

## Development of an amplifier module for measuring X-ray spectra using a photomultiplier tube

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### Abstract

We developed an amplifier module for measuring X-ray spectra using short-decay-time scintillators. The X-ray spectra were measured using a detector consisting of a YAP(Ce) (cerium-doped yttrium aluminum perovskite) crystal and a small PMT (photomultiplier tube). The amplifier module consists of an integrator and inverse voltage-voltage (V-V) and V-V amplifiers. The negative output pulses from the PMT are input to the inverse V-V amplifier, and the amplifier outputs are sent to the integrator to increase the pulse width. The integrator outputs are sent to the V-V amplifier, and the output-event pulses are input to a multichannel analyzer to perform pulse-height analysis. The photon energy was determined by two-point calibration using iodine-K $\alpha$ -fluorescence and tungsten-K $\alpha$  photons. Using the YAP(Ce)-PMT detector, both the maximum and maximum-count energies increased with increasing tube voltage. The energy resolution of the detector was 24% at 59.5 keV.

**Keywords:** inverse V-V amplifier, X-ray spectra, YAP(Ce)-PMT detector, pulse-width extender, high-rate counting

### 1. Introduction

Currently, X-ray spectra are measured using a cadmium telluride (CdTe) detector [1], and the photon energy resolution has been improved to approximately 1% at 59.5 keV. Therefore, we have developed several

energy-dispersive X-ray computed tomography (ED-CT) scanners [2-4] corresponding to the radiographic objectives.

Using short-decay-time scintillators in conjunction with a photomultiplier tube (PMT) [5, 6], the X-ray spectra can be measured. However, it is not easy to measure the pulse height correctly owing to the sampling period of the analog to digital converter (ADC). In this regard, the pulse height should be extended to approximately 1  $\mu$ s to measure the X-ray spectra using the multichannel analyzer (MCA).

In our research, major objectives are as follows: to develop an amplifier module for the PMT, to measure the X-ray spectra using the MCA, to determine the photon energy resolution, and to measure the electric characteristics of the amplifier. Therefore, we developed an amplifier module for a small PMT and measured the X-ray spectra.

## 2. Experimental methods

### 2.1. Measurement of spectra using YAP(Ce)-PMT detector

The block diagram for measuring X-ray spectra using the YAP(Ce)-PMT detector is shown in Fig. 1. To detect scintillation photons from the YAP(Ce) crystal, we used a small PMT module (Hamamatsu, H10721P-110), and the YAP(Ce) crystal was attached to the PMT with optical grease. Using the YAP(Ce)-PMT detector, the event pulses from the amplifier module were input to a multichannel analyzer (MCA;  $\gamma$ PGT, MCA4000) to measure X-ray spectra. The photon energy was determined by two-point calibration using  $K\alpha$  photons of iodine (28.5 keV) and tungsten (58.9 keV). Subsequently, the energy resolution of the YAP(Ce)-PMT detector was measured using an americium-241 ( $^{241}\text{Am}$ ) standard  $\gamma$ -ray source at a maximum-count energy of 59.5 keV.

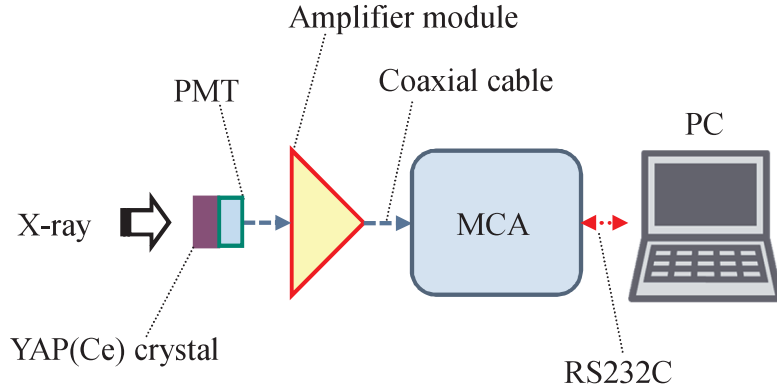


Fig. 1. Block diagram for measuring X-ray spectra using the YAP(Ce)-PMT detector.

### 2.2. Amplifier module

Figure 2 shows the block diagram of the amplifier module (Fig. 3). The module consists of the inverse voltage to voltage (V-V) amplifier with gains ranging from 100 to 200, a 1-ms-time-constant integrator, and a 3-gain V-V amplifier. The negative output pulses from the PMT are input to the first inverse V-V amplifier, and the positive outputs are produced and sent to the integrator. The pulse width is extended to approximately 1  $\mu$ s by the integrator, and the pulse height is amplified again using the second V-V amplifier.

