《原 著》

A New Method of Recording Waveforms of Scintillation Pulses

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and Motoo OSHIMA*

Abstract A new method for recording waveforms of high-speed scintillation pulses in nanoseconds on a CRT screen was made possible using a high speed photomultiplier tube and a wide band oscilloscope with an image intensifier.

This unit for photographing nanosecond signgle-sweep pulse waveforms was used to analyze scintillation pulse waveforms.

I. Introduction

Recording of fast pulse waveforms of random events has a wide range of useful applications in nuclear physics and electric communication engineering. But the technique still presents many practical difficulties.

There have been several reports including that by Hofstadter et al[1], on the technique of recording waveforms of scintillation pulses emitted from NaI(Tl) crystals excited by gamma rays. They pointed out the difficulties of photographing pulse waveforms displayed on a CRT oscilloscope due to insufficient light. Conventionally, the amplitude of pulse waveforms on a CRT screen was minimized in order to increase the apparent light intensity, and then the photographed image was enlarged optically to facilitate analysis. However, this approach obviously lost resolution power in analyzing the recorded waveforms in detail.

As a fundamental study of scintillation pulses we began to analyze their waveforms and developed a technique for photographing single sweep waveforms of randomly repetitive nanosecond pulses which would be useful in analysis of scintillation pulse waveform.

II. Methods and Results

1) The threshold electron density required for photographing waveforms on CRT

In photographing a CRT oscillogram of nanosecond pulses of a signal intensity five times greater than fog density with a conventional camera, the following relation is maintained among the CRT accelerating voltage E_0, lens aperture F, image magnification factor M, film speed (ASA) E_{ASA} and threshold electron density at the CRT screen δ[2]:

$$\delta=\frac{500}{E_{ASA}}\times\frac{2.1\times10^{-9}}{E_0}\times[4F^2(M+1)^2+1]$$
coulomb/cm^2 (1)

When using 35 mm film of ASA 100 speed at F 1.4, M 1/4 and E 14 Kv, the threshold electron density becomes 994×10^{-16} coulomb/mm^2. In Fig. 1, for example, when a pulse falls from P to Q on the CRT screen at 3.0 mm/nsec, with a phosphor screen current of 3.3μA and with a electron beam width of 2.2 mm, the threshold electron density is about 5×10^{-16} coulomb/mm^2. Thus, the sensitivity of the photographing system must be increased by as much as 200 times in this case to obtain a proper photogram.

The image intensifier (I.I.), Fujinon Nightscope FNS-P 101*, which consists of a three stage I.I.

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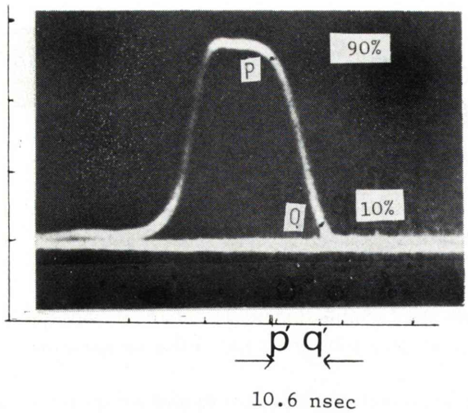
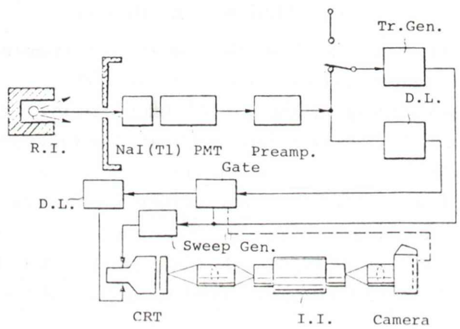
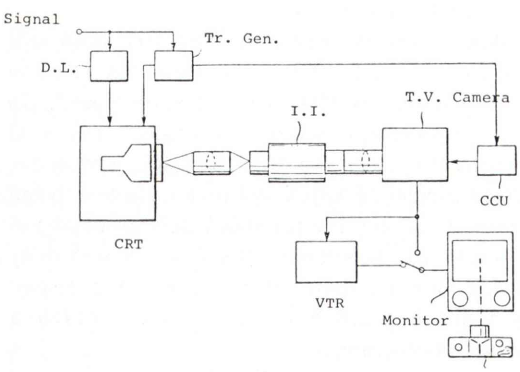


Fig. 1 An example of a fast pulse observed on a CRT. When a pulse fell from point P to point Q, which was 90% and 10% of its maximum pulse height respectively, at a speed of 3.0 mm/nsec on the CRT, the threshold electron density was about 5×10^{-16} coulomb/mm^2.



