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Publication Date
1957-10-01

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UCRL-8000
Particle Accelerators
and High-Voltage Machines

UNIVERSITY OF CALIFORNIA

Radiation Laboratory
Berkeley, California

Contract No. W-7405-eng-48

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William A. Wenzel

October 2, 1957

Printed for the U. S. Atomic Energy Commission

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ABSTRACT

A coincidence circuit of high resolution, which performs reliably under high counting rates is described. The basic circuit, consisting of a pentode limiter feeding a simple Rossi-type diode coincidence circuit, is readily adaptable to a variety of uses.

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INTRODUCTION

Because high energy accelerators are pulsed, associated experimental counting circuitry must often be adapted to handle high counting rates. In particular, the requirement of high resolution in coincidence circuits is often coupled with the need for high efficiency in the separation of individual "rare" events from a large background.

In the timing of photomultiplier pulses associated with Cerenkov or scintillation counters, inherent limitations on the accuracy with which a single event can be timed are set by photoelectron statistics, scintillator decay time, and the spread in photomultiplier transit time. A number of methods have been used to extract a maximum of timing information from photomultiplier pulses. In the circuit of Cottini and Gatti, [1] for example, a harmonic analysis of the pulse is used to give on a slow time scale accurate timing information of fast pulses. In the chronotron-type detector the sensitivity of the timing circuit to pulse-height fluctuations is greatly reduced by the use of several channels of slightly different timing. Again the comparison of channel response is done at a relatively slow rate.

Although such circuits may be very useful in experiments in which the counting rates are low, they are relatively ineffective in the presence of a large background because of either dead time in the analyzing circuit or distortion because of "pile-up". As a result, in most high-resolution circuits used in high-speed counting, the "decision" must be made rapidly as to whether or not a coincidence has occurred.

THE PENTODE AS A LIMITER

The use of high-transconductance pentode limiters ahead of the coincidence circuit itself is common practice. Negative pulses of more than a few volts turn off the tube, switching a fixed amount of plate current. In this way the size of the pulse to the coincidence circuit is largely independent of the input pulse from the photomultiplier. A very widely used circuit of this type is that due to Garwin. [2] This circuit is indicated schematically in Fig. 1(a). Discrimination results largely from the action of diode D_1 in the plate circuit of the limiter pentodes. A current equal to that drawn by all but one tube is carried by this diode, so that if all but one tube is cut off, the voltage on the plate line remains nearly constant. If all tubes are cut off simultaneously, the diode is turned off, the plate voltage rises toward B^+, and a pulse passes through pulse-stretching diode D_2 to a relatively slow amplifier.

