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A NOTE ON THE HIGH GRID RESISTOR AMPLIFIER

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A NOTE ON THE HIGH GRID RESISTOR AMPLIFIER.

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MULDER and Razek [1] have shown that the effective mutual conductance of a three element "vacuum" tube can be greatly increased by operating the tube in a grid circuit containing a high resistance. Their treatment of the problem does not show clearly the conditions which must be met in order to obtain this high mutual conductance without a discontinuous and non-reversible part in the characteristic.

With the plate voltage and the filament current constant in a three element tube, the plate current and the grid current are related to the grid voltage as shown by Figs. 1 and 2. The first of these is of course perfectly familiar and needs no explanation. The second is a composite of three currents. For very small values of grid voltage the current is mainly electron current from the filament. This of course falls off rapidly as the grid is made more and more negative with respect to the filament. There is the leakage current over the base of the tube and the other external parts. This current is usually negligible if the surfaces are clean and the tube is kept in a dry atmosphere. This leakage current *increases* as the grid voltage is made more negative. The third and important component depends on the presence of gas in the tube. It is this component which plays the all important part in the type of amplifier under discussion. The positive ion current to the grid *decreases* as the grid is made more and more negative because the number of positive ions decreases as the electron current from the filament to the plate is decreased. As the subsequent discussion will show, it is the point of inflection (A) in the grid current characteristic that is of primary interest. This characteristic in the immediate

[1] Razek and Mulder, *J. O. S. A., and R. S. I.*, *18*, p. 466, 1929.

FIG. 1.

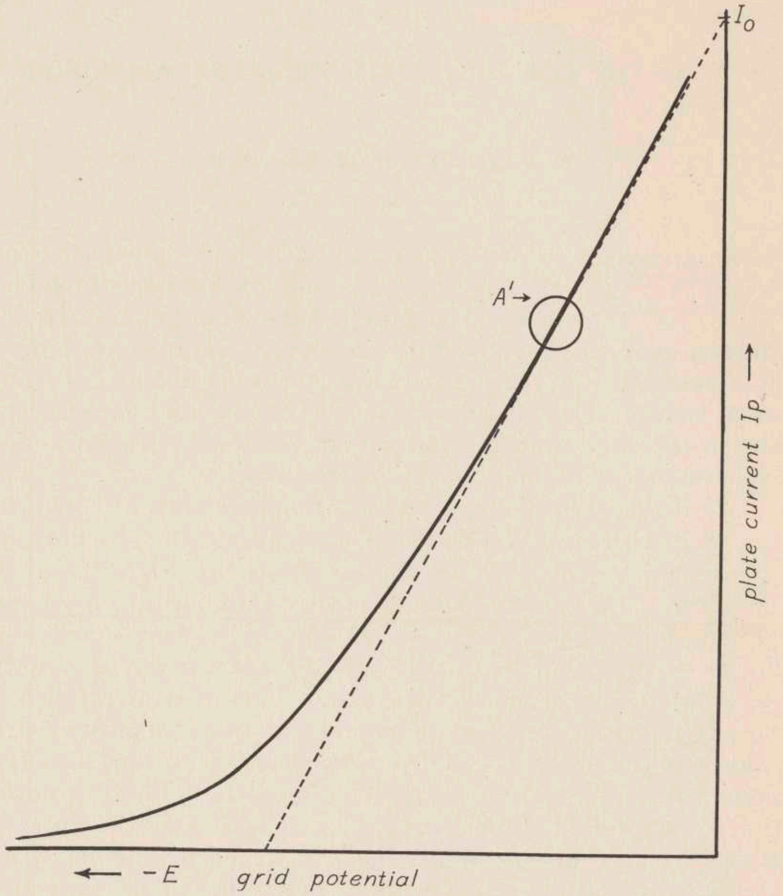


Plate current characteristic of vacuum tube.

neighborhood of the point of inflection can be represented very accurately by the equation

$$i_g = -i_0 - mE, \tag{1}$$

where i_0 = constant,

m = a constant (the slope at (A)),

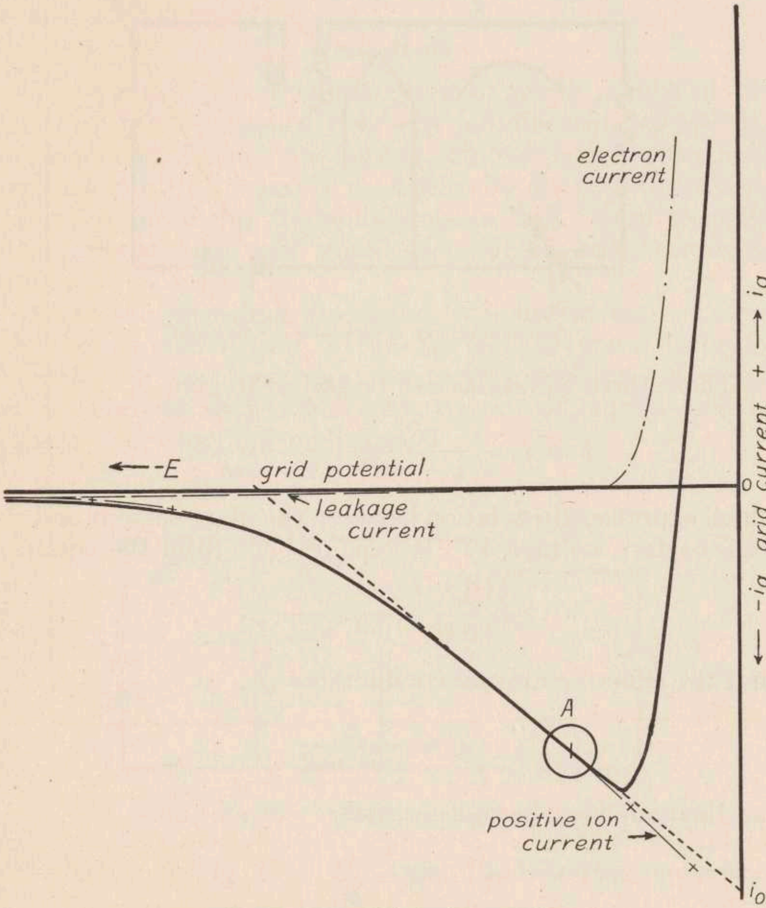
i_g = the grid current,

and E = the grid voltage.

