# PMT

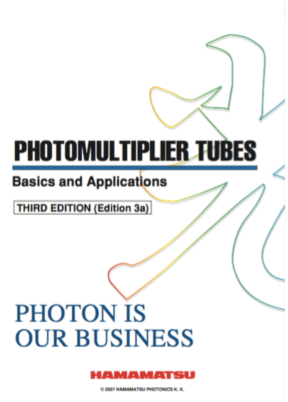
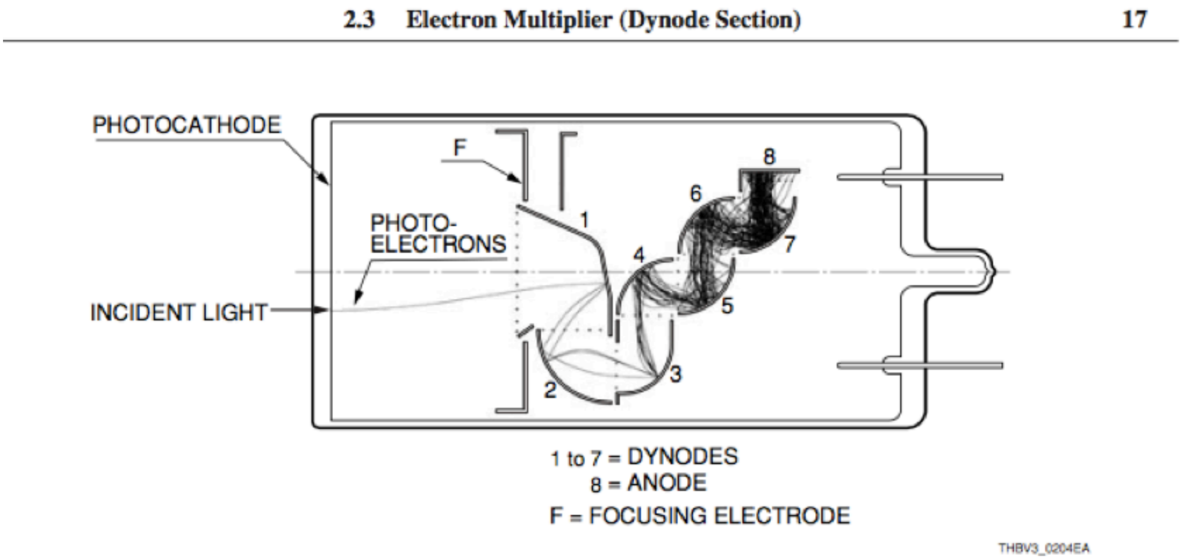



Photo multiplier is used to detect weak light.

What does “weak” mean?

Scintillation light generated by radiation detector, such as Plastic scintillator and NaI(Tl), is very weak. PMT is used to detect such weak light.

You can lean about PMT with PMT handbook from Hamamatsu, which is at
http://www.hamamatsu.com/resources/pdf/etd/PMT_handbook_v3aE.pdf
Individual chapter can be at
http://www.hamamatsu.com/resources/pdf/etd/PMT_handbook_v3aE-Chapter1.pdf
http://www.hamamatsu.com/resources/pdf/etd/PMT_handbook_v3aE-Chapter2.pdf
and so on.




1st Step is photoelectric effect at photocathode.

What does Quantum efficiency mean?

Electron emitted by photoelectric effect is “multiplied” at Dynode.

