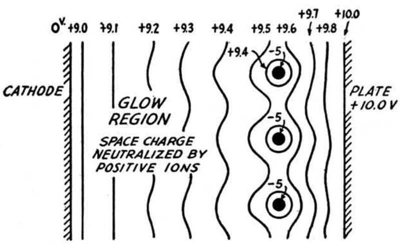
A New Hot-Cathode Gaseous Discharge Amplifier and Oscillator

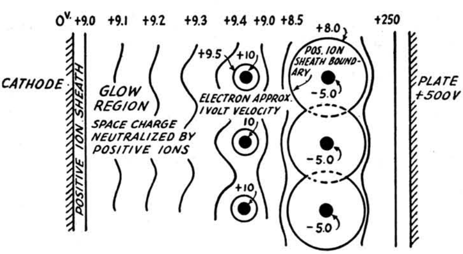
The Mercury-Vapor RK-100 Triode for Audio and Radio-Frequency Service at Low Plate Voltage

By J. R. Nelson and James D. LeVan*

EVERY experienced amateur radio operator is acquainted with some of the bad effects of gas in a radio tube that is intended to operate as a high-vacuum tube. He is also familiar with the performance of grid-controlled mercury rectifier tubes as relay and control devices, which performance is made possible by the presence of



FIELD IN GRID-CONTROLLED MERCURY VAPOR RECTIFIER
FIG. 1



FIELD IN RK-100
FIG. 2

gas or vapor. He has probably wondered why the advantages that the gas or mercury vapor gives in the latter case, such as ability to pass a large plate current with low voltage drop and to oper-

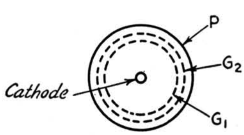


FIG. 3

ate with only a small control grid voltage, cannot be—or at least have not been—incorporated in the ordinary type of radio amplifier or oscillator tube. This idea has occurred to a good many who have been experimenting in this field. The Raytheon Laboratories, working on this problem for a number of years, have finally developed a type of tube in which this result is accomplished; that is, a gas- or vapor-filled tube which performs the normal functions of a high-vacuum tube as amplifier, detector or oscillator, and which (because of its gas filling) has characteristics and operating advantages not obtainable in high-vacuum tubes. It is the purpose of this article to describe a particular practical design (RK-100) of this new type of tube and to give a brief and approximate explanation of its operation.

HOW IT WORKS

The functioning of this new gas-filled amplifier tube can best be understood by comparing its operation with that of the common grid-controlled mercury rectifier. This rectifier structure is represented by Fig. 1. The anode current here cannot in general be completely controlled by the grid. Once the current starts it cannot again be stopped or decreased by making the grid more negative. The only function of the grid is to determine the instant at which the anode current will start.

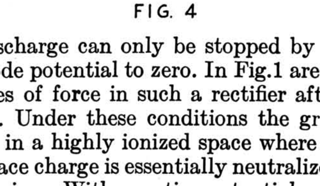


FIG. 4

The discharge can only be stopped by reducing the anode potential to zero. In Fig.1 are pictured the lines of force in such a rectifier after it has started. Under these conditions the grid is immersed in a highly ionized space where the electron space charge is essentially neutralized by the positive ions. With negative potentials applied to the grid, a positive ion sheath will form around the grid whose thickness (x) can be determined by Child's space charge equation:

