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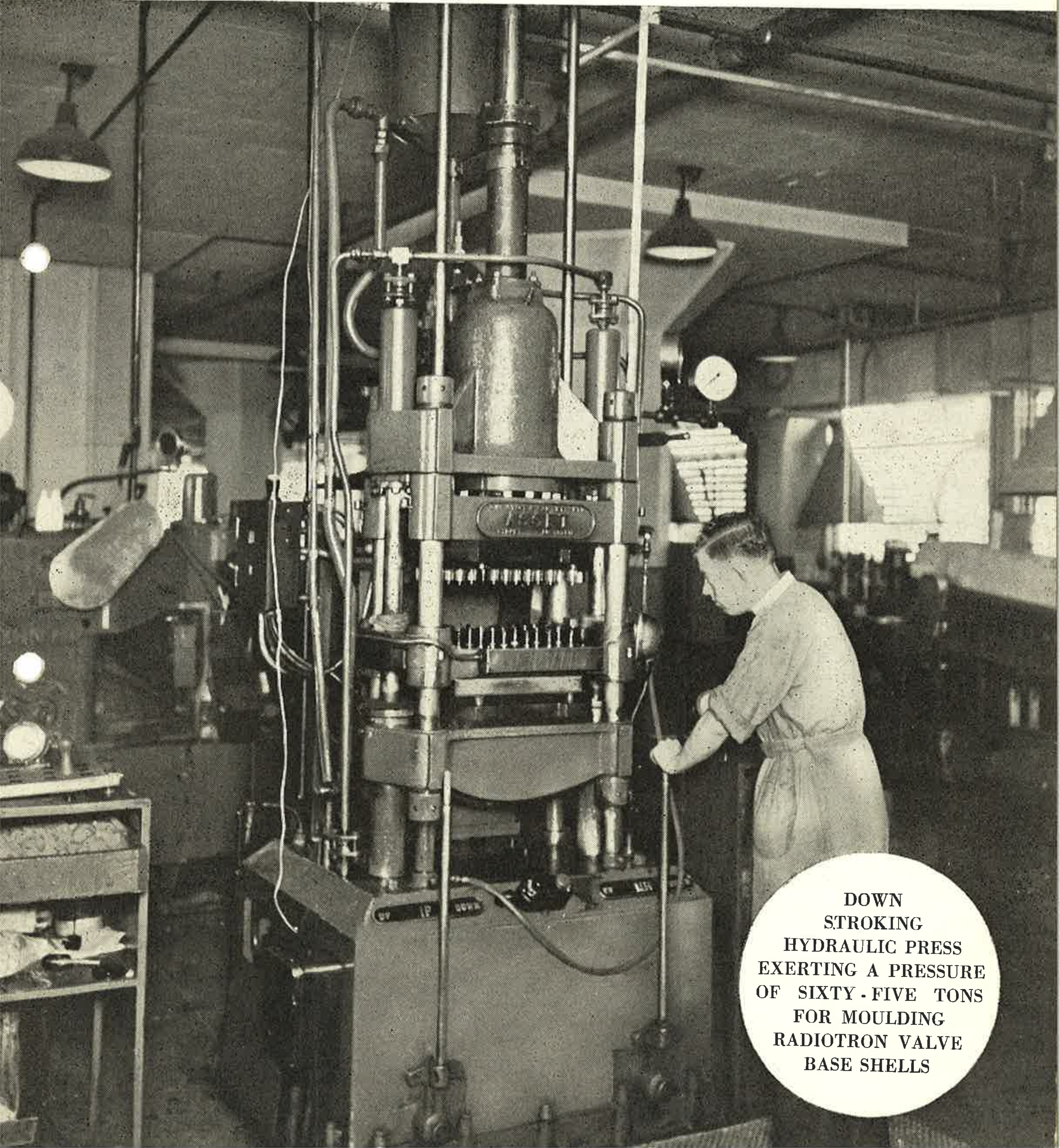

DOWN
STROKING
HYDRAULIC PRESS
EXERTING A PRESSURE
OF SIXTY - FIVE TONS
FOR MOULDING
RADIOTRON VALVE
BASE SHELLS

RADIOTRONICS

Number 122 ★ November/December, 1946

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VALVE DATA SECTION:

Technical Editor
F. Langford-Smith, B.Sc., B.E.

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Valve Conversion Factors

By F. LANGFORD-SMITH, B.Sc., B.E.

(a) THE BASIS OF VALVE CONVERSION FACTORS

Valve Conversion Factors are based on the well-known mathematical expression of valve characteristics

$$I_b = A\,(E_b - \mu E_c)^x \tag{1}$$

where I_b = plate current
E_b = plate voltage
E_g = grid voltage
A = a constant depending upon the type of valve.
μ = amplification factor
and x = an exponent, with a value of approximately 1.5 over the nearly straight portion of the characteristics.

If we are concerned merely with *changes* in the voltages and currents, then we can reduce the expression to the form

$$I_b \propto (E_b - \mu E_c)^x \tag{2}$$

Now if we agree to change the grid voltage in the same proportion as the plate voltage, we obtain the very simple form

$$I_b \propto E_b^x \tag{3}$$

Finally, if we take x as 1.5 or 3/2, we have the approximation

$$I_b \propto E_b^{3/2} \tag{4}$$

Put into words, this means that the plate current of a valve varies approximately as the three-halves power of the plate voltage, provided that the grid voltage is varied in the same proportion as the plate voltage.

The same result may be obtained with pentodes, provided that both the grid and screen voltages are varied in the same proportion as the plate voltage. This result is the basis of Valve Conversion Factors, so that we must always remember that their use is restricted to cases in which all the electrode voltages are changed in the same proportion.

Let F_e be the factor by which all the voltages are changed (i.e. grid, screen, and plate), and let I'_b be the new plate current.

Then $$I'_b \propto (F_e.E_b)^{3/2} \tag{5}$$

But $I'_b = F_i.I_b$

where F_i is the factor by which the plate current is changed.

$$\therefore\ F_i.I_b \propto (F_e.E_b)^{3/2} \tag{6}$$

From the combination of (4) and (6) it will be seen that

$$F_i = F_e^{3/2} \tag{7}$$

Now the power output is proportional to the product of plate voltage and plate current so that

$$P_o \propto E_b.I_b \tag{8}$$

and $$P'_o \propto (F_e.E_b)\,(F_i.I_p) \tag{9}$$

$$\therefore\ P'_o \propto F_e.F_i\,(E_b.I_p) \tag{10}$$

$$\propto F_e.F_i\,(P_o) \tag{11}$$

We may therefore say that the power conversion factor F_p is given by the expression

$$F_p = F_e.F_i \tag{12}$$

$$\therefore\ F'_p = F_e^{5/2} \tag{13}$$

The Mutual Conductance is given by

$$g_m = \frac{\text{change of plate current}}{\text{change of grid voltage}}$$

$$\therefore\ F_{gm} = F_i/F_e = F_e^{3/2}/F_e = F_e^{\frac{1}{2}} \tag{14}$$

The Plate Resistance is given by

$$r_p = \frac{\text{change of plate voltage}}{\text{change of plate current}}$$

$$\therefore\ F = F_e/F_i = F_e/F_e^{3/2} = F_e^{-\frac{1}{2}} \tag{15}$$

This also applies similarly to the load resistance and cathode bias resistance.

We may therefore summarize our results so far:—

$$F_i = F_e^{3/2} \tag{7}$$

$$F_p = F_e^{5/2} \tag{13}$$

$$F_{gm} = F_e^{\frac{1}{2}} \tag{14}$$

$$F_r = F_e^{-\frac{1}{2}} \tag{15}$$

These are shown in graphical form on the Valve Conversion Factor Chart on page 329 of the Radiotron Designer's Handbook (Third Edition) and in the Radiotron Loose-leaf Valve Data Book.

(b) THE USE OF VALVE CONVERSION FACTORS

The use of valve conversion factors is described briefly on page 328 of the Radiotron Designer's Handbook (3rd edition) and on the back of the Loose-Leaf Valve Data Book. The explanation below is somewhat expanded so as to explain the application of these conversion factors as simply as possible.

It is important to remember that the conversion factors may only be used when all the voltages (grid, screen, and plate) are changed simultaneously by the same factor. If it is required to make any other adjustments, these may be carried out before or after using conversion factors, by following the method given at the end of this article under the heading "The Calculation of Valve Characteristics".

