CHAPTER 4

AMPLIFIERS OF 15 TO 30 WATTS

Amplifiers giving from 15W to 50W output are adequately catered for by the three beam pentodes, KT55, KT66 and KT88. This chapter gives details of a 14-15W KT66 triode amplifier, two versions of a 30W ultra-linear amplifier (KT66 and KT88), and a 25W KT55 ultra-linear amplifier for d.c. or a.c. mains. Chapter 5 describes amplifiers of 50W to 100W using the KT55 and the KT88.

The KT66 has achieved a world-wide reputation in setting a standard of performance in its class. Introduced in 1937, it was used in very large quantities by the military services in World War II because of its efficiency and reliability and it has since become the basis of many amplifiers with output powers up to 50W. It is widely used in domestic and industrial amplifiers connected in push-pull triode or ultra-linear circuits for outputs of high quality from 15W to about 30W. A well-known example of a push-pull triode design is the " Williamson " amplifier introduced by the M-O. Valve Co. Ltd. in 1947.

The KT88 might be described as a larger version of the KT66 and this chapter includes details of a high quality KT88 30W amplifier suitable for domestic use. This valve was primarily designed for amplifiers of up to 100W output and Chapter 5 gives circuit information for amplifiers of that class and compares the characteristics of the KT88 and the KT66. Appendix A describes the use of the KT88 in multiple pairs for obtaining outputs of several hundred watts.

The KT55 has a 52V, 0·3A heater and was designed specifically to give a high-power output from the low h.t. voltage inherent in the d.c./a.c. amplifier. Details are given of a d.c./a.c. amplifier of 25W output at 1·5% distortion with notes on operation with low mains voltages.

4-1. KT66 Triode Amplifier.—The circuit of the original Williamson amplifier is shown in fig. 4-1*. An output of 14-15W is given at a distortion of 0·1%. Table 4-I gives the operating conditions of the output stage.

*A complete description of the " Williamson " amplifier and associated tone control circuits is published by Iliffe & Sons Ltd. for *Wireless World*.

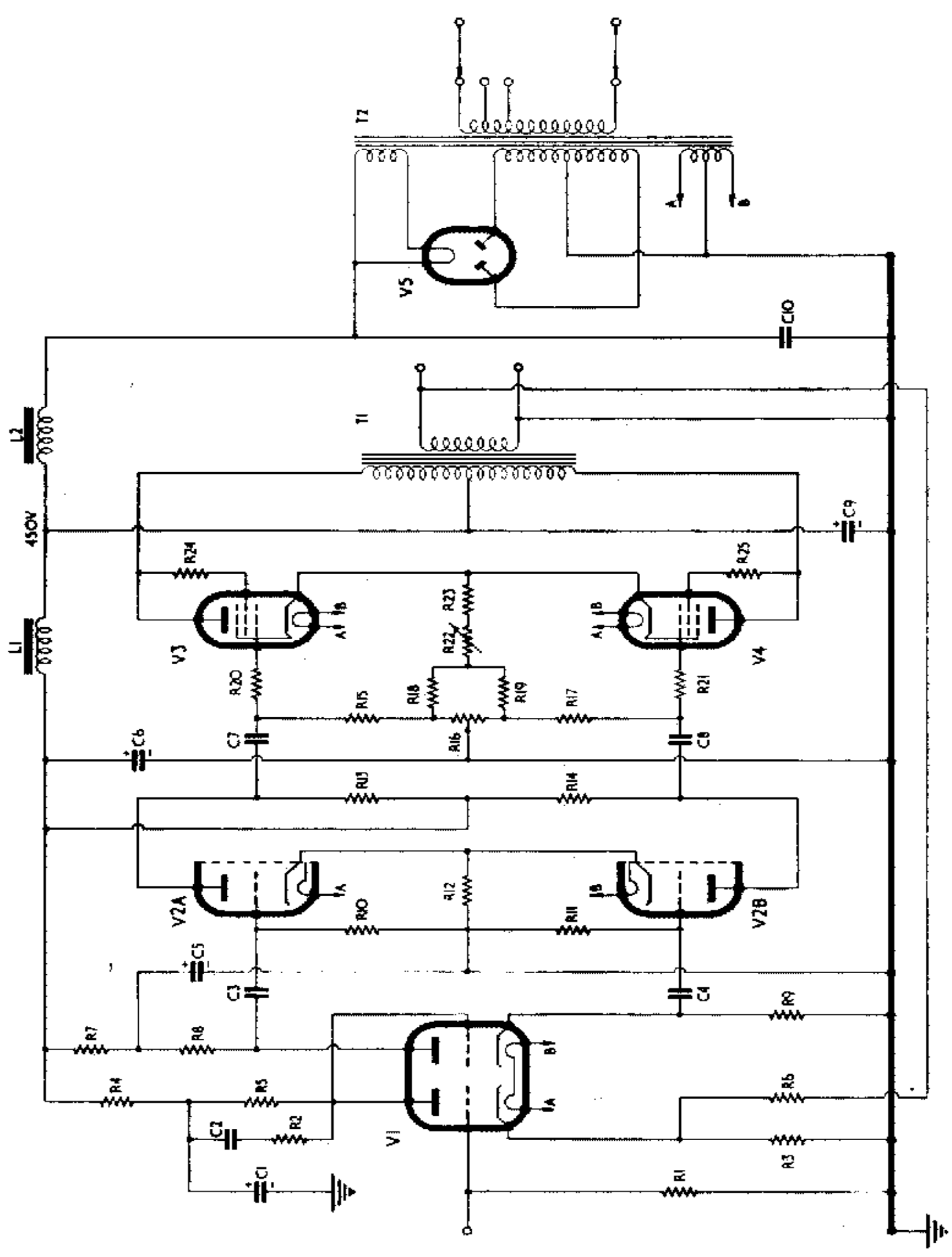

Fig. 4-1. Circuit of the "Williamson" amplifier. R22 is adjusted for a total cathode current of 125mA for the two output valves. The output stage is balanced by connecting a d.c. voltmeter across the whole of the output transformer primary and adjusting R16 for zero reading. C2 and R2 increase the margin of stability at high frequencies.

