APPLICATION REPORT

Mullard

25 WATT PENTODE

EL31

Mullard

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MULLARD ELECTRONIC PRODUCTS LTD.
CENTURY HOUSE, SHAFTESBURY AVENUE, LONDON, W.C.2
MAY, 1948

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1. INTRODUCTION

The EL310 is a 25-watt pentode particularly suited for use in the output stages of power amplifiers. It is primarily intended for use in the push-pull stages of equipments having an effective output of 50 - 100 watts, but for completeness data is provided covering the lower power operating conditions which, however, are normally satisfied by two valves type EL37 in push-pull.

The EL310 has an octal base with an anode top cap, to permit a maximum anode voltage of 800 V to be used with safety. It is on account of the higher operating voltage that a higher output is obtainable than is possible with the EL37.

1.1 Push-pull Operation

In paragraphs 4, 5 and 6 data is presented covering operation both with H.T. supplies having good regulation and with H.T. supplies having poor regulation. Although a supply having good regulation is much to be preferred because higher outputs are then obtainable, it is rarely practicable to fulfil this condition, and in most cases the power supply will have appreciable internal resistance. This means that the H.T. voltage at full drive will be less than at no drive, due to the increase in the cathode current of the output valves.

In order to present data in a useful yet concise form, the full-drive cathode current I_k (max.sig.), the no-signal cathode current $I_{k(o)}$ and the output power Pout are plotted as functions of the total H.T. voltage V_b. This has been done for various operating conditions.

If the regulation curve (I - V characteristic) of the H.T. supply is superimposed upon these figures, the no-signal conditions can be found at the point where this curve cuts the $I_{k(o)}$ curve. The full drive conditions I_k (max. sig.) and V_b are found at the point where the H.T. regulation curve cuts the I_k (max. sig.) curve. The output can be found by drawing a vertical line from this point till it cuts the P_{out} curve.

When maximum power output is required, the H.T. supply should be so designed that its regulation curve cuts the $I_{k(o)}$ curve at the maximum point (extreme right) at which P_a = 25 watts per valve. This, of course, is not always necessary and the process can be reversed if a lower output is required. In this case the vertical line is drawn first, through the required point on the Pout curve, till it cuts the I_k (max. sig.) curve. Thus the H.T. voltage and current necessary at full drive are found. The no-signal H.T. voltage and current can be found by drawing a line corresponding to the expected internal resistance of the H.T. source through the full drive point on the I_k (max. sig.) curve till it cuts the $I_{k(o)}$ curve.

1.2 H.T. Supplies having Good Regulation

The terms 'good regulation' and 'poor regulation' as applied to H.T. supplies, are used relatively. A supply having good regulation is deemed to be one which has a good regulation curve and low internal resistance (of the order of 100 ohms), such as would be obtained by the use of choke input and low resistance transformer windings. A supply having poor regulation, on the other hand, covers the more common case of capacitance input filters and small mains transformers.

2. STATIC DATA

Heater

V_h	6.3	V
I_h	1.4	A

Capacitances

c_{out}	6.5	μμF
c_{in}	17.5	μμF
c_{a-g}	1.2	μμF

Characteristics

V_a	275	600	V
V_{g2}	275	400	V
V_{g1}	-9	-22	V
I_a	91	42	mA
I_{g2}	11	5	mA
gm	14.0	7.0	mA/V
ra	20,000	43,000	Ω
$\mu g1\text{-}g2$	16.5		

Limiting Values

$V_{a(b)}$ max.	1200	V
V_a max.	800	V
$V_{g2(b)}$ max.	800	V
V_{g2} max.	400	V
V_{g1} (I_{g1} =0.3 μA) max.	-1.3	V
V_{h-k} max.	100	V
R_{h-k} max.	20,000	Ω
R_{g1-k} max. (self-bias)	0.5	MΩ
R_{g1-k} max. (fixed bias)	0.1	MΩ
p_a max.	25	W
p_{g2} max.	8	W
I_k max.	200	mA

Characteristic curves

I_a/V_a curves taken with V_{g2} =275V and 400V are shown in figures 1 and 2 respectively.

3. SINGLE VALVE OPERATION

For conventional operation the grid bias is obtained by means of a resistor in the cathode circuit, this resistor being capacitively by-passed for audio frequency currents.

The following table gives typical operating conditions.

V_a	225	250	275	300	V
V_{g2}	225	250	275	300	V
I_a	73	81	91	83	mA
I_{g2} (max. sig.)	17	20.9	24.8	23.9	mA
p_a	16.5	20.2	25	25	W
R_k	93	93	93	126	Ω
R_a	3000	3000	3000	3500	Ω
V_{in} (for 50mW P_{out})	-	-	0.3	-	Vrms
P_{out} (start of I_{g1})	7.0	9.3	12.0	12.5	W
D_{tot} (start of I_{g1})	11	12	13.1	13.5	%
V_{in} (start of I_{g1})	5.3	6.1	7.1	7.5	Vrms

The distortion curve for V_a = V_{g2} = 275V is shown in Fig. 3.

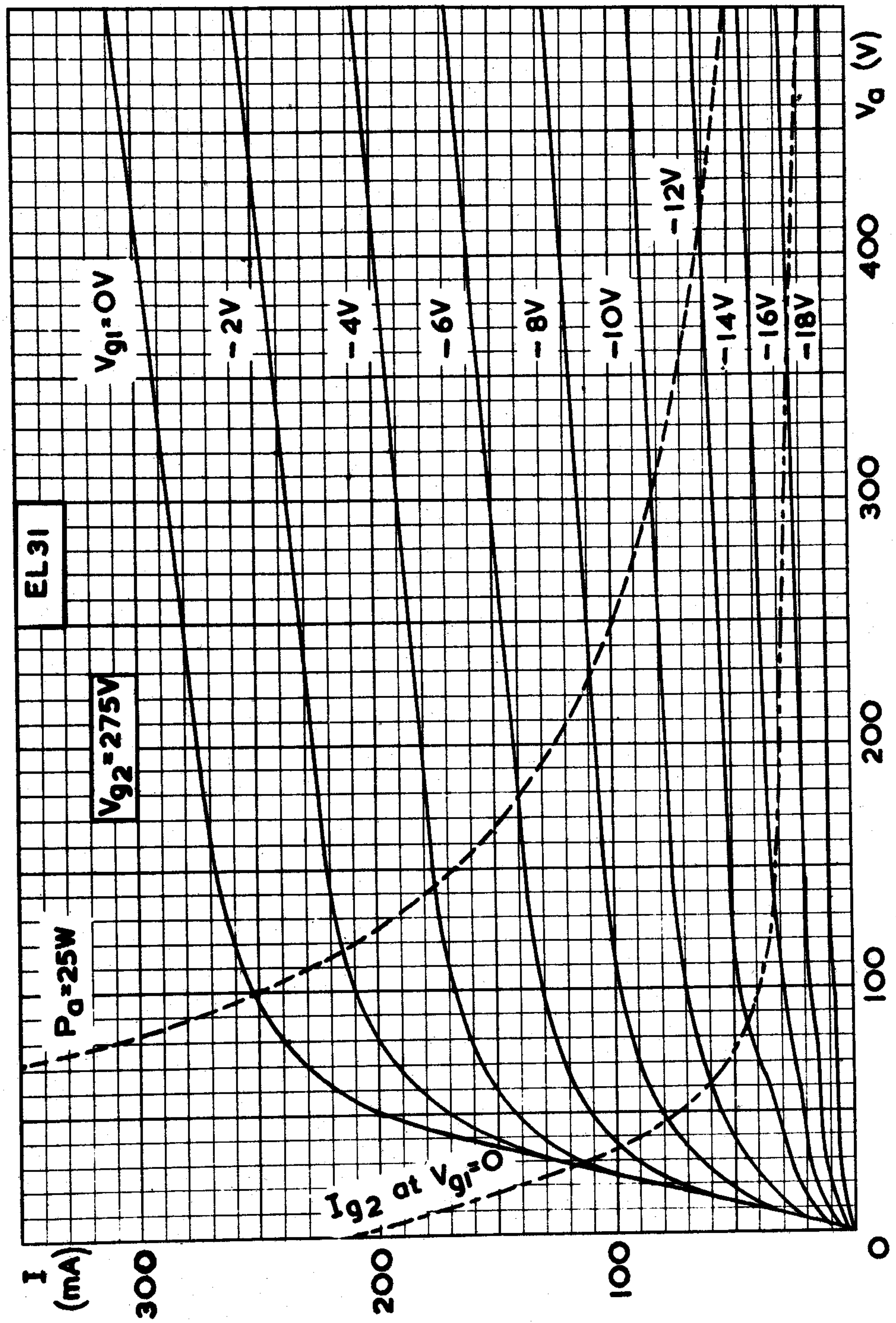

Fig. 1. I_a/V_a curve for V_{g2} = 275 V.

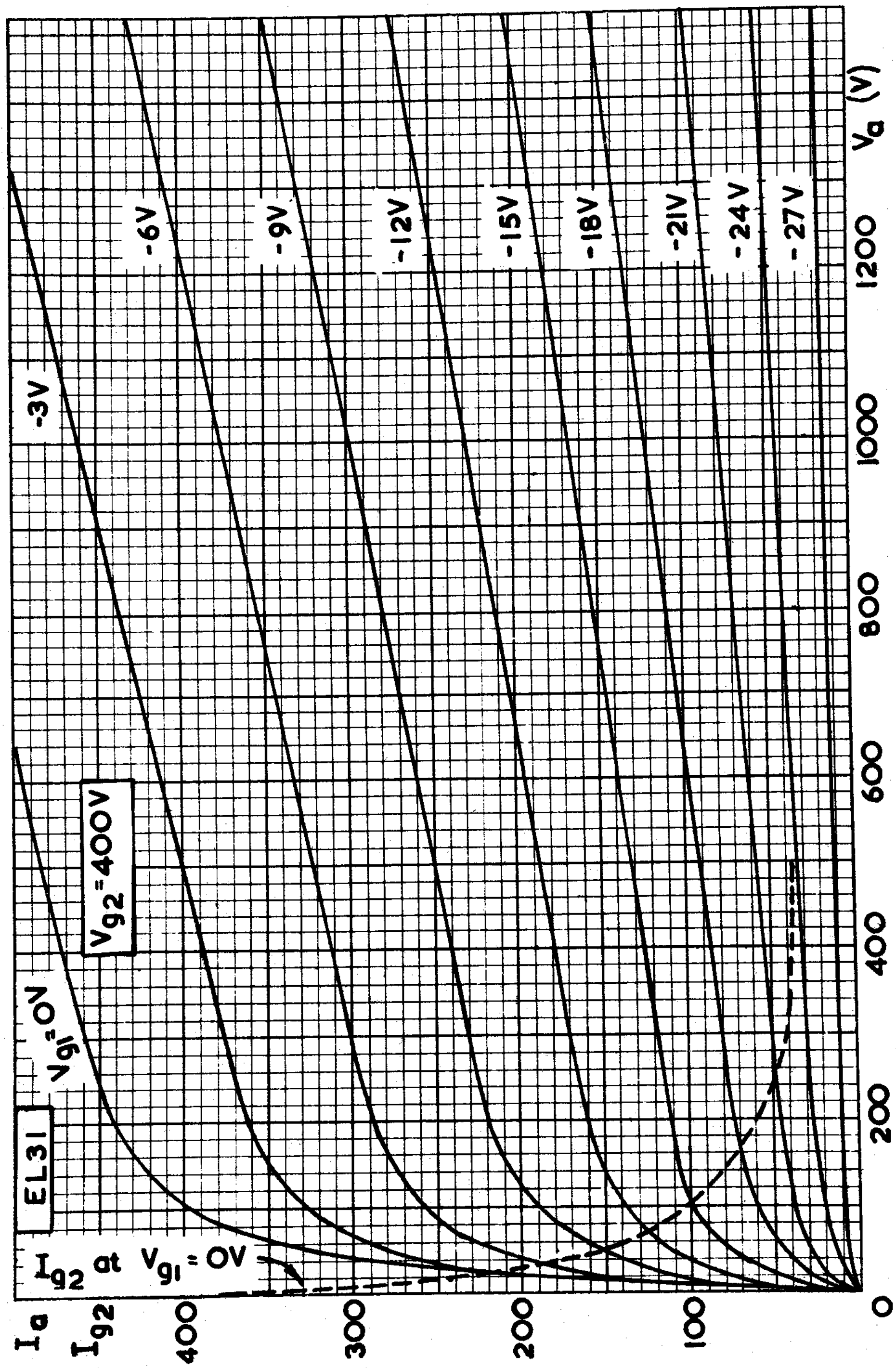

Fig. 2. I_a/V_a curve for V_{g2} = 400 V.

