How to Choose a Valve

The Revealing Story Told by a Single Characteristic

By **THOMAS RODDAM**

SIX times a week, and twice on Sundays, for the last thirty years, someone, somewhere, has introduced a new type of valve. The designers of wide-band amplifiers have attempted to deal with this vast variety by introducing a factor of merit based on the mutual conductance and the capacitances. By the use of this factor of merit the designer can say that valve A is better than valve B. At very high frequencies a new factor, the noise resistance, appears to be the most suitable criterion. The audio designer is left to choose his valves by intuition. In this article I shall point out the merits of two different figures of merit for use by audio designers.

It is, of course, time that the designer is not confronted by the possibility of using any one of the thousand odd valves listed in the valve books. The valves are already classified and sub-classified. Foreign customers, for example, often demand that valves of American type should be used : they say that replacements to fit the new Welsh nine-pin octal are difficult to find in their local suppliers. The use of miniatures makes them think that they really are getting an up-to-date design. Standardization of heater supplies makes it necessary to keep to the 6.3-volt valves except in the most abnormal circumstances. But finally we are faced with the problem of internal standardization : if sections of a complete system are designed by different people, it looks better if the final equipment uses one valve type for one function. We must have our domestic standard. In deciding this from the short list of, perhaps, half-a-dozen valves, the figure of merit can be invaluable.

Very often, the final choice is a matter of chance. The man who is quickest off the mark announces that he is committed to such and such a valve : the man with the loudest voice overrides the discussion : the only type which happens to be available in the local shop is used, because no one wants to wait while an order goes through. But if a single factor of merit can be used to assess the claims of the different valves, there is just a hope that the best type will be chosen.

Characterizing Curve

The basis on which we can best work is the use of a single curve which characterizes the valve, instead of the set of characteristics which are usually used. This set, of course, really represents a three-dimensional surface, and there are quite real difficulties in appreciating the full significance of the normal characteristics. The single curve conveys its meaning much more directly : for some reason, however, the standard text-books seem to have overlooked its merits.

In the discussion of the figure of merit it will be assumed that we are concerned mainly with pentodes. I am fully aware of the advantages of using positive feedback triode pairs, but the problem of type selection is not so acute here, because there is not really a wide range of choice. The pentode valve characteristic can be written in the form

$$I_a = I_o + Ae_g + Be_g^2 + Ce_g^3 + \ldots \quad (1)$$

where I_a is the anode current, I_o the steady component with no signal applied, and e_g the alternating component of the grid voltage. A, B, C etc., are parameters which are fixed by the valve construction.

Differentiating this equation, we have

$$dI_a/de_g = A + 2Be_g + 3Ce_g^2 \quad .. \quad .. \quad (2)$$

which goes to

$dI_a/de_g = A$ if e_g is made small enough. This means that A is simply the mutual conductance of the valve. Let us plot a graph of mutual conductance against grid bias. We can measure this ourselves, and some valve manufacturers give us this graph for some of their valves. Such a graph is shown in Fig. 1. Since $g_m = dI_a/de_g$, we can write

$$I_a = \int_{-\infty}^{e_{go}} g_m de_g \quad .. \quad .. \quad .. \quad (3)$$

$= I_o$, the current at some bias e_{go}. The integral of eq. (3) is the area under the $g_m - e_g$ curve, which is shown shaded in Fig. 1. The single curve of Fig. 1 thus tells us both the standing current and the mutual conductance at any particular bias.