COMPONENT VALUES FOR FIG. 4-1

" WILLIAMSON " AMPLIFIER

G.E.C. VALVES

V1 B65/6SN7 or 2 × L63/6J5
V2 B65/6SN7 or 2 × L63/6J5
V3 KT66
V4 KT66
V5 U52/5U4 or U54

RESISTORS

(20%, 0·25W unless otherwise shown)

R1 1MΩ
R2 4·7kΩ
R3 470Ω 10%
R4 33kΩ 1W
R5 47kΩ 1W
R6 1200√ speech coil impedance
R7 22kΩ 1W
R8 22kΩ 1W } Matched to 5%
R9 22kΩ 1W } Matched to 5%
R10 470kΩ
R11 470kΩ
R12 390Ω 10%
R13 47kΩ 2W } Matched to 5%
R14 47kΩ 2W } Matched to 5%
R15 100kΩ 10%
R16 100Ω 2W w.w.
R17 100kΩ 10%
R18 100Ω 1W
R19 100Ω 1W
R20 1kΩ
R21 1kΩ
R22 100Ω 2W w.w.
R23 150Ω 5% 3W w.w.
R24 100Ω 0·5W
R25 100Ω 0·5W

CAPACITORS

C1 8μF 500V
C2 200pF
C3 0·05μF
C4 0·05μF
C5 8μF 500V
C6 8μF 500V
C7 0·25μF
C8 0·25μF
C9 8μF 500V
C10 8μF 600V

MISCELLANEOUS

L1 30H 20mA
L2 10H 150mA
T1 14W Output transformer
  10kΩ anode-anode
  Primary inductance : $\nless$ 100H
  Leakage inductance : $\ngtr$ 30mH
T2 Mains transformer
  Secondaries :
  425-0-425V 150mA
  6·3V 4A CT
  5V 3A

TABLE 4-I

OPERATING CONDITIONS OF THE KT66 OUTPUT STAGE OF FIG. 4-1

$V_{a\,(b)}$	450	V
$V_{a,\,g2}$ (approx)	410	V
$I_{a+g2\,(o)}$	2 × 62·5	mA
$I_{a+g2\,(max\ sig)}$	2 × 72·5	mA
$p_{a+g2\,(o)}$	2 × 25	W
$p_{a+g2\,(max\ sig)}$	2 × 21	W
R_k	See fig. 4-1	
V_g (approx)	−37	V
P_{out}	15	W
$R_{L(a\text{-}a)}$	10	kΩ
z_{out}	300	Ω
D	<0·1	%
$v_{in\,(pk)}$ (approx) (to first stage)	1·9	V

4-2. Two 30W Ultra-Linear Amplifiers.—The basic circuit of fig. 4-4 may be used with either KT66 or KT88 valves and the components list on page 43 gives suitable values for each type of valve.

With negative feedback, the KT66 amplifier will give 32W output with about 0·5% distortion at an anode potential of 400V and the KT88 will give 32W with 0·25% distortion at an anode potential of 335V.* The input signal to the first stage of the amplifier for full output in the KT66 version is 600mV whereas the KT88 version requires 500mV. With no negative feedback these figures become 120mV and 100mV respectively. It will be noted that the KT88 version has less distortion, higher sensitivity and requires a lower h.t. voltage than the KT66 for the same maximum output. If feedback is omitted the KT88 amplifier has only 1% distortion at 32W output as against the 2% of the KT66 version. As the KT88 valves are conservatively run in this circuit they will have a long life.

The output stage is preceded by a conventional double triode voltage amplifier which is fed by a triode phase-splitter comprising one half of a further double triode. The other half of this valve is the input stage voltage amplifier, which is directly coupled to the phase-splitter. As in other ultra-linear amplifiers in this book, instability is guarded against by the capacitors and resistors across part of each output transformer half-primary and by grid and screen " stopper " resistors in the output stage. The curves of figs. 4-2 and 4-3 illustrate, respectively, the performance of the KT66 and KT88 output stages without feedback.

Negative Feedback.—14db of negative feedback is used and this is adequate for all normal purposes. This value will reduce the output impedance, distortion and sensitivity of the basic amplifiers 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 either 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 30-32W is about 21·5 for a 15Ω load and about 11V for a load of 4Ω, the resistors R2 and R4 are chosen so that 500mV 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=15Ω, R2 should be 1kΩ and if Z_o=4Ω, R2 should be 470Ω.

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

*The KT88 output stage is, in fact, operated here almost in Class A, hence the reduced distortion compared with the KT66 version.

