

## Measurement of X-ray-tube voltage using a 0.3-mm-thick copper filter

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(Accepted July 14, 2016)

### Abstract

To measure X-ray tube voltage corresponding to the maximum photon energy of X-ray spectra, we constructed an experimental setup consisting of an X-ray generator, a silicon X-ray diode (Si-XD), an amplifier module, 10-s-time-constant integrator, a digital voltage meter, and a 0.3-mm-thick copper (Cu) filter. The amplifier outputs with and without the Cu filter are measured, and the tube voltage is determined by the ratio (transmissivity) between the output voltages as a function of tube voltage. In this experiment, we used two aluminum filters of 1.0 and 3.0 mm in thickness for absorbing low energy X-ray photons. Using the Cu filter, the transmissivity as a function of tube voltage varied with changes in the Al-filter thickness.

**Key words:** X-ray, tube voltage, Cu filtration, transmissivity, Si-X-ray diode

### 1. Introduction

To perform molecular imaging, we have developed several photon-counting energy-dispersive X-ray computed tomography (ED-CT) scanners [1-3] using cadmium telluride (CdTe) and silicon-PIN detectors. Lately, an energy-selecting device [4] has been developed and applied to monochromatic and dual-energy CT (DE-CT) scanners [5].

In the former experiment, we found a high-sensitivity silicon photodiode for detecting X-rays and named this a silicon X-ray diode (Si-XD) [6]. Using these Si-XDs, we developed a DE-CT scanner [7] and an X-ray dosimeter. Currently, the dosimeter utilizes two detectors with a tube-voltage measurement function. Therefore, we are interested in the tube-voltage measurement using a filtration method.

In our research, our major objectives are as follows: to measure transmissivity using a Si-XD and a copper (Cu) filter, to convert the photocurrents into voltages, and to determine the tube voltage using the transmissivity. Therefore, we constructed an experimental setup to measure tube voltage using a Si-XD in conjunction with a Cu filter.

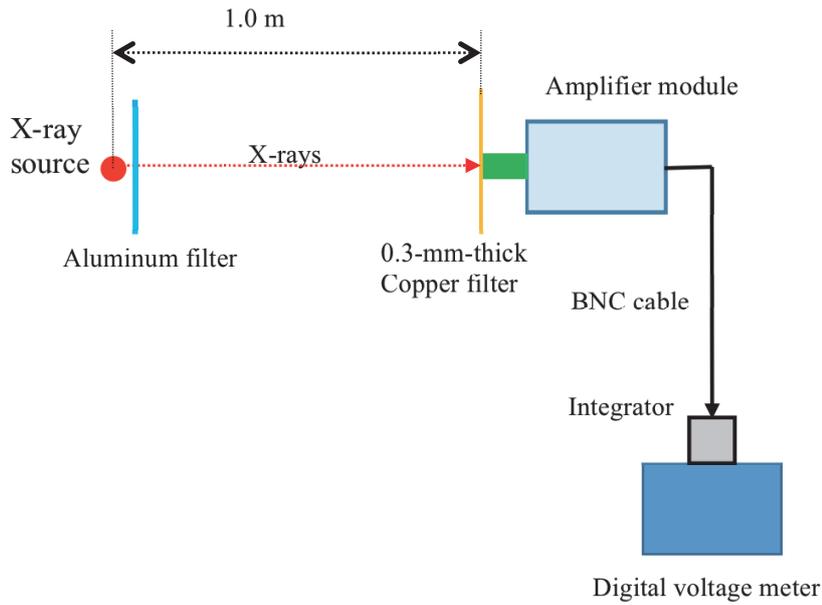


Fig. 1. Block diagram for measuring the output voltages from the amplifier module using a Si-XD and a 0.3-mm-thick Cu filter. The voltage is in proportion to the penetrating X-ray dose rate.

## 2. Experimental methods

Figure 1 shows an experimental setup for measuring output voltages from the amplifier module. Low-energy X-ray photons from an X-ray generator are absorbed using an aluminum filter, and penetrating photons are detected using a silicon X-ray diode (Si-XD) through a 0.3-mm-thick Cu filter. The photocurrents flowing through a Si-XD are converted into voltages and amplified using an amplifier module, and the amplifier output is input to a digital voltage meter through a 10-s-time-constant integrator. To determine the tube voltage, the amplifier output voltages with and without the Cu filter are measured, and the tube voltage is determined by the voltage ratio (transmissivity) as a function of tube voltage.

