G.E.C. VALVES

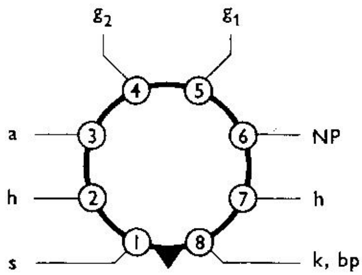
BEAM TETRODE
6·3V INDIRECTLY HEATED

KT88
ISSUE 3

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+g2}	46	40	W
I_k	230	230	mA
V_{h-k}	250	200	V
T_{bulb}	250	250	°C
R_{g1-k} (cathode bias)			
$p_{a+g2} \leqslant 35W$	470		kΩ
$p_{a+g2} > 35W$	270		kΩ
R_{g1-k} (fixed bias)			
$p_{a+g2} \leqslant 35W$	220		kΩ
$p_{a+g2} > 35W$	100		kΩ

CAPACITANCES (Measured on a cold unscreened valve)

$c_{g1-a,g2}$: 7·9pF $c_{g1-\text{all less } a,g2}$: 9·3pF $c_{a,g2-\text{all less } g1}$: 17pF

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

$c_{g1-a,g2}$: 7.9pF $c_{g1-\text{all less } a,g2}$: 9.3pF $c_{a,g2-\text{all less } g1}$: 17pF

Tetrode Connection

c_{g1-a}: 1.2pF $c_{g1-\text{all less } a}$: 16pF $c_{a-\text{all less } g1}$: 12pF

THE M-O VALVE CO. LTD. · BROOK GREEN · LONDON · W.6
a subsidiary of
THE GENERAL ELECTRIC CO. LTD. OF ENGLAND

Printed in England—K-C   *R627*   **OCTOBER, 1961**

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	kΩ
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
$I_{a(max\ sig)}$	2×73	mA
$I_{g2(o)}$	2× 1·7	mA
$I_{g2(max\ sig)}$	2× 9	mA
$R_{L(a-a)}$	9	kΩ
*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
$p_{a(max\ sig)}$	2×12	W
$p_{g2(o)}$	2× 0·5	W
$p_{g2(max\ sig)}$	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
$I_{a(max\ sig)}$	2×145	mA
$I_{g2(o)}$	2× 1·7	mA
$I_{g2(max\ sig)}$	2×15	mA
$R_{L(a-a)}$	4·5	kΩ
*$-V_{g1}$	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 ±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	kΩ
*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	kΩ

*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	kΩ
*$-V_{g1}$	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	kΩ

*It is essential to provide two separately adjustable bias voltage sources, having a voltage adjustment range of ±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	kΩ
$-V_{g1}$	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	kΩ

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

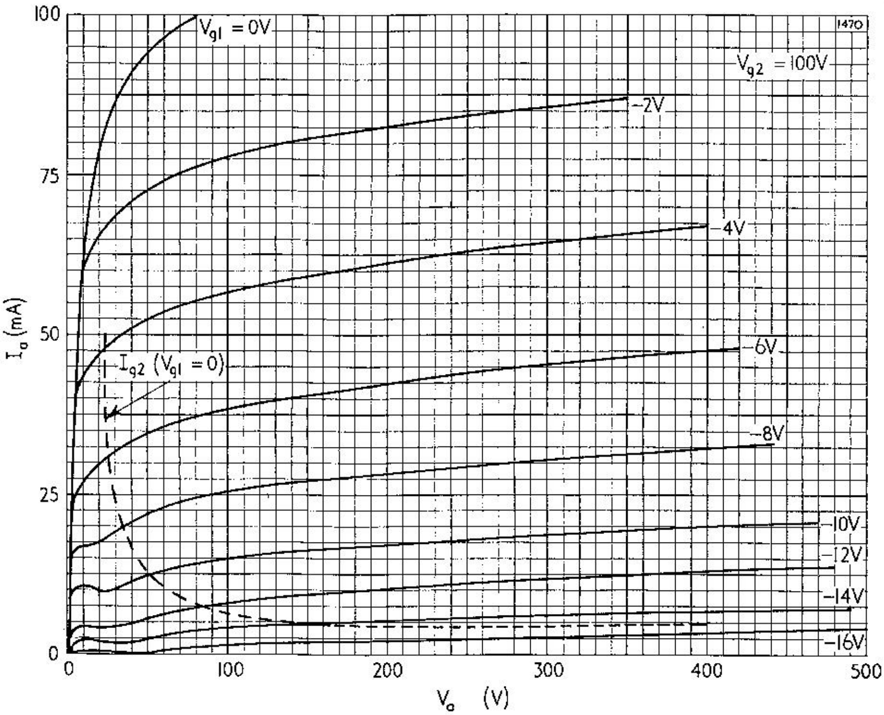
INSTALLATION

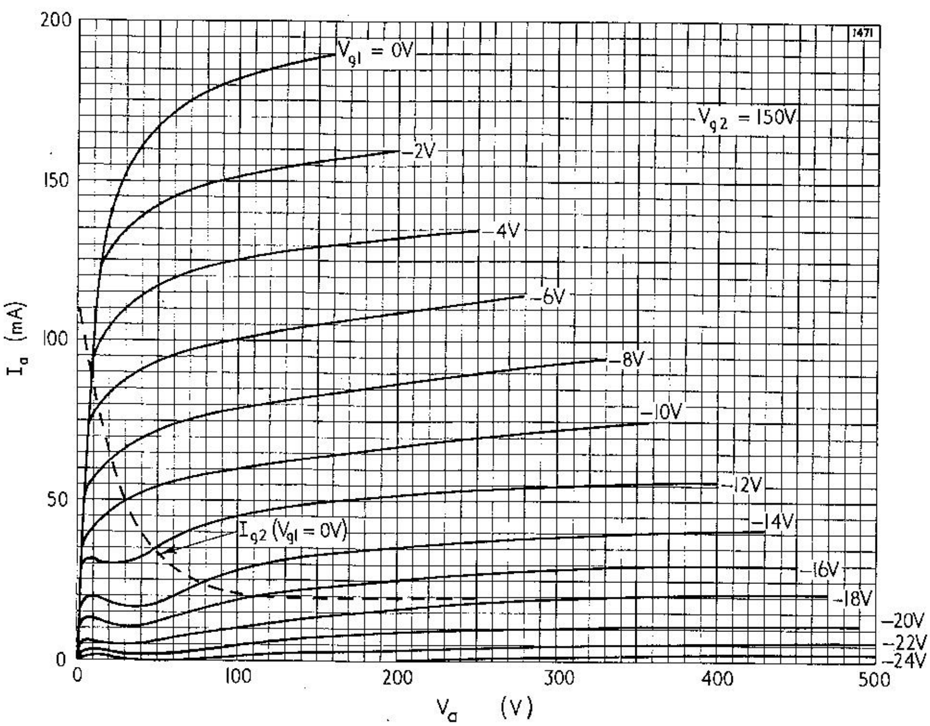
The valve may be mounted either vertically or horizontally.

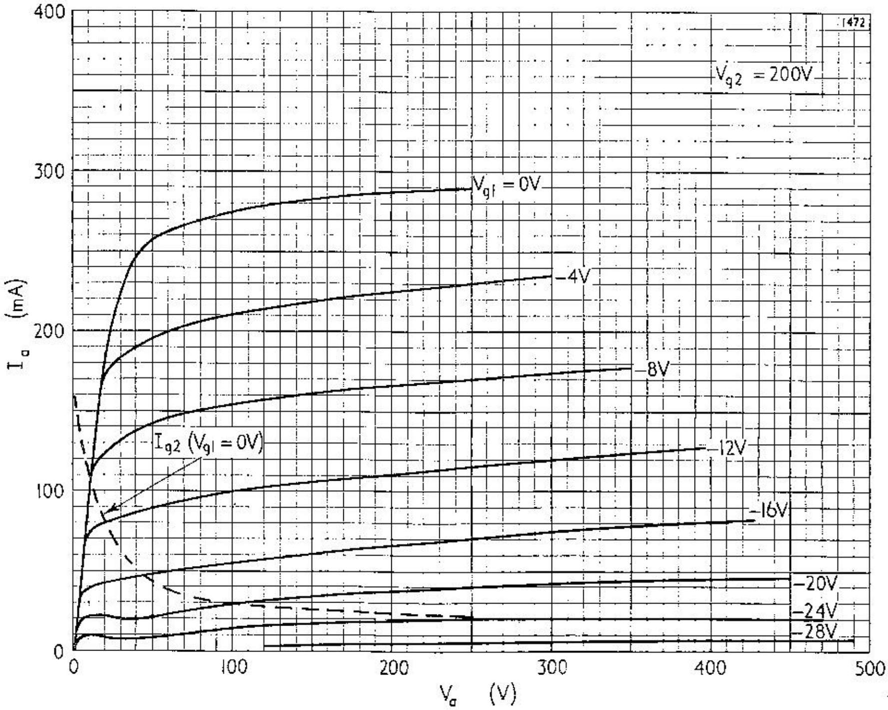
When a pair of valves is mounted vertically it is recommended that the centres of the valve sockets are not less than 4in. apart and that pins 4 and 8 of each valve are in line.

