5 Reliability of Individual Device Types

5.1 Visible LED Lamp Reliability

5.1.1 Overview

(1) General characteristics

(a) Relation ship ship between luminous intensity and current

Figure 5.1.1 shows the relationship between luminous intensity and forward current in light-emitting diodes (LEDs). Red light emission by GaP LEDs is via Zn-0 pairs. Because the level of the radiative recombination center for red light is deep and the probability of recombination is small, the radiative recombination center reaches saturation at a relatively low current density. Consequently, the luminous intensity of red GaP LEDs also reaches saturation at a relatively low current density. On the other hand, green light emission by GaP LEDs is characteristically proportional to the square of the current, since the level of the radiative recombination center in this case is shallow.

Accordingly, green GaP LEDs are well suited to applications where high-level, momentary luminous intensity is required, as in pulse operations. Red GaP LEDs are effective in operations involving DC current, since the luminous power conversion efficiency of DC at small currents is extremely high.

$GaAs_{1-X}P_X$ and $Ga_{1-X}Al_XAs$, although not as efficient as GaP when GaP is emitting green light, have no tendency to saturate at high current density.

These facts should be considered carefully when selecting LEDs for your designs.

(b) Relation ship between luminous intensity and temperature

Because the radiative recombination probability of LEDs is temperature-dependent, LED luminous intensity decreases as the temperature increases. (Figure 5.1.2 shows the characteristic curve for GaP luminous intensity vs. temperature.) It is therefore very important to provide good heat radiation in pulse drive and package designs to counter any temperature rise in junctions due to power dissipation.

(c) Current-voltage characteristics

The primary current-voltage characteristic of LEDs is the rectification property exhibited by general diodes. The forward rise voltage, varying slightly according to the material used in the device, is approximately 1.8 V for GaP (red), 2.0 V for GaP (green), and 1.6 V for $GaAs_{1-X}P_X$ and $Ga_{1-X}Al_XAs$ and InGaAlP. To achieve light emission, a supply voltage greater than the forward rise voltage plus the voltage across the operating junction (normally 0.3 to 0.5 V) is required.

Although the reverse breakdown voltage is approximately 10 V ~ 30 V, device specifications generally stipulate leakage current at a reverse voltage of 4 V.

(d) Response speed

The response speed of LEDs is determined by the velocity at which carriers are captured and dissociated by the radiative recombination center. The rise time is 100 ns for GaP (red), 50 ns for GaP (green), 50 ns for $GaAs_{1-X}P_X$ (red), 100 ns for $Ga_{1-X}Al_XAs$ (red) and 50 ns for InGaAlP (orange and yellow), and is thus much faster than for ordinary LED lamps.

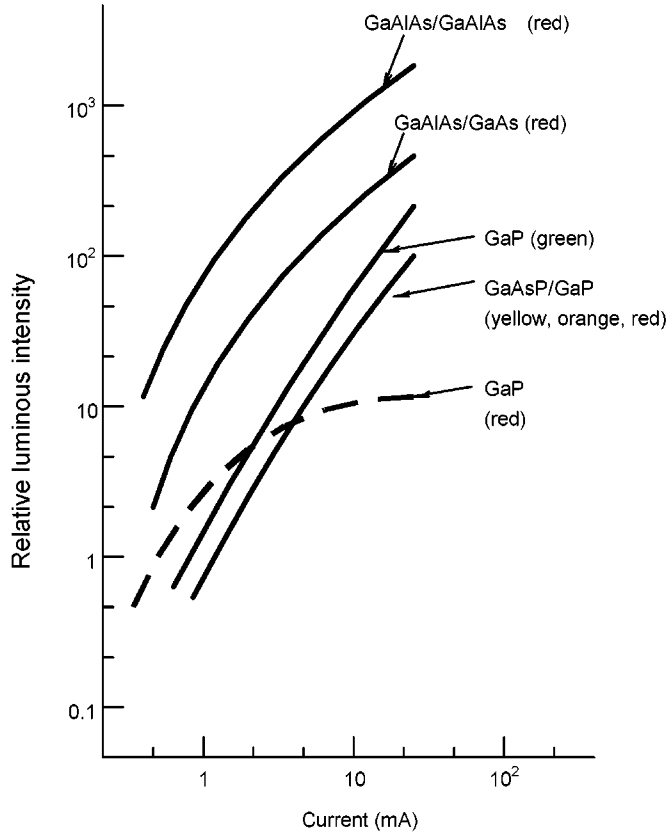


Figure 5.1.1 Forward current vs. luminous intensity

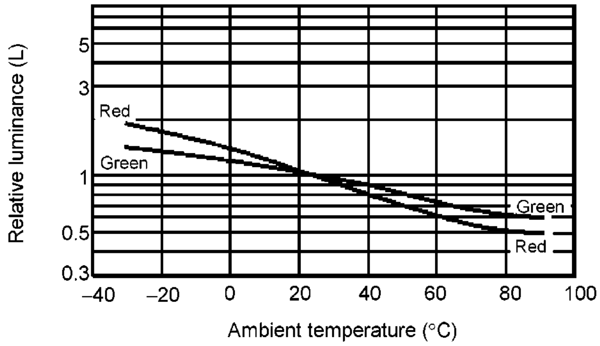


Figure 5.1.2 Relation ship between GaP LED luminance and temperature

(2) LED Materials

Table 5.1.1 shows materials and characteristics of visible LED lamps.

Table 5.1.1 Materials and characteristics of various visible LED lamps

(Ta = 25°C)

Material	Prohibited Bandwidth (eV)	Band Structure	Light Emission Color	Peak Emission Wavelength (nm) (energy (eV))	Luminous Efficiency (external quantum efficiency) (%)	Manufacturing Method
GaP: Zn - O/GaP	2.26	Indirect	Red	700 (1.77)	3	Liquid epitaxy
GaP: N/GaP			Yellow-green	565 (2.20)	0.3	
GaP/GaP			Pure green	555 (2.23)	0.1	
$GaAs_{0.35}P_{0.65}$: N/GaP	2.09	Direct	Red	635 (1.95)	0.3	Vapor epitaxy
$GaAs_{0.25}P_{0.75}$: N/GaP	2.13		Orange	610 (2.03)	0.3	
$GaAs_{0.15}P_{0.85}$: N/GaP	2.18		Yellow	585 (2.12)	0.3	
$Ga_{0.65}Al_{0.35}As$/GaAs (SH)	1.88	Direct	Red	660 (1.88)	1	Liquid epitaxy
$Ga_{0.65}Al_{0.35}As$/GaAs (DH)	1.88		Red	660 (1.88)	8	
$Ga_{0.58}Al_{0.42}As$/GaAs (DH)	1.98		Red	630 (1.97)	2	
$In_{0.5}(Ga_{0.957}Al_{0.043})_{0.5}P$/GaAs (DH)	1.92	Direct	Red	644 (1.92)	6	Metal organic chemical vapor deposition (MOCVD)
$In_{0.5}(Ga_{0.868}Al_{0.132})_{0.5}P$/GaAs (DH)	2.03		Orange	612 (2.03)	6	
$In_{0.5}(Ga_{0.81}Al_{0.19})_{0.5}P$/GaAs (DH)	2.10		Yellow	590 (2.10)	6	
$In_{0.5}(Ga_{0.606}Al_{0.394})_{0.5}P$/GaAs (DH)	2.16		Green	574 (2.16)	1.5	
$In_{0.5}(Ga_{0.546}Al_{0.454})_{0.5}P$/GaAs (DH)	2.21		Pure green	562 (2.21)	0.4	

The light emission wavelength can be change using various combinations of materials and by changing crystal mixture ratio. Even for the same light emission color, the brightness varies according to the material. GaAsP and GaP are being replaced by InGaAlP because it can be used for light emission colors ranging from green to red and because InGaALP LED lamps exhibit ultra-high brightness.

(3) LED Lamp Structure

(3.1) Shelly-Type LED Lamp

Figure 5.1.3 shows an example of the structure of an LED lamp. The main object emitting light is the center LED pellet. In order that voltage can be applied, the pellet is fixed to (mounted on) the cathode lead pin using solder or conductive paste. Between the pellet and the anode lead is a gold filament 25μm to 30 μm in diameter held in place by thermo-compression bonding. In order that light can be obtained efficiently, the light-emission diode pellet is molded in a transparent resin lens. Depending on the shape and material of the lens, LED lamps with different exterior shapes can be created. In one example a colorless transparent lens is used, the lens is colored to the same color as the emitted light, a light-scattering substance is inserted into the lens, and the light-emission area is increased to obtain soft light. Figure 5.1.4 shows a typical LED lamp lead frame. The die attaching post in Figure 5.1.4 corresponds to the cathode lead in Figure 5.1.3, and the bonding post in Figure 5.1.4 corresponds to the anode lead in Figure 5.1.3.
(In the case of the GaAlAs pellet, this is reversed.)

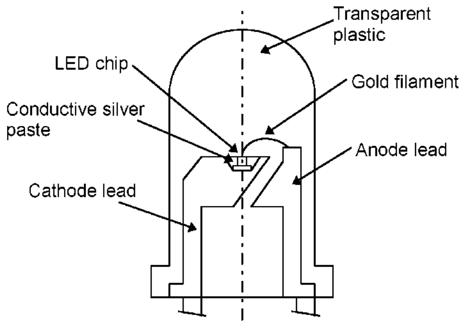


Figure 5.1.3 Structure of an LED lamp

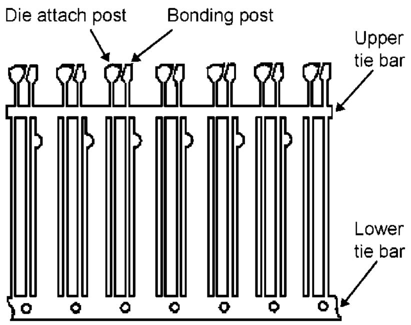


Figure 5.1.4 LED lamp lead frame

(3.2) SMD (Surface-Mount Device) Lamp

Figure 5.1.5 shows an example of the structure of a surface-mount LED lamp (SMD lamp). Cathode and anode electrodes are mounted on the PCB, the LED pellet is fixed to the electrodes, and the area around the LED pellet is sealed with transparent resin.

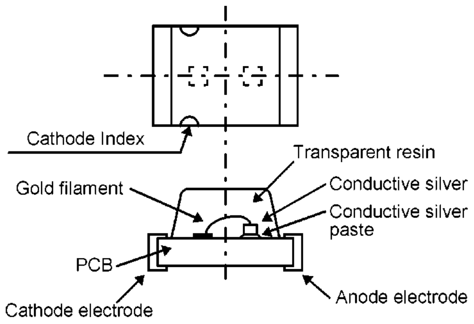


Figure 5.1.5 Basic structure of SMD lamp

(4) Sealing resin

LED lamp packages consist of a lead frame on which the LED chip is mounted and a lens sealed with resin (normally transparent epoxy).
There is a trade-off between resin properties and device reliability; however, there is only a limited choice of resins.
Table 5.1.2 lists properties of the typical epoxy resin employed in high-intensity LED lamps for outdoor use.

Table 5.1.2 Typical properties of epoxy resin used in high-intensity outdoor LEDs

Parameter	Performance
Light transmittance (Visible Spectrum)	80% to 90%
Glass transition temperature (Tg)	Approx. 140°C
Coefficient of linear expansion (α)	Approx. 7×10^{-5} / °C
Elastic modulus of bending	Approx. 2940 N/mm^2
Moisture absorption at boiling point (24 hours)	0.1%

5.1.2 Usage Precautions

(1) Absolute maximum ratings

Absolute maximum ratings must not be exceeded under any circumstances.
In addition, there is no guarantee with any of the product types that operation can be sustained when two or more ratings are at their maximum values simultaneously.
As a supplement to absolute maximum ratings, some product datasheets show ambient temperature versus allowable forward current (or power dissipation) characteristics, as exemplified in Figure 5.1.6.