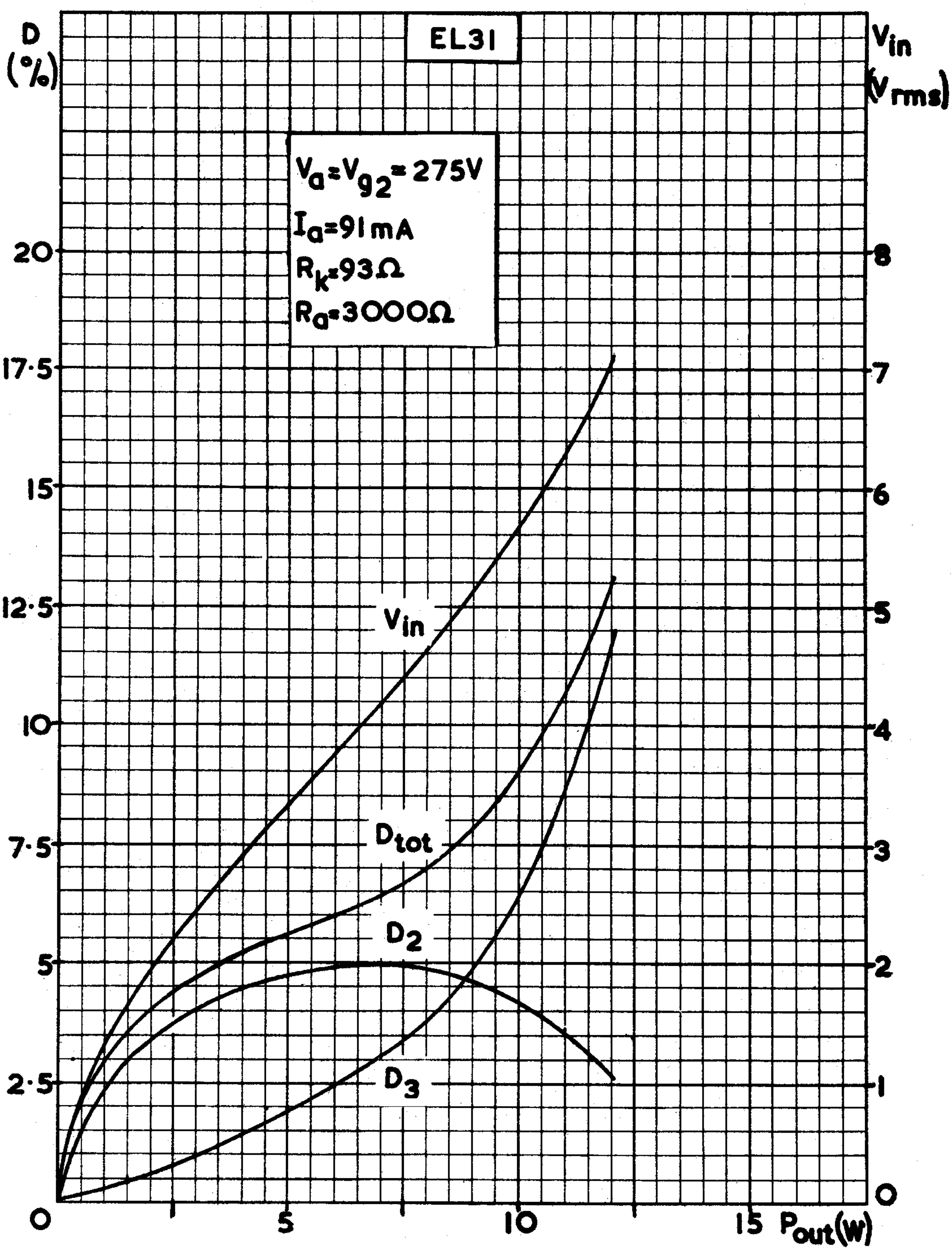

Fig. 3. Distortion curve for single valve at $V_a = V_{g2} = 275$ V.

3.1 Single Valve operation with Simple Feedback

Appreciably lower distortion will be obtained when the cathode by-pass capacitor is omitted but an increased drive voltage will be required.

V_a	225	250	275	300	V
V_{g2}	225	250	275	300	V
I_a	73	81	91	83	mA
P_a	16.4	20.2	25	25	W
R_k	93	93	93	126	Ω
I_{g2} (max. sig.)	15.2	18.3	22.1	21.7	mA
R_a	2800	2800	2800	3250	Ω
P_{out} (start of I_{g1})	6.7	8.9	11.7	12.5	W
D_{tot} (start of I_{g1})	7.8	8.8	10.0	11.0	%
V_{in} (start of I_{g1})	11.3	13.2	15.2	18.9	Vrms.

It will be noted that, when using negative feedback by this method, the optimum load resistance is roughly 7% lower than with no feedback.

Distortion curves for this condition taken at $V_a = V_{g2} = 275V$ are given in Fig.4.

4. PUSH PULL OPERATION WITH EQUAL ANODE AND SCREEN VOLTAGES AND SELF BIAS

The following tables show the operating conditions for different supply voltages when the power output is limited by the start of grid current.

4.1 p_a = 25 watts at $V_a = V_{g2} = 350V$ ($V_b = 367V$)

$R_k = 100\ \Omega$
$R_{a-a} = 5000\ \Omega$

V_b V	$I_{a(o)}$ mA	$I_{g2(o)}$ mA	I_a (max. sig) mA	I_{g2} (max. sig) mA	V_{in} (gl-gl) Vrms	P_{out} W	D_{tot} %
367	2x71	2x8.8	2x83	2x23.5	29.4	38	4.2
350	2x67	2x8.5	2x78	2x21.5	27.0	34	4.0
325	2x62	2x8.0	2x73	2x19	24.8	28.5	3.7
300	2x57	2x7.2	2x66	2x16	22.0	22.8	3.3
275	2x52	2x6.6	2x60	2x14.5	20.0	18.2	3.2
250	2x47	2x5.9	2x55	2x11.9	17.6	15.2	2.4

The distortion curve shown in Fig.5 was taken under this condition with $V_a = V_{g2} = 350V$ ($V_b = 367V$).

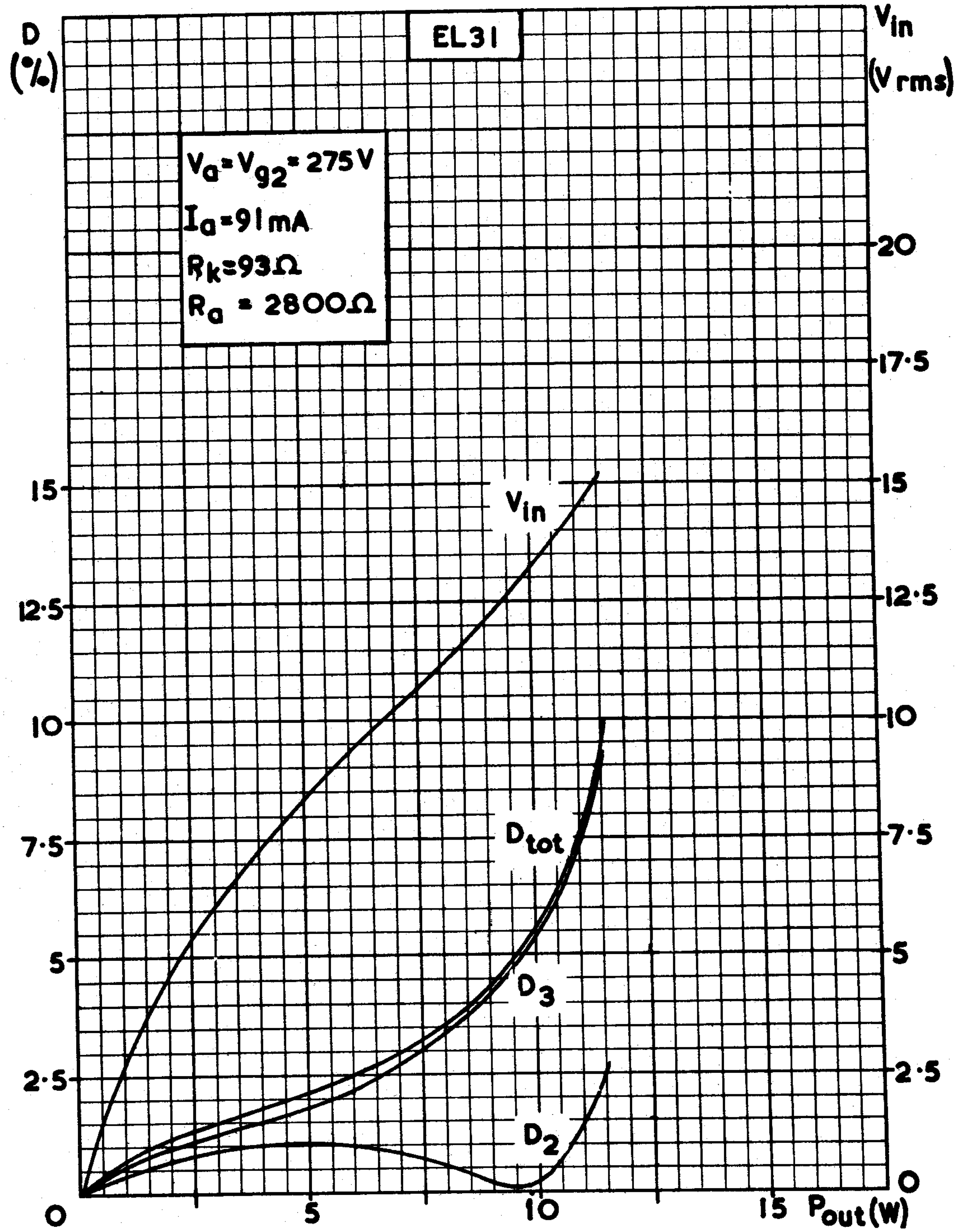

Fig. 4. Distortion curve for single valve at $V_a = V_{g2} = 275$ V. with simple feedback.

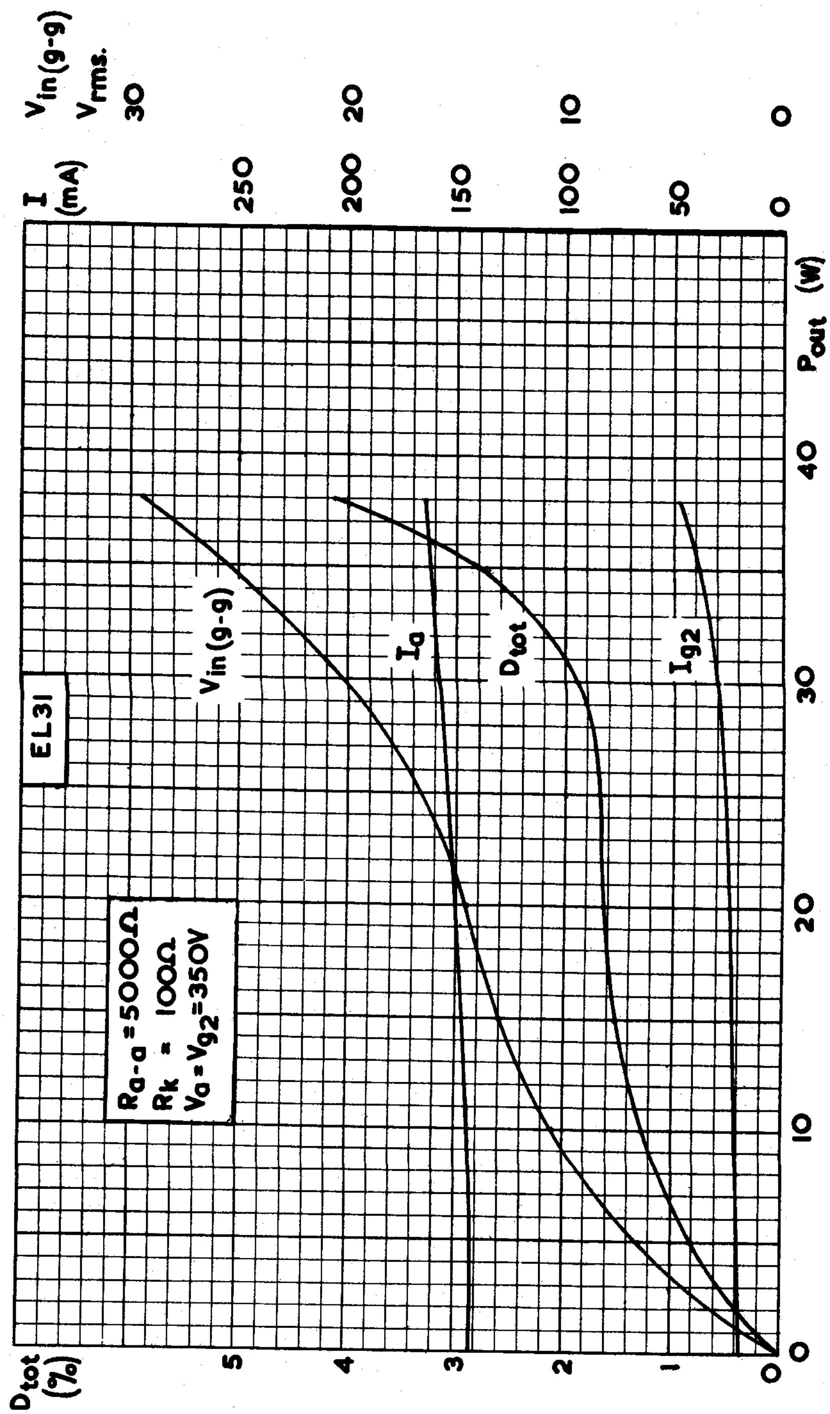

Fig. 5. Push-pull operating conditions for $V_a = V_{g2} = 350$ V. with self bias.