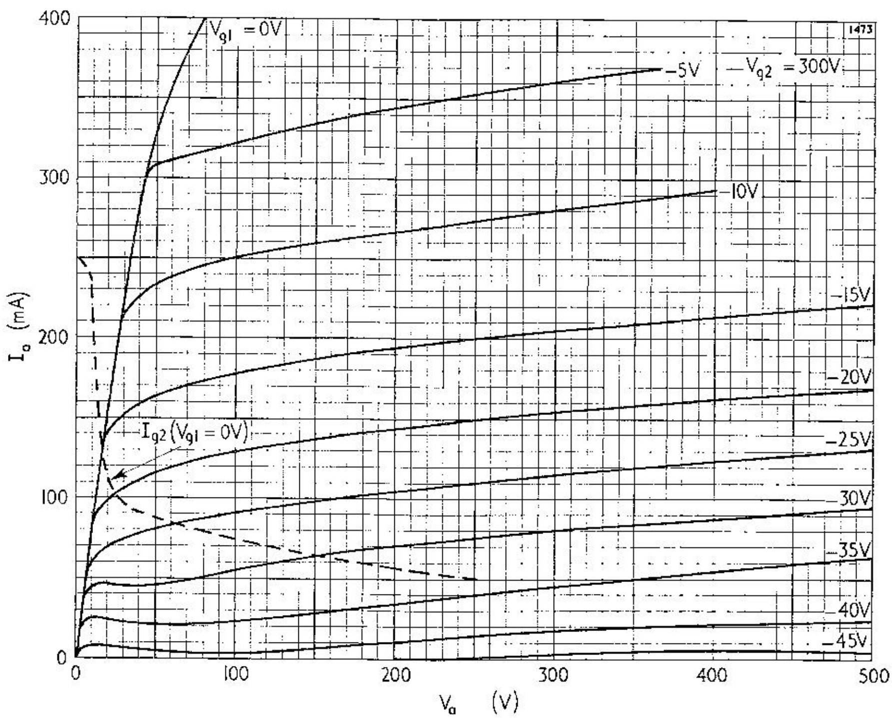
When a pair of valves is mounted horizontally it is recommended that the centres of the valve sockets are not less than 4in. apart and that pins 4 and 8 of each valve are in the same vertical line.

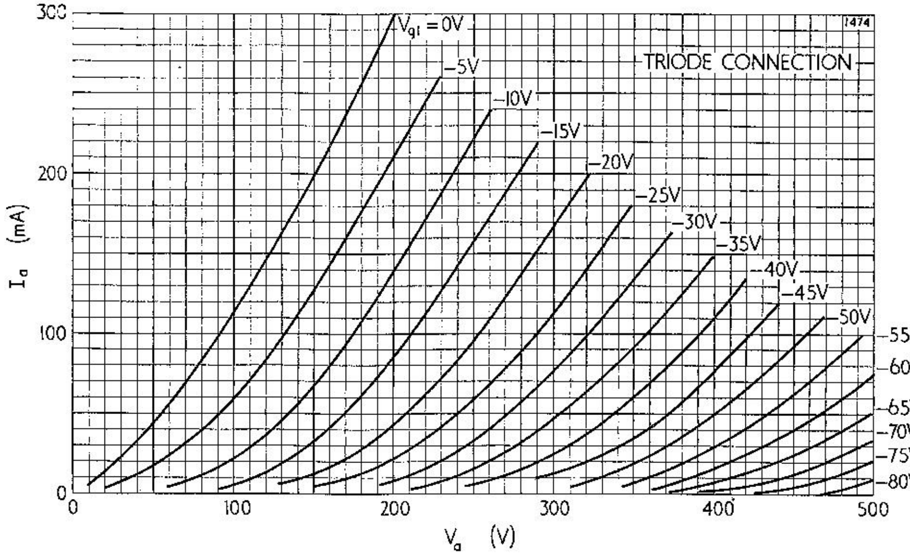
Free air circulation around the valve is desirable.

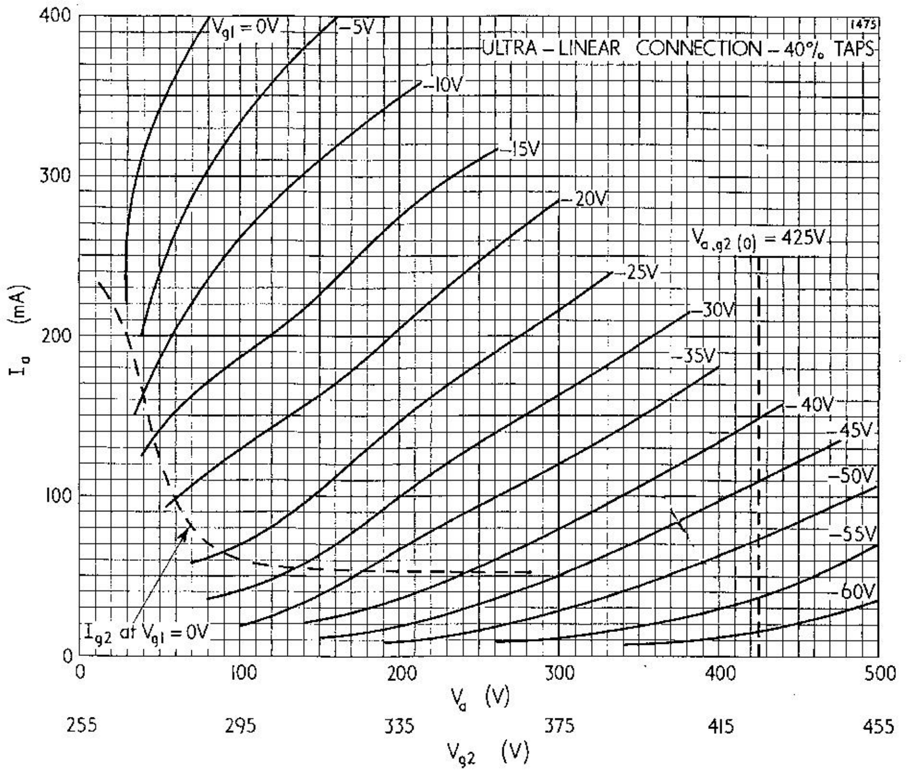

1470
V_{g2} = 100V
V_{g1} = 0V
−2V
−4V
−6V
−8V
−10V
−12V
−14V
−16V
I_{g2} (V_{g1} = 0)
I_a (mA)
V_a (V)
0
25
50
75
100
0
100
200
300
400
500


1471
V_{g2} = 150V
V_{g1} = 0V
−2V
−4V
−6V
−8V
−10V
−12V
−14V
−16V
−18V
−20V
−22V
−24V
I_{g2} (V_{g1} = 0V)
I_a (mA)
V_a (V)
0
50
100
150
200
0
100
200
300
400
500


1472
V_{g2} = 200V
V_{g1} = 0V
−4V
−8V
I_{g2} (V_{g1} = 0V)
−12V
−16V
−20V
−24V
−28V
I_a (mA)
V_a (V)
0
100
200
300
400
500


1473
V_{g1} = 0V
−5V
V_{g2} = 300V
−10V
−15V
−20V
I_{g2} (V_{g1} = 0V)
−25V
−30V
−35V
−40V
−45V
I_a (mA)
V_a (V)
0
100
200
300
400
500





Printed in England R374

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 6·5kΩ in this example, compared with 50kΩ, 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 10kΩ and 270Ω 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.