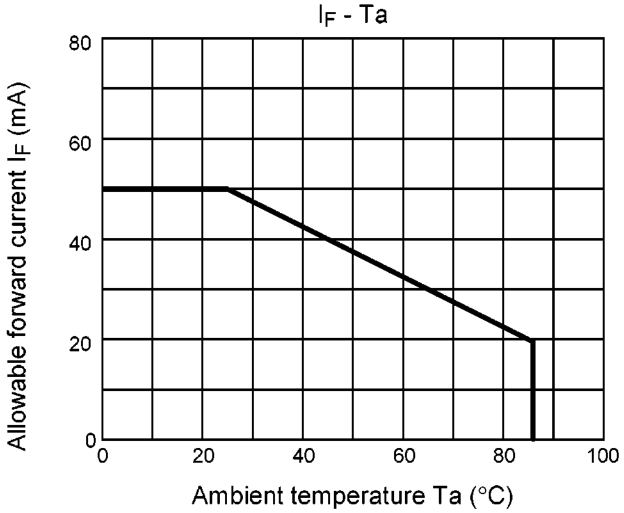


Figure 5.1.6 Relationship between ambient temperature and allowable forward current

(2) Outdoor use

LEDs are widely used in outdoor applications because of their high brightness. However, recently degradation of light emission in GaAlAs series LEDs has been detected under high-temperature and high-humidity conditions. We recommend a GaAlP substrate for ultra-high brightness colors ranging from pure green to red, since GaALP's characteristics are generally unaffected by thermo-mechanical stresses.

(3) Directional sensitivity

The lens of an LED is made of transparent resin and controls the directional sensitivity of the emitted light. Generally the ideal device has wide of direction sensitivity range. However, for a given LED the directional sensitivity is inversely proportional to the luminous intensity.
Therefore, it is important to choose LEDs with the right level of directional sensitivity according to the application.

(4) Storage temperature

LEDs must be stored with in a specified temperature range because of the resin used in the package. Light emission and directional sensitivity are important LED characteristics. However in some cases, its storage temperature (max) does not match to the actual application. When using LEDs, do not exceed the storage temperature.

Table 5.1.3 shows an example of absolute maximum ratings specification.

Table 5.1.3 Example of maximum rating specifications (for TLGD240P, Ta = 25°C)

Absolute Maximum Ratings

Parameter	Symbol	Rating	Unit
DC forward current	I_F	40	mA
DC reverse voltage	V_R	4	V
Power dissipation	P_D	120	mW
Operating temperature	T_{opr}	–30 to 85	°C
Storage temperature	T_{stg}	–40 to 100	°C

(5) LED lamp application circuits

Since the optical output of a light-emitting diode depends on the LED forward current I_F, a circuit for turning the optical output on and off can be implemented easily by controlling the I_F current. Typical DC, pulse and AC LED driver circuits, and precautions that should be observed during design, are described below.

(5.1) DC LED drivers

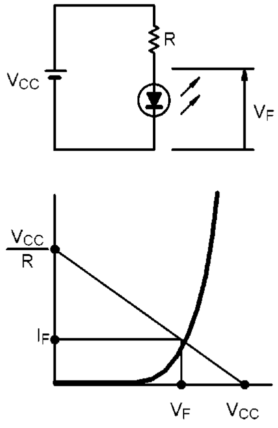


Figure 5.1.7 DC driver circuit for LED

Figure 5.1.7 shows a basic circuit for driving an LED using a DC power supply. In this case, I_F is expressed as:

$$I_F = \frac{V_{CC} - V_F}{2}$$

V_{CC}: supply voltage

V_F: forward voltage of LED

I_F: forward current flowing in LED

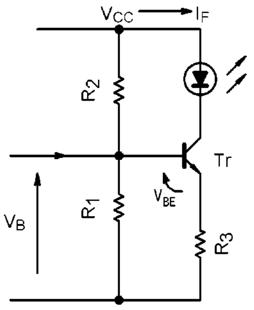


Figure 5.1.8 Constant-current driver circuit for LED

Figure 5.1.8 shows a circuit where non-linearity in V_F for the LED is compensated for by a transistor. In this case, I_F is expressed by as:

$$I_F = \frac{V_B - V_{BE}}{R_3}$$

V_B: base voltage

V_{BE}: base-to-emitter voltage

R_3: emitter resistance

This circuit allows the temperature dependency of the optical output to be minimized by the use of appropriate V_{BE} and V_B settings.

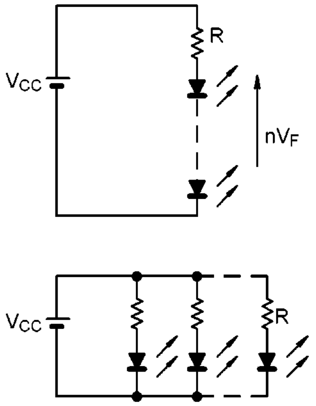


Figure 5.1.9 Increasing the radiant output power

Insufficient radiant output power can be boosted by connecting a diode to another diode in series or in parallel. In these cases, I_F is expressed by the following equations:

$$I_F = \frac{V_{CC} - nV_F}{R} \quad \text{(series connection)}$$

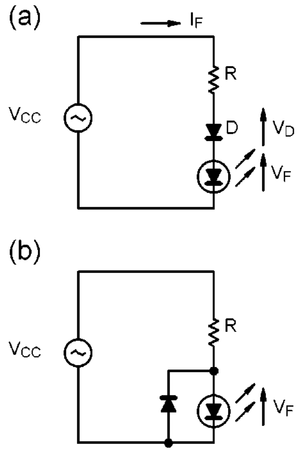
$$I_F = \frac{V_{CC} - nV_F}{R} \quad \text{(parallel connection)}$$

(5.2) AC LED drivers

Figure 5.1.10 shows a basic circuit for driving an LED at half wave using an AC power supply.

In general, there are two drive methods, (a) and (b), as shown below. In both cases, a protective diode prevents the LED from being subjected to a voltage greater than its reverse breakdown voltage.

For (a), the protective diode must have a reverse voltage matched to the supply voltage V_{CC}. For (b), the protective diode reverse breakdown voltage is approximately twice the forward voltage of the LED.



$$I_F = \frac{V_{CC} - V_F - V_D}{R}$$

$$I_F = \frac{V_{CC} - V_F}{R}$$

Figure 5.1.10 AC driver circuit

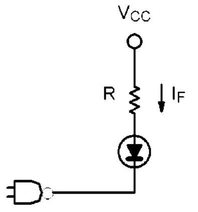
The value of R must be set in accordance with the supply voltage V_{CC}. Also, R must be set so that the LED forward current I_F is suppressed to the rated value when the supply voltage V_{CC} is at its maximum.

(5.3) Pulse LED drivers

Converting an optical signal into pulse-modulated light using a pulse LED driver offers the advantage in battery-powered devices of extending battery life by reducing power consumption.

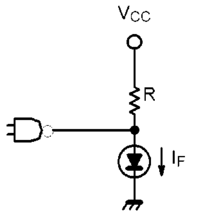
(a) Pulse drive method

The pulse drive method uses a combination of TTL or CMOS logic ICs and transistors.



$$I_F = \frac{V_{CC} - V_F - V_{OL}}{R}$$

(Lit when pulled low)



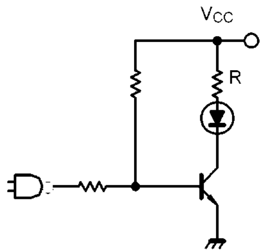
$$I_F = \frac{V_{CC} - V_F}{R}$$

Designed for case where $I_F < I_{OL}$

(Lit when driven high)

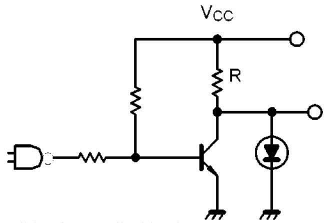
Figure 5.1.11 IC-based driver circuit

Figure 5.1.11 calls attention to the I_{OL} characteristics of TTL and CMOS. To satisfy the condition $I_F < I_{OL}$, these circuits do not allow a large current to flow.
To increase the drive current, it is necessary to use a buffer IC with large output current capacity or to add an external transistor as shown in Figure 5.1.12.



$$I_F = \frac{V_{CC} - V_F - V_{CE}\,(sat)}{R}$$

(Lit when driven high)



$$I_F = \frac{V_{CC} - V_F}{R}$$

(Lit when pulled low)

Figure 5.1.12 Driver circuit using an IC and a buffer transistor

The following table lists the I_{OL} and V_{OL} characteristics of typical, CMOS and buffer ICs for reference.

Type	V_{OL}	I_{OL}	Product Number
CMOS ICs	0.4 V	4 mA V_{DD} = 4.5 V, Ta = 25°C	TC74HC244AP TC74HC245AP
Buffer ICs	1.3 V Ta = 25°C	200 mA	TD62003P/AP TD62004P/AP TD62007P

Constant-Current LED Drive

The TB62xx Series is comprised of a range of drivers with built-in shift registers to drive LEDs at a constant current. Because the constant-current circuits are built in, even if the LED-side power supply voltage fluctuates, there is little fluctuation in the current and the brightness remains almost constant.

Since it is necessary to connect only one current-setting resistor to the IC, the wiring is simplified.

Product Line-up
With Serial/Parallel Output Latch

Product No.	Number of Outputs	V_{out} (max)	I_{OL} (max)	Package
TB62701AN	16 bits	30 V	50 mA/bit	Shrink DIP24 (1.47 mm pitch) SDIP24-P-300
TB62706AN	16 bits	18 V	90 mA/bit	Shrink DIP24 (1.47 mm pitch) SDIP24-P-300
TC62705BP	8 bits	18 V	90 mA/bit	SSOP16 (1.0 mm) SSOP16-P-225A
TB62705BF	8 bits	18 V	90 mA/bit	SSOP24 (1.0 mm) SSOP24-P-300

(5.4) Parallel connection

When parallel connection is required, please insert a resistor for each LED so that the same current flows to each LED, as shown in Figure 5.1.13.

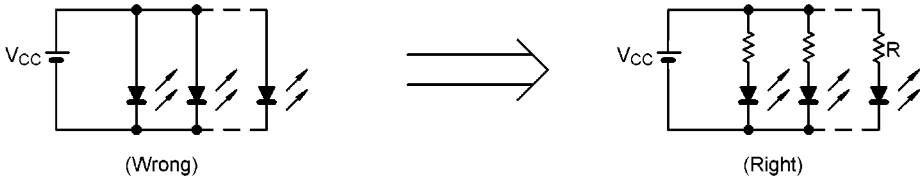


Figure 5.1.13 Parallel connection

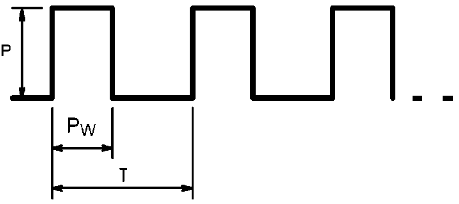
(5.5) Allowable pulse-forward current for LED lamps

When the LED lamp is driven with a periodic square-wave pulse like the one shown below, the allowable pulse-forward current I_{FP} is as shown in Table 5.1.4. Note, however, that the allowable value varies with drive conditions (e.g. pulse width and duty ratio). To obtain the correct value, refer to the characteristic diagrams below.

- Applied pulse

  I_{FP}: allowable pulse-forward current
  P_W: pulse width
  T: period

  D_R: duty ratio (= $\frac{P_W}{T}$)



If the ambient temperature (Ta) exceeds 25°C, I_{FP} must be derated according to Ta (as shown in Figure 5.1.14).