$$X = 0.622 \times 10^{-4} \frac{V^{3/4}}{I^{1/2}} \text{ cm.}$$

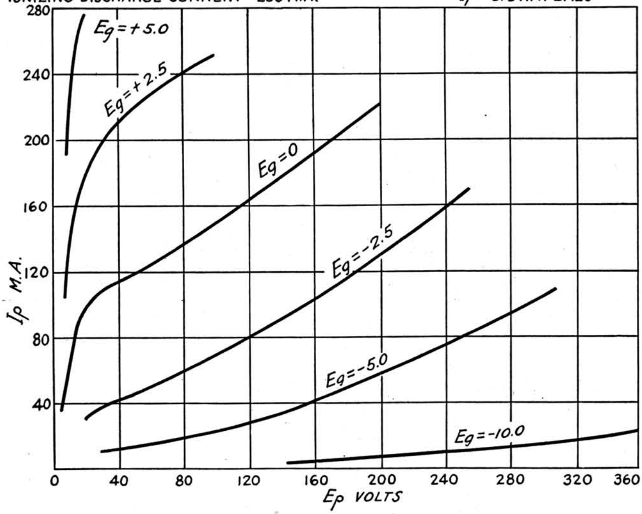
where V = potential applied to grid
I = grid current in amperes per sq. cm.

*Both of Raytheon Production Corp., Newton, Mass.

With **−10** volts on the grid and a current of 10 ma. per sq. cm. flowing, this gives a sheath thickness of .0035 cm., which is very small compared to the openings in the usual grid. This thin sheath will, however, contain nearly the whole voltage drop due to the grid and thus keep the grid from influencing electrons beyond the outer boundary of the sheath. Thus the region filled with highly ionized gas will project through the grid into the plate region in very much the same manner as would happen without the grid.

FIG. 5

RK-100 PLATE CHARACTERISTICS – IONIZING DISCHARGE CURRENT 250 M.A. E_f = 6.3 VOLTS I_f = 0.6 AMPERES



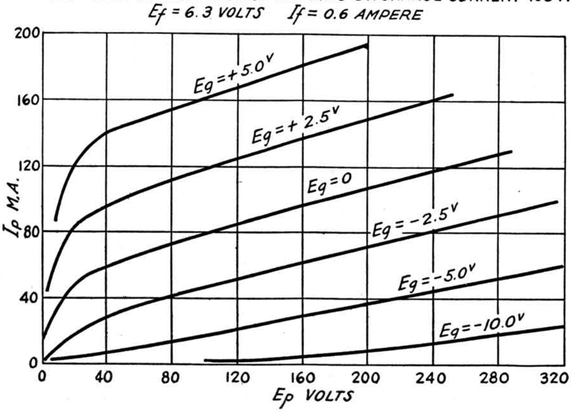
It is apparent, then, that if the grid is to remain in control of the electron stream, the positive ion sheath must be prevented from becoming so thin that the highly ionized region can project through the openings between the sheath boundaries; that is, we must make the sheath boundaries overlap. From Child's space charge equation we see that the sheath thickness can be increased greatly if we can find some way to decrease the current density of positive ion flow to the grid. This can be done by placing the grid in a region of low ionization, which is accomplished in the RK-100 tube by placing another screen electrode near the control grid and between it and the highly ionized space surrounding the cathode.

As shown schematically in Fig. 2, this electrode, G_1, is kept at about 10 volts positive with respect to the cathode and maintains the glow discharge. The control grid, G_2, is always maintained more negative than G_1 and thus electrons are slowed up in the space between G_1 and G_2. However, electrons shoot through G_1 with about 1 volt velocity on the average. We can, therefore, think of G_1 as a kind of cathode with electrons being emitted with 1-volt initial velocity. In fact, the electrode G_1 might be called a "cathanode", since it acts simultaneously as the anode for the discharge from the hot cathode and as the cathode for the amplifying section of the tube.

Since the spacing between G_1, G_2 and the plate is small, and since the mean free path of an electron in mercury vapor at the pressures used is from 10 to 20 cm., electrons traveling from G_1 to the plate hit very few molecules and thus create very few positive ions in this region. *Thus the positive ion-sheath thickness around the grid wires can be made large and the grid allowed to maintain control of all electrons passing through it.* Just enough positive ions are generated in this space to neutralize partially the electron space charge and give us a tube with a very low plate impedance. The short spacing and fine-mesh grid, coupled with the low ionization, give us high mutual conductance and high amplification factor. Furthermore, since the spacing between the cathode and G_1 can be made large as compared with that between G_1 and the plate, we are enabled to make the grid and plate large enough to get ample heat dissipation without the electrode becoming unduly hot. Fig. 3 shows an end view of the element arrangement in one form of gas-filled amplifier and oscillator.