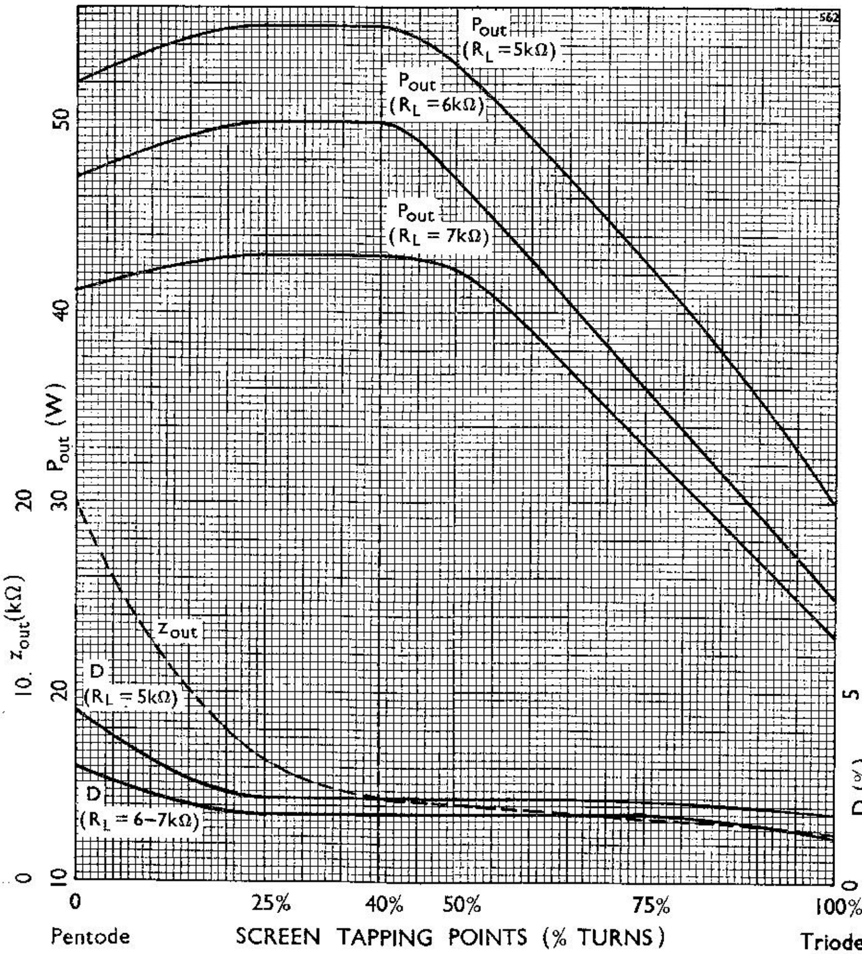


Fig. 1. Output power, distortion and output impedance of KT88 ultra-linear output stage at various positions of the screen taps from 0% to 100% of each half-primary from the centre tap.

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.

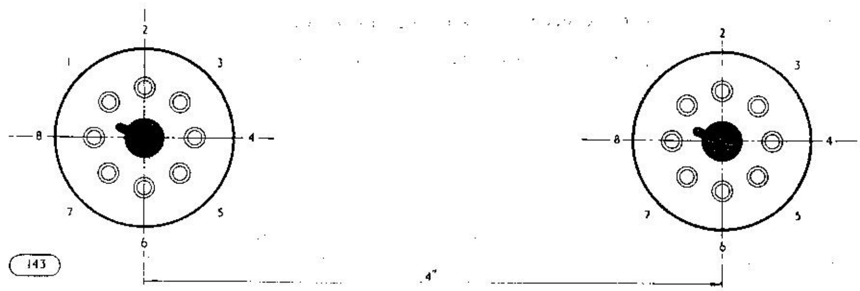


Fig. 3. Correct orientation and spacing of the valve sockets when the valves are mounted vertically.

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—150μF. Two 160μF, 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 1MΩ Log.
R2* $225\sqrt{\text{speech coil impedance}}$
R3 1kΩ
R4 22Ω
R5 100kΩ
R6 15kΩ 0·5W } Matched to 5%
R7 15kΩ 0·5W } Matched to 5%
R8 4·7kΩ
R9 470kΩ 10%
R10 470kΩ 10%
R11 1kΩ
R12 1kΩ
R13 33kΩ 10% 1W
R14 33kΩ 10% 1W
R15 220kΩ
R16 220kΩ
R17 10kΩ
R18 10kΩ
R19 4·7kΩ 1W
R20 400Ω 5% 5W
R21 400Ω 5% 5W
R22 270Ω 0·5W
R23 270Ω 0·5W
R24 470-1500Ω 0·5W
R25 470-1500Ω 0·5W

**For 14db feedback.*

CAPACITORS

C1 50μF 12V
C2 0·05μF
C3 0·05μF
C4 8μF 350V
C5 8μF 450V
C6 0·05μF
C7 0·05μF
C8 50μF 50V
C9 50μF 50V
C10 8μF 500V
C11 1000pF
C12 1000pF
C13 8μF 500V

MISCELLANEOUS

L1 10H 200mA
T1 35W Ultra-linear transformer
6kΩ anode-anode
†Primary Inductance : $\not<$ 50H
Leakage inductances :
†Prim.—sec. : $\not>$ 10mH
†½ prim.—UL tap : $\not>$ 10mH
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.

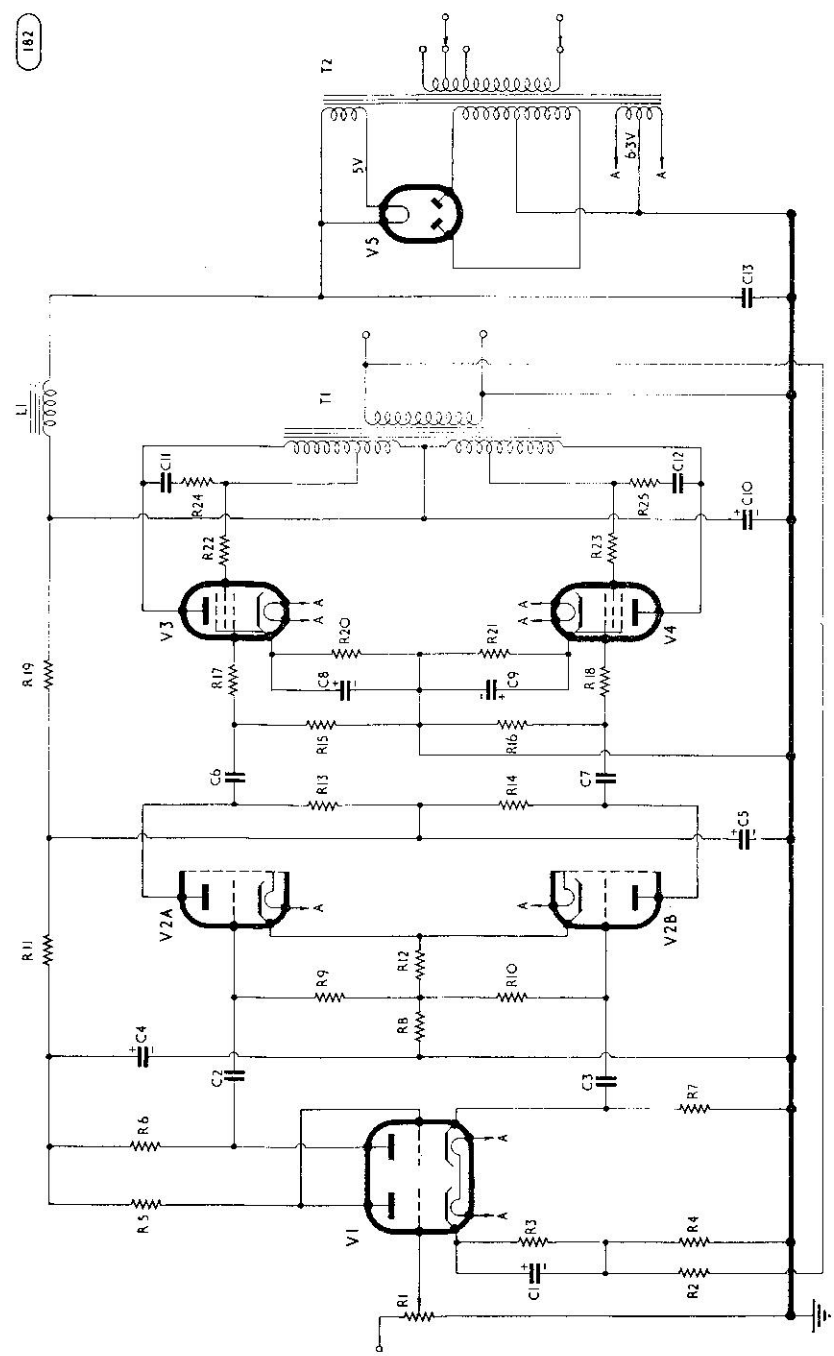


Fig. 4. Circuit diagram of the KT88 30W ultra-linear amplifier. The components list is given opposite.

