BRIMAR

RECEIVING VALVE

6BS7

APPLICATION REPORT VAD/508.4

Standard Telephones and Cables Limited

FOOTSCRAY, KENT, ENGLAND

1.0 INTRODUCTION: The Brimar 6BS7 is an indirectly heated screened pentode of miniature construction intended for use where low AF noise, microphony and hum are required, as in early stages of high gain AF amplifiers. The control grid is brought out to a top cap to reduce stray pick-up in the valve. The heater is intended for operation in parallel with those of other valves in AC operated equipment.

Very effective internal screening is employed, but the input and output capacitances are low enough to allow the valve to be used in RF applications up to frequencies of at least 20 Mc/s.

In this report are characteristic curves and details of the performance of the valve as a resistance capacity coupled amplifier. The anticipated levels of hum, hiss and microphony are given and the precautions necessary to ensure the best performance are discussed.

2.0 DESCRIPTION: The valve is a miniature screened pentode with characteristics similar in most ways to those of the 6J7 valve. The structure is mounted in a $T6\frac{1}{2}$ bulb and is fitted with a B9A (Noval) base. The whole assembly is designed with a view to obtaining the utmost possible rigidity. The control grid is screened internally from the heater to eliminate hum due to electrostatic pick-up from that source, and being connected to the top cap is well removed from pick-up from wiring to the base connections. The heater is wound in the form of a double spiral to reduce, as far as possible, the magnetic field set up by the heater current.

3.0 CHARACTERISTICS:

3.1 Cathode:

	Indirectly heated	
	Voltage	6·3 volts
	Current (Nominal)	0·15 ampere
	Max. DC Heater-Cathode potential	100 volts

3.2 Dimensions:

	Max. Overall Length	2-5/8 ins.
	Max. Diameter	7/8 in.
	Max. Seated Height	2-3/8 ins.

3.3 Base: Type B9A (Noval)

Pin 1 No Connection NC
Pin 2 Internal Connection IC
Pin 3 Cathode k
Pin 4 Heater h
Pin 5 Heater h
Pin 6 Internal Shield   s
Pin 7 Anode a
Pin 8 Screen Grid g_2
Pin 9 Suppressor Grid g_3
Top Cap   Control Grid g_1

3.4 Ratings (Design centre):

PENTODE CONNECTED:

Max. Anode Voltage	300 volts
Max. Screen Voltage	125 volts
Max. Anode Dissipation	0·75 watts
Max. Screen Dissipation	0·3 watts

TRIODE CONNECTED (g_2 connected to anode, g_3 connected to cathode):

Max. Anode Voltage	250 volts
Max. Anode Dissipation	1·75 watts

3.5 Inter-electrode Capacitances (measured with no external shield):

PENTODE CONNECTED:

c_{in}	4·0 pF
c_{out}	4·0 pF
$c_{gl, a}$	0·01 pF

TRIODE CONNECTED:

c_{in}	3·0 pF
c_{out}	6·7 pF
$c_{g, a}$	1·1 pF

3.6 Characteristic Curves: Curves are included in this report which show:—

Anode current versus anode voltage (I_a/V_a) at various values of control grid voltage with a screen voltage (V_{g2}) of 125 volts, No. 308·237. Similar curves for a screen voltage of 100 volts are shown on No. 308·238, for V_{g2} 75 volts, No. 308·239, and for V_{g2} 50 volts, No. 308·240.

Anode current versus control grid voltage at various values of screen grid voltage, No. 308·242.

Anode current versus anode voltage with the valve connected as a triode, No. 308·241.

Mutual conductance and impedance versus control grid voltage for the valve connected as a pentode, No. 308·243.

Mutual conductance, impedance and amplification factor versus grid voltage for the valve connected as a triode, No. 308·244.

4.0 TYPICAL OPERATION:

4.1 PENTODE CONNECTED (g_3 connected to cathode):

Heater Voltage	6·3	6·3	volts
Anode Voltage	100	250	volts
Screen Voltage	100	100	volts
Grid Voltage	—3	—3	volts
Cathode Bias Resistor	1100	1100	ohms
Anode Current	2·0	2·1	mA
Screen Current	0·7	0·6	mA
Anode Impedance	1·5	2·4	MΩ
Mutual Conductance	1·1	1·25	mA/V
Inner Amplification Factor	20	20	
Grid Voltage for 1/100 g_m at V_{gl} — —3	—8	—9	volts

4.2 TRIODE CONNECTED (g_2 connected to anode, g_3 connected to cathode):

Heater Voltage	6·3	volts
Anode Voltage	250	volts
Grid Voltage	—8	volts
Anode Current	6·5	mA
Mutual Conductance	1·72	mA/V
Anode Impedance	11,600	ohms
Amplification Factor	20	

5.0 OPERATION AS A RESISTANCE CAPACITY COUPLED AF AMPLIFIER:

5.1 Pentode Connected: In the table below are given typical operating conditions under various conditions of anode load and supply voltage which yield an output with approximately 5% distortion.

		100			300		volts
Anode Supply Voltage		100			300		volts
Anode Load Resistor	100	220	470	100	220	470	kΩ
Cathode Bias Resistor	1·3	3·3	5·6	0·56	1·5	2·2	kΩ
Series Screen Resistor	0·47	1·5	2·8	0·47	1·5	2·8	MΩ
Succeeding Stage Grid Resistor	1·0	1·0	1·0	1·0	1·0	1·0	MΩ
Peak Output Voltage	21	28	31	70	92	100	volts
Voltage Gain	65	80	140	104	124	185	

Included in this report are curves of anode and screen current versus control grid voltage taken with a supply voltage of 250 volts and various values of anode load resistor. The characteristics for an anode load of 100 kΩ are given on No. 308·247, for 220 kΩ on No. 308·246 and for 470 kΩ on No. 308·245. The method of using these curves for calculating the resistance capacity coupled amplifier performance is as follows:

As an example, assume it is desired to operate with a load resistor of 220 kΩ and a succeeding valve grid leak of 1 MΩ. It can be seen from the curve that control grid current sets in at about —0·5 volts, so that the bias should be chosen to prevent excursion into voltages lower than this. If a value of —2·0 volts is selected, a reasonably linear I_a/V_{gl} characteristic is obtained with the screen grid operating at 50 volts. With such an operating point the anode current is 0·48 mA, and the screen current 0·23 mA. The cathode bias resistor will be $\dfrac{2·0 \times 1000}{0·48 + 0·23}$ or 2800 ohms.

The series screen resistor will be $\dfrac{200 \times 1000}{0·23}$ or 0·87 MΩ.

Allowing a peak input voltage of 0·3 volt, the grid will swing from —2·3 to —1·7 volts, giving an anode current swing of 0·32 mA to 0·68 mA, or 0·36 mA peak to peak. In a 220 kΩ load this corresponds to an output voltage of 79 volts peak to peak or 39·5 volts peak. The voltage gain is then 131 times.

As allowance must be made for the following grid leak of 1 MΩ, these figures must be reduced by a factor of $\dfrac{10^6}{10^6 + 0·22 \times 10^6}$ or 0·82. The stage gain is then 108 times and the output voltage 32·5 volts peak.

The distortion may be estimated by inspection of the relative stage gains at the positive and negative peaks of the signal. The gain at —2·3 volts is

$$\frac{(0·48 - 0·32) \times 220 \times 0·82}{0·3} \text{ or } 96·5 \text{ times.}$$

The gain at —1·7 volts is $\dfrac{(0·68 - 0·48) \times 220 \times 0·82}{0·3}$ or 120 times.

The distortion is then :

$$\frac{120 - \left(\dfrac{120 + 96·5}{2}\right)}{120 + 96·5} \times 100 = 5·3\%$$

5.2 Triode Connected: The valve may be used as a low μ triode resistance capacity coupled amplifier where the requirements for low hum and noise outweigh these for high gain. In the table below are given typical operating conditions under various conditions of anode load and supply voltage which yield an output with approximately 5% distortion.

Anode Voltage		100			300		volts
Anode Load Resistance	100	220	470	100	220	470	kΩ
Cathode Bias Resistor	7·5	14·5	20·0	6·0	14·0	18·6	kΩ
Succeeding Stage Grid Resistor	0·5	1·0	1·0	0·5	1·0	1·0	MΩ
Peak Output Voltage	22	26	28	88	96	105	volts
Stage Gain	12	13	14	13	14	14	times

A curve, No. 308·248, is included in the report, which shows the relation between the various valve parameters and control grid voltage under conditions of RC coupled operation with various values of anode load resistance.

A method of using this curve for calculating performance is as follows. If it is desired to use an anode load of 220 kΩ with a supply of 250 volts, inspection of the curves indicates a reasonably linear portion over the region of grid voltage —2 to —8 volts. Assuming an operating point at —5 volts the anode impedance and amplification factor are shown as 27·2 kΩ and 17 respectively. The anode load is effectively in parallel with the following

valve grid leak, and if this is 1 MΩ the effective load is $\dfrac{220 \times 1000}{1220}$ or 180 kΩ.

