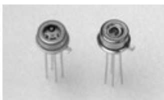
CHAPTER 07

Optical communication detectors

Optical communication detectors

The rapid spread of the Internet and drastic increase in the number of FTTH (fiber to the home) subscribers have led to the flow of vast quantities of data such as video contents over communication networks. If next generation networks (NGN) come into general use in the future, there is no doubt that this trend will accelerate and that the communication networks will require even greater capacity.
HAMAMATSU provides a wide range of detectors to meet various kinds of optical communication applications including 10 Gbps transmission. HAMAMATSU is also taking the concept "even higher speed and higher sensitivity" as its theme to develop next generation devices.

HAMAMATSU optical communication detectors

Wavelength	Product name	Transmission bandwidth (frequency)	Package style			
			Metal	Receptacle	Pigtail	ROSA
0.85 µm	GaAs PIN photodiode with preamp	10 Gbps	—	—	—	
1.3/1.55 µm	InGaAs PIN photodiode	(2 GHz)	—			—
	InGaAs PIN photodiode with preamp	1.25 Gbps				—
		2.5 Gbps				—
		10 Gbps	—	—	—	
	InGaAs APD with preamp	2.5 Gbps	—	—	—	
		10 Gbps	—	—	—	Under development

Note: The following optical communication devices are also available.
- Photodiodes for optical power and wavelength monitor
  InGaAs PIN photodiodes (metal type, bare chip type, sub-mount type)
  InGaAs PIN photodiode arrays, InGaAs linear image sensors
- Photodiodes/infrared LED/photo IC for optical link
- Photodiodes/infrared LED for FSO (free space optics), light emitting/receiving module for VICS (Vehicle Information and Communication System) on vehicle

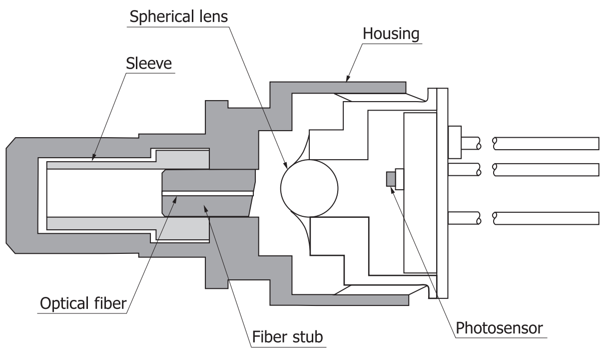
1. 10 Gbps PIN ROSA

Here we introduce a 10 Gbps PIN ROSA (receiver optical sub-assembly) designed to meet the recent demand for high-speed, miniaturized optical communication modules.

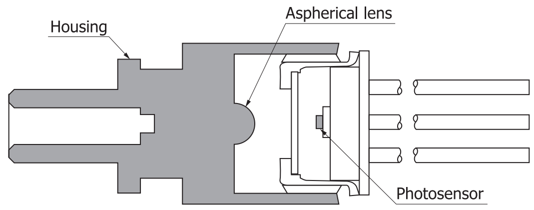
1 - 1 Structure

ROSA has a housing with a mating part for an optical fiber connector, and a TO-CAN type metal-package photosensor is fitted into the housing. Housings are available in metal and plastic types. The metal type shown in Figure 1-1 has an internal anti-reflection structure that suppresses the optical return loss. The plastic type shown in Figure 1-2 has a molded structure formed with an aspherical lens. Though low in cost, it has large optical return loss and so is used for short-distance communications.

[Figure 1-1] Inner view of metal type ROSA



[Figure 1-2] Inner view of plastic type ROSA



1 - 2 Features

Here we describe standards for SONET/SDH (synchronous optical network/synchronous digital hierarchy), Ethernet, and SFP+ (8.5/10 Gbps small form factor pluggable module), as well as products made to meet those standards.

SONET/SDH

SONET/SDH is mainly utilized in trunk lines using long-wavelength single-mode fibers. SONET/SDH standards are grouped as shown in Table 1-2.

Since SONET/SDH requires high transimpedance gain, high sensitivity, and low optical return loss, a metal type ROSA having an anti-reflection structure is used.

Transmissions over long distances greater than 80 km require even higher sensitivity, so APDs should be used instead of PIN photodiodes. In applications using APDs, EDFA (erbium doped fiber amplifiers) are frequently used as the optical amplifiers in the transmission path to ensure long-distance transmissions. However, using the EDFA causes ASE (amplified spontaneous emission) noise to be mixed with the signal light incident on the APD. Therefore, in APD-ROSA, the code error rate characteristics usually become a critical specification when there has been a change in the OSNR (optical signal-to-noise ratio).

[Table 1-1] 10 Gbps PIN ROSA standard comparison tables

(a) 10 Gbps Ethernet (IEEE 802.3)

Communication standard		LRM	SR	LR	ER
Transmission distance		220 m	< 300 m	10 km	40 km
Wavelength		1.3 µm	0.85 µm	1.3 µm	1.55 µm
Optical transceiver standard	XFP	Consult us for more information.	Available	Available	Available
	XPAK		Available	Available	Consult us for more information.
	X2		Available	Available	
	XENPAK				

(b) SONET/OC-192

Communication standard		VSR	SR-1	IR-2	LR-2
Transmission distance		600 m	10 km	40 km	80 km
Wavelength		1.3 µm	1.3 µm	1.55 µm	1.55 µm
Optical transceiver standard	XFP	Available			Under development
	300 pins	Consult us for more information.			

