A High Speed Geiger-Counter Circuit

H. V. NEHER AND W. W. HARPER, *California Institute of Technology*

(Received March 24, 1936)

An improved Geiger-counter circuit is described which has the following characteristics: (1) It will respond to at least 2×10^5 particles per minute. (2) Easily obtainable resistances of not more than a few million ohms are used. (3) Consistency of operation is obtained since surface leakages and surface charges are unimportant. (4) The circuit will operate equally well with very small or very large counting tubes, and at either low or high counting rates. (5) The counts are independent of the voltage on the counter over a wide range. (6) A large pulse is obtained which makes possible the use of low values of resistance and capacity to the mixing tube in case several counters are used to count coincidents. (7) The circuit is simple, inexpensive to make and has given satisfactory performance on several different research problems at this Institute.

INTRODUCTION

THE conventional Geiger-counter circuit, which employs a high resistance (10^8 to 10^{10} ohms) to extinguish the discharge caused by the response of the counter to an ionizing particle, becomes inefficient at high counting rates due to its long recovery time. The use of such high resistances also makes it necessary to take precautions to minimize circuit leakage. In certain applications of Geiger counters these precautions are difficult to carry out. The purpose of the present paper is to disclose an improved Geiger-counter circuit which surmounts these difficulties. Although the virtue of the new circuit is mainly realized in its application to high speed counting, the convenience afforded in the use of a low extinguishing resistance (10^6 to 10^7 ohms) makes it useful in many applications.

DESCRIPTION OF CIRCUIT

The new circuit is shown in Fig. 1. The Geiger counter M is connected to a standard radio receiving tube, such as the Type 57. The anode wire of the counter is directly connected to the plate of the '57 tube, while the cathode cylinder connects to the control grid. The value of the grid resistor R_g depends in general upon the physical constants of the Geiger counter. Its value varies from 10^6 to 5×10^7 ohms. A resistor of 2×10^6 ohms is suitable for use at R_p. The control grid potential E_g, which becomes critical under certain conditions, is regulated by the potentiometer P and the voltmeter V_1. The screen grid potential is not critical. A value of

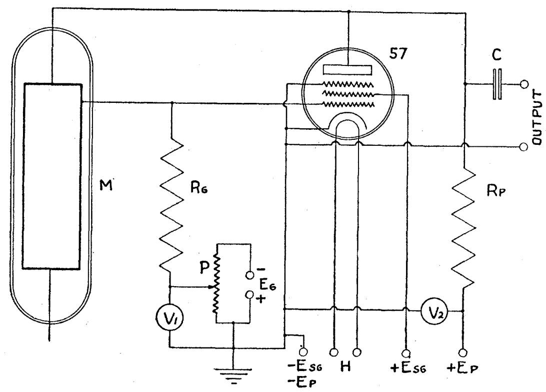

FIG. 1. Counter circuit diagram.

45 volts has been used in taking all the characteristics submitted herewith. The high voltage for both tube and counter is applied at E_p. This potential is measured by an electrostatic voltmeter, V_2. A coupling condenser C, having a capacity of approximately 50 cm is connected in the output circuit. The impluses delivered by the counter circuit are applied to a low frequency amplifier of the transformer coupled type having a voltage gain of 10^3. The amplified impulses are then fed into an electrical counting circuit such as described by Hunt.[1] This circuit provides a means of obtaining an instantaneous indication of the average rate at which random impulses are received.

The Geiger-counter tube employed for taking the data presented herewith has a cylindrical copper cathode 7 cm (2.75 inches) in diameter and 61 cm (24 inches) in length. The coaxial anode wire is of 20-mil tungsten. These electrodes are

[1] Hunt, Rev. Sci. Inst. 6, 43 (1935).

mounted in a Pyrex tube. The counter is filled with argon at a pressure of 5 cm of Hg.

The new circuit has been successfully operated with counter tubes of various sizes and designs. In general it has been found necessary to increase the value of R_g to avoid critical circuit constants when using counter tubes of small dimensions. As an extreme example, a counter 0.63 cm (0.25 inch) in diameter and 2.54 cm (1 inch) in length required a grid resistance of 50 megohms for satisfactory operation.

The circuit may also be operated with vacuum tubes other than the type 57. The '32, '6C6, and '77 give equally good results.

Operation of Circuit

Before proceeding with a discussion of the performance characteristics of the circuit, we will endeavor to describe its operation. Under normal conditions (prior to the passage of an ionizing particle through the counter) the voltage E_g maintains the control grid of the '57 tube sufficiently negative to prevent the flow of appreciable plate current through R_p. The potential E_p is adjusted to such a value that the effective voltage across the counter tube is above its voltage threshold, i.e., the counter is assumed to be in a sensitive state. The passage of an ionizing particle through the counter initiates a discharge between its electrodes. This discharge causes the potential of the control grid to become less negative, thereby increasing the plate current flowing through R_p. If the change in grid potential is of sufficient magnitude, the voltage drop in R_p will result in the effective counter voltage dropping below the threshold value. Thus, the counter discharge is extinguished and the circuit recovers to normal conditions in a period determined by its time constant. The amplifying action of the '57 tube permits satisfactory counter operation with a total circuit resistance far below the value ordinarily employed with Geiger counters.

