Module products

CHAPTER 11

1 Mini-spectrometers
  1-1 Hamamatsu technologies
  1-2 Structure
  1-3 Characteristics
  1-4 Operation mode
  1-5 Evaluation software
  1-6 New approaches
  1-7 Applications

2 MPPC modules
  2-1 Features
  2-2 How to use
  2-3 Characteristics
  2-4 New approaches
  2-5 Applications

3 APD modules
  3-1 Features
  3-2 Characteristics
  3-3 How to use
  3-4 New approaches
  3-5 Applications

4 Radiation detection modules
  4-1 Features
  4-2 Structure and characteristics
  4-3 How to use
  4-4 New approaches
  4-5 Applications

5 Distance sensors
  5-1 Features
  5-2 Structure
  5-3 Characteristics
  5-4 Applications

6 Photosensor amplifiers, Photodiode modules
  6-1 Photosensor amplifiers
  6-2 Photodiode modules
  6-3 Applications

7 Optics modules
  7-1 Features
  7-2 Structure
  7-3 New approaches

8 Balanced detectors
  8-1 Features
  8-2 Hamamatsu technologies
  8-3 How to use
  8-4 New approaches
  8-5 Applications

9 PSD signal processing circuits, PSD modules
  9-1 PSD signal processing circuits
  9-2 PSD modules
  9-3 Applications

10 Color sensor modules/evaluation circuit
  10-1 Color sensor modules
  10-2 Color sensor evaluation circuit

11 Image sensor application products
  11-1 Features
  11-2 Structure
  11-3 How to use
  11-4 New approaches

12 Special-purpose modules
  12-1 Flame eyes
  12-2 Sunlight sensors
  12-3 Driver circuit for Si photodiode array
Hamamatsu provides a wide variety of module products that extract the maximum performance from a rich lineup of opto-semiconductors. Custom products are also available by request. Please feel free to consult us.

### Technologies used in module products

**Opto-semiconductor technology**
- Wide lineup of opto-semiconductors
- Custom devices available

**MEMS* technology**
- High accuracy micromachining
- Contributes to the miniaturization of module components and enhanced functionality

* Micro-electro-mechanical systems

**Packaging/mounting technology**
- Compact, highly functional, and low cost
  - Flip-chip bonding: directly joins flipped chip to the board using bumps
  - Front-end IC: couples to compact first-stage analog signal processing circuit suitable for photosensor
  - COB (chip on board): directly mounts a chip on the board to reduce mounting area, makes the module slimmer, and reduces costs.
  - Integration of photosensor and optical components and the like to miniaturize and reduce costs

**Circuit technology**
- Optimized for opto-semiconductors and applications
  - Supports high sensitivity, low noise, high speed, and multichannel

**Optical technology**
- Optimal optical design achieves high-performance modules.
  - Effective simulation
  - In-house optical simulation allows speedy, flexible optical design.

**Software technology**
- Sample software for speedy evaluation
  - Support for USB, RS-232C, and other interfaces
### Hamamatsu module products

<table>
<thead>
<tr>
<th>Product</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mini-spectrometer</strong></td>
<td>These mini-spectrometers consist of a Hamamatsu image sensor, optical elements, and a driver circuit (except for spectrometer heads), all assembled together in a compact case.</td>
</tr>
<tr>
<td><strong>MPPC module</strong></td>
<td>A full lineup of MPPC modules capable of measuring light over a wide range (10 orders of magnitude) from the photon counting region to nW (nanowatt) region is available. MPPC modules contain an amplifier, a high-voltage power supply circuit, and other components needed for MPPC operation. MPPC modules operate just by connecting them to a power supply (±5 V, etc.).</td>
</tr>
<tr>
<td><strong>APD module</strong></td>
<td>These are high-speed, high-sensitivity photodetectors using an APD. An APD, a low-noise amplifier, and a bias power supply are assembled together in a compact case. Simply connecting to a low voltage DC power supply allows light measurements with an S/N level dozens of times higher than PIN photodiodes.</td>
</tr>
<tr>
<td>** Radiation detection module**</td>
<td>These modules incorporate a scintillator and MPPC and are designed to detect gamma-rays.</td>
</tr>
<tr>
<td><strong>Distance sensor</strong></td>
<td>These modules are designed to measure distances to a reflective sheet attached to the target object. The distance is measured by emitting pulsed light from a 660 nm semiconductor laser to irradiate the reflective sheet and measuring the time-of-flight required for the laser light to return to the sensor.</td>
</tr>
<tr>
<td><strong>Photosensor amplifier</strong></td>
<td>These are current-to-voltage conversion amplifiers specifically designed to amplify photocurrent with low noise.</td>
</tr>
<tr>
<td><strong>Photodiode module</strong></td>
<td>Photodiode modules are high-precision photodetectors integrating a Si or InGaAs photodiode and current-to-voltage conversion amplifier. A dedicated controller is also provided (sold separately).</td>
</tr>
<tr>
<td><strong>Optics module</strong></td>
<td>Optics modules are custom products integrating a photosensor, optical components (lens, filter, etc.), and a circuit (analog, digital).</td>
</tr>
<tr>
<td><strong>Balanced detector</strong></td>
<td>These are differential amplification type photoelectric conversion modules containing two photodiodes. The difference between the incident light levels of two photodiodes is treated as a displacement signal, converted into an electrical signal, and output.</td>
</tr>
<tr>
<td><strong>PSD signal processing circuit</strong></td>
<td>These circuit boards are used for evaluation of a PSD (position sensitive detector).</td>
</tr>
<tr>
<td><strong>PSD module</strong></td>
<td>These modules are high-precision position detectors integrating a PSD (or 4-segment Si photodiode) and current-to-voltage conversion circuit. A dedicated controller is also provided (sold separately).</td>
</tr>
<tr>
<td><strong>Color sensor module/ evaluation circuit</strong></td>
<td>Color sensor modules contain an RGB color sensor. An evaluation circuit is also provided where a color sensor can be mounted.</td>
</tr>
<tr>
<td><strong>Infrared detector module with preamp</strong></td>
<td>These modules integrate an infrared detector and preamp. A variety of products is available for different wavelength regions.</td>
</tr>
<tr>
<td><strong>Multichannel detector head</strong></td>
<td>These products house in a heat dissipating case a driver circuit supporting Hamamatsu’s main image sensors.</td>
</tr>
<tr>
<td><strong>Image sensor driver circuit</strong></td>
<td>Driver circuits for our main image sensors are available to easily evaluate and test Hamamatsu image sensors.</td>
</tr>
<tr>
<td><strong>Special-purpose module</strong></td>
<td>These include “flame eyes” for flame detection, sunlight sensors for automotive air conditioners and the like, and Si photodiode array driver circuit.</td>
</tr>
</tbody>
</table>
1. **Mini-spectrometers**

Mini-spectrometers are compact polychromators made up of optical systems such as a grating, an image sensor, and its driver circuit which are assembled together into a compact case. Spectrum data is acquired by guiding measurement light into a mini-spectrometer through an optical fiber and transferring the sensor output to a PC via the USB connection. Other communication interfaces (Ethernet, serial interface, etc.) can be provided through customization upon customer request.

![Connecting a mini-spectrometer to a PC via USB](image)

High-performance spectrophotometers are used in a broad range of fields including chemical analysis. However, those instruments are usually large and expensive. Moreover, the measurement samples have to be brought into a laboratory where the spectrophotometer is installed. By merging the image sensor technology accumulated over many years with MEMS technology such as nanoimprint (e.g. for diffraction gratings), Hamamatsu succeeded in developing mini-spectrometer products that offer compact size and low cost.

These mini-spectrometers are useful in a wide range of measurement fields including chemical analysis, color measurement, environmental measurement, and process control on production lines. Hamamatsu also provides ultra-compact models specifically designed to be built into mobile measuring devices.

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**Hamamatsu technologies**

**MEMS technology**

Hamamatsu mini-spectrometers (TM/TG series) use a transmission grating fabricated by a nanoimprint as a wavelength dispersive element. Nanoimprint is a technique suited for mass production, and a grating can be formed directly onto the matrix, instead of replicating the grating. This enables highly accurate light dispersion. Since Hamamatsu develops its own grating, which is the core of spectroscopic technology, grating with different specifications (high resolution, wide spectral range, high diffraction in the ultraviolet region, etc.) can be mounted on its mini-spectrometers.

![SEM photo of grating](image)

The detector serving as the core of the mini-spectrometer is a Hamamatsu image sensor (back-thinned CCD image sensor, CMOS linear image sensor, or InGaAs linear image sensor) which holds a long and well-deserved reputation among users in analysis and measurement fields. In the future, Hamamatsu plans to incorporate new image sensors suitable for mini-spectrometer applications as they become available.

![Examples of image sensors used in mini-spectrometers](image)

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**Structure**

Wavelength dispersive spectrometers are broadly grouped into monochromator and polychromator types. Monochromators use a grating as the wavelength dispersing element for separating the incident light into a monochromatic spectrum. Polychromators utilize the principle of monochromators and are designed to allow simultaneous detection of multiple spectra. Mini-spectrometers fall under the polychromator type. In monochromators, an exit slit is usually formed on the focal plane of a focus lens, while in polychromators an array type detector (image sensor) is placed along the focal plane of the focus mirror/lens. To make mini-spectrometers compact, the polychromators use a collimating lens and focus mirror/lens with a shorter focal distance compared to monochromators.

Functions of components used in mini-spectrometers are described below.
Input slit

This is an aperture through which light to be measured is guided inside. The input slit restricts the spatial spread of the measurement light that enters the mini-spectrometer, and the slit image of the incident light is focused on the image sensor. The narrower the input slit, the more the spectral resolution is improved, but the throughput becomes lower. An optical fiber is connected to the mini-spectrometer input slit.

Collimating mirror/lens

The light passing through the input slit spreads at a certain angle. The collimating mirror/lens collimates this slit transmitted light and guides it onto the grating. An aperture (aperture mask) is used along with the collimating mirror/lens to limit the NA (numerical aperture) of the light flux entering the mini-spectrometer.

Grating

The grating separates the incident light guided through the collimating mirror/lens into each wavelength and lets the light at each wavelength pass through or be reflected at a different diffraction angle. There are two types of gratings for mini-spectrometers: transmission type and reflection type.

Focus mirror/lens

The focus mirror/lens focuses the light from the grating onto an image sensor in the order of wavelength.

Image sensor

The image sensor converts the spectrum of light focused by the focus mirror/lens into electrical signals, and then outputs them. Cooled mini-spectrometers incorporate a thermoelectrically cooled image sensor to reduce image sensor noise.