The circuit diagrams of the amplifiers are shown in Fig. 2. The photocurrents are converted into voltages using a current-voltage (I-V) amplifier [Fig. 2(a)], and the output voltage  $V_i$  from the I-V amplifier is written as:

$$V_i = 100 \times 10^6 I \quad (1)$$

where  $I$  is the photocurrent. Subsequently, the output from the I-V amplifier is sent to the voltage-voltage (V-V) amplifier [Fig. 2(b)]. In this experiment, a variable resistor is set to the maximum value of 50 k $\Omega$ , and the output voltage from the V-V amplifier  $V_v$  is given by:

$$V_v = 6.0 \times 10^2 V_i \quad (2)$$

The measurement of X-ray dose rate is important to calculate incident dose for patients. The X-ray dose rate from an X-ray generator was measured using an ionization chamber (Toyo Medic RAMTEC 1000 plus) at a tube current of 0.5 mA without filtration. The chamber was placed 1.0 m from the X-ray source, and we measured the dose rate with changes in the tube voltage from 50 to 109 kV.

## 3. Results

Figure 3 shows the X-ray dose rates at a constant tube current of 0.50 mA using two Al filters of 1.0 and 3.0 mm in thickness. In the two filtrated conditions, both the X-ray dose rates increased with increasing tube voltage. At a tube voltage of 100 kV, the X-ray dose rates with Al thicknesses of 1.0 and 3.0 mm were 40.8 and 28.0  $\mu\text{Gy/s}$ , respectively.

