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A SEARCH FOR A FAST DECAY COMPONENT IN NaI(Tl)/AN EVALUATION OF THE RCA 8575 PHOTOMULTIPLIER TUBE

by

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ABSTRACT

The general performance of selected RCA 8575 photomultiplier tube-NaI(Tl) scintillator combinations has been examined. The measurements were made with NaI(Tl) crystals packaged with both glass and quartz windows. The results of the study show that the 8575 is fast, quiet, and shows virtually no internal interaction effects. In addition it was found that the increased light transmission capabilities of the quartz window produced no measurable changes in the measured resolving times.

SUMMARY

In an attempt to improve timing and noise parameters of scintillation detectors, new and different fabrication techniques continue to be applied to both photomultiplier tubes and scintillation crystals. The present work describes a series of measurements which were made in order to evaluate the performance of some of these new components. The measurements were made with NaI(Tl) crystals packaged with quartz windows as well as with NaI(Tl) crystals packaged with the more conventional glass windows. They were both mounted on RCA type 8575 photomultiplier tubes. The quartz windows were introduced in order to allow transmission of any short-wavelength, fast-decay components which might be present in the scintillator light emission. The results of the measurements indicate, however, that if any fast components are present in the light output they are there in unmeasurable quantities. In addition the results indicate that the 8575 phototube is very fast, is quiet, and is relatively free of internal interaction effects.

1. Introduction

Timing studies using NaI(Tl) scintillators mounted on Phillips type 56 AVP and XP 1020 photomultiplier tubes have been reported by Dolan, et al.[1]). The authors found that the limiting factor in fast timing when using NaI(Tl) appeared to be the slow, approximately 250-ns decay time of the light pulse train.

However, under special conditions previous experimenters have observed a fast decay component from NaI(Tl). Eby and Jentschke[2]) found an approximately 10-ns emission at about 3500 Å from NaI(Tl) activated with alpha particles. Van Sciver[3,4]) observed a deexcitation band from ultraviolet excited NaI(Tl) at around 3450 Å which supplied approximately 25% of the total light output. He found that at 77° K at least a fraction of the emission was fast with a decay constant of approximately 10 ns.

Recently photomultiplier tubes with bialkali (CSKSb) photocathodes have become available. One of these, the RCA type 8575, 5.08 cm ∅ (in diameter), has a maximum quantum efficiency of 28% at about 3350 Å*, dropping to the 10% levels at approximately 2800 Å and 5200 Å. This

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* Radio Corp. of America, Harrison, N. J.

response is ideal for NaI(Tl) scintillators emitting light in the 3450 Å range as well as at the primary emission band of 4200 Å, the normally observed slow component.

In view of the fact that the NaI(Tl) emission band attributed to thallium dimer excitation[3,4]) is at 3450 Å, we obtained NaI(Tl) crystals which were packaged with quartz windows. The crystals were obtained on loan from the Harshaw Chemical Co.* The present measurements were made to measure the effect, if any, that the quartz-transmitted shorter wavelength light would have on time response, as well as to compare the performance of the 8575 phototube to those of the Phillips tubes studied previously[1]). The experiments include coincidence-delay measurements with both glass window and quartz window NaI(Tl) crystals, phototube thermionic noise measurements, and energy resolution measurements. All measurements were made at room temperature.

2. Apparatus and procedure

The block diagram of fig. 1 shows the experimental apparatus as it was arranged for the resolving time measurements. A detailed description of the components and their application to similar measurements has been given in ref. [1]) and will not be repeated here.

The schematic diagram of fig. 2 shows the voltage divider network used in the present work. Again since a detailed discussion of the

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* Harshaw Chemical Co., Cleveland, Ohio.

photomultiplier circuitry is provided in ref. [1]), it will not be repeated here except for one added note. For the coincidence-delay measurements the anode signals were not passed through a biased, fast-switching, type Q5-100 crystal diode*. The diode was removed in order to not limit the response of the photomultiplier to any fast decay component which might be present in the scintillator. The diode was subsequently replaced for the thermionic noise measurements. Note that the anode pulses were clipped by a 30-ns stub. The pulse shaping was necessary in order to prevent after-pulsing in the fast discriminators.