[Figure 1-4] Optical system layouts
(a) TM series

(b) TG series

(c) RC series

(d) MS series

[Figure 1-5] MS series C10988MA-01

The MS series mini-spectrometers are a combination of image sensor technology and MEMS technology. They are thumb-sized, ultra-compact (27.6 × 16.8 × 13 mm) spectrometer heads specifically designed to be built into mobile measuring devices. The adoption of a CMOS linear image sensor with a built-in input slit and the fabrication of reflective grating on a convex lens by nanoimprint for the optical system have achieved less than one third the volume of the previous RC series.
### Table 1-1: Hamamatsu mini-spectrometers

<table>
<thead>
<tr>
<th>Type no.</th>
<th>Type</th>
<th>Spectral response range (nm)</th>
<th>Spectral max. (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>200 400 600 800 1000 1200 1400 1600 1800 2000 2200 2400 2600</td>
<td></td>
</tr>
<tr>
<td>C10082CA</td>
<td>TM-UV/VIS-CCD High sensitivity</td>
<td>200 to 800</td>
<td>6</td>
</tr>
<tr>
<td>C10082CAH</td>
<td>TM-UV/VIS-CCD High resolution</td>
<td></td>
<td>1 typ.</td>
</tr>
<tr>
<td>C10082MD</td>
<td>TM-UV/VIS-MOS Wide dynamic range</td>
<td></td>
<td>6</td>
</tr>
<tr>
<td>C10083CA</td>
<td>TM-VIS/NIR-MOS High sensitivity</td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>C10083CAH</td>
<td>TM-VIS/NIR-MOS High resolution</td>
<td>220 to 1000</td>
<td>1 typ. (320 to 950 nm)</td>
</tr>
<tr>
<td>C10083MD</td>
<td>TM-VIS/NIR-MOS Wide dynamic range</td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>C11697MB</td>
<td>TM-VIS/NIR-MOS Hitachi compatible</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C9404CA</td>
<td>TG-UV-CCD High sensitivity</td>
<td>200 to 400</td>
<td>3</td>
</tr>
<tr>
<td>C9404CAH</td>
<td>TG-UV-CCD High resolution</td>
<td></td>
<td>1 typ.</td>
</tr>
<tr>
<td>C11713CA</td>
<td>TG-RAMAN High resolution</td>
<td>500 to 600</td>
<td>0.3 typ.</td>
</tr>
<tr>
<td>C11482GA</td>
<td>TG2-NIR Non-cooled type</td>
<td></td>
<td>7</td>
</tr>
<tr>
<td>C9913GC</td>
<td>TG-cooled NIR-I Non-cooled type</td>
<td></td>
<td>7</td>
</tr>
<tr>
<td>C9914GB</td>
<td>TG-cooled NIR-II Non-cooled type</td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>C11118GA</td>
<td>TG-cooled NIR-III Non-cooled type</td>
<td>900 to 2500</td>
<td>20</td>
</tr>
<tr>
<td>C11007MA</td>
<td>RC-VIS-MOS Spectrometer module</td>
<td>340 to 780</td>
<td>9</td>
</tr>
<tr>
<td>C11008MA</td>
<td>RC-SWNIR-MOS Spectrometer module</td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>C1109MA</td>
<td>RC-VIS-MOS Spectrometer head</td>
<td>340 to 780</td>
<td>9</td>
</tr>
<tr>
<td>C1110MA</td>
<td>RC-SWNIR-MOS Spectrometer head</td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>C1098MA-01</td>
<td>MS-VIS-MOS Spectrometer head</td>
<td>340 to 750</td>
<td>14</td>
</tr>
<tr>
<td>C11708MA</td>
<td>MS-SWNIR-MOS Spectrometer head</td>
<td></td>
<td>20</td>
</tr>
<tr>
<td>C12666MA</td>
<td>Micro-spectrometer Spectrometer head</td>
<td></td>
<td>15</td>
</tr>
</tbody>
</table>

### Figure 1-6: Mini-spectrometer examples
(1) Definition of spectral resolution

The spectral resolution of mini-spectrometers is defined based on the full width at half maximum (FWHM). FWHM is the spectral width at 50% of the peak power value as shown in Figure 1-7. Figure 1-8 shows examples of spectral resolution measured with different types of mini-spectrometers.

(2) Changing the spectral resolution

The spectral resolution of mini-spectrometers varies depending on the slit width and NA. In the C10082CA, for example, the slit width is 70 µm and the NA is 0.22. Figure 1-9 shows typical examples of spectral resolution when the NA is changed to 0.11 and the slit width is narrowed. This proves that the spectral resolution can be improved down to about 1 nm by changing conditions. However, narrowing the slit width and reducing the NA will limit the light incident on the mini-spectrometer. The light level reaching the image sensor will therefore decrease.

For example, when comparing the C10082CA with the C10082CAH, the slit width of the C10082CA is 70 µm while that of the C10082CAH is 10 µm, which is 1/7 of the C10082CA. This means that the light level passing through the slit of the C10082CAH is 1/7 of the C10082CA.
(3) Spectral detection width assigned per pixel of image sensor

This section describes the spectral detection width that is assigned per pixel of the image sensor mounted in a mini-spectrometer. The spectral detection width is different from spectral resolution. The approximate spectral detection width assigned per pixel is obtained by dividing the spectral response range by the number of pixels of the image sensor.

- Example: C10082CA
  (spectral response range: 200 to 800 nm, 2048 pixels)

  \[
  \text{Spectral detection width assigned per pixel} = \frac{800 - 200}{2048} \approx 0.3 \text{ nm} \quad (1)
  \]

  The detection wavelength of any given pixel is calculated from equation (2) using the wavelength conversion factor that is written in the EEPROM in the mini-spectrometer. This allows obtaining the wavelength assigned to any pixel.

  \[
  \text{Detection wavelength of any given pixel} [\text{nm}] = a_0 + a_1p + a_2p^2 + a_3p^3 + a_4p^4 + a_5p^5 \quad (2)
  \]

  \(a_0\) to \(a_5\): wavelength conversion factor

  \(p\): any pixel number of image sensor (1 to the last pixel)

Hamamatsu mini-spectrometers are designed so that the spectral width assigned per pixel in the image sensor is small relative to the spectral resolution. When a line spectrum is measured with a mini-spectrometer, the output is divided into multiple pixels as shown in Figure 1-10. The center wavelength of the line spectrum can be found by approximating this measurement result with a Gaussian curve.

Stray light

Stray light is generated as a result of extraneous light entering the detector (image sensor), which should not be measured. The following factors can generate stray light.

- Fluctuating background light
- Imperfections in the grating
- Reflection from lens, detector window, and detector photosensitive area

**Definition of stray light**

There are two methods to define stray light: one method uses a long-pass filter and the other method uses reference light in a narrow spectral range (light output from a monochromator or line spectra emitted from a spectral line lamp, etc.).

The long-pass filter method uses light obtained by making white light pass through a long-pass filter for particular wavelengths. In this case, the stray light is defined as the ratio of transmittance in the “wavelength transmitting” region to transmittance in the “wavelength blocking” region. The stray light level (SL) is defined by equation (3). (See Figure 1-11 for the definitions of \(T_l\) and \(T_h\).)

\[
\text{SL} = 10 \times \log \left( \frac{T_l}{T_h} \right) \quad \text{(3)}
\]

This definition allows measuring the effects of stray light over a wide spectral range and so is used as an evaluation method suitable for actual applications such as fluorescence measurement. However, be aware that the intensity profile of white light used as reference light will affect the measurement value.
In the other method using reference light in a narrow spectral range, the stray light level (SL) is defined by equation (4).

\[ SL = 10 \times \log \left( \frac{IM}{IR} \right) \]  \quad (4)

- \( IM \): unnecessary light level that was output at wavelengths deviating from the reference light spectrum
- \( IR \): reference light level

This definition is not affected by the reference light because the measurement conditions are simple.

In both definition methods, the stray light conditions will differ depending on the wavelength to be detected. The stray light should therefore be measured at multiple wavelengths.

The output charge of an image sensor mounted in mini-spectrometers is expressed by equation (5).

\[ Q(\lambda) = k(\lambda) \times P(\lambda) \times T_{exp} \]  \quad (5)

- \( Q(\lambda) \): image sensor output charge [C]
- \( k(\lambda) \): conversion factor for converting the light level entering a mini-spectrometer into image sensor output charge (equals the product of optical system efficiency, diffraction efficiency of grading, and image sensor sensitivity)
- \( P(\lambda) \): incident light level [W] at each wavelength incident on mini-spectrometer
- \( T_{exp} \): integration time [s]

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* A/D count when constant light level enters optical fiber
(Fiber core diameter: 600 μm, assuming no attenuation in optical fiber)
The output charge $Q(\lambda)$ of an image sensor is converted into a voltage by the charge-to-voltage converter circuit and then converted into a digital value by the A/D converter. This is finally derived from the mini-spectrometer as an output value. The output value of a mini-spectrometer is expressed by equation (6).

$$I(\lambda) = \varepsilon \times Q(\lambda) = \varepsilon \times k(\lambda) \times P(\lambda) \times T_{\text{exp}} \quad \text{(6)}$$

$I(\lambda)$: mini-spectrometer output value [counts]
$\varepsilon$: conversion factor for converting image sensor output charge into a mini-spectrometer output value (equals the product of the charge-to-voltage converter circuit constant and the A/D converter resolution)

Meanwhile, the sensitivity of a mini-spectrometer is expressed by equation (7).

$$E(\lambda) = \frac{I(\lambda)}{P(\lambda) T_{\text{exp}}} \quad \text{(7)}$$

$E(\lambda)$: sensitivity of mini-spectrometer [counts/(W∙s)]

When equation (6) is substituted into equation (7), we obtain equation (8).

$$E(\lambda) = \varepsilon \times k(\lambda) \quad \text{(8)}$$

[Table 1-2] Wavelength dependence of parameters that determine conversion factor

<table>
<thead>
<tr>
<th>Parameter determining conversion factor</th>
<th>Wavelength dependence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optical system efficiency</td>
<td>Yes</td>
</tr>
<tr>
<td>Diffraction efficiency of grating</td>
<td>Yes</td>
</tr>
<tr>
<td>Image sensor sensitivity</td>
<td>Yes</td>
</tr>
<tr>
<td>Charge-to-voltage converter circuit constant</td>
<td>No</td>
</tr>
<tr>
<td>A/D converter resolution</td>
<td>No</td>
</tr>
</tbody>
</table>

### 1-4 Operation mode

#### Free-run operation (normal operation mode)

When light enters an image sensor, an electrical charge is generated in each pixel of the image sensor according to the incident light level. This charge accumulates in each pixel during the integration time and is cleared to zero when read out. This means that the charge must be read out before starting integration of newly generated charges. In mini-spectrometers, this cycle of "charge integration → charge readout (A/D conversion) → digital data hold" repeats in a cycle. Digital data is constantly updated with data obtained in the latest integration time. When a data request is received from the PC, the mini-spectrometer sends the latest data at that point to the PC. Figure 1-14 shows the free-run operation.