Ethernet

Ethernet standards are grouped according to optical fiber and transmission distance as shown in Table 1-3.
OMA (optical modulation amplitude) is a measurement parameter for determining optical transmitter characteristics. OMA is expressed by equation (1).

$$OMA = 2 \times Pave \times (1 - ER) / (1 + ER) \quad \cdots\cdots (1)$$

Pave: average power
ER : extinction ratio

When using long-wavelength single-mode fibers for long-distance transmission, low optical return loss is required so a metal type ROSA is employed the same as for SONET/SDH. A plastic type ROSA can be used if optical return loss is not a critical factor.
Next, we describe ROSA for Ethernet using multimode fibers. Multimode fibers usually have a large core diameter which requires using high-speed, large-area photodiodes. HAMAMATSU has newly developed photodiodes with an active area of ϕ60 µm and uses them in ROSA. For short-distance transmissions within 100 m, the 850 nm short-wavelength band is used. When using multimode fibers at distances longer than 100 m, long wavelengths are used and the mode dispersion that occurs along these fibers must be compensated for. LRM (Long-wavelength R-code Multimode fibers) are a standard for multimode fiber transmissions using long wavelengths (1310 nm), where an EDC (electronic dispersion compensation) technique is used to compensate for the mode dispersion. The ROSA output must be linear in order to accurately compensate for the mode dispersion in the latter-stage circuit of ROSA. ROSA for LRM must evaluate CSRS (comprehensive stressed receiver sensitivity) for input waveforms as established in three types of standards called Precursor, Postcursor, and Symmetric.

SFP+

SFP+ is a transceiver with an extremely small size and usually uses the ROSA output as the transceiver output. This means that ROSA must have a large output amplitude (differential of 180 mV to 600 mV) and withstand high ESD or electrostatic discharges (1 kV at output signal terminal and 2 kV at other terminals). ROSA made by HAMAMATSU satisfies SFP+ standards for the output amplitude as well as for ESD robustness at terminals other than the cathode (Vpd) of the photodiode. Standards for the Vpd terminal can be satisfied by adding a decoupling capacitor of 0.022 µF or more on the board.

[Table 1-2] SONET/SDH standards (data rate: 9.95328 Gbps)

Communication standard	Wavelength (nm)	Dispersion compensation method	Maximum transmission distance (km)	Overload (dBm)	Minimum sensitivity (dBm)	Maximum optical return loss (dB)	Minimum allowable extinction ratio (dB)
SR-1	1310	-	7	-1	-11	-14	6
SR-2	1550	-	25	-1	-14	-27	8.2
IR-1	1310	-	20	-1	-11	-14	6
IR-2	1550	-	40	-1	-14	-27	8.2
IR-3	1550	-	40	-1	-13	-27	8.2
LR-1	1310	-	40	-9	-20	-27	6
LR-2	1550	PCH	80	-7	-24	-27	9
LR-2a	1550	PDC	80	-9	-26	-27	10
LR-2b	1550	SPM	80	-3	-14	-27	8.2
LR-2c	1550	PCH	80	-9	-26	-27	10
LR-3	1550	-	80	-3	-13	-27	8.2
VR-2a	1550	PDC	120	-9	-25	-27	10
VR-2b	1550	PDC & SPM	120	-7	-23	-27	8.2
VR-3	1550	-	120	-9	-24	-27	8.2

[Table 1-3] Ethernet standards (data rate: 10.3125 Gbps)

Communication standard	Fiber	Wavelength (nm)	Transmission distance	Overload (dBm)	Minimum sensitivity (dBm)	Minimum sensitivity OMA (dBm)	Stressed minimum sensitivity OMA (dBm)	Maximum optical return loss (dB)	Minimum allowable extinction ratio (dB)
SR	MMF	850	2 m to 82 m	-1	-9.9	-11.1	-7.5	-12	3
LR	SMF	1310	2 m to 10 km	0.5	-14.4	-12.6	-10.3	-12	3.5
ER	SMF	1550	2 m to 40 km	-1	-15.8	-14.1	-11.3	-26	3

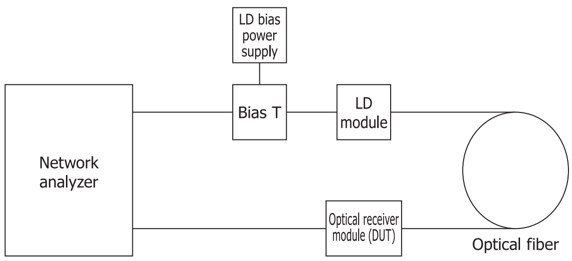
Communication standard	Fiber	Wavelength (nm)	Transmission distance	Overload OMA (dBm)	Stressed minimum sensitivity OMA (dBm)	Stressed minimum sensitivity OMA, symmetrical (dBm)	Maximum optical return loss (dB)	Minimum allowable extinction ratio (dB)
LRM	MMF	1310	0.5 m to 220 m	1.5	-6.5	-6	-12	3.5

1 - 3 Characteristics

Frequency characteristics

Figure 1-3 shows a setup for measuring frequency characteristics of an optical receiver module. The laser diode (LD) should have a sufficiently wide bandwidth compared to the optical receiver module (DUT: device under test), or the measurement system should be calibrated using an LD whose frequency characteristics are already known, so that effects from the measurement system's frequency characteristics can be ignored.