FIG. 6

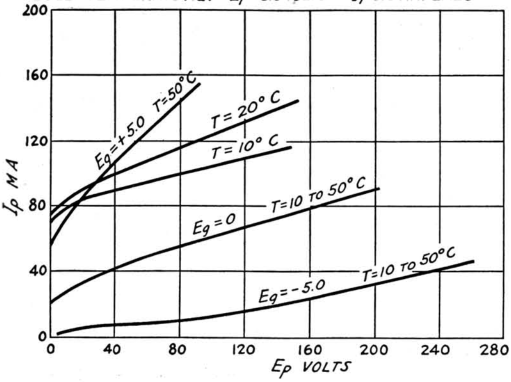
RK-100 PLATE CHARACTERISTICS IONIZING DISCHARGE CURRENT 150 MA E_f = 6.3 VOLTS I_f = 0.6 AMPERE



TYPICAL CHARACTERISTICS

The gas-filled amplifier tube is particularly useful at low voltages where conventional vacuum tubes are not very efficient on account of high internal drop. The introduction of gas to neutral-

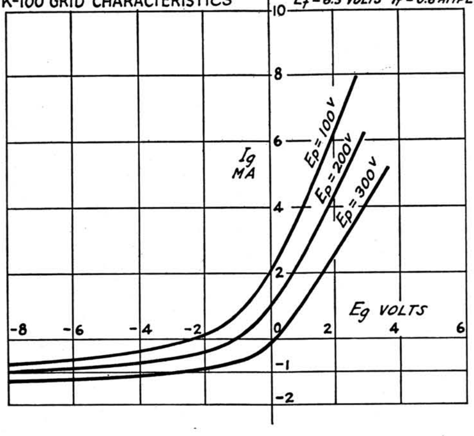
FIG. 7
RK-100 PLATE CHARACTERISTICS FOR SEVERAL VALUES OF BULB TEMPERATURE. E_f=6.3 VOLTS I_f=0.6 AMPERES



ize partially the space charge lowers the drop considerably, thus making possible values of efficiency only obtainable with conventional tubes of the same cathode power at considerably higher voltages.

The characteristics of the tube with regard to the element voltages and the ionizing discharge circuit current are shown by Figs. 5, 6, and 7. Fig. 5 shows the plate family with the ionizing discharge current equal to 250 ma. Fig. 6 shows the results when the ionizing discharge current is equal to 150 ma. The plate current varies somewhat with the bulb temperature when mercury vapor is used as the gas. At the low values of current the effect of temperature is small but the effect increases as the plate current is increased, as shown by Fig. 7. For the RK-100 under the conditions of 100 volts on the plate, 2.5 volts negative bias on G_2 and 150 ma. ionizing current to G_1, the amplification factor is approximately 50 and the mutual conductance 12,000 micromhos. With 250 ma. current to G_1 the mutual conductance is increased to over 20,000 micromhos.

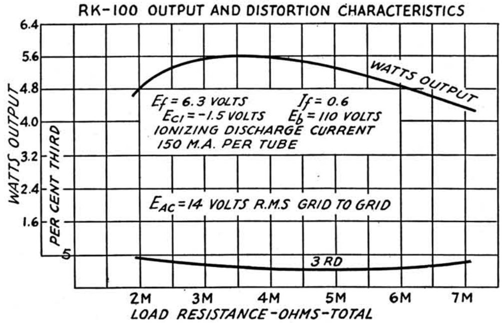
FIG. 8
RK-100 GRID CHARACTERISTICS E_f=6.3 VOLTS I_f=0.6 AMPERES

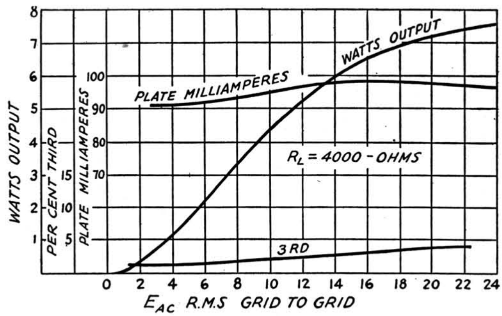


While the control grid draws current at all times, the operation in practical circuits is similar to that of conventional vacuum tubes. The grid impedance is reasonably high with negative values; the grid current is constant and only changes as the grid goes positive, at which time the grid impedance decreases. The ***Ig-Eg*** curves for several values of plate voltage are shown by Fig. 8.