#### Operation mode during external trigger input

Operation mode in the following mini-spectrometers can be changed by external trigger input.

![Figure 1-14 Free-run operation](image1)

Use the A10670 coaxial cable for external trigger (sold separately) to connect the above mini-spectrometer to a device that outputs digital signals at 0 V to 5 V levels.

![Figure 1-15 Mini-spectrometer connectors (C10082CA)](image2)

The external trigger function works with DLL, but does not function on the supplied evaluation software. Therefore, when using an external trigger function, the user software must be configured to support that function.

When a mini-spectrometer is used to detect light emitted from a DC mode light source with a shutter installed, then data accumulated in a predetermined integration time can be held by supplying the mini-
spectrometer with a trigger input for shutter open operation. Measurements can be made under high repeatability conditions by setting a shutter open period that is sufficiently longer than the integration time.

(2) Data labeling during external trigger input
This operation mode attaches a label to digital data during the gate period for external trigger input. A label is attached to digital data during trigger input (high level or low level can be specified). When the digital data is read out from the PC, the label information can be obtained at the same time. When acquiring data under different measurement conditions, this mode is suitable for identifying which measurement condition applies to the measurement data. For example, suppose measurements are made under condition A and condition B. Condition A uses no trigger input to make measurements, so there is no labeling. In contrast, condition B uses a trigger input, so a label is attached to the acquired data. Labeling the acquired data in this way during trigger input makes it possible to distinguish between acquired data measurement conditions.

(3) Asynchronous data measurement at external trigger input
The first piece of digital data that is converted after an external trigger edge (rising or falling edge can be specified) is applied to the trigger connector is acquired.

(4) Synchronous data measurement at external trigger input
Data integration starts when an external trigger edge (rising or falling edge can be specified) is applied to the trigger connector, and then the digital data is acquired.

(5) Asynchronous data measurement at external trigger input level
Digital data is acquired when an external trigger (high level or low level can be specified) is applied to the trigger connector.

Operation mode of trigger
(C11118GA, C11697MA, C11482GA)

In the C11118GA, C11697MA, and C11482GA, the following trigger operation modes are available. You can switch between these modes from the evaluation software supplied with the mini-spectrometer.

(1) Asynchronous data measurement at software trigger input
The first piece of digital data that is converted after a software trigger is applied from the PC is acquired.

(2) Synchronous data measurement at software trigger input
Data integration starts when a software trigger is applied from the PC.
(6) Synchronous data measurement at external trigger input level

Data integration starts when a trigger (high level or low level can be specified) is applied to the trigger connector, and then the digital data is acquired.

![Figure 1-23] Synchronous data measurement at external trigger input level

In any of the above modes (1 to 6), if the trigger input cycle is shorter than the measurement cycle of the mini-spectrometer, the input trigger is ignored.

(7) External trigger signal output

The start timing of integration (pulse width: 10 µs) can be output from the trigger connector (trigger output edge: rising or falling edge can be specified).

![Figure 1-24] External trigger signal output

The evaluation software has measurement modes including Monitor, Measure, Dark, and Reference. Table 1-3 shows the features of each mode. Data measured in Measure mode, Dark mode*, and Reference mode* can be saved in csv format (loadable into Microsoft® Excel®). Table 1-4 shows the arithmetic functions of the evaluation software, and Table 1-5 shows limitations on setting parameters during measurement.

Note: Microsoft and Excel are either registered trademarks or trademarks of Microsoft Corporation in the United States and/or other countries.

### Evaluation software

Most Hamamatsu mini-spectrometers come with an evaluation software package.

#### Evaluation software functions

By installing the evaluation software into a PC, you can perform the following basic operations.

- Load and save measured data
- Set measurement conditions
- Module information acquisition (wavelength conversion factor*, mini-spectrometer type, etc.)
- Display graphs
- Arithmetic functions
  - Pixel number to wavelength conversion/calculation in comparison with reference data (transmittance, reflectance)/dark subtraction/Gaussian approximation (peak position and count, FWHM)

*1: A factor for converting the pixel numbers of the image sensor to wavelengths. However, a factor for converting the count values after A/D conversion into incident light levels is not available.

The following four types of evaluation software are available. Each type can only be used for specific series of mini-spectrometers.

- For the TM/TG series (USB 1.1 interface)
- For the TM/TG series (USB 2.0 interface)
- For the RC series
- For the MS series
### [Table 1-3] Measurement modes of evaluation software

<table>
<thead>
<tr>
<th>Mode</th>
<th>Description</th>
<th>Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monitor mode</td>
<td>Measurement mode not intended to save acquired data</td>
<td>Graphically displays “pixel no. vs. A/D output value” in real time</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Graphically displays “wavelength vs. A/D output value” in real time</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Graphically displays time-series data at a selected wavelength(^*3)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cannot save measurement data</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Performs dark subtraction</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Displays reference data</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cannot set the number of measurement scans. No limit on scan count.</td>
</tr>
<tr>
<td>Measure mode</td>
<td>Measurement mode intended to save acquired data</td>
<td>Graphically displays “pixel no. vs. A/D output value” in real time</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Graphically displays “wavelength vs. A/D output value” in real time</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Graphically displays time-series data at a selected wavelength(^*3)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Saves measurement data</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Performs dark subtraction</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Displays reference data</td>
</tr>
<tr>
<td>Dark mode(^*2)</td>
<td>Measurement mode for acquiring dark data (used to perform dark subtraction)</td>
<td>Graphically displays “pixel no. vs. A/D output value” in real time</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Graphically displays “wavelength vs. A/D output value” in real time</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Saves measurement data</td>
</tr>
<tr>
<td>Reference mode(^*2)</td>
<td>Measurement mode for acquiring reference data</td>
<td>Graphically displays “pixel no. vs. A/D output value” in real time</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Graphically displays “wavelength vs. A/D output value” in real time</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Saves measurement data</td>
</tr>
<tr>
<td>Trigger mode(^*3)</td>
<td>Measurement mode for acquiring data by trigger signal</td>
<td>Software trigger, asynchronous measurement</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Software trigger, synchronous measurement</td>
</tr>
<tr>
<td></td>
<td></td>
<td>External trigger, asynchronous edge</td>
</tr>
<tr>
<td></td>
<td></td>
<td>External trigger, synchronous level</td>
</tr>
<tr>
<td>Continuous measurement mode(^*3)</td>
<td>Continuous data acquisition by batch data transfer</td>
<td>Graphically displays “pixel no. vs. A/D output value” at completion of data transfer</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Graphically displays “wavelength vs. A/D output value” at completion of data transfer</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Saves measurement data</td>
</tr>
</tbody>
</table>

\(^*2\): The C11118GA, C11697MA, C11482GA, and C11351 do not have Dark or Reference mode. The Measure mode serves as the Dark and Reference modes.

\(^*3\): Only supported by the C11118GA, C11697MA, and C11482GA

### [Table 1-4] Arithmetic functions of evaluation software

<table>
<thead>
<tr>
<th>Function</th>
<th>Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dark subtraction</td>
<td>Displays measurement data after dark data subtraction</td>
</tr>
<tr>
<td>Reference data measurement/dispaly</td>
<td>Measures reference data and displays it graphically</td>
</tr>
<tr>
<td>Gaussian fitting</td>
<td>Fits data in a specified range to Gaussian function</td>
</tr>
</tbody>
</table>

### [Table 1-5] Limitations on setting parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Limitation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Integration time</td>
<td></td>
</tr>
<tr>
<td>4 μs to 100 ms(^*4)</td>
<td>C11697MB</td>
</tr>
<tr>
<td>6 μs to 40 ms(^*4)</td>
<td>C11118GA</td>
</tr>
<tr>
<td>5 ms to 1 s</td>
<td>C9914GB</td>
</tr>
<tr>
<td>5 ms to 10 s</td>
<td>C10082MD, C10083MD, C9913GC, C11007MA, C11008MA, C11351, C11351-10</td>
</tr>
<tr>
<td>6 μs to 10 s(^*4)</td>
<td>C11482GA</td>
</tr>
<tr>
<td>10 ms to 10 s</td>
<td>C10082CA, C10082CAH, C10083CA, C10083CAH, C9404CA, C9404CAH, C11713CA</td>
</tr>
<tr>
<td>Gain</td>
<td></td>
</tr>
<tr>
<td>High/Low</td>
<td>C10082MD, C10083MD, C11482GA, C9913GC, C9914GB, C11007MA, C11008MA, C11118GA</td>
</tr>
<tr>
<td>Scan count</td>
<td>The number of times continuous measurement can be performed in continuous measurement mode depends on the memory size and operation status of the PC (not limited during Monitor mode).</td>
</tr>
</tbody>
</table>

\(^*4\): Specified in 1 μs steps
Mini-spectrometers come with DLLs. By using this DLL, users can create Windows applications for controlling mini-spectrometers in a software development environment such as Microsoft® Visual C++® and Microsoft Visual Basic®. Because Windows application software cannot directly access a USB host controller, the necessary functions should be called from the DLL to allow the software to access the USB host controller via the device driver and USB driver and to control the mini-spectrometer (see Figure 1-26). The DLL provides functions for opening/closing USB ports, setting measurement conditions, getting data and module information, and so on.

*1: Operation has been verified using Microsoft Visual Studio® 2008 (SP1) Visual C++ and Microsoft Visual Studio 2008 (SP1) Visual Basic on .NET Framework 2.0 and 3.0 (Microsoft Windows® 7).

*2: The C11351 MS series evaluation board comes with a DLL, but because the board is for evaluation only, the specifications of functions are not disclosed.

Note: Microsoft, Windows, Visual C++, Visual Basic, and Visual Studio are either registered trademarks or trademarks of Microsoft Corporation in the United States and/or other countries.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>TM/TG series</th>
<th>RC series</th>
<th>Evaluation board for MS series</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compatible OS</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Disclosure of DLL function specifications</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Connecting and driving multiple mini-spectrometers from a single PC</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Compatible development environment</td>
<td>Visual Basic®</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Visual C++®</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

1 - 6 New approaches

To improve the spectral resolution of mini-spectrometers, Hamamatsu is developing new optical systems and fine-pitch grating. Moreover, we are planning to adopt a tandem grating optical layout, which arranges fine-pitch gratings in parallel. A technology that achieves spectral resolution less than 0.1 nm is on the verge of being established owing to the use of a new optical system. Examples of applications that require a spectral resolution less than 0.1 nm are surface enhanced raman spectroscopy (SERS), optical coherence tomography (OCT) for ophthalmology, and laser induced breakdown spectroscopy (LIBS).