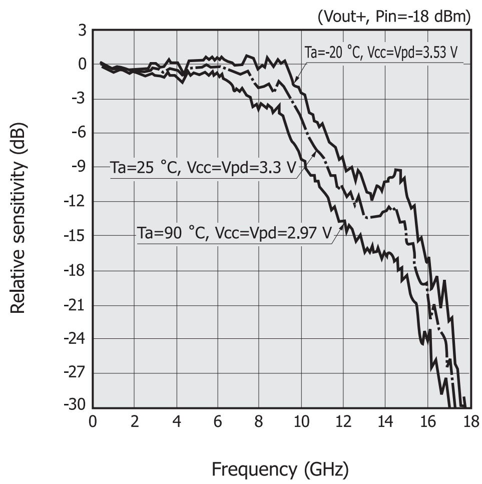
[Figure 1-3] Setup for frequency characteristic measurement (optical receiver module)



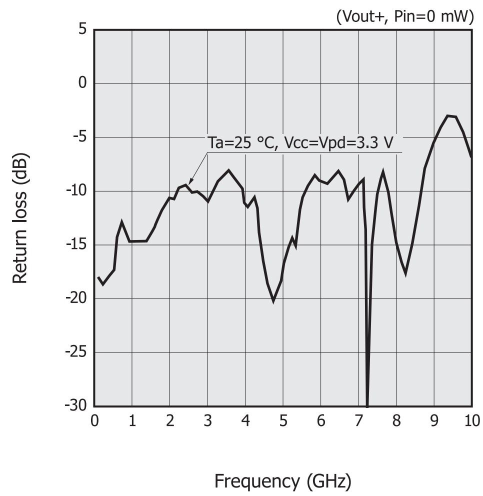
Optical receiver modules used for digital optical communications usually contain an internal AGC (automatic gain control) function or a limiting amplifier to obtain a wide dynamic range. In frequency measurement, if an AGC amplifier is used, the LD output is adjusted to a light level that turns off the AGC function, and if a limiting amplifier is used, the LD output is adjusted to a light level that is within the linear range. Figure 1-4 shows typical examples of frequency characteristics and their temperature characteristics of a metal type 10 Gbps PIN ROSA. Figure 1-4 (a) shows the transmission characteristics, and the cut-off frequency (fc) is defined as the frequency at which the electrical signal drops by 3 dB from the value at low frequencies. Figure 1-4 (b) shows electrical reflection characteristic at the output end. The reflection must be minimal within the required bandwidth. Figure 1-4 (c) shows group delay characteristic that must be kept at a constant value as much as possible within the required bandwidth.

[Figure 1-4] Frequency characteristics (10 Gbps PIN ROSA, typical example)

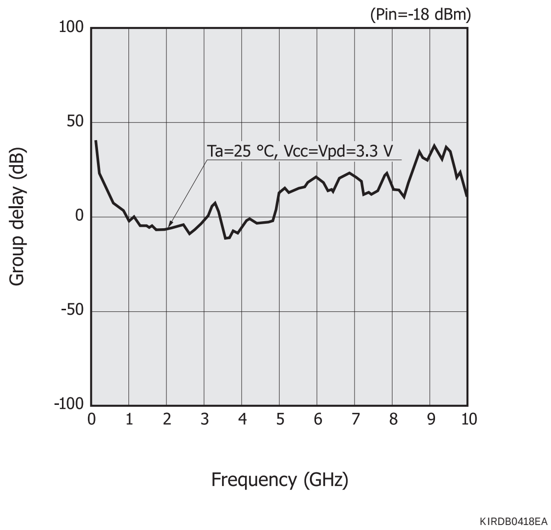
(a) Transmission characteristics



(b) Reflection characteristic



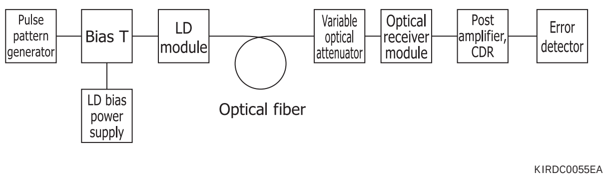
(c) Group delay characteristic



Bit error rate

Figure 1-5 shows a setup for measuring the bit error rate. A pulse pattern generator outputs a pseudo-random pattern that directly modulates the LD intensity. The power level of this modulated light is changed by a variable optical attenuator and is input to the optical receiver module. The output from the optical receiver module is input to the error detector via the post amplifier and CDR (clock data recovery), and then the bit error rate is measured by comparing the received pattern with the pattern driving the LD.

[Figure 1-5] Setup for measuring bit error rate



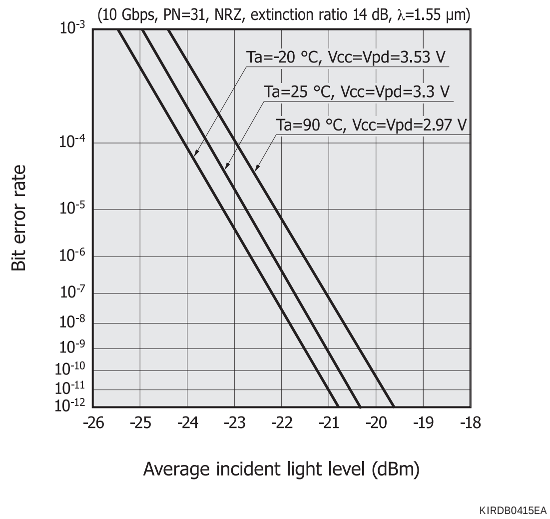
The minimum light input power required for maintaining a specified bit error rate is called the minimum sensitivity. The maximum light input power is called the overload.

On the Ethernet, the minimum sensitivity must be evaluated while the eye pattern is degraded, by applying a specified load to the transmission signal. The minimum sensitivity under this condition is called the stressed minimum sensitivity. The load is expressed by VECP (vertical eye closure penalty) and jitter.

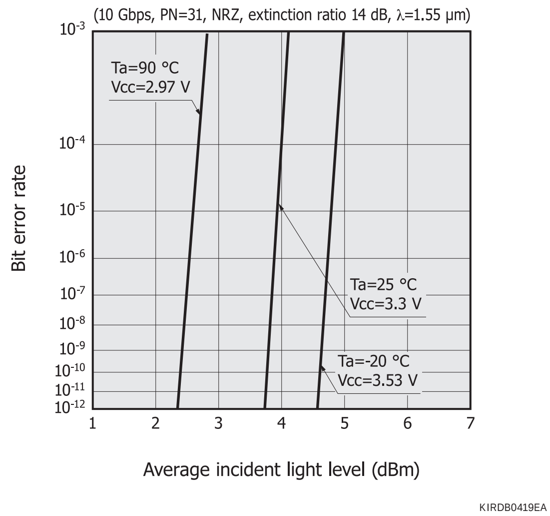
Figure 1-6 shows typical examples of bit error rate in a metal type 10 Gbps PIN ROSA.