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
$I_{a+g2(max\ sig)}$	2×85	mA
$p_{a+g2(o)}$	2×27	W
$p_{a+g2(max\ sig)}$	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

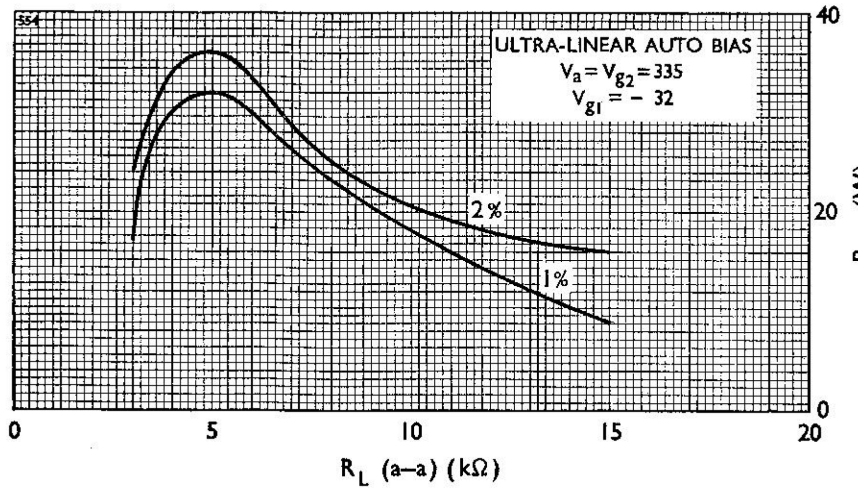


Fig. 5. Performance of the KT88 30W ultra-linear amplifier of fig. 4.

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 nverter 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.

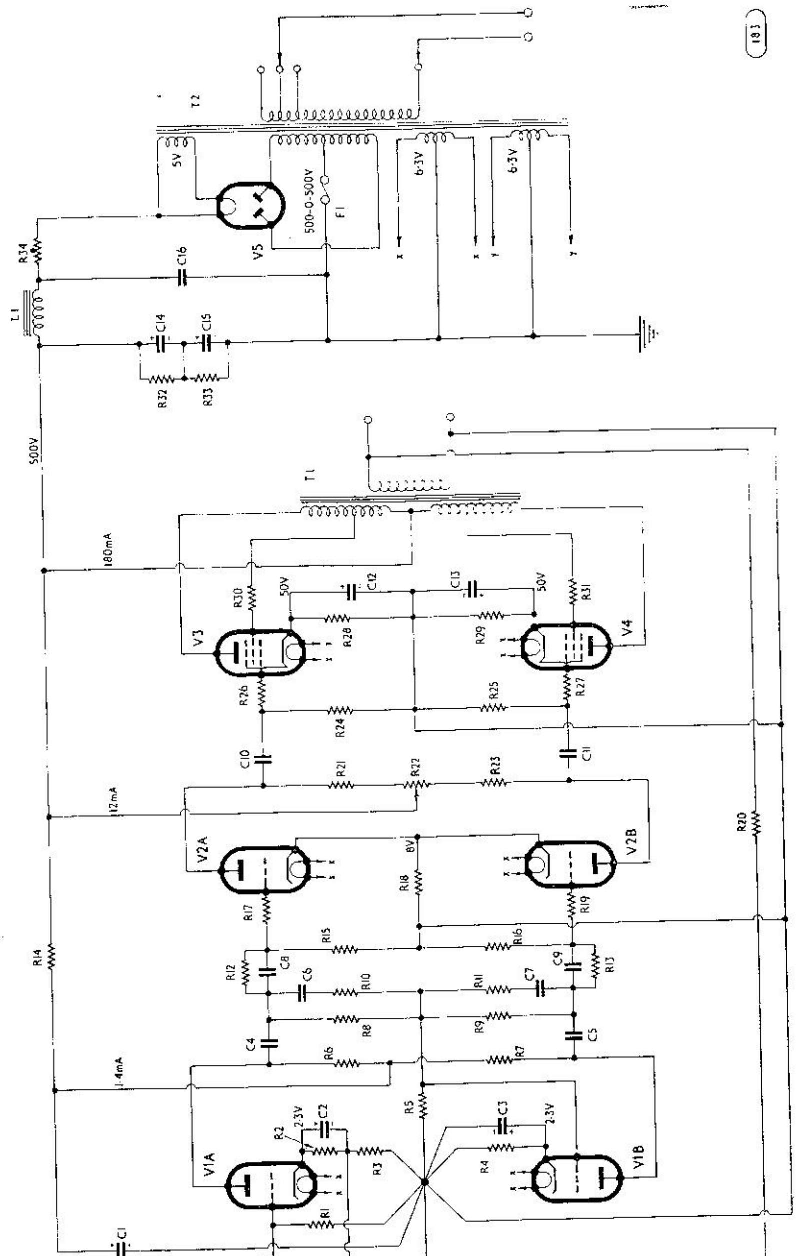


Fig. 6. Circuit diagram of the KT88 50W ultra-linear amplifier.

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

RESISTORS

(20%, 0·5W unless otherwise shown)

R1	1MΩ		
R2	3·3kΩ		
R3	100Ω		
R4	3·3kΩ		
R5	1MΩ		
R6	220kΩ	10%	
R7	220kΩ	10%	
R8	1MΩ		
R9	1MΩ		
R10	10kΩ		
R11	10kΩ		
R12	4·7MΩ		
R13	4·7MΩ		
R14	100kΩ		
R15	470kΩ		
R16	470kΩ		
R17	10kΩ		
R18	680Ω		
R19	10kΩ		
R20	4·7kΩ		
R21	33kΩ	2W	
*R22	25kΩ	4W	
R23	33kΩ	2W	
R24	220kΩ		
R25	220kΩ		
R26	10kΩ		
R27	10kΩ		
R28	525Ω	5%	6W
R29	525Ω	5%	6W
R30	100Ω		
R31	100Ω		

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

CAPACITORS

C1	8μF	500V
C2	50μF	12V
C3	50μF	12V
C4	0·25μF	
C5	0·25μF	
C6	470pF	
C7	470pF	
C8	0·005μF	
C9	0·005μF	
C10	0·5μF	
C11	0·5μF	
C12	50μF	100V
C13	50μF	100V
C14	24μF	350V
C15	24μF	350V
C16	4μF	750V
C17	8μF	500V

MISCELLANEOUS

L1 5H 250mA

T1 50W Ultra-linear transformer
5kΩ anode-anode
Primary inductance : ≮30H
Leakage inductances :
Prim.—sec. : ≯10mH
½ prim.—UL tap : ≯10mH

T2 Mains transformer
Secondaries :
500—0—500V 250mA
6·3V 5A CT
6·3V 1—2A CT
5V 3A

F1 1A delayed fuse

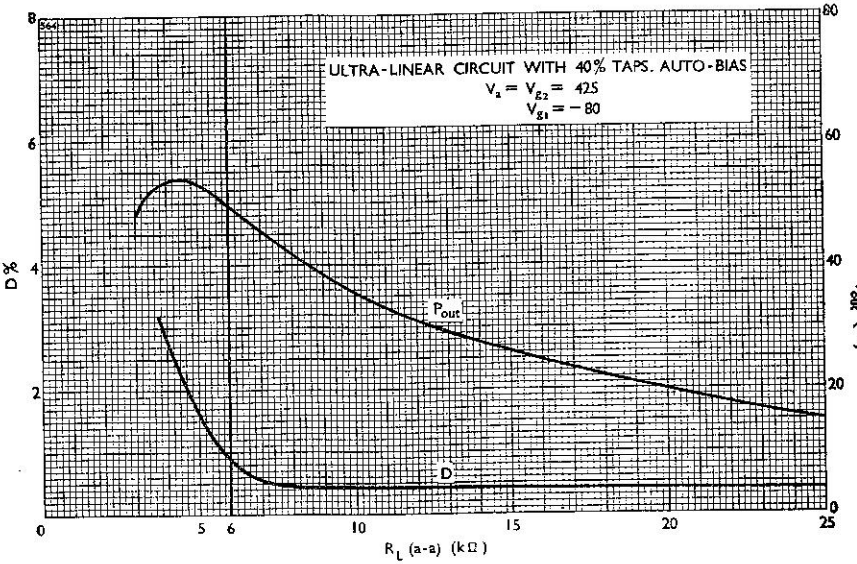


Fig. 7. Performance of the KT88 50W ultra-linear amplifier of fig. 6.