The event pulses from the Output 1 can be used to perform high-speed photon counting for ED-CT, and the width-extended pulses from the Output 2 are useful for measuring X-ray spectra using the MCA.

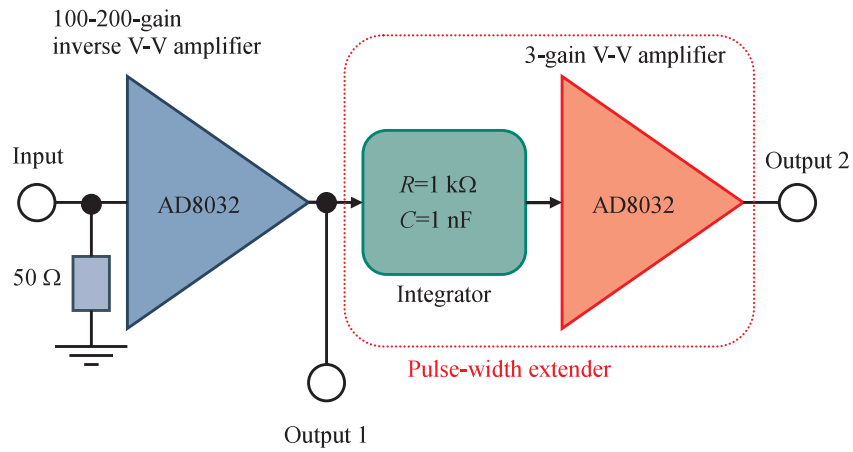


Fig. 2. Block diagram of the amplifier module. The pulse extender consists of the integrator and the 3-gain V-V amplifier and is used to measure the pulse height correctly.

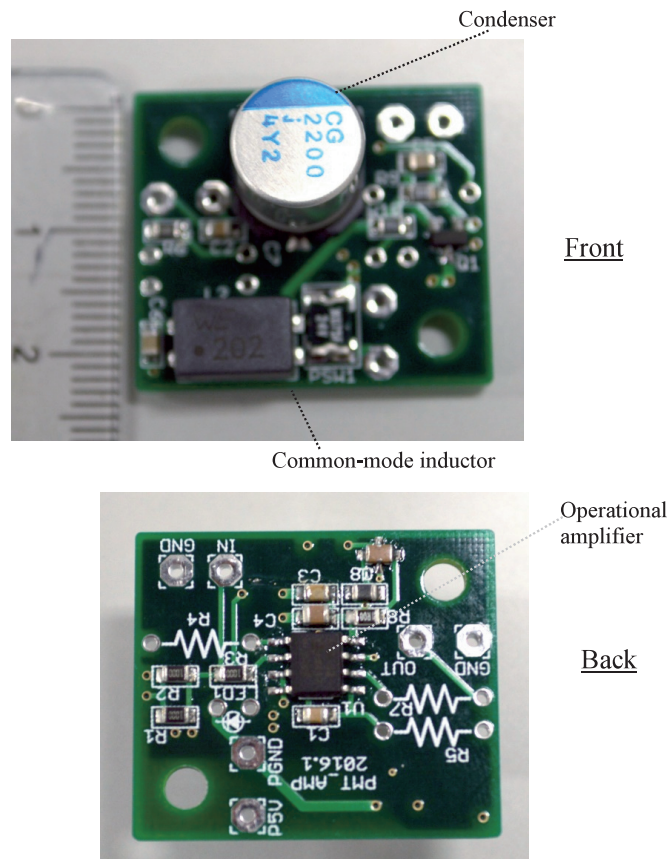


Fig. 3. Compact amplifier module including the first V-V amplifier and the pulse extender.

### 3. Results

#### 3.1. Event pulses

The time relation between the first and second-V-V-amplifier (pulse-extender) outputs is shown in Fig. 4. The pulse widths from the first amplifier were 400 ns, and the widths were extended to 1  $\mu$ s using the extender.

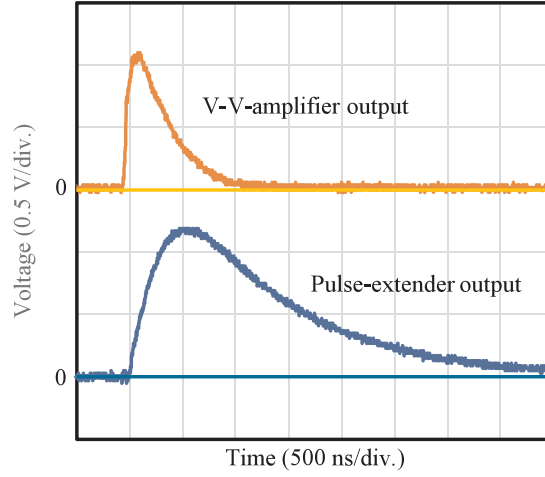


Fig. 4. Time relation between the first-V-V-amplifier and the second-pulse-extender outputs.