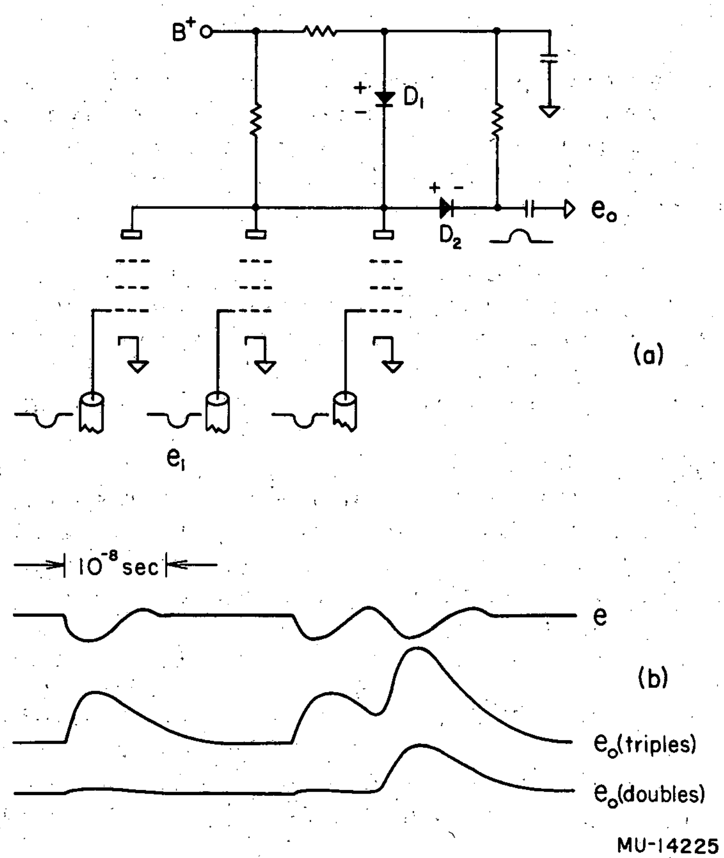

Fig. 1. (a) Coincidence circuit of Garwin type
(b) Performance with input pulses including overshoot.

This circuit is convenient to use because a large discrimination factor is easily obtained through the action of D_1 and D_2. The chief disadvantages are related to the difficulties of obtaining short pulses from present-day photomultipliers. Use of clipping lines to shorten the photomultiplier pulses leads to some improvement of time resolution, but difficulties arise because of the clipping reflections which produce positive overshoot. At high frequencies this overshoot has a detrimental effect on the operation of the circuit of Fig. 1(a). In Fig. 1(b) is shown the behavior of the circuit when grid clipping is employed. The normal behavior of the circuit is shown at the left of the traces. To the right is shown the behavior when two pulses come close together, a likely occurrence if the counting rate is high. In this case the good discrimination of the threefold coincidence circuit against doubles is lost. The reason for this is that the positive overshoot of the first pulse increases temporarily the current in the diode D_1. The succeeding negative pulse is not able to reduce this diode current instantly because of the phenomenon of charge storage, which occurs in even the fastest diodes such as the G7A. Diodes that are heavily conducting cannot be turned off in less than a few millimicroseconds. Consequently, when the second negative pulse turns off the tube, which has been drawing a greater than usual current, a larger pulse than usual appears on the plate line and feeds out through D_2.

PLATE CLIPPING

In an effort to eliminate the effects of overshoot associated with grid-line clipping, several circuits using plate clipping were investigated. First, it is apparent that the circuit of Fig. 1(a) is not directly suited to plate clipping because of the low dynamic impedance of D_1. Therefore, plate-clipping lines of any reasonable impedance could not be properly terminated, and multiple reflections would result. Elimination of D_1 from the plate circuit makes such termination feasible, because D_2 is not normally conducting and the dynamic loading of the plate itself is relatively low. The threefold coincidence circuit shown in Fig. 2(a) was constructed, and tests made to determine its suitability for work at high counting rates. This circuit is in essence identical to that used by Bell, Graham, and Petch.[3] Because on the plate line a linear addition of pulses occurs before discrimination, the circuit is not well suited to coincidences of a large number of signals. Moreover, as is shown in Fig. 2(b), the circuit is very sensitive to positive overshoot on the grid line. Since grid line clipping is not used, this is not necessarily a problem. In the use of this circuit at high counting-rates, however, care should be taken to prevent reflections on the grid lines.

Another shortcoming of the circuit of Fig. 2(a) became evident in the performance of a high-counting-rate experiment using RCA 1P21 photomultipliers.[4] Because the pulses required amplification, all signals were capacitively coupled to the inputs of the coincidence circuit. At high counting rates, appreciable loss of discrimination occurred. This is attributed to the base-line shift at the grid of the pentode limiters. As a result, more plate current is switched at higher pulse rates. This problem does not arise if each input to the coincidence circuit is directly coupled to the anode of the photomultiplier. High-gain photomultipliers such as the RCA 6810 have made this feasible in many cases, but for Cerenkov counters, amplifiers are usually required.