For the resolving time measurements the high voltage combinations applied to the phototubes were selected such that noise pulse amplitudes were slightly under 100 mV, the triggering level of the fast discriminators. Three pairs of resolving time measurements were then made. Using annihilation radiation from ^{22}Na as the gamma-ray source, the full-energy peak at 511 keV was selected in each single channel analyzer for the first measurement of each pair. The second measurement was made with each energy selecting channel adjusted to a position corresponding to 122 keV on the Compton-scattered distribution below the 511 keV full-energy peak. The energy calibration was made by using the 122 keV gamma ray from ^{57}Fe.

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* Manufactured by the International Diode Corp., Jersey City, N. J.

For the first pair of measurements NaI(Tl) crystals contained in glass window packages were mounted on the photomultiplier tubes. The scintillators each measured 4.45 cm ø by 5.08 cm. For the second set of measurements the crystals were replaced by crystals covered with quartz windows. One of these scintillators measured 4.45 cm ø by 5.08 cm, while the other measured 4.45 cm ø by 1.27 cm. For the last set of measurements a wafer of ordinary glass was interposed between each quartz-window scintillator and the corresponding phototube. The glass, an absorber of ultraviolet radiation, was employed to block whatever fast-decay components might exist at the shorter wavelengths around 3400 Å, while still allowing the use of the same crystals.

For the thermionic noise measurements the phototube voltage combination was adjusted to -1500 V and +1500 V, the maximum recommended by the manufacturer. The measurements were made both with and without the Q5-100 diode in series with the anode output. A normal 4.45 cm ø by 5.08 cm crystal was used. The amplitudes of the noise pulses generated by the phototube were measured by observing the various anode pulses directly with a Tektronix 585 oscilloscope.

The energy resolution measurements were made at two different phototube voltage combinations, (-1200 V) - (+1200 V), and (-1500 V) - (+1500 V). A normal 4.45 cm ø by 5.08 cm NaI(Tl) scintillator was activated by 661.5 keV gamma rays from ^{137}Ba.

3. Results and discussion

The results of the resolving time measurements are displayed in fig. 3, where representative coincidence-delay curves have been plotted. Each set of curves corresponds to a selected pair of scintillators.

Fig. 3A displays coincidence-delay data recorded with 4.45 cm ø by 5.08 cm crystals covered with glass windows, while the data shown in the remaining figures correspond to crystals with the quartz window container. The data in fig. 3C differ from those in fig. 3B in that 2-mm thick glass discs were interposed between the photomultiplier tubes and their scintillators for the data of fig. 3C. The voltages were -1300 V and +1400 V for each set of curves.

The curves are, as expected, broader when energies around 120 keV are selected than when the full-energy peaks at 511 keV are used. The increase in line width is much less than that found with tubes tested previously[1]), however. Comparing the three sets of curves indicates that there are no significant differences among them. The small variations which exist can be traced to slight non-uniformities in packaging and mounting procedures. These data agree with those of Lynch[5]) who found no difference in time response between glass window crystals and those packaged with quartz windows. Furthermore, the quartz-window scintillators used by Lynch had an approximately three-times normal concentration of thallium, which, according to the dimer formation theory[3,4]), might be expected to enhance the short wavelength component.

The phototube voltage network recommended by RCA* was used for the present measurements and no attempt was made to vary resistor combinations in order to improve timing. The shortest resolving time measured in the present work was 1.12 ns with 511 keV selected in each detector. Lynch[5]), using the same voltage divider, was able to improve this figure by a factor of two, obtaining 0.52 ns with the same energy selections. However, in using crystals which measured only 2.54 cm ⌀ by 2.54 cm Lynch may have improved the light collection speed enough to account for the difference. Note that the best resolving time obtained in the present work is nearly a factor of two shorter than that obtained in ref. [1]).

The noise pulse measurements are summarized semi-quantitatively in the following way. At 3000 V noise pulse amplitudes were measured at greater than 100 mV into 50 ohms with no crystal diode inserted into the anode series output. However, when the diode was introduced into the anode output circuit and the reverse bias was adjusted for minimum noise, the noise pulse amplitudes were reduced until they were under 100 mV, the triggering level of the Chronetics Model 101 fast discriminator. While at the 3000 V level the crystal diode still seems to be useful as a means of reducing noise level, at lower voltages it

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* Radio Corporation of American Specification Manual 8575 4-65.

was not needed. At 2400 V noise pulse amplitudes were found to be less than 100 mV without the diode. In general the 8575 is considerably less noisy than any tube tested previously[1]).