1 - 7 Applications

[Figure 1-26] Software configuration example

[Figure 1-27] Connection example (measurement of liquid absorbance)
Fluorescence measurement

Figure 1-28 is an example of measuring fluorescence from a 1000 ppm quinine solution (buffer solution: dilute sulfuric acid).

[Figure 1-28] Fluorescence measurement example (C10083CA)

LED emission measurement

(1) Visible LED

[Figure 1-29] Visible LED measurement example (C10082MD)

(2) White LED and 3-color LED

Figure 1-30 is an example of measuring emissions from a white LED and 3-color LED. White LED light contains wavelength components of various colors as well as blue, and appears white because those colors are mixed together.

[Figure 1-30] White LED and 3-color LED measurement example (C11007MA)

Transmittance measurement

[Figure 1-31] Transmittance (1 mm thick optical window) measurement example (C11482GA)

(a) Measurement value

(b) Calculation result
Here we show an example that measures the film thickness of 10 µm thick food wrap (polyvinylidene chloride). In film thickness measurement utilizing white light interferometry, a rippling interference spectrum is obtained due to reflections between the front and back surfaces of the film. The film thickness can then be determined by calculation from the spectral peak count, wavelength range, refractive index of film, and the angle of incident light.

**Figure 1-32** Film thickness measurement example (C11482GA)
2. MPPC modules

Hamamatsu provides a full lineup of MPPC modules capable of measuring light over a wide range (10 orders of magnitude) from the photon counting region to nW (nano watt) region. MPPC modules contain an amplifier, a high-voltage power supply circuit, and other components needed for MPPC operation. MPPC modules operate just by connecting them to a power supply (e.g., ±5 V).

Hamamatsu offers a wide lineup of MPPC modules including cooled modules that give a low dark count and non-cooled modules with a temperature compensation function for stable measurement. Hamamatsu also provides starter kits developed for making initial MPPC evaluations and a high-accuracy temperature-compensated high-voltage power supply module designed to operate an MPPC.

2-1 Features

- **Wide lineup to meet various applications and incident light levels (number of photons)**
  
  Our lineup includes analog output types for applications handling relatively high levels of light where analog signals are required, digital output types for photon counting, and a starter kit for initial MPPC evaluation.

- **Contains a high-precision temperature compensation circuit or temperature control circuit**
  
  The MPPC is used in Geiger mode where the gain is very high. Ambient temperature fluctuations cause the gain to vary even if the same reverse voltage is applied. To keep the MPPC gain constant, the MPPC modules use temperature compensation circuit that adjusts the MPPC reverse voltage as the ambient temperature changes or temperature control circuit that regulates the MPPC element temperature using a thermoelectric cooler.

In temperature compensation circuit, a high-precision temperature sensor is installed near the MPPC element to accurately sense the MPPC temperature. The reverse voltage applied to the MPPC is then adjusted according to changes in the ambient temperature so that the gain is kept constant with high accuracy and stability. In temperature control circuit, the MPPC chip and a temperature sensor are mounted on a thermoelectric cooler. Based on information from the temperature sensor, the MPPC chip temperature is precisely controlled and maintained at a constant level so that the MPPC gain is kept constant even if the ambient temperature changes.

- Includes a signal readout circuit optimized for MPPC
- Includes a low-noise high-voltage power supply
- Compact and lightweight

[Figure 2-1] Block diagram (C11205 series)

[Figure 2-2] Measurable light level range

[Figure 2-3] Connection example (analog output type)
2 - 2 How to use

To use the MPPC module, connect it to an external power supply by using the power cable that came supplied with the MPPC module. The signal is output from the coaxial connector on the MPPC module. If using an analog output type MPPC module, the output waveforms can be monitored by connecting to an oscilloscope and the like. If using a digital output type, the number of output pulses can be counted by connecting to a frequency counter and the like.

[Figure 2-4] Output waveforms
(a) Analog output type

(2) Photon detection efficiency (digital output type)

On digital output types, photon detection efficiency is defined as the number of photons detected by the MPPC module divided by the number of incident photons and is expressed as a percentage.

[Figure 2-6] Photon detection efficiency vs. wavelength
(C12661 series)

2 - 3 Characteristics

[Figure 2-5] Photoelectric sensitivity vs. wavelength
(C11205 series)

(1) Photoelectric sensitivity (analog output type)

On analog output types, photoelectric sensitivity is defined as the output voltage from the MPPC module divided by the incident light level (unit: W) at a given wavelength, and is expressed in volts per watt (V/W).

(b) Digital output type (TTL compatible)

(2) Dynamic range

(1) Analog output type

Figure 2-7 shows typical dynamic ranges for analog output types (non-cooled type). Comparing the C11205-150 (photosensitive area: 1 mm sq.) with the C11205-350 (photosensitive area: 3 mm sq.) proves that the C11205-350 exhibits better linearity since it contains a larger number of pixels [Figure 2-7 (a)].

When the incident light level is high, the heat generated in the chip becomes too large to ignore. In this case, decreasing the duty ratio of the incident light is recommended [Figure 2-7 (b)]. If using a thermoelectrically cooled type, the element temperature will be maintained at a constant level, so the heat generated in the chip can be ignored in most cases.
Figure 2-7 Output voltage vs. incident light level
(a) C12105-150 (photosensitive area: 1 mm sq.), C12105-350 (photosensitive area: 3 mm sq.) [when pulsed light is input]

![Graph](typ. Ta=25 °C, λ=λp)

Incident light level (W)

Output voltage (V)

Ideal value

C12105-150
C12105-350

Pulse condition
Repeat rate: 5 kHz
Pulse width: 2 μs
Duty ratio: 1%

(b) C12105-150 (when pulsed light or DC light is input)

![Graph](typ. Ta=25 °C, λ=λp)

Incident light level (W)

Output voltage (V)

Ideal value

Pulsed light
DC light

Pulse condition
Repeat rate: 5 kHz
Pulse width: 2 μs
Duty ratio: 1%

Figure 2-8 Number of detected photons vs. number of incident photons (C12661 series)

![Graph](Typ. Ta=25 °C, λ=λp, threshold 0.5 p.e.)

Number of incident photons (cps)

Number of detected photons (cps)

Ideal value

C12661-150
C12661-350

(2) Digital output type

Figure 2-8 shows dynamic ranges for digital output types. Since the lower detection limit is determined by the dark count, the C12661-150 (photosensitive area: 1 mm sq.) is better at the lower limit than the C12661-350 (photosensitive area: 3 mm sq.). The upper detection limit is determined by the output pulse width, and the output pulse width is determined by the pixel pitch. So the upper detection limits on the C12661-150 and C12661-350 are nearly the same because they have the same pixel pitch. When the number of incident photons becomes larger, the output begins to deviate from the ideal linearity due to overlapping of pulses, and eventually no pulses will appear in the output.

2-4 New approaches

- MPPC array modules

In accordance with the greatly improved characteristics of the MPPC (low afterpulse, low dark count, etc.), Hamamatsu will develop modules that include one-dimensional or two-dimensional MPPC array for medical, analytical, and industrial applications.

- Compact power supply modules

Running the MPPC requires a voltage around 70 V and since the gain changes when the ambient temperature changes, a temperature compensation function is necessary to deal with temperature changes. Hamamatsu has developed a high-voltage power supply module with such features. Since the MPPC has excellent gain uniformity characteristics, it is sometimes used in large quantities in PET and other similar applications, and thus miniaturization of the power supply module itself is being called for. To meet this demand, Hamamatsu is working to make it even smaller by utilizing lamination and wafer-level assembly technologies.
### Applications

#### Flow cytometry

To detect the type, quantity, and nucleic acid (DNA, RNA), etc. of cells, laser light is incident on a fast running solution containing the cells. This enables the MPPC to capture the minute fluorescence that is emitted.

#### Particle measurement

Laser is transmitted through a chamber containing gas or liquid with particles. By detecting the scattered light from the particles, the quantity and diameter distributions of the particles can be attained.

#### Fluorescence measurement

The MPPC module can detect minute fluorescence emission of reagents.

#### Scintillation measurement

MPPC modules arranged around 360° detect pair annihilation gamma-rays to capture the target position such as cancer tissue.
3. **APD modules**

APD modules are high-sensitivity photodetectors that integrate an APD (avalanche photodiode), a temperature-compensation bias circuit (or temperature control circuit), and a current-to-voltage converter. Operating an APD module is easy since it works by simply supplying a DC voltage from an external source. The current-to-voltage converter uses high-speed, low-noise bipolar transistors and op amps optimally configured for signal readout from the APD. These APD modules also include a voltage controller with low ripple noise to detect light with high sensitivity. APD modules contain a short wavelength or near infrared type Si APD.

A temperature-compensation type and a thermoelectrically cooled type with stabilized gain are provided. Temperature-compensation APD modules (standard type, high sensitivity type, high-speed type) keep the APD gain nearly constant using the high-precision temperature-compensation circuit. Thermoelectrically cooled APD modules maintain a stable gain by controlling the APD temperature at a constant level, thereby allowing high-precision measurement.

**Features**

- Stable operation against temperature fluctuations

Applying a high reverse voltage to an APD increases its sensitivity higher than general Si photodiodes. However, ambient temperature fluctuations cause the sensitivity to change even if the same reverse voltage is applied. There are two methods to maintain the APD sensitivity constant: one is a temperature-compensation type that adjusts the reverse voltage applied to the APD according to the ambient temperature, and the other is a thermoelectric cooled type that keeps the APD temperature itself constant.

In temperature-compensation APD modules, a high-precision temperature sensor is installed in close proximity to the APD to accurately monitor the APD temperature so that the appropriate reverse voltage relative to the temperature is applied to maintain the gain with high stability. We also provide a digital temperature-compensation APD module that uses an internal microcontroller to perform even more accurate temperature compensation for the APD. In digital temperature-compensation APD modules, the gain is kept very stable over a wide temperature range even at a high gain (250 times).

In thermoelectrically cooled APD modules, the APD chip is mounted on a thermoelectric cooler that is kept at a constant temperature by the internal temperature control circuit so that a stable gain is achieved.

- Low noise

- Compact and lightweight

**Characteristics**
### 3 - 3 How to use

Connect the APD module to the DC power supply using the dedicated cable that comes with the APD module (except the C5658). Since the signals from the APD module are output via a coaxial connector, just connect it to output to a measuring device such as an oscilloscope to start making measurements. The C5658 is supplied with a power connector (D-sub). Solder this power connector to a cable (cable is not supplied), The C5658 output is an SMA connector.

### 3 - 4 New approaches

APD modules are used in a variety of low-light-level measurement applications, such as medical, analytical, and industrial applications, and there is a growing demand for even better S/N and miniaturization. Hamamatsu will strive to attain even higher S/N by reducing the noise in the readout circuit. In addition, we will miniaturize the high-voltage power supply circuit, temperature-compensation circuit, and temperature control circuit to make the module smaller.

