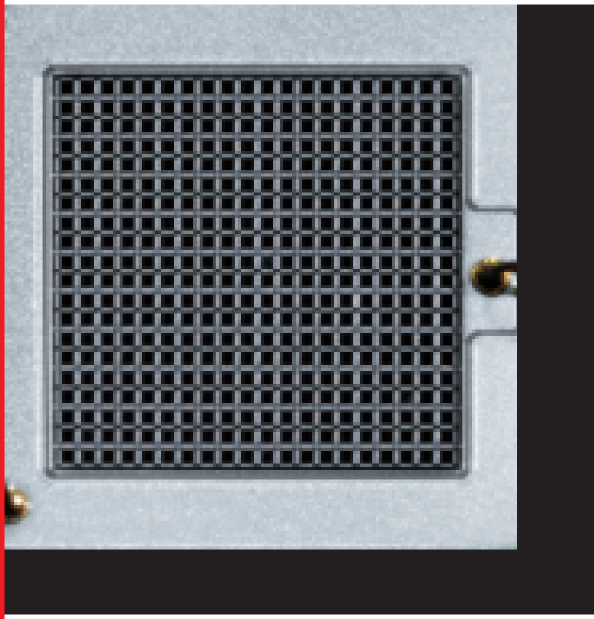
SOLID STATE DIVISION

MPPC®

Multi-Pixel Photon Counter



TECHNICAL INFORMATION

HAMAMATSU

MPPC®

Multi-Pixel Photon Counter

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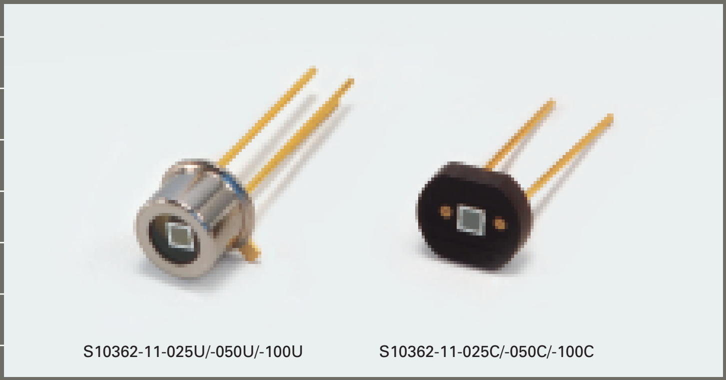
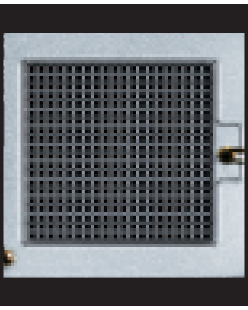
The MPPC (Multi-Pixel Photon Counter) is a new type of photon-counting device made up of multiple APD (avalanche photodiode) pixels operated in Geiger mode. The MPPC is essentially an opto-semiconductor device with excellent photon-counting capability and which also possesses great advantages such as low voltage operation and insensitivity to magnetic fields.

Features

- Excellent photon-counting capability (Excellent detection efficiency versus number of incident photons)
- Room temperature operation
- Low bias (below 100 V) operation
- High gain: 10^5 to 10^6
- Insensitive to magnetic fields
- Excellent time resolution
- Small size
- Simple readout circuit operation
- MPPC module available (option)



S10362-11-025U/-050U/-100U S10362-11-025C/-050C/-100C



What is the MPPC ?

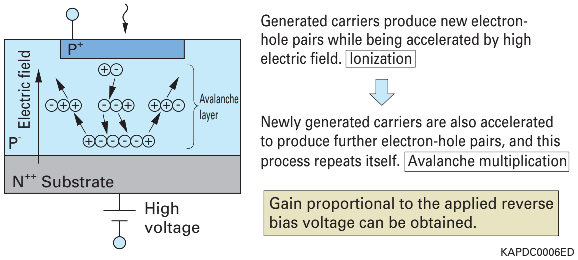
The MPPC is a kind of so-called Si-PM (Silicon Photomultiplier) device. It is a photon-counting device consisting of multiple APD pixels operating in Geiger mode. Each APD pixel of the MPPC outputs a pulse signal when it detects one photon. The signal output from the MPPC is the total sum of the outputs from all APD pixels. The MPPC offers the high performance needed in photon counting and is used in diverse applications for detecting extremely weak light at the photon-counting level.

Contents

Photon counting by MPPC

The light we usually see consists of a stream of light particles (photons) that produce a certain brightness. When this brightness falls to a very low level, the incoming photons are now separate from each other. Photon counting is a technique to measure low light levels by counting the number of photons. Photomultiplier tubes and APDs (avalanche photodiodes) are the most popular photon-counting devices.

Operating principle example of APD



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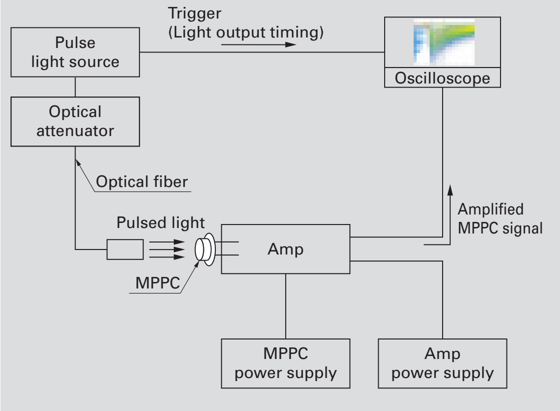
APDs are high-speed, high-sensitivity photodiodes that internally amplify photocurrent when a reverse voltage is applied.
When the reverse voltage applied to an APD is set higher than the breakdown voltage, the internal electric field becomes so high that a huge gain (10^5 to 10^6) can be obtained. Operating an APD under this condition is called “Geiger mode” operation. During Geiger mode, a very large pulse is generated when a carrier is injected into the avalanche layer by means of incident photon. Detecting this pulse makes it possible to detect single photons.
One pixel consists of a Geiger mode APD to which a quenching resistor is connected. An MPPC is made up of an array of these pixels. The sum of the output from each pixel forms the MPPC output, which allows the photons to be counted. HAMAMATSU MPPC has high sensitivity to short wavelength light emitted from commonly used scintillators. Its structure allows a high fill factor to ensure high photon detection efficiency.

Connection example (MPPC output signal is displayed on an oscilloscope.)



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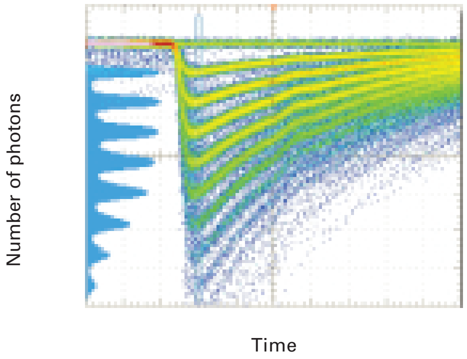
Excellent photon counting capability

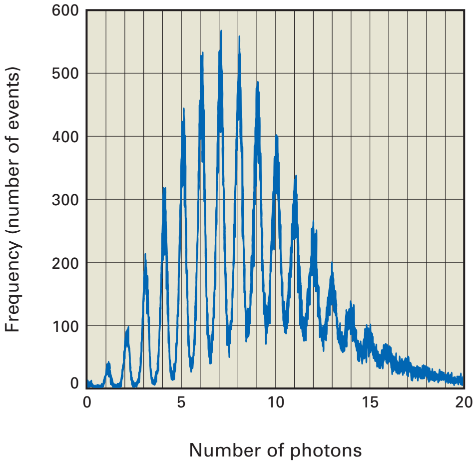
The MPPC delivers superb photon-counting performance. Connecting the MPPC to an amplifier will show sharp waveforms on an oscilloscope according to the number of detected photons.

Pulse waveform when using an amplifier (120 times) (S10362-11-050U, M=7.5 · 10^5)



The fact that the individual peaks are clearly separate from each other in the pulse height spectrum below, proves there is little variation between the gains of APD pixels making up the MPPC.