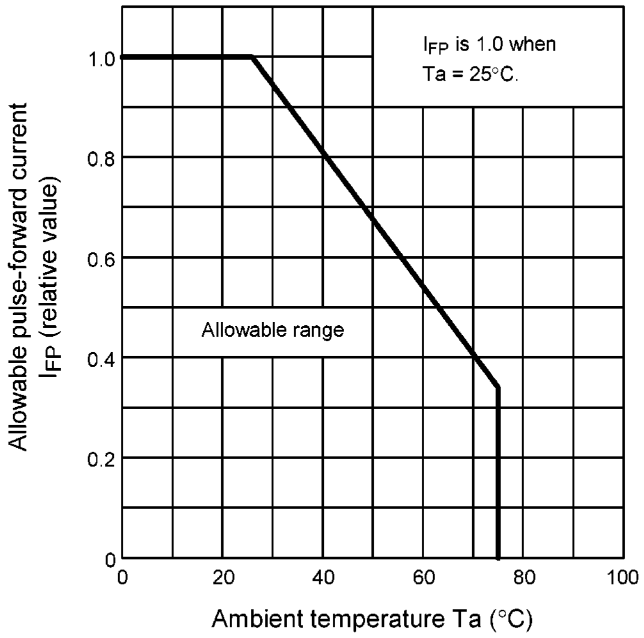


Figure 5.1.14 I_{FP}-Ta characteristics

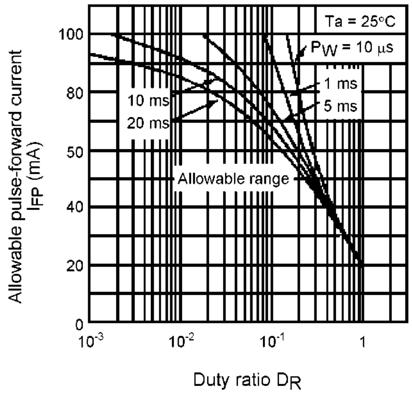
Table 5.1.4 Allowable pulse-forward current rating (Ta = 25°C)

Type	DC forward current I_F (max) (mA)	Allowable forward pulse current I_{FP} (max) (see Note 2) (ma)	Characteristics diagram number
GaP (red) TLRxxx type	20	100	1
	25		2
Colors and types other than the above (see Note 1)	40	160	3
	50	200	4
	25	120	5
	30		6

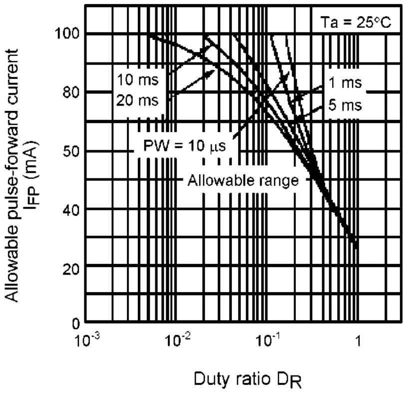
Note 1: When turning on both colors of a two-color LED simultaneously, treat this figure as the total rating.

Note 2: Pulse width P_W = 100 μs, duty ratio DR = 10^{-1}.

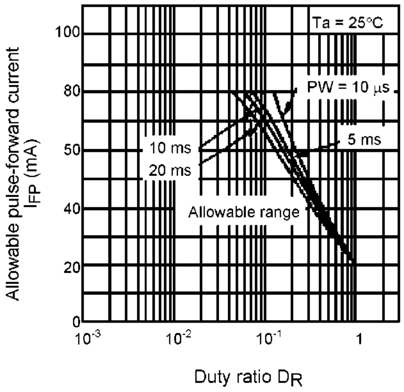
Characteristics Diagram 1



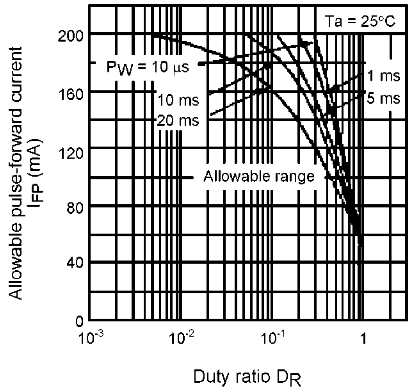
Characteristics Diagram 2



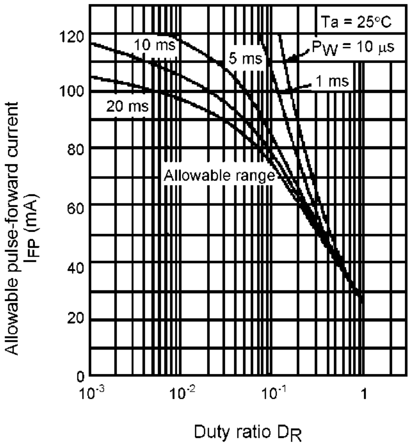
Characteristics Diagram 3



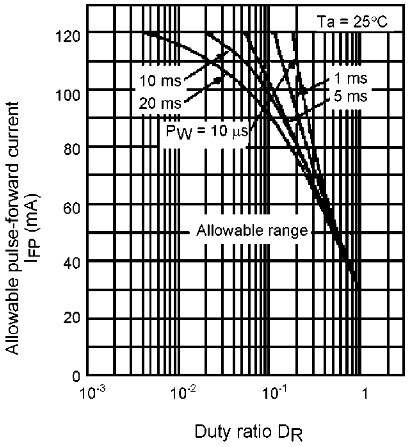
Characteristics Diagram 4



Characteristics Diagram 5



Characteristics Diagram 6



(6) Precautions when mounting LEDs

Optical semiconductors are normally mounted on printed circuit boards (PCBs). The following describes recommended methods for mounting each type of device and several precautions that should be observed.

(6.1) Soldering conditions

Unless otherwise specified in technical data, perform soldering work under the following conditions:

Solder temperature:	260°C or less (solder dip) 300°C or less (manual soldering). See note.
Time limit:	Complete soldering within 3 seconds
Location:	On the lead, 2 mm or more from the device package

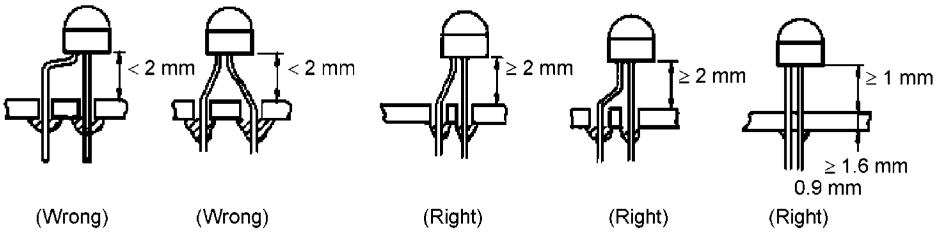
Note: Use a 30W or less soldering iron rated for, and adjust the supply voltage so that the temperature at the tip is below 300°C.

Meeting these conditions prevents most problems, such as diminished LED illumination, open or short failures and mold breakage due to solder heat.
If one or more of these conditions cannot be met, for reasons of available space or proximity to other components, then be careful during soldering not to apply stress or excess heat to leads.

(6.2) Precautions for each device type

(a) ϕ3 plastic stem

Devices of this type, such as the TLR102A, have a lead-to-lead distance of only 0.9 mm. When mounting on a standard PCB with a 2.54 mm pitch, make sure the devices are positioned such that, when solder is applied, the solder point on each lead is at least 2 mm from the device package.
Do not force devices into contact with the board when mounting. Even with a perfectly matched PCB pitch and device pitch, leave at least a 1-mm gap between the bottom of the device and the PCB. With a through-hole board, the device must sit 2 mm or more above the board surface.



(b) Subminiature

There are two methods for mounting double-ended subminiature devices like the TLR121. (Note that this cannot be done with devices which stand above the PCB when mounted.) In one method, mounting is carried out from the PCB top surface as shown in Figure 5.1.15. In the other, subminiature devices are mounted from the PCB bottom side (see Figure 5.1.16).

In the first method, providing a cavity on the PCB that accepts the plastic base of the device is recommended. This keeps the device oriented properly and firmly. However, the device must not be forced into the hole and no undue mechanical stress should be applied (see Figure 5.1.17).

Subminiature devices are very small, therefore resin temperature can increase rapidly during soldering. To prevent this, when soldering grasp the lead with tweezers or some other similar tool to radiate heat away from the lead and package.

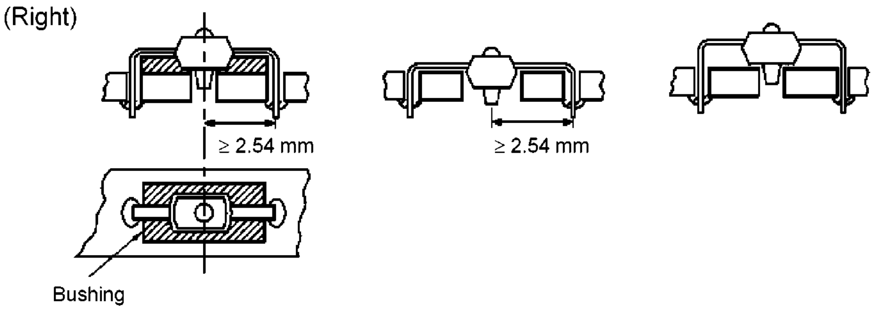


Figure 5.1.15

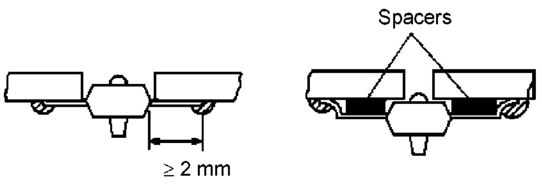


Figure 5.1.16

(Wrong)

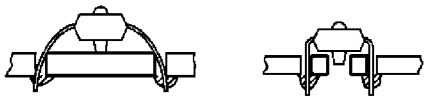


Figure 5.1.17

Precautions when mounting

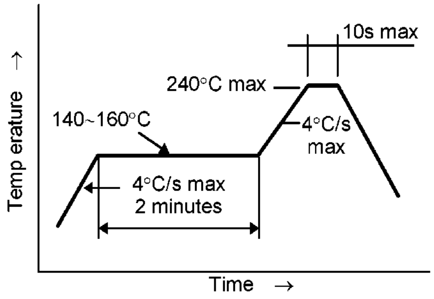
Do not apply stress to the resin part at high temperature. As the resin is easily scratched, avoid friction with any hard materials. When installing an assembly board in equipment, ensure that this product does not come into contact with other components.

(c) SMD Lamps

Soldering method

Recommended soldering conditions

Temperature profile (reflow)



* ≥ 210°C, 30s (max)

Figure 5.1.18

(*) For recommended soldering conditions please refer to each technical datasheet.

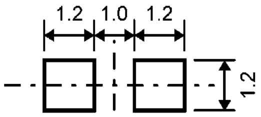


Figure 5.1.19

Manual soldering

Manual soldering should be performed for no more than three seconds at a maximum temperature of 300°C and using a 25-W soldering iron.

When cleaning is required after soldering, the following specifications apply:

Chemical:	alcohol
Temperature:	50°C
Time:	3 minutes
Ultrasonic cleaning	
Frequency:	27 kHz to 29 kHz
Output:	300 W or less (0.25 W/cm^2 or less)
Time:	30 seconds or less

(7) Handling precautions

(7.1) Wear resistance

The plastic used in molded LED devices is of relatively low hardness since clarity of the lens is required. Friction from metal or even a fingernail can leave scratches. Normal handling should present no problems, however.

(7.2) Heat resistance

The plastic parts of a device can become discolored if subjected to heat for an extended period of time. Do not expose devices to temperatures higher than the rated storage temperature.

(7.3) Mechanical stress to leads

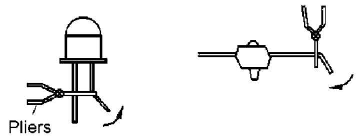
If leads are subjected to stress during soldering, or if tensile, torsional or compressive stress is applied to hot leads immediately after soldering, opens can occur inside the device. Be sure to let the leads cool before altering their position or direction.

(7.4) About lead forming

(a) Standalone devices · · · · · · Use pliers to grasp the lead near the package base while bending the lead, so as not to impose stress at the point where the lead connects to the package. Ensure that the lead bend starts at least 2 mm from the package base.