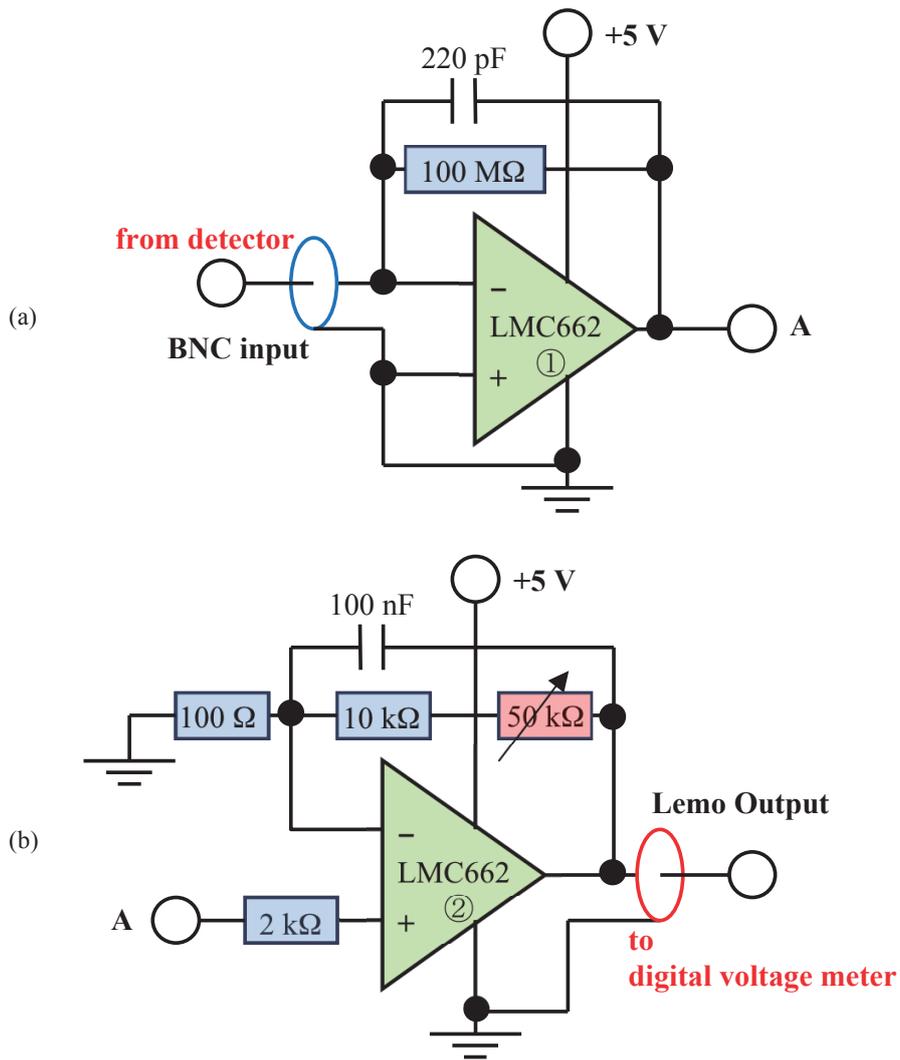


Fig. 2. Circuit diagram of the amplifier module. (a) I-V amplifier and (b) V-V amplifier.

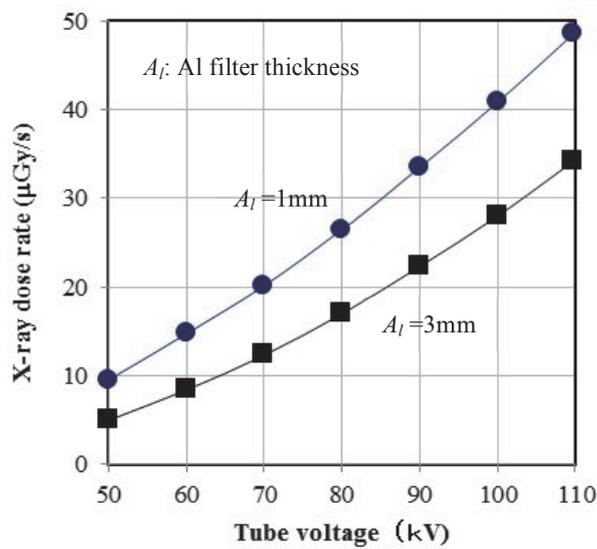


Fig. 3. X-ray dose rates after penetrating two Al filters with changes in the tube voltage at a constant tube current of 0.5 mA.

