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Photomultiplier-Based Scintillation Radiation Detectors of Increased Sensitivity and Time Resolution for Measurements under Conditions of High Electromagnetic Interference

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Abstract—Scintillation detectors for detecting X-ray, gamma, and neutron radiation with time resolutions of 3–4 ns and having high noise stability have been developed. The detector housings are shielded from the strong electromagnetic interference produced at the moment of discharge. The detector design features an original voltage divider. With these detectors, the parameters of the high-energy radiation from a megavolt atmospheric nanosecond discharge can be studied at the limit of sensitivity of this class of devices.

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INTRODUCTION

Investigation of the initial phase of atmospheric discharge is an important area of gas discharge physics that has attracted much attention for many years. Large-scale investigations of atmospheric discharges are now under way, both in the laboratory and in the field [1–16].

Under a variety of conditions, multiple observations of high-energy radiation have been made from the ground and from airplanes, balloons, and artificial satellites [8–14] during lighting storms. These include bursts of X-ray radiation (XRR) with energy quanta of up to 20 MeV [4–15], gamma radiation at energies of 11–34 MeV [8, 10–14], and neutrons with energies of 0.5–3 MeV [8, 13–15].

Insufficient knowledge of the physical processes in the early phase of discharge formation and the complexity of measurements under field conditions prevent us from establishing the general patterns of discharge development and verify proposed hypotheses. However, this problem can be solved with the use of laboratory installations having parameters that ensure high temporal and spatial separation of different processes. It is assumed that a discharge represented by a long spark in air is the closest laboratory analog of an atmospheric discharge.

The main problem in measuring these is the brief time scale of the phenomenon (the required temporal resolution is on the order of <1 ns) and the high level of electromagnetic interference from the discharge. The possibilities of domestic radio engineering allow registration with a maximum time resolution of ~10 ns using photomultiplier tubes (PMTs). This means of detection has been elaborated (the PMT-30 model), yielding detectors with time resolutions of 3–4 ns. The detector's housing was designed to ensure protection from strong electromagnetic interference originating at the time of discharge, so the structural elements were made from 79NM permalloy.

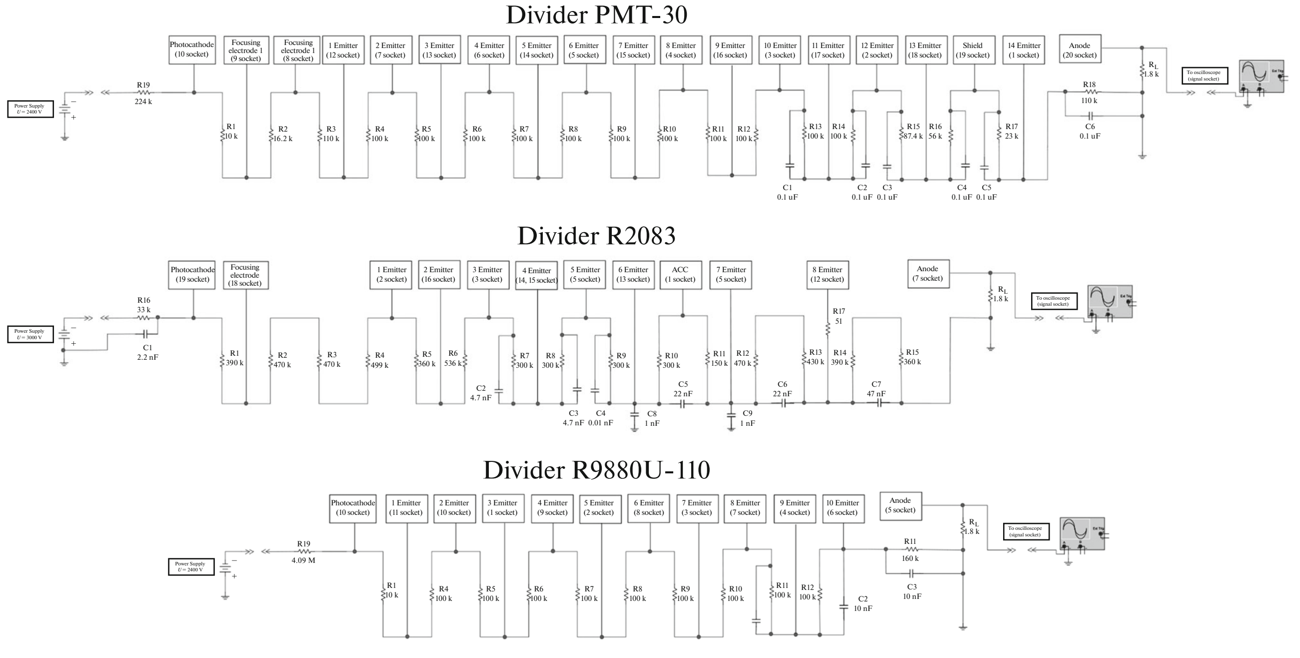
PMTs manufactured by Hamamatsu (R2083 and 80U-110) have also been used to improve time resolution. In assemblies with fast scintillators, these allow resolution of time signals ~1 ns in duration.