(b) Double-ended devices · · · · If the lead is tapered, bend it at the point at which it starts to taper.
If the lead is not tapered, bend it at a point at least 2 mm from where the lead joins the package.

(Example)



(7.5) Moisture-proof packing

After unpacking the SMD lamps, which are packed in a moisture-proof package (an aluminum envelope), use the devices within the certain period of time specified in the individual datasheets.

(7.6) Cleaning LED display

Do not clean the whole LED display. It could cause cracks in its case.

5.1.3 Reliability Characteristics

(1) Test data for typical product types

Various reliability tests are described below, using the TLGD240P as an example.

Table 5.1.5 LED (TLGD240P) reliability test data

1. Table of Test Conditions

1-1 Thermal Environment Tests

Test Item	Applicable Standard	Test Conditions	Remarks
Soldering heat	JIS C7021 A-1	T_{sol} = 260°C, 10 secs, once	
Temperature cycling	JIS C7021 A-4	−30°C to 25°C to 100°C to 25°C 30 mins 5 mins 30 mins 5 mins	100 cycles
Thermal shock	JIS C7021 A-3	0 ←→ 100°C 5 mins 5 mins	50 cycles
Moisture resistance	JIS C7021 A-5	25°C to 65°C to −10°C, 90% to 98%, 24 hrs/cycle	10 cycles

1-2 Mechanical Environment Tests

Test Item	Applicable Standard	Test Conditions	Remarks
Vibration	JIS C7021 A-10	100 Hz to 2000 Hz to 100 Hz 196 m/s^2 (20 g) 4 times each in 3 directions	
Mechanical shock	JIS C7021 A-7	14,700 m/s^2 (1,500 g), 0.5 ms 3 times each in 4 directions	
Constant acceleration	JIS C7021 A-9	196,000 m/s^2 (20,000 g), 1 minute once each in 6 directions	
Solderability	JIS C7021 A-2	230°C, 5 secs, once	95% or more (using flux)
Lead integrity	JIS C7021 A-11	Load 2.5 N (0.25 kgf) 0° to 90° to 0° bent 3 times	No separation or breakage allowed

1-3 Life time Tests

Test Item	Applicable Standard	Test Conditions	Remarks
Steady-state operation	JIS C7021 B-1	I_F = 40 mA Ta = 25°C	1,000 hours
High-temperature storage	JIS C7021 B-10	Ta = 100°C	1,000 hours
High-temperature, High-humidity storage	JIS C7021 B-11	Ta = 60°C, RH = 90%	1,000 hours

2. Failure Criteria (Ta = 25°C)

Parameter	Symbol	Measuring Conditions	Criteria	
			Minimum	Maximum
Forward voltage	V_F	$I_F = 20$ mA	—	USL × 1.2
Reverse current	I_R	$V_R = 4$ V	—	USL × 2
Luminous intensity	I_V	$I_F = 20$ mA	LSL × 0.5	—

USL: Upper specification limit; LSL: Lower specification limit

3. Test Results

3-1 Environment Tests

Test	No. of Samples	No. of Failures	Test Item	No. of Samples	No. of Failures
Soldering heat	32	0 / 32	Vibration	11	0 / 11
Temperature cycling	50	0 / 50	Mechanical shock	11	0 / 11
Thermal shock	32	0 / 32	Constant acceleration	11	0 / 11
Moisture resistance	32	0 / 32	Solderability	11	0 / 11
			Lead integrity	11	0 / 11

3-2 Lifetime Tests

Test Item	No. of Samples	168 hrs	500 hrs	1000 hrs
Steady-state operation	30	0 / 30	0 / 30	0 / 30
High-temperature storage	30	0 / 30	0 / 30	0 / 30
High-temperature, High-humidity storage	30	0 / 30	0 / 30	0 / 30

(2) Change in characteristics with the passage of time

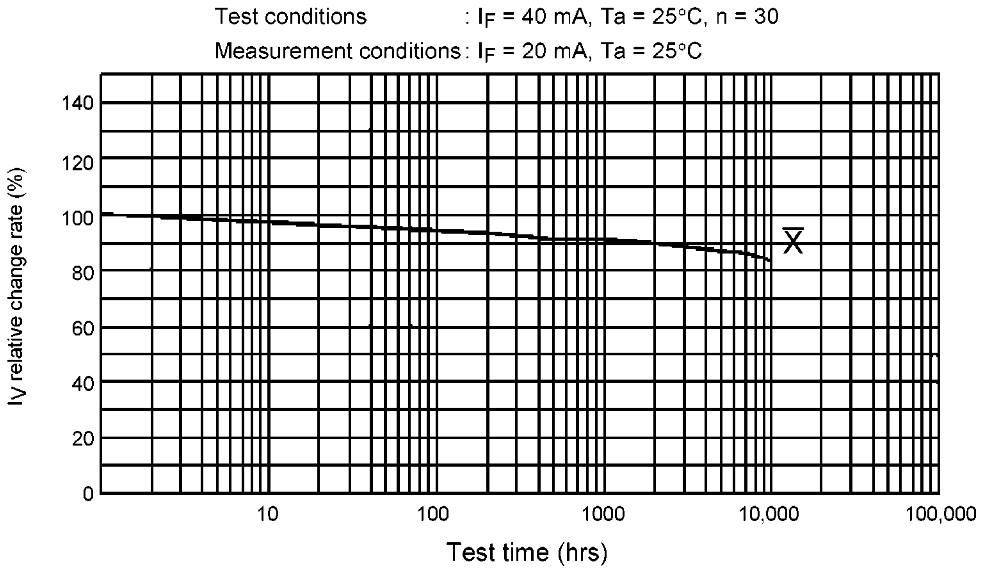


Figure 5.1.20 Change in characteristics of TLGD240P

(3) Optical output degradation mechanism

LEDs have an inherent mechanism whereby the optical output power degrades gradually as the LED conducts current. Although details of the mechanism are not fully known, it is believed that phonon emission (lattice vibration) caused by non-radiative recombination of electrons and holes near a junction facilitates dislocation in the crystal and movement of minute dislocation loops. Acceleration of this movement causes non-radiative recombination to increase, resulting in a reduction in the amount of emitted light. Several other mechanisms are also involved and can be summarized as follows:

(3.1) Quick degradation in several tens to several hundreds of hours:

This does not occur in properly controlled lots.

(a) Crystalline degradation:	A large defect, such as continuous dislocation extending from the substrate, can cause a rapid degradation due to the above-mentioned mechanism. The electroluminescence (EL) image shows up as a DLD (dark line defect) or DRD (dark region defect).
(b) Degradation by heavy metal contamination:	This occurs in heavy metals such as Cu. Reduction of the junction barrier by forward biasing causes heavy metal to diffuse around the junction, forming a deep energy level. This results in increased non-radiative recombination which causes rapid degradation of the LED.

(3.2) Slow degradation in several hundreds to several thousands of hours:

This can occur even in properly controlled lots.

(a) Crystalline degradation: A small defect or dislocation grows gradually larger due to the above-mentioned mechanism. Since this results in uniform degradation, the EL image looks dark overall, with neither DLDs nor DRDs being observable.

(b) Stress-induced degradation:

Conduction at low temperature results in gradual degradation due to the above-mentioned mechanism plus stress in the plastic resin. DRDs etc. can be observed in the EL image; in addition, the crystal slide plane can be observed in the cathode-luminescence (CL) image. Coupler LED chips are structurally immune to resin stress because they are covered with a silicone resin. Consequently, no stress degradation has been found in this type of device.

(c) Using GaAlAs LEDs in a high-temperature, high-humidity environment: Applying power to GaAlAs series LEDs in high-temperature, high-humidity environments (e.g. 60°C, 90%) creates an aluminum oxide film on the LED chip surface; the formation of this light-absorbing layer decreases the optical output efficiency. To avoid large reductions in performance, do not use these devices under high-temperature or high-humidity conditions.

In GaAlP series LEDs are known for their high reliability compared to other LED devices and they exhibit excellent characteristics. Therefore, we highly recommend In GaAlP series LEDs, particularly in high-temperature, high-humidity environments.

5.2 Photosensor Reliability

5.2.1 Overview

(1) Infrared LED characteristics

LEDs feature compact size, long life, fast response and high-efficiency light emission capability. Infrared LEDs are in wide use because their spectral emission is closely matched to that of photodiodes and phototransistors. Figure 5.2.1 shows the emission wavelength of an LED and the receiving wavelength of an Si photodiode (TPS708). New products developed in recent years, such as the TLN200 series GaAlAs infrared LED, show significant improvement in emission distance.

Photodiodes and phototransistors generally operate in the 400 ~ 1000 nm wavelength spectrum. Visible LEDs other than the GaAs type, such as those of the GaP and GaAsP types, are capable of activating and producing signal output in phototransistors. However, their optical power is small and you should use them with caution.

Figure 5.2.2 shows radiant intensity (I_E) versus forward current (I_F) in the TLN108 and TLN201. You can see that the radiant intensity becomes large as I_F increases. (Radiant intensity, the radiant power emanating from a source per unit solid angle in a particular direction, is used here as a truer representation of radiant power under actual LED usage conditions, in stead for total radiant power P_O.)

Figure 5.2.3 shows the radiation pattern characteristics of the TLN108 and TLN103A. In devices with a narrow radiation pattern, like the TLN108, the on-axis radiant intensity I_E is large, producing a large output signal in the detector device. However, an axial tilt of only 10° will decrease the radiant intensity by some 60%, with a resultant reduction in the detector output. You should therefore guard against misalignment problems when mounting these types of device.

With devices that emit light in a wide radiation pattern, such as the TLN103A, even a large axial tilt will not significantly change the detector output. However, even though total radiant power P_O equals that of the TLN108, the radiant intensity I_E is smaller, resulting in a smaller output from the detector.

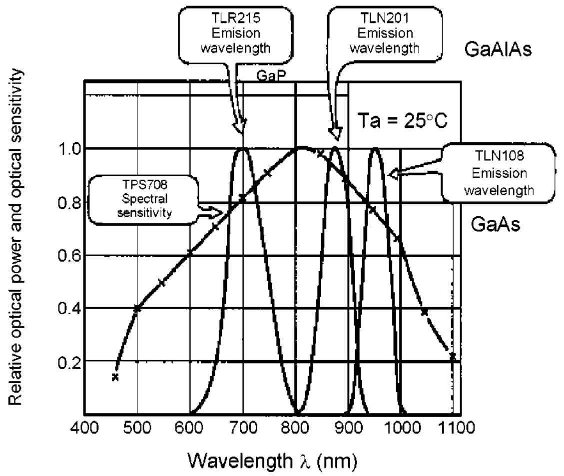


Figure 5.2.1 Emitting and receiving

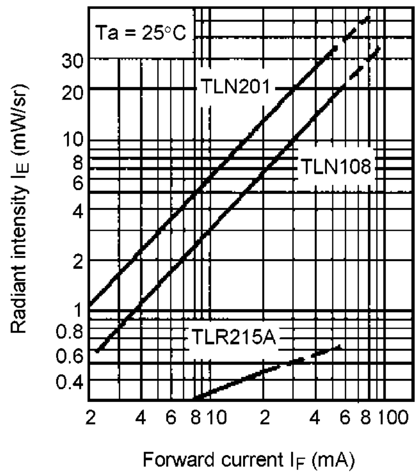


Figure 5.2.2 I_E - I_F characteristic

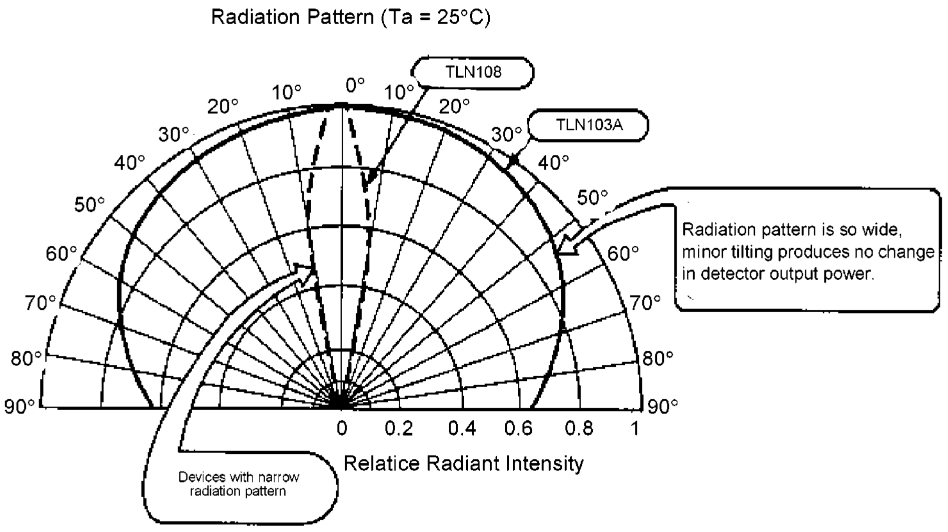


Figure 5.2.3 Radiation pattern characteristics of the TLN103A and TLN108

(2) Phototransistor (photodiode) characteristics

A phototransistor can be thought of as a photodiode plus a transistor. They come in two types: single and darlington.