The gas-filled amplifier tubes may be used in the same classes of service as conventional tubes. In fact, there are several possible applications where they may give considerable advantage. They may be used as audio amplifiers, either in

FIG. 9
RK-100 OUTPUT AND DISTORTION CHARACTERISTICS





an intermediate or the output stage, or as r.f. amplifiers (Class A, B, or C), and as oscillators. The radio frequencies over which the tubes will amplify and oscillate cover the range now in common use, including at least as high as 150 megacycles (2 meters). This is contrary to the commonly accepted idea that gas filled tubes are very limited in their frequency range.

The results obtained when tubes of the particular design described here are used in the audio output stage are shown by Figs. 9 and 10, showing that the use of ionized gas in tubes, with its resultant advantages, does not introduce distortion. The curves were taken under ideal conditions and show the capabilities of the tubes. It is evident that the results are very good for

(*Continued on page 82*)

antenna. TW has M.O.P.A. UH builds new receiver. PE and UD are going c.c. PW builds new receiver. LI has gone to the Pas. EL tries Collins antenna matcher. FW keeps schedule with Calgary and Los Angeles. The Moose Jaw gang will have transmitter on 3.5, 7 and 28 mc. at Y.M.C.A. Fair to originate traffic and stimulate public interest in amateur radio. CM is replacing burnt-out junk.

Traffic: **VE4**CM 228 CC 58 RZ 48 PL 42 FW 38 GA 25 PM-EL 7 RE 2.

Hamdom

(Continued from page 26)

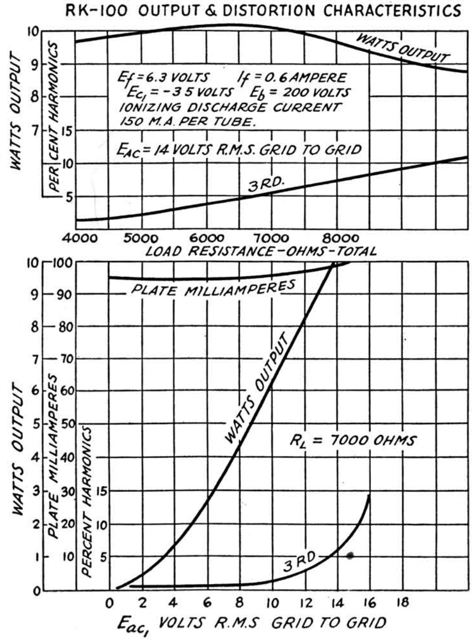
radio men, he joined the Burgess Battery Co. In 1929 he went with Radio and Television Institute. In October, 1932, while flying to Kansas City, he was overcome by carbon monoxide poisoning and invalided for eighteen months. Now he's back in harness again, for General Household Utilities. The tricks at W9UZ are still maintained, however; get that automatic transmitter singing at you some night and have the time of your life—or have your sending recorded on the automatic recorder.

A New Hot-Cathode Tube

(Continued from page 25)

the cathode wattage used, namely 4 watts. Considerably more efficiency may be obtained, of course, with the tubes used as either oscillators or high frequency amplifiers, where distortion is

FIG 10
RK-100 OUTPUT & DISTORTION CHARACTERISTICS



permissible and relatively high values of peak current may be drawn.

Editor's note: The adaptability of this type tube to both audio- and radio-frequency circuits is demonstrated in the 14-mc. 'phone transmitter described elsewhere in this issue.