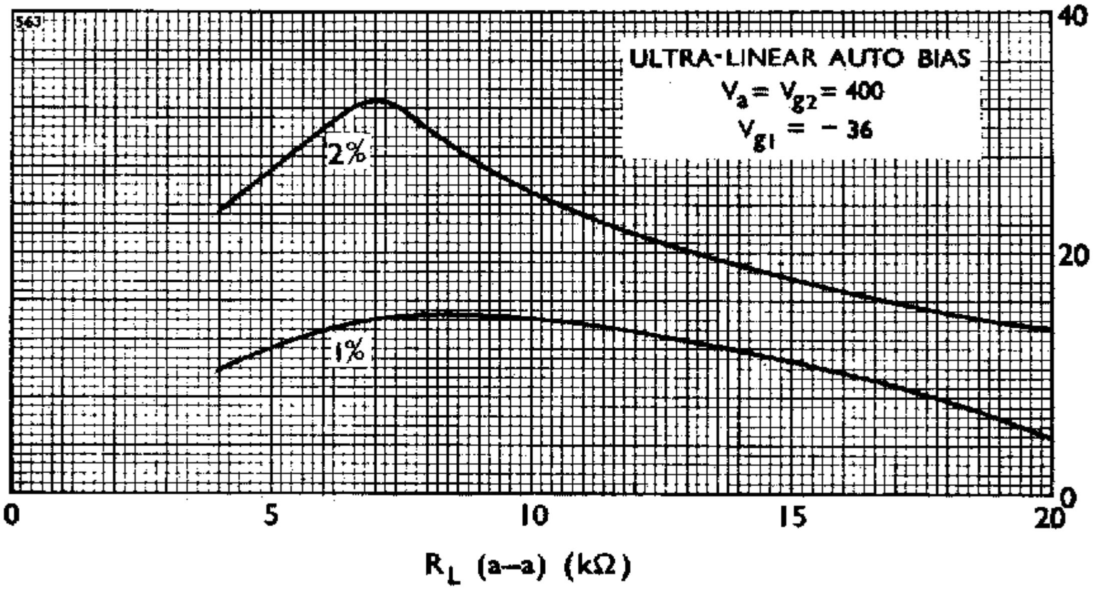

Fig. 4-2. Performance of the KT66 version of the amplifier in fig. 4-4.

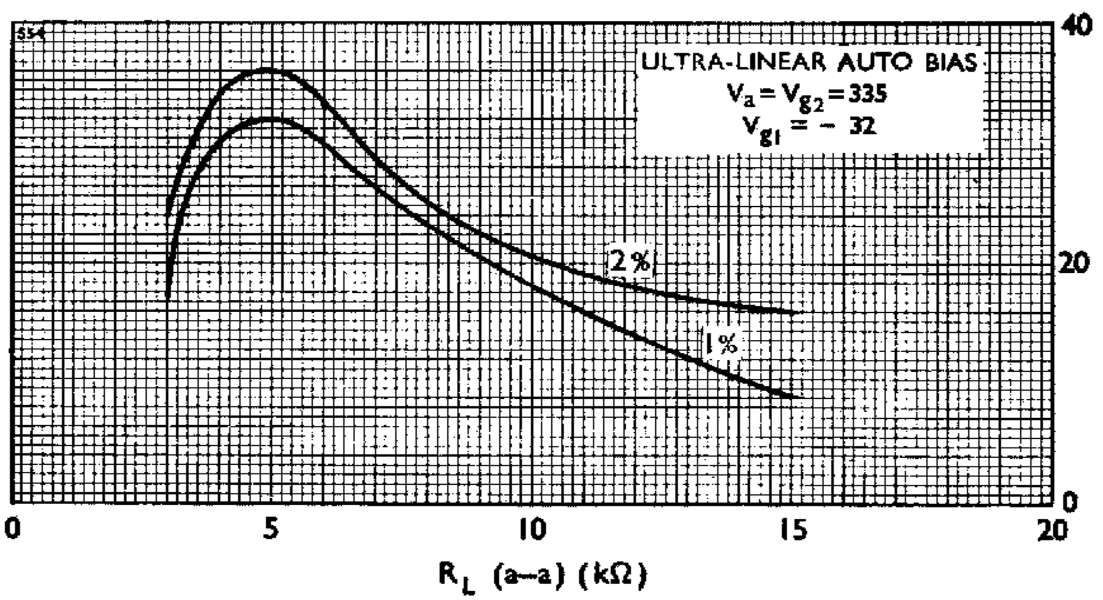

Fig. 4-3. Performance of the KT88 version of the amplifier in fig. 4-4.