Conversion factors may be used on any type of valve whether triode, pentode or beam tetrode, and in any class of operation whether class A, class AB1, class AB2 or class C.

The use of conversion factors is necessarily an approximation, so that errors will occur which become progressively greater as the voltage factor becomes greater. In general it may be taken that voltage conversion factors down to about 0.7 and up to about 1.5 times will be approximately correct. When the voltage factors are extended beyond these limits down to 0.5 and up to 2.0, the accuracy becomes considerably less, and any further extension becomes only a rough indication.

The example given below is a straightforward case of a pentode valve whose characteristics are given for certain voltages and which it is desired to operate at a lower plate voltage.

Plate and screen voltage	250 volts
Control grid voltage	–15 volts
Plate current	30 mA.
Screen current	6 mA.
Mutual conductance	2,000 µmhos
Power Output	2.5 watts

It is required to determine the optimum operating conditions for a plate voltage of 200 volts.

The Voltage Conversion Factor (F_e) = 200/250 = 0.8.

The new screen voltage will be 0.8 × 250 = 200 volts.

The new control grid voltage will be — (0.8 × 15) = –12 volts.

Reference to the chart then gives the following:

Current Conversion Factor (F_i)	0.72
Mutual Conductance Conversion Factor (F_{gm})	0.89
Power Output Conversion Factor (F_p)	0.57

The new plate current will be 0.72 × 30 = 21.6 mA.

The new screen current will be 0.72 × 6 = 4.3 mA.

The new mutual conductance will be 0.89 × 2,000 = 1,780 µmhos.

The new power output will be 0.57 × 2.5 = 1.42 watts.

There are two effects not taken into account by conversion factors. The first is contact potential, but its effects only become serious for small grid bias voltages. The second is secondary emission, which occurs with the old type of tetrode (not beam valves) at low plate voltages; in such a case the use of conversion factors should be limited to regions of the plate characteristic in which the plate voltage is greater than the screen voltage. With beam power amplifiers the region of both low plate currents and low plate voltages should also be avoided for similar reasons.

Greater accuracy in the use of conversion factors over a wide range of screen voltages may be obtained, if curves are available for zero bias at a number of different screen voltages.*

These are shown in the Loose-Leaf Valve Data Book under type 6L6-G (front of Sheet 3) for screen voltages of 50, 100, 150, 200, 250 and 300

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* R.C.A. Application Note No. 61 "The conversion of a 6L6 plate family to new screen voltage conditions."

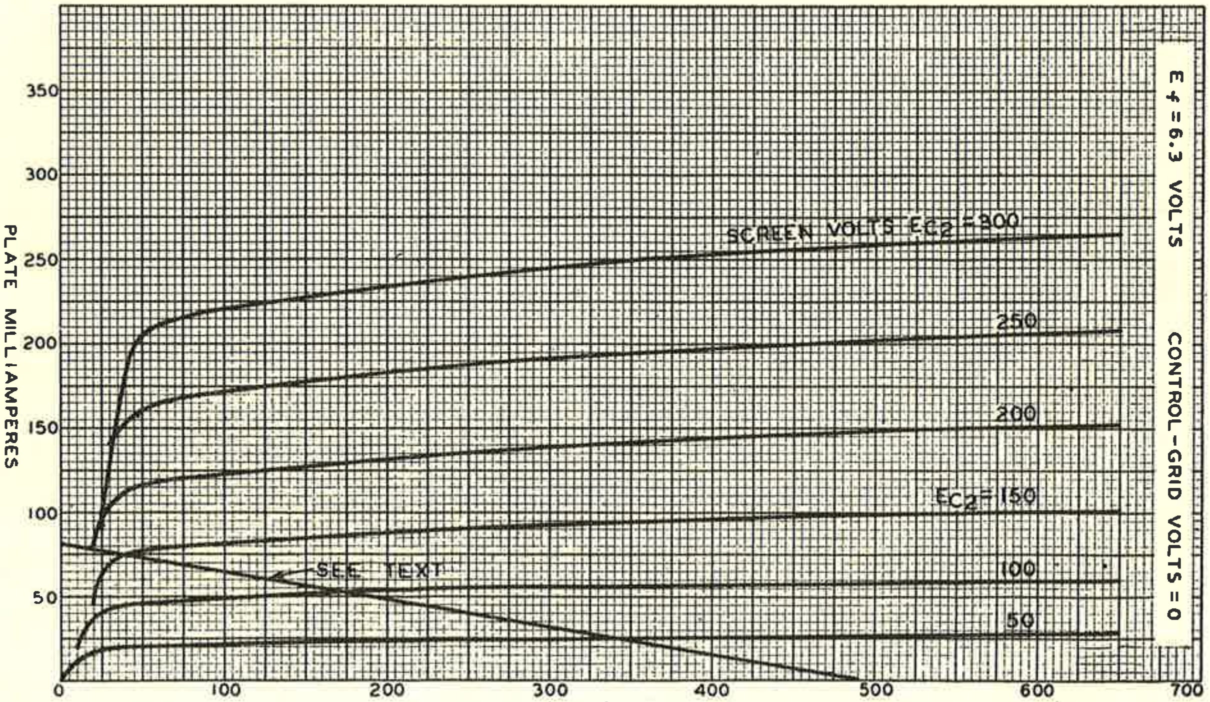


FIG. I

Fig. 1.—Average plate characteristics of type 6L6 or 807 with screen voltage as variable.

volts. When the plate, screen, and grid voltages of a pentode or beam power amplifier are multiplied by the same voltage conversion factor, the ratio of the plate current at a given grid bias to that at zero bias does not change. In order to convert a given family of plate characteristics to a new screen voltage condition, it is therefore only necessary to have a zero-bias plate characteristic for the screen voltage of interest.

Example

Suppose that the family of plate characteristics shown in Fig. 2, which obtains for a screen voltage of 250 volts, is to be converted for a screen voltage of 300 volts. The zero-bias plate characteristic for E_{c2} = 300 volts, which is shown in Fig. 1, is replotted, as at top in Fig. 3.

Since all bias values shown in Fig. 2 must be multiplied by 300/250 = 1.2, corresponding plate characteristics for the new family obtain for bias values that are 20 per cent. higher than those shown in Fig. 2. Consider the conversion of the –10–volt characteristic of Fig. 2. At a plate voltage (F_b) of 250 volts in Fig. 2, AB/AC = 100/187 = 0.535. On the new characteristic in Fig. 3, which corresponds to a bias of –12 volts, A′B′/A′C′ must also equal 0.535 at E_b = 300 volts. Therefore, A′B′ = 0.535 × A′C′. From the given zero-bias characteristic of Fig. 3, A′C′ = 244 at E_b = 300 volts; hence A′B′ = 131 milliamperes. At E_b = 200 volts in Fig. 2, DE/DF = 98/183 = 0.535. Therefore, at E_b = 200 × 1.2 = 240 volts in Fig. 3, D′E′ = 0.535 × 238 = 127 milliamperes. This process is repeated for a number of plate voltages and a smooth curve is drawn through the points on the new characteristic.

The factor 0.535 can be used for the –10–volt characteristic at plate voltages greater than that at which the knee on the zero-bias characteristic of Fig. 2 occurs; for plate voltages in the immediate region of the knee, a new factor should be determined for each point. The plate characteristics of Fig. 2 should not be converted to the left of the dashed line of Fig. 2 because of space-charge effects. This limitation is not a serious one, however, because the region over which the valve usually operates can be converted with sufficient accuracy for most applications. The converted plate characteristic of Fig. 3 for E_{c1} = –30 volts was obtained in a similar manner to that for E_{c1} = –12 volts.

The curves of Fig. 3 were checked under dynamic conditions by means of a cathode-ray tube. The dotted portions show regions where measured results departed from calculated results. Because the usual load line does not pass through regions in which plate current is affected by space charge, the calculated and measured curves yield nearly the same dynamic characteristics.