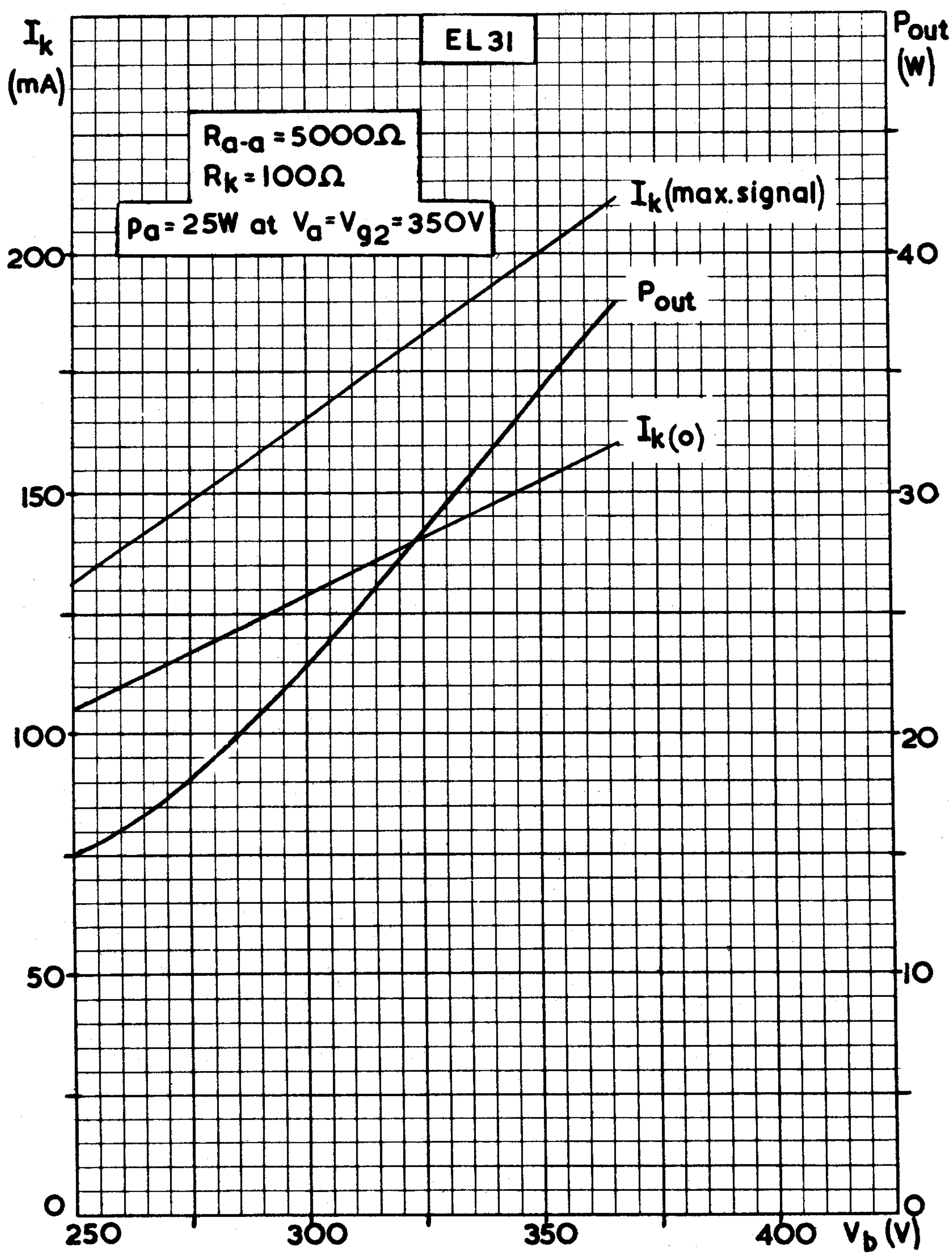

Fig. 6. Push-pull operating conditions with self bias and HT supply having poor regulation. (V_b = 367 V).

To enable the optimum conditions to be obtained with a power supply having poor regulation the above figures are shown graphically fig. 6.

4.2 p_a = 25 watts at $V_a = V_{g2}$ = 375V (Vb = 393V).
R_k = 122 Ω
R_{a-a} = 6000 Ω

V_b V	$I_{a(o)}$ mA	$I_{g2(o)}$ mA	I_a (max.sig) mA	I_{g2} (max.sig) mA	V_{in} (g-g) Vrms	P_{out} W	D_{tot} %
393	2 x 67	2 x 8.8	2 x 75	2 x 24.5	30	37.5	5.0
375	2 x 63	2 x 8.2	2 x 71	2 x 22.5	28.2	33	5.0
350	2 x 59	2 x 7.7	2 x 66	2 x 21.0	26.4	28.5	5.0
325	2 x 54	2 x 7.0	2 x 61	2 x 18.5	24.6	24	5.0
300	2 x 50	2 x 6.3	2 x 56	2 x 17.0	22.6	20	5.0
275	2 x 45	2 x 5.7	2 x 51	2 x 15.0	20.6	16.5	5.0

The distortion curve shown in Fig.7 was taken under this condition with $V_a = V_{g2}$ = 375 (V_b = 393V). These results are shown graphically in Fig. 8.

4.3 p_a = 25 watts at $V_a = V_{g2}$ = 400V (V_b = 420V)
R_k = 145 Ω
R_{a-a} = 7000 Ω

V_b V	$I_{a(o)}$ mA	$I_{g2(o)}$ mA	I_a (max.sig) mA	I_{g2} (max.sig) mA	V_{in} (gl-gl) Vrms	P_{out} W	D_{tot} %
420	2 x 63	2 x 8.3	2 x 69	2 x 24	31	37	5.0
400	2 x 59	2 x 7.8	2 x 65	2 x 22.5	29.4	33	5.0
375	2 x 55	2 x 7.2	2 x 61	2 x 21	28	29	5.0
350	2 x 51	2 x 6.6	2 x 57	2 x 19	26	25	5.0
325	2 x 47	2 x 6.2	2 x 53	2 x 17	24	20.8	5.0
300	2 x 44	2 x 5.1	2 x 48	2 x 16	22.2	17.7	5.0

The distortion curve shown in Fig.9 was taken under this condition with $V_a = V_{g2}$ = 400V (V_b = 420V). The above figures are shown plotted in Fig. 10.

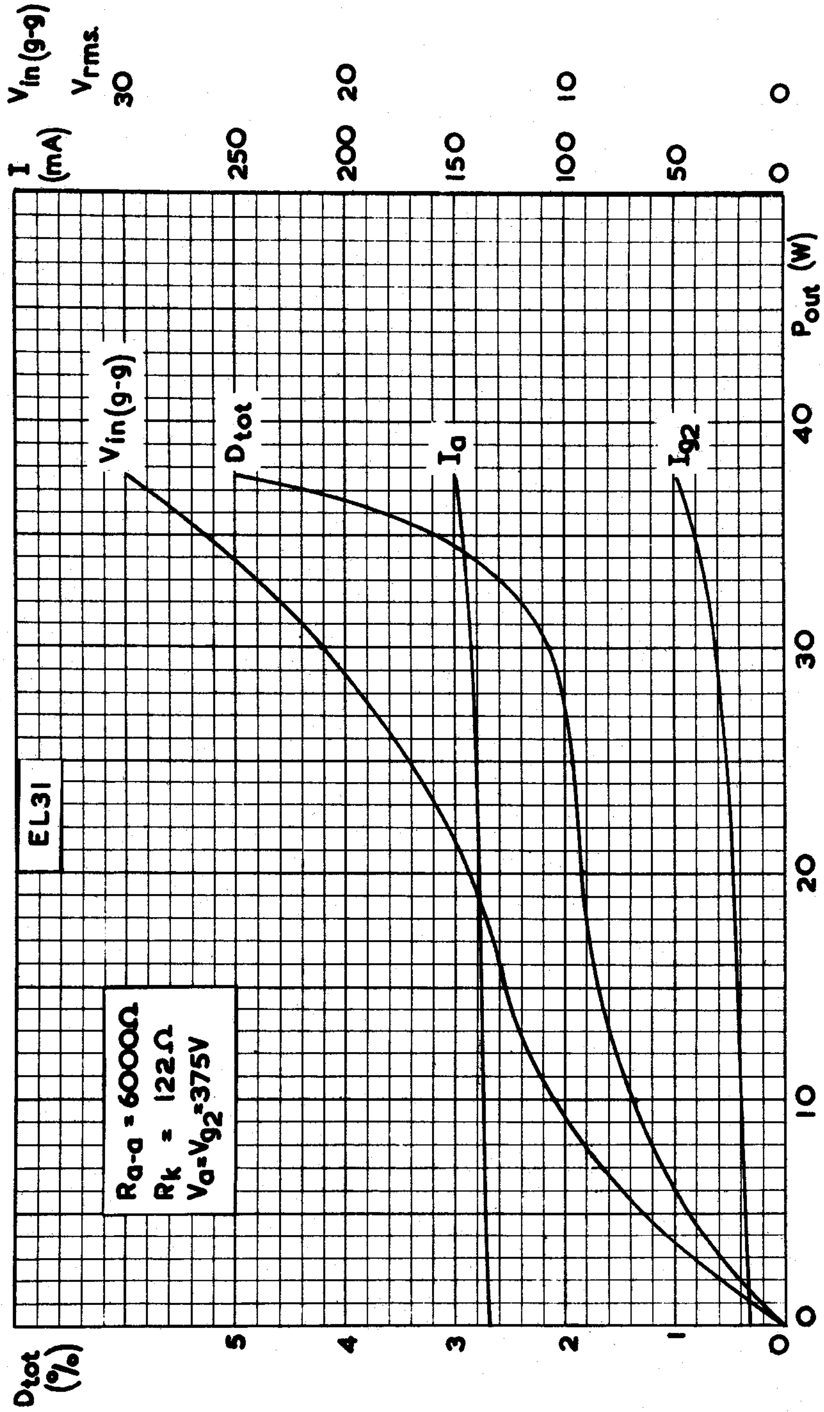

Fig. 7. Push-pull operating conditions for $V_a = V_{g2} = 375$ V. with self bias.