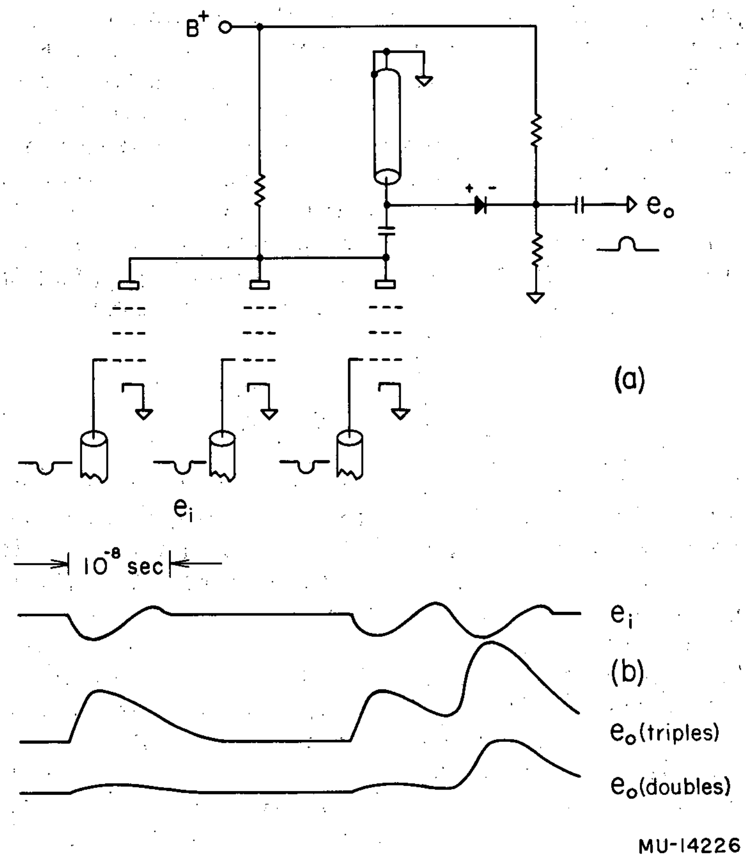

Fig. 2. (a) Plate-addition coincidence circuit
(b) Performance with input pulses including overshoot.

DIODE COINCIDENCE CIRCUIT WITH LIMITER

Diode coincidence circuits are widely used. They are relatively simple to construct and perform reliably in many applications. In operation with millimicrosecond pulses, however, the capacitive feed through of even the best diodes is appreciable. As a result, high-resolution diode coincidence circuits are pulse-height sensitive.

In Fig. 3(a), the Rossi-type[5] diode coincidence circuit is preceded by a limiter in each channel to reduce the pulse height sensitivity. The performance with this arrangement is very satisfactory. Figure 3(b) shows that, as with the circuit of Figure 2(a), positive overshoot on the grid of the limiter may cause a large pulse to be fed into the diode circuit. But unlike the two previous circuits considered, the threefold-coincidence circuit of Figure 3(a) has enough additional discrimination through the action of the diode circuit to suppress the feed through of doubles. For the same reason one or more of the inputs can be capacitively coupled without appreciable change in the output level of the coincidence circuit at high counting rates.

CIRCUIT RESOLVING TIME

Delay curves for the circuits of Fig. 2(a) and 3(a) are shown in Figs. 4 and 5 respectively. In obtaining these data both circuits were operated as threefold coincidences. The inputs were directly-coupled from RCA 6810 photomultipliers looking at plastic-scintillators through lucite light pipes. The scintillators were arranged in a simple telescope which looked directly at an internal Bevatron target. Because there was no momentum selection of the particles entering the telescopes, 4 inches of lead was placed between the last two scintillators of each telescope in order to eliminate coincidences due to slow particles. The circuits were compared directly; one was used as a monitor as the timing of a single counter in the other was varied. The pentode limiters were 6AH6's; the diodes were all G7A's; and each clipping line was 1 ft of Amphenol RG63/U cable. Each coincidence output was amplified by two Hewlett-Pachard 460A distributed amplifiers and scaled, following a final discrimination.