[Figure 1-6] Bit error rate (metal type 10 Gbps PIN ROSA, typical examples)

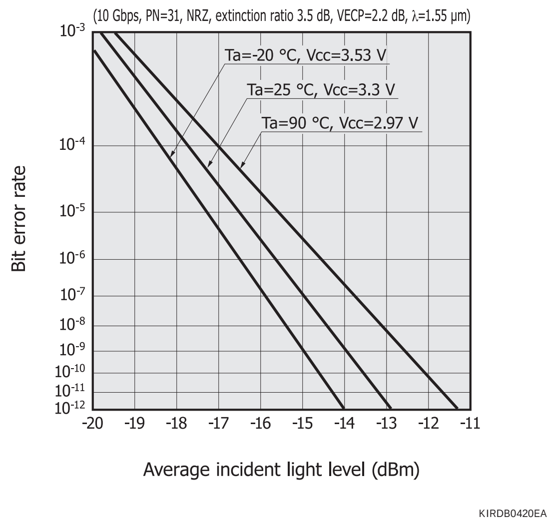
(a) Minimum sensitivity



(b) Overload



(c) Stressed minimum sensitivity



1-4 Precautions

Precautions during handling

Opto-semiconductors are easily damaged or destroyed by static charges, surges from power supplies and test equipment, and leakage current from soldering irons, etc. So the following precautions must be taken when handling these devices. High-speed devices such as 10 Gbps PIN ROSA are especially vulnerable to ESD, and except for ROSA for SFP+, have a low ESD robustness of ±200 V.

· Wear a grounding wrist strap during soldering, assembly, and measurement, etc., and if necessary use an ionizer to suppress generation of static electricity.

· Make sure that the device, workbench, jigs, and measuring instruments are all at the same voltage potential.

· Be careful about possible surges from the power supply when turning it on, and apply voltages in the order of Vpd and then Vcc (order in which voltage is applied may vary according to the product).

· Dirt or scratches on the fiber end faces for the optical module make it difficult for signal light to enter the photodiode and cause an apparent drop in sensitivity. Check carefully for dirt or scratches on the fiber end faces and clean them if dirt is found.

Precautions during mounting

Take the following precautions during mounting in order to extract full performance from the high-speed device. Figure 1-7

[Table 1-4] Electrical and optical characteristic examples

(a) For single-mode fibers

Parameter	Symbol	Metal type				Plastic type				Unit
		Condition	Min.	Typ.	Max.	Condition	Min.	Typ.	Max.	
Photo sensitivity	R	λ=1.31 µm	-	0.85	-	λ=1.31 µm	0.7	0.8	-	A/W
		λ=1.55 µm	-	0.9	-					
Supply current	Icc	Dark state, R_L=∞	-	32	45	Dark state, R_L=∞	-	32	45	mA
Cut-off frequency	fc	λ=1.55 µm, -3 dB	7	9	-	λ=1.31 µm, -3 dB	7	9	-	GHz
Low cut-off frequency	fc-L	λ=1.55 µm, -3 dB	-	10	50	λ=1.31 µm, -3 dB	-	10	50	kHz
Transimpedance*	Tz	R_L=50 Ω, f=100 MHz	4	6	-	R_L=50 Ω, f=100 MHz	4	6	-	kΩ
Minimum sensitivity (average)	Pmin	λ=1.55 µm, PRBS=2^{31}-1 BER=10^{-12} Extinction ratio=14 dB	-	-20.5	-	λ=1.31 µm, PRBS=2^{31}-1 BER=10^{-12} Extinction ratio=14 dB	-	-20	-17.5	dBm
Overload (average)	Pmax		1	3.5	-		1.5	3.5	-	
Output amplitude	Vomax	Differential	300	450	650	Differential	300	450	650	mVp-p
Optical return loss	ORL	λ=1.31/1.55 µm	27	35	-	λ=1.31 µm	12	14	-	dB

(b) For multimode fibers

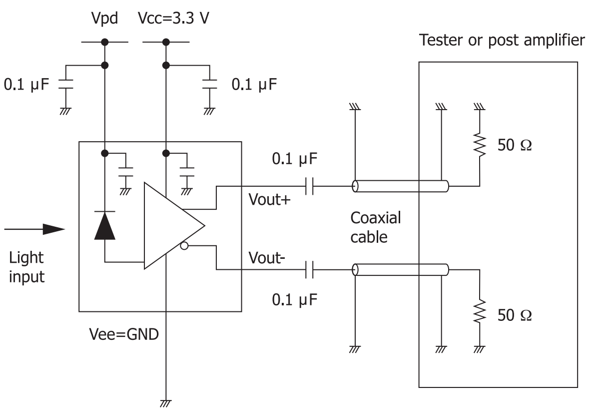
Parameter	Symbol	For short wavelength					For LRM				Unit
		Condition		Min.	Typ.	Max.	Condition	Min.	Typ.	Max.	
Photo sensitivity	R	λ=0.85 µm		0.4	0.55	-	λ=1.31 µm	0.68	0.8	-	A/W
Supply current	Icc	Dark state, R_L=∞		-	32	45	Dark state, R_L=∞	-	60	-	mA
Cut-off frequency	fc	-3 dB		6	8	12.3	-3 dB, fref=1 GHz Pin=-6.5 dBm (average)	-	10	-	GHz
Low cut-off frequency	fc-L	-3 dB		-	10	50	-3 dB	-	30	-	kHz
Transimpedance*	Tz	R_L=50 Ω, f=100 MHz		4	6	-	R_L=50 Ω, f=1 GHz Pin=-18 dBm (average)	0.6	1	-	kΩ
Minimum sensitivity (OMA)	Pmin	PN=31 BER=10^{-12}	ER=3 dB	-	-14	-12	λ=1.31 µm 10.3125 Gbps NRZ, PN=31, BER=10^{-12} ER=3.5 dB	-	-13	-	dBm
Overload (OMA)	Pmax		ER=7 dB	0.5	2	-		-	1.5	-	
SRS	SRS	PN=31, BER=10^{-12} ER=3 dB, λ=0.85 µm VECP=3.5 dB		-	-12	-					dBm
Output amplitude	Vomax	Differential		300	450	650	Differential Pin=-6.5 dBm (OMA)	180	270	-	mVp-p
Optical return loss	ORL	λ=0.85 µm		12	14	-	λ=1.31 µm	12	14	-	dB