2a



2b

Figs. 2a, 2b Block diagrams of the recording systems of the single-sweep nanosecond pulses.

tube (VARO, U.S.A.), produces a gain in the order of 10^4. This implies that even if an optical system (F 2.0, M 1.0) between the I.I. output and the film has a 26 dB loss, the I.I. combined with the optical system can still ensure a gain of up to 54dB. This simple combined system even makes possible the photographing of such high speed waveforms as 30 mm/nsec. When the film is in close contact with the I.I. output surface, pulse waveforms of 600 mm/nsec can be photographed, provided that the frequency characteristics of the CRT deflection system can be extended sufficiently to an ultrahigh frequency range.

2) A system for photographing pulse shape

A block diagram of our system for photographic recording single-sweep nanosecond pulses based on the above principle is shown in Figs. 2a and 2b. Fig. 2a shows our system for photographing pulses on a CRT screen directly through the lens, and Fig. 2b shows another system for recording pulse waveforms using a vidicon camera and a VTR system.

In this experiment, high time resolution photomultiplier tube (PMT),** a CRT oscilloscope*** with a band width of 100 MHz and a CRT with an acceleration voltage of 14kV were used. A Fujinon Nightscope with I.I., and a lens of F 1.4 and f 50 mm were attached to a 35 mm camera body or preferably a vidicon camera through a Fujinon camera adaptor lens (effective FNo 1:1.4, at M=1).

When recording the signals with the VTR through a vidicon, the recorded pulses were played back as still pictures or as slow-motion pictures.

High-speed transient signals from an NaI(Tl) detector were supplied to a trigger generator (Tr. Gen.) through a preamplifier and a delay circuit (D.L.). The phenomena were displayed as a signal by the wideband oscilloscope (CRT). When the camera gives a READY signal to the gate circuit, the trigger generator opens the gate, allowing the transient signal to pass the gate and be delayed by the delay circuit. The trigger pulse opens the gate and enters the CRT sweep generator to start the sweep. Thus, the dalayed signal is displayed on the CRT. The pulse waveformi s imaged through the

* Fuji Photo-optical Co., Ltd. (Japan)
** R329-S, 50 MHz, Hamamatsu TV Inc., Japan
*** Hitachi Oscilloscope V-1011, 100 MHz, Hitachi Denshi Ltd., Japan

lens (F 1.4, f 50 mm, M 1/4) on the I.I. which intensifies the signal, and is recorded on film. The still camera in Fig. 2a may be replaced by a cine camera. In this case, film feeding is synchronized with the Ready signal to the gate circuit.

In Fig. 2b, pulse waveforms are recorded with a VTR instead of the still camera, and pulse waveforms displayed on a monitor can be recorded on film whenever necessary.

3) Photomultiplier tube (PMT) and oscilloscope electronic circuit

The PMT was shielded by a permalloy cylinder and signal output was received directly by a 65MHz IC amplifier. Signal output from the amplifier was supplied to the CRT oscilloscope through a 75 Ω HF cable. The PMT placed in the dark box and covered with lead block was cooled to dry-ice temperature to eliminate the dark current pulses, which is cirtical for the measurement of low evergy radiation.

In order to check the time resolution power of this system, signals from a light pulse generator were recorded with this system. The rise time of the optical pulse was 1.0 nsec or less and the rise time of the recorded pulse was 10 nsec (Fig. 3). Thus the total frequency characteristics of the system were reliable for measuring nanosecond pulse events. The total rise time of approximately 10 nsec was shared 3 nsec by the PMT, 5.5 nsec by the preamplifier and the rest of all by CRT.

4) Observation at scintillation pulse waveforms

The scintillation pulses of NaI(Tl) excited by ^{99m}Tc and ^{59}Fe gamma rays were observed. The NaI(Tl) scintillator was 1″ diam. × 1″ thick. Figs. 4a and 4b show scintillation pulses excited by ^{99m}Tc 2.0 mCi, source to NaI(Tl) distance 3 cm using the I.I. systems. The sweep rate was 200 nsec per division in Fig. 4a and 20 nsec in Fig. 4b. The vertical scale was 0.1 V per division in both Figs. 4a and 4b. Fig. 5 shows pulse shapes of ^{99m}Tc which were directly photographed from the CRT without using the I.I. systems. In this experiment, the photographed film was developed for as long as 16 minutes to increase the film speed equivanlent to ASA 3,200. ^{99m}The Tc scintillation pulses of Fig. 5 were difficult to analyze compared with Figs. 4a and 4b in spite of the longer development. Figs. 6a and 6b were obtained with a ^{59}Fe source of 50 μCi with the source to NaI(Tl) distance set to