Pulse height spectrum when using charge amplifier (S10362-11-025U, M=2.75 · 10^5)



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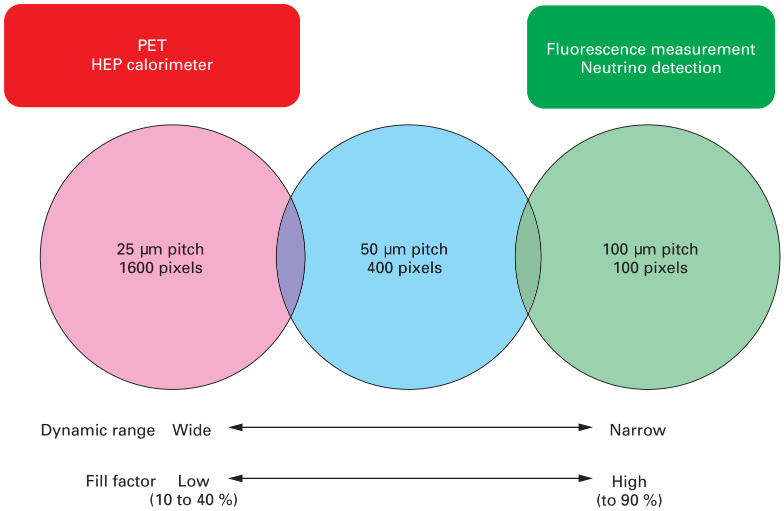
Applications that utilize low-light-level detection

The MPPC is used in diverse applications for detecting extremely weak light at the photon counting level.
The MPPC offers the high-performance needed in photon counting. It offers the advantages of high gain under operation at a low bias voltage, high photon detection efficiency, high-speed response, high count rate, excellent time resolution, and wide spectral response range. Because the MPPC is a solid-state device, there are additional benefits, such as high resistance to shock and impact, no burn-in phenomenon from input light saturation, and photon counting at room temperature since the MPPC needs no cooling. All these features make the MPPC a substitute for existing detectors that have been used in photon counting and opens up all kinds of future possibilities.
The fact that the MPPC operation is simple and provides high-performance detection makes it promising for photon counting applications where extreme photodetector sensitivity is needed. The MPPC is ideal for a wide range of fields including fluorescence analysis, fluorescence lifetime measurement, biological flow cytometry, confocal microscopes, biochemical sensors, bioluminescence analysis, and single molecular detection.
Another great feature of the MPPC is that it is not susceptible to magnetic fields. This means that, for example, when the MPPC is used as a detector for a PET (Positron Emission Tomography) scanner, the PET can be integrated into an MRI (Magnetic Resonance Imaging) system to create a new type of equipment. Furthermore, the MPPC can be put into use in high energy physics experiments because of features, such as room temperature operation, low bias voltage, and small size suitable for high density assembly.

Examples of MPPC applications



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In PET scanners and high-energy calorimeter applications, the number of incident photons is usually large so the MPPC with wide dynamic range, large number of pixels and small pixel pitch is used.
High photon detection efficiency is essential in applications, such as fluorescence measurement and Cherenkov light detection where the number of incident photons is extremely small. In these fields, the MPPC with small number of pixels, large pitch and high fill factor is used.

2

Characteristics and use

2-1

Geiger mode

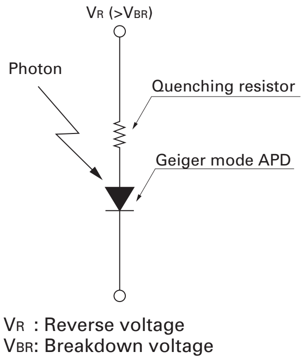
Geiger mode is a method for operating an APD at a reverse voltage higher than the breakdown voltage. A high electric field is produced in the APD during Geiger mode so that a discharge occurs even from a weak light input. This phenomenon is known as “Geiger discharge”. The electron gain at this point is as high as 10^5 or 10^6 and the magnitude of the output current is constant regardless of the number of input photons.

Connecting a quenching resistor to a Geiger mode APD configures a circuit that outputs a pulse at a constant level when it detects a photon.

[Table 1] Operation modes of APD

Operation mode	Reverse voltage	Gain
Normal mode	Below breakdown voltage	Dozens to several hundred
Geiger mode	Above breakdown voltage	10^5 to 10^6

[Figure 1] Geiger mode APD and quenching resistor



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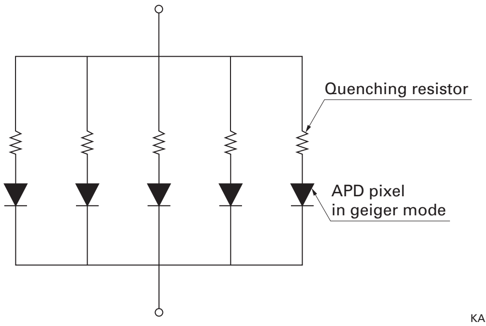
Operating principle

MPPC is made up of multiple APD pixels connected in parallel and operated in Geiger mode (Figure 2). When photons enter each APD pixel during Geiger mode, the pulse output from the pixel is constant regardless of the number of photons. This means that each APD pixel only provides information on whether or not it received one or more photons. A quenching resistor is connected to each APD pixel to allow output current to flow through it. Since all APD pixels are connected to one readout channel, the output pulses from the APD pixels overlap each other, creating a large pulse. By measuring the height or electrical charge of this pulse, the number of photons detected by the MPPC can be estimated.

$$Q_{out} = C \cdot (V_R - V_{BR}) \cdot N_{fired} \quad \cdots\cdots\cdots (1)$$

C: Capacitance of one APD pixel
Nfired: Number of APD pixels that detected photons

[Figure 2] Equivalent circuit



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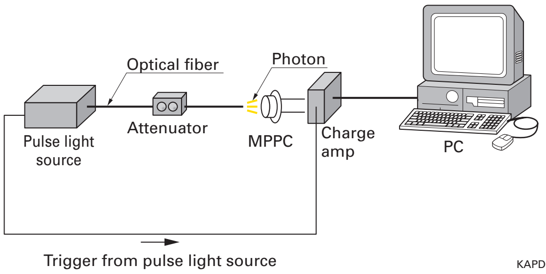
Gain measurement

Gain can be estimated from the output charge of the MPPC that detected photons. The gain varies with the reverse voltage applied to the MPPC. Figure 3 below shows a typical connection for gain measurement.

[Figure 3] Connection diagram for gain measurement setup (using charge amplifier)



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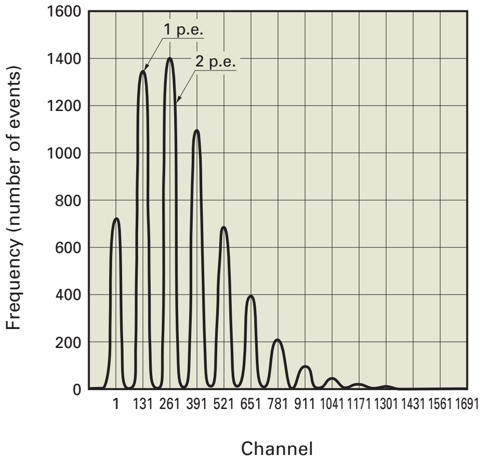
Pulsed light is sufficiently reduced in intensity by the optical attenuator and is irradiated onto the MPPC. The MPPC output is then processed by the PC to obtain a frequency distribution for that output charge. A distribution example is shown in Figure 4.

[Figure 4] Frequency distribution example of output charge



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In Figure 4, the horizontal axis is the ADC channels that represent the amount of digitized output charge from the MPPC. The ADC conversion rate (electric charge per channel) in Figure 4 is 0.382 fC/ch. The output charge is increasing to the right on the horizontal axis. The vertical axis is the frequency (number of events) at each channel (output charge). As can be seen from Figure 4, the distribution curve is separate, indicating output results characteristic of the MPPC. The peak of each curve starting from the left shows: the pedestal, 1 p.e. (one photon equivalent), 2 p.e., 3 p.e., etc. This example indicates that pulsed light of mostly one or two photons detected by the MPPC.

The distance between adjacent peaks exactly equals the output charge of one detected photon. The gain (multiplication) is therefore expressed by the following equation.

$$\text{Gain} = \frac{\text{Number of channels between 2 peaks} \cdot \text{ADC conversion rate}}{\text{1 electron charge}} \quad \cdots (2)$$

The number of channels between two adjacent peaks is 130 ch as seen from Figure 4, the ADC conversion rate is 0.382 fC/ch, and the electric charge of an electron is $1.6 \cdot 10^{-19}$ C, so the gain can be given as follows:

$$\frac{130 \cdot 0.382 \cdot 10^{-15}}{1.6 \cdot 10^{-19}} = 3.10 \cdot 10^{5}$$

To enhance accuracy, the gain is calculated by averaging the peak values between multiple channels.

