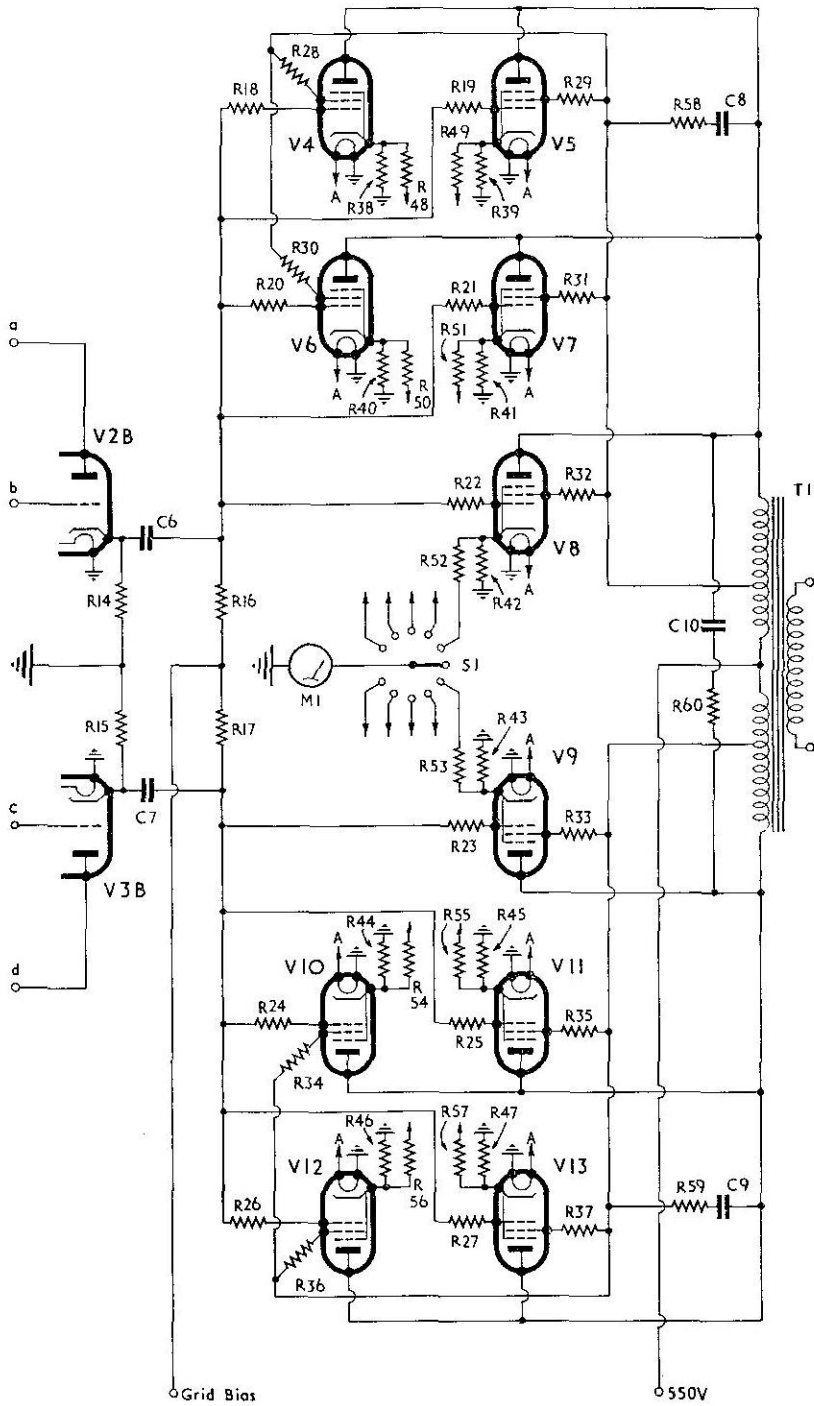


Fig. 14. (Above and opposite) Circuit diagram of the 400W multiple-pair amplifier. Component values are given on page 23.



It is not essential to use accurately matched valves but the total current in each half of the push-pull stage should be equalised as closely as possible. This becomes easier with an increasing number of pairs and is facilitated by the cathode current meter built into the amplifier. The individual cathode currents will vary from about 35mA to about 60mA and each valve should be measured in turn and the valves sorted into two groups of approximately similar total current.

When the valves have been sorted and the two groups plugged into their respective halves of the amplifier, the optimum operating condition is obtained by adjusting the grid bias with R5 (fig. 15) so that the current drawn by any single valve does not exceed 60 mA. In this way an output of 400W will be obtained at a distortion of about 5%.