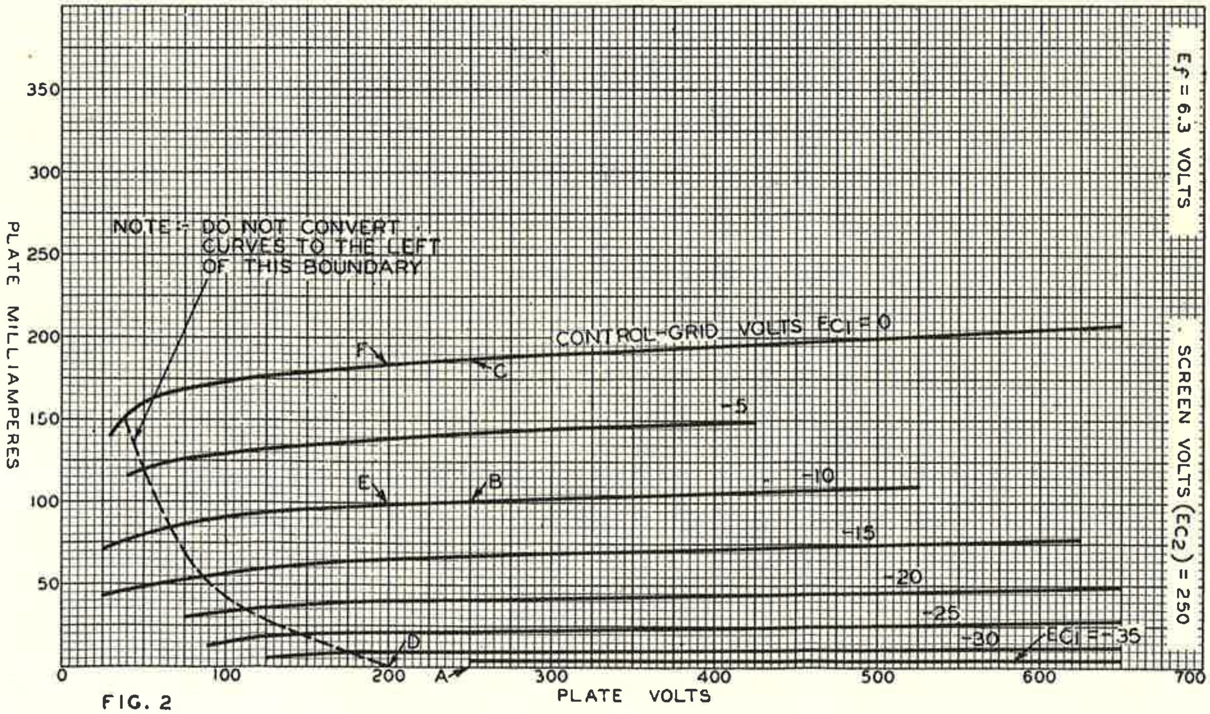


FIG. 2

Fig. 2.—Average plate characteristic of type 6L6 or 807 with control grid voltage as variable.

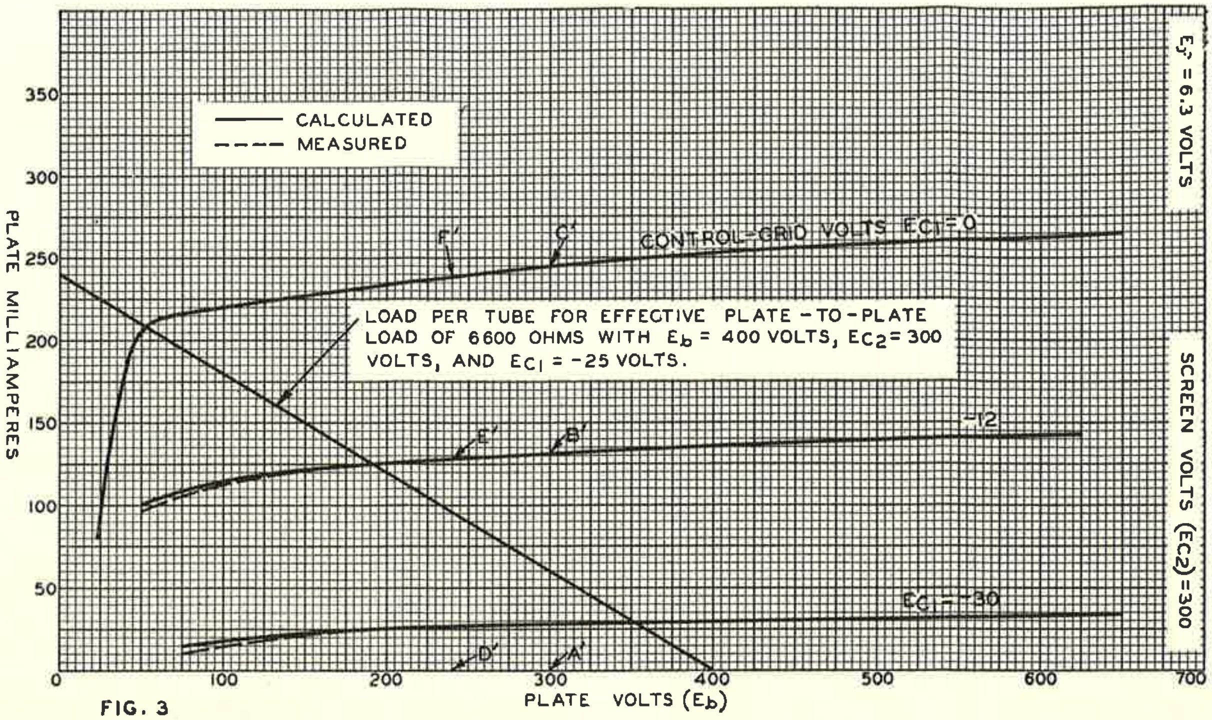


FIG. 3

Fig. 3.—Plate characteristics of type 6L6 or 807 obtained by conversion.

The Calculation of Second Harmonic Distortion

A formula is given on page 282 of the Radiotron Designer's Handbook for the calculation of second harmonic distortion from a knowledge of the relative lengths of the upper and lower portions of the load-line. In figure 1, the operating point is at Q and the loadline is EQG. If there is no second harmonic distortion, EQ will be equal in length to QG, but in all practical cases with triodes, and in the majority of cases with pentodes, there will be a certain amount of second harmonic. The formula given in the Radiotron Designer's Handbook is

$$\% \text{ second harmonic } (H_2) = \frac{EQ - QG}{2\,(EQ + QG)} \times 100$$

This may be put into a form more convenient for operation on a slide rule, using the ratio EQ/QG as a basis —

$$H_2 = \frac{\dfrac{EQ}{QG} - 1}{2\left(\dfrac{EQ}{QG} + 1\right)} \times 100$$

An example will show how simple this becomes with a slide rule:—

If $EQ/QG = 1.2$
Then $EQ/QG - 1 = 0.2$
and $EQ/QG + 1 = 2.2$

$$\therefore H_2 = \frac{0.2}{2 \times 2.2} \times 100$$
$$= 4.55\%$$

The procedure may be carried out by a single operation on the slide rule which is considerably more rapid and more accurate than referring to a curve showing the relationship between second harmonic and EQ/QG, although the latter is helpful in giving a general picture of the relationship.

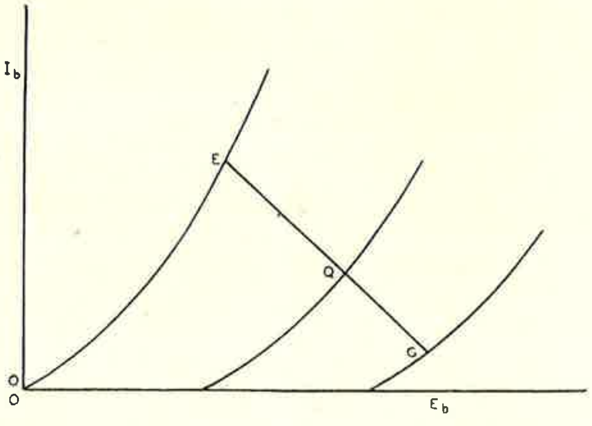


FIG I

The Calculation of Valve Characteristics Other Than Those Published

By F. LANGFORD-SMITH, B.Sc., B.E.

It is frequently desired to make minor modifications in the operating conditions of a valve, such as by a slight increase or decrease of the plate voltage, change in grid bias or load resistance. The purpose of this article is to describe the effects which these changes will have on the other characteristics of the valve.

SUMMARY OF PROCEDURE

The procedure to be adopted is summarized below:—

(a) IN THE ABSENCE OF VALVE CURVES.

Triode.—Use conversion factors to adjust the plate voltage to its new value, and apply the correct conversion factors to all other characteristics; then adjust the grid bias to its desired new value by the method given below, and finally adjust the load resistance.

Pentode or beam power amplifier.—Use conversion factors to adjust the screen voltage to its new value, and apply the correct conversion factors to all other characteristics; then adjust the plate voltage to the desired new value by the method given below; then adjust the grid bias to its desired new value, and finally adjust the load resistance.