2-4

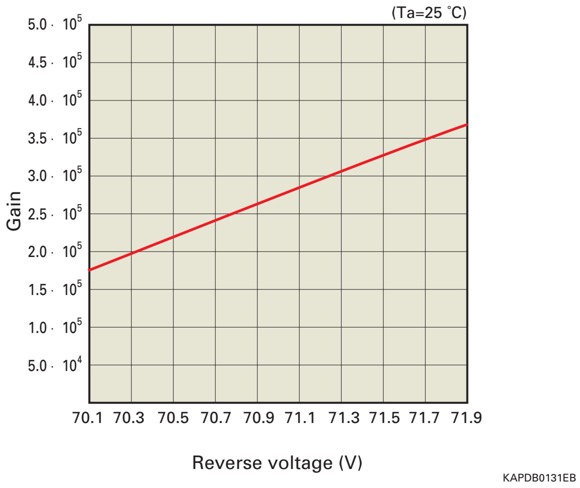
Gain characteristic

Gain linearity

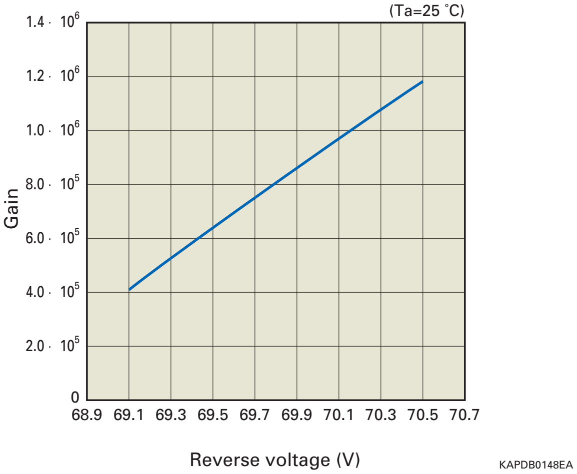
The MPPC gain has an excellent linearity near the recommended operating voltage.

[Figure 5] Gain vs. reverse voltage

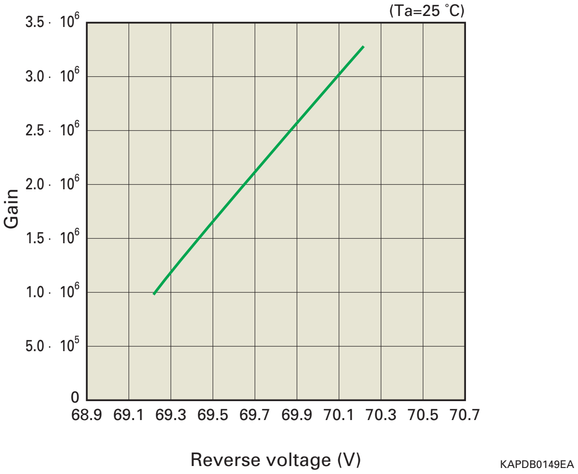
(a) S10362-11-025U/C



(b) S10362-11-050U/C



(c) S10362-11-100U/C

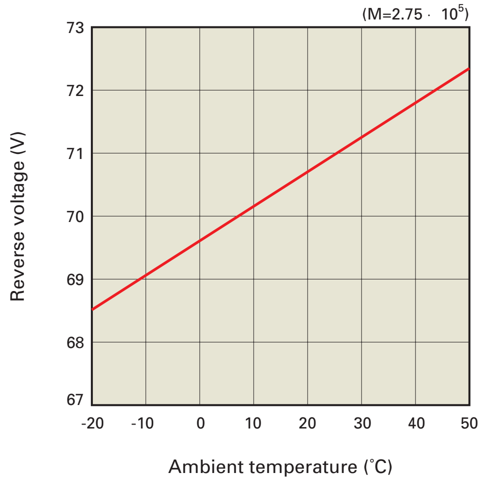


Temperature characteristic of gain

The MPPC gain is temperature dependent. As the temperature rises, the lattice vibrations in the crystal become stronger. This increases the probability that carriers may strike the crystal before the accelerated carrier energy has become large enough, and make it difficult for ionization to occur. Moreover, as the temperature rises, the gain at a fixed reverse voltage drops. In order to obtain a stable output, it is essential to change the reverse voltage according to the temperature or keep the device at a constant temperature.

[Figure 6] Reverse voltage vs. ambient temperature

(a) S10362-11-025U/C



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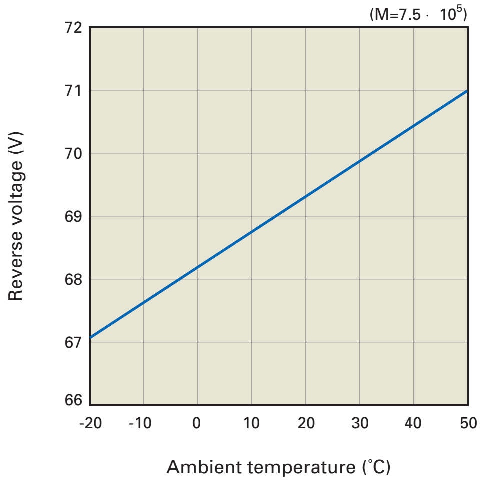
(b) S10362-11-050U/C



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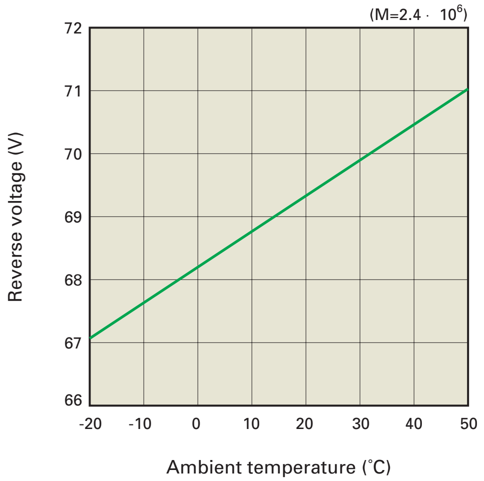
(c) S10362-11-100U/C



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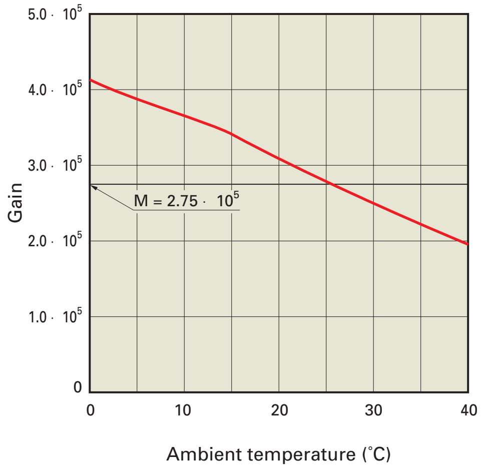
[Figure 7] Gain variation vs. temperature (at constant voltage)

(a) S10362-11-025U/C



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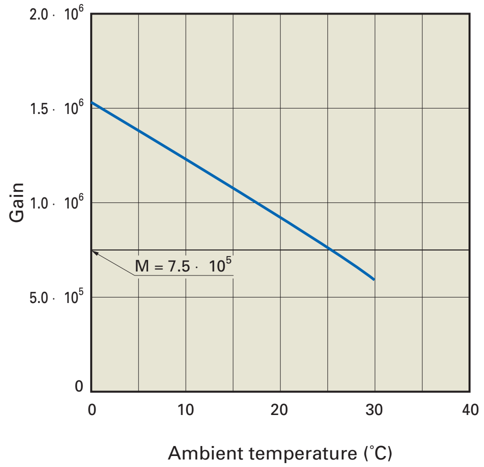
(b) S10362-11-050U/C



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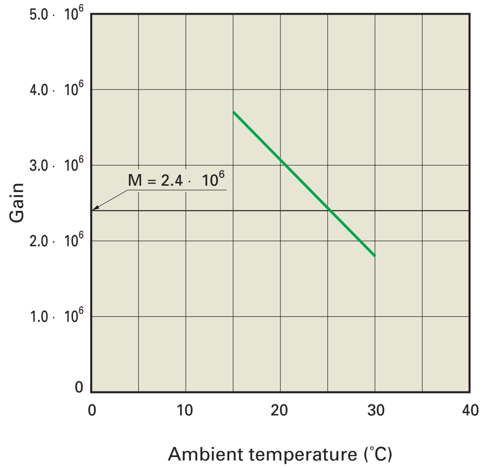
(c) S10362-11-100U/C



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2-5

Setting the photon detection threshold, Dark count measurement

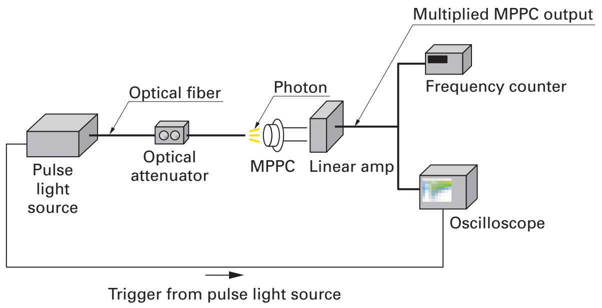
The MPPC is a solid-state device so it generates noise due to thermal excitation. The noise component is amplified in Geiger mode operation and the original photon detection signal cannot be discriminated from the noise. This noise occurs randomly so its frequency (dark count) is a crucial parameter in determining MPPC device characteristics.
The dark count in the MPPC is output as a pulse of the 1 p.e. level, making it difficult to discern a dark count from the output obtained when one photon is detected. However, it is very unlikely that dark counts at 2 p.e., 3 p.e. or 4 p.e. level are detected. This means that, when a large amount of photons are input and detected, the effects of dark counts can be virtually eliminated by setting a proper threshold level. If the time at which light enters the MPPC is known, the effects of dark counts during measurement can be further reduced by setting an appropriate gate time.