Going back to equation (2), we can differentiate again, and we have

$$\frac{dg_m}{de_g} = 2B$$

This is the slope of the curve shown in Fig. 1, and it is actually a measure of the second harmonic dis-

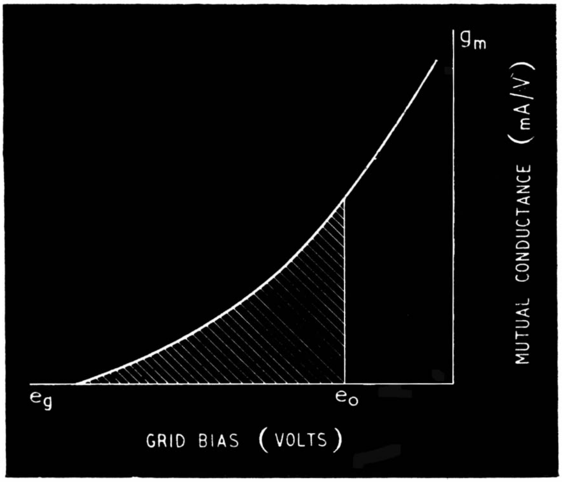


Fig. 1. The basic valve characteristic. showing mutual conductance as a function of bias. The shaded area is the anode current.

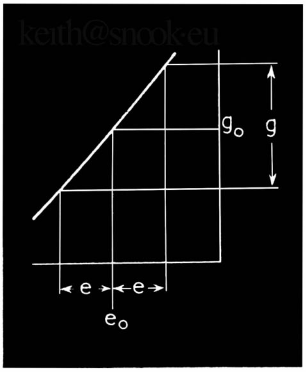
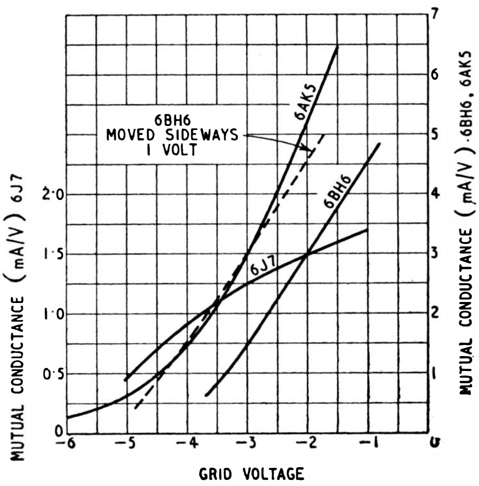


Fig. 2. The slope of the characteristic is specified by g and is a measure of the second harmonic.

Fig. 3. Characteristics of three pentodes, showing linear $g_m - e_g$ characteristic for 6BH6 and parabolic characteristics, 6AK5 and 6J7.



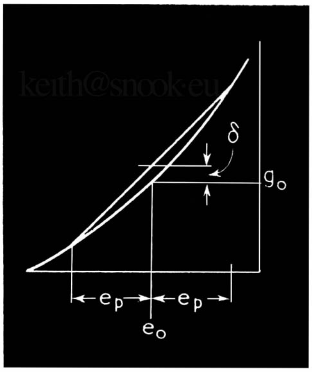


Fig. 4. The sag of a curved characteristic is a measure of the third harmonic distortion.

tortion. We can see this by putting $e_g = e \sin \omega t$ so that

$$I_a = I_o + g_m\, e \sin \omega t + Be^2 \sin^2 \omega t \ . \ . \ .$$
$$= I_o + g_m\, e \sin \omega t + \frac{Be^2}{2}(1 - \cos 2\omega t) \ . \ . \ .$$

The second harmonic distortion is therefore

$$\frac{Be^2}{2g_m\, e} = 100\% = \frac{B}{2g_m}.\, e\,.100\%$$

Looking at Fig. 2, we see that $B = g/2e$, as B is the slope of the $g_m - e_g$ characteristic: putting g_o for the value of the mutual conductance at the working point, the distortion is

$$(g/4g_o)\,.\,100\%$$

From the single curve of $g_m - e_g$, we can therefore derive the following information.

(1) The mutual conductance, and thus the gain, at any particular working point. This is read straight off the curve.

(2) The anode current. This is the area under the curve, and can be obtained by counting squares, or by any other convenient method of graphical integration, such as a planimeter.

(3) The second harmonic distortion for a given working level, or the working level for given distortion. This is given by reading off g_o and g from the graph, and calculating $(g/4g_o)\,.\,100\%$.