* Single-ended (Vout+) measurement

shows a measurement circuit example for an optical receiver module.

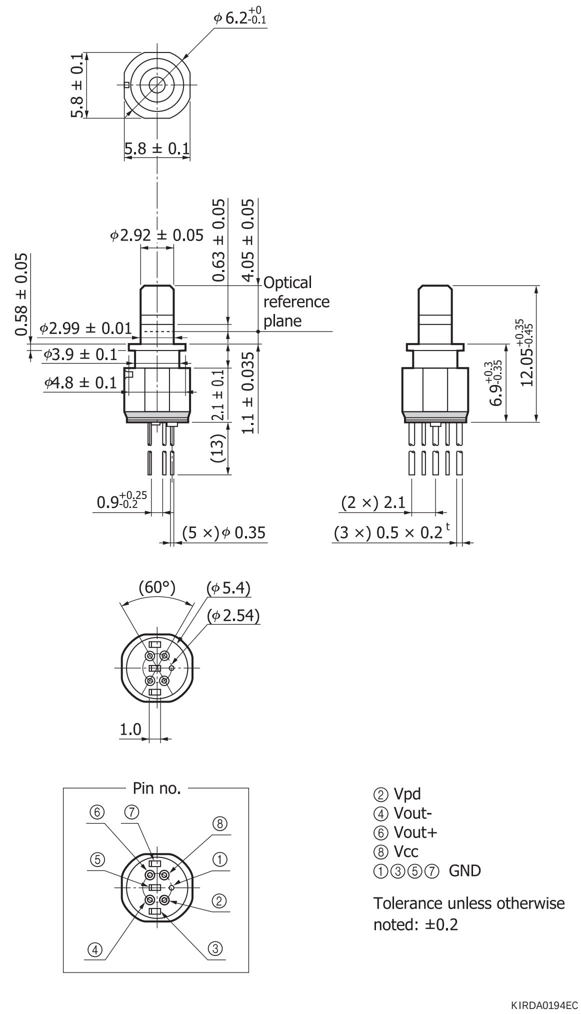
· During the mounting, keep the wire leads as short as possible and solder them to the board.
· Connect a capacitor with good frequency characteristics as a bypass capacitor between Vcc/Vpd and ground, in the shortest possible distance.
· Modules for 10 Gbps handle signals at high speeds so the ground connections are critical. On the 10 Gbps PIN ROSA G10342 series, ground terminals are added on both sides of the Vout+ and Vout- [Figure 1-8]. So soldering these terminals to ground will not only effectively ground but will also form an optimal coplanar line for extracting high-frequency signals.
· The lead sections may sometimes break or weaken due to mechanical stress, so use care during mounting. HAMAMATSU provides a ROSA with a flexible board that reduces the mechanical stress applied to the lead section when connected to the circuit board [Figure 1-8 (b)].
· Caution is also needed with boards where 10 Gbps modules are mounted. Figure 1-9 shows an evaluation board example. One side is used for the signal lines and ground pattern, and the reverse side serves as a ground pattern. The ground patterns on both sides are connected by through-holes. The signal line pattern is a coplanar line or microstrip line whose impedance matches that of the latter-stage circuit.

[Figure 1-7] Measurement circuit example for optical receiver module

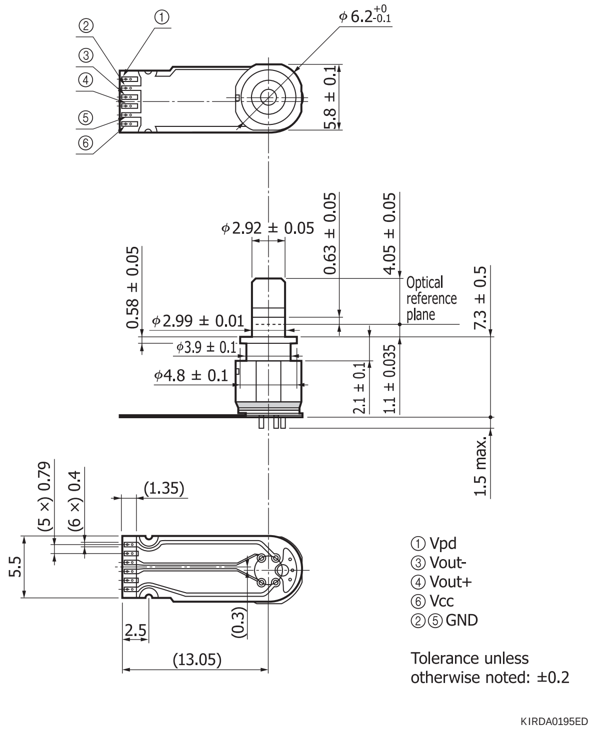


[Figure 1-8] Dimensional outlines (unit: mm)