Figure 5.2.4 shows light-induced current I_L (collector current I_C) and irradiance E. As E increases (becomes brighter), so does I_L. The TPS605, which is of the darlington type, produces a larger collector current than the TPS606, which is of the single type.

Even when not illuminated, phototransistors exhibit a very small "dark current" I_D.

Figure 5.2.5 shows the temperature characteristics for I_D. The dark current increases logarithmically as the temperature rises. This increase is greater in the TPS605 because its photosensitivity is greater than that of the other device. Therefore, when designing circuits for high-temperature applications, make sure that the dark-current-to-light-current ratio, I_L (i.e. the S/N ratio), is sufficiently large.

Phototransistor radiation patterns are such that, as illustrated in Figure 5.2.3, the TPS601A with its narrow pattern (and the same package as the TLN108) has a larger on-axis photo-induced current I_L than the TPS603A with its wide pattern (and the same package as the TLN103A). However, a slight off-axis inclination can reduce I_L for the TPS601A to less than that of the TPS603A. It is therefore important to choose devices appropriately according to the intended application and mounting conditions.

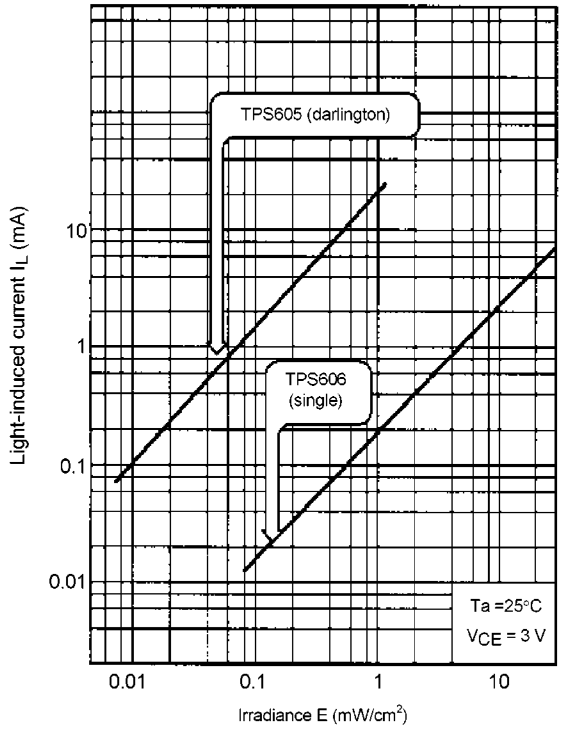


Figure 5.2.4 I_L - E characteristics of phototransistors

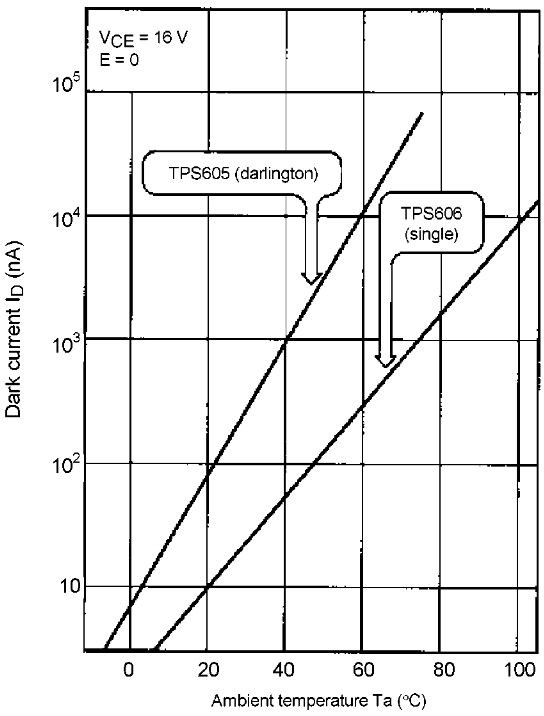


Figure 5.2.5 Phototransistor I_D - Ta

(3) Photointerrupter characteristics

The most important characteristic to consider with photointerrupters is the current transfer ratio CTR (I_C/I_F), equivalent to h_{FE} in transistors. Naturally, CTR is higher for the darlington than for single devices because of the darlington's greater optical sensitivity. Figure 5.2.6 shows the CTR temperature characteristic. Figure 5.2.7 shows how CTR changes over time during an operation test. Hence, the CTR given by these parameters in combination drops in both the low- and high-temperature regions, as shown in Figure 5.2.6. The gradual decrease in CTR in Figure 5.2.7 is attributable primarily to a reduction in LED radiant power due to aging.

In general, as the temperature increases, an LED's radiant power decreases; however, the light-induced current in a photo transistor increases as temperature increases.

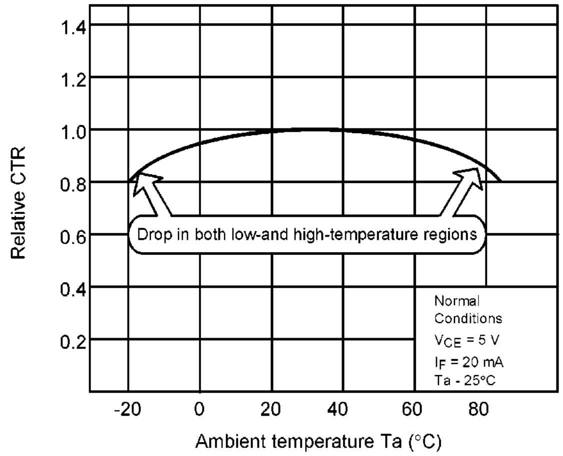


Figure 5.2.6 CTR - Ta characteristics of TLP800

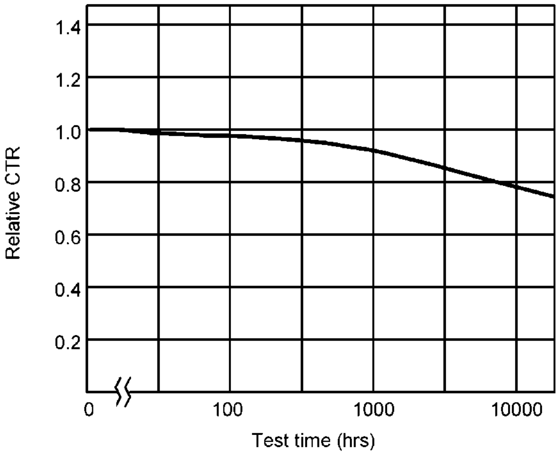


Figure 5.2.7 Change in CTR during operation (TLP800)

The response speed under equal load conditions is slower for the darlington type (TLP850) than for the single type (TLP800A), as can be seen from Figure 5.2.8. This means that as the load decreases, t_{OFF} becomes shorter; that is, response becomes faster.

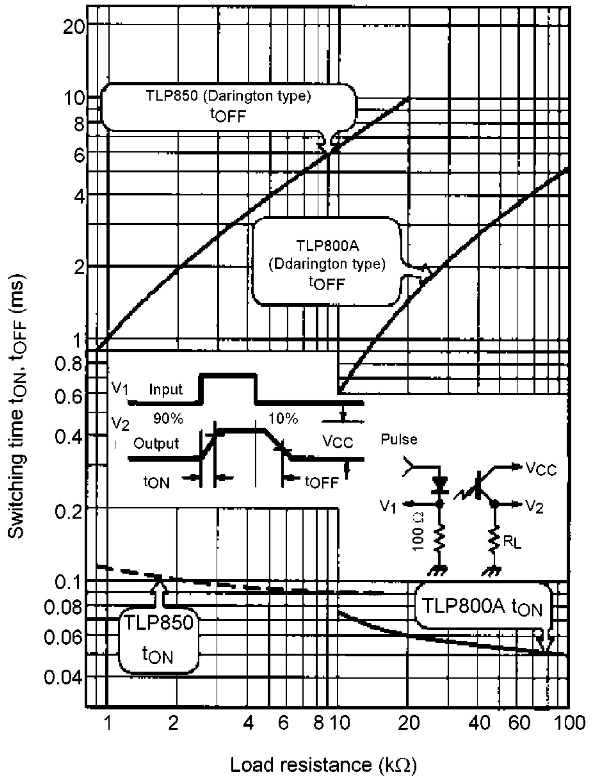


Figure 5.2.8 Photointerrupter switching time vs. load resistance (during saturation)

(4) Package structures

Figure 5.2.9 shows the various photosensor package structures.

(a) TO-18 can

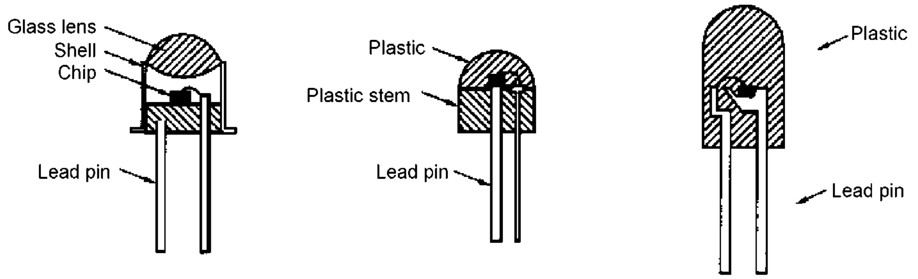
This package houses a chip mounted on a metal stem and is sealed with a lens to provide a window. It resists heat, moisture and corrosion better than other package types, making it well suited to harsh environmental conditions

(b) Plastic stem

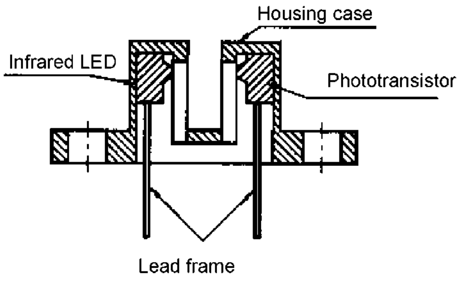
This package houses a chip mounted on a plastic stem and is sealed with light-transmitting resin.

(c) Plastic-molded

This package contains a chip mounted on a lead frame, with the entire structure encapsulated by a light-transmitting resin. A photodetector consists of an emitter and a detector in separate plastic-molded packages housed together in a single case.