The energy resolution measurements for the tubes tested in the present work typically gave a value of 8.0% at 662 keV for a voltage of 2400 V. At 3000 V the resolution figure increased to approximately 8.25%. These values can be compared with the manufacturer's typical value of 7.5%. Note that the resolution, while still very good, worsened slightly as the tube voltage was raised. This effect was the only internal problem noted with the 8575. None of the internal feedback effects noted in previous tests[1]) were encountered. The pulse height spectra remained linear with energy and the slow output wave forms remained smooth and undistorted as the voltages were varied. These results are in sharp contrast to those reported in ref. [1]).

The overall high performance of the tube is marred by one puzzling design feature. The tube base consists only of clear, transparent glass, so that when the tube is inserted in the translucent socket provided for it, a severe light leak results. We have temporarily solved the problem by painting the tube base with a black paint called Velvet Coating, 101-C10, Black*. However, there are indications that

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* Minnesota Mining and Manufacturing, St. Paul, Minn.

even though the paint appears to be an excellent insulator it may contribute to tube noise by providing low leakage paths between pins. Clearly, an improved tube base or socket mount design is needed if the 8575 phototube is to be used at its best.

To summarize, the RCA type 8575 photomultiplier tubes used in the present work performed in a manner that is clearly superior to any tube previously encountered. The tube is quieter, has better energy resolution, better timing characteristics, and fewer internal effects than any tube we have tested. Only the problem of the base light leak detracts from its quality. The present measurements also indicate that if a fast-decay component does exist in NaI(Tl) crystal light emission at room temperature, it is unmeasurable. It would appear, then, that the improvement in timing found in the present work was primarily a result of the phototube.