■ Setting the photon detection threshold (when counting the number of times that a certain number of photons are simultaneously detected)

Connecting an amplifier to the MPPC and measuring the height of the output pulses allow counting the number of times that a certain number of photons are simultaneously detected. This section explains the method for measuring the number of pulses exceeding a threshold with a frequency counter *. The threshold is set, as shown in Figure 9, according to the number of photons which were input before measurement.

* An instrument for measuring the number of pulses exceeding a threshold level.

[Figure 8] Dark count measurement setup



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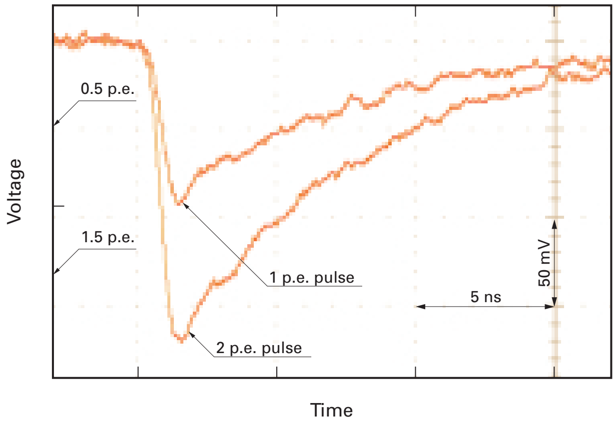
(1) Counting the number of times that one or more photons are detected

Set the threshold at one-half (0.5 p.e.) height of the "1 p.e." (Refer to Figure 9). Counting the number of pulses that exceeds this threshold gives the number of times that one or more photons are detected.

[Figure 9] MPPC output waveform seen on oscilloscope



(2) Detecting two or more (or N or more) photons simultaneously

To count the number of times that two or more photons are detected simultaneously, set the threshold at the midpoint (1.5 p.e.) between "1 p.e." and "2 p.e.". To count the number of times that N or more photons are simultaneously detected, set the threshold at a point of "N - 0.5 p.e.". Counting the number of pulses that exceed the threshold gives the number of times that N or more photons are simultaneously detected.

■ Dark count and crosstalk

The number of output pulses measured with no light incident on the MPPC under the condition that the threshold is set at "0.5 p.e." is usually viewed as a dark count (0.5 p.e. thr.). In some cases, the threshold set at "1.5 p.e" for measurement of the dark count (1.5 p.e. thr.) is used to evaluate crosstalk.

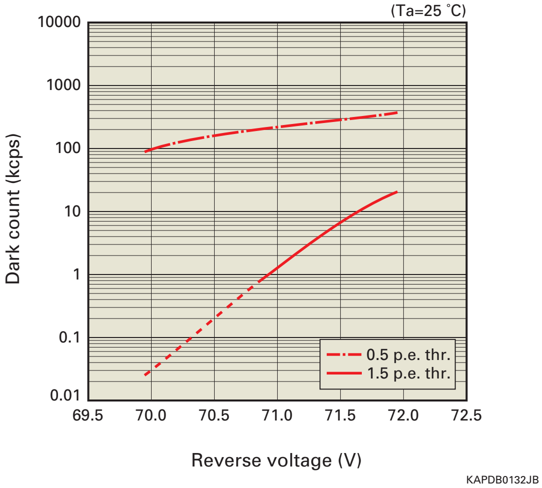
2-6

Dark count rate

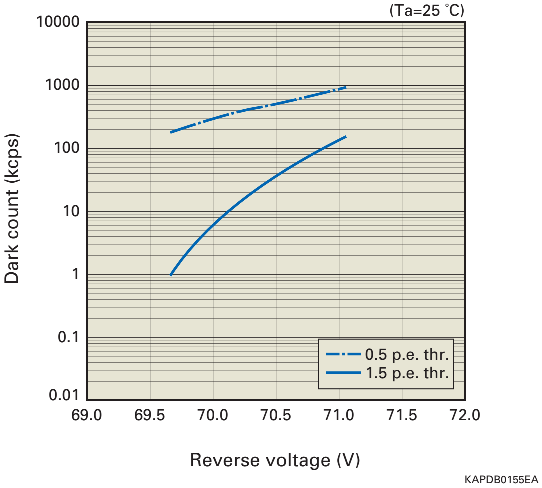
Measurement examples of dark count rate are indicated below.

[Figure 10] Dark count vs. reverse voltage

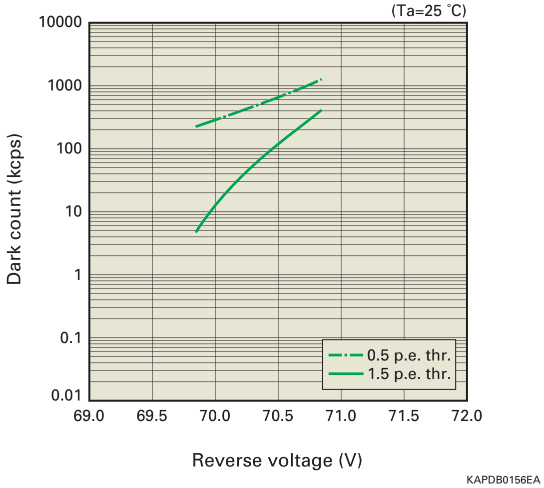
(a) S10362-11-025U/C



(b) S10362-11-050U/C

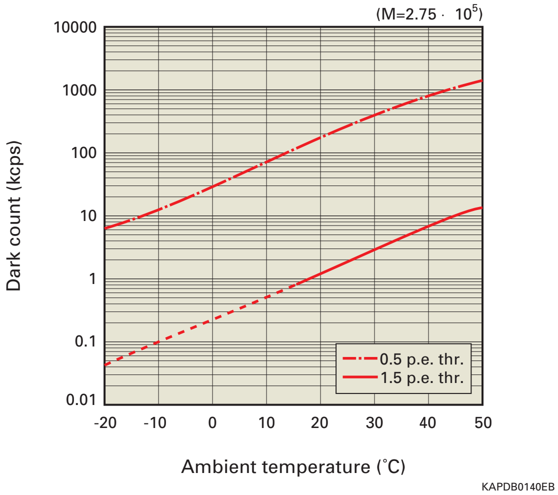


(c) S10362-11-100U/C

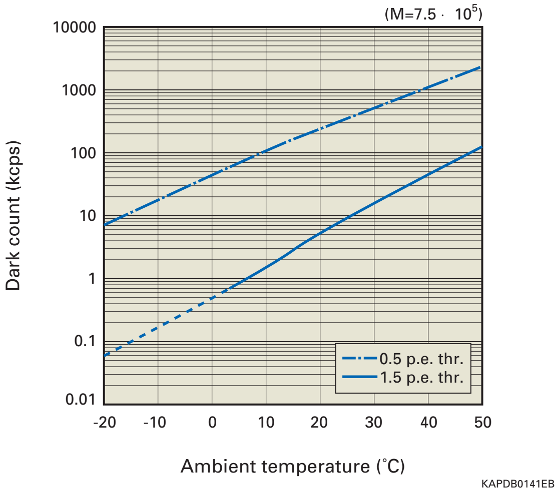


[Figure 11] Dark count vs. ambient temperature

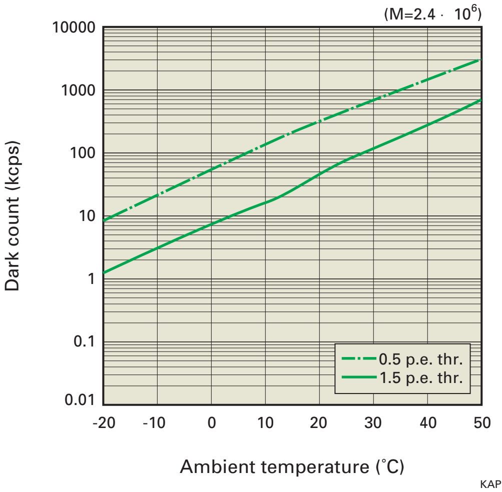
(a) S10362-11-025U/C



(b) S10362-11-050U/C



(c) S10362-11-100U/C



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2-7 Photon detection efficiency (PDE), Dynamic range

Photon detection efficiency is a measure that indicates what percentage of the incident photons is detected. Not all carriers generated by the incident photons will create pulses large enough to be detected, so photon detection efficiency is expressed as the following equation. Photon detection efficiency increases as the bias voltage is increased.