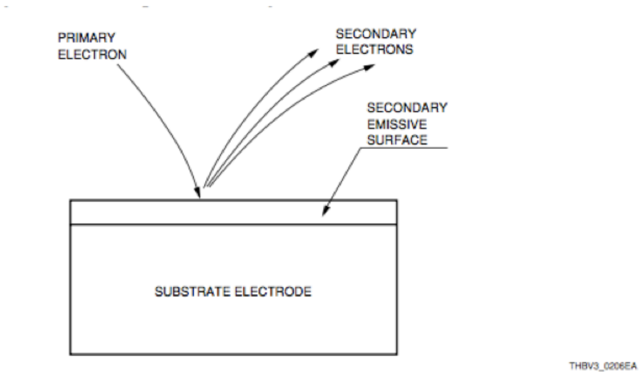



**Figure 2-6: Secondary emission of dynode**

### (2) Gain (current amplification)

Secondary emission ratio δ is a function of the interstage voltage of dynodes E, and is given by the following equation:

$$\delta = a \cdot E^k \quad \text{(Eq. 4-3)}$$

Where a is a constant and k is determined by the structure and material of the dynode and has a value from 0.7 to 0.8.

The photoelectron current Ik emitted from the photocathode strikes the first dynode where secondary electrons Idl are released. At this point, the secondary emission ratio $\delta_1$ at the first dynode is given by

$$\delta_1 = \frac{I_{d1}}{I_K} \quad \text{(Eq. 4-4)}$$

These electrons are multiplied in a cascade process from the first dynode → second dynode → .... the n-th dynode. The secondary emission ratio δn of n-th stage is given by

$$\delta_n = \frac{I_{dn}}{I_{d(n-1)}} \quad \text{(Eq. 4-5)}$$

The anode current Ip is given by the following equation:

$$Ip = I_K \cdot \alpha \cdot \delta_1 \cdot \delta_2 \cdots \delta_n \quad \text{(Eq. 4-6)}$$

Then

$$\frac{Ip}{Ik} = \alpha \cdot \delta_1 \cdot \delta_2 \cdots \delta_n \quad \text{(Eq. 4-7)}$$



where α is the collection efficiency.

The product of α, $\delta_1$, $\delta_2$ .....δ n is called the gain μ (current amplification), and is given by the following equation:

$$\mu = \alpha \cdot \delta_1 \cdot \delta_2 \cdots \delta_n \quad \text{(Eq. 4-8)}$$

Accordingly, in the case of a photomultiplier tube with a=1 and the number of dynode stages = n, which is operated using an equally-distributed divider, the gain m changes in relation to the supply voltage V, as follows:

$$\mu = (a \cdot E^k)^n = a^n \left(\frac{V}{n+1}\right)^{kn} = A \cdot V^{kn} \quad \text{(Eq. 4-9)}$$

where A should be equal to $a^n/(n+1)^{kn}$. From this equation, it is clear that the gain μ is proportional to the kn exponential power of the supply voltage. Figure 4-13 shows typical gain vs. supply voltage. Since Figure 4-13 is expressed in logarithmic scale for both the abscissa and ordinate, the slope of the straight line becomes kn and the current multiplication increases with the increasing supply voltage. This means that the gain of a photomultiplier tube is susceptible to variations in the high-voltage power supply, such as drift, ripple, temperature stability, input regulation, and load regulation.