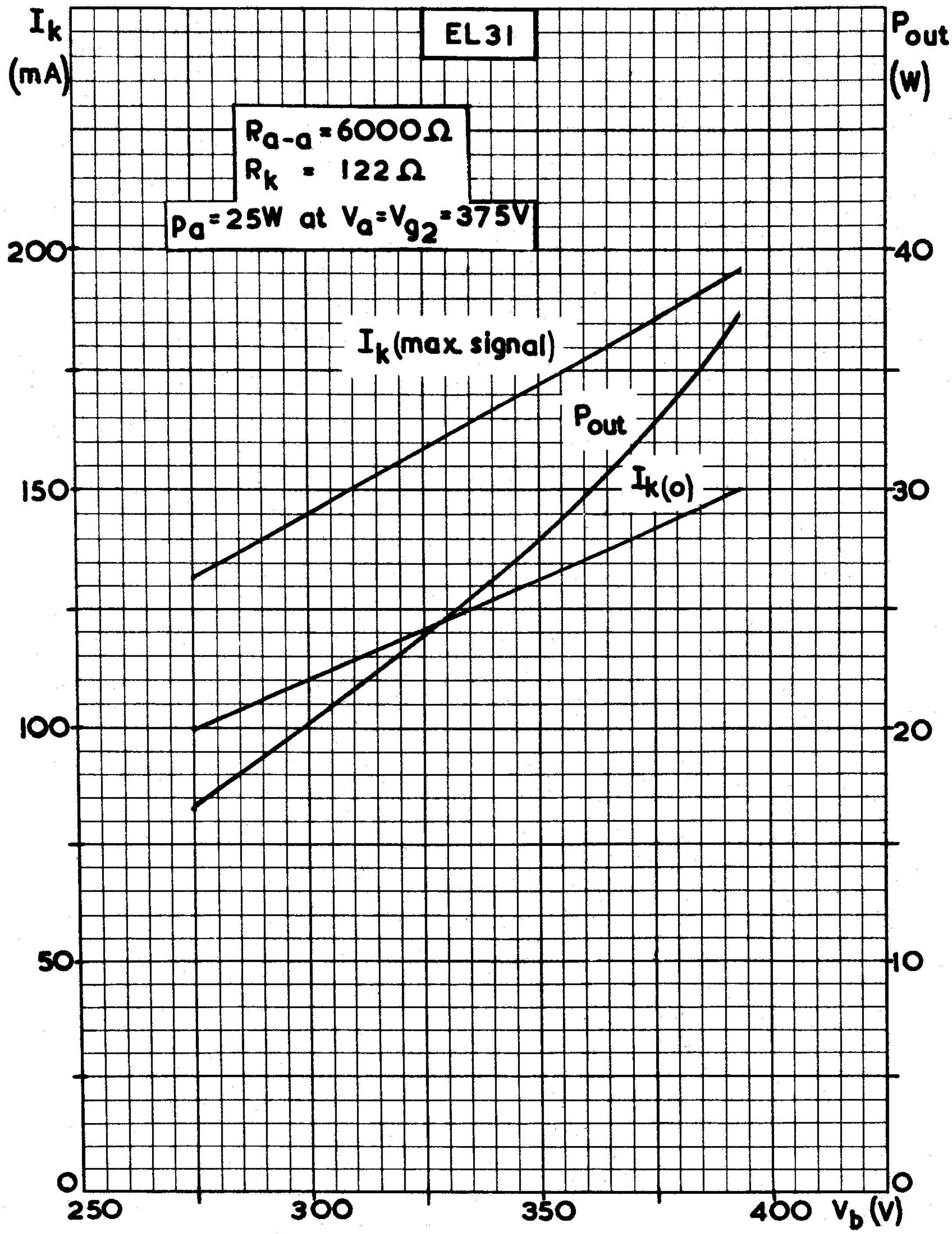

Fig. 8. Push-pull operating conditions with self bias and HT supply having poor regulation. ($V_b = 393$ V).

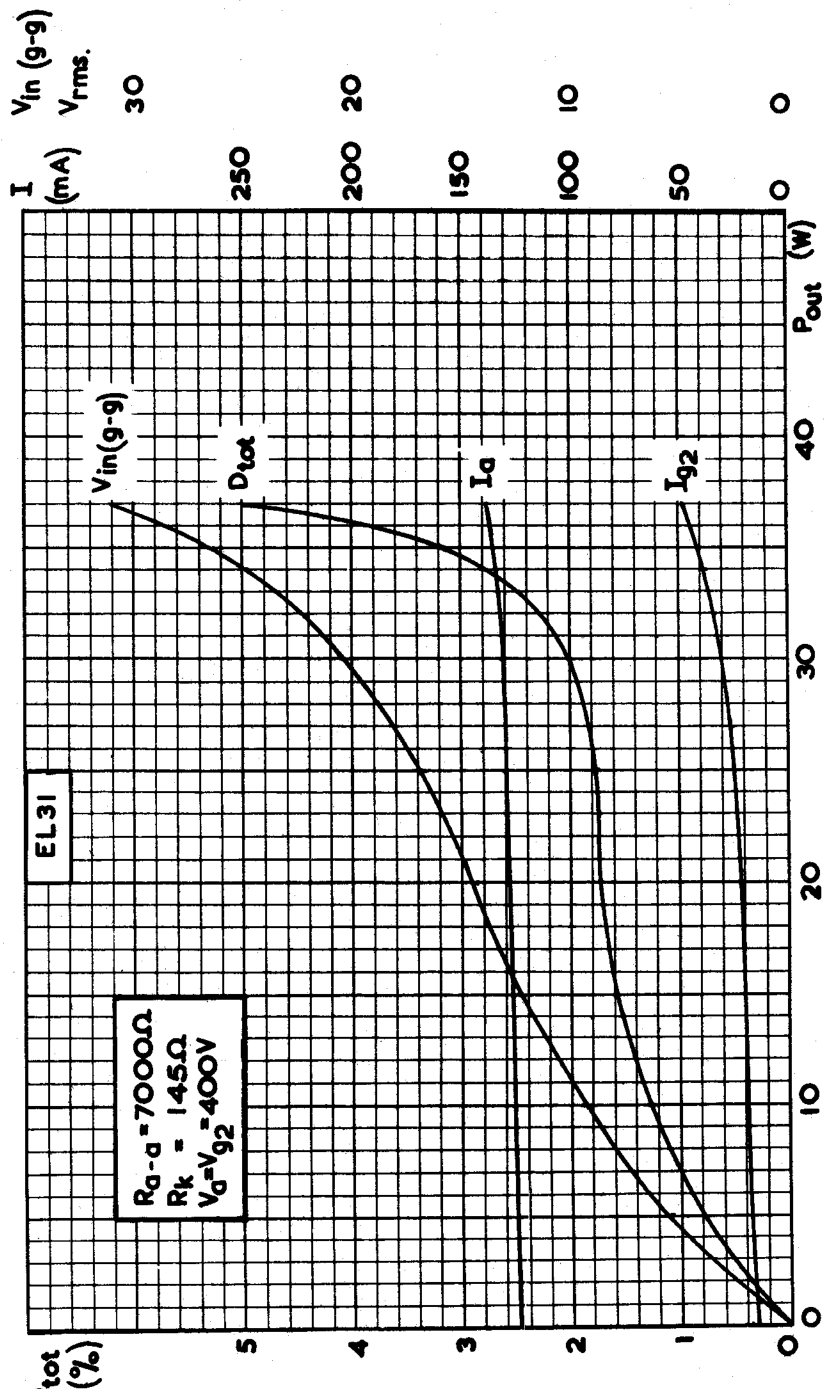

Fig. 9. Push-pull operating conditions for $V_a = V_{g2} = 400$ V. with self bias.

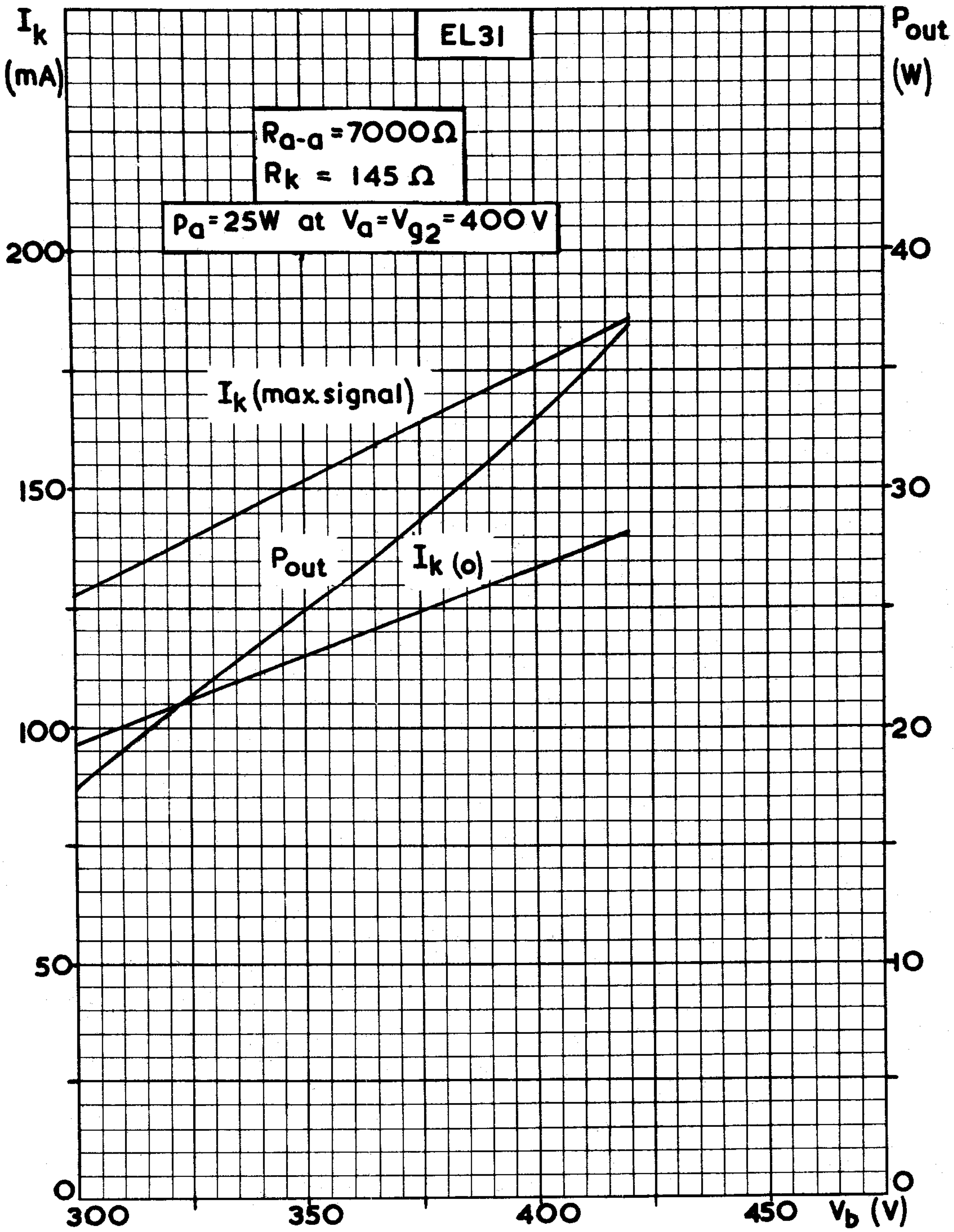

Fig. 10. Push-pull operating conditions with self bias and HT supply having poor regulation. (V_b = 420 V).

5. PUSH PULL OPERATION WITH RC FILTERING FOR SCREEN

The following data is given in view of the modern tendency to dispense with smoothing chokes in the H.T. smoothing circuit. Under such conditions, in order to keep the ripple voltage (approx. 10 volts max.) and the ripple current within the safe limits of the average electrolytic capacitor, it is necessary to use a combination of two 16μF capacitors in parallel. This permits the anodes of the output valves to be fed from the reservoir capacitor and the screen grids and pre-amplifier supplies via an RC filter.

A filter resistor of 1000 ohms is recommended which, together with another 16μF capacitor, provides sufficient smoothing. This results in the cheapest possible reliable smoothing consistent with good performance.

NOTE. The use of lower values of input capacitance and over-running them as far as ripple current is concerned is not recommended.

The following figures were taken under the above mentioned conditions with self bias, the output power being limited by grid current or 5% distortion.

5.1 p_a = 25 watts at V_a = 375 V. (V_b = 392 V)
R_k = 114 ohms.
R_{g2} = 1000 ohms.
R_{a-a} = 6000 ohms.

V_b V	$I_{a(o)}$ mA	$I_{g2(o)}$ mA	I_a (max. sig) mA	I_{g2} (max. sig) mA	V_{in} (g-g) Vrms	P_{out} W	D_{tot} %
392	2 x 67	2 x 8.6	2 x 75	2 x 21	28.4	36.5	5.0
375	2 x 64	2 x 8.2	2 x 70	2 x 20	27.2	33.0	5.0
350	2 x 59	2 x 7.5	2 x 65	2 x 18.5	25.6	28.0	5.0
325	2 x 55	2 x 6.9	2 x 60	2 x 16.8	24.0	24.0	5.0
300	2 x 50	2 x 6.3	2 x 55	2 x 14.3	21.4	19.7	4.5
275	2 x 46	2 x 5.7	2 x 51	2 x 13.2	19.6	16.5	4.4

The above figures are shown graphically in Figs. 11 and 12.