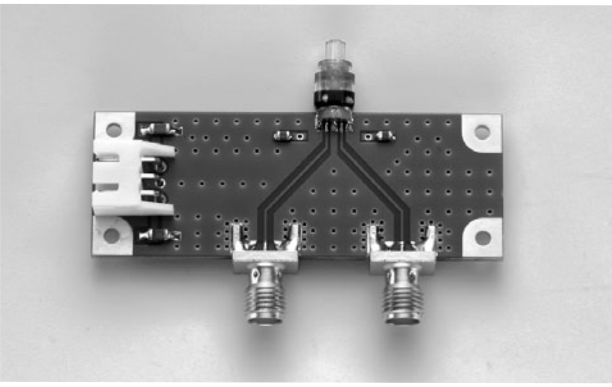
(a) G10342-51: metal type



(b) G10342-54: metal type (with flexible board)



[Figure 1-9] Evaluation board for 10 Gbps PIN ROSA

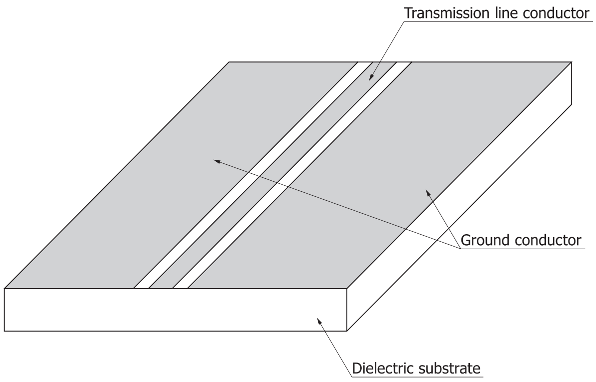


Note: If a module requires capacitive coupling to a load resistor, then switch the measuring instrument to AC coupling, or insert a coupling capacitor between the measuring instrument and the evaluation board.

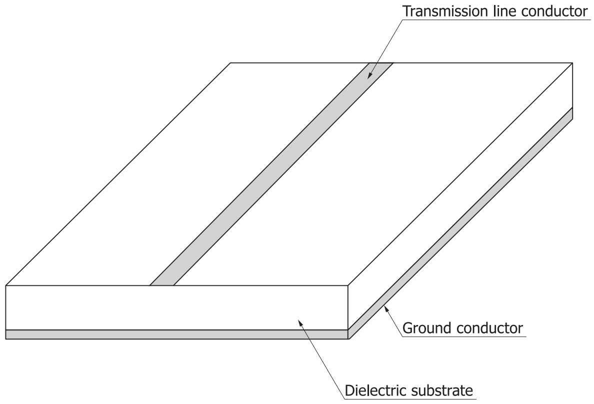
As shown in Figure 1-10, a coplanar line has a structure containing a transmission line conductor and a ground conductor in the same plane on one side of the dielectric substrate. The characteristic impedance is determined by: the dielectric constant of the substrate, the width of the transmission line conductor, and the gap between the transmission line conductor and ground conductor.

A microstrip line as shown in Figure 1-11 has a structure containing a transmission line conductor on one side of the dielectric substrate, and a ground conductor on the backside of that substrate. The characteristic impedance is determined by the dielectric constant and thickness of the substrate, and by the width of the transmission line conductor.

[Figure 1-10] Coplanar line



[Figure 1-11] Microstrip line



Precautions when soldering (ROSA with flexible board)

(1) Pre-drying

The polyimide used in the flexible board absorbs moisture very easily, and will reach a moisture-saturated state in approx. 4 hours. Soldering the board by reflow soldering or wave soldering while in this state will make the flexible board tend to expand due to the rapid change in temperature. This absorbed moisture must be removed prior to soldering, so the components must undergo a pre-drying process before mounting them. A pre-drying condition is maintaining a temperature of 120 °C for at least 2 hours and preferably soldering the board on that same day. If soldering on the following day or later, then please store along with silica gel in a moisture-proof bag. Using the bag and silica gel may extend the waiting time for about a 1 month period (this period varies according to the type of moisture-proof bag, etc.).

(2) Soldering

When soldering, use a soldering iron that is 4.5 W or less. The temperature of the solder iron tip should be 350 °C or less, and the soldering should be performed within 3 seconds. If the soldering iron tip is too hot or the soldering time is too long, then the wiring pattern might peel away from the board or the flexible board might swell up.

Bending the board excessively while heat is applied or applying too much pressure from the solder iron tip might cause the solder lands to separate from the board so use caution.

1 - 5 New approaches

Optical communications will continue to achieve higher speeds in the future. Standardization planning has already started for Ethernet to follow up on the current 10 Gbps version to include 40 Gbps Ethernet for data center applications and 100 Gbps Ethernet for metropolitan area networks. However, sending data serially at 100 Gbps is currently extremely difficult because of the technical level of photodiodes and transimpedance amplifiers, etc., so wavelength division multiplexing methods are under study.

100 Gbps transmission methods for single-mode fibers (10 km, 40 km)

Methods under study for making 10 km and 40 km transmissions over single-mode fibers are wavelength division multiplexing of "25 Gbps × 4 ch."

The 1310 nm wavelength band is being considered since there is little dispersion in this wavelength band. Externally or directly modulated laser light is wavelength-multiplexed by a wavelength division multiplexing filter and is transmitted along a single-mode fiber.

In the 40 km version, using an optical amplifier such as a SOA (semiconductor optical amplifier) on the receiving (or transmitting) side is under study to boost the power of the light being received.