(b) WHEN VALVE CURVES ARE AVAILABLE.

Triode with no d.c. load resistance in plate circuit.

Refer to the published characteristics to find the maximum plate dissipation; calculate the maximum plate current which can be permitted at the desired new plate voltage; select a suitable plate current for the particular application (which must not exceed the maximum); and refer to the curves to find the grid bias to give the desired plate current.

If the valve is a power amplifier, the load resistance may be determined by one of the methods described below.

Triode with resistor in plate circuit.

Use conversion factors, with adjustments as required in accordance with the method given below. The plate supply voltage may be up to twice the maximum valve plate voltage, since approximately half the voltage drop occurs in the plate load resistor.

Pentode or beam power amplifier.

If curves are available for the published value of screen voltage, use the method below to obtain the characteristics for a plate voltage such that, when conversion factors are applied, the plate voltage is the desired value. For example, if curves and characteristics are available for plate and screen voltages of 250 volts, and it is desired to determine the characteristics for a plate voltage of 360 volts and screen voltage of 300 volts: firstly determine the characteristics for a plate voltage of 300 and screen voltage of 250; then apply voltage conversion factors of 1.2 to the plate, screen and grid voltages so as to provide the desired conditions.

If curves are available for the new value of screen voltage, use conversion factors to bring the screen voltage to the desired value, then apply the method below to adjust the plate voltage, load resistance and grid bias.

THE EFFECT OF CHANGES IN OPERATING CONDITIONS

1. EFFECT OF CHANGE OF PLATE VOLTAGES OF PENTODES AND BEAM POWER AMPLIFIERS.

(a) On Plate Current.

The plate current of a pentode or beam power valve is approximately constant over a wide range of plate voltages, provided that the plate voltage is maintained above the "knee" of the curve. The increase of plate current caused by an increase in plate voltage from E_{b1} to E_{b2} is given by the expression

$$\Delta I_b = \frac{\Delta E_b}{r_p} = \frac{E_{b2} - E_{b1}}{r_p} \quad \ldots\ldots\ldots \quad (1)$$

In many cases the plate characteristic curves are available, and the change in plate current may be read from the curves.

(b) On Screen Current.

In the case of both pentodes and beam power valves the total cathode current (i.e., plate plus screen currents) is approximately constant over a wide range of plate voltages. The increase in plate current from E_{b1} to E_{b2} is approximately equal to the decrease in screen current over the same range.

(c) On Load Resistance and Power Output.

The plate characteristics of a typical power pentode are shown in Fig. 1 in which I_{b1} is the "published" plate current at plate voltage E_{b1} and grid bias $-E_{c1}$. The loadline MPJ swings up to I_{max} at $E_c = 0$ and down to I_{min} at $2E_c$, the assumption being made that the $2E_c$ curve is straight and horizontal over the range of plate voltages in which we are interested.

If the plate voltage is increased to E_{b2}, the new loadline will be MP'H, the point M being common to both, since it is at the knee of the characteristic. The quiescent operating point P' is at a higher plate current than P, the difference being ΔI_b.

Since the power output is proportional to the area of the triangle under loadline, it is also proportional to the value of the load resistance, all triangles having ML as a common side. It may readily be shown that

$$R_L = \frac{E_{b1} - E_{min}}{I_{max} - I_{b1}}$$

and

$$R'_L = \frac{E_{b2} - E_{min}}{I_{max} - I_{b2}}$$

$$\therefore \frac{R'_L}{R_L} = \frac{E_{b2} - E_{min}}{E_{b1} - E_{min}} \cdot \frac{I_{max} - I_{b1}}{I_{max} - I_{b2}} \quad \ldots (2)$$

which is also the ratio of the output powers. If $I_{b2} = I_{b1}$ or the rise of plate current is neglected as an approximation, then

$$\frac{R'_L}{R_L} = \frac{E_{b2} - E_{min}}{E_{b1} - E_{min}} \quad \ldots\ldots\ldots (3)$$

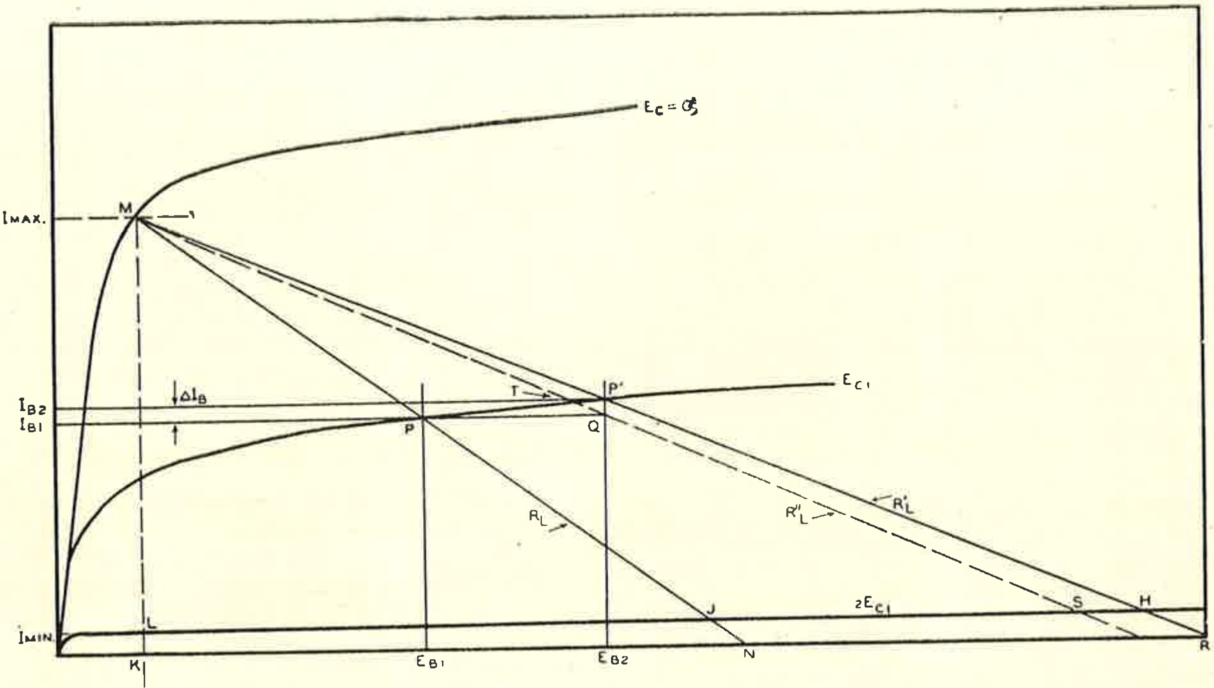


Fig. 1.—The effect of change of plate voltage on load resistance and power output of a typical power pentode.

As an example, apply this to type 6V6-GT under the following conditions:—

	Published Condition.	Desired Condition.	
Plate voltage	250	300	V
Screen voltage	250	250	V
Grid voltage	—12.5	—12.5	V
Load resistance	5000	see below	ohms
Plate current (I_{b1})	47	48*	mA.
Peak plate current (I_{max})	90*	90*	mA.
Min. plate current (I_{min})	8*	8*	mA.
Min. plate voltage (E_{min})	35	35	V
Power output	4.5	see below	W