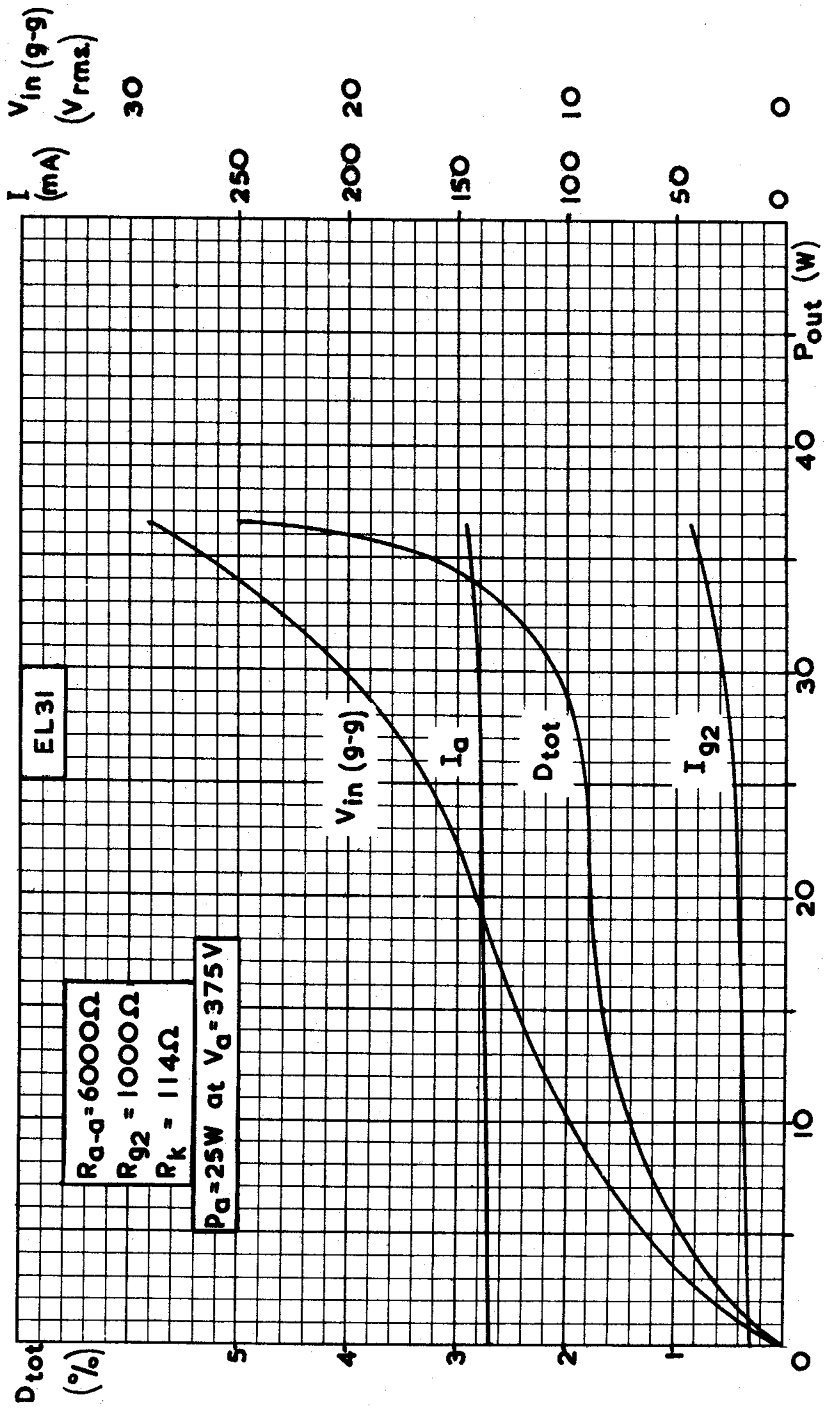

Fig. 11. Push-pull operating conditions with RC filtering for the screen and self bias. (p_a = 25W at V_a = 375 V).

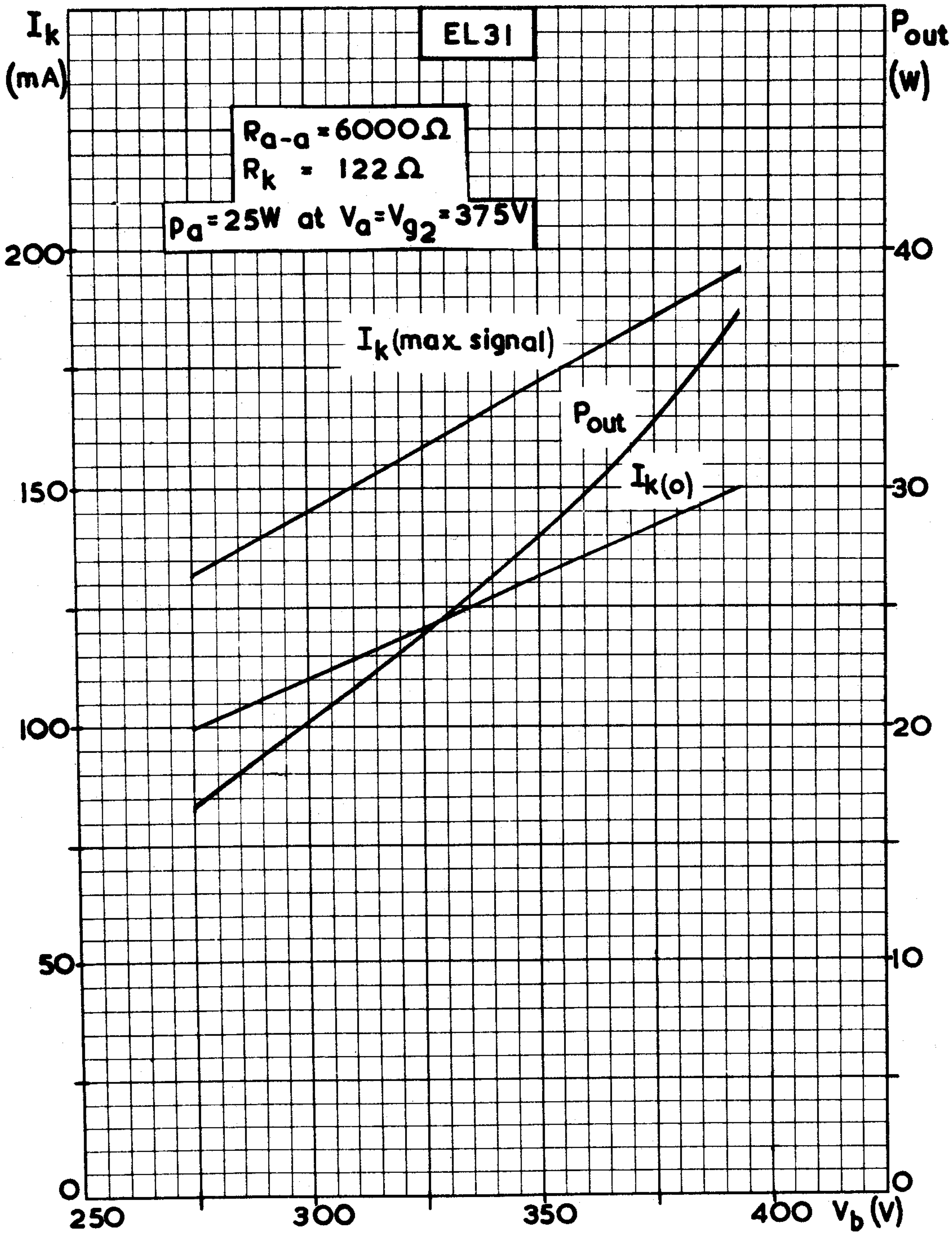

Fig. 12. Push-pull operating conditions with RC filtering for the screen, self bias, and HT supply having poor regulation. (V_b = 393 V).

5.2 p_a = 25 watts at V_a = 400 V. (V_b = 419 V)
R_k = 137 ohms.
R_{g2} = 1000 ohms.
R_{a-a} = 7000 ohms.

V_b V	$I_{a(o)}$ mA	$I_{g2(o)}$ mA	I_a (max. sig) mA	I_{g2} (max. sig) mA	V_{in} (g-g) Vrms	P_{out} W	D_{tot} %
419	2 x 63	2 x 8.2	2 x 67	2 x 21.3	30	36	5.0
400	2 x 60	2 x 7.9	2 x 64	2 x 20.3	28.6	33	5.0
375	2 x 55	2 x 7.2	2 x 60	2 x 18.3	26.8	29	5.0
350	2 x 52	2 x 6.7	2 x 56	2 x 17	25.4	25	5.0
325	2 x 48	2 x 6.1	2 x 52	2 x 15.9	24	21.4	5.0
300	2 x 44	2 x 5.5	2 x 48	2 x 14.5	22	17.7	5.0

The above figures are shown graphically in Figs. 13 and 14.

6. PUSH PULL OPERATION WITH FIXED BIAS

If the H.T. Voltage is decreased when fixed bias is employed the operating conditions approach Class C and distortion becomes intolerable. The no-signal conditions are therefore limited to a fixed point.

6.1 Push-pull operation at Equal Voltages on Anode and Screen

The output figures were measured at the start of grid current.

$V_a = V_{g2}$ = 400 V $I_{a(o)}$ = 2 x 40 mA
R_{a-a} = 4000 ohms V_{g1} = -23V

$V_a = V_{g2}$ V	$I_{a(o)}$ mA	$I_{g2(o)}$ mA	I_a (max. sig) mA	I_{g2} (max. sig) mA	V_{in} (g-g) Vrms	P_{out} W	D_{tot} %
400	2 x 40	2 x 5.2	2 x 110	2 x 26.8	31.4	55	3.5
375			2 x 99	2 x 23.8	31.4	44	3.5
350			2 x 88	2 x 19.3	31.4	36	5.4

Curves for this condition are shown in Figs. 15 and 16.

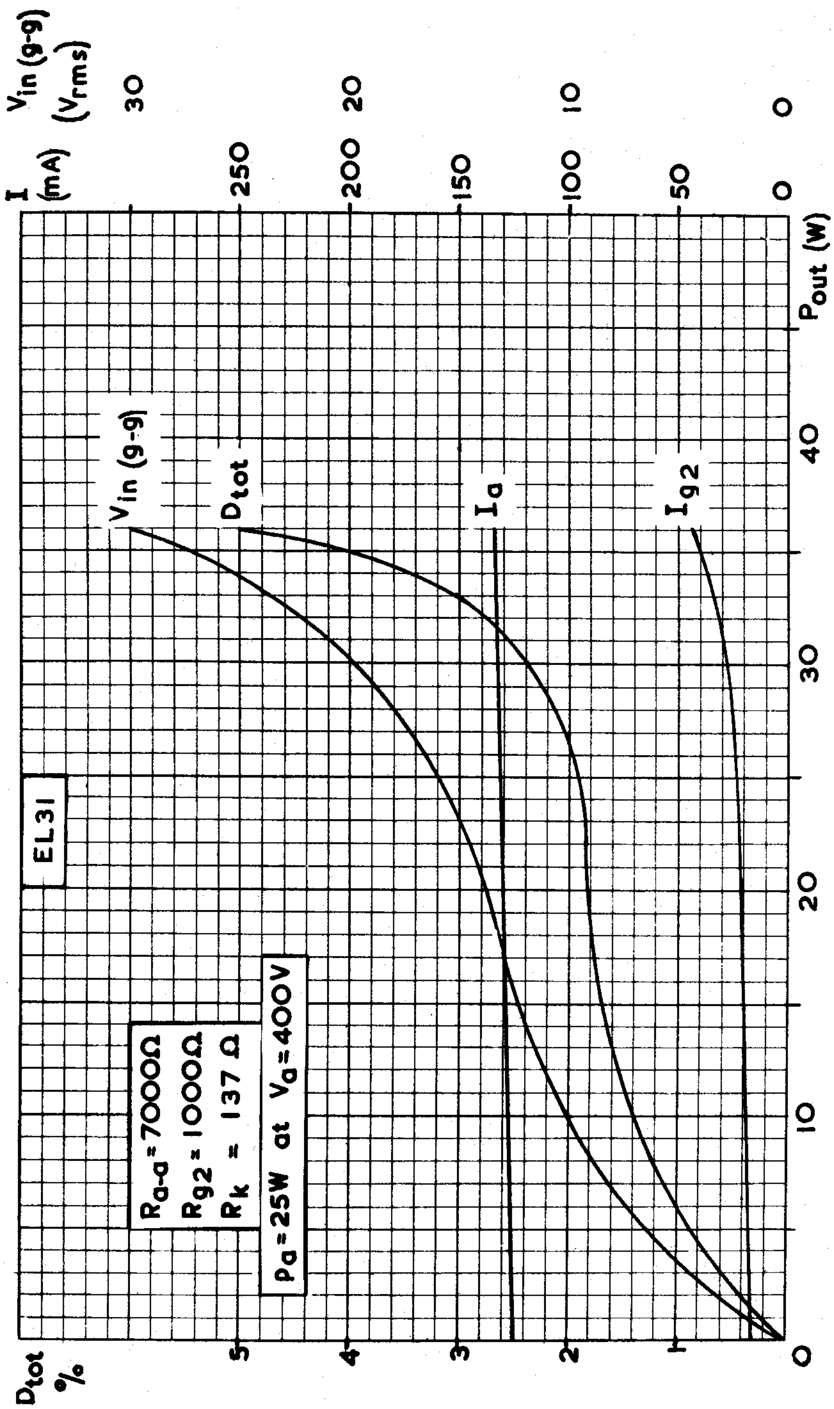

Fig. 13. Push-pull operating conditions with RC filtering for the screen and self bias. (p_a = 25W at V_a = 400 V).