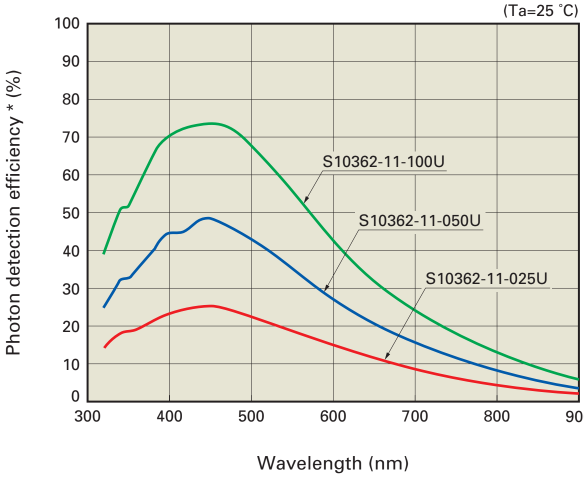
$$\text{PDE} = \text{Quantum efficiency} \cdot \text{Fill factor} \cdot \text{Avalanche probability} \cdots (3)$$

$$\text{Fill factor} = \frac{\text{Effective pixel size}}{\text{Total pixel size}}, \text{Avalanche probability} = \frac{\text{Number of excited pixels}}{\text{Number of photon-incident pixels}}$$

The fill factor has a trade-off relation with the total number of pixels.

[Figure 12] Photo detection efficiency (PDE)* vs. wavelength (measurement example) –

(a) S10362-11-025U/-050U/-100U



* Photon detection efficiency includes effects of crosstalk and afterpulses.

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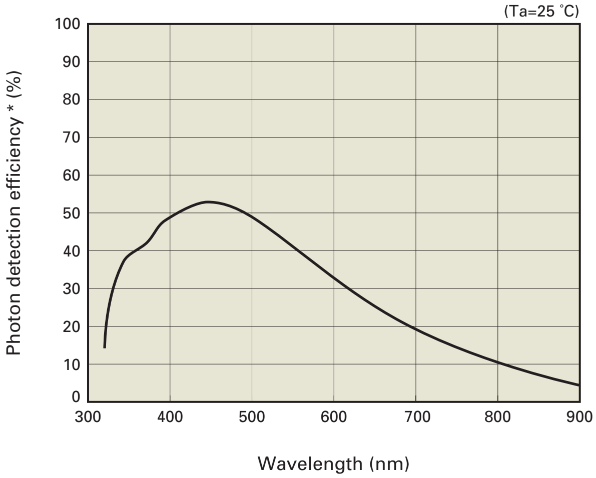
(b) S10362-33-050C



* Photon detection efficiency includes effects of crosstalk and afterpulses.

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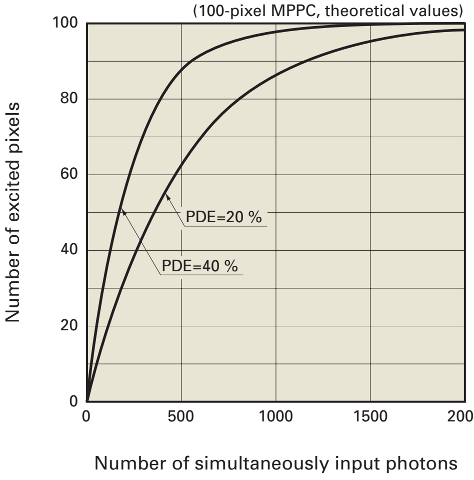
On the other hand, the total number of pixels determines the dynamic range for the simultaneously incident photons. Since each pixel only detects whether or not one or more photons have entered, the photon detection linearity lowers if the number of incident photons becomes large relative to the total number of pixels. This is because two or more photons begin to enter individual pixels.

$$\text{Nfired} = \text{Ntotal} \cdot \left[1 - \exp\left(\frac{-\text{Nphoton} \cdot \text{PDE}}{\text{Ntotal}}\right)\right] \cdots (4)$$

Nfired : Number of excited pixels
Ntotal : Total number of pixels
Nphoton: Number of incident photons

[Figure 13] Number of excited pixels vs. number of incident photons (Theoretical values for 100-pixel MPPC)



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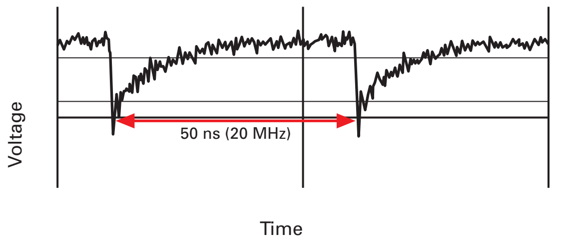
When a charge amplifier is used to measure the incident light having a certain time width, the substantial dynamic range widens. This is because, after a certain time period, the pixels which have produced pulses are restored to a state capable of detecting the next photons again. The time required for pixels to be restored 100 % is approximately 20 ns for the S10362-11-025U/C, 50 ns for the S10362-11-050U/C, and 100 to 200 ns for the S10362-11-100U/C. Figure 14 shows an output waveform measured when pulsed light enters a particular pixel of the S10362-11-050U/C, at a period nearly equal to the pulse width. It can be seen that the pulse is restored to a height equal to 100 % of output.

[Figure 14] Pulse level recovery (S10362-11-050U/C)



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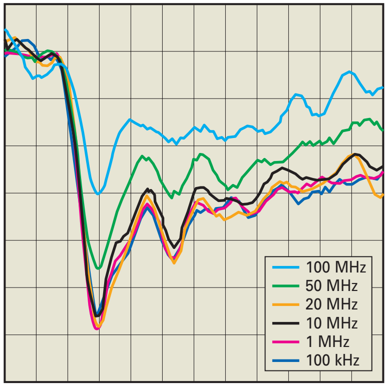
If the next input pulse enters before the output pulse is completely restored, then a pulse smaller than expected is output. (The latter part of the pulse indicates the process for charging the pixel. When the next photon is detected before the pixel is fully charged, the output pulse will have an amplitude that varies according to the charged level.). Figure 15 shows pulse shapes obtained when light at different frequencies was input to a particular pixel of the S10362-11-050U/C. It is clear that the output pulse is sufficiently restored at frequencies below 20 MHz.

[Figure 15] Pulse shapes obtained when light at different frequencies was input

[Pulse length: 50 ns Max. (1/50 ns=20 MHz)]



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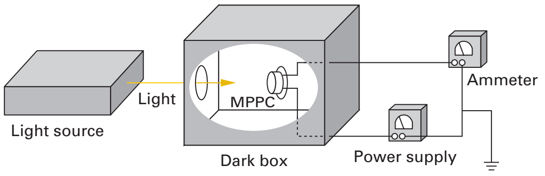
Their values (fill factor, total number of pixels, and dynamic range) determine possible applications suitable for the MPPC. (Refer to page 3.)

2-8

Photon detection efficiency measurement

This section describes how to calculate the photon detection efficiency from the MPPC output current using a monochromator.

[Figure 16] Measurement setup for MPPC photon detection efficiency (using monochromator)



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First, a photodiode with known spectral response characteristics is prepared. Based on its photo sensitivity at a given wavelength (ratio of photocurrent to incident light intensity, expressed in A/W units), the “number of photons incident on the photodiode” can be calculated from the photocurrent.

Next, the MPPC is installed in the same position as the photodiode and the MPPC spectral response is then measured. The gain obtained when a reverse voltage is applied should already be known by checking it beforehand. By dividing the photocurrent obtained from the spectral response measurement by the electric charge ($1.6 \cdot 10^{-19}$ C) of an electron, the “Number of photons detected by the MPPC” can be found.