When using six or more valves in this type of amplifier, the value of the grid return resistors R14 and R15 is of importance and a low value is desirable. In order to facilitate the production of the necessary distortion-free input signal of $55 \pm 55V$ r.m.s., the output stage is driven by a pair of cathode followers V2B and V3B. With four output valves the grid resistors could be increased to 100 k Ω and the cathode followers dispensed with. However, as they form parts of double triodes, the saving in cost is insignificant and, on the whole, it is preferable to retain them.

The method of measuring the cathode current of each KT88 valve is shown in fig. 14. A resistor of 10 Ω is inserted in the cathode lead of each valve i.e. R38, R39, etc.) and a meter M1 is connected across this resistor through switch S1 and a series resistor (R48, R49, etc.).

It was found convenient to use a meter with a full-scale deflection of 200 μA , the value of the series resistor being such that the meter indicated 0-200mA. At full output each cathode current is about 100mA to 125mA. It may be preferred to substitute the individual cathode series resistors with a single resistor inserted between the meter and switch but the possibility of instability should be borne in mind as the individual resistors act as cathode circuit isolators.

The ultra-linear output transformer must have low leakage inductance between : primary and secondary ; half-primary and half-primary ; and each half-primary and its tap. The absolute values of leakage inductance will depend upon the number of valves used but a 400W transformer used in the prototype had the following characteristics :

Primary Inductance :	4H
Leakage Inductances :	
Primary to secondary :	0.75mH
Half-primary to half-primary :	0.75mH
Each half-primary to tap :	1.5mH

To prevent ultrasonic oscillation, resistor/capacitor combinations are connected between each tap and the anode terminal of each half-primary. In the prototype, C10 and R60 were also found to be desirable, the values used being 3500pF and 1k Ω respectively.

Negative feedback may be added to this amplifier in the normal way, from the secondary of the output transformer to the cathode circuit of the input valve. The values of the resistors R2 and R3 in fig. 14 are determined by the amount of feedback and the ratio of the transformer.

Fig. 16 illustrates a recommended layout for the output valves and is self-explanatory. Adequate ventilation should be provided ; if in doubt, temperature sensitive paint should be used. (See page 2).

Power Supply

The design of the power supply is an important factor in the satisfactory operation of an amplifier of this type. The regulation should be good ; better than 10% with a current variation of 400-1200mA was obtained in the prototype. This order of regulation was achieved by using the xenon filled rectifier GXU1 which, in this application, is considerably under-run at a PIV of 1kV as against the rated PIV of 10kV. For up to six output valves, the smaller xenon rectifier GXU50 is suitable.

The circuit of a complete power supply is given in fig. 15 and this provides the lower h.t. voltage required by the earlier stages as well as the grid bias supply.

A single inductance-input filter is shown and, with a smoothing capacitance of 150-200 μF (obtained by series-connecting two larger capacitors), this should be satisfactory for most purposes. A further filter section may be inserted if desired. The smoothing inductor(s) should have a value of 2-3H and a d.c. resistance of about 25 Ω .

COMPONENT VALUES FOR FIG. 14**400W AMPLIFIER****G.E.C. VALVES**

V1-V3 B65/6SN7

V4-V13 KT88

R58 1k Ω 2WR59 1k Ω 2W

R60 See p. 22

RESISTORS

20%, 0.25W unless otherwise shown)

R1 1M Ω

R2 } See page 22

R3 }

R4 1k Ω R5 100k Ω 0.5WR6 15k Ω 0.5WR7 15k Ω 0.5W } matched to 5%R8 1M Ω R9 1M Ω R10 4.7k Ω 10% 0.5WR11 33k Ω 0.5WR12 220k Ω 1WR13 220k Ω 1W } matched to 5%R14 47k Ω 1WR15 47k Ω 1W } matched to 5%R16 47k Ω 10% 0.5WR17 47k Ω 10% 0.5WR18-R27 15k Ω R28-R37 220 Ω

R38-R47 Meter shunts, see p. 22

R48-R57 Meter series resistors,
see p. 22**CAPACITORS**C1 0.01 μ FC2 50 μ F 12VC3 0.01 μ FC4 0.01 μ FC5 8 μ F 450VC6 0.25 μ FC7 0.25 μ F

C8 1000pF

C9 1000pF

C10 See p. 22

MISCELLANEOUSM1 200 μ A meter (see p. 22)

S1 1-pole 11-way switch b.b.m.