The stage gain is then $\dfrac{\mu R_a}{R_a + r_a} = \dfrac{17 \times 180}{207\cdot2}$ or 14 times.

The distortion may be estimated in the same way as for pentode operation by calculating the stage gain at the extremes of the input signal.

6.0 LOW HUM APPLICATIONS:

6.1 Pentode Connected: Due to the extensive internal screening very little magnetic and electrostatic hum pick-up occur in the electrode structure. The double ended construction with the grid connection well separated from the heater wiring enables the grid to heater capacity to be reduced to a negligible value, with the result that hum levels below 1μV referred to the grid are obtainable.

Curve No. 308·249 shows the maximum hum level referred to the grid plotted against the percentage of valves giving this level, or less, with a grid circuit impedance of 100 kΩ. A hum balancing resistor with its slider connected to earth was connected across the heater. From this curve it can be estimated how many samples from a large batch will have a hum level below a certain value. It will be seen that to expect a hum level of the order of 2μV is reasonable as 90% of the valves would be better than this.

In order to achieve low hum levels from this valve in the first stage of a high gain amplifier, precautions must be taken to see that the valve is not situated in any AC fields from chokes, transformers or heater wiring. Similar precautions must also be taken with the input wiring, and decoupling earth returns pertaining to the stage should be connected to a single point and not distributed around the chassis forming closed loops liable to couple with AC magnetic fields.

A screened top cap connector is necessary to obtain the full low hum advantages from the 6BS7. An external screen around the bulb is desirable, as although an internal screen is provided, the effect of electrostatic charges on the glass envelope is not entirely eliminated, nor can a single screen give complete protection from strong magnetic fields. If the valve is not being used at very low input levels the external screen will not be required.

Although the figures shown on Curve No. 308·249 were measured with a hum balancing resistor across the heater, in general, direct earthing of one heater pin will result in only slightly increased hum from valves otherwise exhibiting the lowest hum levels.

The figures quoted for hum were obtained with a grid leak of 100 kΩ. Wherever possible the grid circuit impedance should be limited to this figure. A higher value is permissible, but the danger of electrostatic pick-up is increased.

6.2 Triode Connected: The same considerations apply as in paragraph 6.1 with regard to precautions to ensure low hum. Triode connection yields even lower hum levels than pentode connection. No curve of expected hum level is given as it was found impossible to obtain reliable measurements at such low levels.

Both pentode and triode connection hum levels are affected by the anode current. All the figures quoted are for RC coupled amplifiers, where the anode current is less than 1 mA. If the valve is operated with a choke or transformer load the anode current should be held below 1·5 mA to maintain low hum level.

7.0 Microphony: It is not possible to specify the microphony level because this is so much dependent on the circumstances of the application. The valve has been designed with a very rigid structure to minimise the effect of vibration, but there will always be some movement of individual grid wires when vibrated at their resonant frequency. By careful design, all low frequency resonances due to loose electrodes have been removed, so that there are no internal resonances below 1000c/s. This is shown on the curves No. 308·252 and 308·253, which indicate the amplitude of the resonances when the valve is vibrated across the major and minor axes respectively. The frequency of vibration was varied from 10 to 3000 c/s with a constant acceleration of 2·5g.

It is interesting to note that the amplitude of vibration to produce an acceleration of 2·5g varies from 0·25 in. at 10 c/s to approximately 0·001 in. at 150 c/s, while at 5000 c/s the peak amplitude is only two millionths of an inch. Most of the higher frequency vibrations are heavily damped by the chassis and valve holder mounting. The use of an antimicrophonic type of valve-holder usually eliminates vibration effects at these frequencies.

Where the valve is being used at the limit of its sensitivity it is important to minimise as far as possible by flexible valve holder mountings all mechanical and acoustical vibrations. This is particularly important where the valve is included in the same cabinet as the loudspeaker, or a motor, such as in magnetic tape recorders and sound film projectors.

8.0 Valve Shot Noise (Hiss): A certain amount of random noise will be generated in the valve by the random arrival of electrons at the anode, and this is further increased by the partition of the cathode current between anode and screen, as the random collection of electrons by the screen must have its effect as an increased variation in the number of electrons arriving at the anode. This is inherent in the valve and cannot be entirely eliminated. A major contribution to valve noise, however, is noise produced by leakage between electrodes over the mica insulators and stray fibres or "lint" between electrodes. Also a poorly activated cathode can produce a noise voltage swamping the normal valve noise.

The shot noise in the 6BS7 has been reduced to a minimum by careful design, and the noise due to leakage controlled by careful assembly and inspection. A certain amount of leakage noise is unavoidable in a mass produced valve, and this reveals itself as a small variation in noise level from valve to valve.

The Curve No. 308·250 shows the maximum hiss voltage plotted against the percentage of valves, using a grid resistor of 100 kΩ and a bandwidth of 10 kc/s. The curve is very steep, and indicates that a hiss level on the grid always lower than 7μV is to be expected.

The Curve No. 308·251 shows the same parameters with the valve triode connected. Here partition noise has been eliminated. As would be expected the higher noise levels are unaltered because they are due mainly to leakage which is not greatly affected by whether the valve is triode or pentode connected. The lower noise level is reduced, and in fact falls below the thermal agitation noise generated by the 100 kΩ grid resistor, which in a 10 kc/s bandwidth at 20° C is about 4μV.

9.0 Other Applications: By virtue of the precautions taken to ensure low grid leakage, the 6BS7 may be of use where a valve with exceptionally low control grid current is required and the use of a special electrometer valve is not warranted. Curve No. 308·254 shows the maximum control grid current plotted against the number of valves giving this value or less. This is for the valve connected as a triode with an anode voltage of 100 volts and grid bias of —3 volts. 50% of the valves show a grid current of less than $10^{-3}\mu$A.

The value of grid current is affected, in the case of valves with lowest leakage, by incident light due to stray photo-emission. The figures quoted are for normal room daylight, and some improvement may be obtained by shielding the valve from incident light.

BRIMAR 6BS7
ANODE & SCREEN CURRENTS versus
ANODE VOLTAGE
Screen voltage V_{g2} = 125 Volts