The MPPC photon detection efficiency is then calculated as follows:

$$\text{PDE} = \frac{\text{Number of photons detected by MPPC}}{\text{Number of photons incident on photodiode}} \cdot \frac{\text{Photodiode active area}}{\text{MPPC active area}} \quad \cdots (5)$$

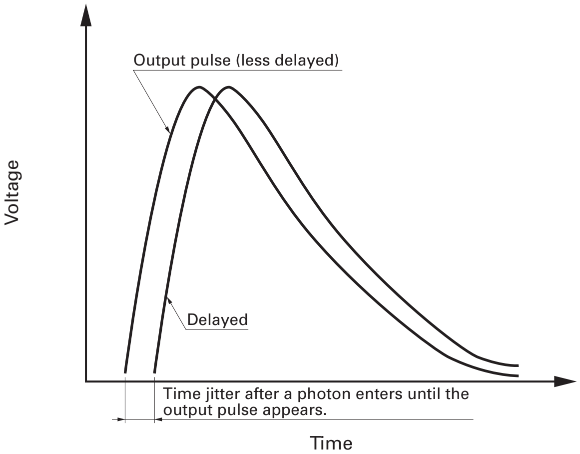
Note: Since the number of photons detected by the MPPC is calculated from the photocurrent, the photon detection efficiency obtained by the above equation also takes into account the effects from crosstalk and afterpulses.

2-9

Time jitter of signal output

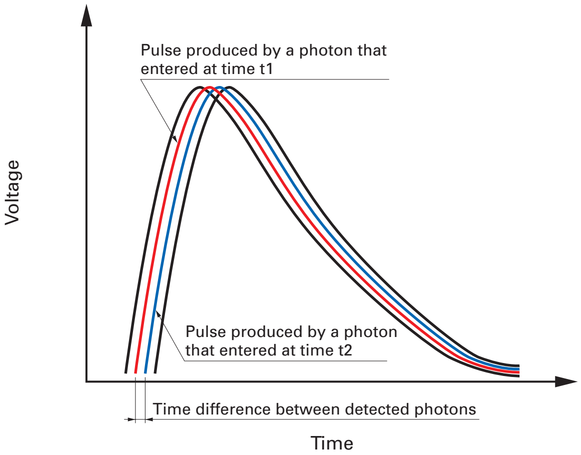
Like all other photodetectors, the MPPC signal output contains time jitter.

(1) A time jitter is present from the time a photon enters the MPPC until the output pulse appears.



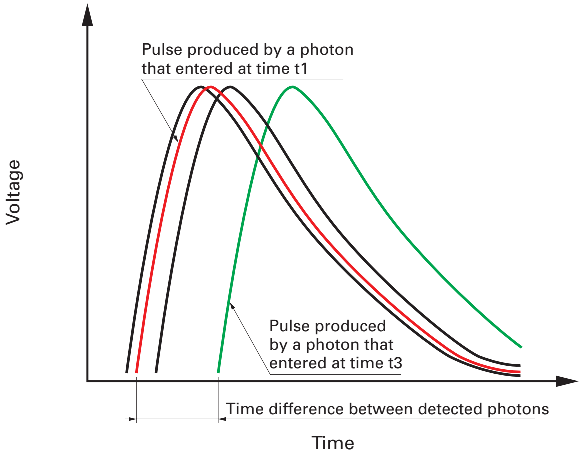
KAPDC0035EA

(2) When two photons enter the MPPC in a time period (between t1 and t2) shorter than the time jitter, then those two output pulses are embedded within the time jitter range, so the MPPC cannot measure the time difference between the two detected photons.



KAPDC0036EA

(3) When two photons enter the MPPC with a time period longer than the time jitter, the MPPC can measure the time difference between the two detected photons.



KAPDC0037EA

As shown above, time jitter of signal output has significant effects on detector time resolution. As an example for measuring the MPPC time resolution, the transit time spread measurement technique is described in the next section “2-10”.

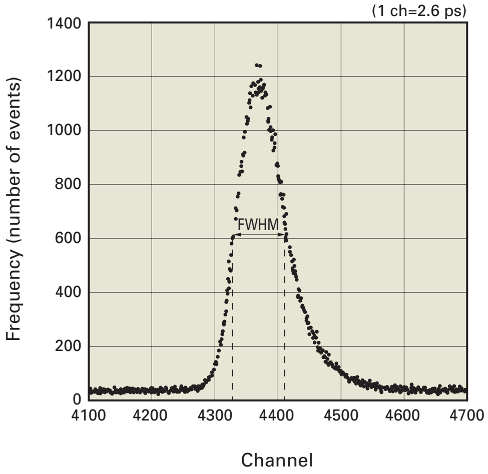
2-10

Time resolution measurement
(by Transit Time Spread)

Time resolution is an important factor in applications requiring time accuracy.

The MPPC time resolution is obtained from the time jitter distribution. Figure 17 shows a time jitter distribution graph in which the horizontal axis represents the channel and the vertical axis the frequency. The time resolution is defined as the FWHM that is found by fitting this distribution using multiple Gaussian functions and a constant.

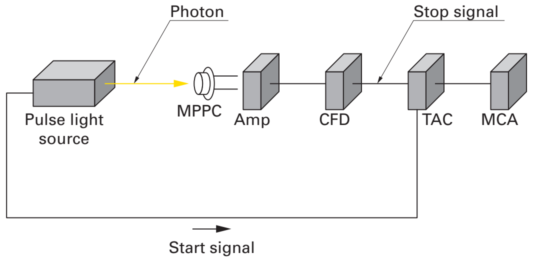
[Figure 17] Pulse response distribution



KAPDB0137EA

A connection diagram for MPPC time resolution measurement is shown below.

[Figure 18] Connection diagram for time resolution measurement



CFD : Constant Fraction Discriminator
TAC : Time-to-Amplitude Converter
MCA: Multichannel Analyzer

KAPDC0030EA

The pulse light source emits photons and simultaneously sends a start signal to the TAC. The TAC starts measuring the time upon receiving the start signal. Meanwhile, the photons enter the MPPC and the detected signals are amplified by the amplifier and sent to the CFD. The TAC receives each signal from the CFD as a stop signal and then provides a pulse output proportional to the time from when a photon entered the MPPC until the signal is measured. The MCA analyzes the pulses received from the TAC and sorts them into different channels according to pulse height. The data stored in the MCA displays a frequency distribution of MPPC responses (Figure 17).

2-11

Trade-off of MPPC specifications

	Gain	Dark count	Crosstalk	Afterpulse	PDE	Time resolution
Increasing reverse voltage	△	△	△	△	△	△
Decreasing reverse voltage	▼	▼	▼	▼	▼	▼
Increasing ambient temperature (at constant gain)	-	△	-	▼	-	-
Decreasing ambient temperature (at constant gain)	-	▼	-	△	-	-

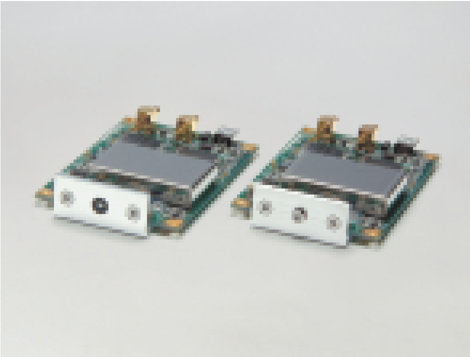
△: Increases
▼: Decreases
- : Depends on conditions (or does not change)

The following table shows characteristics that change when the reverse voltage and ambient temperature are changed. Various characteristics change depending on the reverse voltage applied to the MPPC. For example, the gain, PDE (photon detection efficiency), and time resolution can be improved by increasing the reverse voltage. However, this is also accompanied by an increase in the dark count, crosstalk, and afterpulses. Take this trade-off into account when using the MPPC.

3 Related product

MPPC module — C10507-11 series

The MPPC module is a photon counting module capable of low-light-level detection. This module consists of an MPPC device, current-to-voltage converter circuit, high-speed comparator circuit, high-voltage power supply circuit, temperature-compensation circuit, counter circuit, and microcomputer. The module also has a USB port for connecting to a PC. The threshold level (detection level for one photon) can be changed from a PC. The MPPC module is designed to extract maximum MPPC performance and so yields excellent photon counting characteristics. Potential applications include, fluorescence measurement, DNA analysis, environmental chemical analysis and high energy physics experiments, as well as many other areas in a wide range of fields.



Specifications (Typ. Ta=25 ˚C, unless otherwise noted)

Parameter	Symbol	Condition	C10507-11 series						Unit
			-025U	-025C	-050U	-050C	-100U	-100C	
Internal MPPC	-		S10362-11 series						-
			-025U	-025C	-050U	-050C	-100U	-100C	
Effective active area	-		1 · 1						mm
Number of pixels	-		1600		400		100		-
Peak sensitivity wavelength	λp		440						nm
Analog output voltage	-		100						mV/p.e.
Dark count	-	0.5 p.e.	500		600		900		kcps
Photon detection efficiency *1	PDE	λ=λp, 0.5 p.e.	20		35		45		%
Temperature stability of analog output	-	25 ± 10 ˚C	±2.5						%
Comparator threshold level	-		Adjustable						-
Interface	-		USB1.1						-
Board dimension	-		80 · 55						mm

Note: The last letter of each type number indicates package materials (U: metal, C: ceramic).