Delay curves for each circuit are shown for two settings of the final discriminator. It is apparent that the width of the delay curve is a function of the discriminator setting. For too high a setting the maximum counting efficiency is less than 100%. The one characteristic of the delay curve which seems to be independent of discriminator setting is the (logarithmic) slope of the tail of the curve. In many experiments, this portion of the curve is the most important insofar as the rejection of background is concerned. In this case the measured slope is about one order of magnitude per millimicrosecond for each circuit.

Under the test described, the performances of the two circuits were for all practical purposes indistinguishable. The singles counting rate was kept high, 10^5 to 10^6 sec^{-1}, in order to expose instabilities in the coincidence circuits themselves. It is felt that much if not most of the observed width of the delay curves can be attributed to sources other than circuit resolving time. Some transit-time spread is introduced by the size of the scintillators

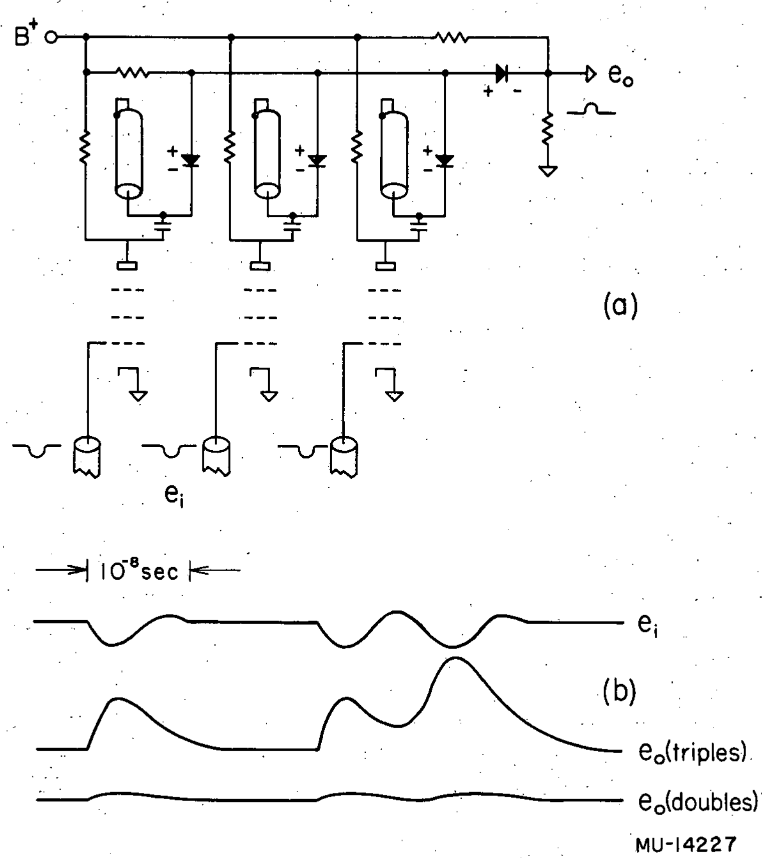

Fig. 3. (a) Rossi-type coincidence circuit with limiter.
(b) Performance with input pulses including overshoot.