[TO-18 can type] [Plastic-stem type] [Plastic-molded type]



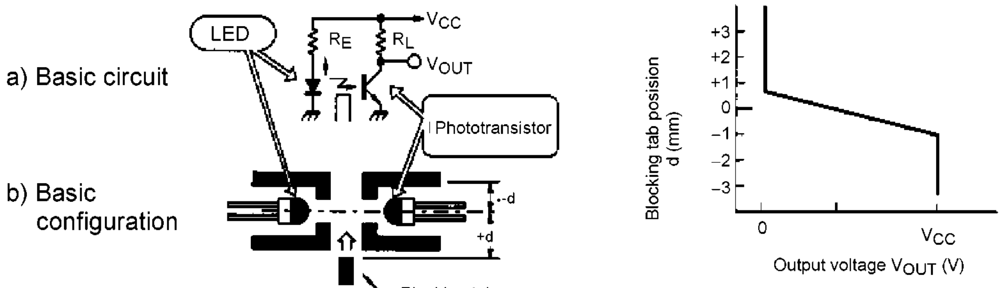
[Photointerrupter]

Figure 5.2.9 Photosensor package structures

5.2.2 Design Precautions

(1) Operating principles of photosensor

Figure 5.2.10(a) shows the basic circuit for a photosensor. The LED anode is connected to the power supply line V_{CC} via resistor R_E and the cathode is grounded to earth. The forward current I_F causes the LED to emit light (invisible to the human eye because it is infrared).



c) Detection signal characteristic

Figure 5.2.10 Photosensor operating principles

The phototransistor collector is connected to the power supply line V_{CC} via resistor R_L and the emitter is tied to ground. The input pins of the comparator and the IC in the next stage are connected in common to the phototransistor collector and thus to V_{CC}.

The emitter and detector devices are arranged as shown in Figure 5.2.10(b). When the blocking tab passes through the slot, the collector voltage goes high, as shown in Figure 5.2.10(c). Conversely, when the blocking tab moves out of the slot, the voltage drops. The blocking tab is therefore detected, and an electrical signal generated, without any contact having been made with the tab. Normally the generated signal is input to a subsequent signal-processingstage circuit which is used to control various peripheral functions.

(2) Designing photosensor circuits

Finding values for R_E and R_L

(a) Finding the optimum R_E value

Find the current I_F that flows in the LED shown in Figure 5.2.10(a) using the following equation (where V_F denotes the LED forward voltage drop).

$$I_F = \frac{V_{CC} - V_F}{R_E} \quad \cdots\cdots\cdots\cdots \quad (1)$$

The following condition must be met:

$$I_F \leq I_F(\max)\ (Ta = Topr(\max)) \quad \cdots\cdots\cdots\cdots \quad (2)$$

From equations (1) and (2), R_E is given by:

$$R_E \geq \frac{V_{CC} - V_F}{I_F(\max)} \quad \cdots\cdots\cdots\cdots \quad (3)$$

As Figure 5.2.2 shows, the greater the magnitude of I_F, the greater the radiant intensity I_E; therefore, R_E must first be determined, then $I_F(\min)$ must be calculated, taking into account the variations in allowable forward current I_F and radiant intensity I_E.

(b) Appropriate value of R_L

Find the upper limit of R_L.

When the blocking tab in Figure 5.2.10(b) is in the slot, the current generated when the LED illuminates the detector ceases to flow in the phototransistor; only the current I_L' (generated when extraneous light strikes the detector) and the dark current I_D flow in the detector. The collector voltage V_{OH} at this time is given by the following equation:

$$V_{OH} = V_{CC} - R_L \times (I_D + I_L')$$

Here we assume that input/output currents supplied to the next stage are negligible and can be ignored. Since I_D increases rapidly as the ambient temperature rises, as shown in Figure 5.2.5, and assuming that the high-level input voltage at the next stage is V_{IH}, then the condition

$VIH < VOH$

must be met when

$Ta = T_{opr}\,(\max)$.

Thus

$$R_L\,(\max) \geq \frac{V_{CC} - V_{IH}}{I_D + I_L'} .$$

Next, determine the lower limit of R_L.

When the blocking tab is out of the slot, light from the LED is received by the phototransistor, and the light-induced current I_L and the above-mentioned $I_D + I_L'$ flow in the phototransistor. Unless

$$I_L \geq I_D + I_L'$$

the presence of the blocking tab cannot usually be detected because of the S/N ratio. The collector voltage V_{OL} at this time becomes

$$V_{OL} = V_{CC} - R_L (I_L + I_D + I_L') \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (4).$$

Assuming that the low-level input voltage at the next stage is V_{IL}, the following equation must be met:

$$V_{IL} > V_{OL} \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (5).$$

Equations (4) and (5) must be fully satisfied, even for the lower-limit value of I_L.

$$I_L(\text{min}) = I_C/I_F(\text{min})\ I_F \times D_t \times D_{Ta} \times D_n$$

D_t: coefficient of change with time

D_{Ta}: temperature coefficient

D_n: coefficient for effects of dust and dirt

From equations (4) and (5), the following is obtained:

$$R_L \geq \frac{V_{CC} - V_{IL}}{I_L(\text{min}) + I_D + I_L'}\ .$$

However, the smaller the magnitude of R_L, the shorter the switching time, as can be understood from Figure 5.2.8.

For information concerning the change in device characteristics with time, please refer to Section 5.2.4 Reliability Characteristics.

For photosensors, change in characteristics over time results mainly from degradation of the LED in the initial operation period.

Be sure to incorporate sufficient margins into the circuit design, carefully taking into account the current and temperature characteristics of the LED being used.

Applications have become more demanding in recent years because of the need to detect non-opaque currency bills and other paper products (as opposed to metal or other opaque materials). In these applications, it is more difficult to incorporate appropriate circuit margins so as to ensure that malfunctions do not occur during operation.

5.2.3 Flux cleaning for photosensors

(1) Single devices

When cleaning photosensors to remove flux, make sure that no residual reactive ions remain. Do not rub device markings with a brush or with your hand during cleaning or while the devices are still wet with the cleaning agent. Doing so can rub off the markings or scratch the surface of the devices, especially the lens. For a description of flux cleaning, please refer to section 1.4.2. Ultrasonic cleaning should not be used with metal can-type packages (hermetically-sealed packages) because the bonding wires can become disconnected due to resonance during the cleaning process.

(2) Complex devices

Do not completely immerse devices in the solvent bath. If residual reactive ions are left on the emitter or detector, it will affect the light-emitting characteristics. When cleaning devices to remove flux, clean only the leads with alcohol. We also recommend using no-cleaning flux(*). For surface-mount photosensors, use no-cleaning flux and do not clean the device.

(*) No-cleaning flux contains 0.05 wt% or less halogen, as (e.g. Cl)specified by JIS A.

5.2.4 Reliability Characteristics

(1) Test data for typical product types

The following lists the results of various reliability evaluations performed on typical photosensor product types. For estimated lifetimes of Toshiba photosensor LEDs, please refer to Section 5.3.3(2).

Table 5.2.1 Infrared LED (TLN113) reliability test data

1. Tables of Test Conditions

1-1 Thermal Environment Tests

Test	Applicable Standard	Test Conditions	Remarks
Soldering heat	JIS C7021 A-1	T_{sol} = 260°C, 10 secs, once	
Temperature cycling	JIS C7021 A-4	−30°C to 25°C to 100°C to 25°C 30 mins 5 mins 30 mins 5 mins	100 cycles
Thermal shock	JIS C7021 A-3	0 $\longleftrightarrow$ 100°C 5 mins 5 mins	50 cycles
Moisture resistance	JIS C7021 A-5	25°C to 65°C to −10°C, 90% to 98% 24 hrs/cycle	10 cycles

1-2 Mechanical Environment Test

Test	Applicable Standard	Test Conditions	Remarks
Vibration	JIS C7021 A-10	100 Hz to 2000 Hz to 100 Hz 196 m/s^2 (20 g) 4 times each in 3 directions	
Mechanical shock	JIS C7021 A-7	14,700 m/s^2 (1,500 g), 0.5 ms 3 times each in 4 directions	
Constant acceleration	JIS C7021 A-9	196,000 m/s^2 (20,000 g), 1 minute once each in 6 directions	
Solderability	JIS C7021 A-2	230°C, 5 secs, once	95% or more (using flux)
Lead integrity	JIS C7021 A-11	Load 2.5 N (0.25 kgf) 0° to 90° to 0° bent 3 times	No separation or breakage allowed

1-3 Lifetime Tests

Test	Applicable Standard	Test Conditions	Remarks
Steady-state operation	JIS C7021 B-1	I_F = 40 mA Ta = 25°C	1,000 hours
High-temperature storage	JIS C7021 B-10	Ta = 100°C	1,000 hours
High-temperature, high-humidity storage	JIS C7021 B-11	Ta = 60°C, RH = 90%	1,000 hours

2. Failure Criteria (Ta = 25°C)

Parameter	Symbol	Measurement Conditions	Criteria	
			minimam	maximum
Forward voltage	V_F	I_F = 20 mA	—	USL × 1.2
Reverse current	I_R	V_R = 4 V	—	USL × 2
Luminous intensity	I_V	I_F = 20 mA	LSL × 0.5	—

USL: Upper specification limit; LSL: Lower specification limit

3. Test Results

3-1 Environment Test

Test Item	No.Samples	Failures	Test Item	Samples	Failures
Soldering heat	32	0 / 32	Vibration	11	0 / 11
Temperature cycling	50	0 / 50	Mechanical Shock	11	0 / 11
Thermal shock	32	0 / 32	Constant Acceleration	11	0 / 11
Moisture resistance	32	0 / 32	Solderability	11	0 / 11
			Lead Integrity	11	0 / 11

3-2 Life Test

Test Item	Samples	168 hrs	500 hrs	1000 hrs	Remarks
Steady-State operation	30	0 / 30	0 / 30	0 / 30	
High temperature storage	30	0 / 30	0 / 30	0 / 30	
High temperature and high humidity storage	30	0 / 30	0 / 30	0 / 30	

Table 5.2.2 Phototransistor (TPS01A) reliability test data

1. Tables of Test Conditions

1-1 Thermal Environment Tests

Test Item	Applicable Standard	Test Conditions	Remarks
Soldering heat	JIS C7021 A-1	T_{sol} = 60°C, 10 secs, once	Immersed to within 1.5 mm of the base
Temperature cycling	JIS C7021 A-4	–30°C to 25°C to 100°C to 25°C 30 mins 5 mins 30 mins 5 mins	100 cycles
Thermal shock	JIS C7021 A-3	0 ↔ 100°C 5 mins 5 mins	50 cycles
Moisture resistance	JIS C7021 A-5	25°C to 65°C to –10°C, 90% to 98% 24 hrs/cycle	10 cycles

1-2 Mechanical Environment Tests

Test Item	Applicable Standard	Test Conditions	Remarks
Vibration	JIS C7021 A-10	100 Hz ~ 2000 Hz ~ 100 Hz 196 m/s^2 (20 g) 4 times each in 3 directions	
Mechanical shock	JIS C7021 A-7	14,700 m/s^2 (1,500 g), 0.5 ms 3 times each in 4 directions	
Constant acceleration	JIS C7021 A-9	196,000 m/s^2 (20,000 g), 1 minute once each in 6 directions	
Solderability	JIS C7021 A-2	230°C, 5 secs, once	95% or more (using flux)
Lead integrity	JIS C7021 A-11	Load 2.5 N (0.25 kgf) 0° to 90° to 0° bent 3 times	No separation or breakage allowed

1-3 Life Tests

Test Item	Applicable Standard	Test Conditions	Remarks
Steady-state operation	JIS C7021 B-1	P_C = 150 mA Ta = 25°C	1,000 hours
High-temperature reverse bias	JIS C7021 B-19	V_{CE} = 30 V Ta = 100°C	1,000 hours
High-temperature storage	JIS C7021 B-10	Ta = 150°C	1,000 hours
High-temperature, High-humidity storage	JIS C7021 B-11	Ta = 60°C, RH = 90%	1,000 hours

2. Failure Criteria (Ta = 25°C)

Parameter	Symbol	Measurement Conditions	Criteria	
			minimum	maximum
Dark current	I_D	V_{CE} = 30V, *E = 0	—	USL × 2
Light current	I_L	V_{CE} = 30V, *E = 10 mW/cm^2	LSL × 0.7	—
Collector-emitter saturation voltage	V_{CE} (sat)	I_C = 0.3 mA, *E = 10 mW/cm^2	—	USL × 1.2