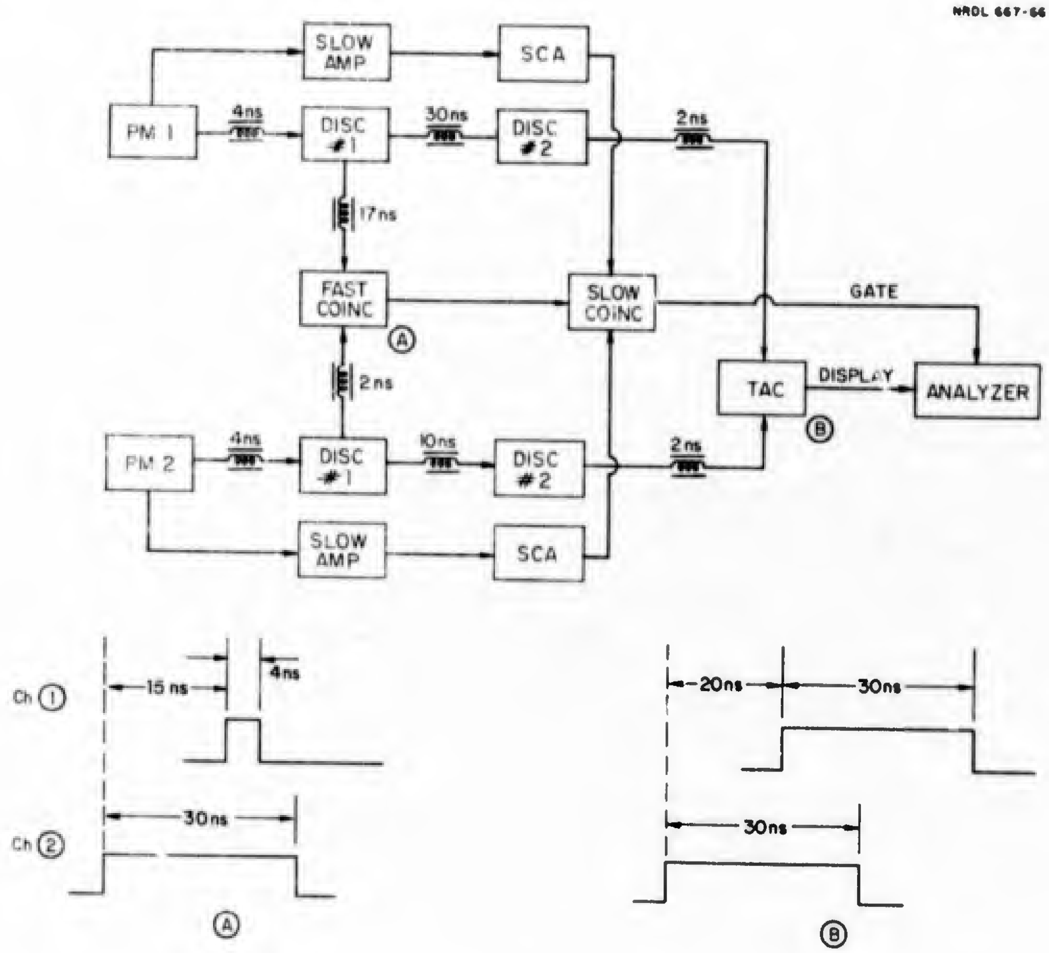

Fig. 1 Block diagram of the experimental equipment and the relative timing sequence for a pair of pulses in prompt coincidence.