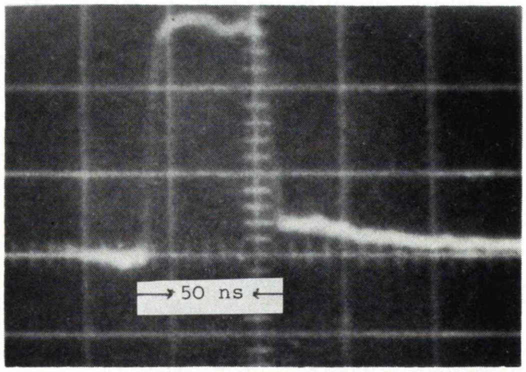
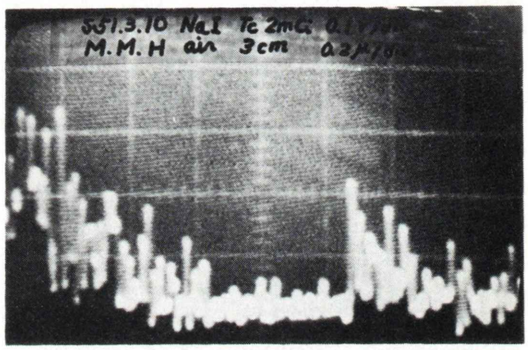


Fig. 3 The time resolution power of our system measuring the signals from light pulse generator. The rise time of the light pulse was 1.0 nsec or less. The sweep rate was 50 nsec per division.



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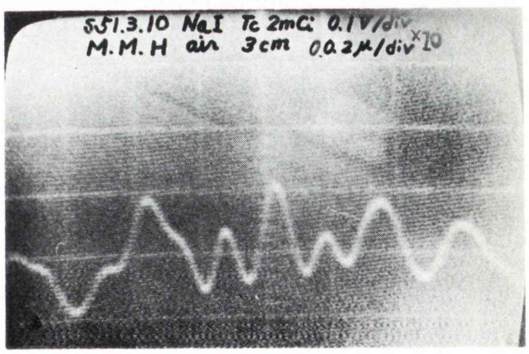


b

Figs. 4a, 4b Two single scintillation pulses produced in NaI (Tl) which was excited by two ^{99m}Tc gamma photons.
The sweep rate was 200 nsec per division in Fig. 4a and 20 nsec per division in Fig. 4b.

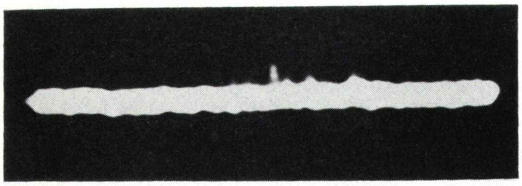
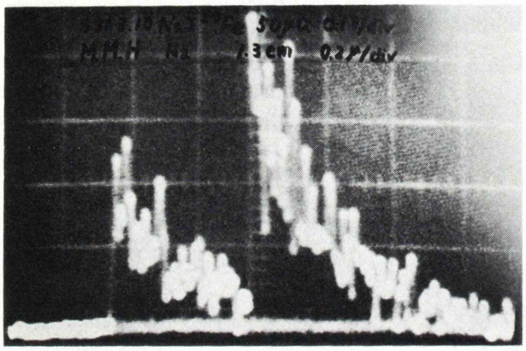


Fig. 5 Pule shape of the ^{99m}Tc-NaI(Tl) system. The pulse was directly photographed from CRT without using I. I. system.



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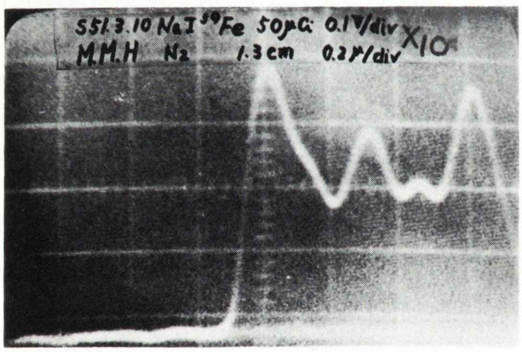

b

Figs. 6a, 6b Two single scintillation pulses produced in NaI(Tl) which was excited by two ^{59}Fe gamma photons.
The sweep rate of Fig. 6a and 6b was same as in Fig. 5a and 5b respectively.

1.3 cm. Scaling is equal to that tin Fig. 4a and 4b.

5) Noise during scintillation pulse measurement

When a ^{99m}Tc source was directed at the optical window of the scintillator by turning around the latter itself, the light pulse could be blocked by an aluminum wall and only the electric noise component obtained. Other experimental conditions were equal to those of scintillation pulse measurement. Fig. 7 shows the results of noise measurement, where the vertical scale in the photogram was shown as 0.05 V or 14 mm per division. Since the amplitude distribution of these noises showed a linear relation on a normal probability chart, where 10 mm of the noise amplitude at the CRT screen in the abscissa corresponded to 35.7 mV, they seem to indicate Gaussian distribution. The vertical scale showed the integrated frequency. The S/N ratio was calculated as about 30 dB in Fig. 4a, where signal and noise amplitude showed about 300 mV and 8.2 mV respectively.