* from curve

Using equation (2) —

$$\frac{R'_L}{R_L} = \frac{300 - 35}{250 - 35} \cdot \frac{90 - 47}{90 - 48}$$

$$= \frac{265}{215} \cdot \frac{43}{42}$$

$$= 1.26$$

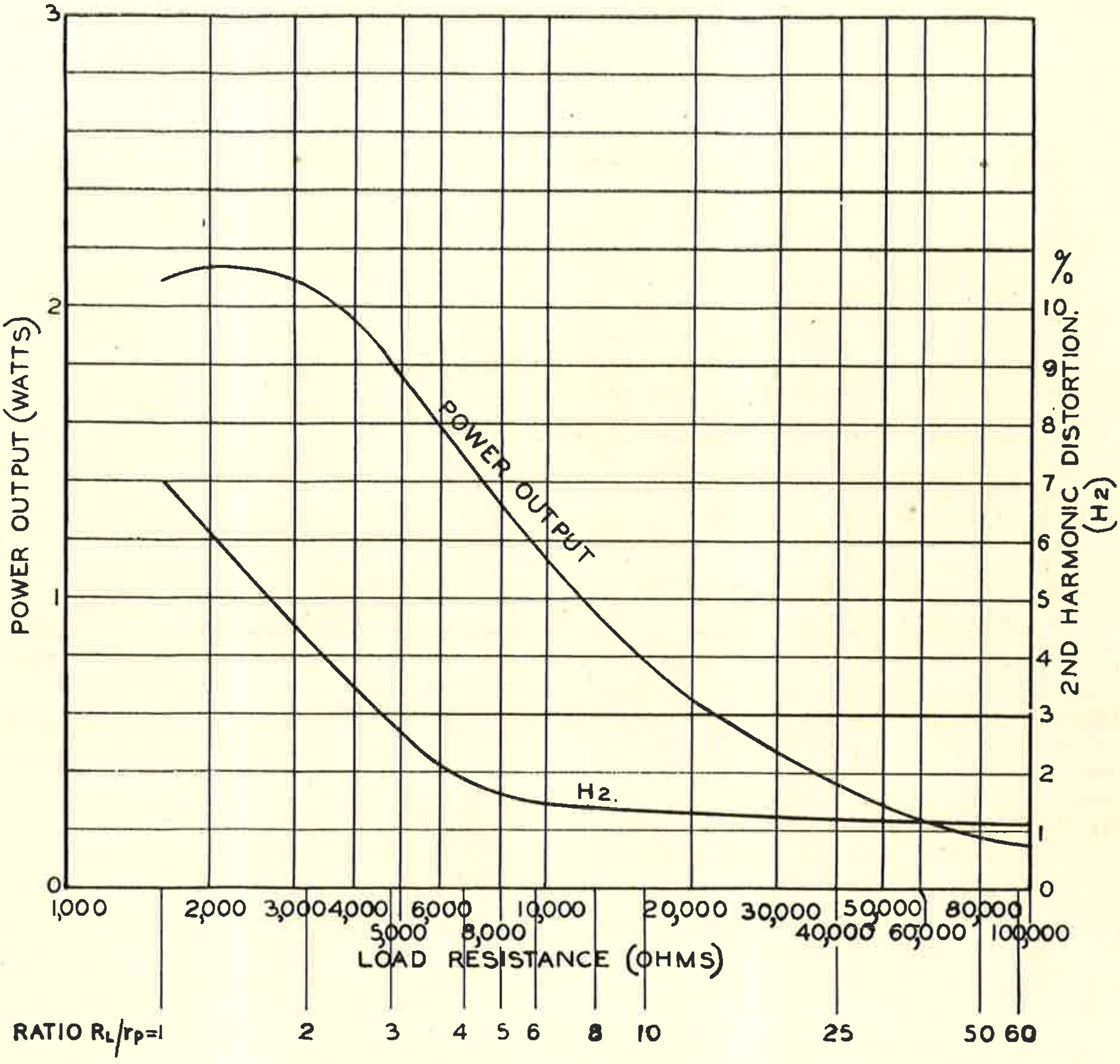
$$\therefore R'_L = 1.26 \times 5{,}000 = 6{,}300 \text{ ohms}$$

The increase of power output is in proportion to the increase in load resistance.

i.e. $P_o = 4.5 \times 1.26 = 5.66$ watts.

This method is remarkably accurate when there is very small rectification in the plate circuit, as is usually the case with power pentodes. With beam power amplifiers of the 6L6 and 807 class, in which the rectification is considerable (strong second harmonic component), the "corrected" loadline should be used as a basis, and the values of I_{max}, I_{b1} and E_{min} should be those corresponding to the corrected loadline.

If the rise in plate current (ΔI_b) is considerable, the point P' will be above the centre point of the loadline MH, and there will be an appreciable amount of second harmonic distortion; this may be reduced to zero (if desired) by increasing the load resistance slightly.



(fig. 2).

Fig. 2.—The variation of power output and distortion with load resistance for type 45 triode. Maximum power output occurs with a load resistance of about 1.5 r_p, but the peak is so flat that there is very little drop in power output at $R_L = 2\ r_p$; even with $R_L = 6\ r_p$ the power output is over half the maximum.

The second harmonic distortion falls steadily as the load resistance is increased, more rapidly for load resistances up to 4r_p, while it tends to flatten-out at slightly over 1% for high load resistances.

The curves were derived graphically, with due allowance for shifting loadline as for a transformer-coupled load. The conditions are

Plate voltage	250 *volts*
Grid voltage	–50 *volts*
Peak grid signal voltage	50 *volts*
Plate resistance	1600 *ohms*

2. EFFECT OF CHANGE OF LOAD RESISTANCE.

(a) On Class A Triodes.

Class A triodes are very uncritical as regards load resistance. For a given grid voltage swing the distortion becomes smaller as the load resistance is increased, and becomes very low for load resistances above 10 times the plate resistance; the distortion increases steadily as the load resistance is reduced (fig. 2).

The power output reaches a broad maximum at a load resistance of about twice the plate resistance for a transformer coupled load, but the reduction in power output with load resistances above the optimum is only gradual. Many class A power triodes are therefore operated with load resistances of three or even four times the plate resistance, in order to reduce the distortion to an acceptable figure.

The use of the word "matching" with reference to the choice of load impedance to suit a class A triode is therefore inclined to be misleading, and we prefer to avoid it. The selection of load resistance should be made on the basis of distortion, power output and convenience.

If the plate characteristic curves are available, the load resistance to give maximum power output for 5% second harmonic distortion may be determined by the use of a 5% second harmonic distortion rule (see Radiotron Designer's Handbook, pages 280 to 282).

Alternatively, if any published characteristics are available, these may be converted to the desired plate voltage by the use of Conversion Factors, thus calculating the load resistance for the new conditions.

The variation of load resistance does not affect the plate current or the dissipation at zero signal; the effects on the plate current and dissipation at maximum signal are normally of no importance in design.

(b) On Class A Pentodes.

Pentodes are fairly critical as regards plate loads, and careful attention to this point is essential for best results. Maximum power output is always given when the loadline passes through the "knee" of the zero grid characteristic. A useful formula based on this condition is approximately correct for most pentodes:—

$$R_L = \frac{E_b}{I_b}$$

For example, type 6V6-GT at E_b = 250V. and I_b = 45 mA., R_L = 250/0.045 = 5560 ohms, compared with the published value of 5000 ohms. The error is usually on the high side, owing to the knee of the curve being at a plate voltage (E_{min}) which is not allowed for in the formula, and a slight adjustment may be made to suit.

The distortion with pentodes at maximum grid voltage swing is partly second harmonic and partly third and higher order harmonics, the latter being most objectionable. The second harmonic is usually zero (or very close to it) at the load resistance for maximum power output, and rises as the load is made either higher or lower. The higher order harmonic distortion becomes progressively greater as the load resistance is increased. There is therefore every reason for avoiding load resistances above that giving maximum power output, and a good compromise is a load resistance slightly below this point. If the lower power output can be tolerated, an even lower load resistance may be used, particularly if the grid input voltage is limited.

Owing to the rectification effect which occurs in the plate circuit with even harmonic distortion, the plate current tends to rise or fall with the application of the signal voltage to the grid. A rise of plate current indicates that the load resistance is less than that giving zero second harmonic distortion (a desirable condition) while fall of plate current indicates the generally undesirable condition when the load resistance is too high.

The optimum load resistance is not much affected by the use of negative feedback, and no change need be made under most circumstances.

(c) On Class A Beam Power Amplifiers.

Beam power amplifiers are in two main classes—the first comprising types 6L6, 807 and other near equivalents, the other including all other beam power amplifiers such as type 6V6-GT or 25L6-GT. This latter group has plate characteristics with rounded "knees" very similar to those of power pentodes, and may be treated as such in regard to the load resistance. Beam power amplifiers of the 6L6, 807 class have sharp "knees" and a considerable second harmonic component when operated to give maximum power output; their third and higher harmonic distortion is, however, lower than that of pentodes. The load resistance should not be greater than that to give maximum power output, and it is wise to err on the low side, as with pentodes.

(d) On Resistance-coupled Pentodes.

With resistance-coupled pentodes the plate load resistance is an important factor in the audio frequency high limit response, and the only one normally capable of adjustment. For further information, see the Radiotron Designer's Handbook page 5. To maintain correct operation, the screen dropping resistor and the cathode bias resistor should both be adjusted in the same proportions as the plate load resistor. The distortion is very little affected by the plate load resistor, for the same plate voltage amplitude—the input voltage should be increased with lower load resistances, on account of the lower gain. The plate load resistor is normally less than the following grid resistor, and should never exceed it.