Such detectors have been used to register X-ray, gamma, and neutron radiation. For partial separation of the radiation, external lead filters of different thicknesses have been used along with the selective sensitivity of some organic scintillators (polystyrene + POPOP, BC-501A).

The aim of this work was to develop a highly sensitive detector based on a PMT and capable of functioning under conditions of powerful pulsed broadband electromagnetic interference in the immediate proximity of an atmospheric discharge.

PMT-BASED DIAGNOSTIC DETECTORS OF RADIATION

Scintillation detectors based on PMTs are widely used in physics experiments because of their high efficiency and good operational and design parameters. Measurements are often made in the presence of intense background radiation that accompanies the investigated processes of short duration. This makes it difficult to use a detector, as it is a comparatively slow device. Nevertheless, similar detectors can be made


Divider PMT-30

Divider R2083

Divider R9880U-110

Fig. 1. Scheme of the modified PMT divider.

faster without loss of data by using more sophisticated circuitry.

It is known that the gain coefficient (GC) of a PMT depends on the average anode current. In [17–23], it was found that stabilizing the anode current with an error of 5% will stabilize the GC of a PMT with an error of 0.5%. In [18–21, 24], it was established that at a constant load, the dynamic detector characteristics remain linear, allowing its use at high loads as well.

PMT-30, Hamamatsu R2083, and Hamamatsu R9880U-110 were used in our experiments. These models have a number of unique parameters, the most important of which is the photocathode's region of maximum spectral sensitivity, which corresponds to the 400–440 nm flashing spectrum of the types of scintillator that are used.

Figure 1 compares our modified voltage divider circuits to standard ones recommended by manufacturer for obtaining the best amplitude and time characteristics of a signal.

To register atmospheric discharge radiation with a time resolution of several nanoseconds, we used different types of PMTs with modified dividers mated to corresponding detector structures at the input window (fast scintillators specially selected for X-ray, gamma, and neutron radiation).

ASSEMBLING THE REGISTERING DEVICES

For detectors based on the PMT-30 (and on the Hamamatsu R9880U-110) we used plastic scintillators (matched with the PMT in the spectral region of 400–450 nm) made using polystyrene with dissolved scintillating additives *p*-terphenyl + POPOP and manufactured by machining with subsequent polishing of the faces to obtain good reflecting surfaces (for grazing incidence of the light beam). The flashing time of such scintillators is ~1 ns.

All scintillators were painted with a special reflecting compound to improve light collection and wrapped in thick black paper for better external light insulation on all sides, except the one facing the PMT.

For detectors based on the Hamamatsu R2083, we used a Saint-Gobain BC-501A liquid scintillator that matched the PMT in the spectral region of 400 nm and consisted of a fluid poured into a hermitically sealed aluminum housing in the shape of a 2.5 mm thick cylinder (base diameter $d = 50.8$ mm, height $l = 55$ mm). The flashing time was ~1 ns.

A glycerin lubricant was used to interface the scintillator and the photomultiplier tube, in order to reduce the effect of the loss of light caused by boundary re-reflections in air where the scintillator surface joins the photomultiplier tube glass. Measurements showed that the amount of light collected in the counter using the glycerin lubricant was higher by 10%.