### 3 - 5 Applications

#### Optical topography

To monitor changes in blood volume in the cerebral cortex, near infrared rays are emitted above the scalp and the APD module detects the scattered light to capture the changes in the hemoglobin concentration in the blood.

#### Scanning laser ophthalmoscope (SLO)

In ophthalmoscopy, the level of laser light applied to the eyeball is limited due to safety reasons. The APD module is used to detect the low-level reflected light from the eyeball with superb resolution and contrast.
Distance measurement

Laser light is incident on the subject, and the APD module captures the reflected light. The distance to the subject is then calculated using the TOF (time-of-flight) method.

4. Radiation detection modules

These modules incorporate a scintillator and MPPC (multi-pixel photon counter) and are designed to detect gamma-rays from $^{137}$Cs (cesium 137) and the like. The incident gamma-rays are converted into visible light using the scintillator, and the MPPC detects extremely low-level light to measure low-energy gamma-rays with high accuracy. The signal processing circuit and A/D converter are housed in a compact case. And, the module provides a USB interface. The product includes sample software with functions for setting measurement conditions, acquiring and saving data, drawing graphs, etc.

4 - 1 Features

- Includes an ultra-high sensitivity MPPC semiconductor detector
- Includes a CsI(Tl) scintillator
- Gamma-ray energy discrimination
- Easy integration in devices
- Compact and lightweight
- Built-in temperature compensation circuit

4 - 2 Structure and characteristics

The C12137 series radiation detection modules can acquire energy spectra and therefore can perform energy discrimination. It is known that when $^{137}$Cs disintegrates, gamma-rays with energies near 662 keV and 32 keV are emitted. Whether gamma-rays are from $^{137}$Cs can be determined by acquiring the energy spectrum from the low-energy gamma-rays at around 30 keV. As the gamma-

[Table 4-1] Hamamatsu radiation detection modules

<table>
<thead>
<tr>
<th>Type no.</th>
<th>Interface</th>
<th>Dimensions (W × D × H) (mm)</th>
<th>Detector</th>
<th>Scintillator (mm)</th>
<th>Counting efficiency min. $^{137}$Cs, 0.01 μSv/h (cpm)</th>
<th>Energy range (MeV)</th>
<th>Energy resolution $^{137}$Cs, 662 keV (%)</th>
<th>Measurement range $^{137}$Cs, 662 keV $^1$ (μSv/h)</th>
<th>Power supply</th>
<th>Operating temperature (%C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C12137</td>
<td>USB 2.0</td>
<td>110 × 55 × 27</td>
<td>MPPC</td>
<td>CsI(Tl) 13 × 13 x 20</td>
<td>40</td>
<td>0.03 to 2</td>
<td>8</td>
<td>0.01 to 100</td>
<td>110 × 55 × 27</td>
<td>-10 to +50</td>
</tr>
<tr>
<td>C12137-01</td>
<td>USB 2.0 (Full speed)</td>
<td>71 × 55 × 68.5</td>
<td>MPPC</td>
<td>CsI(Tl) 38 × 38 x 25</td>
<td>400</td>
<td>0.06 to 2</td>
<td>8.5</td>
<td>0.001 to 10</td>
<td>71 × 55 × 68.5</td>
<td>0 to +40</td>
</tr>
<tr>
<td>C12137-08</td>
<td>RS-232C</td>
<td>112 × 94 × 53.3</td>
<td>MPPC</td>
<td>CsI(Tl) 80 × 80 x 25</td>
<td>2000</td>
<td>0.06 to 2</td>
<td>9</td>
<td>10</td>
<td>112 × 94 × 53.3</td>
<td>0 to +40</td>
</tr>
<tr>
<td>C12137-10</td>
<td>RS-232C</td>
<td>122 × 122 × 53.3</td>
<td>MPPC</td>
<td>CsI(Tl) Φ110 × 25</td>
<td>2000</td>
<td>0.06 to 2</td>
<td>9</td>
<td>10</td>
<td>122 × 122 × 53.3</td>
<td>0 to +40</td>
</tr>
<tr>
<td>C12137-00D</td>
<td>RS-232C</td>
<td>110 × 55 × 27</td>
<td>MPPC</td>
<td>CsI(Tl) 13 × 13 x 20</td>
<td>40</td>
<td>0.03 to 2</td>
<td>8</td>
<td>0.01 to 100</td>
<td>+5 V</td>
<td>0 to +40</td>
</tr>
<tr>
<td>C12137-01D</td>
<td>RS-232C</td>
<td>71 × 55 × 68.5</td>
<td>MPPC</td>
<td>CsI(Tl) 38 × 38 x 25</td>
<td>400</td>
<td>0.06 to 2</td>
<td>8.5</td>
<td>0.001 to 10</td>
<td>71 × 55 × 68.5</td>
<td>0 to +40</td>
</tr>
<tr>
<td>C12137-08D</td>
<td>RS-232C</td>
<td>112 × 94 × 55.6</td>
<td>MPPC</td>
<td>CsI(Tl) 80 × 80 x 25</td>
<td>2000</td>
<td>0.06 to 2</td>
<td>9</td>
<td>10</td>
<td>112 × 94 × 55.6</td>
<td>0 to +40</td>
</tr>
<tr>
<td>C12137-10D</td>
<td>RS-232C</td>
<td>122 × 122 × 55.6</td>
<td>MPPC</td>
<td>CsI(Tl) Φ110 × 25</td>
<td>2000</td>
<td>0.06 to 2</td>
<td>9</td>
<td>10</td>
<td>122 × 122 × 55.6</td>
<td>0 to +40</td>
</tr>
</tbody>
</table>

$^1$: Measurement range of these products is defined by $^{137}$Cs. When detecting environmental radiation that mainly consists of low energy radiation, the maximum measurement value will be approx. 1/3 to 1/2 of this figure. The lower limit of the measurement range depends on the environmental radiation.

$^2$: The C12137-08D/-08D/-10/-10D do not perform conversion into dose equivalent rate using the G(E) function.
rays become lower in energy, the level of light emitted by
the scintillator weakens. However, the C12137 series, which
uses a high sensitivity MPPC, is able to detect gamma-
rays over a wide range from a low energy region around 30
keV to 2 MeV. The low-light-level detection performance
of high gain MPPCs also contributes greatly to reducing
the measurement time. To reduce the measurement time,
the scintillator capacity must be increased to improve
the detection efficiency. However, as the scintillator
capacity is increased, the level of light that reaches the
photosensor is attenuated inside the scintillator, and the
lower limit of detection degrades accordingly. This means
that the detection of low-energy gamma-rays will become
more difficult. The MPPC offers higher gain than the PIN
photodiode or APD and makes low-light-level detection
possible. Even when it is combined with a large capacity
scintillator, low-energy gamma-rays can still be measured.

[Figure 4-1] Radiation measurement examples (C12137)

![Figure 4-1 Radiation measurement examples (C12137)](image)

[Figure 4-2] Block diagram

![Figure 4-2 Block diagram](image)

**Superb temperature stability**

The level of emitted light by the scintillator due to incident
gamma-rays and the photosensor sensitivity are temperature
dependent. This temperature dependence causes a shift
in the detection energy when the ambient temperature
changes even when gamma-rays with the same energy are
incident and leads to measurement errors and hindrance
to radionuclide identification. The C12137 series’ gamma-
ray detector unit employs a structure with high temperature
stability as well as a temperature-compensation circuit.
Figure 4-3 illustrates its excellent temperature stability
performance against drastic temperature changes. The
temperature stability of the radiation detector module is ±5%
max. in the ambient temperature range of 0 to +50 °C.

[Figure 4-3] Ambient temperature and detected energy
shift (typical example)

![Figure 4-3 Ambient temperature and detected energy shift (typical example)](image)

**Easy integration in devices**

Figure 4-4 shows the cross section of the C12137-01 radiation
detection module.

Since the radiation detection module includes a scintillator,
photosensor (MPPC), signal processing circuit, interface
circuit, and the like in a small case, it can easily be
incorporated into portable measuring instruments and
in-line measuring instruments.

In the C12137 series, the photosensor MPPC is a small, thin
type. The amount of space it takes up is relatively small. The
amount of space taken up by the scintillator is predominant.
This shows that even though the radiation detection module
is small, it can provide high detection efficiency.

Because the radiation detection module is compact, it is
advantageous in applications where the radiation dose from
the object under measurement is minute. Such applications
include inspection of food, beverages, and seafood. In these
types applications, the periphery of the detector must be
covered with lead to eliminate the effects of environmental
radiation. Because the radiation detection module is compact,
the amount of used lead can be reduced, which in turn
reduces the volume and weight of the entire device.

[Figure 4-4] Cross section diagram (C12137-01)

![Figure 4-4 Cross section diagram (C12137-01)](image)
4 - 3 How to use

Install the device driver and sample software supplied with the C12137 series into a PC, start the software, and then connect the C12137 series to the PC through USB. The power for the C12137 series is supplied through the USB bus. The sample software is designed to enable the basic functions of the radiation detector module to be used easily. The sample software provides functions for setting measurement conditions, acquiring and saving data, drawing graphs, etc. The C12137 series counts the number of pulses that exceed the specified threshold and acquires the peak value at the same time. The acquired data is shown on the PC.

(a) Count vs. energy

(b) Measured value vs. time

4 - 4 New approaches

In the area of radiation detection, there is a growing demand for high sensitivity, high speed, high stability measurements. Hamamatsu will meet these demands as well as offer customization of the shape and volume of the scintillator, communication interface, and so on.

4 - 5 Applications

- Environmental monitoring and mapping
- Screening such as incoming and shipment inspections at the production site
- Incorporation into portable, high sensitivity detectors
5. Distance sensors

These distance sensors are designed to measure distances to a reflective sheet attached to the target object. The distance is measured by emitting pulsed light from a 660 nm semiconductor laser to irradiate the reflective sheet and measuring the time-of-flight required for the laser light to return to the sensor.

[Figure 5-1] Measurement of distance to reflective sheet

5-1 Features

- High-speed response by pulse method
  Measurement count: at least 160 measurements per second
  The distance sensors can detect objects moving at a high speed.
- High accuracy
  To achieve a time measurement accuracy level of better than 1 ps and a wide operating temperature range, optical self-calibration is performed by switching the lighting of two lasers for measurement and for self-calibration at high speeds. This allows compensating in real time for electronic circuit characteristics which vary during measurement.

- Red (660 nm) semiconductor laser
  The red beam makes it easy to check the optical axis.