T1 400W Ultra-linear transformer
1k Ω anode-anodePrimary inductance : ≤ 4 H

Leakage inductances :

Prim.—sec. : $\geq 750\mu$ H $\frac{1}{2}$ prim.—UL tap : $\geq 750\mu$ H**TABLE V****400W MULTIPLE-PAIR AMPLIFIER****Operating Conditions**

(Fig. 14)

$V_{a(b)(o)}$	570	V
$V_{a(b)(\max \text{ sig})}$	530	V
$V_{a,g2(o)}$	565	V
$V_{a,g2(\max \text{ sig})}$	525	V
$I_{a+g2(o)}$ (per valve)	35 to 60	mA
$I_{a+g2(\max \text{ sig})}$ (per valve)	100 to 125	mA
$I_{a+g2(o)}$ (total)	450	mA
$I_{a+g2(\max \text{ sig})}$ (total)	1200	mA
$P_{a+g2(o)}$ (per valve)	35	W
$P_{a+g2(\max \text{ sig})}$ (per valve)	25	W
V_{g1} (approx)	-75	V
P_{out}	400	W
$R_{L(a-a)}$	1	k Ω
z_{cut}	1.2	k Ω
D	5 to 7	%
$V_{in(rms)}$ to first stage	250	mV

If 10db of negative feedback is applied, the last three values become 400 Ω , 2% and 750mV respectively.

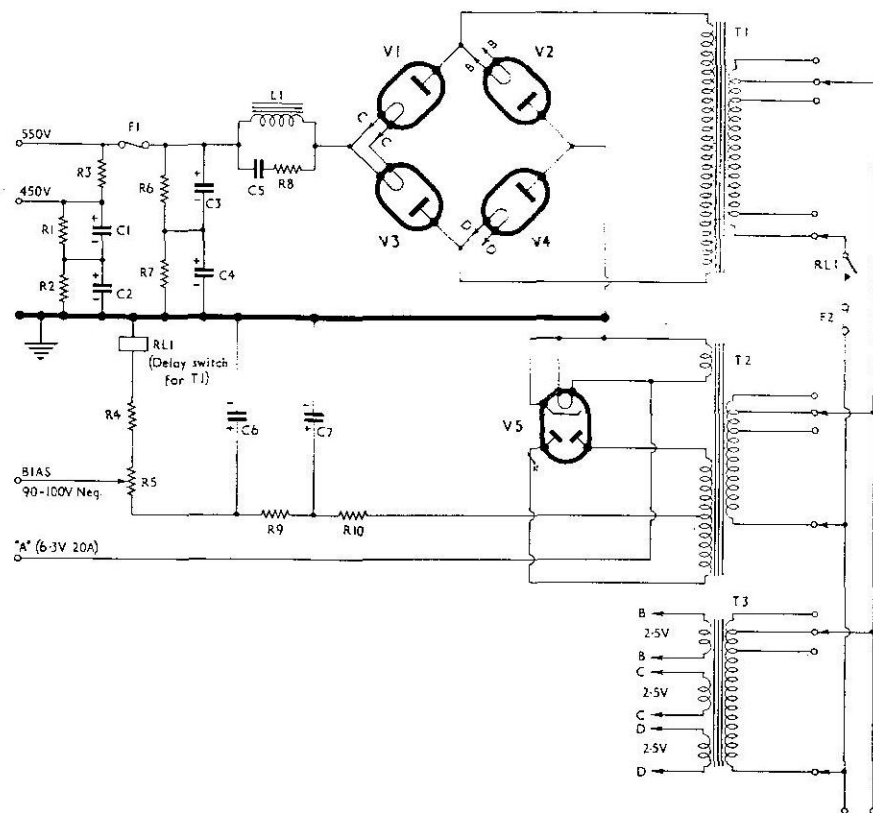


Fig. 15. Power supply circuit for the 400W multiple-pair amplifier. The winding of T3 is simplified if four identical secondaries are used. To prevent mains-borne interference with nearby receivers, generated by the xenon rectifiers, a pair of capacitors (0.05 μ F, 700V a.c.) should be connected in series across the 700V winding and their junction connected to the negative (earth) line.

COMPONENT VALUES FOR FIG. 15

POWER SUPPLY FOR 400W AMPLIFIER

G.E.C. VALVES

V1-V4 GXU1

V5 U709 or U78/6X4

RESISTORS

R1	100k Ω	10%	0.5W
R2	100k Ω	10%	0.5W
R3	4.7k Ω	20%	2W
R4	22k Ω	20%	1W
R5	10k Ω	w.w.	
R6	47k Ω	10%	1W
R7	47k Ω	10%	1W
R8	10k Ω	20%	1W
R9	22k Ω	20%	1W
R10	1.5k Ω	20%	0.25W

CAPACITORS

C1	32 μ F	350V
C2	32 μ F	350V

C3	300 μ F	350V	} each 100+200 dual
C4	300 μ F	350V	
C5	0.01 μ F	500V	
C6	2 μ F	250V	
C7	2 μ F	250V	

MISCELLANEOUS

L1	2H	1200mA	25 Ω
T1	700V	1200mA*	
T2	Bias transformer		
	Secondaries :		
	150-0-150V 10mA		
	6.3V 20A		
T3	2.5V	5A	
	2.5V	5A	
	2.5V	10A (or 2 $\times$ 5A)	
F1	2A		
F2	5A		

*10V taps on primary.