C10751 series (Conforms to CE marking)

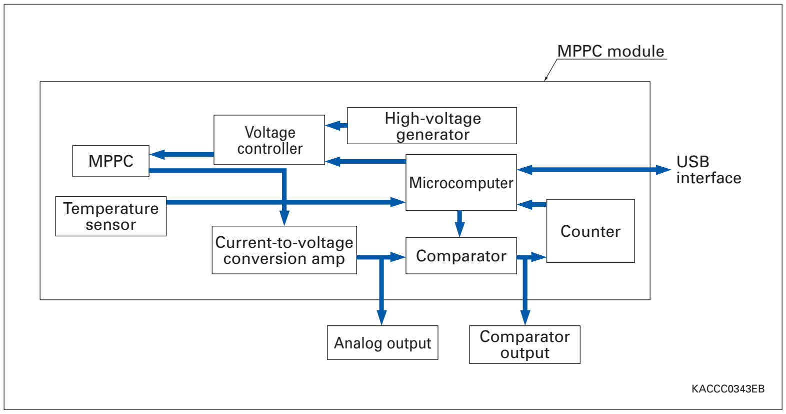
This MPPC module conforms to EU EMC directives (applicable standards: EN61326 Class B) and has an FC-type optical fiber connector for easy coupling to an optical fiber.

Specifications (Typ. Ta=25 ˚C, unless otherwise noted)

Parameter	Symbol	Condition	C10751-01	C10751-02	C10751-03	Unit
Internal MPPC	-		S10362-11 series			-
			-025U	-050U	-100U	
Effective active area	-		1 · 1			mm
Number of pixels	-		1600	400	100	-
Peak sensitivity wavelength	λp		440			nm
Analog output voltage	-		100			mV/p.e.
Dark count	-	0.5 p.e.	500	600	900	kcps
Photon detection efficiency *1	PDE	λ=λp, 0.5 p.e.	20	35	45	%
Temperature stability of analog output	-	25 ± 10 ˚C	±2.5			%
Comparator threshold level	-		Adjustable			-
Interface	-		USB1.1			-
Dimension	-		90.7 · 77 · 35			mm

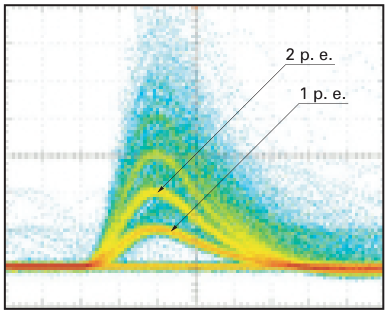
*1: Photon detection efficiency includes effects of crosstalk and afterpulses.

Block diagram



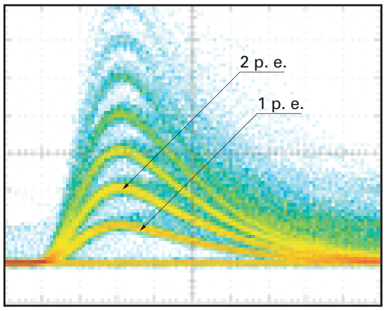
Measurement example

Analog output (C10507-11-025U)



Time (4 ns/div)

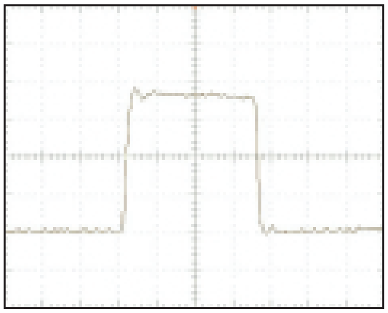
Analog output (C10507-11-050U)



Time (4 ns/div.)

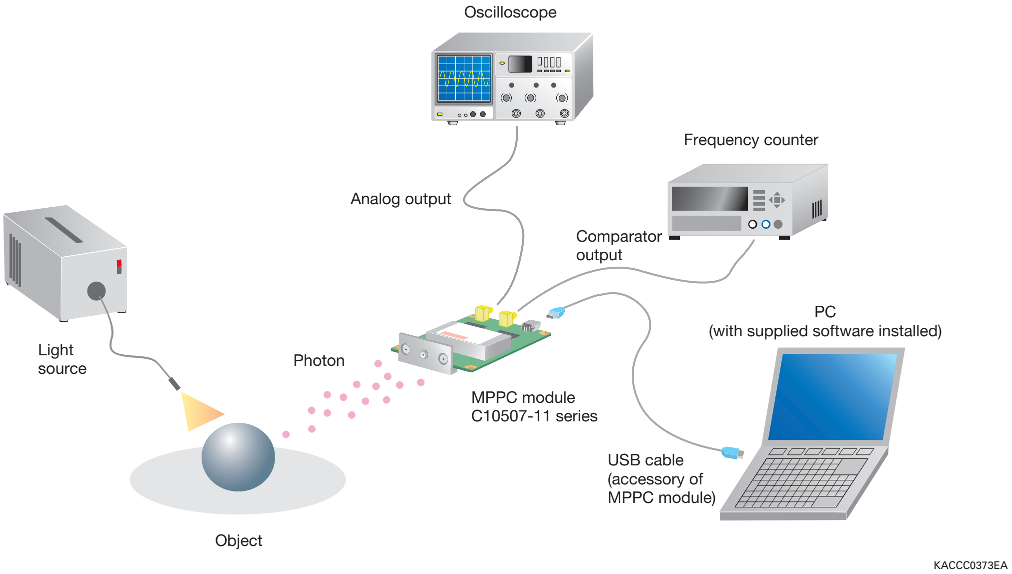
Comparator output

TTL compatible



Connection example

To use the MPPC module, it must be connected to a PC through a USB 1.1 interface. The MPPC is powered by the USB bus power from the PC. Various MPPC module operations are performed on the PC, and the measurement data can be monitored on the PC. Connecting the analog output to an oscilloscope allows monitoring the output waveforms. Connecting the comparator output to a frequency counter allows obtaining the count value.



Sample software (supplied)

The sample software is designed to easily perform basic MPPC module operations. Using the sample software makes it easy to perform measurements. Basic functions of the sample software are acquiring data, displaying measurement data graphs, and saving data.

■ System requirements for sample software
The sample software operation is verified by the following systems. Operation with other systems is not guaranteed.

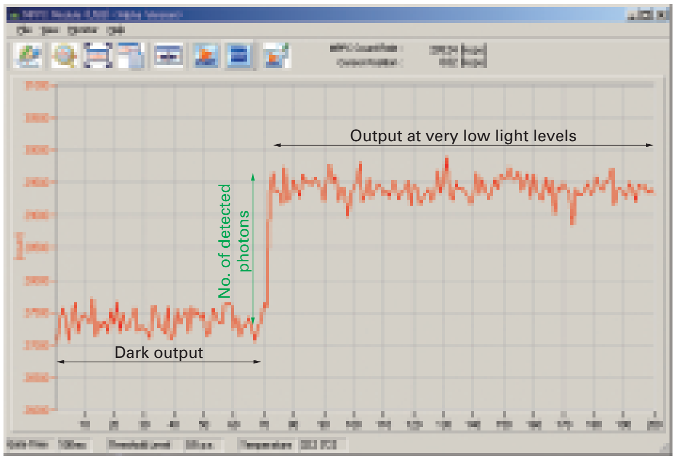
Microsoft Windows 2000 Professional SP4 *2
Microsoft Windows XP Professional SP2

We recommend using a PC with a high-performance CPU and a large capacity memory. A high-performance CPU and large memory are especially important when operating two or more MPPC modules simultaneously.

*2: Microsoft Windows is either registered trademarks or trademarks of Microsoft Corporation in the United States and/or other countries

Example of measuring very low level light

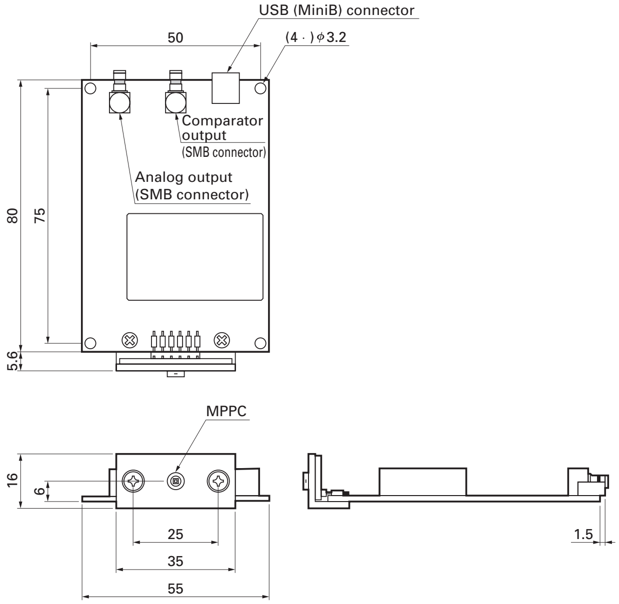
This graph shows an output change when very low level light is input in dark conditions.