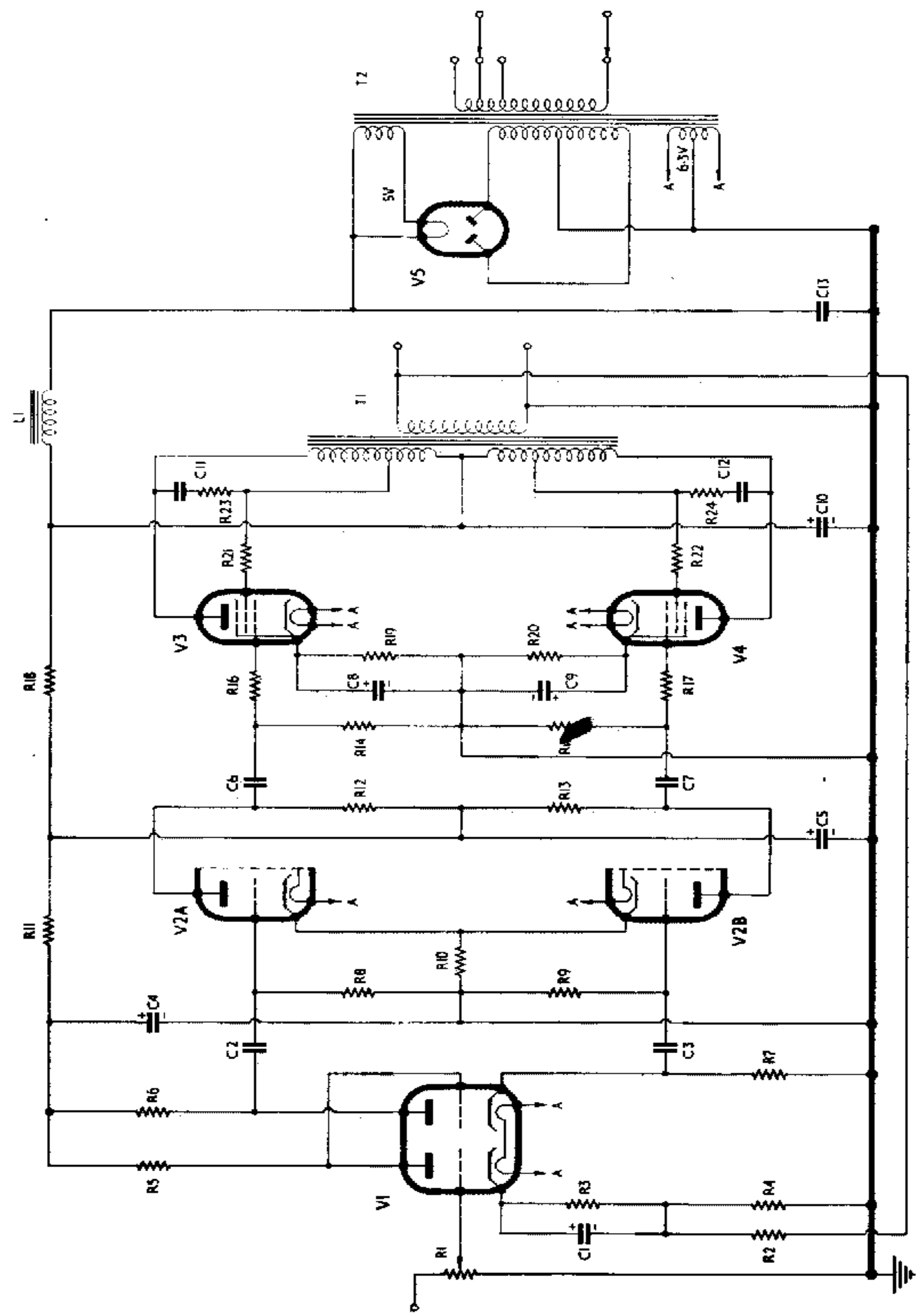

Fig. 4-4. Circuit of a 30W ultra-linear amplifier using KT66 or KT88 valves in the output stage. The component values and circuit conditions differ: see the components list opposite.

COMPONENT VALUES FOR FIG. 4-4

KT88 30W ULTRA-LINEAR AMPLIFIER

Values required for KT66 valves are indicated where necessary

G.E.C. VALVES

V1 B65/6SN7
V2 B65/6SN7
V3 KT88 (KT66)
V4 KT88 (KT66)
V5 U54

RESISTORS

(20%, 0·25W unless otherwise shown)

R1 1MΩ Log.
*R2 $225\sqrt{\text{speech coil impedance}}$
R3 1kΩ
R4 47Ω
R5 100kΩ
R6 15kΩ 0·5W } Matched to 5%
R7 15kΩ 0·5W } Matched to 5%
R8 470kΩ 10%
R9 470kΩ 10%
R10 1kΩ
R11 22kΩ 1W
R12 33kΩ 10% 1W
R13 33kΩ 10% 1W
R14 220kΩ
R15 220kΩ
R16 10kΩ
R17 10kΩ
R18 4·7kΩ 1W
R19 400Ω (KT66 : 560Ω) 5% 5W
R20 400Ω (KT66 : 560Ω) 5% 5W
R21 270Ω 0·5W
R22 270Ω 0·5W
R23 470—1500Ω 0·5W
R24 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 (KT66 : 600V†)

MISCELLANEOUS

L1 10H 200mA
T1 35W Ultra-linear transformer
 6kΩ anode-anode (KT66 : 7kΩ)
 ‡Primary Inductance : ≮ 50H
 Leakage inductances :
 ‡Prim.—sec. : ≯ 10mH
 ‡½ prim.—UL tap : ≯ 10mH
T2 Mains transformer
 Secondaries :
 375-0-375V 200mA
 (KT66 : 450-0-450V 150mA)
 6·3V 5A CT (KT66 : 4A)
 5V 3A

†Or two 16μF 350V in series.

‡With these values, R23, R24 and C11, C12 may be omitted.

TABLE 4-II

OPERATING CONDITIONS OF THE OUTPUT STAGE OF FIG. 4-4

	KT66 Valves	*KT88 Valves*	
$V_{a\ (b)}$	450	375	V
$V_{a,\ g2}$	400	335	V
$I_{a+g2\ (o)}$	2×62·5	2×80	mA
$I_{a+g2\ (max\ sig)}$	2×72·5	2×85	mA
$p_{a+g2\ (o)}$	2×25	2×27	W
$p_{a+g2\ (max\ sig)}$	2×15	2×12	W
R_k	2×560	2×400	Ω
V_g (approx)	−36	−32	V
P_{out}	32	30	W
$R_{L\ (a-a)}$	7	5	kΩ
Z_{out}	1·8	1	kΩ
D	0·5	0·25	%
$V_{in\ (rms)\ (approx)}$ (to first stage)	600	500	mV

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

Z_{out}	9	4·5	kΩ

4-3. A 25W d.c./a.c. Amplifier.—The main problem in the design of an amplifier for d.c./a.c. operation lies in providing adequate output power with a limited h.t. voltage, and the KT55 beam pentode has been specifically designed for this purpose.

Two KT55 valves in push-pull will provide 25W output with a mains supply of 225V.

Circuit Description.—The recommended circuit is shown in fig. 4-5 and it is designed round one Z729, one L63 and two KT55 valves, the h.t. supply being provided by a metal rectifier when the amplifier is operated on a.c. mains. The use of a thermionic rectifier is impracticable due to the high current required, which is about 275mA.

The input signal is applied to a Z729 voltage amplifier, followed by a conventional triode phase splitter which feeds the KT55 ultra-linear output stage.

The sensitivity of the amplifier without negative feedback is high, full output being obtained for an input of 55mV. The sensitivity is reduced to 300mV by the application of negative feedback as indicated in fig. 4-5. Before feedback is applied, the hum and noise level with the volume control at maximum is 55db below full output.