I_a ——————
I_{g2} – – – – –

CONTROL GRID VOLTAGE V_{g1} = 0 VOLTS

ANODE & SCREEN CURRENTS I_a & I_{g2} mA

ANODE VOLTAGE V_a VOLTS

VAD/308·237

VAD/308-238
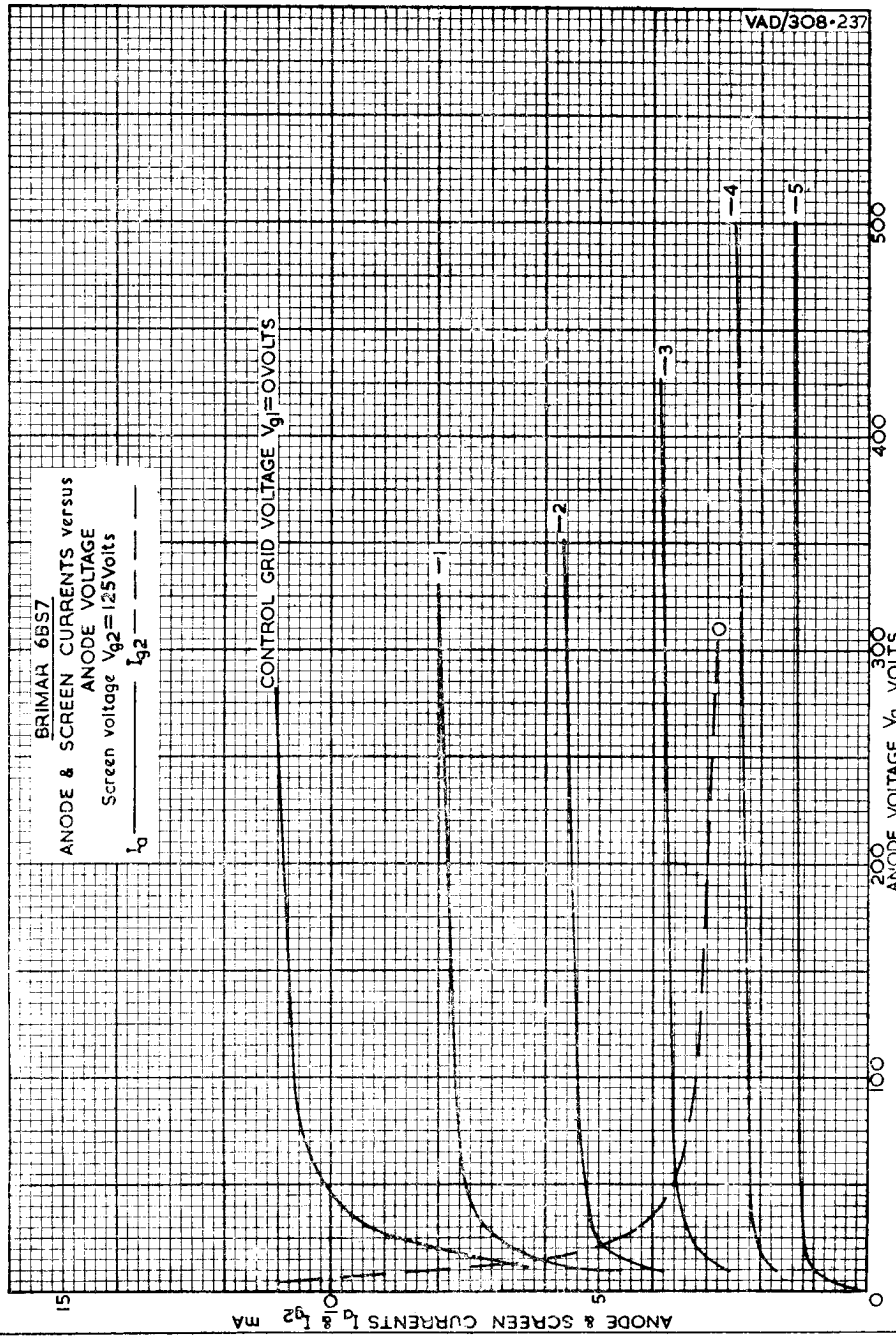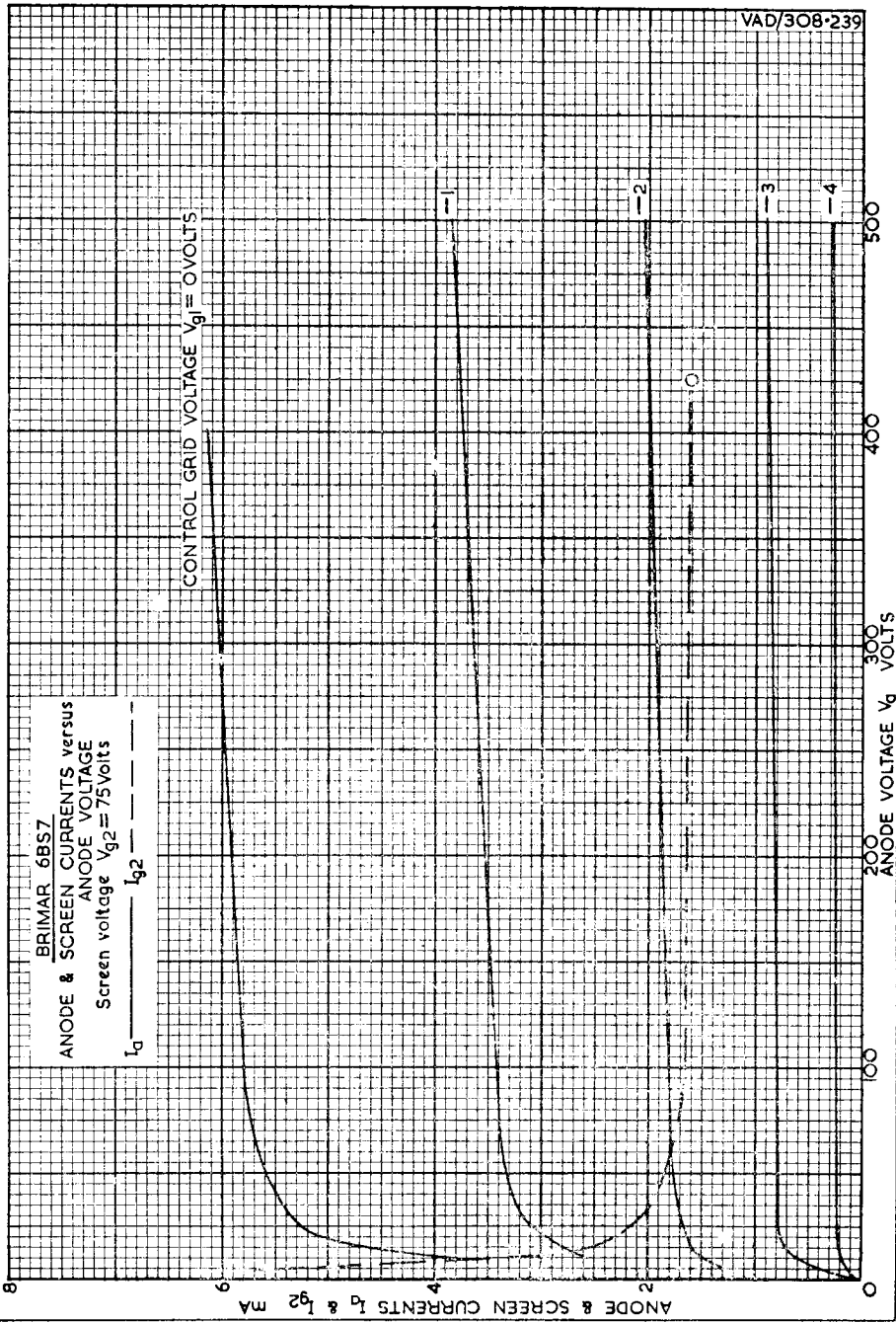
BRIMAR 6BS7
ANODE & SCREEN CURRENTS versus
ANODE VOLTAGE
Screen voltage V_{g2} = 100Volts

I_a ——— I_{g2} — — —

CONTROL GRID VOLTAGE V_{g1} = 0 VOLTS

ANODE VOLTAGE V_a VOLTS

ANODE & SCREEN CURRENTS I_a & I_{g2} mA
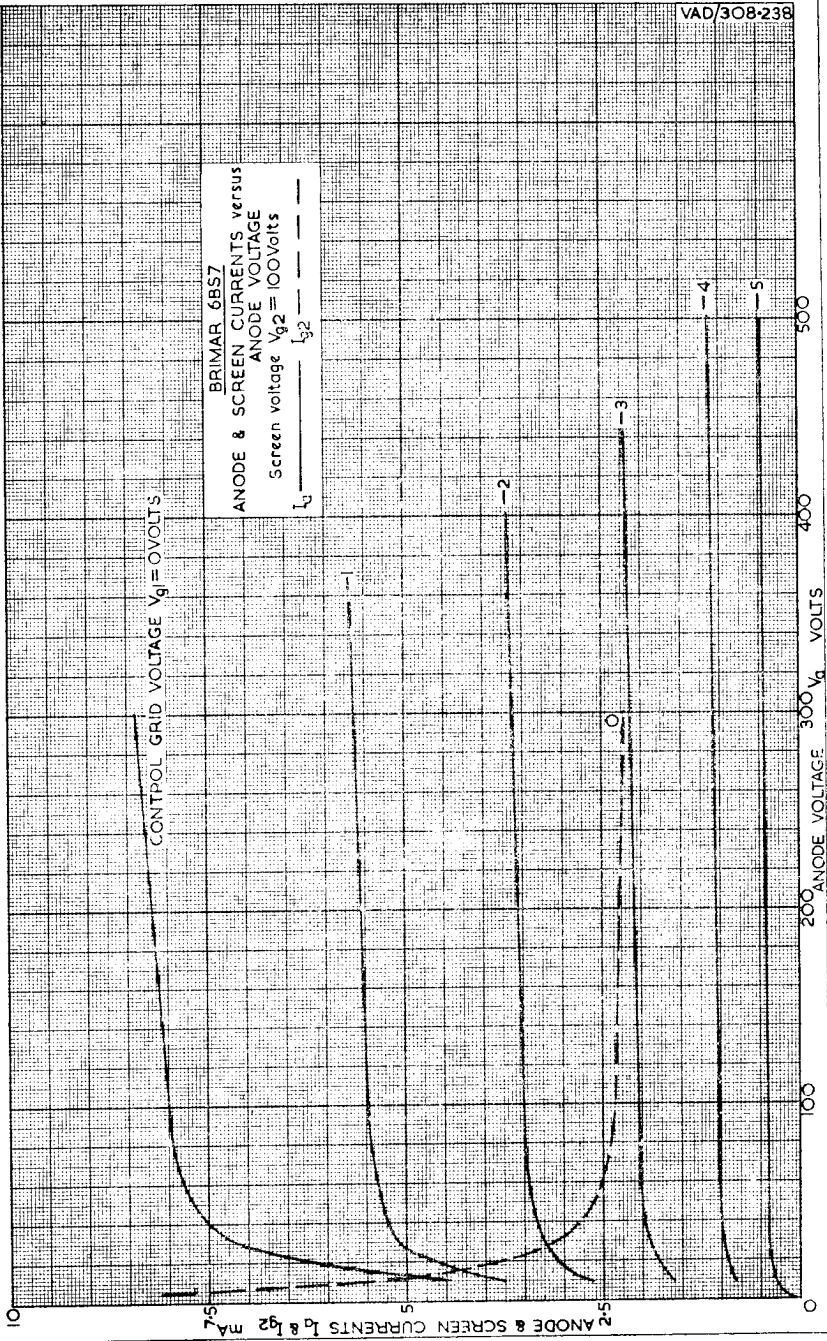
BRIMAR 6BS7
ANODE & SCREEN CURRENTS versus
ANODE VOLTAGE
Screen voltage V_{g2} = 75 volts