USL: Upper specification limit; LSL: Lower specification limit

3. Test Results

3-1 Environment Tests

Test	No. of Samples	Failures	Test	No. of Samples	No. of Failures
Soldering heat	32	0 / 32	Vibration	11	0 / 11
Temperature cycling	50	0 / 50	Mechanical shock	11	0 / 11
Thermal shock	32	0 / 32	Constant acceleration	11	0 / 11
Moisture resistance	32	0 / 32	Solderability	11	0 / 11
			Lead integrity	11	0 / 11

3-2 Lifetime Tests

Test Item	Samples	168 hrs	500 hrs	1000 hrs
Steady-state operation	30	0 / 30	0 / 30	0 / 30
High-temperature reverse bias	30	0 / 30	0 / 30	0 / 30
High-temperature storage	30	0 / 30	0 / 30	0 / 30
High-temperature, high-humidity storage	30	0 / 30	0 / 30	0 / 30

Table 5.2.3 Photointerrupter (TLP806) reliability test data

1. Tables of Test Conditions

1-1 Thermal Environment Tests

Test	Applicable Standard	Test Conditions	Remarks
Soldering heat	JIS C7021 A-1	T_{sol} = 260°C, 10 secs, once	Immersed to within 1.5 mm of the base
Temperature cycling	JIS C7021 A-4	−40°C to 25°C to 100°C to 25°C 30 mins 5 mins 30 mins 5 mins	100 cycles
Thermal shock	JIS C7021 A-3	0 ⟷ 100°C 5 mins 5 mins	50 cycles
Moisture resistance	JIS C7021 A-5	25°C to 65°C to −10°C, 90% to 98% 24 hrs/cycle	10 cycles

1-2 Mechanical Environment Tests

Test Item	Applicable Standard	Test Conditions	Remarks
Vibration	JIS C7021 A-10	100 Hz to 2000 Hz to 100 Hz 196 m/s^2 (20 g) 4 times each in 3 directions	
Mechanical shock	JIS C7021 A-7	14,700 m/s^2 (1,500 g), 0.5 ms 3 times each in 4 directions	
Constant acceleration	JIS C7021 A-9	196,000 m/s^2 (20,000 g), 1 minute once each in 6 directions	
Solderability	JIS C7021 A-2	230°C, 5 secs, once	95% or more (using flux)

1-3 Lifetime Tests

Test Item	Applicable Standard	Test Conditions	Remarks
Steady-state operation	—	I_F = 50 mA, P_C = 75 mW Ta = 25°C	1,000 hours
High-temperature reverse bias	JIS C7021 B-20	Ta = 85°C, V_{CE} = 24 V	1,000 hours
High-temperature storage	JIS C7021 B-10	Ta = 100°C	1,000 hours
High-temperature, high-humidity storage	JIS C7021 B-11	Ta = 60°C, RH = 90%	1,000 hours

2. Failure Criteria (Ta = 25°C)

Parameter	Symbol	Measurement Conditions	Criteria	
			minimum	maximum
LED forward voltage	V_F	$I_F = 10$ mA	LSL × 0.8	USL × 1.2
LED reverse current	I_R	$V_R = 5$ V	—	USL × 2
Dark current	I_D	$I_F = 0$, $V_{CE} = 24$ V	—	USL × 2
Current transfer ratio	I_C / I_F	$I_F = 10$ mA, $V_{CE} = 2$ V	LSL × 0.7	—
Collector-emmiter saturation voltage	V_{CE} (sat)	$I_F = 20$ mA, $I_C = 0.25$ mA	—	USL × 1.2

USL: Upper specification limit; LSL: Lower specification limit

3. Test Results

3-1 Environment Tests

Test	No. of Samples	No. of Failures	Test Item	No. of Samples	No. of Failures
Soldering heat	32	0 / 32	Vibration	11	0 / 11
Temperature cycling	50	0 / 50	Mechanical shock	11	0 / 11
Thermal shock	32	0 / 32	Constant acceleration	11	0 / 11
Moisture resistance	32	0 / 32	Solderability	11	0 / 11
			Lead integrity	11	0 / 11

3-2 Lifetime Tests

Test	No. of Samples	168 hrs	500 hrs	1000 hrs
Steady-state operation	30	0 / 30	0 / 30	0 / 30
High-temperature reverse bias	30	0 / 30	0 / 30	0 / 30
High-temperature storage	30	0 / 30	0 / 30	0 / 30
High-temperature, high-humidity storage	30	0 / 30	0 / 30	0 / 30

5.3 Photocoupler Reliability

5.3.1 Overview

Photocouplers typically consist of an electrically insulated infrared LED and photodetector optically coupled by a light-transmitting material. Photocouplers are often used instead of insulating transformers and mechanical relays to provide an interface between circuits with different ground potentials.

General-purpose photocouplers have structures similar to that shown in Figure 5.3.1 (internal view) and Figure 5.3.2 (cross-sectional view). The TLP521-1 is used as an example because of its simple form.

Photocouplers are manufactured with the infrared LED and phototransistor chip die-bonded to independent frames with a conductive paste. Au wire is connected to each electrode with a wire bonder. The emitter and detector frames are positioned so that they oppose each other with their optical axes aligned. The gap between the chips is filled with transparent resin and then transfer-molded with white epoxy resin (single-mold type).

There is also a double-molded type photocoupler in which the gap between the chips is mold-coupled with light-transmitting epoxy resin and then covered with light-blocking epoxy resin.

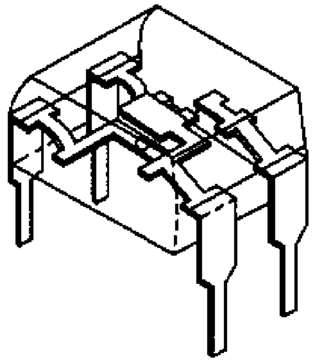


Figure 5.3.1 Internal view of TLP521-1

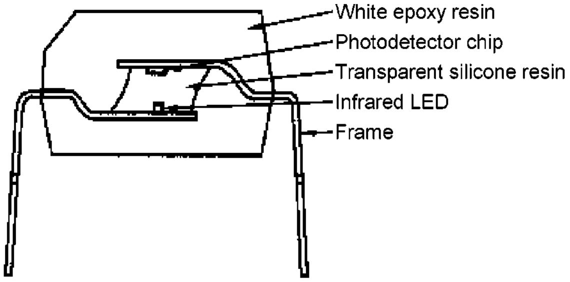


Figure 5.3.2 Cross-sectional view of TLP521-1

The TLP521-1 shown in Figure 5.3.1 comes in a 4-pin DIP package and consists of an LED and phototransistor pair. Other package types are also available, including 6-, 8-, 12- and 16-pin DIPs and mini-flat couplers (MFCs). In addition, some devices have a photothyristors, phototriac or photo IC serving as the photodetector. Such a wide selection of device types allows you to meet any application need.

Photocoupler basic characteristics are as follows:

(a) Input-output (I/O) isolation breakdown voltage (BV)

BV indicates I/O isolation performance, the most important function of photocouplers. With all input pins shorted together on one side and all output pins shorted together on the other side, BV is measured from input to output. Toshiba offers photocoupler product lines guaranteed at 2500 V_{rms}, 3750 V_{rms}, 4000 V_{rms} and 5000 V_{rms} for one minute. (When measuring BV, be sure to insert a circuit for overcurrent protection. Dielectric breakdown can occur even below the maximum rated voltage.)

(b) I/O coupling characteristic

This characteristic describes the electrical output signal strength relative to the input signal strength. It is represented by the current transfer ratio (CTR) for transistor couplers, and by the trigger LED current (I_{FT}) for thyristor and triac couplers.

There are many factors which influence a photocoupler's coupling characteristic:

① Electrical-to-optical conversion efficiency of the infrared LED
② Optical-to-optical transfer efficiency in the optical coupling section
③ Optical-to-electrical conversion efficiency of the photodetector
④ Electrical-to-electrical DC current gain of the photodetector

Thus, the I/O coupling characteristic of photocouplers is generally smaller than that of discrete devices (for example, only item ④, DC current gain, applies to transistors). CTR and I_{FT} are discussed further in Section 2.3.2 Design Precautions on the next page.

(c) Absolute maximum ratings

Photocoupler technical sheets give absolute maximum ratings for the infrared LED and photodetector chip individually as well as for the package as a whole. As with general-purpose discrete semiconductor devices, the absolute maximum ratings of photocouplers must not be exceeded, even momentarily. Note also that although Toshiba photocouplers are manufactured using mold resins that meet UL flammability level 94V-0, careful attention must be paid to the risk of overcurrent and overvoltage, since excessive current or voltage can cause fumes, fire or breakage.

5.3.2 Design Precautions

This section describes design precautions specific to photocoupler circuits. General precautions concerning semiconductor design are not discussed here.

(1) Transistor couplers

In a transistor coupler, the ratio between current I_F flowing through the input LED and current I_C flowing through the transistor output is given by

$CTR = I_C / I_F$ (%)

It is important to note that the parameters affecting CTR include input current I_F, output collector voltage V_{CE}, temperature Ta and elapsed time t.

A general-purpose TLP521-1 transistor coupler is rated as follows:

CTR = 50 ~ 600%
@I_F = 5 mA, V_{CE} = 5 V, Ta = 25°C and t = 0 (initial value)

Therefore, if circuit conditions in your design differ from those specified for the device, you must consider the effect each condition will have on CTR (I_C/I_F). Using the TLP521-1 as an example, Figure 5.3.3 shows I_C vs. I_F and Figure 5.3.4 shows I_C vs. Ta for reference.

Note that the respectively rather high and low CTR values of arbitrary samples A and B in Figure 5.3.3 do not necessarily represent the actual limits of the characteristic.

(2) Thyristor and triac couplers

In a thyristor or triac coupler, the thyristor or triac turns on when sufficient I_F current flows in the input LED. This is referred to as the trigger current I_{FT}.

If specifications guarantee that I_{FT} = 10 mA maximum, for example, the output device will turn on when no more than 10 mA is applied to the LED. Accordingly, I_F = 10 mA or greater is required for the circuit design in this case. Generally, I_F should be designed to be 1.5 to 2.5 times the I_{FT} maximum to take into account the effects of temperature and aging on the I_{FT} characteristic, as was described for transistor couplers above. Figure 5.3.5 shows I_{FT} vs. T_a. I_F must be designed to suit actual application conditions and requirements (for example, the temperature range and operation lifetime).

Note that triac couplers require a snubber circuit (e.g. Rs + Cs = 47 Ω + 0.033 μF) to prevent erratic triac operation due to external noise.

(3) Photo-IC couplers

IC couplers include a photodetector and a processing circuit. The I/O optical coupling characteristic is expressed for transistor-type IC couplers, such as the TLP550, by the current transfer ratio (CTR), as in (1) above. For phototriac-type IC couplers, such as the TLP552, the I/O optical coupling characteristic is expressed as by the LED input current necessary to turn on the detector logic, as in (2) above.

Precautions specific to photo-IC couplers are as follows:

(a) Devices with low pin-to-pin surge tolerance require caution suring handling and mounting.

(b) Some devices require a bypass capacitor of around 0.1 µF between the ground and power supply pins on the output side to prevent V_{CC} oscillation.

For further details, refer to the relevant photocoupler and discrete semiconductor databooks.