If the valve $g_m - e_g$ characteristic is a straight line, we need only concern ourselves with the second harmonic distortion, because the factor C in equation (1), which is a measure of the third harmonic, will be zero. Two types for which this is true are the 6BH6 and the 6AG7. We shall not use $(g/4g_o)$ as a figure of merit, however, for reasons which must be discussed. Provided that the designer is sufficiently skilful, the distortion can be reduced by the use of negative feedback, and the price to be paid is in the gain of the system. The gain reduction and the distortion reduction are directly proportional, so that the important quantity for the audio designer is

(gain)/(distortion).

This is clearly proportional to $g_o/(g/4g_o)$, and dropping the factor 4 we have as a figure of merit the quantity g_o^2/g.

The *best* valve to use in an audio amplifier is the valve which has the highest value of (g_o^2/g), provided that gain and distortion are the criteria of choice. To indicate how we can make use of this rule, the characteristics of three different pentodes, the 6AK5, 6BH6 and 6J7 are plotted in Fig. 3. If we consider these valves for low-level applications, we can tabulate the values of g_o and g for a peak swing of 0.25 volts. We have:

	g for $e = 0.25$	g_o	Fig. of merit	I_o
6AK5	1.3	5.8	26	9
6BH6	0.75	3.35	15.2	4.5
6J7	0.125	1.5	18	3.3

It will be seen that the 6AK5 is the best of the three, and that the 6J7, in spite of its low mutual conductance, is better than the 6BH6. Unfortunately, as any critical reader can check for himself, I have not been quite fair here. The curves shown are published characteristics, and they apply for different supply voltages. It is, however, not necessary to make the comparison under identical conditions, because if we get better results from the 6AK5 at 180 volts (the maximum) than from the 6BH6 at 300 volts, we shall choose this valve.

Sometimes we have other requirements for our valve. We may say that all the distortion occurs in the output stage, and demand only high gain in the previous stages. Then, of course, g_o is the factor which decides which valve we are to use. For the designer who really wants the best possible result, however, this is only part of the story, because he can add positive feedback to the early stages, and it is easy to see that with the design worked out for the best performance, the figure of merit already quoted is the one to use. With the increasing demand for miniaturization, another criterion may be needed: we may want to get as much gain as possible for each milliamp of anode current. It is necessary to take account of the tail which appears in some valves, and to compare the characteristics closely. By shifting the 6BH6 characteristic sideways in Fig. 3, it can be seen that the 6AK5 has a longer tail, and so will take rather more anode current for the same gain. It is much more difficult to provide a single figure of merit for this application, because the relative merits of two valves may differ as the working level is altered. The $g_m - e_g$ characteristic, however, contains the complete story.

Some valves, of course, have a curved $g_m - e_g$ characteristic. The simplest form of this is shown in Fig. 4. This parabolic characteristic is due to the fact that the coefficient C in equation (1) is not zero. The result in practice is that there is a third harmonic term in the distortion. I am not going to work out the distortion in detail, because the mathematics is quite straightforward, but I will just quote the results. The third harmonic for any peak level is obtained by joining the two points on the curve corresponding to the maximum working peak level, ($e_o \pm e_p$). The dip of the curve below the straight line, measured at e_o, is δ, and is a measure of the third harmonic. For any signal peak level e_s less than e_p, the third harmonic is given by the formula

$$\frac{3\delta}{g_o} \cdot \left(\frac{e_s}{e_p}\right)^2 . \ 100\%$$

When $e_s = e_p$, this reduces to $3\delta/g_o$ .100% which may be compared with the expression for the second harmonic, $g/4g_o$ .100%. Which harmonic dominates depends on whether δ is greater than $g/12$. It is easy to test this on any particular characteristic.