I_a ————
I_{g2} — — — —

CONTROL GRID VOLTAGE V_{g1} = 0 VOLTS

ANODE & SCREEN CURRENTS I_a & I_{g2} mA

ANODE VOLTAGE V_a VOLTS

VAD/308·239

VAD/308·240

CONTROL GRID VOLTAGE Vg1 = 0 VOLTS

BRIMAR 6BS7
ANODE & SCREEN CURRENTS versus
ANODE VOLTAGE
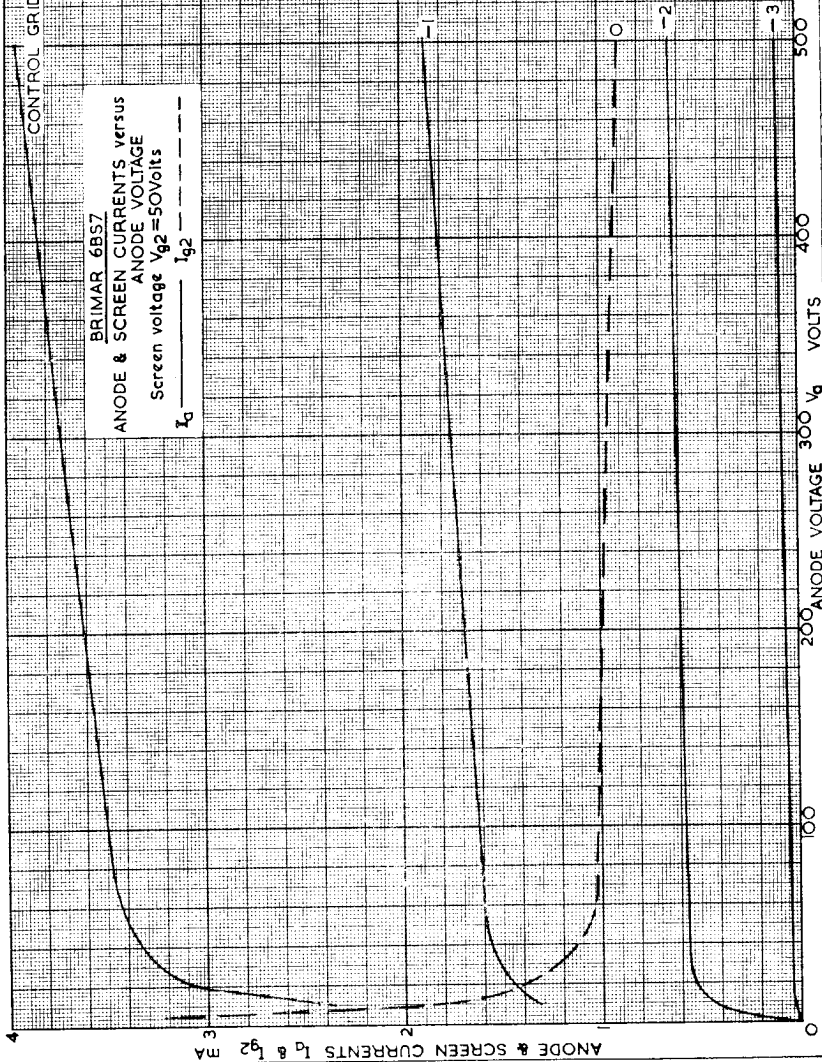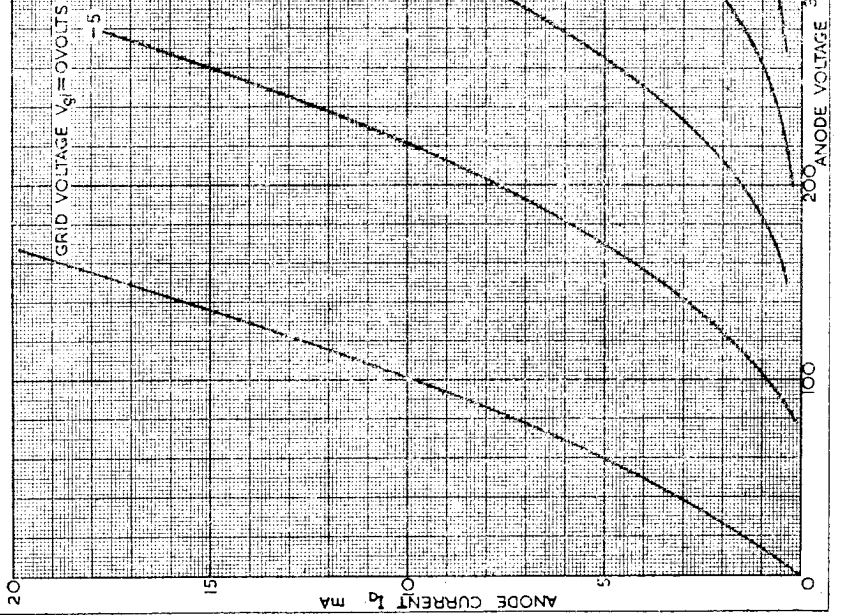Screen voltage Vg2 = 50 Volts
Ia ——— Ig2 — — — —

ANODE VOLTAGE Vg VOLTS

ANODE & SCREEN CURRENTS Ia & Ig2 mA

BRIMAR 6BS7
ANODE CURRENT versus ANODE VOLTAGE
Triode connected
g2 connected to a
g3 connected to k

VAD/308·241

VAD/308·242

BRIMAR 6BS7
ANODE & SCREEN CURRENTS versus
CONTROL GRID VOLTAGE
Anode voltage $V_a = 250$ Volts
I_a —————— I_{g2} — — — —