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	kΩ
*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—150μF. The circuit diagram shows two 160μF 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 4kΩ 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	kΩ
z_{out}	6·5	6·5	kΩ
†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 ±25% is recommended.

†The distortion will vary according to the degree of matching by R11.

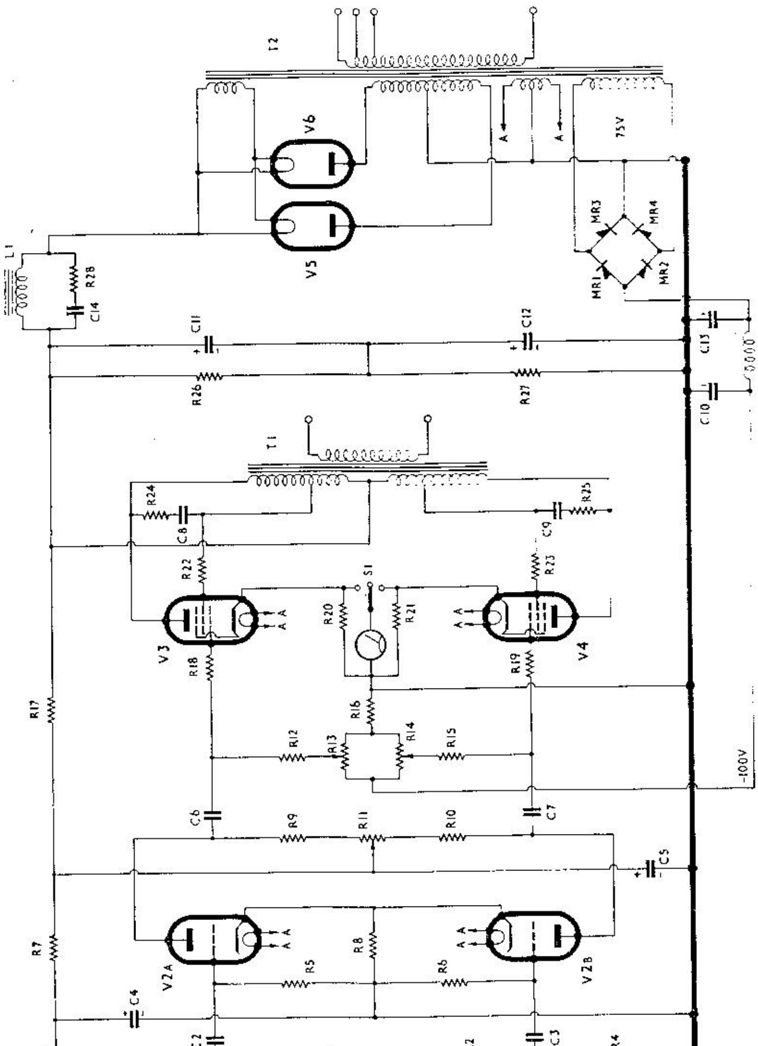


Fig. 8. Circuit diagram of the KT88 100W fixed bias ultra-linear amplifier. R26 and R27 equalise the voltages across C11 and C12, the series-connected smoothing capacitors. C14 and R28 prevent the build-up of high voltage transients across L1.

COMPONENT VALUES FOR FIG. 8

100W FIXED BIAS AMPLIFIER

G.E.C. VALVES

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

RESISTORS

(20%, 0·25W unless otherwise shown)

R1	1MΩ
R2	1·5kΩ
R3	33kΩ 1W (R3, R4 matched to 5%)
R4	33kΩ 1W (R3, R4 matched to 5%)
R5	470kΩ 10%
R6	470kΩ 10%
R7	33kΩ 1W
R8	1kΩ
R9	33kΩ 10% 1W
R10	10kΩ
R11	33kΩ 10% 1W
R12	100kΩ 10% 0·5W
R13	20kΩ w.w. preset
R14	20kΩ w.w. preset
R15	100kΩ 10% 0·5W
R16	10kΩ 10% 1W
R17	4·7kΩ 1W
R18	5·6kΩ
R19	5·6kΩ
R20, R21	Meter shunts
R22	270Ω 0·5W
R23	270Ω 0·5W
R24	470-1500Ω 0·5W
R25	470-1500Ω 0·5W
R26	100kΩ 10% 1W
R27	100kΩ 10% 1W
R28	10kΩ 0·5W

CAPACITORS

C1	0·01μF
C2	0·05μF
C3	0·05μF
C4	8μF 350V
C5	8μF 450V
C6	0·1μF
C7	0·1μF
C8	1000pF
C9	1000pF
C10	8μF 250V
C11	160μF 450V (C11, C12 each 100+60 dual)
C12	160μF 450V (C11, C12 each 100+60 dual)
C13	8μF 250V
C14	0·01μF 750V

MISCELLANEOUS

L1 5H 325mA

L2 20H 10mA

T1 100W Ultra-linear transformer
4·5kΩ anode-anode (100W)
4kΩ anode-anode (65W)
Primary inductance : $\nless$40H
Leakage inductances :
Prim.—sec. : $\ngtr$6mH
½ prim.—UL tap : $\ngtr$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, MR3, MR4 75V 10mA

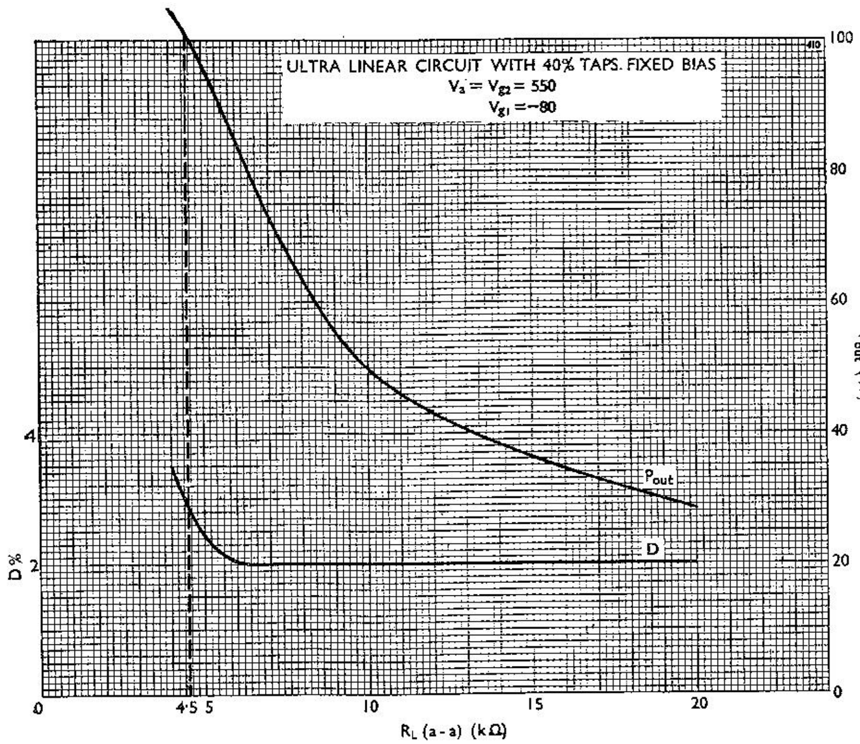


Fig. 9. Performance of the KT88 100W amplifier of fig. 8.

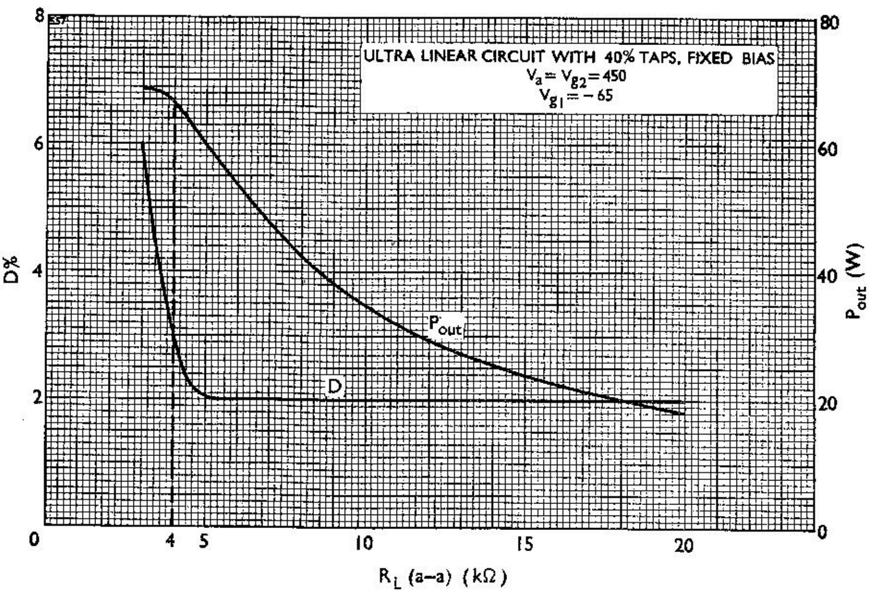


Fig. 10. The modified characteristics of the amplifier in fig. 8 when it is arranged for 65W maximum output (see Table III).