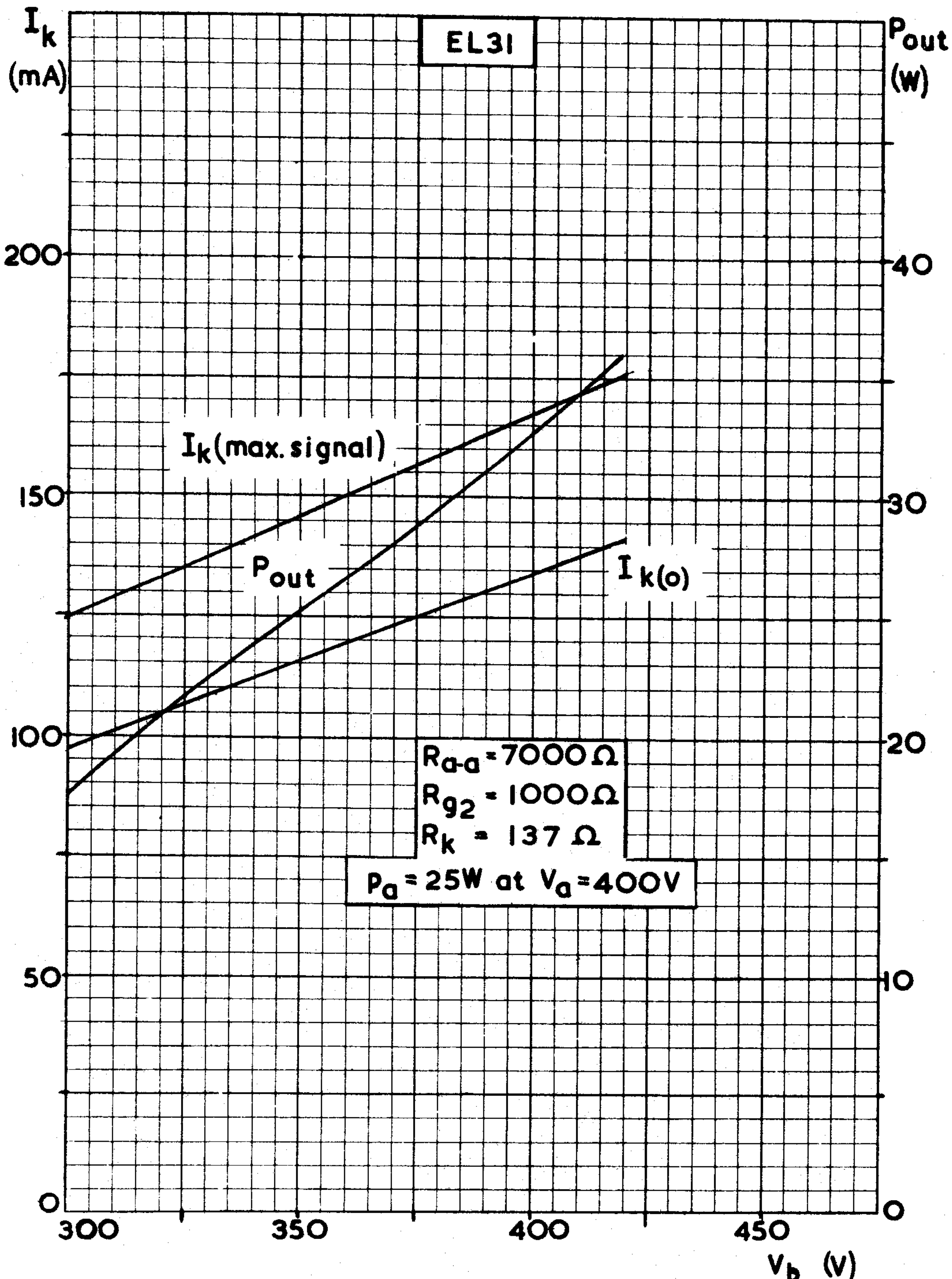

Fig. 14. Push-pull operating conditions with RC filtering for the screen, self bias, and HT supply having poor regulation. ($V_b = 419$ V).

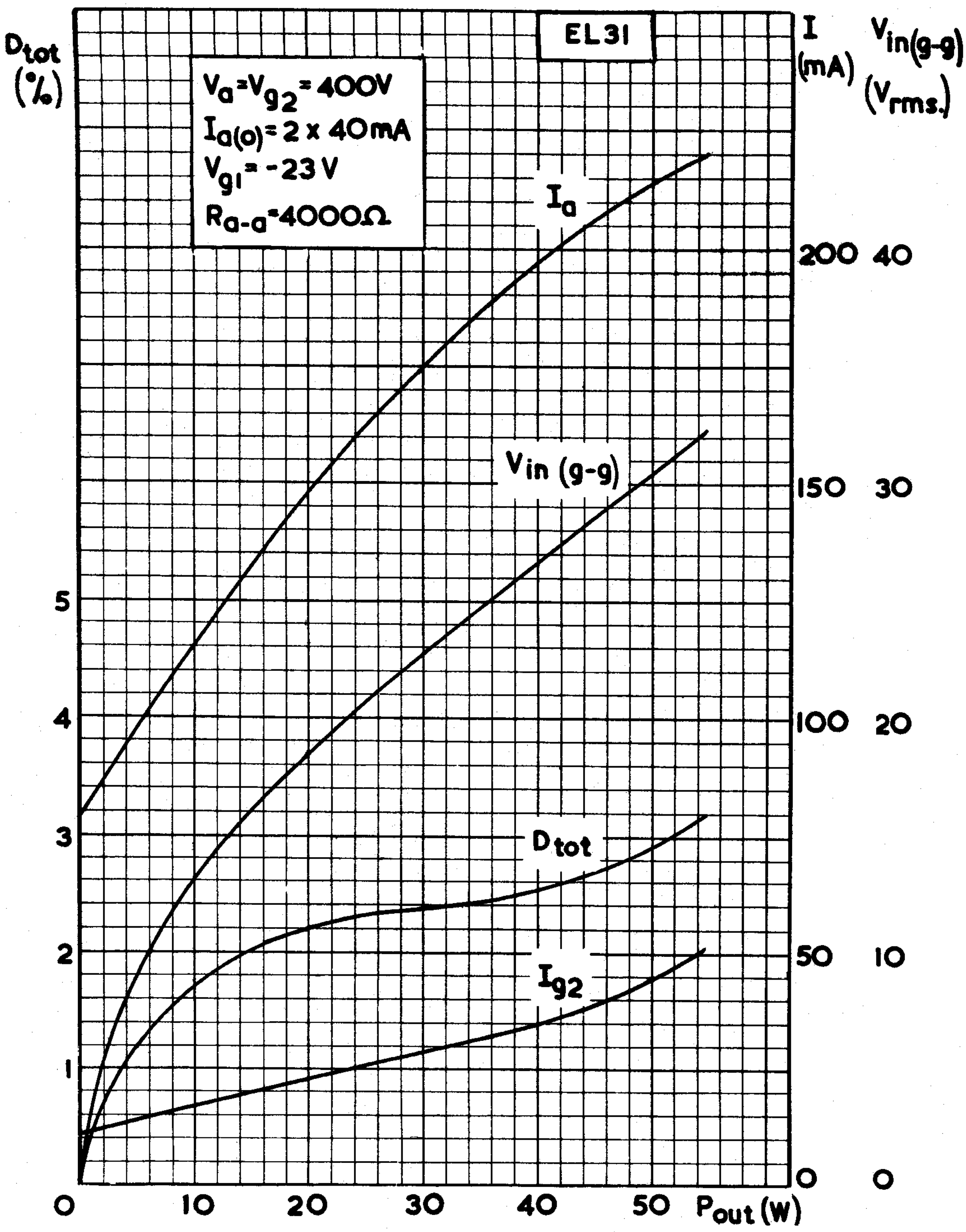

Fig. 15. Push-pull operating conditions for $V_a = V_{g2} = 400$ V. with fixed bias.

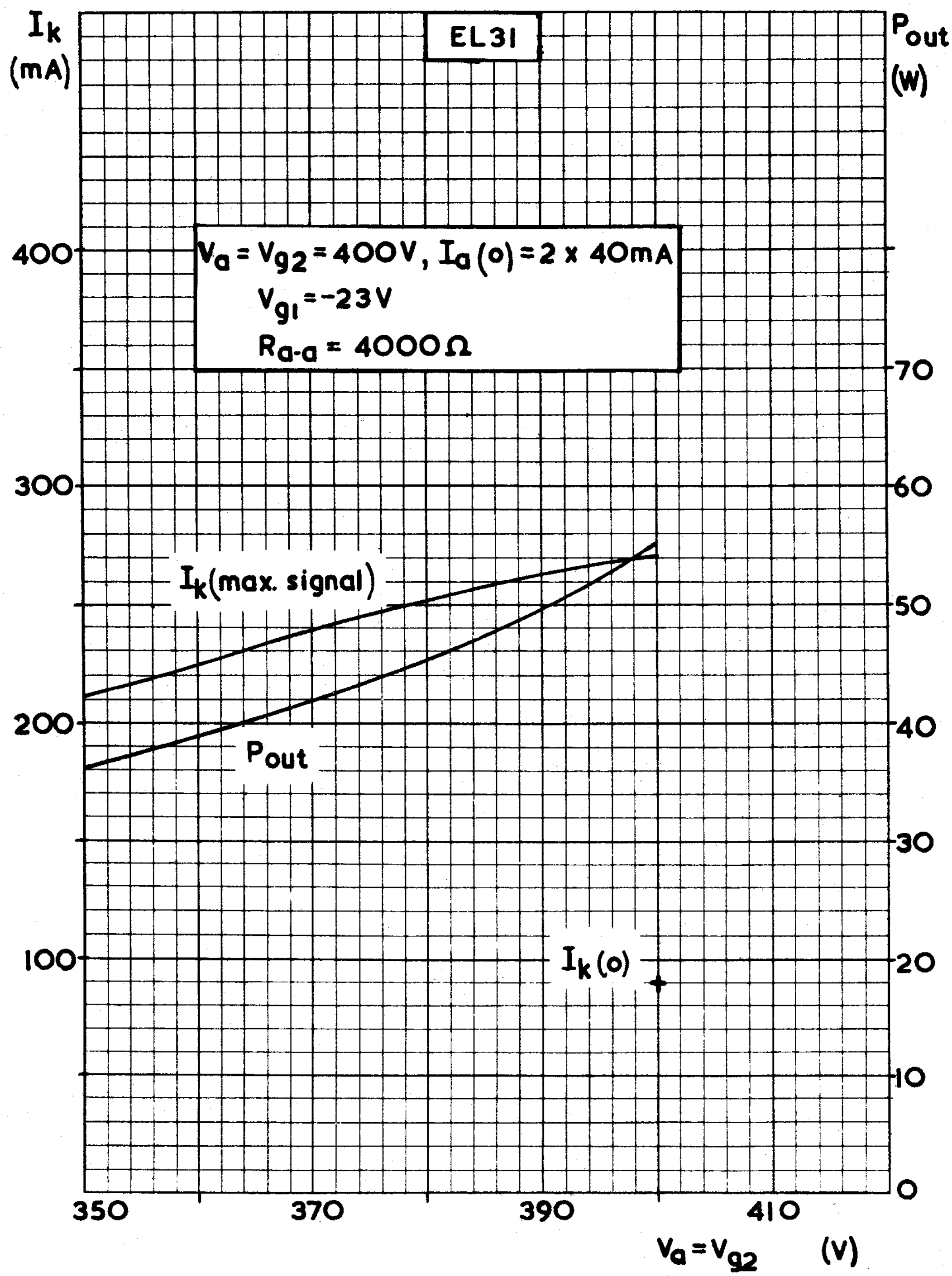

Fig. 16. Push-pull operating conditions with fixed bias and HT supply having poor regulation. ($V_b = 400$ V).

6.2 Push-pull operation at Unequal Voltages on Anode and Screen

Under this condition, when the regulation curve of the anode and screen power supplies are plotted against the respective curves of anode and screen current the lower of the two values of output power should be taken as the obtainable output.

V_a = 600V
V_{g2} = 400V
$I_{a(o)}$ = 2 x 30 mA
V_{g1} = -25.2V
R_{a-a} = 7500 ohms

V_a V	V_{g2} V	$I_{a(o)}$ mA	$I_{g2(o)}$ mA	I_a (max. sig) mA	I_{g2} (max. sig) mA	V_{in} g-g Vrms	P_{out} W	D_{tot} %
600	400	2 x 30	2 x 3.4	2 x 103	2 x 28.5	34.6	84	5.0
562	375			2 x 89	2 x 23	34.6	67	5.2
525	350			2 x 79	2 x 20	34.6	54	7.6

These figures are shown graphically in Figs. 17, 18 and 19.