SCREEN VOLTAGE $V_{g2} = 125$ VOLTS

125
100
100
75
75
50
50

SCREEN CURRENT I_{g2} mA

ANODE CURRENT I_a mA
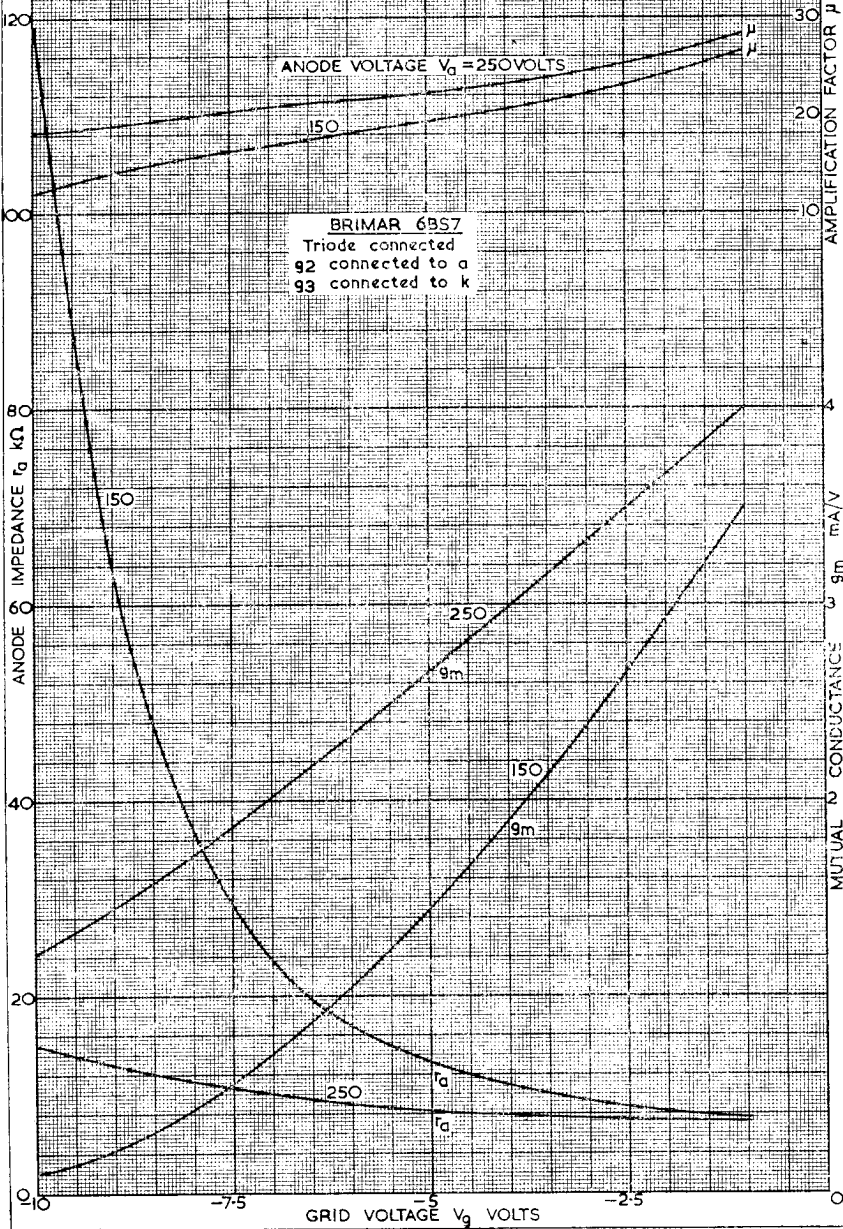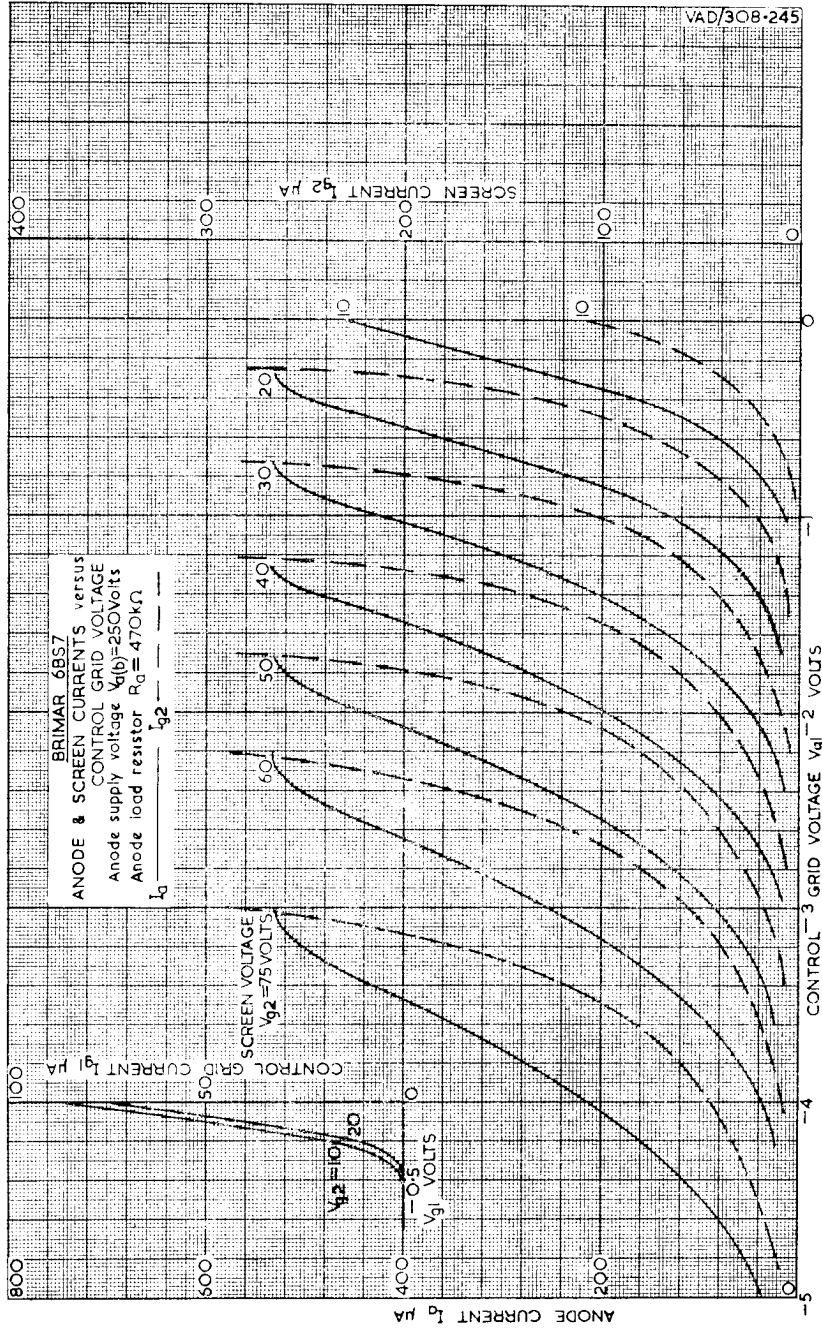
CONTROL GRID VOLTAGE V_{g1} VOLTS