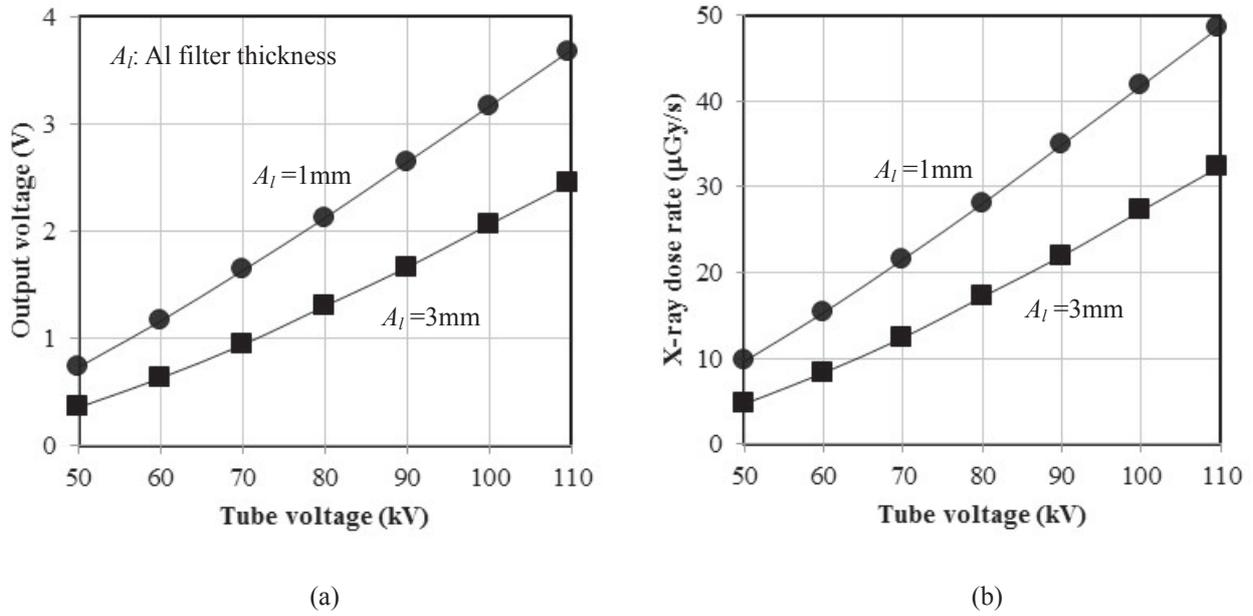


Fig. 4. Output voltages and X-ray dose rates measured using the Si-XD without the Cu filter according to changes in the tube voltage and the insertion of the two Al filters. (a) Output voltages and (b) X-ray dose rates.

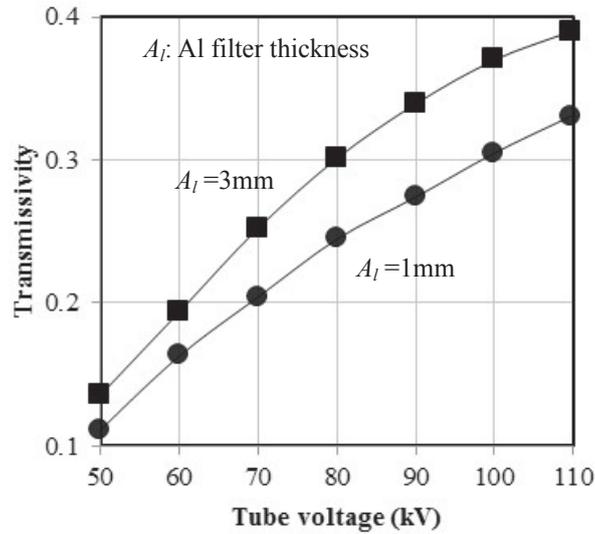


Fig. 5. Transmissivities with the Cu filter with changes in the tube voltage.

The X-ray dose rates were also measured using the Si-XD and the amplifier for reference and shown in Fig. 4. Using the two Al filters, the output voltages increased with increasing tube voltage. To convert the output voltage into the dose rate, we assume that the output voltage is proportional to the dose rate, and the maximum voltage of 3.64 V corresponds to the dose rate of 48.5  $\mu\text{Gy/s}$ . The dose rates corresponded qualitatively to those measured using the dosimeter.

The transmissivities with changes in the tube voltage are shown in Fig. 5, and the transmissivity  $T$  is written by:

$$T = V_f / V \quad (3)$$

where  $V_f$  is the output voltage using the Cu filter, and  $V$  is the output without Cu filtration. Both the transmissivities using two Al filters increased with increasing tube voltage, and the transmissivity slightly increased with increasing Al filter thickness.

#### 4. Discussion

In the present research, we used a Si-XD in conjunction with an amplifier module to measure the dose rate approximately proportional to the output voltage from the module. Compared with a dosimeter with an ionization chamber, the sensitivity of the Si-XD slightly decreased with increasing tube voltage.

Using a 0.3-mm-thick Cu filter, a tube voltage range from 50 to 109 kV could be measured. However, the filter thickness should be reduced to less than 0.2 mm to measure the tube voltage below 50 kV. In addition, since the transmissivity increased with increasing the total filtration of the X-ray source, the total filtration should be determined to a constant value before measuring the tube voltage.

#### 5. Conclusions

First, we measured the dose rate using a Si-XD and an amplifier module, and the results using the Si-XD corresponded well to those obtained using a dosimeter with an ionization chamber. Second, the transmissivities were measured using a 0.3-mm-thick Cu filter, and the transmissivity increased with increasing tube voltage. Therefore, the tube voltage can be determined by the transmissivity as a function of tube voltage.

#### Acknowledgments

This work was supported by Grants from Keiryō Research Foundation, Promotion and Mutual Aid Corporation for Private Schools of Japan (PMAC), Japan Science and Technology Agency (JST), and Japan Society for the Promotion of Science (JSPS) KAKENHI (26461804, 2014-2016). This was also supported by a Grant-in-Aid for Strategic Medical Science Research (S1491001, 2014–2018) from the Ministry of Education, Culture, Sports, Science and Technology of Japan (MEXT).

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