40 Gbps and 100 Gbps transmission methods for multimode fibers (100 m)

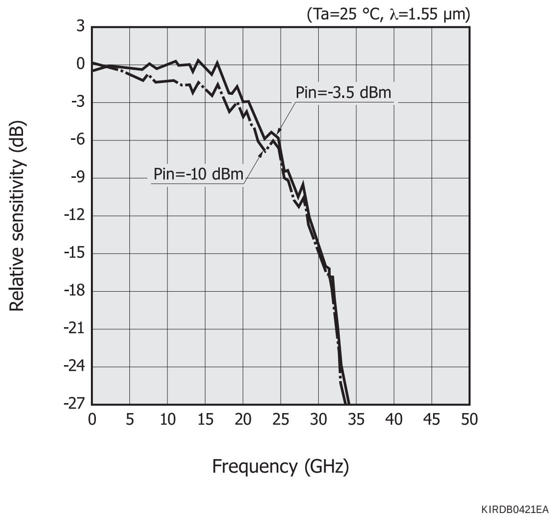
For 40 Gbps and 100 Gbps transmissions via multimode fibers, a 4- or 10-channel parallel transmission method using parallel fibers are being studied. This method performs parallel transmission at a rate of 10 Gbps per channel in order to achieve a data rate of 40 Gbps on 4 channels and 100 Gbps on 10 channels. Multichannel parallel transmission at 10 Gbps has the drawback that transmission distances are very short due to use of multimode fibers. However, devices for this transmission method can be made from already available technology.

The transmission method of "25 Gbps × 4 ch" not only uses devices operating at higher speeds than before, but also requires using wavelength division multiplexing technology.

HAMAMATSU is developing photodiodes and modules that can handle these high speeds. Photodiode structures and other factors were reviewed to develop products usable at 25 Gbps. Regarding the modules, we have developed packages that deliver both internal wiring capable of handling higher frequencies and optimal impedance, and will manufacture 25 Gbps PIN ROSA products. Figures 1-12 and 1-13 show frequency characteristics and eye diagrams of a prototype 25 Gbps PIN ROSA product.

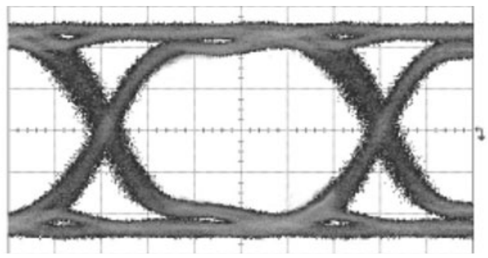
We are also studying optical splitting methods and arrays to make multichannel devices for wavelength division multiplexing. This work is aimed at developing 100 Gbps modules with optical splitting functions.

[Figure 1-12] Frequency characteristics (25 Gbps PIN ROSA, typical example)

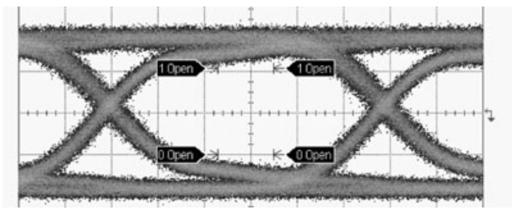


[Figure 1-13] Eye diagrams (25 Gbps PIN ROSA)

(a) Pin=+3 dBm



(b) Pin=-10 dBm



Bit rate 10 Gbps, NRZ, PN=31, λ=1.55 μm
Extinction ratio 14 dB

2. Photodiodes for monitoring optical power and wavelength

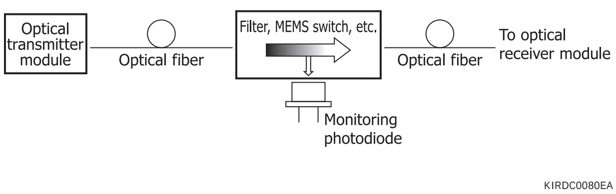
In optical fiber communications, photodiodes for monitoring optical power and wavelength are used to perform various tasks. At HAMAMATSU we provide a wide product lineup that allows customers to select a device that matches their application.

2 - 1 Metal type

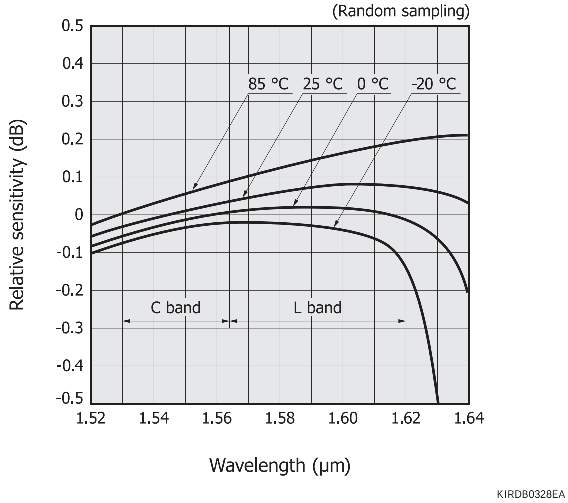
[Figure 2-1] Subminiature metal type

This type contains an InGaAs PIN photodiode in a hermetically sealed metal package, and is mainly used for monitoring optical power on transmission lines in optical networks. When measuring the optical power of light passing through a fiber, those methods that detect light from the ends of the fiber cannot constantly monitor light. This therefore requires placing a filter and MEMS switch, etc. between the fibers and also using a module to detect just a small portion of the passing light. Along with high reliability, the photodiodes that do the monitoring in such a module must be small in size and also be inexpensive. Our metal type InGaAs PIN photodiodes for monitoring meet these requirements and also have sensitivity with stable temperature characteristics and low wavelength dependence over a wide spectral range.