(e) On Resistance-coupled Triodes.

Resistance-coupled triodes should preferably be used with a plate load resistor having a resistance at least five times the nominal value plate resistance; higher values give less distortion provided that the load resistance is well below that of the following grid resistor. Within certain limits, the plate load resistor may be varied with only slight effect on the gain or distortion, provided that the cathode bias resistor is varied in the same proportion; with fixed bias, no change of bias voltage is necessary.

(f) On Class AB1 Triodes.

The optimum load resistance plate-to-plate for class AB1 triodes is approximately 1.6 E_b/I_{max} where I_{max} is the current in one valve at zero bias with a plate voltage of 0.6 E_b, giving a total power output of approximately $(I_{max}.E_b)/5$. Higher load resistances result in lower power output, lower plate current and good efficiency. Lower load resistances result in lower power output but higher plate current and lower efficiency, with the danger of exceeding the maximum plate dissipation.

(g) On Class B or AB2 Triodes.

The load resistance has a pronounced effect on both the power output and driving power of class B triodes. A high load resistance results in low plate current and low power output, but the plate efficiency is good. The normal (published) condition usually is that giving maximum power output without exceeding either the plate dissipation or peak plate current limit. Any arbitrary reduction in plate load resistance is therefore dangerous, in that it is likely to lead to excessive plate dissipation and peak plate current.

(h) On Class AB1 Pentodes and Beam Power Amplifiers.

The optimum load resistance is fairly critical and any variation results in a decrease in power output. An increase in load resistance results in greater third and higher-order harmonic distortion which is very objectionable, while a decrease in load resistance is beneficial as regards distortion, but a low load resistance results in lower efficiency and hence higher plate dissipation, unless the input voltage is reduced.

(i) On Class AB2 Pentodes and Beam Power Amplifiers.

The power output is proportional to the area of the triangle beneath the loadline of each valve, that is to $\frac{1}{2}(E_b - E_{min}) I_{max}$ where E_{min} is the extreme bottom plate voltage excursion, at which the plate current rises to I_{max} (for further information see pages 290 and 291 of the Radiotron Designer's Handbook). This is far less critical than in the case of a class AB1 amplifier and the load resistance of a class AB2 amplifier also has much less effect on the distortion. An increase of load resistance will merely reduce the power output, plate current and plate dissipation. A decrease of load resistance will increase the plate and screen currents and dissipations and will be in danger of exceeding the maximum ratings of the valve.

To calculate the load resistance for an increased or decreased plate voltage, the procedure set out in 1(c) may be followed, maintaining the same peak grid driving voltage, peak plate current and E_{min}. If the plate voltage is increased, it will also be necessary to check for plate and screen dissipation at zero and maximum signal.

3. EFFECT OF CHANGE OF GRID BIAS.

In any valve which is being operated with fixed voltages on all electrodes and without any resistance in any of the electrode circuits, a change of grid bias will result in a change of plate current as given by the expression

$$\Delta I_b = \Delta E_c \times g_m \quad \ldots\ldots\ldots\ldots\ldots \quad (1)$$

where ΔI_b = increase of plate current,
ΔE_c = change of grid bias in the positive direction, and
g_m = mutual conductance of valve at the operating plate current.

In most practical cases, however, the valve is being operated with an impedance in the plate circuit and in some cases also in the screen circuit. The effect of a change in grid bias is therefore treated separately for each practical case.

(a) On Resistance-coupled Triode.

In this case a plate load resistor is used, resulting in a considerable voltage drop and a decrease in the effective slope of the valve.

The change in plate voltage brought about by a change in grid bias is given by the expression

$$\Delta I_b = \Delta E_c \times \mu/(r_p + R_L) \quad \ldots\ldots \quad (2)$$

where μ = amplification factor of valve,
r_p = plate resistance of valve,
and R_L = plate load resistor.

The resistance-coupled triode has highest gain and lowest distortion when the bias is the lowest possible, provided that the valve does not run into positive grid current at any portion of the cycle. As the bias is increased, so the gain is steadily reduced due to the lower slope of the dynamic characteristics, while the distortion rises for the same reason. With low-mu triodes operating at comparatively low output voltage amplitudes, the bias may be increased considerably without any appreciable reduction in gain or increase in distortion,but these become important with low-mu triodes operating at high voltage amplitudes or with high-mu triodes under all conditions.

(b) On Resistance-coupled Pentode.

The change of plate current with grid bias is given by the expression.

$$\Delta I_b = \Delta E_g \times g_d \quad \ldots\ldots\ldots\ldots \quad (3)$$

where g_d = dynamic transconductance.
= slope of dynamic characteristic.

The change of screen current is approximately proportional to the plate current up to plate currents of 0·5 E_{bb}/R_L and the change in screen current is given by the expression

$$\Delta I_{c2} = \Delta I_b \ (I_{c2}/I_b) \text{ approx.} \quad \ldots\ldots \quad (4)$$

where I_{c2} = screen current.
and E_{bb} = plate supply voltage.

As the plate current is increased above 0·5 E_{bb}/R_L, the voltage drop in the plate load resistor becomes great enough to reduce the plate voltage sufficiently to affect the ratio of plate and screen currents, and as the current rises the plate voltage may reach a point where it is considerably less than that of the screen; under these conditions the screen current may be considerably greater than the plate current. It may therefore be taken as a safe rule that all resistance coupled pentodes may have increased grid bias with perfect safety, but a decrease in grid bias should not be permitted without a careful check of screen current. If the screen is supplied through a suitable voltage dropping resistor, this objection does not hold and no damage can be done to the valve through any variation in grid bias.

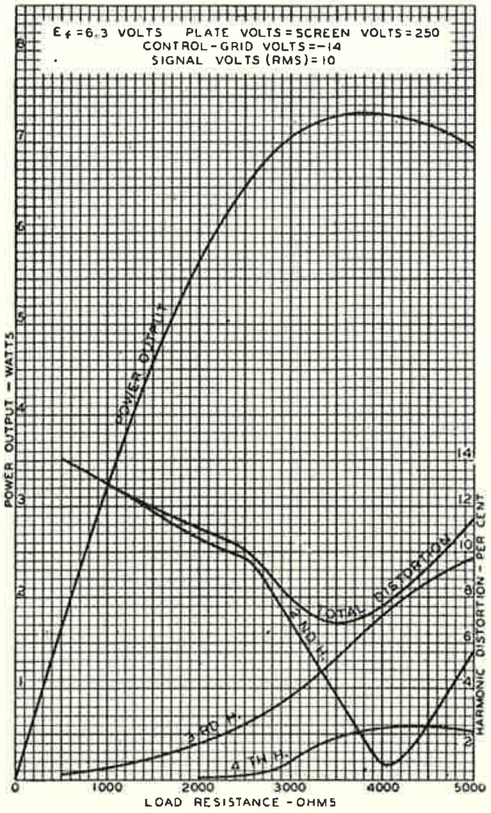


Fig. 3.—The variation of power output and distortion with load resistance for type 6L6 (*or* 807) *as a class A beam power amplifier. The second harmonic becomes practically zero with a load resistance of* 4,000 *ohms, but the published load is* 2,500 *ohms, which gives less third harmonic distortion at the expense of increased second harmonic.*

The gain of a resistance-coupled pentode is given by the expression

$$M = g_d . R_L . R_g / (R_L + R_g) \quad \ldots (5)$$

where M = voltage gain
and R_g = following grid resistor.

The maximum dynamic transconductance occurs with a plate voltage about 0.7 E_{bb}/R_L, but operation at this point is not generally to be recommended since overloading occurs very readily and the maximum plate amplitude is very limited. In addition, the point is fairly critical and tends to vary from valve to valve. The recommended operating conditions published in the Radiotron Valve Data Book are for plate currents between 0.5 and 0.6E_{bb}/R_L, where the valve is capable of giving a high output voltage with low distortion, and where the operation is far from critical. The gain is not quite as great as it would be at the point of maximum dynamic transconductance but this is a small price to pay for other advantages.

The distortion in the lower part of the characteristic is much less objectionable than that which occurs in the upper portion owing to the generation of higher order harmonics in the region of the top bend. The third harmonic distortion reaches a very low level between 0.2 and 0.3 E_{bb}/R_L, although the second harmonic is larger for high voltage amplitudes.