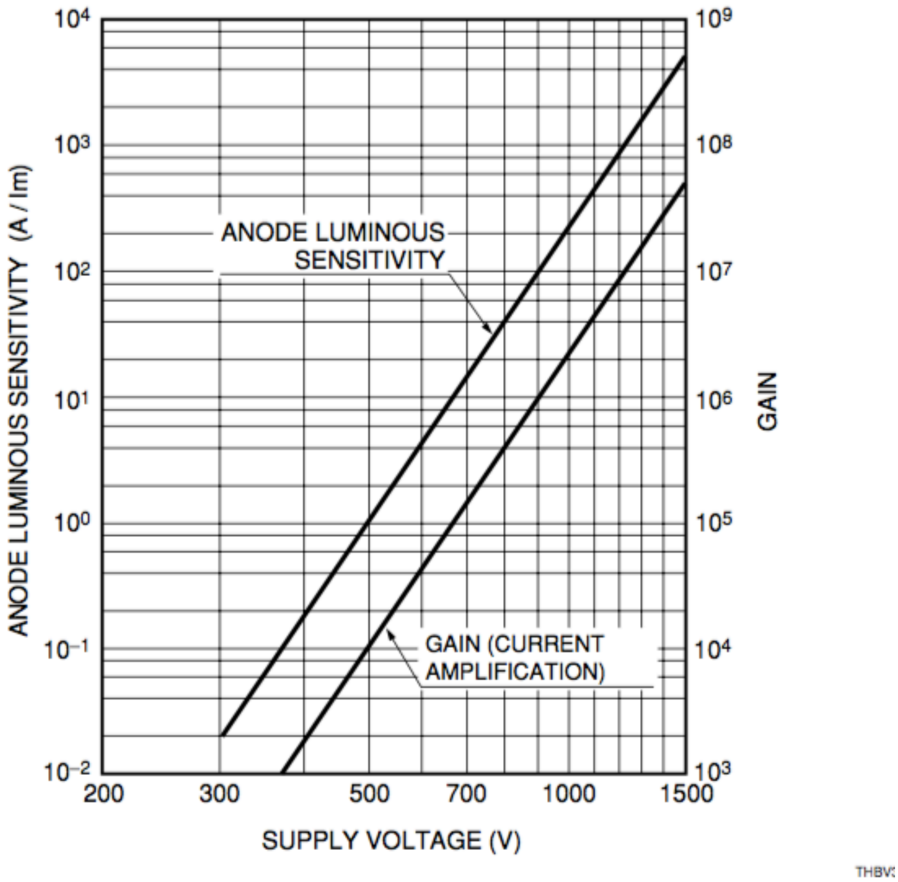



**Figure 4-13: Gain vs. supply voltage**

How much charge is generated by single electron?

Charge at the anode is proportional to input. We observe voltage on 50 Ohm.

$$Q = \int I dt = \frac{1}{R}\int V dt = \frac{1}{R}\sum_i V_i \Delta t$$

Integrating the waveform is proportional to the charge at Anode.

## 4.3.1 Time characteristics

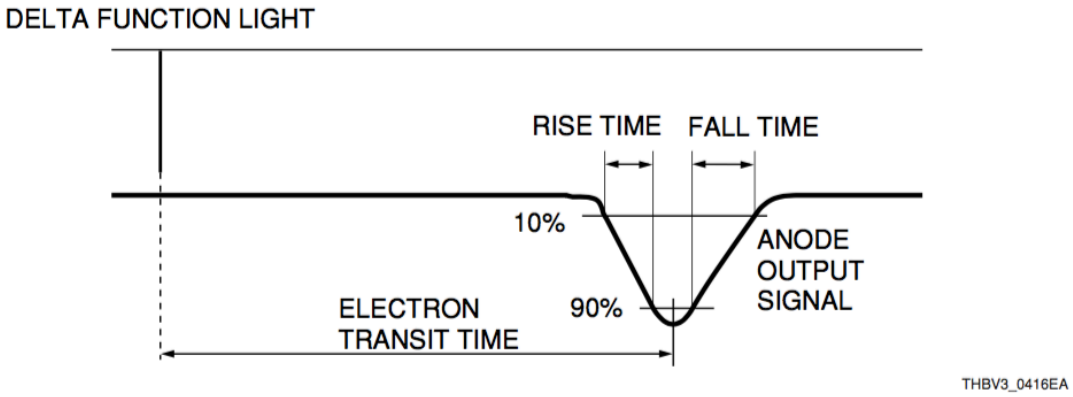



**Figure 4-16: Definitions of rise/fall times and electron transit time**

In our measurement, propagation delay in cable/electronics is included. The light pulse is not delta function.