Vertical axis: Number of input counts per gate time setting
Horizontal axis: Time [1 second per scale division (10)]

Dimensional outlines (unit: mm)

C10507-11-025U/-050U/-100U



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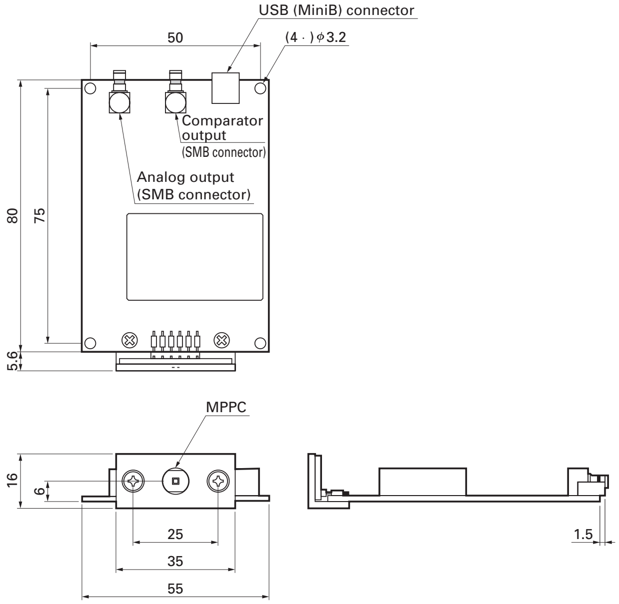
C10507-11-025C/-050C/-100C



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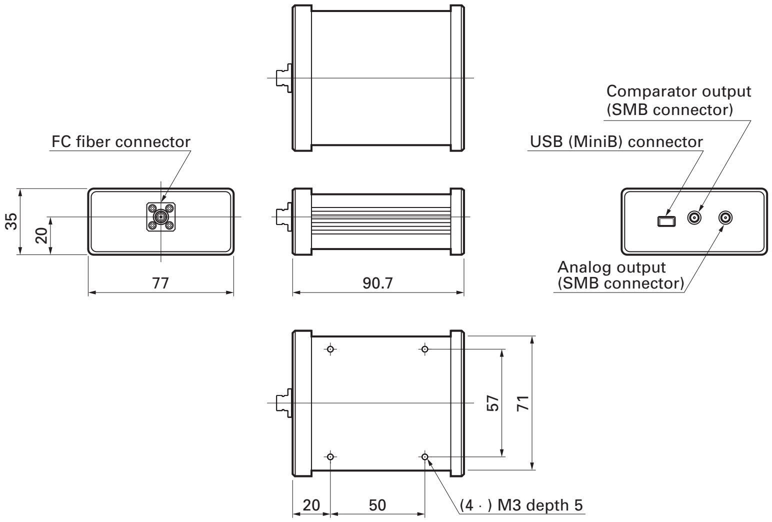
C10751 series



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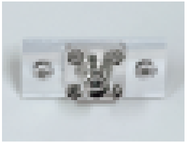
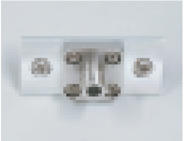
Both cooled type and scintillator-coupled type MPPC modules are under development.

Option (sold separately)

Fiber adapter (for C10507-11-025U/-050U/-100U)
A10524 series

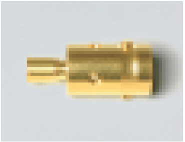
A10524 series fiber adapters are designed to couple the MPPC module to an optical fiber. Two types are available for FC and SMA connectors. Using this adapter allows efficiently coupling the MPPC module to a GI-50/125 multi-mode fiber. This adapter screws on for easy attachment.

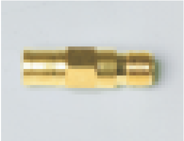

A10524-01 (FC type)


A10524-02 (SMA type)

Coaxial converter adapter
A10613 series

A10613 series is a coaxial adapter that converts the SMB coaxial connector for signal-output on the MPPC module to a BNC or SMA coaxial connector. This adapter allows connecting a BNC or SMA cable to the MPPC module.


A10613-01 (SMB-BNC)


A10613-02 (SMB-SMA)

④

Description of terms

[Afterpulse]

Afterpulses are spurious pulses following the true signal, which occur when the generated carriers are trapped by crystal defects and then released at a certain time delay. Afterpulses cause detection errors. The lower the temperature, the higher the probability that carriers may be trapped by crystal detects, so afterpulses will increase.

[Crosstalk]

In an avalanche multiplication process, photons might be generated which are different from photons initially incident on an APD pixel. If those generated photons are detected by other APD pixels, then the MPPC output shows a value higher than the number of photons that were actually input and detected by the MPPC. This phenomenon is thought to be one of the causes of crosstalk in the MPPC.

[Dark count]

Output pulses are produced not only by photon-generated carriers but also by thermally-generated dark current carriers. The dark current pulses are measured as dark count which then causes detection errors. Although increasing the reverse voltage improves photon detection efficiency, it also increases the dark count. The dark count can be reduced by lowering the temperature.

[Excitation]

This is a phenomenon in which electron-hole pairs are generated in a photodiode by the energy of input photon when the photon energy is greater than the band gap.

[Fill factor]

The ratio of the active area size of a pixel to the total pixel size including circuits.

[Gain (Multiplication)]

The ratio of the number of multiplied electrons to one electron excited by one photon incident on the APD.

[Geiger discharge]

When an APD is operated at a reverse voltage higher than the breakdown voltage, a high electric field is produced, so that a discharge occurs even from a weak light input. This phenomenon is “Geiger discharge”.

[Geiger mode]

Operation mode in which an APD is operated at a reverse voltage higher than the breakdown voltage. Geiger mode operation makes it possible to detect single photons.

[Multi-channel Analyzer: MCA]

This is a pulse height analyzer for analyzing and sorting the input analog pulses into different channels according to pulse height.

[p.e.]

This is an abbreviation for “photon equivalent”.

Example: 1 p.e pulse = pulse with amplitude equivalent to one detected photon (including noise component)

[Time-to-Amplitude Converter: TAC]

Instrument for generating an output pulse height representing the time difference between two input signals.

[Time resolution]

The output pulse timing from an APD pixel may vary with the position of the APD pixel where a photon entered or with the photon input timing. Even if photons simultaneously enter different pixels at the same time, the output pulse from each pixel will not necessarily be the same time so that a fluctuation or time jitter occurs. When two photons enter APD pixels at a certain time difference which is shorter than this jitter, then that time difference is impossible to detect. Time resolution is the minimum time difference that can be detected by APD pixels and is defined as the FWHM of the distribution of the time jitter.

[Photon detection efficiency: PDE]

This is a measure of what percent of the incident photons were detected. Photon detection efficiency (PDE) is expressed by the following equation.

Pa becomes larger as the reverse voltage is increased.

$$PDE = QE \cdot fg \cdot Pa$$

QE: Quantum efficiency
fg : Geometric factor
Pa : Avalanche probability

[Quantum efficiency: QE]

Quantum efficiency is a value showing the number of electrons or holes created as photocurrent divided by the number of incident photons, and is usually expressed as a percent. Quantum efficiency QE and photo sensitivity S (in A/W units) have the following relationship at a given wavelength λ (in nm units).

$$QE = \frac{S \cdot 1240}{\lambda} \cdot 100\ [\%]$$

[Quenching]

This is the process of decreasing the voltage from V_R to V_{BR} to stop the Geiger discharge.

5

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IEEE, “2006 Nuclear Science Symposium” record CD-ROM

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K. Yamamoto, K. Yamamura, K. Sato, T. Ota, H. Suzuki, and S. Ohsuka

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K. Yamamoto, K. Yamamura, K. Sato, S. Kamakura, T. Ota, H. Suzuki, S. Ohsuka

2) “Study of the Multi Pixel Photon Counter for the GLD Calorimeter”

S. Uozumi et al.,
On behalf of the GLD Calorimeter Group / KEKDTP Project Photon Sensor Group

© IEEE, 2007 Nuclear Science Symposium, 27th Oct. to 3th Nov., 2007, Honolulu, Hawaii

http: //www-conf.kek.jp/PD07/

International workshop on new photon-detectors PD07, 27th Jun. to 29th Jun. 2007 kobe, Japan

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