III. Discussion

When recording high-speed transient signals in nanoseconds, such as those of scintillation pulses by a single sweep, the limited electron beam power of wide frequency oscilloscopes results in insufficient signal intensity on the CRT screen and makes acurate recording of waveforms difficult.

If we endeavor to photograph a dim pulse wave-

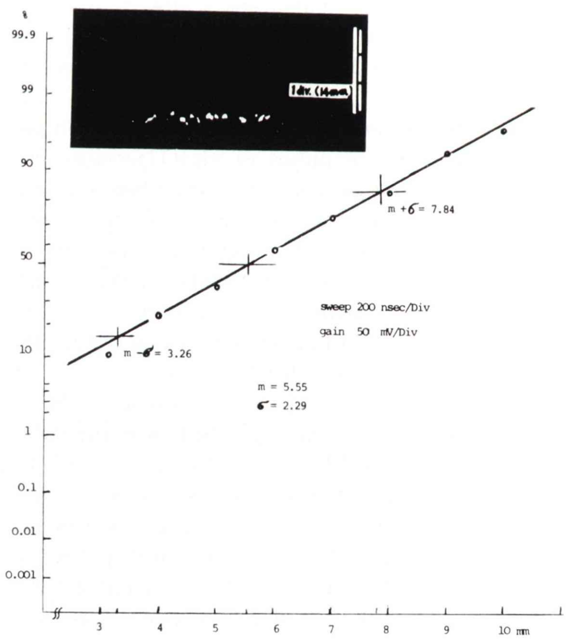

Fig. 7 Noise during scintillation pulse measurement.

form on the CRT screen which gives only 5×10^{-16} coulomb/mm^2 simply by increasing the film speed, we must use a very fast film with a speed as high as 2×10^4 ASA. Otherwise, if we use a film ordinarily available and increase the CRT electron beam current, a beam as high as 600 μA would be needed. The recording system using the recent high speed storage oscilloscope such as Tektronix 7000 seems not to be superior in memory capacity to our simple and cheap system. The transient digitizer is slow compared with the storage oscilloscope unless the sampling and the quantizing techniques are improved drastically. Though Tektronix 485 oscilloscope with P 11 phosphor has a rated photographable writing speed of 24 mm per nsec using standard Polaroid film (ASA 3000), serial recording of repetitive pulse signals is not possible, but only one waveform by single sweep. Polaroid film for cine recording is not now available. In our method using I.I., however, the measurement speed is limited only by the actual CRT. This can be appreciably solved by using a highfrequency CRT, for example, a CRT unit using a traveling wave deflection system. The measurement time is virtually unlimited provided that we use a VTR.

Since the I. I. has sufficient amplification capacity, even such high-speed pulses can be clearly observed by increasing the sweep speed, However, note that the currently available I. I. has certain distortions in their electron lens system which causes distortion of a few percent in the displayed waveform. These disadvantages may be overcome by using a channeltron or by improving the electronic optical system.

Factors to be emphasized in determining high-speed pulse shape include frequency characteristics of the PMT, amplifier system and CRT, and the S/N of the system.

Hofstadter (1949), Eby and Jentschke (1954)[4], Storney (1958)[5], Jones et al (1960)[6], Lynch (1966)[7], and Ishikane (1974)[8] and (1975)[9], have reported works on scintilation pulse measurements. When the frequency characteristics and/or the S/N ratio of the measurement system was poor, considerable errors resulted from the analysis of measured waveforms. Most attention should be paid to these points: i.e. selected PMT of high time resolution power and CRT oscilloscopes with a wide frequency band should be used. This method can be applied for studying the characteristics of the new type scintillators, such as BGO and CsF for positron camera. Response characteristics of electronic circuit to the separate pulses in the field of nuclear medicine can also be studied by this method.

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要　旨

シンチレーションパルス波形記録法に関する研究

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核医学領域の機器開発に関する基礎的研究の一つとして，シンチレーションパルスの波形解析を行う場合，ナノ秒レベルの高速度過渡現象信号を写真撮影することは CRT 面の螢光光量が不足のため容易でない．そこで CRT 面パルス波形を写真撮影する場合に必要とする電子密度の閾値を理論的に求め，市販されているファイバー結合 3 段の Image Intensifier を接続することでナノ秒あたり 30 mm 程度の波形が臨床病院のレベルでも容易に測定可能となった．本法を用いて ^{99m}Tc や ^{59}Fe 線源で NaI (Tl) シンチレーターを刺激して得られたシンチレーションパルスを解析した。

Key words: Recording method of scintillation pulses, waveform of nanosecond pulse, analysis of ^{99m}Tc and ^{59}Fe scintillation pulses