4.3 Characteristics of Photomultiplier Tubes 51

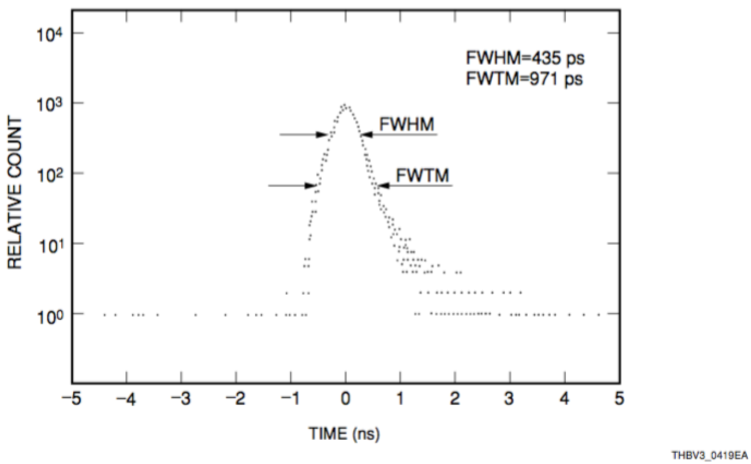



**Figure 4-19: TTS (transit time spread)**

## R6236

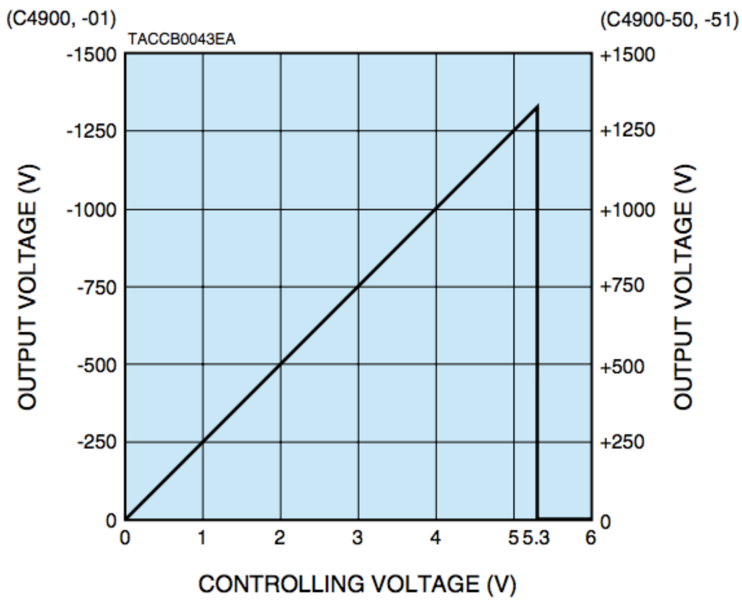
60 x 60 mm Rectangular, Head-on type, Bialkali photocathode, Spectral response : 300 to 650 nm), for Gamma camera

| | |
|---|---|
| Type | Special envelope type |
| Photocathode Area Shape | Square |
| Photocathode Area Size | 54 x 54 mm |
| Wavelength (Short) | 300 nm |
| Wavelength (Long) | 650 nm |
| Wavelength (Peak) | 420 nm |
| Spectral Response Curve Code | 400K |
| Photocathode Material | Bialkali |
| Window Material | Borosilicate glass |
| Dynode Structure | Box-and-grid+Linear-focused |
| Dynode Stages | 8 |
| [Max. Rating] Anode to Cathode Voltage | 1500 V |
| [Max. Rating] Average Anode Current | 0.1 mA |
| Anode to Cathode Supply Voltage | 1000 V |
| [Cathode] Luminous Sensitivity Min. | 80 μA/lm |
| [Cathode] Luminous Sensitivity Typ. | 110 μA/lm |
| [Cathode] Blue Sensitivity Index (CS 5-58) Typ. | 12.0 |
| [Cathode] Radiant Sensitivity Typ. | 95 mA/W |
| [Anode] Luminous Sensitivity Min. | 3 A/lm |
| [Anode] Luminous Sensitivity Typ. | 30 A/lm |
| [Anode] Radiant Sensitivity Typ. | $2.6 \times 10^4$ A/W |
| [Anode] Gain Typ. | $2.7 \times 10^5$ |
| [Anode] Dark Current (after 30min.) Typ. | 2 nA |
| [Anode] Dark Current (after 30min.) Max. | 20 nA |
| [Time Response] Rise Time Typ. | 9.5 ns |
| [Time Response] Transit Time Typ. | 52 ns |