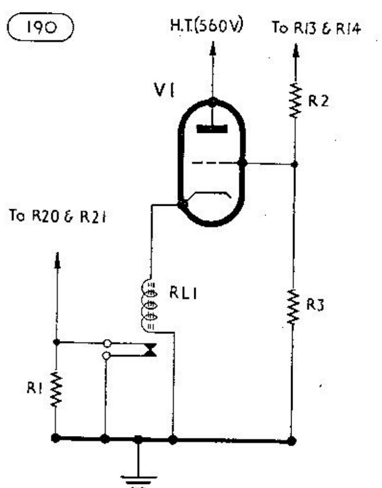


Fig. 11. Bias failure protection for the KT88 fixed bias amplifier. R2 is connected to the positive (earthy) junction of R13 and R14 in fig. 8. R2 and R3 take the place of R16 in the amplifier. The earth connection to the meter in fig. 8 is broken and the meter (and R20, R21) taken to R1. Component values : 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 R 19.

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 VALVES FOR FIG. 12

CLASS B 150W AMPLIFIER

G.E.C. VALVES

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

RESISTORS

(20%, 0·25W unless otherwise shown)

R1	470kΩ
R2	1kΩ
R3	33kΩ } Matched to 5% 1W
R4	33kΩ } Matched to 5% 1W
R5	220kΩ
R6	220kΩ
R7	10kΩ
R8	10kΩ
R9	22kΩ 1W
R10	600kΩ 5% 3W w.w.
R11	600kΩ 5% 3W w.w.
R12	220kΩ
R13	220kΩ
R14	100kΩ 10% 1W w.w.
R15	100kΩ 10% 1W w.w.
R16	5kΩ 5% 20W w.w.
R17	5kΩ 5% 20W w.w.
R18	22-100kΩ 1W
R19	22-100kΩ 1W
R20	100kΩ 10% 1W
R21	100kΩ 10% 1W
R22	10kΩ

CAPACITORS

C1	0·01μF
C2	0·05μF
C3	0·05μF
C4	8μF
C5	25μF
C6	25μF
C7	32μF
C8	32μF
C9	0·5μF
C10	0·5μF
C11	0·01μF
C12	0·01μF
C13	160μF
C14	160μF
C15	0·01μF
C16	160μF

*ICAS : Intermittent commercial and amateur service.

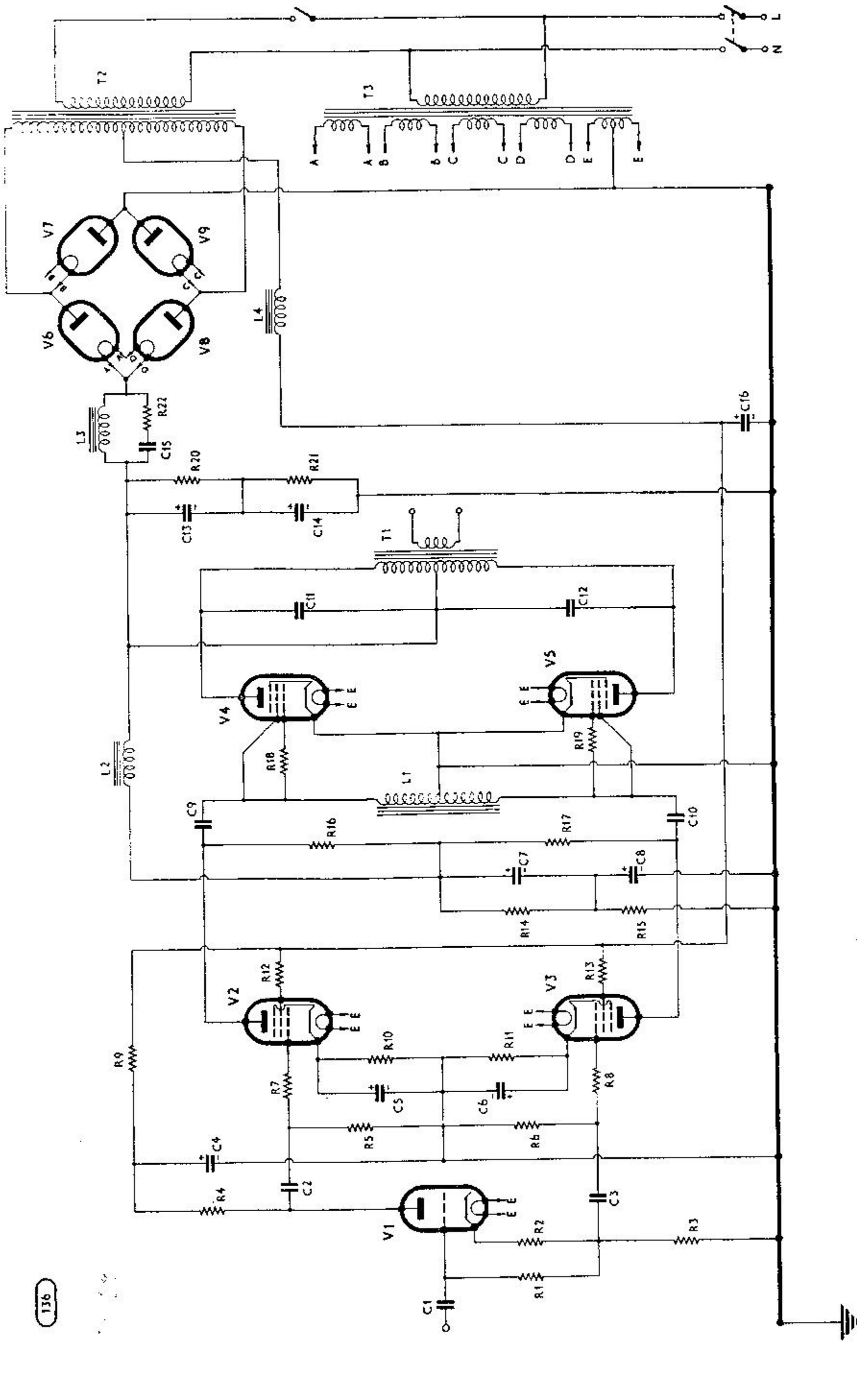


Fig. 12. Circuit diagram of the 150W Class B amplifier.

An inductance L1 is used in place of grid return resistors as the output stage grids draw some 30mA at full output. The characteristics of L1 are not critical. It should have a d.c. resistance not exceeding 500Ω, 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	kΩ
z_{out}	25	kΩ
D	6 to 8	%
p_{dr} (approx)	7	W
$V_{in(g-g)(rms)}$	360	V
z_{in}	18	kΩ
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 7·5kΩ. At V_a=600V an output of approximately 100W is given.