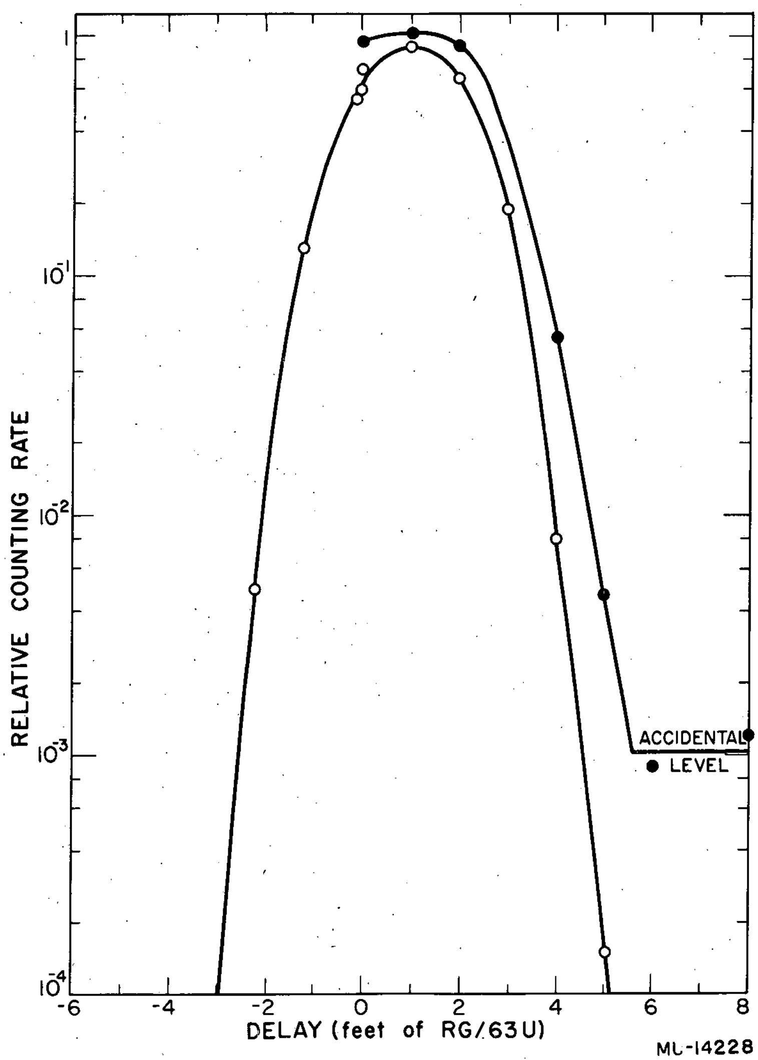

Fig. 4. Delay curve measured with circuit of Fig. 2a. The coincidence circuit is threefold, with delay of one counter varied. The photomultipliers were 6810's. The plastic scintillators were 4 in. by 4 in. in area. Other experimental details are given in the text.