6.3

V_a = 800 V
V_{g2} = 400 V
$I_{a(o)}$ = 2 x 30 mA
V_{g1} = - 26 V
R_{a-a} = 10,000 ohms

V_a V	V_{g2} V	$I_{a(o)}$ mA	$I_{g2(o)}$ mA	I_a (max. sig) mA	I_{g2} (max. sig) mA	V_{in} g-g Vrms	P_{out} W	D_{tot} %
800	400	2 x 30	2 x 3.1	2 x 107	2 x 28.5	36	120	5.0
750	375			2 x 92	2 x 22.5	36	94	5.5
700	350			2 x 80	2 x 17.5	36	75	8.4

These figures are shown graphically in Figs. 20, 21 and 22.

It is essential in this last application that meters are included in the anode circuits because a small decrease in grid bias will cause the anode dissipation to be exceeded. For speech amplification the no-signal anode current could be reduced to 2 x 20 mA in order to effect a greater economy in H.T. Current.

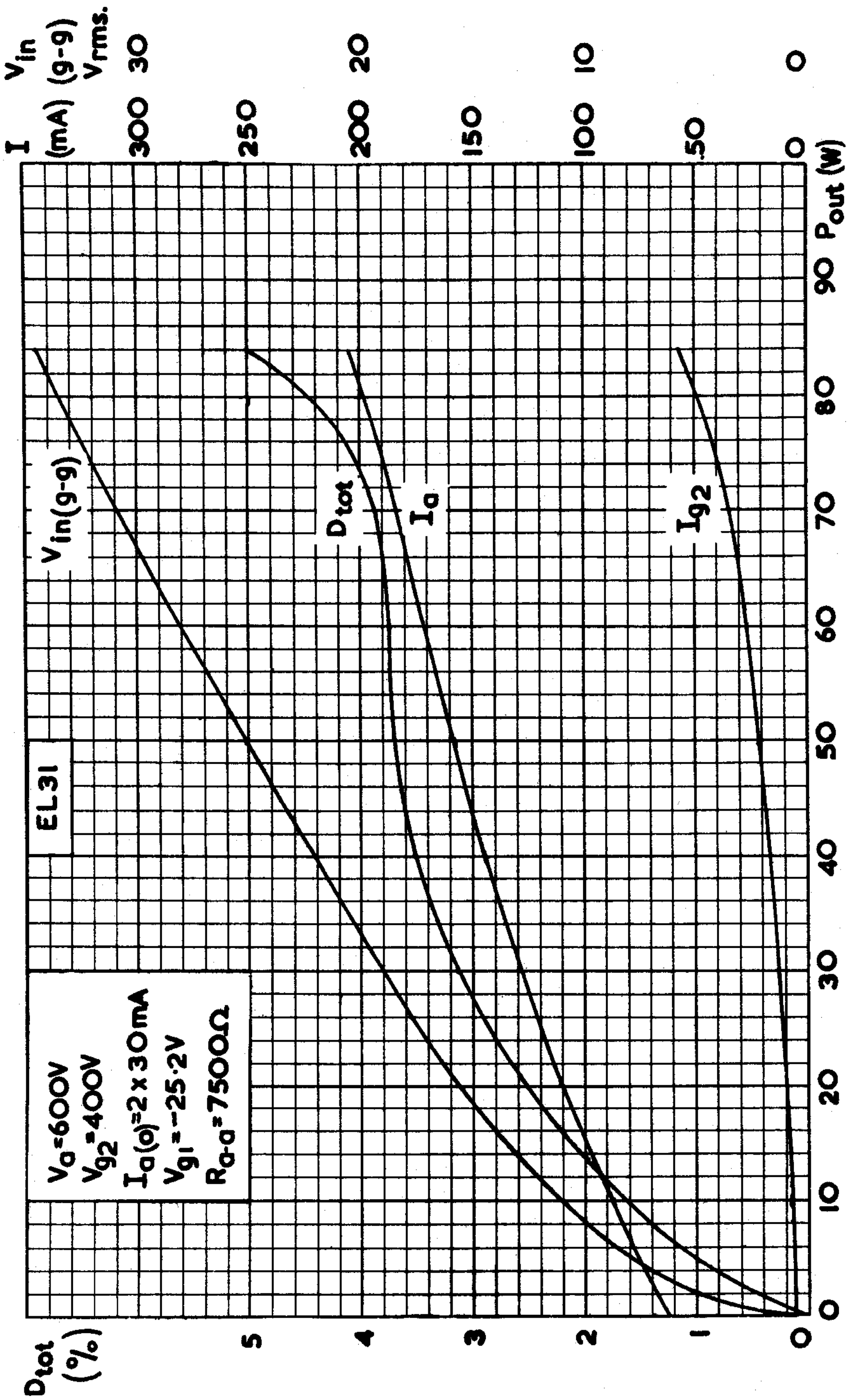

Fig.17. Push-pull operating conditions for V_a = 600 V. V_{g2} = 400 V. with fixed bias.

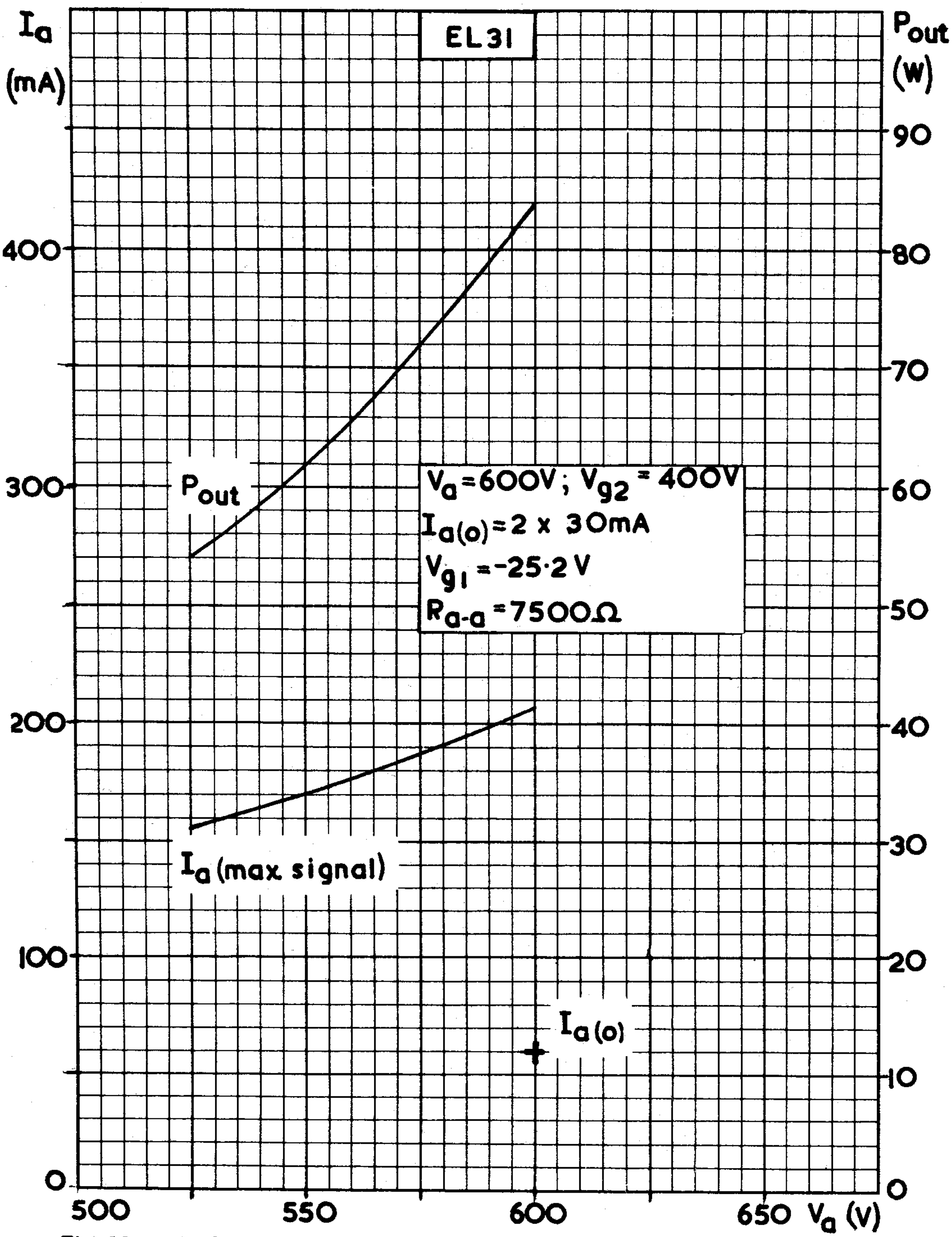

Fig. 18. Push-pull operating conditions with fixed bias and anode supply having poor regulation. ($V_{a(b)}$ = 600 V).

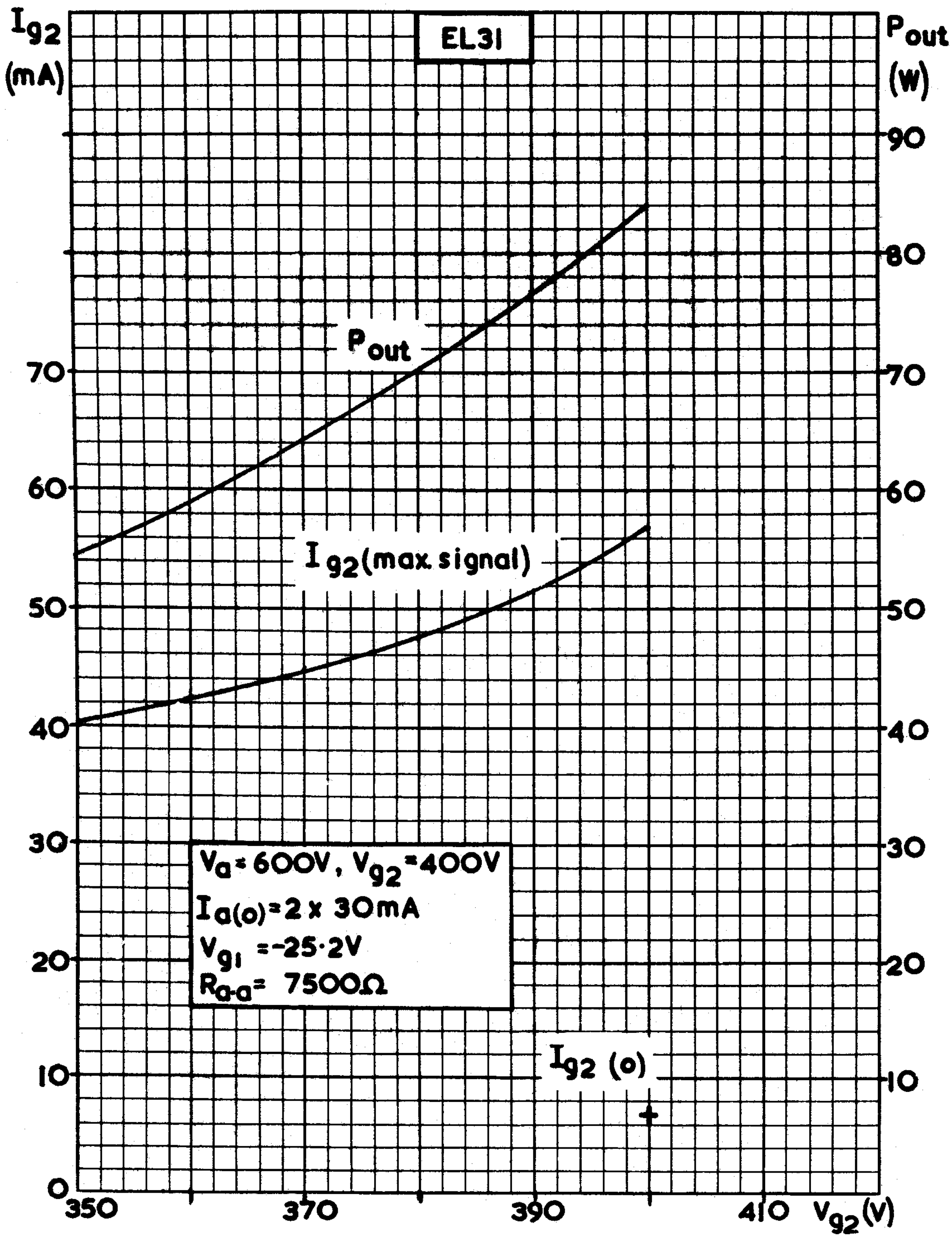

Fig. 19. Push-pull operating conditions with fixed bias and screen supply having poor regulation. ($V_{g2(b)}$ = 400 V. at V_a = 600 V).