Clearly, the value of the grid potential E_g, must be within certain limits. If E_g is made too negative the voltage impulse developed in R_g due to the passage of a particle through the counter will not be able to affect the plate current by an amount sufficient to cause extinction of the discharge. Under these conditions of steady discharge the counter is insensitive to ionizing particles. At certain high negative grid potentials, one finds that this "blocking" action occurs intermittently, with a resulting reduction in counting efficiency.

An operating limit is also reached when the negative grid bias is made too low. In this instance, the plate current may be increased to the point where the voltage drop in R_p will bring the effective counter voltage below the necessary threshold value. Even before threshold voltage is reached a loss in counting efficiency is noted.

Circuit Characteristics

The comparative performance of the abovementioned counter tube in both a conventional circuit and in the new circuit is shown in Fig. 2. The broken curves show the count-voltage characteristics of the large counter in a conventional circuit. The lower curve is the natural background counting rate. The upper broken curve depicts the increase in counting rate by placing an intense gamma-ray source at a distance of 10 meters from the counter tube. The solid curves illustrate the performance of the new circuit under equivalent conditions. The extinguishing resistor used in the case of the conventional circuit was 10^9 ohms. In the new circuit, both R_g and R_p had a value of 2×10^6 ohms. The coupling capacity, C, was the same in both cases.

The count-voltage characteristics of the im-

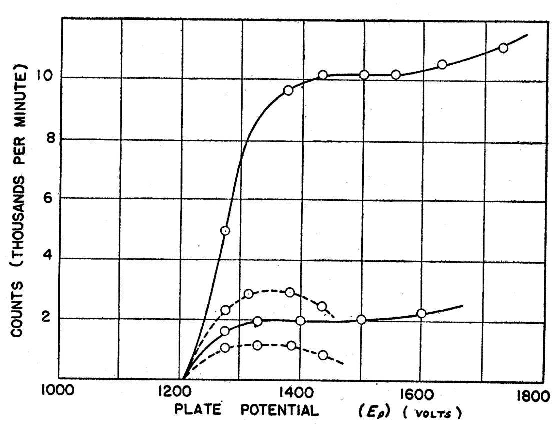

FIG. 2. Comparative performance of a counter tube in the conventional circuit (broken curves) and in the new circuit (full curves).

proved circuit are shown in Fig. 3, where R_g has been taken as a parameter. The values of R_g range from 1 to 20 megohms. With the counter in use it was not feasible to operate with less than 1 megohm. These data were taken with a gamma-ray source 2 meters from the counter tube. The negative grid potential is different for each curve. The procedure in determining the optimum value of E_g for a given grid resistance will be described in the following paragraph. It will be noted that with the exception of the curve representing operation with 20 megohms, a very satisfactory range exists in which the count is substantially independent of voltage. It should be mentioned that when using high values of resistance the percentage of counts lost decreases with the counting rate, i.e., as the counting rate is decreased all the curves in Fig. 3 tend to coalesce.

The proper value of grid potential consistent with satisfactory operation may be roughly determined by listening with headphones to the impulses delivered by the circuit while adjusting the potentiometer P. The potential E_p, of course, should be set at a value above threshold. For a given grid resistance, it will be observed that the counter functions normally only when E_g is within certain limits. Intermittent or permanent "blocking" occurs if the negative grid bias is made too great. Decreasing the negative bias, on the other hand, drops the counter voltage below threshold due to the plate resistor R_p. Between these two limits an operating range of grid potential is found. The magnitude of this range of grid potentials depends on both R_g and E_p as will be shown.

The behavior of the circuit with respect to the grid potential value is best understood by studying the counting rate as a function of E_g; the plate potential as measured by V_2 being considered a parameter. Fig. 4 illustrates the nature of the count-grid potential characteristic. These curves were made using a grid resistance of 4 megohms. For a plate potential of 1275 volts a region occurs between negative grid potentials of 5.5 and 6.0 volts where the counting rate is quite constant. At higher plate potentials this constant region moves toward lower grid potentials. In taking these curves the gain control on the amplifier was turned down so that the "blocking" action referred to above was not effective in operating the frequency meter.

In general, for various values of R_g, it is possible to determine empirically the relationship between grid potential and grid resistance. The results of such measurements are plotted in Fig. 5. The solid curve gives the optimum value of E_g for various grid resistances. This curve applies only to the large counter previously described. For each value of grid resistance used, the plate potential is adjusted so as to be approximately 50 volts beyond the knee of the count-plate potential curve. Between the limits of "blocking" and "threshold" the counting rate is practically independent of grid potential.