Each scintillator–photomultiplier tube–PMT divider unit was placed in a purpose-made hermetic aluminum housing (3 mm) to protect it from strong electromagnetic interference induced by an atmospheric discharge at the time of measurement, along

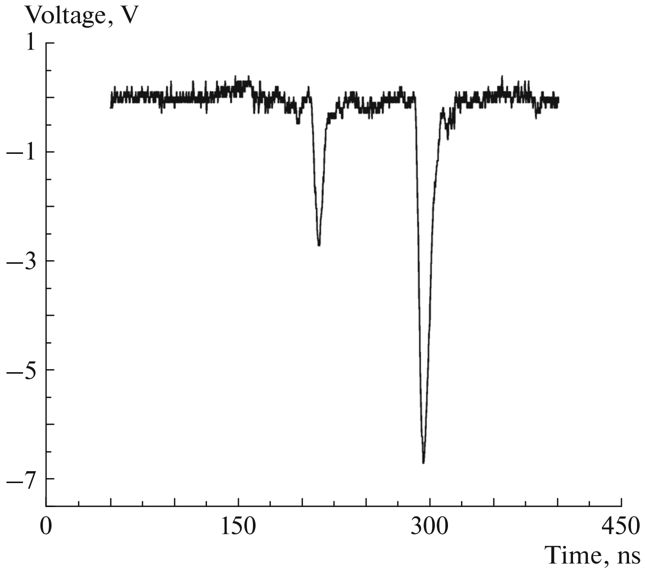


Fig. 2. Oscillogram of the current signal from the new type of detector based on the PMT-30.

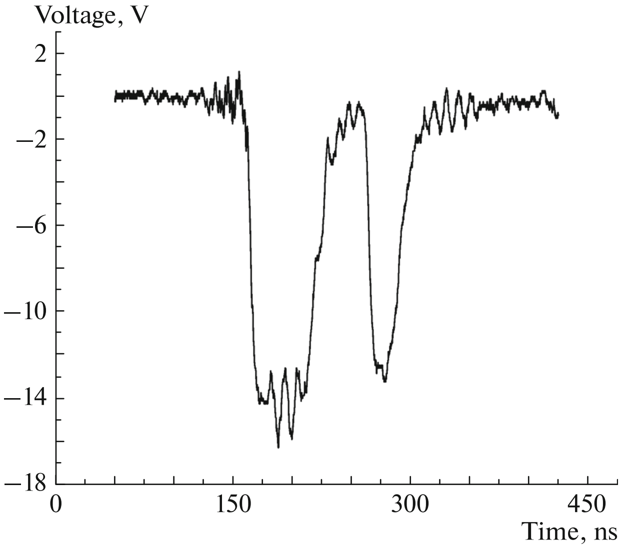


Fig. 3. Oscillogram of the current signal from a standard detector based on the PMT-30.

with parasitic light exposure of the PMT. A spiral magnetic shield made from tape (0.5 × 250 mm) of high-nickel (82%) 79NM permalloy (magnetic permeability $\mu \sim 50000$), coiled in outer contact manner in an aluminum jacket, was used to additionally protect the detector electronics from the magnetic component of the powerful electromagnetic interference from an atmospheric discharge. Use of the magnetic shield substantially reduced (by an order of magnitude) the noise level in PMT at the time of a discharge.

Teflon rings were used to ensure additional insulation of the detector's insides and improve heat removal.

The fabricated device (detector) was an aluminum cylinder (base diameter d = 106 mm, height l = 400 mm) into whose base two hermetic connectors were inserted. One was a high-voltage CP-75 for powering the PMT; the second was a BNC connector for PMT signal collection.

External detectors were mounted on an insulating surface to eliminate parasitic effects from capacitances and contours in the grounding circuit of the measuring apparatus.

MEASUREMENT RESULTS

Characteristics of optimal device operation regimes were obtained as a result of our research and design modifications:

The PMT-30's supply voltage is 2.4 kV, and the divider current is 1.4 мA. The region of maximum spectral sensitivity is 360–440 nm. The diameter of the cathode's working area is 50 mm. The anodic sensitivity is 1000–5000 A lm^{-1}. The time resolution of PMT signals for the current divider scheme is 3–4 ns. The electron transfer time is 53–55 ns, depending on specific PMT unit.

The supply voltage of the Hamamatsu R2083 PMT is 3 kV, and the divider current is 0.2 мA. The region of maximum spectral sensitivity is 300–650 nm. The diameter of the cathode working area is 46 mm. The anodic sensitivity is 200 A lm^{-1}. The time resolution of the PMT signals for the current divider scheme is 0.7 ns. The electron transfer time is 16 ns.

The Hamamatsu R9880U-110 PMT's supply voltage is 1.1 kV, and the divider current is 0.1 mA. The region of maximum spectral sensitivity is 350–450 nm. The diameter of the cathode working area is 8 mm. The anodic sensitivity is 80 A lm^{-1}. The time resolution of the PMT signals for the current divider scheme is 0.57 ns. The electron transfer time is 2.7 ns.