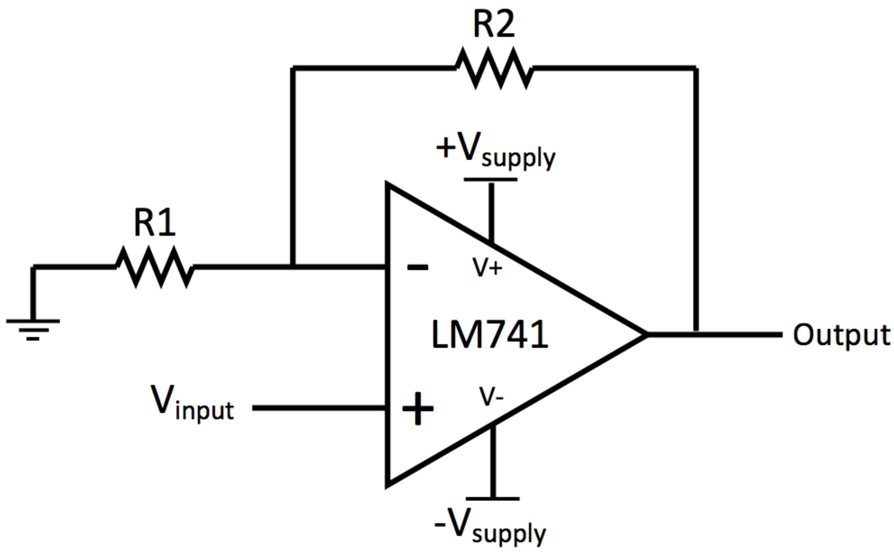
# High Voltage power supply

https://www.hamamatsu.com/resources/pdf/etd/C4900_TACC1013E.pdf

Figure 2: Output Voltage Controlling Characteristic




DAC output is 0.000-4.096 V. It is amplified with OP amp

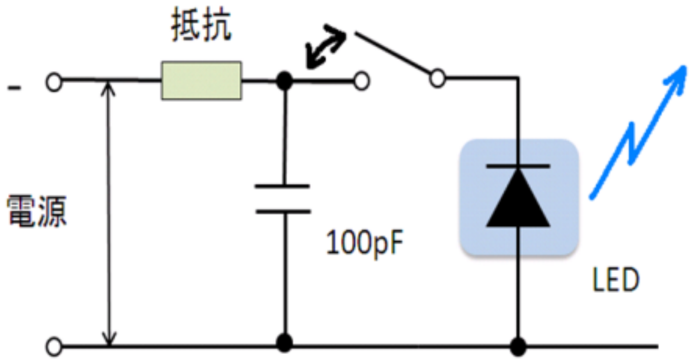



Gain = (R1+R2)/R1 = (10+22)/22 = 1.45

Output cannot be lower than (-V + 2.8).

Here +V = 12 [V],–V = 0 [V]. Output is 2.8V to 4x1.45 V.

LED




Charge in the capacitor is discharged. The number of photon is proportional to the number of electron (charge) discharged. The Charge in the capacitor is proportional to the supply voltage. Capacitor cannot be made empty by discharging through LED. Why?

Discharge does not happen if the voltage is lower than diode-drop of the LED.
Please study what is diode-drop and how des it related to its wavelength.
Blue LED requires more than 3.5V. Why?

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Exercises
Set HV at -1000V. Carefully increase the LED light.
Don’t put strong light on the PMT. Keep the signal less than 100 mV at -1000 V.

1) Measure amount of charge for one pulse.
   Guess the number of photon using the gain in the data sheet.
2) Measure distribution of the charge.
3) Measure High Voltage dependence
   N=8. Obtain “k” in the Hamamatsu Handbook.
4) Measure rise time and fall time
5) Measure TTS