#### 3.2. X-ray spectra

Figure 5 shows the X-ray spectra measured using the YAP(Ce)-PMT detector. Both the maximum and the maximum-count energies increased with increasing tube voltage. The  $\gamma$ -ray spectra from  $^{241}\text{Am}$  source are shown in Fig. 6, and the photon-energy resolution was determined as 24% at 59.5 keV.

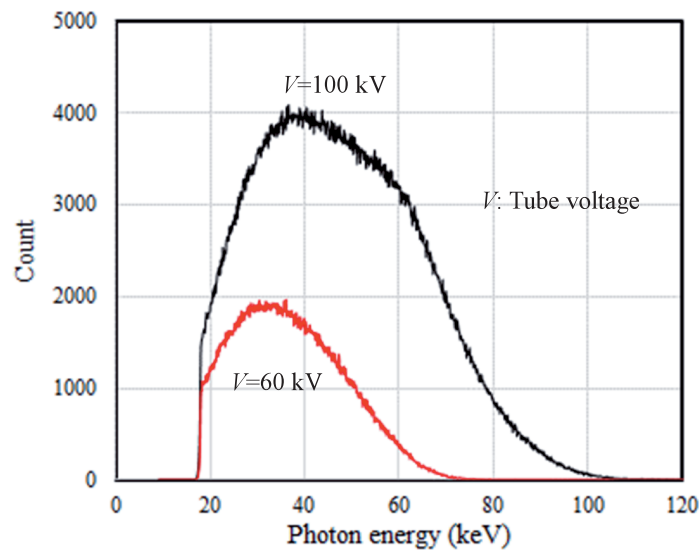


Fig. 5. X-ray spectra measured using the YAP(Ce)-PMT detector with changes in the tube voltage.

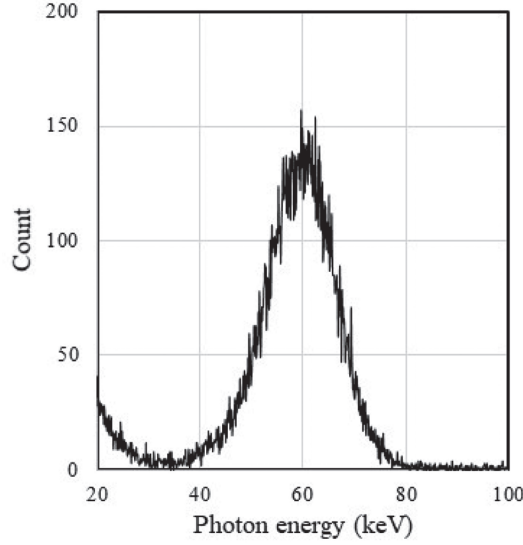


Fig. 6.  $\gamma$ -ray spectra from the  $^{241}\text{Am}$  source for determining the energy resolution of the detector.

#### 4. Discussion

We have developed several photon-counting ED-CT scanners to perform K-edge CT using iodine and gadolinium media. In the first-generation ED-CT, the image quality improves with increasing photon count. Therefore, we have been performing high-speed photon counting using short-decay-time scintillators. Compared with the energy resolution of the CdTe detector, the resolution of the YAP(Ce)-PMT is low. However, the rate can be increased beyond 1 megacounts per second, and dual-energy (DE) CT will be performed.

To improve the contrast variations using the DE-CT, the energy resolution should be improved. In this regard, the improvement of the first inverse-V-V amplifier for the PMT is important for the scintillation-type detector.

Using the MCA, the effective pulse height detected decreases with decreases in the pulse width. In addition, since the short-width pulse height measured also decreases when using a DE photon counter with comparators, the pulse width should be extended to approximately 1  $\mu\text{s}$  to measure the height correctly.

#### 5. Conclusions

We developed a compact V-V amplifier module consisting of an inverse V-V amplifier and a pulse extender. The dimensions of the module are quite small, and the module can be used to perform DE-CT and to measure X-ray spectra. In particular, the 400-ns-width event pulses are useful for high-speed photon counting, and the 1- $\mu\text{s}$ -width pulses are used to measure pulse height correctly using an ADC.

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