- Safety: Laser Class 1 (IEC JIS FDA)

- Long service life (MTTF: 90000 h)
  Laser is pulse-driven, so temperature increases in the laser are suppressed. This also helps extend the service life.

- Interface: flexible response to meet customer needs
  - Low power consumption
  - Compact and lightweight
  - High reliability

[Figure 5-2] Distance sensors and user options

- Reducing distance-dependent changes in detection light level
  The signal light level returning from a target object decreases in proportion to the square of the distance. If the optical system is configured to match a long distance point, this may cause a focus shift and measurement errors due to excessive signal levels when measuring short distance points. To cope with this, our distance sensors use a large aspherical plastic lens having three focal points: long distance, mid-distance, and short distance, so that changes in the detection light level due to different distances are reduced to a minimum. The area ratio of the lens with three types of focal points is set so that a nearly constant amount of signal is obtained up to about 30 m when all signals are summed.
  The signal level is high when detecting short distances, so a satisfactory signal is obtained even on the small area on the short-distance lens. The long-distance lens has a focal distance of infinity over approximately the entire lens surface which is made large to maintain a sufficient signal level.

- Cables for C7776
  A8035-03: 44 cm sq
  A8034-03: 44 cm sq
  A8034: 15 cm sq

- Cables for C9417
  A8035-05: for C7776 series
  A8035-06: for C9417 series

- PC cable for evaluation (cable with RS422-USB converter)
  A8035-05D: for C7776 series
  A8035-06D: for C9417-10
Our distance sensors are highly reliable during vibration and shock as well as during long-term continuous operation since there are no mechanically moving parts which are used in general optical distance measuring devices. Even if signal light is interrupted, measurement starts immediately after the signal light resumes.

### 5 - 2 Structure

**[Figure 5-3] Distance sensor configuration**

- Distance sensor
- Light receiving lens
- Long-distance lens
- Mid-distance lens
- Short-distance lens
- Reflective sheet (mid-distance)
- Reflective sheet (short-distance)
- Light projection lens
- Laser
- Photosensor
- Light receiving lens

**[Figure 5-4] Internal view of distance sensor (C9417-10)**

- Photosensor
- Laser for self-calibration
- Laser for measurement
- Light projection lens
- Light receiving lens

**[Figure 5-5] Signal level vs. distance (distance sensor light receiving lens)**

- Total output
- Short-distance lens
- Long-distance lens
- Mid-distance lens

### 5 - 3 Characteristics

Figure 5-6 shows a measurement example of the difference (distance error) between the distance data obtained by the distance sensor and the actual distance.

**[Figure 5-6] Distance error vs. distance (C9417-10, typical example)**
Level meter

Detects river water levels

Distance measurement

Measures distances to and speeds of a moving object

Level meter

Measures height, shape, and volume of cargo

Area detection sensor

Automatically controls door opening/closing

Crane position control in automated warehouse

Controls crane movement and up/down position by means of high-speed, high-accuracy distance measurement

Applications
To make our photodiodes easier to use, we offer photosensor amplifiers and photodiode modules with an internal current-to-voltage conversion amplifier. Several types with different conversion impedance and frequency characteristics are available as shown in Figure 6-2.

Photosensor amplifiers are current-to-voltage conversion amplifiers designed to amplify low-level photocurrent in photodiodes with very low noise.

### Features

- High accuracy and low noise
- High-precision, low-noise components are used and arranged in a noise-resistant configuration. The C6386-01 and C9329 have a zero adjustment function to eliminate the offset.
- Dry battery operation (C6386-01, C9329)
- Switchable detection sensitivity (C6386-01, C9329)
- Wide bandwidth type available (C8366/-01)
  The C8366 wide-band type achieves high-speed response since a trimmer can adjust the feedback capacitance according to the PIN photodiode being connected.
- Optical fiber type available (C6386-01)
  The C6386-01 optical fiber type uses an optical fiber that guides light to the internal photodiode. This reduces effects from noise on the photodiode and circuitry even if there is a noise source near the location of the light being measured.
- With a data logger function (C9329)

### Table 6-1 Hamamatsu photosensor amplifiers

<table>
<thead>
<tr>
<th>Type no.</th>
<th>Feature</th>
<th>Photodiode</th>
<th>Cutoff frequency</th>
<th>Conversion impedance (V/A)</th>
<th>Power supply</th>
<th>Output</th>
<th>Zero adjustment knob</th>
</tr>
</thead>
<tbody>
<tr>
<td>C6386-01</td>
<td>With optical fiber (1 m)</td>
<td>Internally mounted</td>
<td>10 MHz</td>
<td>10³</td>
<td>External power supply (±15 V) or dry battery (9 V × 2)</td>
<td>Analog</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3 MHz</td>
<td>10⁴</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1 MHz</td>
<td>10⁵</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C8366</td>
<td>Wide bandwidth (high-speed Si PIN photodiode)</td>
<td>Sold separately</td>
<td>100 MHz</td>
<td>10³</td>
<td>External power supply (±15 V)</td>
<td>Analog</td>
<td>No</td>
</tr>
<tr>
<td>C8366-01</td>
<td>Wide bandwidth (InGaAs PIN photodiode)</td>
<td>Sold separately</td>
<td>100 MHz</td>
<td>10³</td>
<td>External power supply (±15 V)</td>
<td>Analog</td>
<td>No</td>
</tr>
<tr>
<td>C9051</td>
<td>Small board type (terminal capacitance: 15 nF or less)</td>
<td>Sold separately</td>
<td>16 Hz</td>
<td>10⁵</td>
<td>AC adapter (12 V)</td>
<td>Analog</td>
<td>No</td>
</tr>
<tr>
<td>C9329</td>
<td>For low-level light (terminal capacitance: 5 nF or less)</td>
<td>Sold separately</td>
<td>1600 Hz (10⁸, 10⁷)</td>
<td>AC adapter (12 V) or dry battery (9 V)</td>
<td>Digital</td>
<td>Yes</td>
<td></td>
</tr>
</tbody>
</table>
Usage (C9329)

The input section of the C9329 photosensor amplifier is a BNC connector, so use a BNC plug coaxial cable to connect it to a photodiode.

Use a dry battery or AC adapter (supplied) to supply power to the photosensor amplifier.

Analog or digital operation mode is selectable for data output. In analog mode, measurements are made by connecting the output to a measuring device such as an oscilloscope using a BNC plug coaxial cable. In digital mode, digital signals (16 bits) can be obtained by serial connection (RS-232C) to a PC.

Features

- Internal photodiode
- The lineup includes six types of Si photodiodes and two types of InGaAs photodiodes.
- Voltage output for easy handling
- Selectable sensitivity (high/low range)
- Compact size (half the size of a business card)
- Can be mounted on optical bench rod (M4)
- Photodiode module controller is provided (sold separately).

Measurement data can be easily loaded into a PC using sample software that comes with the controller.

Photodiode modules

Photodiode modules are high-precision photodetectors that include a Si or InGaAs photodiode together with a current-to-voltage conversion amplifier. The output is an analog voltage and can be easily checked with a voltmeter and the like.

Photodiode modules have a sensitivity range (high/low) switching function, so a highly accurate output can be obtained by selecting a sensitivity range that matches the light level to be detected.

Hamamatsu also provides a photodiode module controller (sold separately) that converts the output of a photodiode module into digital signals. High-resolution digital signals (16 bits) can be obtained by serial connection (RS-232C) to a PC. Measurement data can then easily be stored into the PC using sample software that comes with the controller. Measurement data can also be stored in the internal memory (data logger function). The controller operates also on dry battery and so can be used easily.
### Table 6-2: Hamamatsu photodiode modules

<table>
<thead>
<tr>
<th>Type no.</th>
<th>Photodiode</th>
<th>Photosensitive area (mm)</th>
<th>Output</th>
<th>Conversion impedance (V/A)</th>
<th>Cutoff frequency</th>
<th>Supply voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>C10439-01</td>
<td>Si</td>
<td>2.4 × 2.4</td>
<td>Analog</td>
<td>High gain: $10^9$</td>
<td>High gain: 10 Hz</td>
<td>External power supply (±5 to ±12 V)</td>
</tr>
<tr>
<td>C10439-02</td>
<td>Si</td>
<td>5.8 × 5.8</td>
<td>Analog</td>
<td>Low gain: $10^7$</td>
<td>Low gain: 1 kHz</td>
<td>±5 to ±12 V</td>
</tr>
<tr>
<td>C10439-03</td>
<td>Si</td>
<td>10 × 10</td>
<td>Analog</td>
<td>High gain: $10^6$</td>
<td>High gain: 1 kHz</td>
<td>±5 to ±12 V</td>
</tr>
<tr>
<td>C10439-07</td>
<td>Si</td>
<td>2.4 × 2.4</td>
<td>Analog</td>
<td>Low gain: $10^6$</td>
<td>High gain: 1 kHz</td>
<td>±5 to ±12 V</td>
</tr>
<tr>
<td>C10439-08</td>
<td>Si</td>
<td>5.8 × 5.8</td>
<td>Analog</td>
<td>High gain: $10^4$</td>
<td>Low gain: 100 kHz</td>
<td>±5 to ±12 V</td>
</tr>
<tr>
<td>C10439-09</td>
<td>Si</td>
<td>10 × 10</td>
<td>Analog</td>
<td>Low gain: $10^4$</td>
<td></td>
<td>±5 to ±12 V</td>
</tr>
<tr>
<td>C10439-10</td>
<td>InGaAs</td>
<td>φ1</td>
<td></td>
<td>Low gain: $10^4$</td>
<td></td>
<td>±5 to ±12 V</td>
</tr>
<tr>
<td>C10439-11</td>
<td>InGaAs</td>
<td>φ3</td>
<td></td>
<td>Low gain: $10^4$</td>
<td></td>
<td>±5 to ±12 V</td>
</tr>
</tbody>
</table>
## 7. Optics modules

The optics module is a customized opto-semiconductor module that integrates photodiodes (or photodiode array), optical system, signal processing circuit (analog, digital), case, and so on. Hamamatsu semiconductor process technology, assembly technology, and module technology can be combined to provide optics modules that meet customers' specifications. In blood analysis devices, the optics module is used to measure the blood absorbance as well as measure the fluorescence emission when light is incident on blood that has been reacted with a reagent to detect the amount of various substances in blood.

[Figure 7-1] Optics module used in a blood analysis device

### 7-1 Features

- **Supports custom order products**
  The optics module can be customized to meet customers' needs. The optics module also supports mounting interference filters with high accuracy and COB (chip on board) technology for mounting photodiodes on circuit boards with high accuracy.
- **High accuracy and low noise**
- **Wide dynamic range**
- **Low crosstalk**
- **High-speed response**

### 7-2 Structure

The optics module consists of the following components.

### Photodiodes

The photodiodes built into the optics module feature high sensitivity, low crosstalk, and high-speed response.