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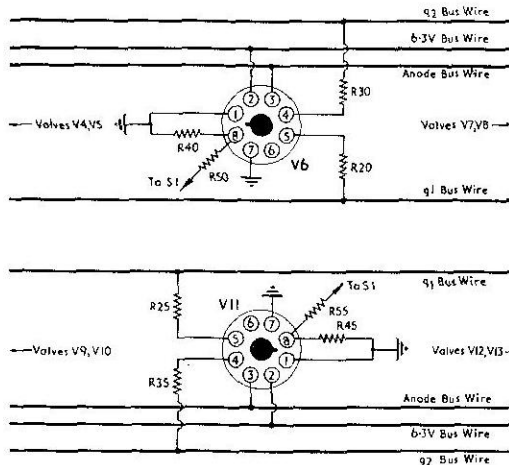


Fig. 16. Recommended layout for the output valves of the 400W amplifier. If the distance between pairs of valves is reduced to the minimum of 4 in centre to centre, they should be orientated as shown on page 3.

APPENDIX
INTERMODULATION IN ULTRA-LINEAR AMPLIFIERS

The curves below illustrate the various degrees of intermodulation with varying positions of the screen taps on the output transformer from 0% (pentode operation) to 100% (triode operation). The measurements were made under SMPE conditions using frequencies of 50 and 6000 c/s at a ratio of 4 : 1. It will be noticed that the lowest level of intermodulation is obtained with taps of about 40%. A slight increase in intermodulation is produced at 33% or 57% and a significant increase at 25% or 75%.

The triode performance (100%) is inferior to the ultra-linear at all outputs except below 10W with 25% taps. The high intermodulation of the pentode arrangement (0%) is to be expected.

The application of negative feedback will reduce intermodulation roughly in proportion to the reduction in gain. For example, a 3 : 1 reduction in intermodulation is obtained with 10db and a 5 : 1 reduction with 14 db feedback. It can be seen from fig. 17 that it is not difficult to reduce intermodulation to below 1% at 50W output.

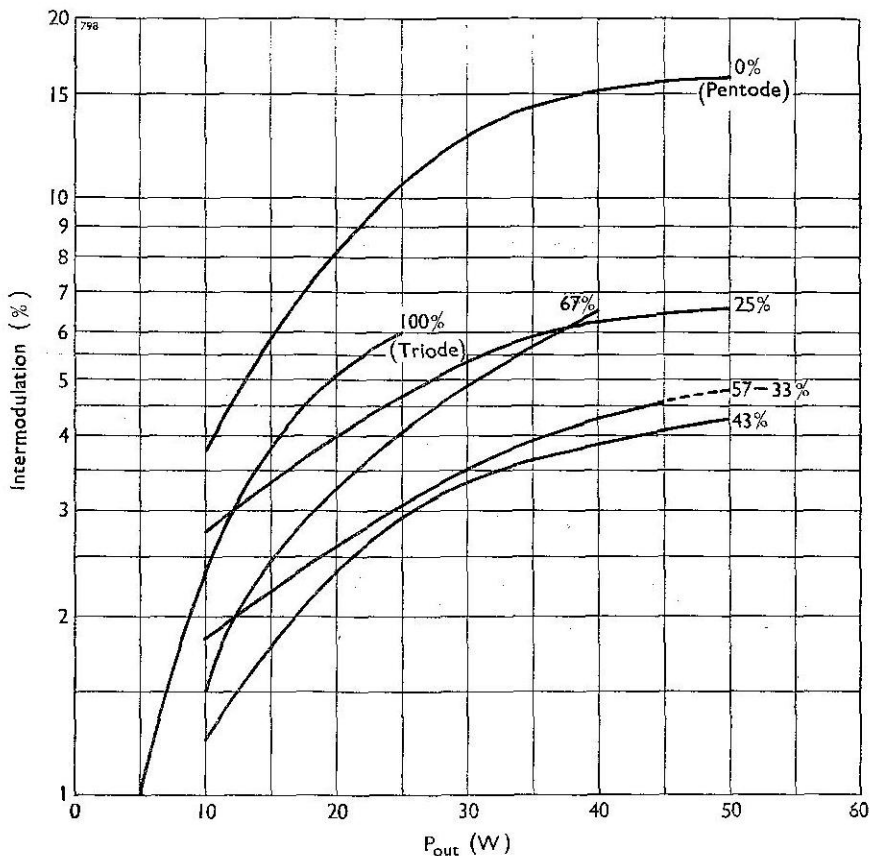


Fig. 17.