It will be observed that when using 1 megohm the operating range of grid potential becomes very small. This presents no serious difficulty since the grid bias may easily be held to within 10^{-1} volt.

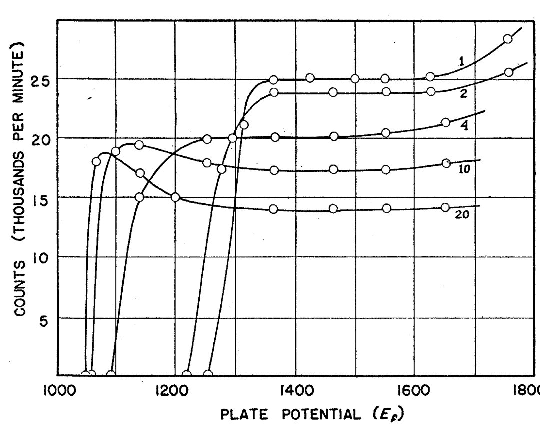

FIG. 3. The count-voltage characteristics of the improved circuit.

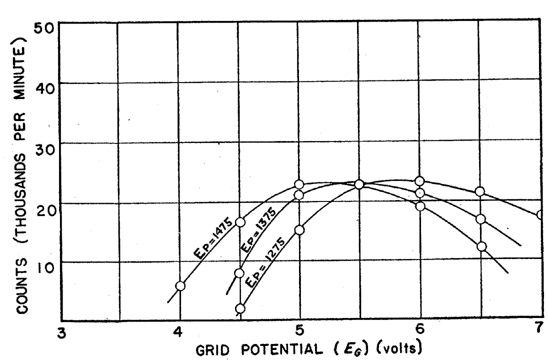

FIG. 4. The count-grid potential characteristic.

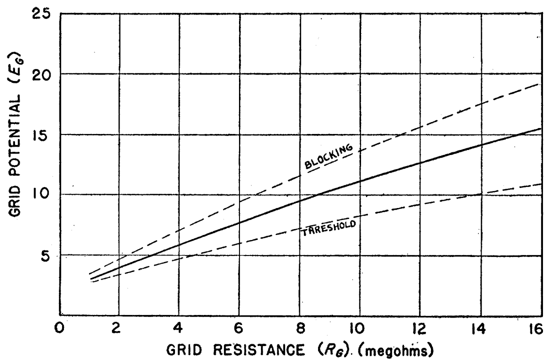

FIG. 5. Relation between grid potential and grid resistance.

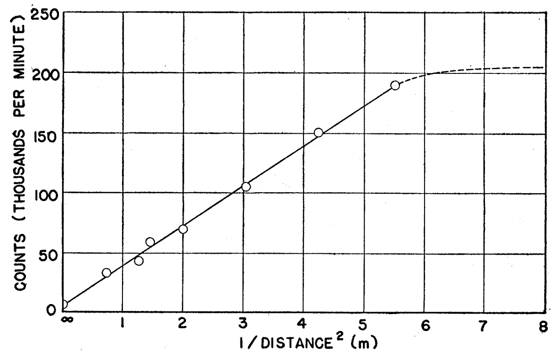

FIG. 6. The test of the circuit response.

The response of the circuit can be appreciated from the inverse square law curve of Fig. 6. The counting rate is plotted as a function of the inverse of the square of the distance between the gamma ray source and the counting tube. No precautions were taken to guard against the effect of scattered radiation. Linearity is attained until distances are reached which are comparable to the dimensions of the counting tube. Failure to find linearity in this relationship may result from a deficiency of amplification between the counter circuit proper and the frequency meter. At high counting rates the average impulse voltage may drop below the threshold required by the frequency meter. The gain control on the amplifier provides a reliable test as to whether or not the threshold voltage of the frequency meter is being satisfied. As the gain control is increased from zero, the counting rate as indicated by the frequency meter should increase until the average voltage of the impulses passes the threshold. Further increase in gain will have no effect on the counting rate. Unless the gain control can be carried beyond the point where no increase in counting rate occurs, one cannot be certain that the threshold conditions are satisfied for the frequency meter.

CONCLUSION

The new circuit, in combination with a suitable amplifier and frequency meter, constitutes a reliable means of detecting either photons or ionizing particles. The low resistances employed result in a time constant small enough to permit counting at rates as high as 2×10^5 particles per minute. Even where high counting rates are not involved, the fact that satisfactory operation may be had with low values of extinguishing resistance is of importance in numerous applications. As an example, the use of a conventional Geiger-counter circuit in connection with a mass spectrometer became difficult due to surface leakage. With the new circuit this leakage was unimportant.

The large negative pulse developed in the plate resistance makes it possible to use a small coupling capacity to the "mixer" tube of a coincident counting system. The new circuit has been found to give improved results in such systems.