### Optical system

The optical system consists of a beam splitter, band-pass filter, and lens. The light that passes through the sample is split by the beam splitter, is passed through the band-pass filter to extract the light at a specific wavelength, and is incident to the photodiodes.

### Signal processing circuit

The low level photocurrent from the photodiodes is converted into voltage through the current-to-voltage conversion amplifier. Finally, the optics module outputs the resultant analog signal. The optics module offers high-speed signal processing with high accuracy and low noise.

[Figure 7-2] Block diagram example

### 7-3 New approaches

#### Dispersive optics modules for detecting specific wavelengths

We are considering to develop a dispersive optics module for detecting specific wavelengths. This module would use a grating to separate light into about 10 to 16 channels. The light separated by the grating would be detected by a photodiode array. The photodiode array would be optimized for detecting specific wavelengths, and it would include a color filter for eliminating unneeded light.
**Optics modules for detecting fluorescence**

We are thinking of developing an optics module for detecting fluorescence. This module would use LEDs for excitation light source. The optics module for detecting fluorescence would consist of an LED as an excitation light source, dichroic mirror for separating the fluorescence from excitation light, and band-pass filter for passing through specific range of wavelengths.

**Signal processing circuit diversification**

We are planning to incorporate A/D converter, microcontroller, and the like to expand the signal processing circuit options.

---

**8. Balanced detectors**

These are differential amplification type photoelectric conversion modules containing two photodiodes. The photodiodes are connected in a direction that cancels out the photocurrent of each photodiode. This configuration cancels out the common mode noise of the two incident light rays. The minute difference in light levels is treated as a displacement signal, converted into an electrical signal, and output. We offer a built-in InGaAs PIN photodiode type covering a spectral range of 0.9 to 1.7 μm.

**8 - 1 Features**

- Employs our unique structure that reduces multiple reflections at the incident light wavelength of 1.0 μm or 1.3 μm
- Cutoff frequency: 200 MHz
- Common-mode rejection ratio (CMRR): 35 dB typ.
- FC receptacle for the input section
  A single-mode fiber with an FC connector [APC (angled physical contact) polished] can be connected.
- SMA receptacle for the output section
- Small size

**8 - 2 Hamamatsu technologies**

The balanced detector contains two characteristically aligned Hamamatsu photodiodes and allows detection of the minute difference in light levels between two photodiodes. Moreover, it employs a structure that reduces multiple reflections of incident light, which reduces light interference that would be caused by such reflections. With customer order products, it is possible to reduce reflections at specific wavelengths.

[Figure 8-1] Block diagram
### Table 8-1 Specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>C12668-01</th>
<th>C12668-02</th>
</tr>
</thead>
<tbody>
<tr>
<td>Photosensor</td>
<td>InGaAs PIN photodiode</td>
<td></td>
</tr>
<tr>
<td>Detection wavelength</td>
<td>1.0 μm</td>
<td>1.3 μm</td>
</tr>
<tr>
<td>Spectral response range</td>
<td>0.9 to 1.7 μm</td>
<td></td>
</tr>
<tr>
<td>Frequency bandwidth</td>
<td>DC to 200 MHz</td>
<td></td>
</tr>
<tr>
<td>Common-mode rejection ratio</td>
<td>35 dB</td>
<td></td>
</tr>
<tr>
<td>Transimpedance gain</td>
<td>$3 \times 10^4$ V/A</td>
<td></td>
</tr>
<tr>
<td>Output impedance</td>
<td>50 Ω</td>
<td></td>
</tr>
<tr>
<td>Input section</td>
<td>FC receptacle (APC polished)</td>
<td></td>
</tr>
<tr>
<td>Output section</td>
<td>SMA receptacle</td>
<td></td>
</tr>
<tr>
<td>Supply voltage</td>
<td>±12 V (200 mA)</td>
<td></td>
</tr>
<tr>
<td>Dimensions</td>
<td>65 × 75 × 25 mm</td>
<td></td>
</tr>
</tbody>
</table>

### 8-3 How to use

For optical input, two single mode fibers with FC connectors (APC polished) are used to apply a reference light and a signal light. If the light level and phase of these two light rays are uniform, the output would be zero. If there is a difference in the light levels between the reference light and signal light, the difference becomes the displacement signal, and this signal is converted into an electric signal, and output from the SMA receptacle. Note that since the output impedance is 50 Ω, you will need to set the input impedance of the connected measuring device to 50 Ω.

![I/O of balanced detector](image)

### 8-4 New approaches

We plan to offer a high-speed type (cutoff frequency: 500 MHz). We are also considering a built-in Si photodiode type covering a spectral range of 300 to 1000 nm.

### 8-5 Applications

It is planned to be used in optical coherence tomography (OCT) in high accuracy measuring instruments, such as medical instruments and analytical instruments.
9. PSD signal processing circuits, PSD modules

These are easy-to-use circuits and modules specifically designed for Hamamatsu PSDs (position sensitive detectors). PSD signal processing circuits are “circuit board” types on which a PSD (sold separately) can be mounted. PSD modules contain a PSD.

9-1 PSD signal processing circuits

PSD signal processing circuits have a current-to-voltage converter that converts photocurrent from a PSD into voltage. The signal is then processed and output as an analog voltage (analog output type) or converted into digital data by an A/D converter and output (digital output type).

Structure (C3683-02)

The C3683-02 PSD signal processing circuit for DC signals is configured as shown in Figure 9-1. The current-to-voltage converter converts photocurrent from a PSD into voltage which is then processed by the signal processing circuit and is output as an analog voltage matching a corresponding position.

Usage (C3683-02)

The C3683-02 comes with a connector for wiring to the D-sub connector. Solder this wiring connector to a cable that connects to an oscilloscope (or voltmeter) and power supply (cable is not supplied).

9-2 PSD modules

PSD modules are position detection modules that integrate a PSD (or 4-segment Si photodiode) and current-to-voltage converter into a compact case. When used with a PSD module controller (sold separately), position signals are available from two connectors for analog output and digital output.

Structure

The C10443 series PSD modules use a Hamamatsu PSD (or 4-segment Si photodiode) and a current-to-voltage converter which are assembled together in a case.

Table 9-1 Hamamatsu PSD signal processing circuits

<table>
<thead>
<tr>
<th>Type no.</th>
<th>Applicable PSD</th>
<th>Compatible signal</th>
<th>Output</th>
<th>Conversion impedance (V/A)</th>
<th>Response speed</th>
<th>Supply voltage (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C3683-02</td>
<td>1D</td>
<td>DC</td>
<td>Analog</td>
<td>$1 \times 10^4$ $1 \times 10^5$ $1 \times 10^6$</td>
<td>16 kHz (cutoff frequency)</td>
<td>±15</td>
</tr>
<tr>
<td>C4674-01</td>
<td>2D</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C9068</td>
<td>1D</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C9069</td>
<td>2D</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>+12</td>
</tr>
</tbody>
</table>

Note: The output voltage (unit: V) values indicate the light spot position (unit: mm) from the center of the photosensitive area.
Usage (C10443-01/-02/-03/-04)

Connect the PSD module to the PSD module controller. Position signals from the controller are available from the two connectors for analog and digital outputs. When using the analog output, connect an oscilloscope or voltmeter to the analog output connector on the controller. The output voltage (unit: V) values indicate the light spot position (unit: mm) from the center of the photosensitive area. When using the digital output, connect a PC to the digital output connector on the controller by serial connection (RS-232C). Position information can be easily loaded into the PC by using the sample software that comes with the controller.

Table 9-2: Hamamatsu PSD modules

<table>
<thead>
<tr>
<th>Type no.</th>
<th>Photosensor</th>
<th>Photosensitive area (mm)</th>
<th>Compatible signal</th>
<th>Output</th>
<th>Cutoff frequency (kHz)</th>
<th>Supply voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>C10443-01</td>
<td>Two-dimensional PSD</td>
<td>4 × 4</td>
<td>AC, DC</td>
<td>Analog</td>
<td>16</td>
<td>External power supply (±5 to ±12 V)</td>
</tr>
<tr>
<td>C10443-02</td>
<td>9 × 9</td>
<td></td>
<td></td>
<td></td>
<td>160</td>
<td></td>
</tr>
<tr>
<td>C10443-03</td>
<td>12 × 12</td>
<td></td>
<td></td>
<td></td>
<td>160</td>
<td></td>
</tr>
<tr>
<td>C10443-04</td>
<td>4-segment photodiode</td>
<td>10 × 10</td>
<td></td>
<td></td>
<td>160</td>
<td></td>
</tr>
<tr>
<td>C10443-06</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: When PSD module is used with PSD module controller (sold separately).
- Output can be changed to digital output.
- Output can be set so that the output voltage (unit: V) value indicates the light spot position (unit: mm) from the center of the photosensitive area (excluding the C10443-06).

Figure 9-4: Example of sample software displayed on PC screen

Figure 9-5: Connection example (PSD module)

* Supplied with PSD module controller
## 10. Color sensor modules/evaluation circuit

### 10-1 Color sensor modules

#### For white balance detection of LCD backlight (RGB-LED type) (C9303 series)

In order to monitor color changes caused by TFT-LCD backlight's RGB-LED temperature characteristics and performance degradation, Hamamatsu provides the C9303 series color sensor modules that detect the white balance on the LCD backlight optical waveguide. Based on these detection results, feedback-controlling the light level of each LED for RGB stabilizes the color on the LCD backlight. The C9303 series comes in a small size that can easily be mounted on the side of the LCD backlight optical waveguide. The shape and RGB gain can be made to match customer specifications.

#### [Figure 10-1] Connection example (C9303 series)

The C9315 comes with an objective optical fiber. The internal RGB color sensor detects light reflected from an object illuminated with the white LED and outputs RGB digital data. This objective optical fiber can measure light in very small areas.

The C9315 connected to a PC is suitable for simple color management and detection of difference of colors with a relatively different spectral reflectance. The C9315 cannot be used to detect the absolute color.

Output from the C9315 is 12-bit digital data conforming to RS-232C. This data is loaded into the PC by using sample software that comes supplied with the C9315. The numerically converted RGB color information can also be transferred in real time directly into Microsoft® Excel® spreadsheet cells.

Note: Microsoft and Excel are either registered trademarks or trademarks of Microsoft Corporation in the United States and/or other countries.

#### [Figure 10-3] Connection example (C9315)

The C9315 comes with an objective optical fiber. The internal RGB color sensor detects light reflected from an object illuminated with the white LED and outputs RGB digital data. This objective optical fiber can measure light in very small areas.

The C9315 connected to a PC is suitable for simple color management and detection of difference of colors with a relatively different spectral reflectance. The C9315 cannot be used to detect the absolute color.