Characteristic oscillograms of the signals registered using these detectors in a series of experiments are presented below in Figs. 2–5. All oscillograms represent PMT current signals picked up from the matched load of the oscilloscope.

Figure 2 shows an oscillogram of the current signal from a detector based on a PMT-30 built according to the described scheme. Figure 3 shows an oscillogram of the current signal from a detector based on a PMT-30 built according to the standard scheme used in high-energy physics. This scheme contains no special means of noise abatement (a permalloy shield) or a special power supply circuit. As is seen in Figs. 2 and 3, using the scheme described in this work effectively eliminates electromagnetic interference coming from a megavolt nanosecond discharge and brings the time

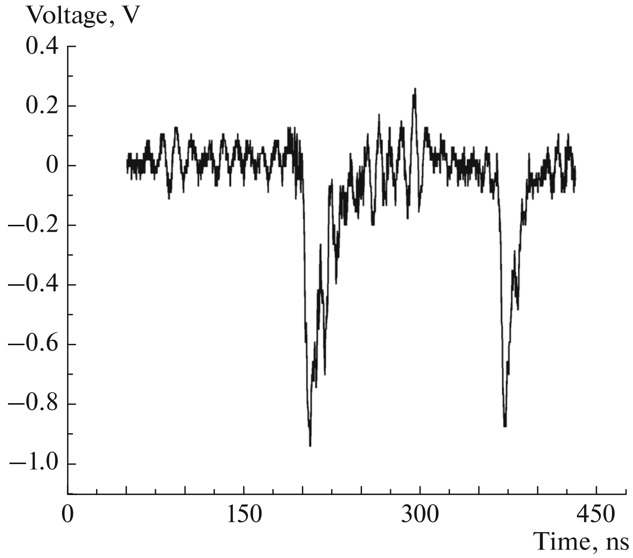


Fig. 4. Oscillogram of the current signal from the new type of detector based on the Hamamatsu R2083 PMT.

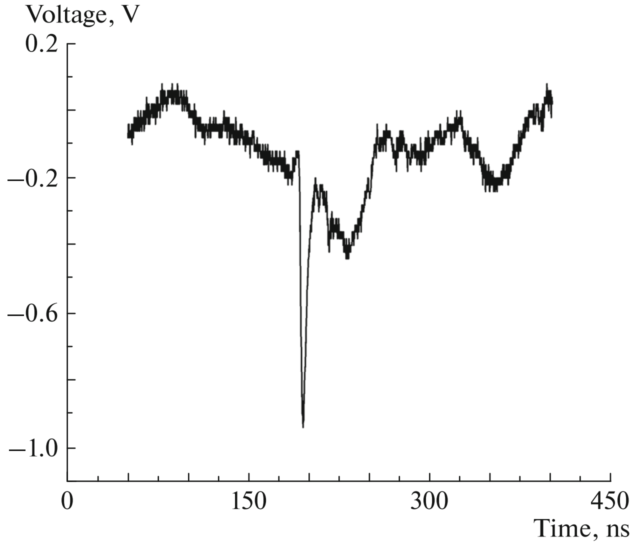


Fig. 5. Oscillogram of the current signal from the new type of detector based on the Hamamatsu R9880U-110 PMT.

resolution of the high-energy radiation registration system up to 3–4 ns. At the same time, the standard scheme is not suitable for performing the task at hand—investigating the parameters of high-energy radiation in the initial stage of megavolt nanosecond atmospheric discharge.

As is seen in Figs. 4 and 5, the flasks of the Hamamatsu PMT exhibit better amplitude and time resolution characteristics than those of the PMT-30. The maximum possible supply voltage is used in detectors based on Hamamatsu flasks, which allows maximum sensitivity to be obtained in detecting low-amplitude radiation pulses. However, these devices are more sensitive to interference and their signal/noise ratio is lower.

CONCLUSIONS

A supply voltage divider for the PMT-30 was developed that considerably improves some of its parameters (gain coefficient and time resolution) and thus raises the detecting efficiency of diagnostic devices assembled on its basis.

Fast radiation detectors were fabricated (time resolution, 3–4 ns and 1 ns) assembled using a variety of scintillators. The housings designed for the detectors are shielded from electromagnetic interference from a discharge, as elements of their structure are made of permalloy 79NM.

These measuring devices can withstand the impact of powerful pulses of broadband electromagnetic interference in areas close to an atmospheric discharge.

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