BRIMAR 6BS7
Anode voltage $V_a = 250$ Volts

VAD/308·243

SCREEN VOLTAGE $V_{g2} = 50$ VOLTS

CONTROL GRID VOLTAGE V_{g1} VOLTS

ANODE IMPEDANCE r_a kΩ

MUTUAL CONDUCTANCE g_m mA/V

VAD/308·244

ANODE VOLTAGE V_a = 250 VOLTS

150

BRIMAR 6BS7
Triode connected
g2 connected to a
g3 connected to k

AMPLIFICATION FACTOR μ

ANODE IMPEDANCE r_a KΩ

MUTUAL CONDUCTANCE g_m mA/V

150

250

g_m

150

g_m
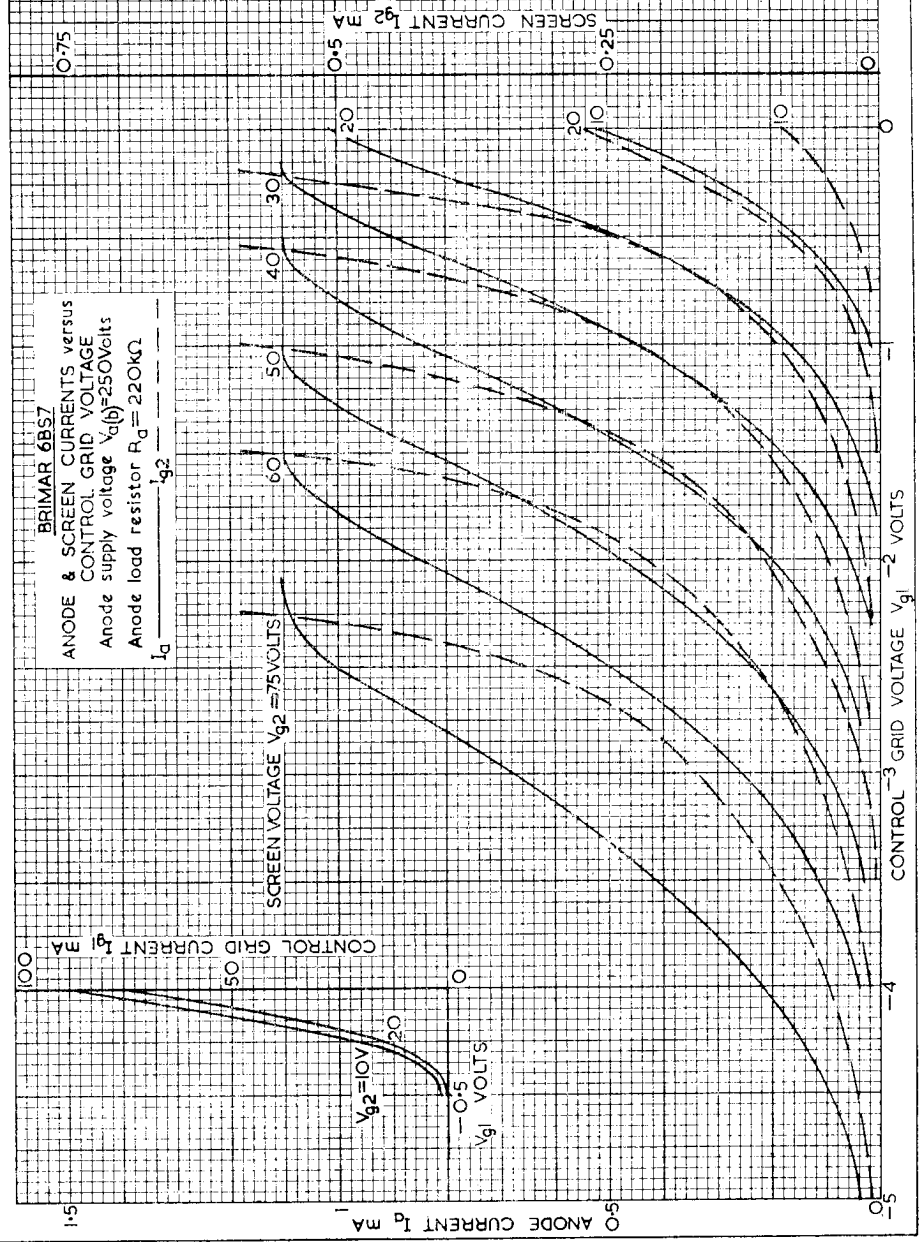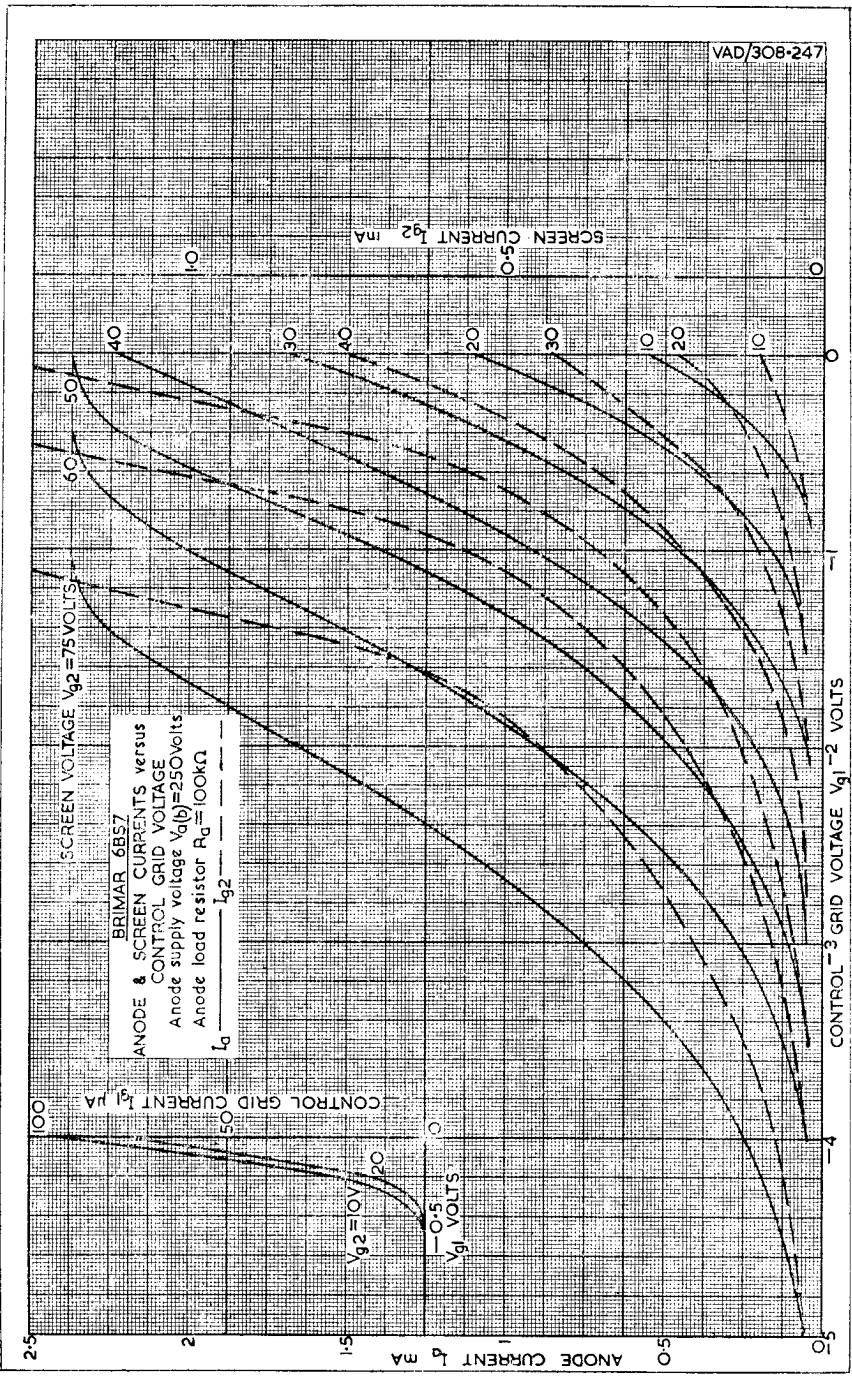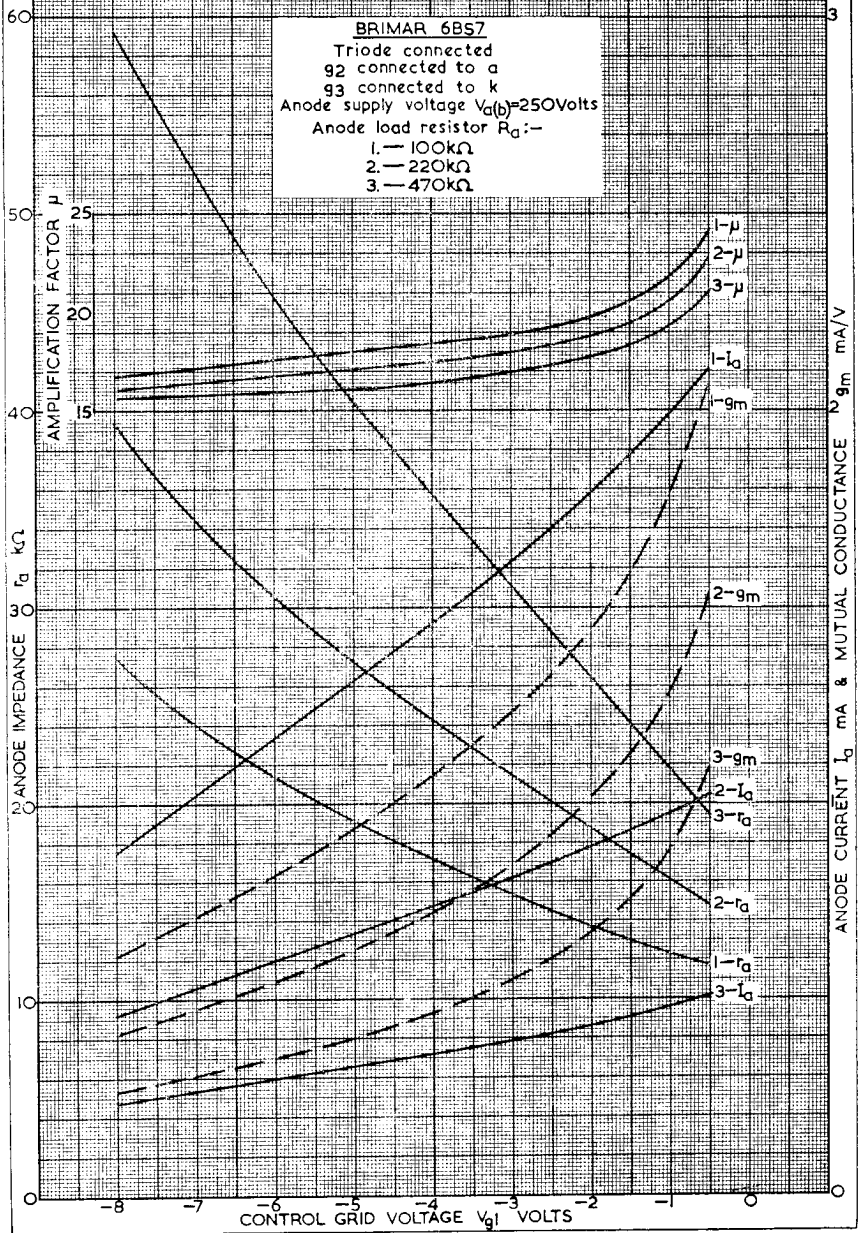
250

r_a

r_a

GRID VOLTAGE V_g VOLTS

VAD/308·245

BRIMAR 6BS7
ANODE & SCREEN CURRENTS versus
CONTROL GRID VOLTAGE
Anode supply voltage $V_{a(b)}=250$ Volts
Anode load resistor $R_a = 470 k\Omega$

VAD/308·246

BRIMAR 6BS7

ANODE & SCREEN CURRENTS versus
CONTROL GRID VOLTAGE
Anode supply voltage $V_{a(b)}$=250Volts
Anode load resistor R_a= 220KΩ

I_a ————
I_{g2} − − − −

BRIMAR 6BS7
ANODE & SCREEN CURRENTS versus
CONTROL GRID VOLTAGE
Anode supply voltage Va(b)=250volts
Anode load resistor Ra=100kΩ

I_a ———
I_{g2} — —

VAD/308·247

VAD/308·248

BRIMAR 6BS7
Triode connected
g2 connected to a
g3 connected to k
Anode supply voltage $V_{a(b)}$=250Volts
Anode load resistor R_a:—
1.— 100kΩ
2.— 220kΩ
3.— 470kΩ