The reader who wishes to apply this method of assessing valves will encounter one very serious difficulty. Some valve makers consider it sufficient to announce that Venus valves are Versatile, and support this claim with a photograph of an attractive young lady—the same one who uses a well-known soap, eats chocolate and drives the most expensive motor cars. True, engineers, unlike editors, like these pictures, but we are also interested in the anatomy of the valves and would like to see some of their curves too. In theory the $g_m - e_g$ characteristic can be derived from the ordinary $I_a - E_a$ characteristics, but if you look at Fig. 5 you will see that this does not seem to be a very reliable method. The only ways out of this are, either measure the characteristics yourself, using methods given in the standard text-books, or say to the maker, " no tell, no buy." Even after all these years I still cherish the hope that one day we shall have a uniform base and numbering system : but by then we shall probably all be using transistors instead.

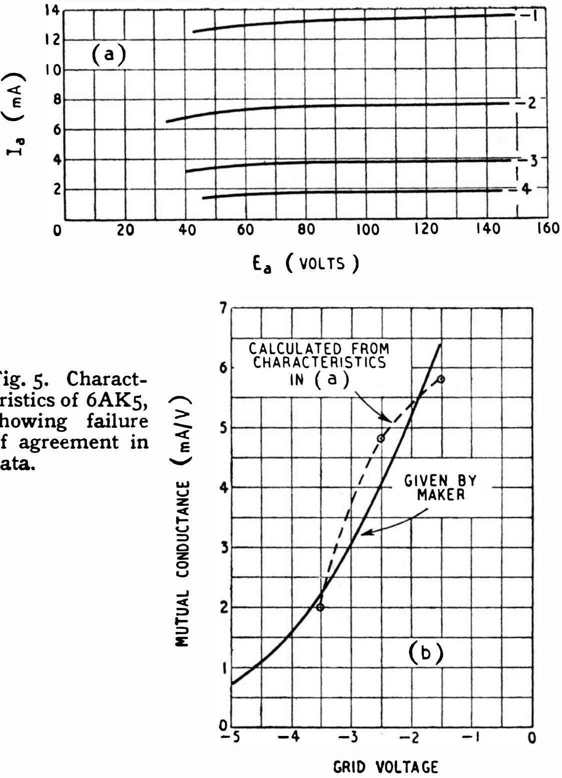


Fig. 5. Characteristics of 6AK5, showing failure of agreement in data.

To sum up what I have said, the most useful single valve characteristic is the mutual conductance-grid bias curve, and from this we can immediately determine the anode current, the stage gain and the distortion. To compare two valves for audio amplifier service we can make use of a figure of merit which is easily calculated.

STEREOPHONIC SOUND

Demonstration in the Telekinema

A THREE-CHANNEL system has been adopted for the demonstration of stereophonic sound in the Telekinema. Reproduction is through the main B.T.H. sound film installation and separate loudspeaker units have been placed at right, left and centre of the stage. Magnetic tape is the recording medium, and a special machine has been developed in conjunction with E.M.I. for use with stock 35mm. film base, which has been coated with oxide. In addition to the three tracks for the main groups of speakers, there is a fourth track for special effects from loudspeakers at the back of the hall.

The use of wide film has brought many problems not associated with standard 0.25in. tape. Pressure pads are necessary on each of the recording, replay and wipe heads, and heavy Mumetal screening has been provided to prevent ingress of hum into the comparatively large volume of the recording head assembly.

Pre-emphasis and complementary de-emphasis of high frequencies to a law equivalent to a circuit time constant of 40μsec has been adopted. The figures given for the final overall frequency response are 30c/s to 15kc/s; signal/noise ratio is 55 to 60db, and total harmonic distortion less than 2 per cent.

The microphone used for recording stereophonic sound is of the twin ribbon type in which the ribbons are mounted at 90 degrees to each other in a common magnetic field. Each ribbon has a figure-of-eight polar diagram and the relative amplitudes of the signal in each channel are determined by the position of the source. Cross talk between the two channels is less than -45db and has been found to be quite satisfactory.