Output from the C9315 is 12-bit digital data conforming to RS-232C. This data is loaded into the PC by using sample software that comes supplied with the C9315. The numerically converted RGB color information can also be transferred in real time directly into Microsoft® Excel® spreadsheet cells.

Note: Microsoft and Excel are either registered trademarks or trademarks of Microsoft Corporation in the United States and/or other countries.

#### [Figure 10-4] Example of sample software displayed on PC screen (C9315)

#### [Figure 10-5] Monitoring color of opaque objects by comparing their color differences (application example of C9315)

Trying to faithfully convey an object color is difficult in cameras because the color changes due to the background light and sensitivity. However, the C9315 color sensor module makes this task simple by numerically converting the object color. The C9315 uses a method similar to the stimulus value direct-reading method for detection and allows simple management of the object color. This method is fully practical for applications that monitor color by relative comparison with the color difference of "opaque objects with a close spectral reflectance."
The C9331 is a circuit board designed for evaluating Hamamatsu color sensors (S7505-01, S9032-02). It has a current-to-voltage conversion amplifier that simultaneously converts each component of the RGB photocurrents to voltage and outputs it. Three trimmers are provided to adjust the photocurrent gains for individual RGB colors.

### Table 10-1: Hamamatsu color sensor modules and evaluation circuit

<table>
<thead>
<tr>
<th>Product name</th>
<th>Color sensor module</th>
<th>Color sensor evaluation circuit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type no.</td>
<td>C9303-03</td>
<td>C9303-04</td>
</tr>
<tr>
<td>Photo</td>
<td><img src="image1" alt="Standard type" /> <img src="image2" alt="High gain type" /></td>
<td><img src="image1" alt="Standard type" /> <img src="image2" alt="High gain type" /></td>
</tr>
<tr>
<td><strong>Features</strong></td>
<td>For RGB information measurement of object color</td>
<td>Has an internal white LED as the light source, converts the reflected light into RGB data, and outputs them to a PC</td>
</tr>
<tr>
<td>Internal light source</td>
<td>No</td>
<td>Yes (white LED)</td>
</tr>
<tr>
<td>Internal color sensor</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Conversion impedance</td>
<td>R: 91 kΩ G: 91 kΩ B: 100 kΩ</td>
<td>R: 680 kΩ G: 680 kΩ B: 680 kΩ</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>DC to 16 kHz (-3 dB)</td>
<td>DC to 2.4 kHz (-3 dB)</td>
</tr>
<tr>
<td>Applications</td>
<td>White balance detection of LCD backlight (RGB-LED type)</td>
<td>Object color measurement</td>
</tr>
<tr>
<td>Object color measurement</td>
<td>No (Light source and optical system are required.)</td>
<td>Yes</td>
</tr>
<tr>
<td>Light source color measurement</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Accessories</td>
<td>Dedicated cable with connector</td>
<td>Dedicated AC adapter</td>
</tr>
</tbody>
</table>
11. Image sensor application products

Driver circuits and multichannel detector heads compatible with our main image sensors are available to easily evaluate and test Hamamatsu image sensors. The driver circuit is a circuit board type and can be used to evaluate the image sensor at low cost. It can also be integrated into a device. The multichannel detector head is a product that houses a driver circuit in a heat dissipating case. The case can easily be connected to an optical system, and depending on the product, it includes a lens mount adapter. The driver circuit and multichannel detector head consist of the following components and are optimized for evaluating the characteristics of the image sensor.

- Power supply section
- Timing generator for driving the image sensor
- Video signal processing circuit
- A/D converter
- Controller
- Digital interface for various PCs

Using the supplied application software, you can connect with a PC, easily set various parameters, acquire and analyze data, and so on. You can evaluate the characteristics of the sensor quickly and efficiently. The driver circuit and multichannel detector head can be customized in shape, size, interface type, etc.

We have an extensive lineup of products supporting various types of image sensors (CCD linear/area image sensors, CMOS linear image sensors, and InGaAs linear/area image sensors). Moreover, these products support general-purpose interfaces such as USB, Camera Link, or Ethernet. The USB type can be connected to a USB port of a PC. The Camera Link type is used in applications that handle high-speed, large image data. It supports general-purpose Camera Link frame grabber boards made by frame grabber board manufacturers. The Ethernet type is designed for industrial and other high-speed applications where the controller PC is connected to remote devices through long cables.

<table>
<thead>
<tr>
<th>Type no.</th>
<th>Product name</th>
<th>Interface</th>
<th>Applicable image sensors</th>
</tr>
</thead>
<tbody>
<tr>
<td>C11287</td>
<td>Driver circuit for CCD area image sensor</td>
<td>USB</td>
<td>S10420-01 series</td>
</tr>
<tr>
<td>C11288</td>
<td></td>
<td></td>
<td>S11071 series</td>
</tr>
<tr>
<td>C11160</td>
<td>Driver circuit for CCD linear image sensor</td>
<td>USB</td>
<td>S11151-2048</td>
</tr>
<tr>
<td>C11165-01</td>
<td></td>
<td></td>
<td>S11155-2048-01, S11156-2048-01</td>
</tr>
<tr>
<td>C13015</td>
<td>Driver circuit for CMOS linear image sensor</td>
<td>USB</td>
<td>S11639</td>
</tr>
<tr>
<td>C10854</td>
<td>InGaAs multichannel detector head</td>
<td>Camera Link</td>
<td>G10768 series</td>
</tr>
<tr>
<td>C11512 series</td>
<td></td>
<td></td>
<td>G11097 series</td>
</tr>
<tr>
<td>C11513</td>
<td>Driver circuit for InGaAs area image sensor</td>
<td>USB</td>
<td>G11135-512D, G11477-256D</td>
</tr>
<tr>
<td>C11514</td>
<td></td>
<td>Camera Link</td>
<td>G11147-256D</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>G11135-32S/-64S</td>
</tr>
</tbody>
</table>

[Table 11-1] Hamamatsu image sensor application products
### 11 - 2 Structure

[Figure 11-3] Block diagram (typical example: C11287)

![Block diagram](image)

### 11 - 3 How to use

You can quickly start collecting data by simply installing the supplied application software and driver into your PC. Since the software also includes a function library (DLL), you can efficiently develop software applications in a development environment such as Microsoft® Visual C++®, Microsoft Visual Basic®, and LabVIEW®.

With the Camera Link type, you can develop original software applications by using a frame grabber board sold in the market, a Camera Link cable, the application software and DLL that comes with the frame grabber board.

Note: Microsoft, Visual C++, and Visual Basic are either registered trademarks or trademarks of Microsoft Corporation in the United States and/or other countries. LabVIEW is a registered trademark of National Instruments.

### 11 - 4 New approaches

We plan to introduce additional products that support new diversified, high-speed image sensors as well as develop original signal processing ASICs. Furthermore, we plan to quickly develop products supporting new PC interface and industrial interface standards.
12. Special-purpose modules

12 - 1 Flame eyes

The “flame eye” is a sensor that monitors flames in oil boilers and heating equipment. It detects light emitted from the flame so that the combustion state can be observed. This flame eye utilizes a photo IC diode instead of the conventional CdS cell. This flame eye ensures stable detection performance compared to types using a CdS cell. The flame eye is easy to install since the sensor is integrated into the cable assembly. Two types with different light input directions (head-on type and side-on type) are available.

Features

• Internal photo IC diode
  The internal photo IC diode boosts the photocurrent generated from the photodiode approx. 13000 times. The photo IC diode outputs current and can be used the same as a photodiode applied with a reverse voltage.
• Spectral response suitable for detecting oil burner flames
• Cable assembly for easy installation into equipment
• Small output current variations and good output linearity

Applications

• Oil boilers
• Heating equipment
• Safety devices for heaters
• Alarms

12 - 2 Sunlight sensors

Sunlight sensors detect the amount of sunshine and ambient light level. A photodiode with superb linearity relative to the incident light level is built in a small case with a connector. These sensors deliver high reliability and can be used as sunlight sensors for automotive air conditioners.

How to use

Unlike CdS cells, the photo IC diode has polarity (anode and cathode), so always be sure to use it with a positive voltage applied to the cathode.

A load resistance ($R_L$) must also be set according to the latter-stage circuit. If high-frequency components must be eliminated, we recommend that a low-pass filter load capacitor ($C_L$) be inserted in parallel with the load resistance. The cutoff frequency ($f_c$) obtained from inserting the low-pass filter load capacitor is expressed by equation (1).

$$f_c \approx \frac{1}{2\pi C_L R_L} \quad \ldots \ldots \ldots (1)$$
Features

• High reliability (for automotive use)
• Optical design of cover allows adjusting the directivity to meet application requirements.
• Photosensor (visible light sensor, near infrared light sensor) is selectable according to application.
• Cover shape suitable for dashboard installation

Applications

• Sunlight sensors
  Sunlight sensors detect the amount of sunshine to control the temperature and the volume of air flow for automotive air conditioners.
• Auto light sensors
  Auto light sensors detect the ambient light level to automatically turn on the vehicle headlights in tunnels and the like.
• Head-up display brightness adjusting sensors
  Sunlight sensors detect the ambient brightness to automatically adjust the brightness on the head-up display.
• Simple sunlight measurements

12-3 Driver circuit for Si photodiode array

Here we introduce a driver circuit for our 16-element Si photodiode array. The combination of these allows high-accuracy, high-speed measurements by simultaneously reading out each signal of the 16 elements. The driver circuit provides a voltage output which makes signal processing easy.

The driver board has solder through-holes that allow direct mounting of the 16-element Si photodiode array. By adding a commercially available sub-board, this driver circuit can also be used to evaluate Hamamatsu 16-element InGaAs PIN photodiode array.

[Figure 12-4] Driver circuit for Si photodiode array (C9004)

Features

• Simultaneous measurement of 16 elements and serial output
  Simultaneous readout of 16-element signals allows high-accuracy, high-speed measurements.
• Internal pulse generator
  Oscillating frequency is selectable in eight steps with a switch.
• Gain: settable in two steps
  (1 × 10^6 V/A, 1 × 10^7 V/A)
• Noise: 5 mVp-p (1 × 10^6 V/A)
• Board size: 70 × 95 mm

How to use

Mount the Hamamatsu 16-element Si photodiode array directly on the board. Power is supplied from an AC adapter (comes with the product).

[Figure 12-5] Connection example

Applications

• Color measurement (print, paper, fire, ink, liquid, etc.)
• Film thickness measurement (SiO2 film, photoresist film, film, oil film, etc.)
• Emission measurement (plasma monitor, sunlight, quality control for light source and optical fiber)
• Non-destructive measurement (fruit, grain, soil, plastic, blood, oil, etc.)
• Density measurement (chemicals, plating liquid, etching liquid, etc.)
• Simple position measurement