AMPLIFICATION FACTOR μ

ANODE IMPEDANCE r_a kΩ

ANODE CURRENT I_a mA & MUTUAL CONDUCTANCE g_m mA/V

CONTROL GRID VOLTAGE V_{g1} VOLTS

1–μ
2–μ
3–μ
1–I_a
1–gm
2–gm
3–gm
2–I_a
3–r_a
2–r_a
1–r_a
3–I_a

VAD/308·249

BRIMAR 6BS7
PENTODE CONNECTED
DISTRIBUTION OF HUM AS AN R.C.
COUPLED AMPLIFIER.
Control grid resistor $R_{g1}=100k\Omega$
Cathode by pass condenser $=50\mu F$
Bandwidth $=340c/s$
Hum bucking adjusted for minimum hum
$R_a=220k\Omega$ $R_{g2}=1.5M\Omega$
$R_k=1.5k\Omega$ $V_{a(b)}=300V$
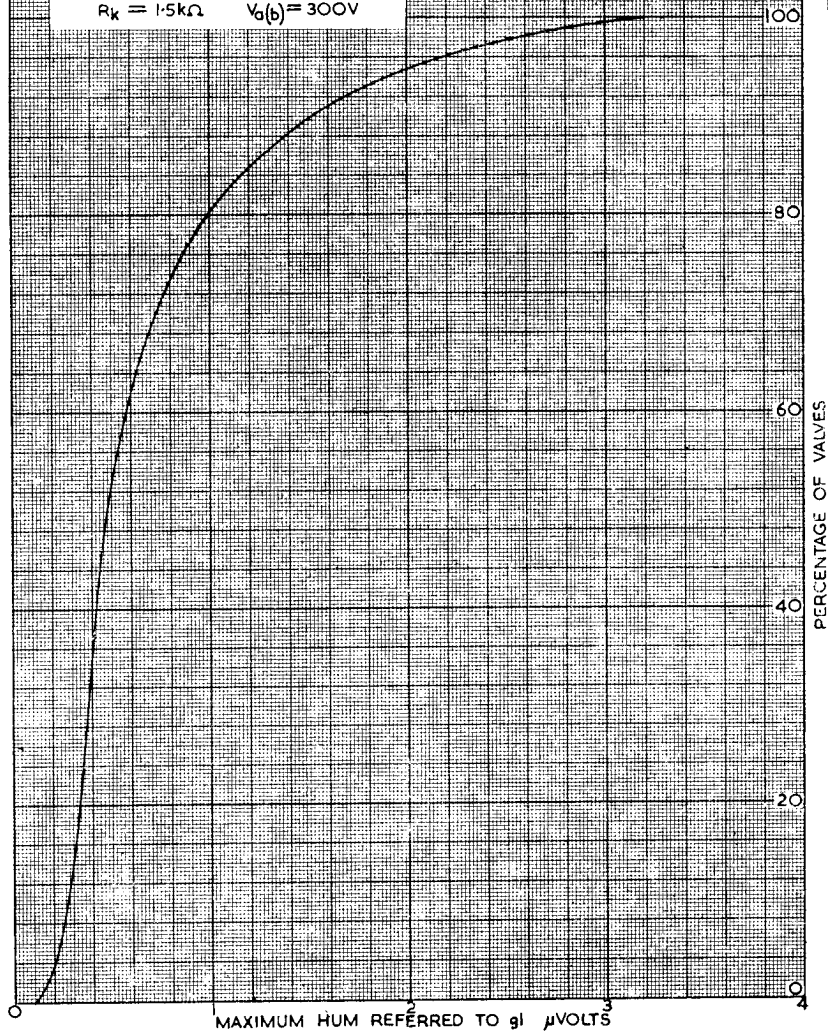
MAXIMUM HUM REFERRED TO g1 µVOLTS

PERCENTAGE OF VALVES

VAD/308·250

BRIMAR 6BS7
PENTODE CONNECTED
DISTRIBUTION OF HISS AS AN R.C.
COUPLED AMPLIFIER
Control grid resistor $R_{g1} = 100k\Omega$
Cathode by pass condenser $= 50\mu F$
$R_a = 220k\Omega$ $R_{g2} = 1\cdot5M\Omega$
$R_k = 1\cdot5k\Omega$ $V_{a(b)} = 300V$
Bandwidth 10kc/s
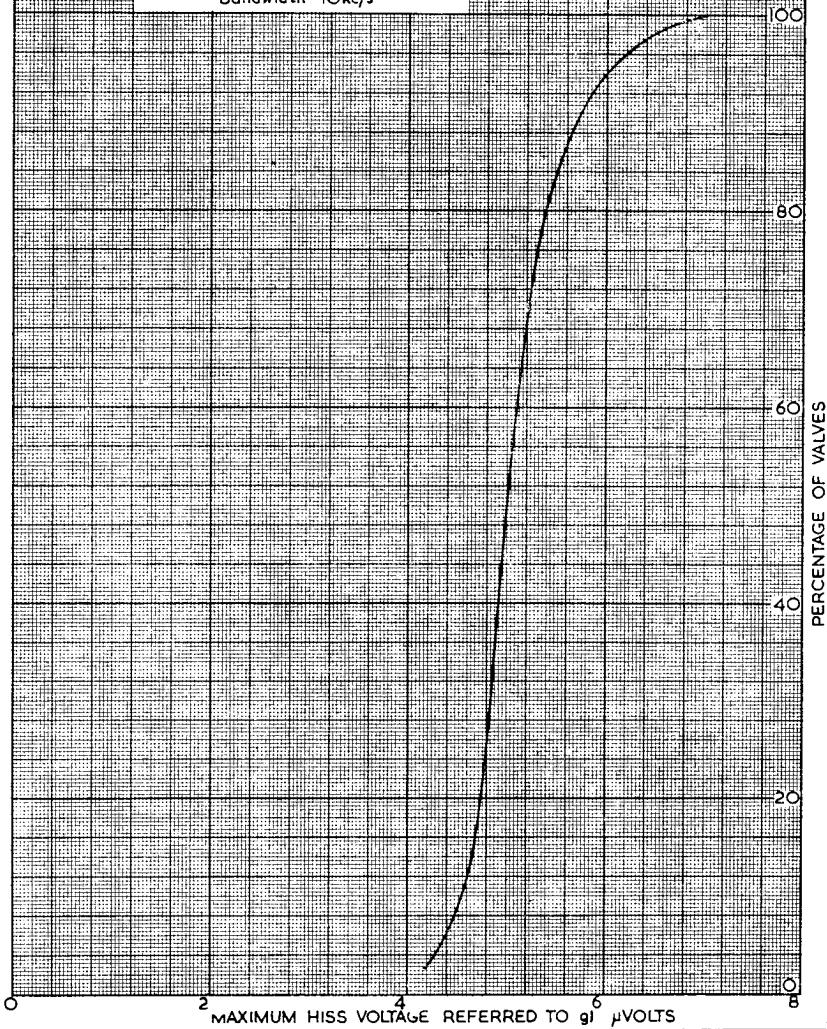
PERCENTAGE OF VALVES