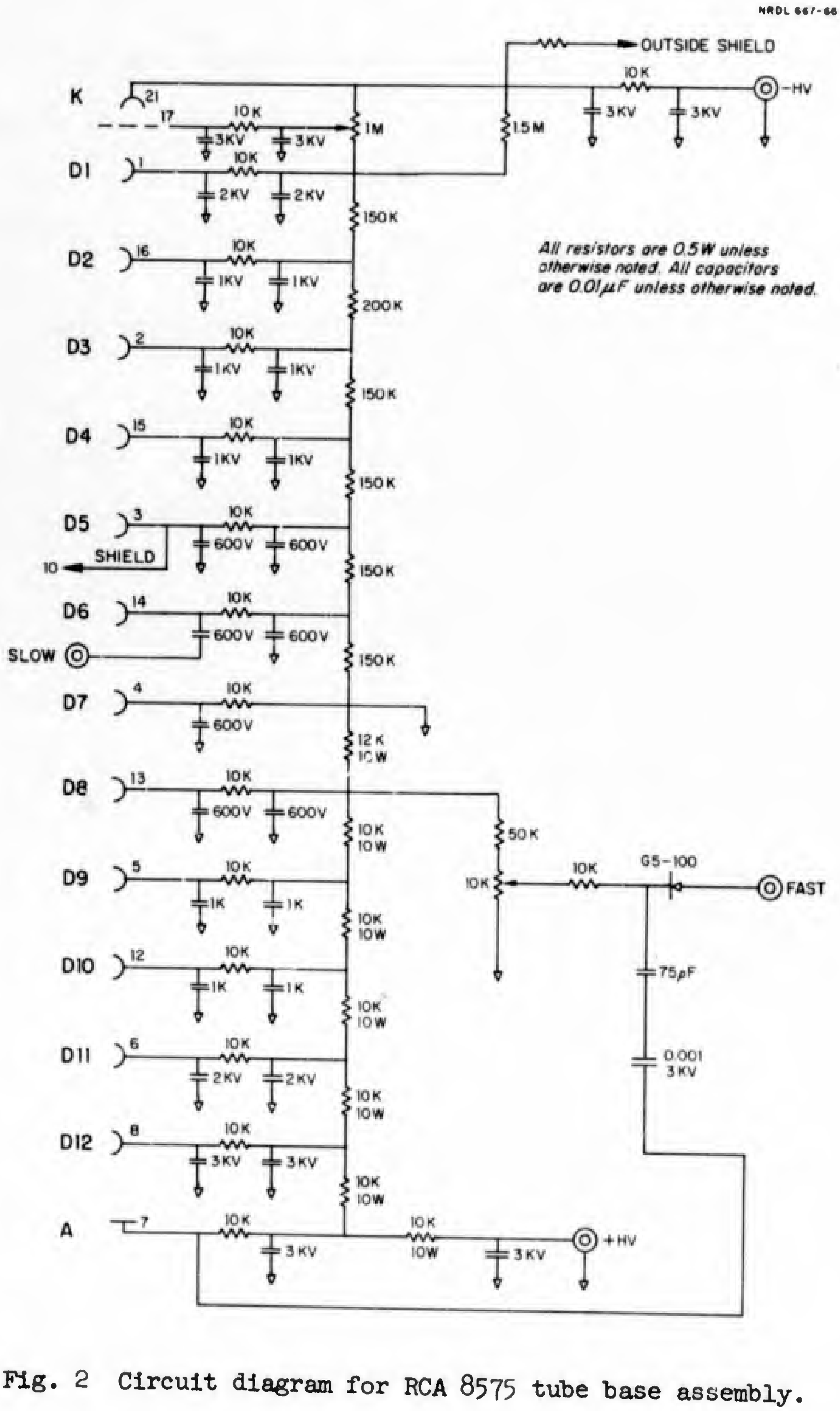

Fig. 2 Circuit diagram for RCA 8575 tube base assembly.

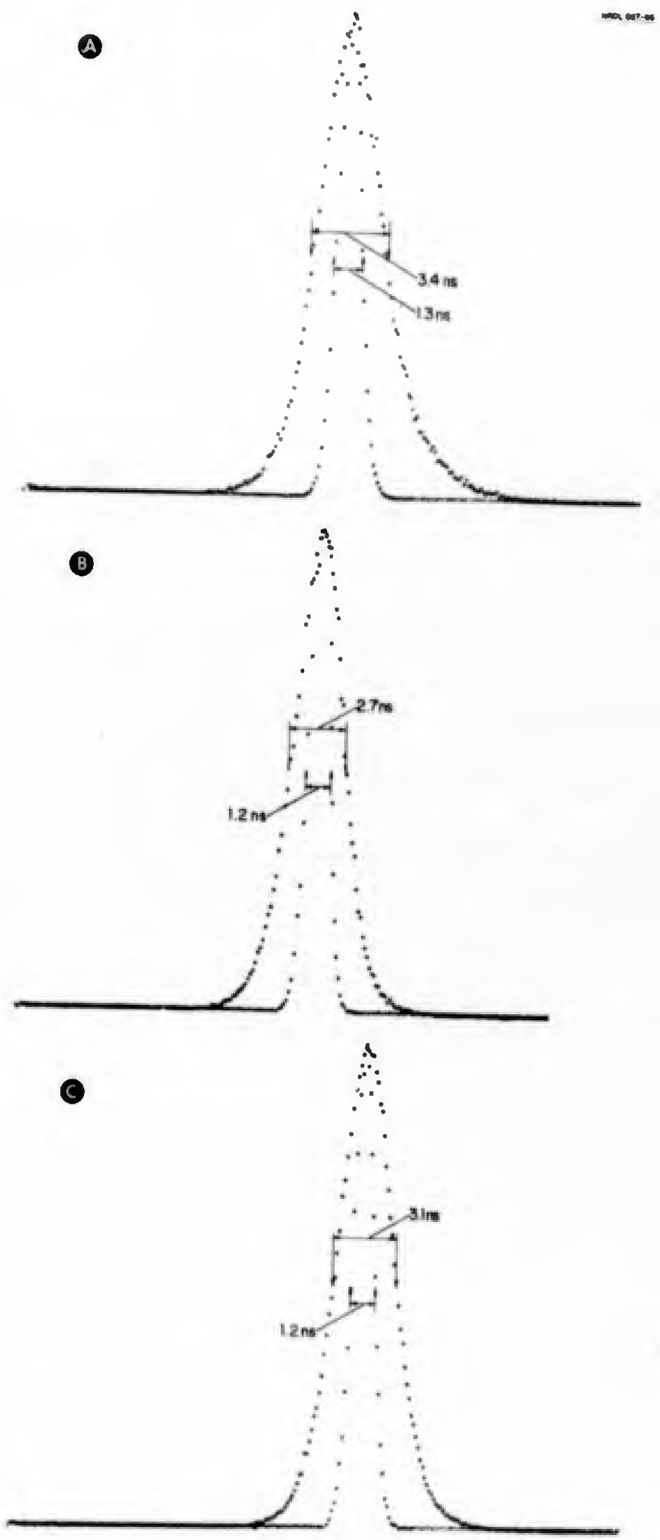

Fig. 3 Coincidence-delay curves measured with high voltage combinations of -1300 V and +1400 V for each measurement. The X's were measured with 511 keV selected in each energy channel, while the O's were measured with 122 keV selected in each energy channel. See the text for a discussion of the three sets of curves.

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