COMPONENT VALUES FOR FIG. 4-5

KT55 25W DC/AC AMPLIFIER

G.E.C. VALVES

V1 Z729
V2 L63/6J5
V3 KT55
V4 KT55
V5 Barretter 303

RESISTORS

(20%, 0·25W *unless otherwise shown*)
R1 1MΩ Log.
*R2 300 √speech coil impedance
R3 2·2kΩ
R4 22Ω
R5 220kΩ 10% 0·5W
R6 1MΩ 10%
R7 10kΩ
R8 1MΩ
R9 22kΩ 0·5W } matched to 5%
R10 22kΩ 0·5W } matched to 5%
R11 1·5kΩ
R12 220kΩ
R13 220kΩ
R14 10kΩ
R15 10kΩ
R16 185Ω 5% 5W w.w.
R17 185Ω 5% 5W w.w.
R18 10kΩ 10% 1W
R19 47Ω
R20 47Ω
R21 15+15Ω 10% 10W w.w.
R22 Thermistor CZ1 or TH1
R23 63Ω 5% 5W
R24 470-1500Ω 0·5W
R25 470-1500Ω 0·5W

**For 14 db feedback*

CAPACITORS

C1 0·01μF
C2 50μF 12V
C3 0·1μF
C4 50 pF
C5 0·01μF
C6 0·1μF
C7 0·1μF
C8 16μF 350V
†C9 50μF 25V
†C10 50μF 25V
C11 200μF 275V
C12 1000pF
C13 1000pF
C14 100μF 275V

MISCELLANEOUS

L1 1·5-2H 300mA 75Ω
T1 25W Ultra-linear transformer
2kΩ anode-anode
Primary Inductance : $\nless$ 10H
Leakage inductances :
Prim.—sec. : $\ngtr$ 20mH
½ prim.—UL tap : $\ngtr$ 10mH
MR1 250V 275mA (G.E.C. 13H16XG)

†*See page 47.*

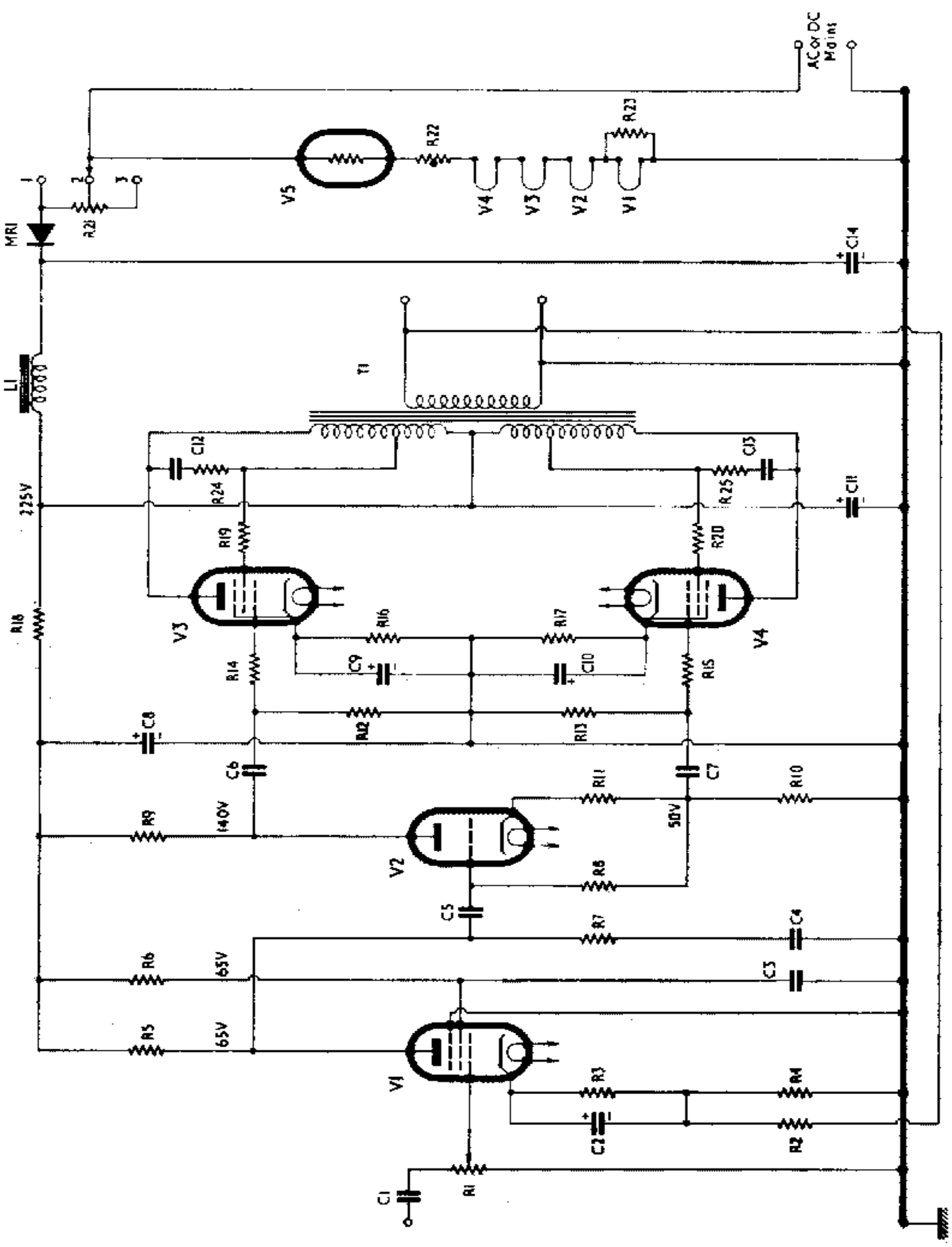

Fig. 4-5. Circuit of the 25W d.c./a.c. amplifier. R7 and C4 increase the margin of stability at high frequencies (see Appendix B, page 119).