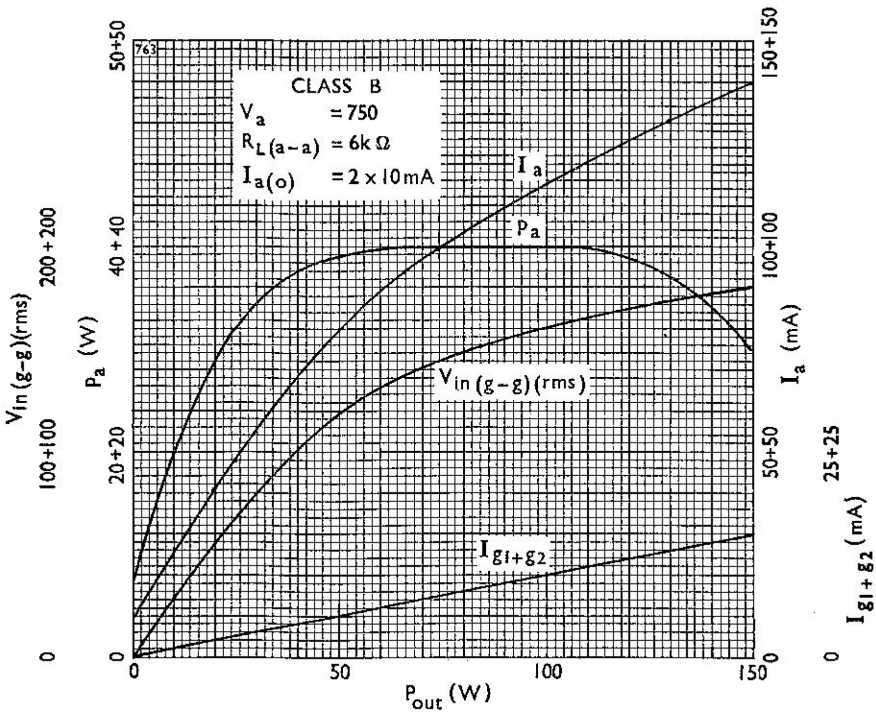


Fig. 13. Performance of the 150W Class B amplifier of fig. 12.

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.

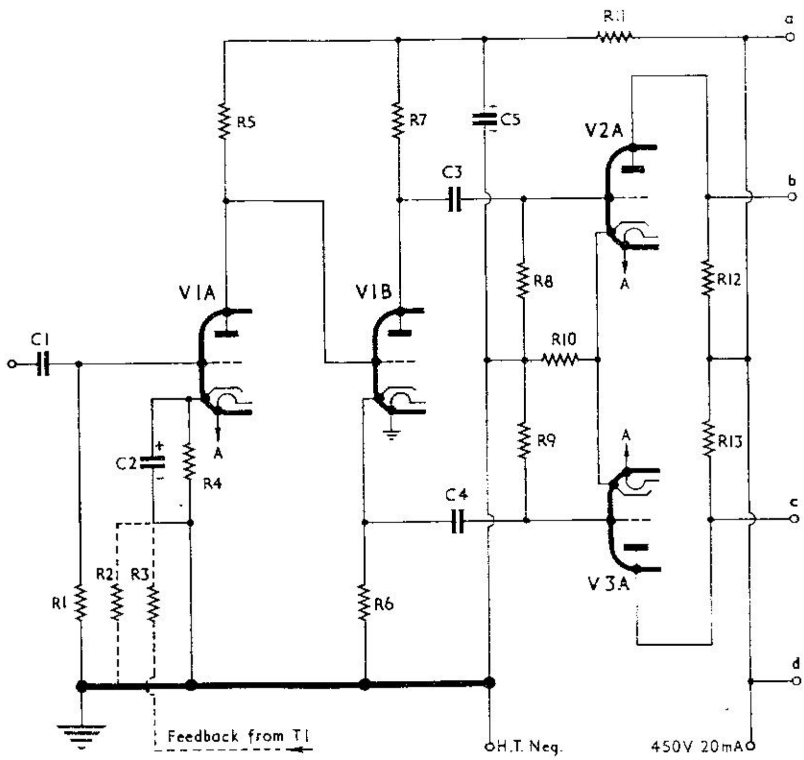
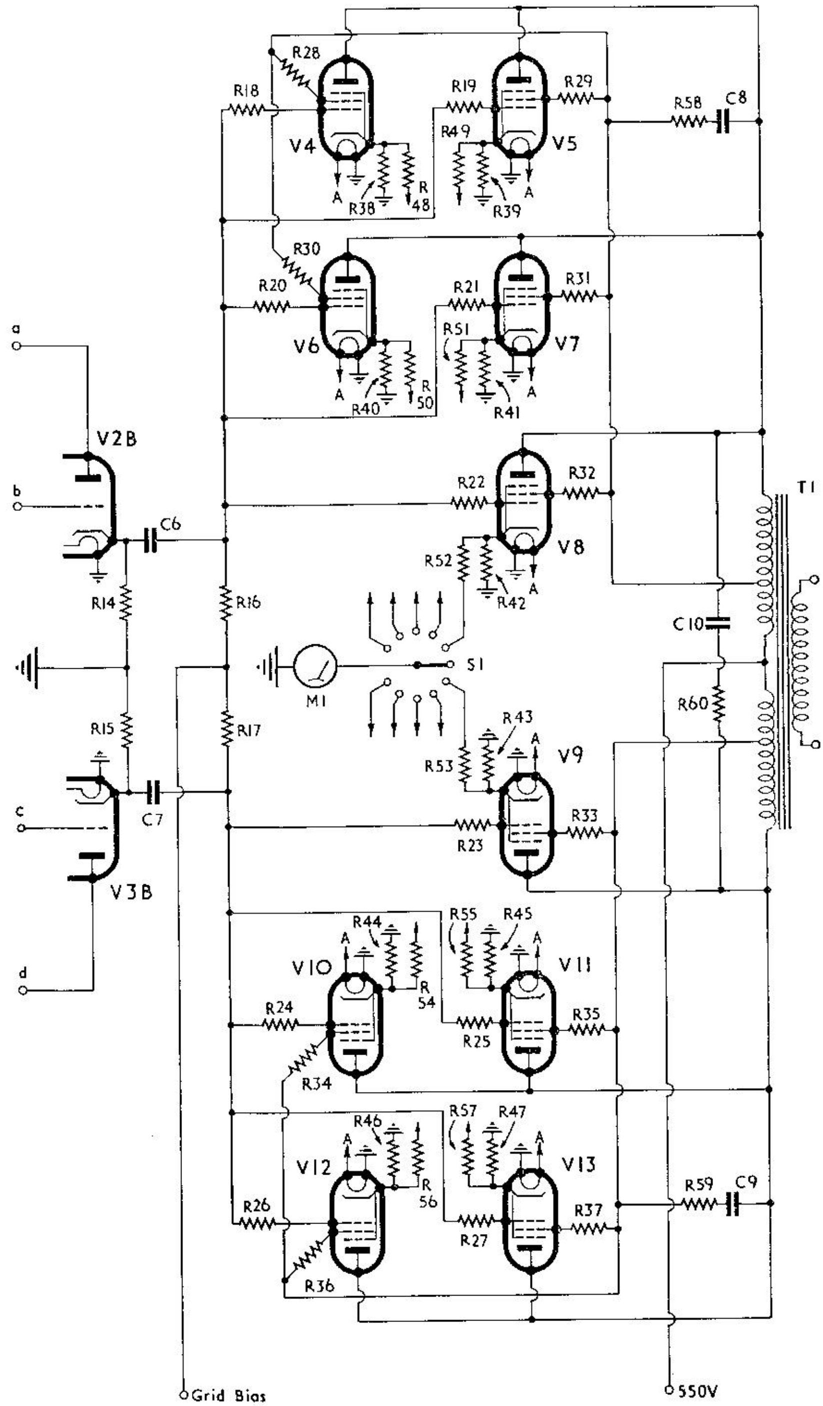


Fig. 14. (Above and opposite) Circuit diagram of the 400W multiple-pair amplifier. Component values are given on page 23.



a
b
c
d
V2B
V3B
C6
C7
R14
R15
R16
R17
V4
V5
V6
V7
V8
V9
V10
V11
V12
V13
R18
R19
R20
R21
R22
R23
R24
R25
R26
R27
R28
R29
R30
R31
R32
R33
R34
R35
R36
R37
R38
R39
R40
R41
R42
R43
R44
R45
R46
R47
R48
R49
R50
R51
R52
R53
R54
R55
R56
R57
R58
R59
R60
C8
C9
C10
T1
S1
M1
A
Grid Bias
550V

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+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 kΩ 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 10Ω 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 200μA, 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 1kΩ 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 150-200μF (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 25Ω.