[Figure 2-2] Optical power monitor on optical network transmission line

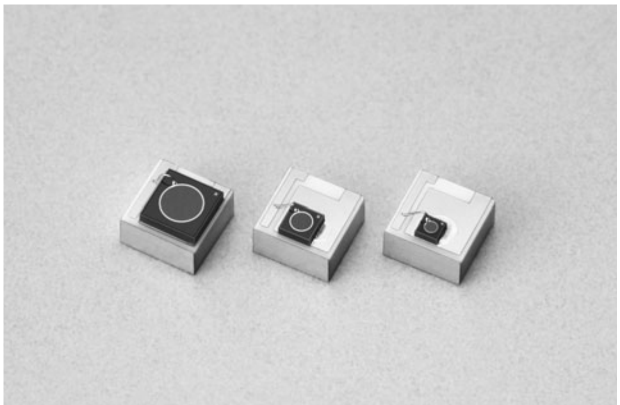


[Figure 2-3] Spectral response (InGaAs PIN photodiode for C/L band)



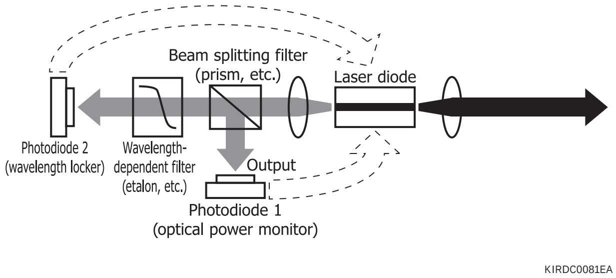
2 - 2 Bare chip type and sub-mount type

[Figure 2-4] Sub-mount type



These monitoring photodiodes do not come sealed within a package. These are bare chip or sub-mount type photodiodes and are mostly built into laser modules for monitoring the optical power or for wavelength locker. In tunable laser modules, the current vs. optical power characteristics and output wavelength tend to fluctuate due to effects from heat and other factors when the laser diode chip emits light. To ensure stable optical power and wavelength output, these monitoring photodiodes measure the optical power and wavelength and then feedback this data to the laser diode.
Figure 2-5 shows a configuration example of a tunable laser module with a built-in beam splitting filter and wavelength-dependent filter, etc. in a single package.

[Figure 2-5] Configuration example of a tunable laser module



Since bare chip and sub-mount photodiodes are not sealed in a package, they are suitable for use in designing miniature modules for short optical paths.
To allow mounting as close to the filter and optical waveguide as possible, HAMAMATSU also offers back-illuminated photodiodes having no wiring on the chip upper surface. These help design even smaller modules.

Precautions when handling bare chip type

Handling bare chip type products requires taking special precautions to avoid damaging or contaminating the device.
Keeping the following precautions in mind will help prevent trouble.

(1) Preventing contamination

Ionic substances that adhere to the bare chip surface will cause a change in electrical characteristics of the device. If fingerprints or saliva adhere, then they will cause characteristics to deteriorate. Wear dust-proof gloves and dust-proof masks when handling the device. During soldering, do not let flying flux particles or vapor come in contact with the device. If condensation forms, the adhered substances might be ionized, so use caution not to allow condensation to form on the device.
If contaminants such as dust adhere to the device, then remove them by blowing air. Do not attempt to wipe or wash the device.

(2) Preventing damage

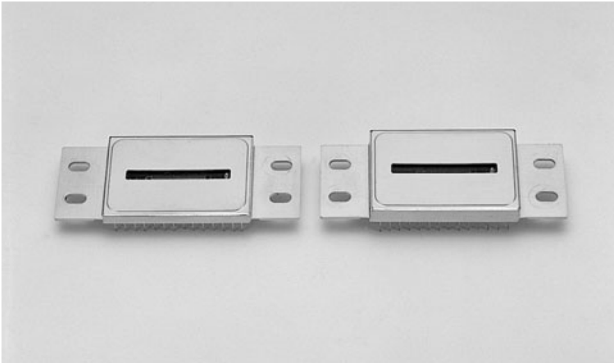
Bare chips are fragile and easily fracture. Physical damage will degrade electrical characteristics of the device. Do not let hard or pointed objects come in contact with the bare chip. Any dropped devices should be treated as defective devices and discarded.

(3) Storage and usage environment

· Store in an inert gas atmosphere to avoid condensation.
· Avoid directly stacking bare chip products on each other.
· Maintain an empty space around the bare chip surface and also around the wiring. Never allow anything to come in contact with these locations.
· Avoid storing in containers that are easily electrostatically charged.

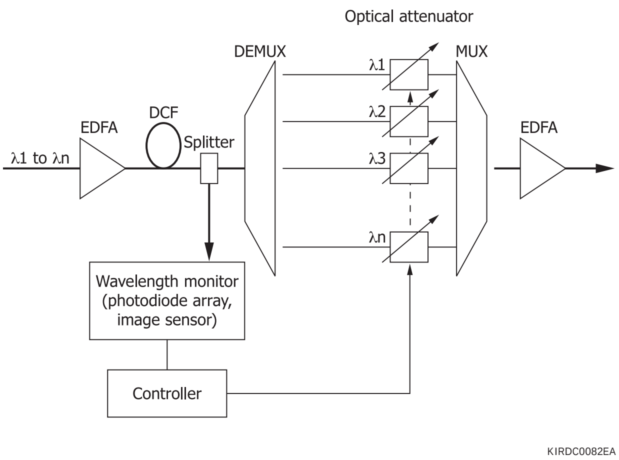
2 - 3 Photodiode arrays and image sensors

[Figure 2-6] InGaAs linear image sensors



These InGaAs PIN photodiode arrays and InGaAs linear image sensors are used mainly in DWDM transmission for monitoring optical power and wavelengths.
In DWDM transmission, the interval between wavelength signals is narrow, so the optical power and wavelength stability at each wavelength must be strictly monitored. On systems that combine and extract light as it is while handling multiple light wavelengths on networks, this wavelength stability is even more critical.
In order to monitor all the DWDM signals, a photodiode must be prepared for each particular wavelength. Photodiode arrays and image sensors are effective in ensuring that devices are kept small and easy to handle.
In photodiode arrays, signals from adjacent elements must be kept sufficiently separated (low crosstalk) from each other.
For image sensors, it is essential that there are no defective pixels. The signal processing circuit for the image sensor is formed inside the device, so signals from all channels can be output from just a few video lines by supplying a control signal.

[Figure 2-7] Usage example in DWDM transmission



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