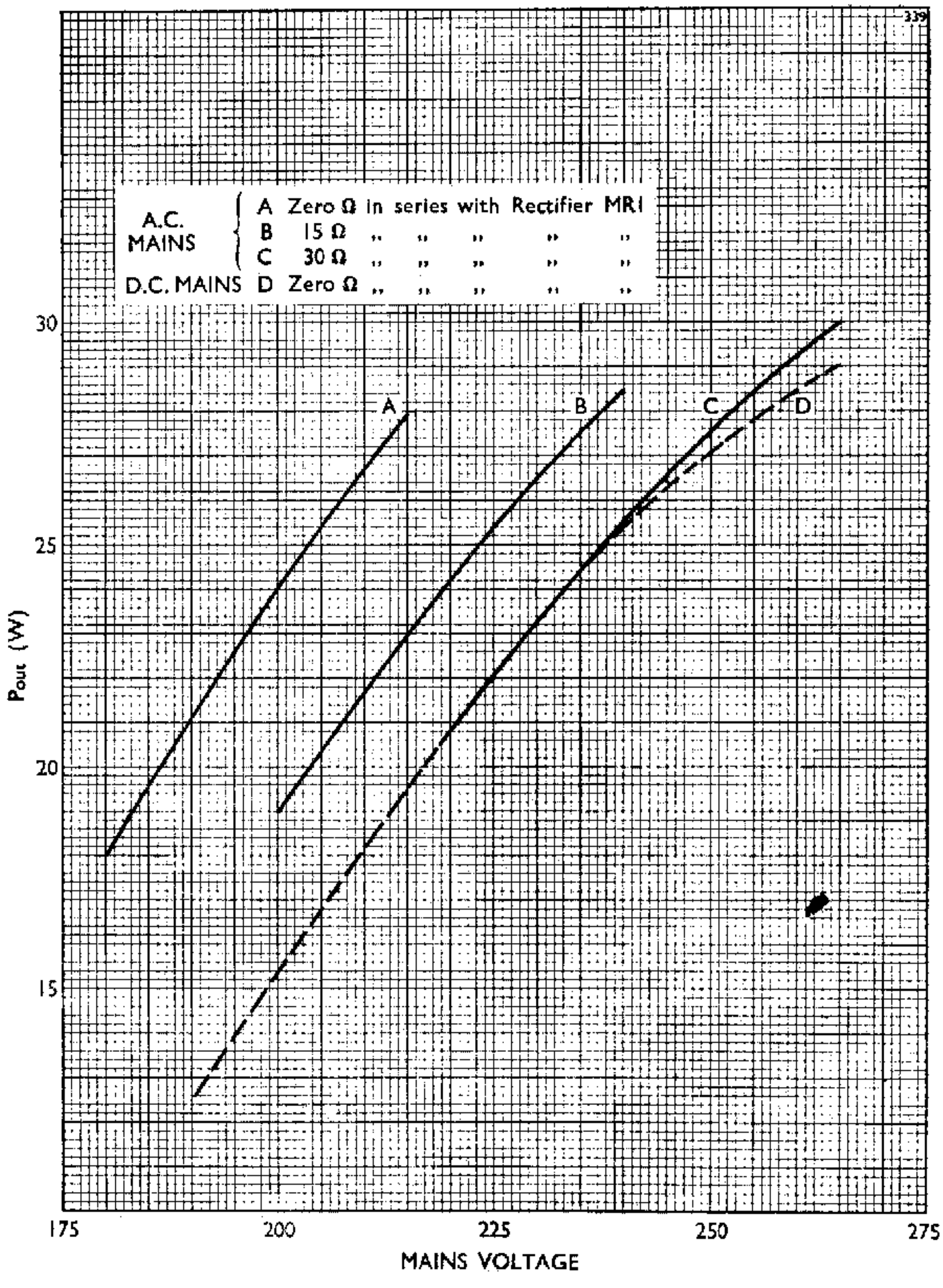

Fig. 4-6. The output power obtained from the amplifier of fig. 4-5 at mains voltages from 180 to 265. The appropriate value of rectifier series resistance is also given.

Separate bias resistors are essential in the output stage in view of the high mutual conductance. The 50μF cathode bypass capacitors give a loss of 6db at 50 c/s. They may be increased to 250μF when this loss is objectionable.

The output transformer is tapped at 40% of the turns on each half-primary from the centre tap. The small capacitors, C12, C13 and resistors R24, R25 are required with some output transformers to prevent the possibility of spurious oscillation.

Negative feedback is applied over three stages, about 14db giving a satisfactory reduction in distortion and output impedance without introducing the danger of instability. It is probable that more could be applied with high-quality output transformers but with this value of feedback an output of 25W at 0·25% distortion is obtained. R7 and C4, in the grid circuit of the phase splitter, assist in ensuring stability by reducing the loop gain at ultrasonic frequencies—they result in a loss of 6db at 20kc/s. (See Appendix B, page 119).

A low impedance power supply is obtained by the use of components primarily designed for television receivers. L1, which should have an inductance of about 2H and a d.c. resistance of about 75Ω, is used with two large-value electrolytic capacitors C11 and C14. On d.c. the mains adjusting resistor is not in circuit and the metal rectifier protects the capacitors against reversed polarity. The heater current of 0·3A is controlled by a barretter and thermistor.