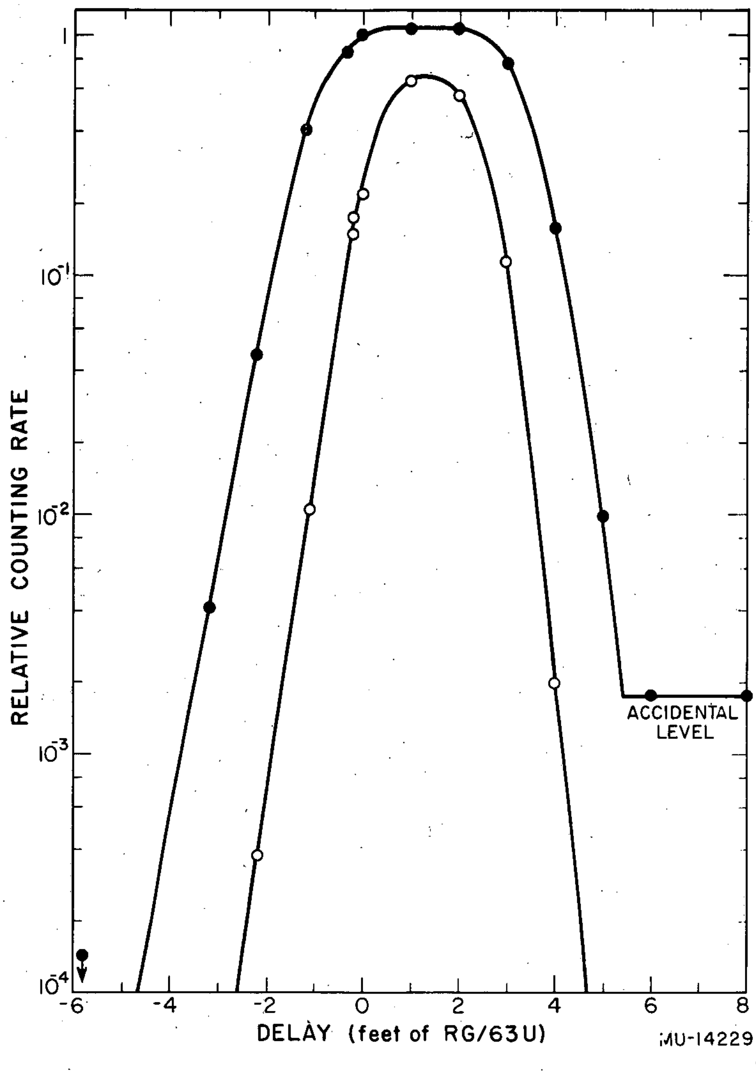

Fig. 5. Delay curve measured with circuit of Fig. 3a. Other experimental details are the same as those given for Fig. 4.

(4 x 4 x 1/4 inch) and some pulse deterioration may occur in the rather long signal cables used [170 ft of amphenol RG 63/U]. Most of the loss of timing information, however, probably occurs in the 6810 photomultiplier, for which the spread in transit time is several times the resolution measured.

It is significant that a negligible accidental coincidence rate is measured on the left side of the delay curves. This is a consequence of two factors, one related to the use of the limiter followed by a clipping line, and the other arising from the experimental arrangement. A particle closely following another through a given scintillator does not send a pulse into the coincidence circuit, since the limiter remains cut off for the duration of both pulses. Because of the proximity of adjacent counters in the telescope, most of the particles that passed through any given scintillator also passed through its neighbors. Hence, for delays over the range of one pulse width, the coincidence circuit was dead during the time when an accidental coincidence might otherwise have occurred. In the experiment under consideration, the asymmetry of the effect is related to the fact that the front counter, which was delayed relative to the other two, counted particles that were not counted by the rest of the telescope.

This particular feature of the delay curves obtained with these kinds of coincidence circuits suggests at least one application potentially useful in experimental physics. In a collimated beam in which particles are to be separated by time of flight, the coincidence-circuit dead time would automatically eliminate accidental coincidences provided that a particle passing through any given counter also pass through another counter separated from the first by a significant distance. Because it is often feasible to require that particles reaching the end of a time-of-flight channel pass through the first counter in line, a material reduction in accidental coincidences can occur if fast particles are to be detected in the presence of slow ones. Unfortunately the reverse condition, in which slow particles could be separated more easily is not so readily achieved.

EXPERIMENTAL

Use of Coincidence Circuits

The circuit illustrated by Fig. 3(a) has been used extensively during the past year. It has proved to be particularly satisfactory in experiments in which counting rates were as high as 10^6 sec^{-1}.[6, 7, 8, 9] Timing curves showing the separation by time-of-flight of K^- mesons and antiprotons from fast particles are given in References 7 and 8, respectively.

A more detailed circuit diagram is given in Fig. 6. for a threefold coincidence circuit now in use. The pentodes are amperex E 180F's which draw a plate current of 20 ma. Input-cable and clipping-line impedances are either 125 or 197 ohm, depending upon the input-pulse level available and the resolution required. The diodes of the coincidence circuit are operated at low current, about 1 ma per diode. In this way the diode is turned off relatively easily, and difficulties associated with charge storage are minimized. Furthermore, proper termination of the clipping line is possible. because the dynamic loading from each coincidence diode is small.