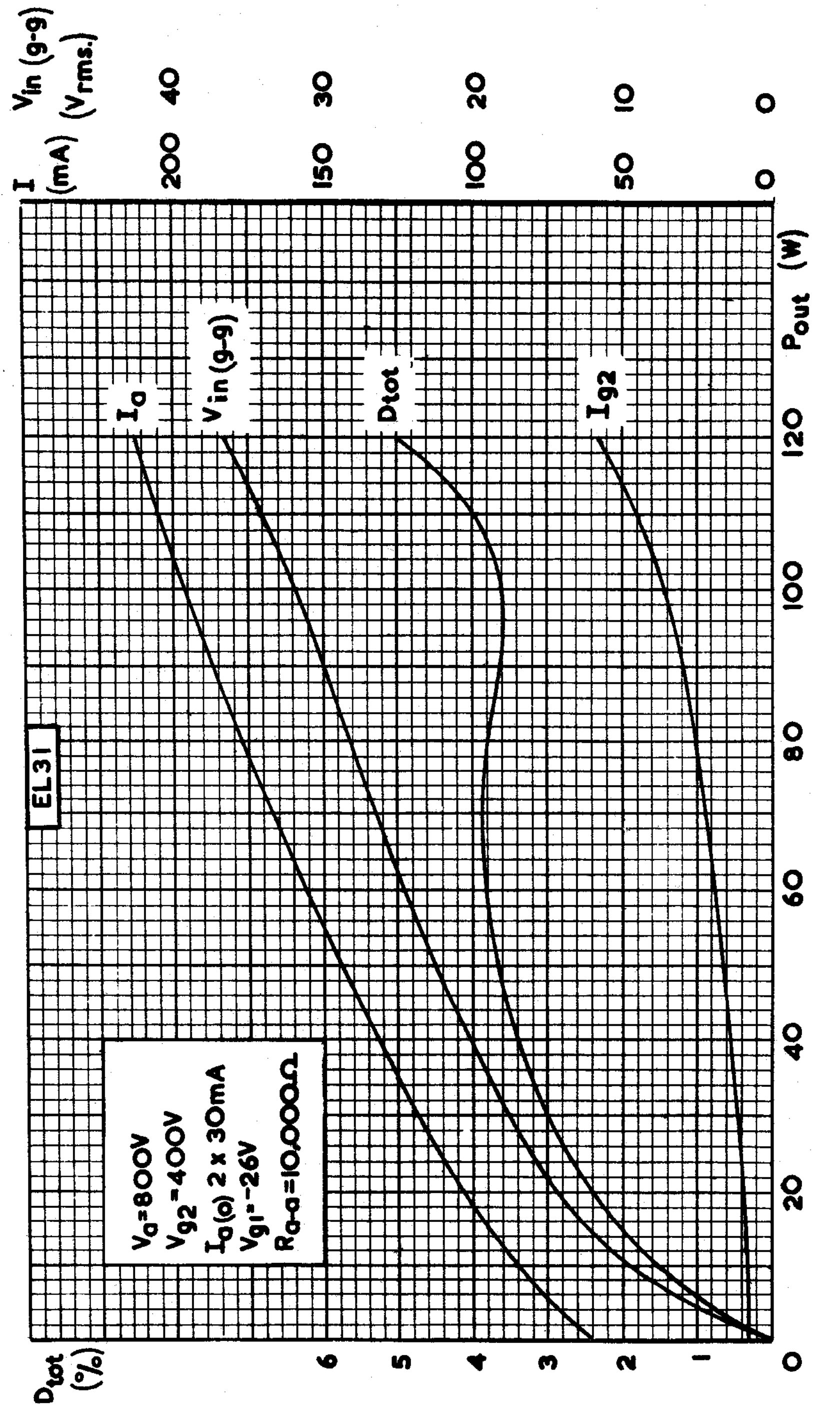

Fig. 20. Push-pull operating conditions for V_a = 800 V. V_{g2} = 400 V. with fixed bias.

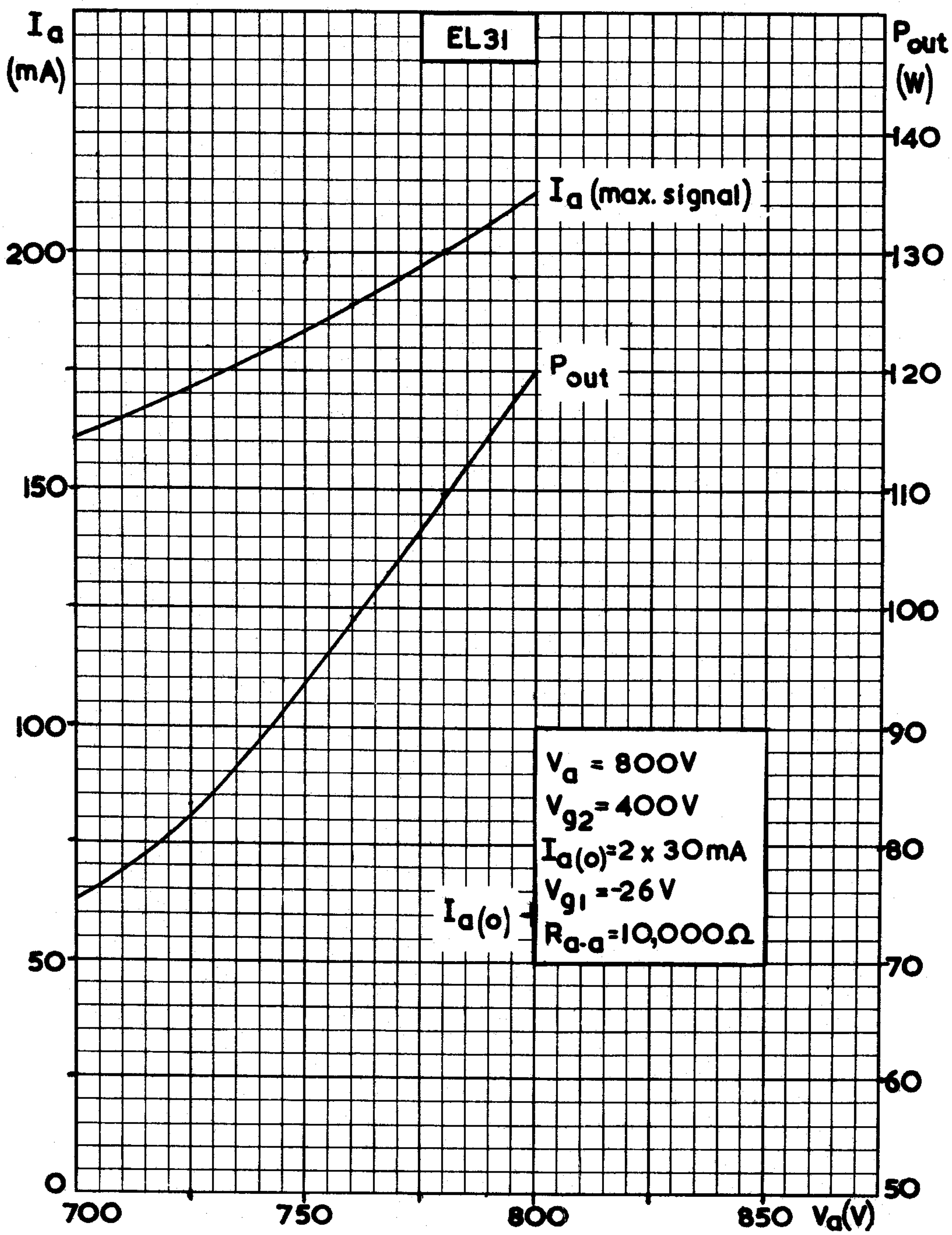

Fig. 21. Push-pull operating conditions with fixed bias and anode supply having poor regulation. ($V_{a(b)}$ = 800 V).

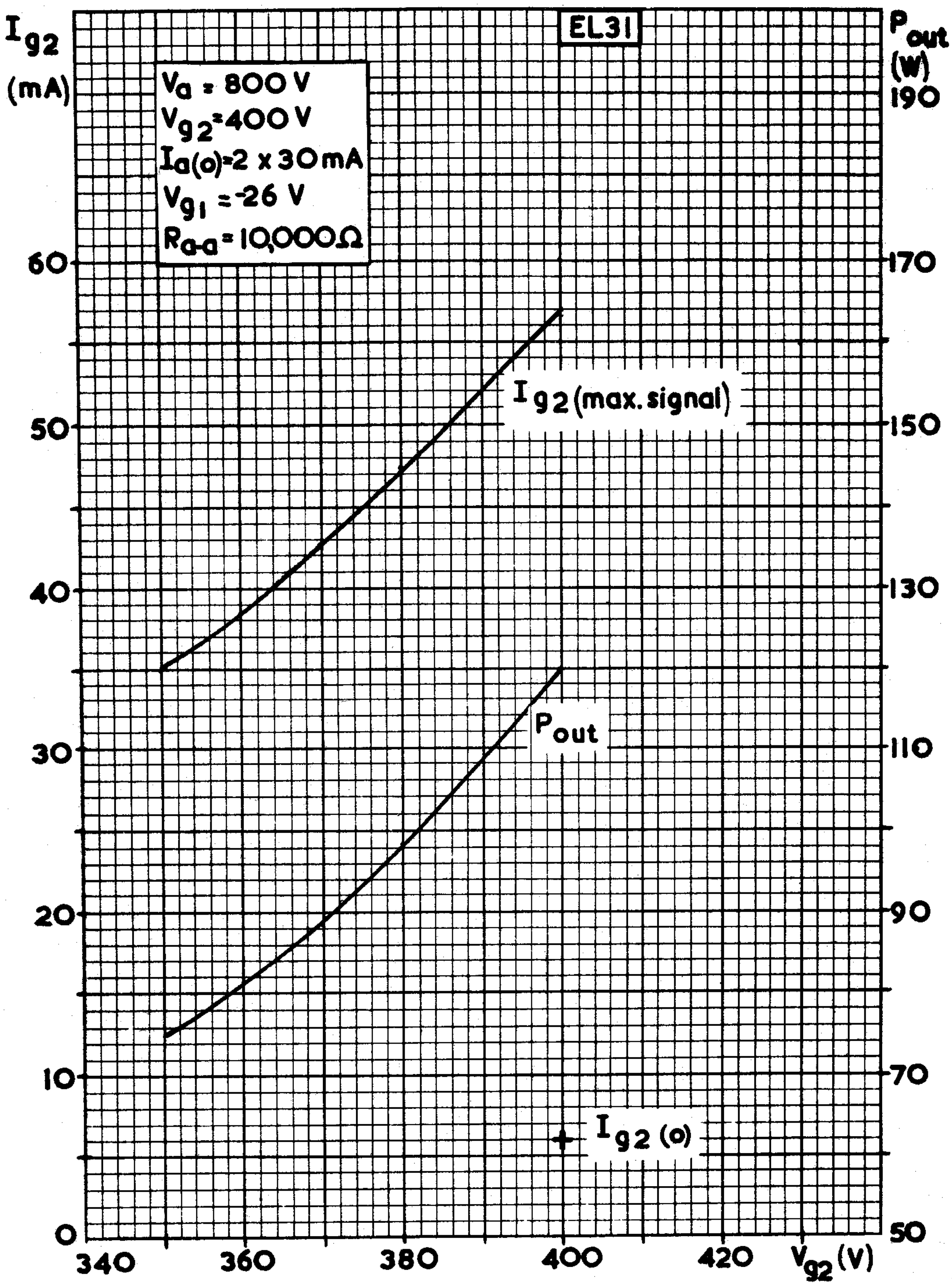

Fig. 22. Push-pull operating conditions with fixed bias and screen supply having poor regulation. ($V_{g2(b)}$ = 400 V. at V_a = 800 V).

7. GENERAL NOTES

7.1 Prevention of Parasitic Oscillation

In order to prevent parasitic oscillation in the output stage it is advisable to include resistors of the values stated below in the screen grid and control grid leads, as close to the valve holder as possible.

Screen grid circuit	47 ohms	½ watt.
Control grid circuit	1000 ohms	½ watt.

7.2 Full drive values of I_a and I_{g2}

All the measurements given in this publication were taken with a sinusiodal input voltage. Under normal conditions of speech and music input, the full drive valves of I_a and I_{g2} will be smaller.

7.3 Screen dissipation

The EL31Ø in push-pull stages is intended for speech and music amplification, and it is unwise to drive the valves fully with a continuous sine wave. In applications where there is a risk of over-running the screens, as for instance in amplifiers which are often over-loaded or which are occasionally mis-matched, a common limiting resistance of 2000 ohms in the lead to the two screens is a suitable precaution.

As, however, this would result in an appreciable loss in the maximum available power output, a better solution is to connect a 200-230 V 25 watt electric lamp in series with the screens. At the low screen currents which normally occur, the resistance of such a lamp is low, but increases rapidly with increasing current. In this manner the screens are protected against overloads at the cost of only about 10% loss in maximum power output.

7.4 Output Power

The figures quoted for output power in the previous paragraphs are for the power delivered by the valve or valves into the output transformer. The power obtained in a load connected in the secondary circuit of the transformer will be slightly smaller owing to losses in the transformer.