The circuit of fig. 4-5 may be changed to pentode operation by simply connecting R19 and R20 to the output transformer centre tap. This will, of course, result in somewhat higher distortion. Compared with pentode operation the ultra-linear circuit reduces the output impedance from 9kΩ to 2·35kΩ, giving unity ratio with the anode-to-anode load. The distortion is 1·5% compared with the 2% of pentode operation. The advantages of ultra-linear operation are gained at the expense of a slight fall in the overall sensitivity of the amplifier, that is, it will require a slightly larger input signal to give the same output.

Performance.—The performance of the output stage in fig. 4-5 may be judged from the curves of fig. 4-6 and the data in Table 4-III. The curves, which cover four different groups of mains voltages, were prepared with two considerations in mind : (*a*) the maximum dissipation of the KT55, and (*b*) the maximum rating of the metal rectifier. For d.c. mains voltages between 190 and 260 and for a.c. voltages between 190 and 215, no limiting resistance is required in series with the rectifier to meet either of the two conditions (*a*) or (*b*). With a.c. mains exceeding 215V, a series resistor (R21) is necessary and this is tapped to cover operation up to 260V.

The curves of fig. 4-6 overlap at the low voltage end in order to convey a complete picture of the performance ; it is suggested that the three mains taps be marked as follows :

1. 190-215V a.c. and 190-260V d.c.
2. 215-235V a.c.
3. 235-260V a.c.

The heater current is maintained within the limits 285mA to 315mA by the barretter Type 303. A satisfactory performance will be obtained over a rather wider range than the usual 200-250V without adjustment. The thermistor prevents surges during switching-on periods when the valves are cold. No thermistor shunt is required.

TABLE 4-III

OPERATING CONDITIONS OF THE KT55 OUTPUT STAGE OF FIG. 4-5

$V_{a\,(b)}$	225	V
$V_{a,\,g2}$	200	V
$I_{a+g2\,(o)}$	2×120	mA
$I_{a+g2\,(max\,sig)}$	2×127	mA
$p_{a+g2\,(o)}$	2×23	W
$p_{a+g2\,(max\,sig)}$	$2\times11{\cdot}5$	W
R_k	2×185	Ω
V_g	−22	V
P_{out}	25	W
$R_{L\,(a-a)}$	2	kΩ
z_{out}	325	Ω
D	0·25%	%
$V_{in\,(rms)}$ (to first stage)	1·5V	mV

If negative feedback is omitted, the last three values become 2·35kΩ, 1·5% and 300mV.

Operation from Sub-Normal Mains Voltages.

Low d.c. Mains.—The KT55 may be used successfully on low-voltage d.c. mains supplies, as in some marine installations. The curve in fig. 4-7 shows the expected output on mains voltages of 100-200.

The recommended circuit in this case is similar to fig. 4-5 but, to obtain maximum h.t., the rectifier should be omitted and the output transformer connected to the mains side of the smoothing inductor. C14 also should be omitted and C8 and C11 made 4μF paper capacitors. The output stage bias resistors R16 and R17 should be reduced to 150Ω and the optimum load to 1·5kΩ.

The heater connections depend upon the value of the mains voltage. From 150 to 200V the existing series arrangement may be used with a 305 barretter, which is replaced by a suitable resistor for 125-150V. Below 125V two chains will be required, the KT55 valves being connected in series in one chain with a small resistor, if necessary, and a 303, 304 or 305 barretter in series with the remaining valves in the second chain. A suitable tapped resistor may be used, if preferred, instead of the barretter.