MAXIMUM HISS VOLTAGE REFERRED TO g1 μVOLTS

VAD/308-251

BRIMAR 6BS7
TRIODE CONNECTED
DISTRIBUTION OF HISS AS AN R.C.
COUPLED AMPLIFIER.
Control grid resistor $=100\text{k}\Omega$
Cathode by-pass condenser $=50\mu\text{F}$
$R_a = 220\text{k}\Omega$. $R_k = 14\text{k}\Omega$
$V_{a(b)} = 300\text{V}$
Bandwidth $= 10\text{kc/s}$
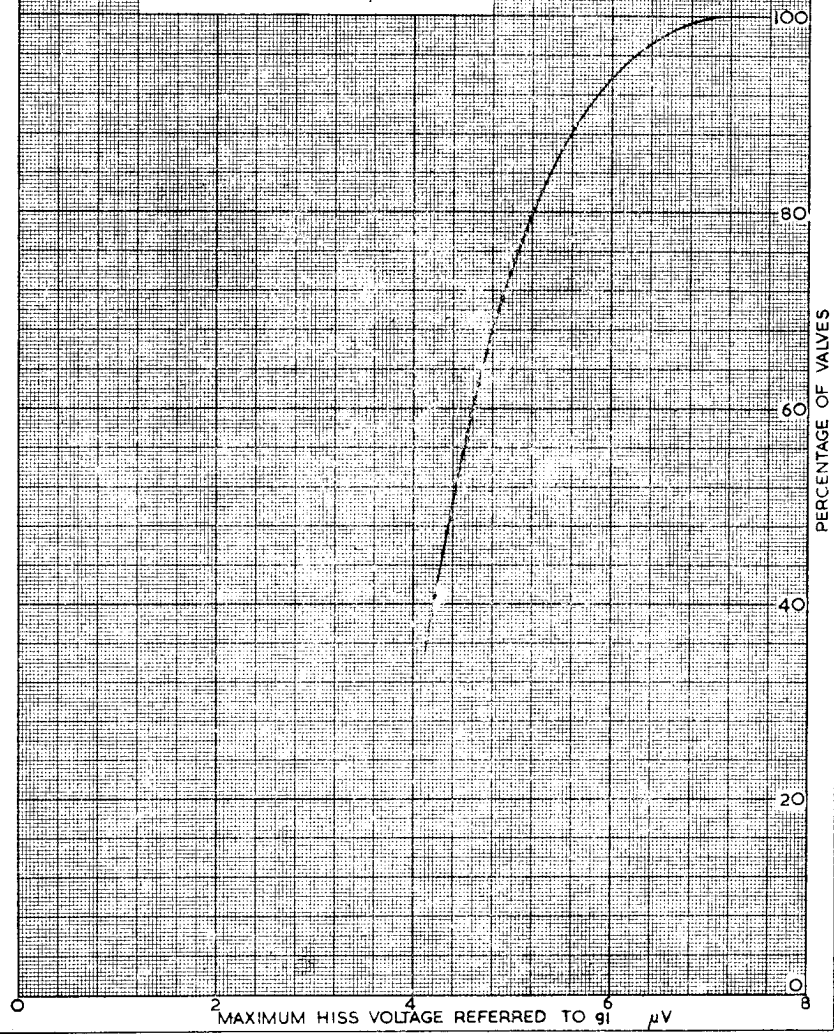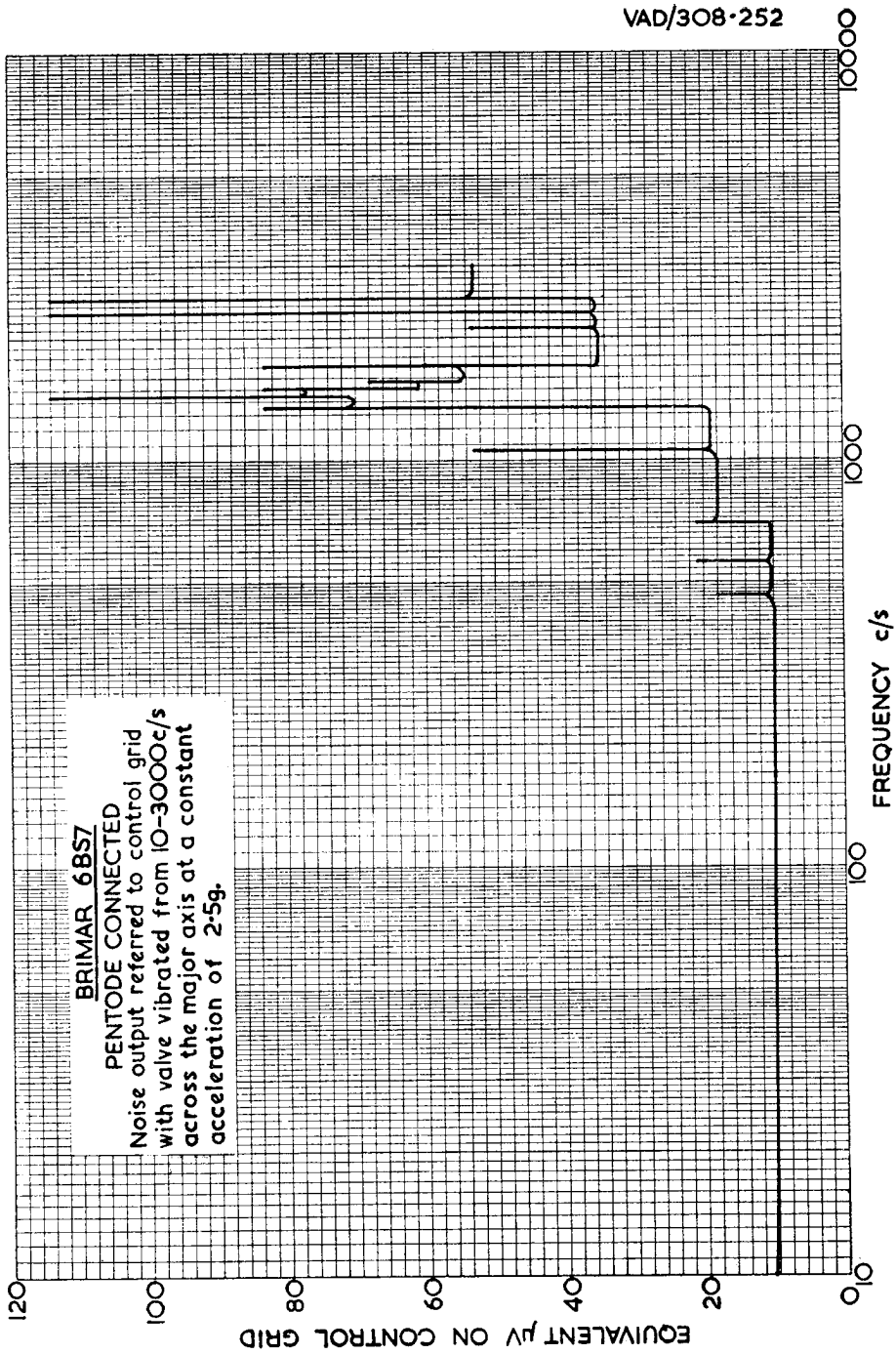
PERCENTAGE OF VALVES

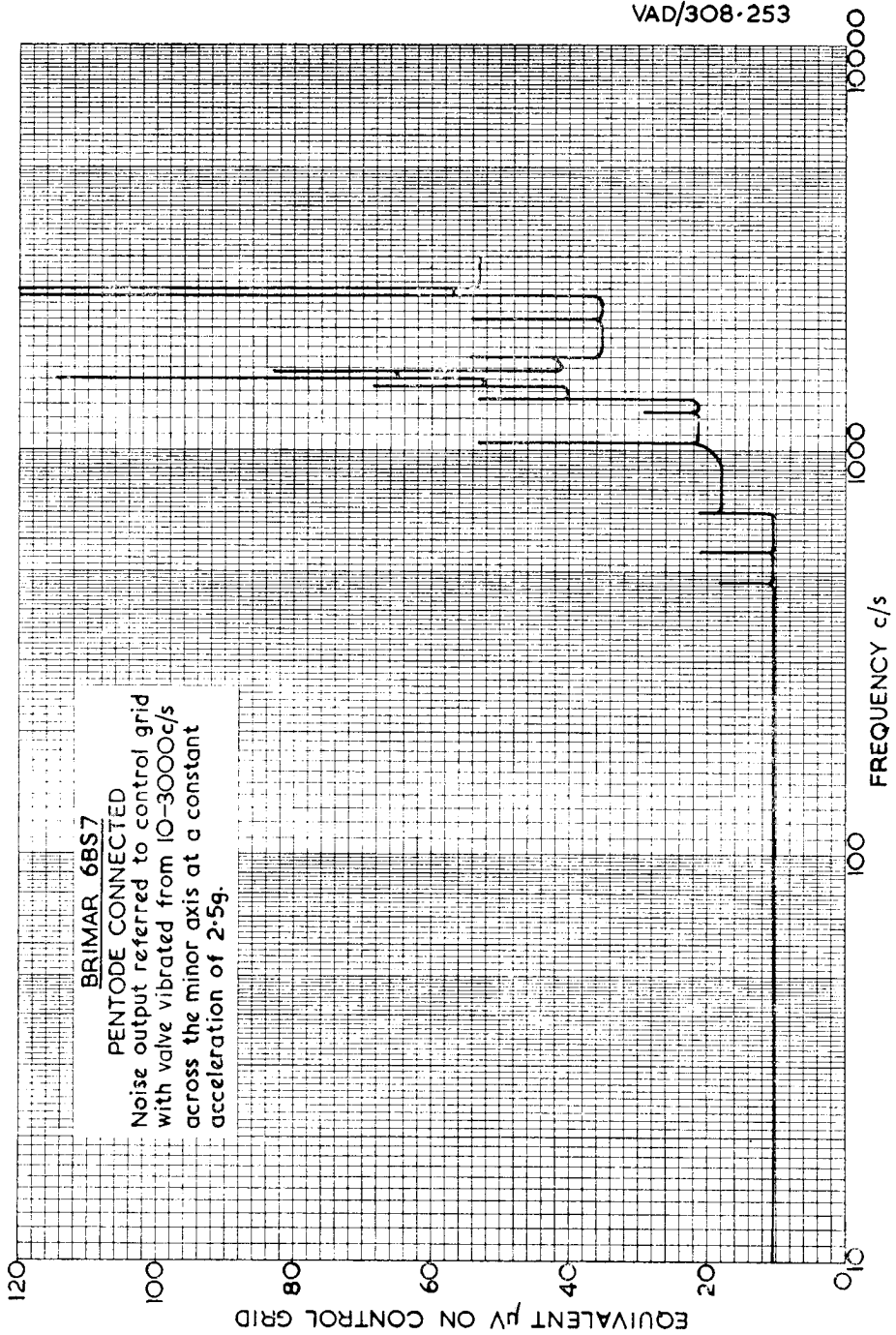MAXIMUM HISS VOLTAGE REFERRED TO g_1 μV

BRIMAR 6BS7
PENTODE CONNECTED
Noise output referred to control grid
with valve vibrated from 10-3000c/s
across the major axis at a constant
acceleration of 2·5g.

FREQUENCY c/s

EQUIVALENT μV ON CONTROL GRID

BRIMAR 6BS7
PENTODE CONNECTED
Noise output referred to control grid
with valve vibrated from 10–3000c/s
across the minor axis at a constant
acceleration of 2·5g.

FREQUENCY c/s

EQUIVALENT μV ON CONTROL GRID

BRIMAR 6BS7
TRIODE CONNECTED
Distribution of
Grid leakage currents
$V_a = 100$ Volts
$V_g = -3$ Volts

VAD/308·254

PERCENTAGE OF VALVES

GRID CURRENT   μA