(c) On i-f or r-f Amplifier.

In this case there is no d-c load resistor and the full supply voltage reaches the plate of the valve. The change of plate current is given by equation (1) while the change in screen current may be calculated approximately from the ratio of screen and plate currents which remains approximately constant. The voltage gain is proportional to the mutual conductance of the valve, and is therefore a maximum for the highest plate current at the minimum bias. A decrease in bias will therefore result in increased gain, while increased bias will result in decreased

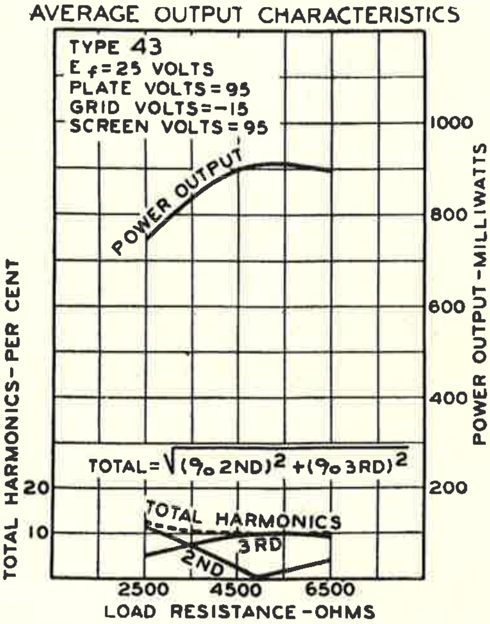


Fig. 4.—The variation of power output and distortion with load resistance for a typical power pentode (type 43). *The second harmonic is zero with a load resistance of* 4,900 *ohms, which gives maximum power output, but the published load is* 4,500 *ohms. The load might be reduced to* 2,500 *ohms with considerable reduction of third harmonic distortion, but at the expense of a* 17% *reduction in power output and increased second harmonic distortion* (11%).

gain. The limit to increased gain is set by the plate or screen dissipation of the valve, by positive grid current and, in some circuits, by instability. In most cases the mutual conductance curves are published so as to enable the change of gain to be calculated.

(d) On Class A Power Triode.

In this case the d.c. load in the plate circuit is very small, being limited to the d.c. resistance of the primary of the transformer, which is almost negligible. The effect on plate current which occurs with change of grid bias is therefore given by equation (1). The upward limit for plate current is fixed by the plate dissipation. If the valve is being operated at a fairly low level, the grid bias may be varied quite considerably without having any appreciable effect on the power output or distortion, provided that the valve does not run into positive grid current at any point of the cycle. The distortion is slightly less at high plate currents so that there is some slight advantage in operating it with the minimum bias, provided that the plate dissipation is not exceeded. Economy in plate current may be achieved under these conditions by an increase in grid bias up to the point where the distortion becomes noticeable.

The voltage gain or a power triode is given by the expression.

$$M = \mu R_L/(r_p + R_L) \quad \ldots\ldots\ldots \quad (6)$$

which is based on the assumption that the amplification factor remains constant—which is approximately correct except in the region of bottom bend curvature.

(e) On Class A Pentode or Beam Power Amplifier.

Change of grid bias causes a change of plate current as indicated by equation (1). The screen current is also affected by a change of grid bias, but is not necessarily proportional to the plate current, except with pentode valves at low power outputs. As the power output is increased, so the screen current increases and the increase becomes quite rapid as the point of maximum power output is approached. Beam power amplifier valves have a ratio of screen to plate currents which is variable under all conditions; the ratio becomes lower as the grid bias voltage is increased.

The voltage gain of a class A power pentode or beam power amplifier is given approximately by the expression

$$M = g_m.R_L \text{ approx.} \quad \ldots\ldots\ldots\ldots \quad (7)$$

which is on the assumption that the load resistance is small compared with the plate resistance.

The power output is not much affected by the grid bias, except when approaching the maximum power output of the valve, when the grid bias becomes critical. Most pentode valves are designed to operate with approximately zero second harmonic at maximum power output. An increase of grid bias under these conditions will cause decreased power output, increased second harmonic and decreased third harmonic distortion. A decrease of grid bias, in addition to increasing the screen and plate currents and dissipations, will also cause an increase of both second and third harmonic distortion.

(f) On Class AB_1 Triode, Beam Power Amplifier or Pentode.

Class AB_1 triodes, pentodes and beam power amplifiers are not particularly critical as to grid bias, a change of which has only slight effect on the power output and distortion. The bias may be any value between that for a single valve and that equal to one-half the grid bias voltage required to produce plate current cut-off at a plate voltage of 1.4 times the plate-to-cathode voltage. A change of grid bias will affect the zero-signal plate and screen currents and dissipations but will have very slight effect on the maximum signal values. The operating conditions given in the published valve data are generally selected for minimum distortion, but the grid bias is such that the plate and screen currents at zero signal are within the maximum limits.

(g) On Class AB_2 Triode, Beam Power Amplifier or Pentode.

The change of grid bias in a class AB_2 stage affects not only the plate current but also the peak voltage and power required to be delivered by the driver. A reduction in the grid bias will increase the zero-signal plate and screen currents and dissipations, while an increase of grid bias will generally result in increased distortion.

4. TO CHANGE FROM FIXED BIAS TO CATHODE BIAS.

(a) Calculate the maximum signal cathode current (I_{max}).

(b) Calculate the resistance of the cathode bias resistor (R_k) from the expression

$$R_k = E_c.I_{max}$$

where E_c = fixed grid bias.

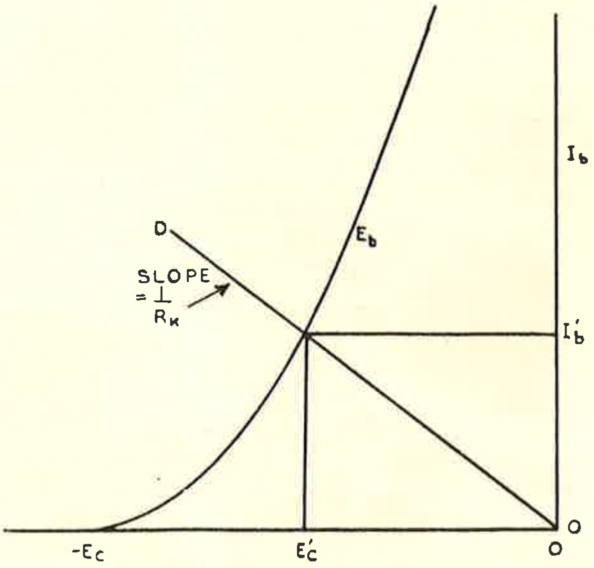


Fig. 5.—The plate current of a triode valve at no signal input may be determined, with cathode bias, by this simple procedure.

This will give identically the same power output and distortion as fixed bias, provided that the plate supply voltage is increased by E_c so as to maintain the same voltage from plate to cathode.

(c) It is then necessary to check whether the plate and screen dissipation limits are exceeded at zero signal. This may be done experimentally or by the following calculation, using the mutual characteristic corresponding to the voltage from plate to cathode (E_b).

Draw OD (figure 5) with slope corresponding to the cathode bias resistance (R_k). The point (P) of intersection between OD and the mutual characteristic curve E_b, will be that corresponding to zero signal. The zero-signal plate current will therefore be I'_b and grid bias E'_c; the plate dissipation will be $E_b . I'_b$.

With pentode or beam tetrode valves it is necessary to make an adjustment for the screen current. If the "triode" mutual characteristics (with plate tied to screen) are available, it is possible to use them as for triode valve. Otherwise, the same result may be achieved by drawing OD with a slope equal to

$$-\frac{1}{R_k} \cdot \frac{I_b}{I_b + I_{c2}}$$

where I_b and I_{c2} may be taken to a sufficient degree of accuracy as being the values under fixed bias conditions. The plate current (I'_b) may then be read from the curve, and the screen currents calculated from the ratio of screen to plate currents.

If the plate or screen dissipation under zero signal conditions is above the limit, it is then necessary to bring it within the limits by increasing R_k. This will have the effect of altering the maximum signal power output and distortion, which will therefore differ from those for fixed bias.

The method described above is not capable of being used in the reverse direction, to convert from cathode bias to fixed bias.

It is hoped to publish, in some future issue, a general article on the subject of cathode bias.