COMPONENT VALUES FOR FIG. 14

400W AMPLIFIER

G.E.C. VALVES

V1-V3 B65/6SN7
V4-V13 KT88

RESISTORS

(20%, 0·25W unless otherwise shown)

R1 1MΩ
R2, R3 } See page 22
R4 1kΩ
R5 100kΩ 0·5W
R6 15kΩ 0·5W } matched to 5%
R7 15kΩ 0·5W } matched to 5%
R8 1MΩ
R9 1MΩ
R10 4·7kΩ 10% 0·5W
R11 33kΩ 0·5W
R12 220kΩ 1W } matched to 5%
R13 220kΩ 1W } matched to 5%
R14 47kΩ 1W } matched to 5%
R15 47kΩ 1W } matched to 5%
R16 47kΩ 10% 0·5W
R17 47kΩ 10% 0·5W
R18-R27 15kΩ
R28-R37 220Ω
R38-R47 Meter shunts, see p. 22
R48-R57 Meter series resistors, see p. 22
R58 1kΩ 2W
R59 1kΩ 2W
R60 See p. 22

CAPACITORS

C1 0·01μF
C2 50μF 12V
C3 0·01μF
C4 0·01μF
C5 8μF 450V
C6 0·25μF
C7 0·25μF
C8 1000pF
C9 1000pF
C10 See p. 22

MISCELLANEOUS

M1 200μA meter (see p. 22)
S1 1-pole 11-way switch b.b.m.
T1 400W Ultra-linear transformer
1kΩ anode-anode
Primary inductance : ≮4H
Leakage inductances :
Prim.—sec. : ≯750μH
½ prim.—UL tap : ≯750μH

TABLE V

400W MULTIPLE-PAIR AMPLIFIER

Operating Conditions

(Fig. 14)

$V_{a(b)(o)}$	570	V
$V_{a(b)(max\ sig)}$	530	V
$V_{a,g2(o)}$	565	V
$V_{a,g2(max\ sig)}$	525	V
$I_{a+g2(o)}$ (per valve)	35 to 60	mA
$I_{a+g2(max\ sig)}$ (per valve)	100 to 125	mA
$I_{a+g2(o)}$ (total)	450	mA
$I_{a+g2(max\ sig)}$ (total)	1200	mA
$p_{a+g2(o)}$ (per valve)	35	W
$p_{a+g2(max\ sig)}$ (per valve)	25	W
V_{g1} (approx)	−75	V
P_{out}	400	W
$R_{L(a-a)}$	1	kΩ
Z_{out}	1·2	kΩ
D	5 to 7	%
$V_{in(rms)}$ to first stage	250	mV

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

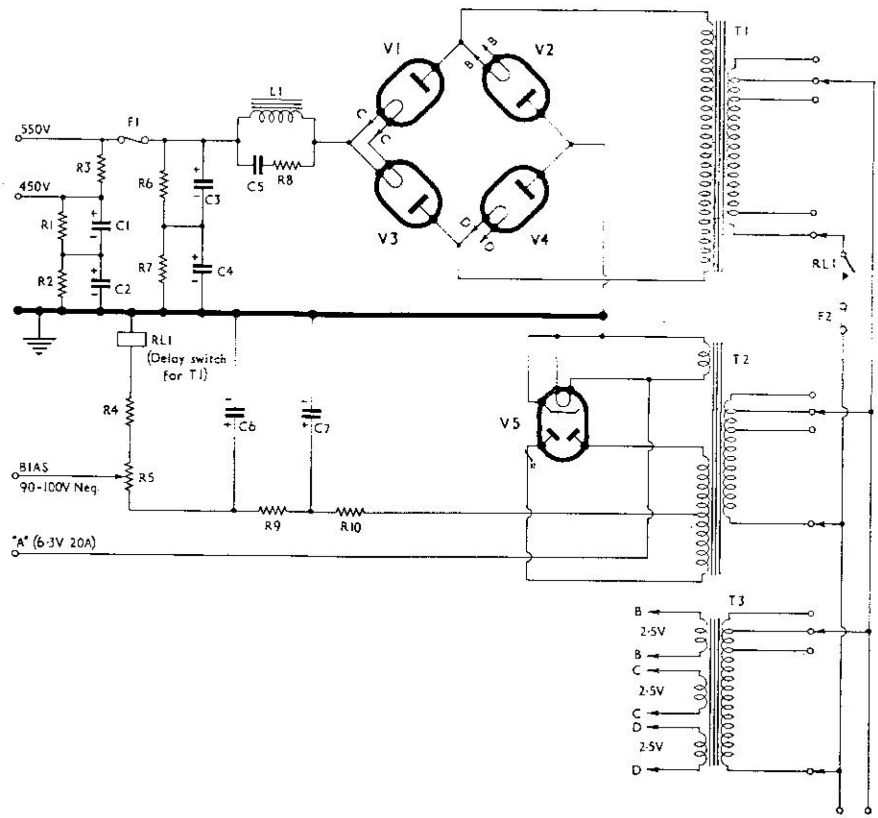


Fig. 15. Power supply circuit for the 400W multiple-pair amplifier. The winding of T3 is simplified if four identical secondaries are used. To prevent mains-borne interference with nearby receivers, generated by the xenon rectifiers, a pair of capacitors (0·05μF, 700V a.c.) should be connected in series 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	100kΩ	10%	0·5W
R2	100kΩ	10%	0·5W
R3	4·7kΩ	20%	2W
R4	22kΩ	20%	1W
R5	10kΩ w.w.		
R6	47kΩ	10%	1W
R7	47kΩ	10%	1W
R8	10kΩ	20%	1W
R9	22kΩ	20%	1W
R10	1·5kΩ	20%	0·25W

CAPACITORS

C1	32μF	350V	
C2	32μF	350V	
C3	300μF	350V	each 100+200 dual
C4	300μF	350V	each 100+200 dual
C5	0·01μF	500V	
C6	2μF	250V	
C7	2μF	250V	

MISCELLANEOUS

L1 2H 1200mA 25Ω
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 2×5A)
F1 2A
F2 5A

*10V taps on primary.

184

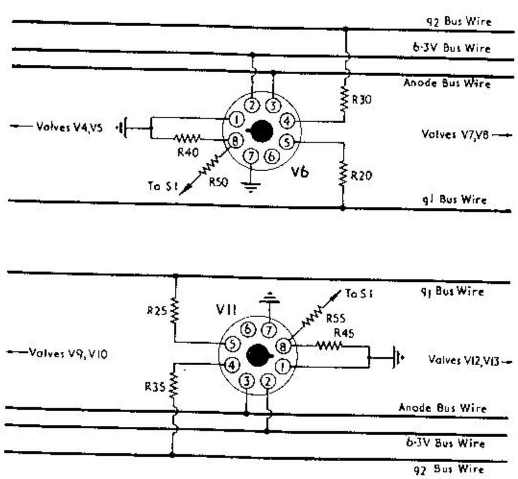


Fig. 16. Recommended layout for the output valves of the 400W amplifier. If the distance between pairs of valves is reduced to the minimum of 4 in centre to centre, they should be orientated as shown on page 3.

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.

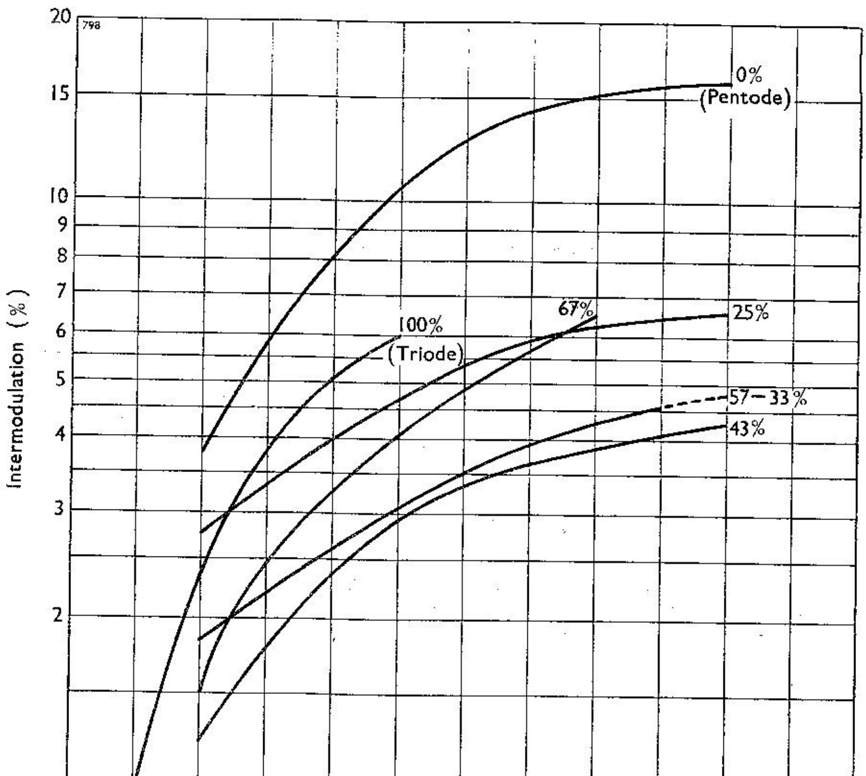


Fig. 17.