The corresponding part of the plate current characteristic can also be represented by a straight line

$$I = I_0 + gE, \qquad (2)$$

FIG. 2.



Grid current characteristic of vacuum tube.

where I_0 = constant,

g = constant (mutual conductance or slope at A' of Fig. 1),

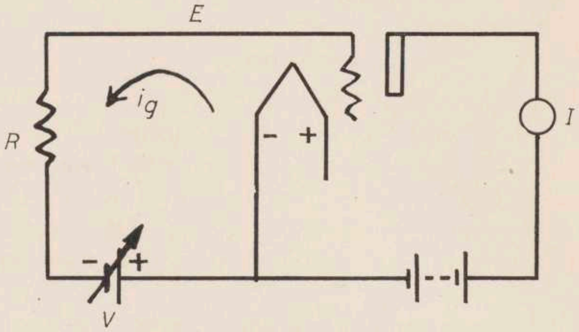
I = plate current,

E = grid voltage.

Referring to the circuit sketched in Fig. 3, we have a third relationship given by

$$V = Ri_g + E. \tag{3}$$

Fig. 3.



Schematic diagram of three element tube circuit.

These three equations can be solved to give

$$I = I_0 - \frac{gRi_0}{1 - mR} + \frac{g}{1 - mR} V, \tag{4}$$

which expresses the relation between the plate current and the "*C*" battery voltage *V*. We see at once from the equation

$$\frac{\Delta I}{\Delta V} = \frac{g}{1 - mR} \tag{5}$$

that the effective mutual conductance

$$g' = \frac{g}{1 - mR} \tag{6}$$

can be made very large if we make

$$R = \frac{1}{m} \tag{7}$$

in the limit.

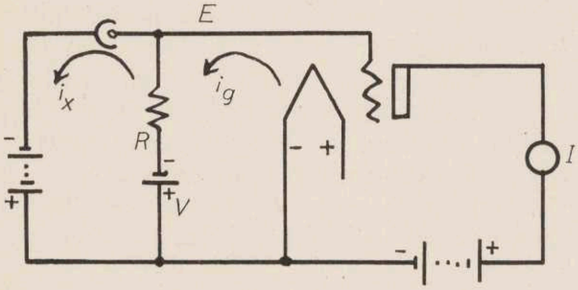
It is at once obvious that in order to make use of this high effective mutual conductance severe requirements must be met as regards filament, plate and grid batteries and also the tube must be so constructed that the amount and kind of gas does not change with time. It is thought that this requirement can be met if the tube is so designed that the metal and glass parts can be thoroughly baked out under good vacuum conditions and purified argon or some other inert gas is introduced to produce the required gas pressure. The "balanced bridge" circuit could probably be used to make battery maintenance a little easier.

APPLICATIONS.

The most important application to which a tube of this character can be applied is to the amplification of thermocouple potentials since this type of amplifier is in a sense really "voltage sensitive," that is, its sensitivity does not necessarily depend on producing the voltage as an "IR" drop as in the usual photoelectric cell application which has become so popular.

From the preceding discussion, it is not at once obvious that there would be any advantage in this type of tube for photoelectric or other high resistance problems. The following analysis shows that here too an advantage can be realized under certain conditions.

FIG. 4.



Schematic diagram of photoelectric cell and three element tube circuit.

Referring to Fig. 4, we can write the following equations:

$$V = E + R(i_g - i_x) \text{ (From Fig. 4)}, \tag{8}$$

$$I = I_0 + gE \text{ (From Fig. 1)}, \tag{9}$$

$$i_g = -i_0 - mE \text{ (From Fig. 2)}. \tag{10}$$

These equations are essentially the same as (1), (2) and (3) above. In this case, V is to be constant and the relation between i_x (the photoelectric current) and I (the plate current) is of interest. Solving these equations, we have

$$I = I_0 + \frac{g(V + Ri_0)}{1 - mR} + \frac{g}{1 - mR} Ri. \qquad (11)$$

This can be more simply written

$$I = K + g'Ri, \qquad (12)$$

where $K = \text{constant}$

and $$g' = \frac{g}{1 - mR}. \qquad (13)$$

Again the sensitivity is represented by

$$\frac{\Delta I}{\Delta i_x} = \frac{gR}{1 - mR} \qquad (14)$$

and this is very large when

$$R = \frac{1}{m}.$$

From the equations, we see that for values of R less than $1/m$ the plate current characteristic has no discontinuity and is stable for all values of V or i_x as the case may be. On the other hand, if R is greater than $1/m$ there will be a discontinuous region which can be marked out on the grid current characteristic by locating the two points of tangency of the line of slope $1/R$ with the grid current curve. The region between these points of tangency is that in which a discontinuity is certainly to be found.

A very complete treatment of the subject of "Direct-current Amplifiers" by Ebbe Rasmussen, Ann. d. Phys. (5) *2*, 357 (1929), has come to my attention since the writing of this paper. Although Rasmussen's discussion of the question of gas in a three element tube is made from a different point of view, his results and those presented here are in agreement.

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