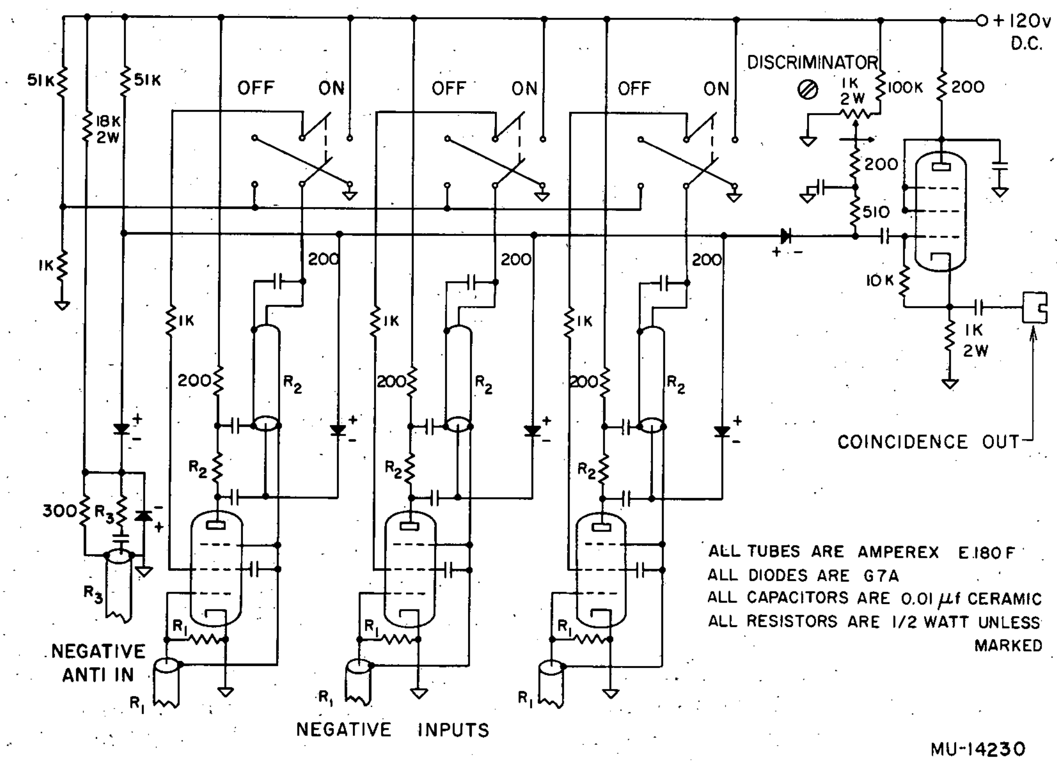

Fig. 6. Schematic details of circuit indicated in Fig. 3a.

The output discriminator is set to give maximum rejection of doubles when the circuit is set for threefold coincidences. When the circuit is to be operated as a twofold coincidence circuit, one pentode and its associated diode are turned off. No change in the output discriminator is required, and the output pulse height for a coincidence remains essentially unchanged. In the same way, the single inputs can be tested separately. The output discriminator stretches the coincidence pulse to a length of about 10^{-8} sec. For short clipping lines, the output pulse height is roughly proportional to the length of the clipping line. With 125 Ω clipping lines 1 ft. in length, the output-pulse level into 197 ohms is about 0.1 volt. The rejection of twofolds in this case is about 10 to 1 when the circuit is set to detect threefold coincidences. The output pulse is reproducible, and for this reason it may be used as an input in subsequent coincidence circuits of the simplest possible design.

Anticoincidence

A simple anticoincidence circuit that has performed reliably at rates of at least 10^5 per sec is included in the circuit shown in Fig. 6. In this arrangement, both coincidence and anticoincidence information are not obtained simultaneously. On account of the reproducibility of the coincidence pulse height and shape however, it is feasible to postpone the anticoincidence to a simple diode circuit following the coincidence circuit of Fig. 6. This procedure has been found satisfactory in cases where both coincidence and anticoincidence information are required simultaneously.

CONCLUSIONS

Many coincidence circuits capable of short-time resolution in diverse applications have been presented in the literature. In this report, circuits have been considered only from the point of view of reliability under conditions of high counting rates, that is, with a pulse duty cycle of the order of 1% or more. Some circuits in common use in high-counting-rate applications have not been discussed. This is due in part to oversight, and in part to the absence of first-hand knowledge of their performances under these conditions.

ACKNOWLEDGMENTS

The author would like to express his gratitude to Bruce Cork, Glen Lambertson and Oreste Piccioni, in collaboration with whom the work described herein was undertaken. Most of the electronic circuits used were built by the group working with F. C. Caldera.

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