RADIOTRON APPLICATIONS LABORATORY

We give below some views of the equipment used in the A.W.V. Applications Laboratory which has now been fitted up, to provide improved service and cope with the increasing demands made by manufacturers and others on the Radiotron Technical Resources which are under the direct supervision of Mr. F. Langford-Smith, the Company's Applications Engineer.

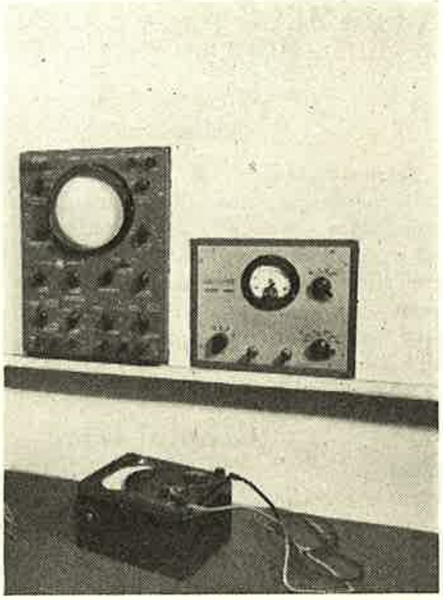
The equipment so far installed includes the latest model A.W.A. Signal Generator, 5 inch Cathode Ray Oscillograph, Beat Frequency Oscillator, Output Meters, and subsidiary equipment, with two high quality laboratory type Multimeters and a number of ordinary Voltmeters, Milliammeters and Microammeters. Distortion is measured by means of a General Radio Wave Analyzer. Additional equipment is being built and purchased so as to extend the flexibility of the laboratory, this including v-h-f and F-M testing.

The equipment is grouped in two sections, one primarily covering radio frequencies, and the other audio frequencies, so that work on an audio frequency amplifier may be carried out simultaneously with that on a radio receiver.

A high grade laboratory type valve tester is now being constructed and will be used in the testing of valve characteristics. This will include laboratory type measuring instruments with provision for measuring all electrode currents and voltages including positive and negative grid currents, mutual conductance, amplification factor and plate resistance.

In cases where the equipment of this laboratory is insufficient to meet special requirements, arrangements have been made for the use of certain apparatus from the Company's laboratories at Ashfield.

The radio frequency and audio frequency equipment is installed in a screened room so as to be free from radio interference, and is capable of carrying out all normal tests on receivers and amplifiers. This equipment is used in the design of circuits published in Radiotronics and is also available to assist receiver manufacturers in tracking down faults in receivers, particularly those concerned with valves.



VALVE DATA SECTION

NEW R.C.A. RELEASES

Radiotron type 2X2-A is a half-wave high-vacuum rectifier for applications critical as to severe shock and vibration.

Maximum ratings are 12,500 volts peak inverse, 60 mA. peak plate current, and 7.5 mA. d-c output current. The type 2X2-A can withstand, on the average, a value of 250 g when tested in the NRL standard shock machine for Electron Tubes, under specified conditions.

Type 2X2/879 is still standard for ordinary use, and is not superseded by type 2X2-A.

REVISED CHARACTERISTICS

Type 2X2/879: Half-Wave High Vacuum Rectifier

Three amendments have been made to the data. The peak plate current should now read 60mA. max. instead of 100mA. max.; a rating for a hot-switching transient current of 100mA. max. for a duration of 0.2 second max. has been added; typical operating information is now included in the data.

It should be carefully noted that these revised characteristics apply only to the American type 2X2/879 and not to the Australian 879 as given in Radiotronics 117 page 19.

Type 802: R-F Power Amplifier Pentode

The modifications proposed are that the input capacitance be altered from 12 μμF to 11 μμF, and the output capacitance from 8.5 μμF to 6.8 μμF. Confirmation of these proposed changes will be given in a later edition of Radiotronics.

Type 2E24: VHF Beam Power Amplifier

The filament of this valve type is designed for intermittent operation only, and should not be operated continuously. All C.C.S. ratings and associated typical operating conditions are now deleted. Previous I.C.A.S. ratings remain unchanged.

Type 2E26 ratings remain unaltered.

Type 6AU6 R-F Amplifier Pentode (Miniature type with sharp cutoff)

Errors were made in the measurement of plate resistance values previously published. The modifications are as set out below.

	Previously Published			New Values		
Plate Volts	100	250	250	100	250	250
Grid—No. 2 Volts	100	125	150	100	125	150
Grid—No. 1 Volts	–1	–1	–1	–1	–1	–1
Plate Resistance (megohms approx.)	.6	2.5	2.0	0.5	1.5	1.0

RADIOTRON 6AU6 R.F. AMPLIFIER PENTODE WITH SHARP CUTOFF

Miniature Type

(Tentative Data)

Radiotron 6AU6 is a miniature r-f triple-grid valve with a sharp cutoff characteristic, low grid-plate capacitance, and high transconductance. The low value of grid-plate capacitance minimizes regenerative effects, while the high transconductance makes possible a high signal-to-noise ratio. Because of its high transconductance and sharp cut-off, the 6AU6 is particularly useful as a limiter valve in FM receivers.

General Data

Electrical

Heater, for Unipotential Cathode:		
Voltage (a.c. or d.c.)	6.3	Volts
Current	0.3	amp.
Direct Interelectrode Capacitances:		
Grid No. 1 to Plate C_{g1p}	0.0035 max.	μμF.
Input C_{g1} ($k+h+g_2+g_3+$ internal shield)	5.5	μμF.
Output C_p ($k+h+g_2+g_3+$ internal shield)	5.0	μμF.

Mechanical

Mounting Position	Any
Maximum Overall Length	2-1/8″
Maximum Seated Length	1-7/8″
Length from Base Seat to Bulb Top (excluding tip)	1-1/2″ ± 3/32″
Maximum Diameter	3/4″
Bulb	T-5-1/2
Base	Miniature Button 7-Pin
Basing Designation	7BK

Pin 1–Grid No. 1 (control grid)
Pin 2–Grid No. 3 (suppressor) Internal Shield
Pin 3–Heater
Pin 4–Heater
Pin 5–Plate
Pin 6–Grid No. 2 (screen)
Pin 7–Cathode

AMPLIFIER

Maximum Ratings, Design-Centre Values

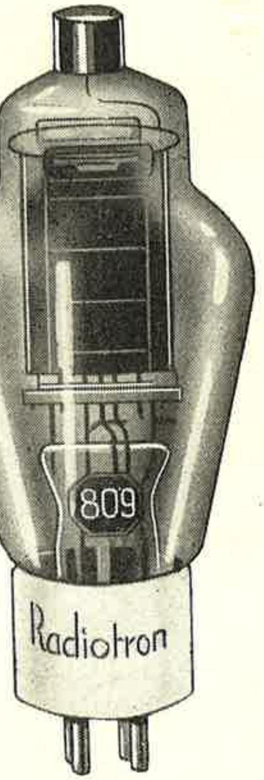
Plate Voltage	300 max.	volts
Grid–No. 2 (Screen) Voltage	150 max.	volts
Grid–No. 2 Supply Voltage	300 max.	volts
Plate Dissipation	3 max.	watts
Grid–No. 2 Dissipation	0.65 max.	watt
Grid–No. 1 (Control grid) Voltage:		
Negative Bias Value	50 max.	volts
Positive Bias Value	0 max.	volts
Peak Heater-Cathode Voltage:		
Heater negative with respect to cathode	90 max.	volts
Heater positive with respect to cathode	90 max.	volts

Typical Operation and Characteristics—Class A_1 Amplifier

Plate Voltage	100	250	250	volts
Grid–No. 3 (Suppressor)	Connected to cathode at socket			
Grid–No. 2 Voltage	100	125	150	volts
Grid–No. 1 Voltage	–1	–1	–1	volt
Plate Resistance (Approx.)	0.5	1.5	1.0	megohms
Transconductance	3900	4450	5200	micromhos
Grid–No. 1 Bias for plate current of 10 microamperes	–4.2	–5.2	–6.2	volts
Plate Current	5.2	7.6	10.8	milliamperes
Grid–No. 2 Current	2.0	3.0	4.3	milliamperes

RADIOTRON 809

Radiotron 809 is a high-mu triode valve which finds extensive application in class B modulators or R-F power amplifiers.



Two of these valves in a class B audio stage are capable of giving a power output of 145 watts under I.C.A.S. ratings. A single valve used in class C telegraphy service will give an output as high as 75 watts with 1,000 volts on the plate.