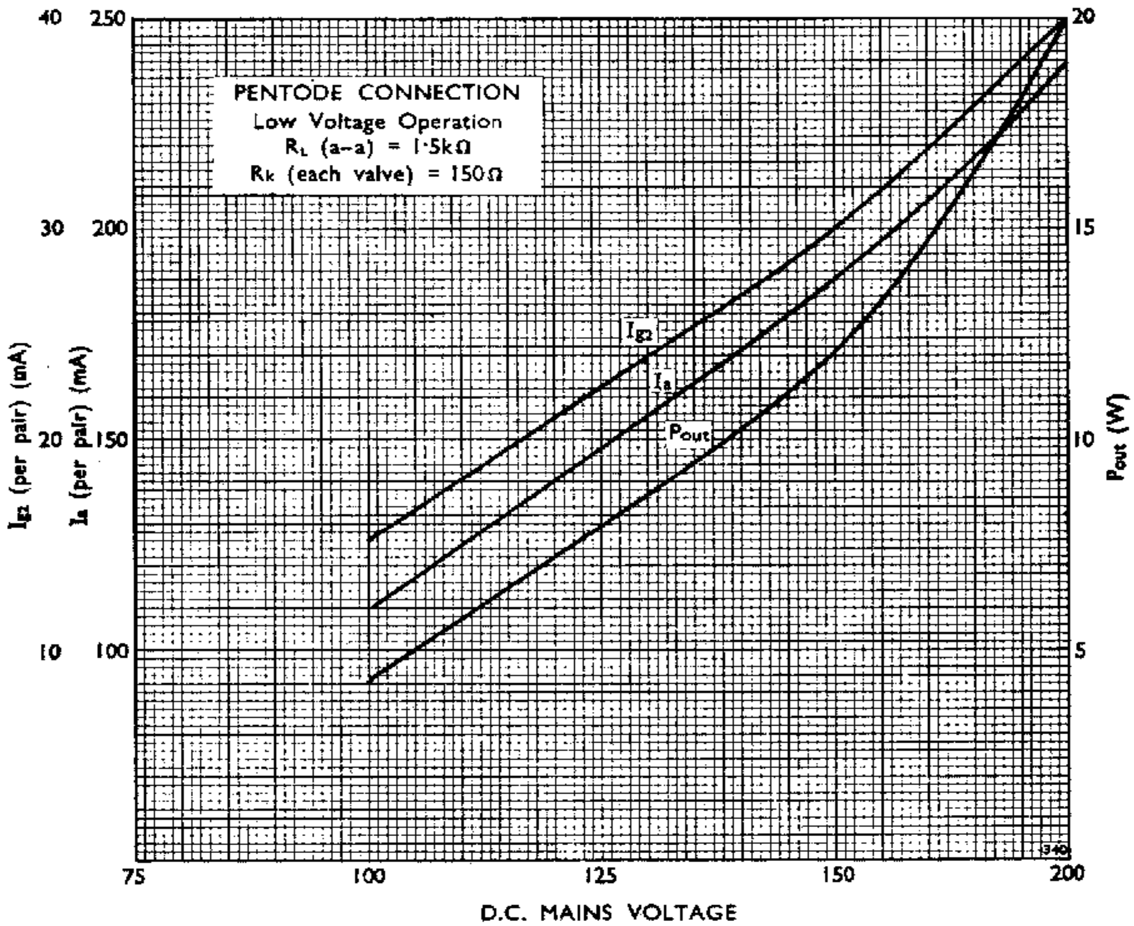

Fig. 4-7. Characteristics of the amplifier of fig. 4-5 on low d.c. mains. The circuit is modified as described opposite. Although drawn for pentode operation, these curves apply also to the ultra-linear circuit but the screen current will be about half that shown.

Low a.c. Mains.—For low a.c. mains voltages an auto-transformer may be used for the h.t. supply, with the heaters connected as for d.c. mains. An alternative method of obtaining the h.t. supply from low a.c. mains is shown in fig. 4-8. A voltage doubler circuit is used to give an h.t. of 220V from 110V a.c.

The smoothing inductor used for the circuit of fig. 4-8 has a lower resistance (20Ω) and the specified rectifier is specially designed for voltage doubling.

The h.t. voltage and power output at various mains voltages is as follows :

AC Mains Voltage	*HT Voltage*	*Output Power*
110	200	19W
110	220	23W
120	235	27W

Heater Circuit for Four Valves.—The heaters of four KT55 valves may be connected (via a shunted thermistor) directly to a mains supply between 200 and 215V. For supplies between 215 and 250V, additional series resistance is necessary. See fig. 4-9 for details of the recommended arrangement.

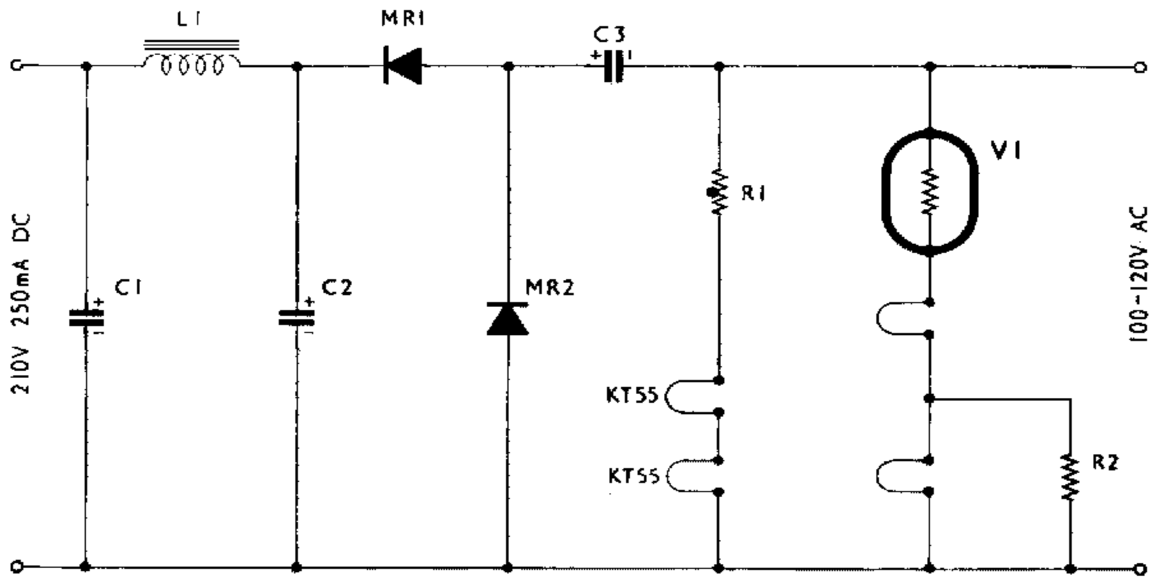

Fig. 4-8. Voltage doubler circuit for the KT55 amplifier. Component values : V1 : G.E.C. Barretter 303, 304 or 305 (depending upon voltage across heater chain) ; R1 : Thermistor CZ1 or TH1 ; R2 : 60Ω 5W ; C1 and C3 : 200μF 275V ; C2 : 100μF 275V ; L1 : 1H 20Ω ; MR1 and MR2 : 250V 300mA (G.E.C. 13D8XG).

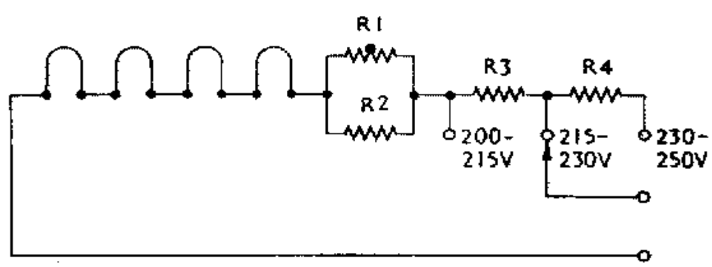

Fig. 4-9. Heater circuit for four KT55 valves. Component values : R1 : Thermistor CZ1 or TH1 ; R2 : 750Ω 10% 2W ; R3 and R4 : 50Ω 5% 10W.