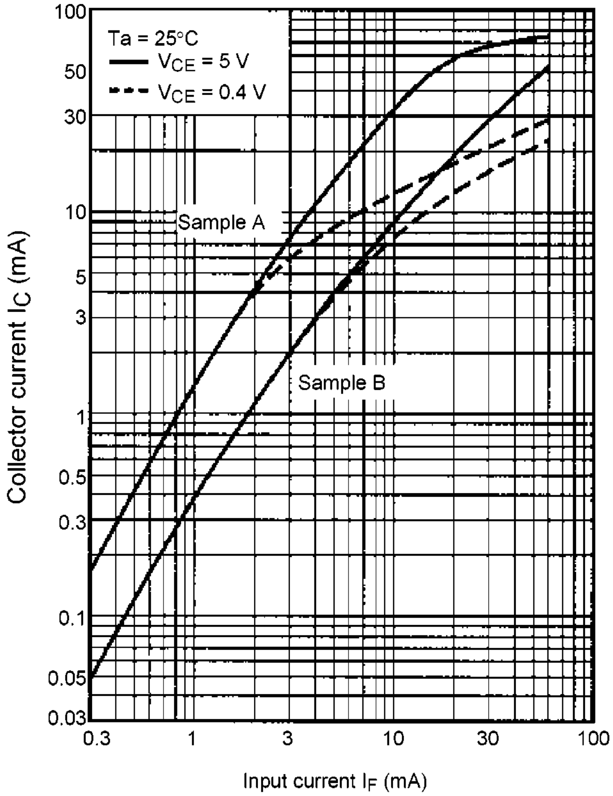


Figure 5.3.3 I_C **vs.** I_F **characteristic for TLP521-1**

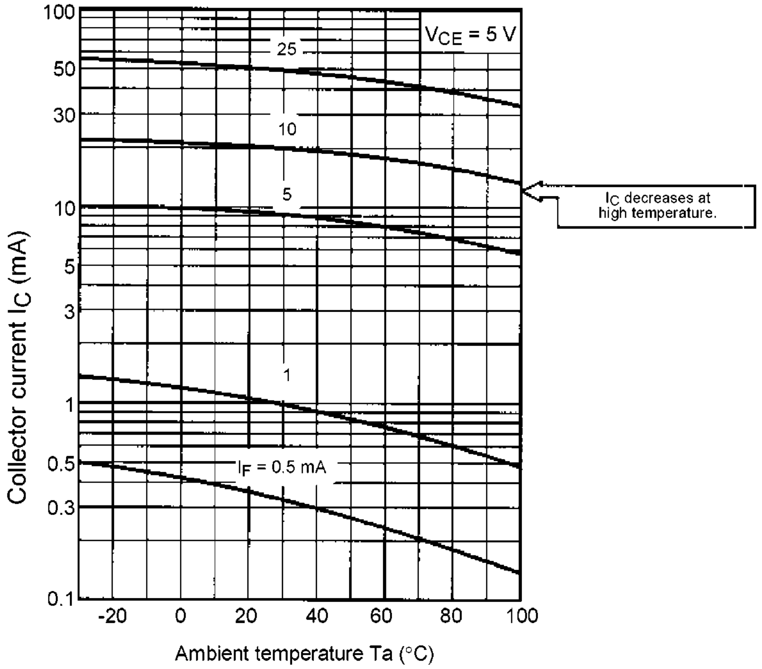


Figure 5.3.4 I_C vs. Ta characteristic for TLP521-1

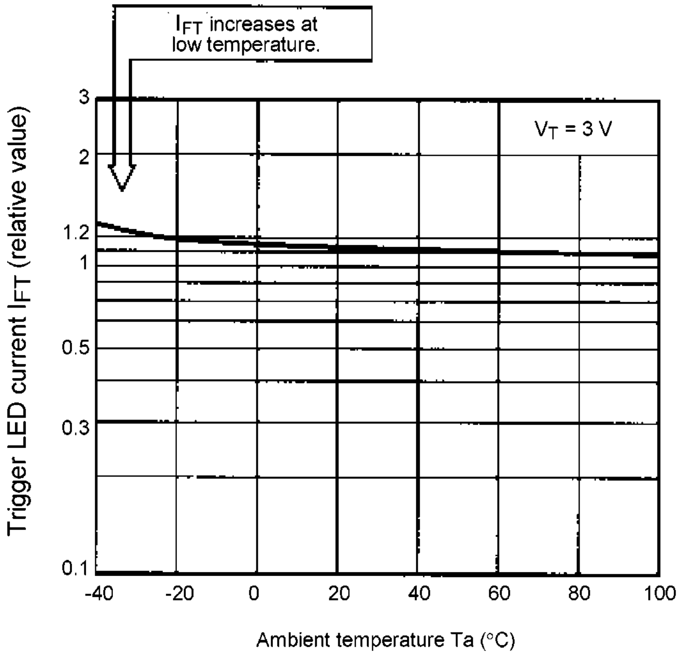


Figure 5.3.5 I_{FT} vs. Ta characteristic for TLP521-1

5.3.3 Reliability Characteristics

(1) Test data for typical product types

Table 5.3.1 Phototransistor coupler (TLP521-1) reliability test data

1. Table of Test Conditions

1-1 Thermal Environment Tests

Test	Applicable Standard	Test Condition	Remarks
Soldering heat	JIS C7021 A-1	T_{sol} = 260°C, 10 secs, once	Immersed 1.5 mm from base of device
Temperature cycling	JIS C7021 A-4	–55°C to 25°C to 125°C to 25°C 30 mins 5 mins 30 mins 5 mins	100 cycles
Thermal shock	JIS C7021 A-3	0 ←→ 100°C 5 mins 5 mins	50 cycles
Moisture resistance	JIS C7021 A-5	25°C to 65°C to –10°C, 90 to 98% 24 hrs/cycle	10 cycles

1-2 Mechanical Environment Tests

Test	Applicable Standard	Test Condition	Remarks
Vibration	JIS C7021 A-10	100 Hz to 2,000 Hz to 100 Hz 196 m/s^2 (20 g) 4 times each in 3 directions	
Mechanical shock	JIS C7021 A-7	14,700 m/s^2 (1,500 g), 0.5 ms 3 times each in 4 directions	
Constant acceleration	JIS C7021 A-9	196,000 m/s^2 (20,000 g), 1 minute once each in 6 directions	
Solderability	JIS C7021 A-2	230°C, 5 secs, once	95% or more (using flux)
Lead integrity	JIS C7021 A-11	Load 2.5 N (0.25 kgf) 0 ~ 90° ~ 0, bent 3 times	No separation or breakage allowed

1-3 Lifetime Tests

Test	Applicable Standard	Test Condition	Remarks
Steady-state operation	—	I_F = 70 mA, P_C = 112.5W Ta = 50°C	Applies to the TLP521. 1,000 hours
High-temperature reverse bias	JIS C7021 B-8	Ta = 100°C, V_{CE} = 24 V	1,000 hours
High-temperature Storage	JIS C7021 B-10	Ta = 125°C	1,000 hours
High-temperature, and high-humidity storage	JIS C7021 B-11	Ta = 60°C, RH = 90%	1,000 hours

1-4 Others

Test	Applicable Standard	Test Condition	Remarks
Autoclave test (PCT)	EIAJ SD-121 M-18, Condition E	Ta = 121°C, 203 kPa (2.0 atm) (RH = 100%)	24 hours

2. Failure Criteria (Ta = 25°C)

Parameter	Symbol	Measurement Conditions	Criteria	
			Minimum	Maximum
LED forward voltage	V_F	I_F = 10 mA	LSL × 0.8	USL × 1.2
LED reverse current	I_R	V_R = 5 V	—	USL × 2
Dark current	I_{CEO}	I_F = 0, V_{CE} = 24 V	—	USL × 2
Current transfer ratio	I_C/I_F	I_F = 5 mA, V_{CE} = 5 V	LSL × 0.7	USL × 1.3
Collector-emitter breakdown voltage	V_{CEO}	I_C = 0.5 mA	LSL × 0.9	—

USL: Upper specification limit; LSL: Lower specification limit

3. Test Results

3-1 Environment Tests

Test	No. of Samples	No. of Failures	Test	No. of SAMPLES	No. of FAILURES
Soldering heat	32	0 / 32	Vibration	11	0 / 11
Temperature cycling	50	0 / 50	Mechanical shock	11	0 / 11
Thermal shock	32	0 / 32	Constant acceleration	11	0 / 11
Moisture resistance	32	0 / 32	Solderability	11	0 / 11
			Lead integrity	11	0 / 11

3-2 Lifetime Tests

Test	No. of SAMPLES	168 hrs	500 hrs	1,000 hrs
Steady-state operation	30	0 / 30	0 / 30	0 / 30
High-temperature reverse bias	30	0 / 30	0 / 30	0 / 30
High-temperature storage	30	0 / 30	0 / 30	0 / 30
High-temperature and high-humidity storage	30	0 / 30	0 / 30	0 / 30

3-3 Other

Test	No. of Samples	24 hrs
Autoclave test (PCT)	20	0 / 20

Table 5.3.2 Phototriac coupler (TLP560J) reliability test data

1. Table of Test Conditions

1-1 Thermal Environment Tests

Test	Applicable standard	Test conditions	Remarks
Soldering heat	JIS C7021 A-1	T_{sol} = 260°C, 10 secs, once	Immersed 1.5 mm from base of device
Temperature cycling	JIS C7021 A-4	−40°C to 25°C to 125°C to 25°C 30 mins 5 mins 30 mins 5 mins	100 cycles
Thermal shock	JIS C7021 A-3	0 ↔ 100°C 5 mins 5 mins	50 cycles
Moisture resistance	JIS C7021 A-5	25°C to 65°C to −10°C, 90 to 98% 24 hrs/cycle	10 cycles

1-2 Mechanical Environment Test

Test	Applicable standard	Test conditions	Remarks
Vibration	JIS C7021 A-10	100 Hz to 2000 Hz to 100 Hz 196 m/s^2 (20 g) 4 times each in 3 directions	
Mechanical shock	JIS C7021 A-7	14,700 m/s^2 (1,500 g), 0.5 ms 3 times each in 4 directions	
Constant acceleration	JIS C7021 A-9	196,000 m/s^2 (20,000 g), 1 minute once each in 6 directions	
Solderability	JIS C7021 A-2	230°C, 5 secs, once	95% or more (using flux)
Lead integrity	JIS C7021 A-11	Load 2.5 N (0.25 kgf) 0 to 90° to 0, bent 3 times	No separation or breakage allowed

1-3 Lifetime Tests

Test	Applicable standard	Test conditions	Remarks
Steady-state Operation	—	I_F = 50 mA, I_T (RMS) = 70 mA Ta = 50°C	1,000 hours
High-temperature Reverse Bias	JIS C7021 B-20	Ta = 85°C, V_{DRM} = 600 V_{peak}	Applies to the TLP521. 1,000 hours
High-temperature Storage	JIS C7021 B-10	Ta = 125°C	1,000 hours
High-temperature, and high-humidity storage	JIS C7021 B-11	Ta = 60°C, RH = 90%	1,000 hours

1-4 Others

Test	Applicable standard	Test conditions	Remarks
Autoclave test (PCT)	EIAJ SD-121 M-18, Condition E	Ta = 121°C, 203 kPa (2.0 atm) (RH = 100%)	24 hours

2. Failure Criteria (Ta = 25°C)

Parameter	Symbol	Measuring Conditions	Criteria	
			minimum	maximum
LED forward voltage	V_F	I_F = 10 mA	LSL × 0.8	USL × 1.2
LED reverse current	I_R	V_R = 5 V	—	USL × 2
Repetitive peak off-state current	I_{DRM}	V_{DRM} = 600 V	—	USL × 2
Peak forward current	V_{TM}	I_{TM} = 100 mA	—	USL × 1.2
Trigger LED current	I_{FT}	V_R = 6 V	—	USL × 1.3

USL: Upper specification limit; LSL: Lower specification limit

3. Test Results

3-1 Environment Tests

Test	No. of Samples	No. of Failures	Test	No. of Samples	No. of Failures
Soldering heat	32	0 / 32	Vibration	11	0 / 11
Temperature cycling	50	0 / 50	Mechanical shock	11	0 / 11
Thermal shock	32	0 / 32	Constant acceleration	11	0 / 11
Moisture resistance	32	0 / 32	Solderability	11	0 / 11
			Lead integrity	11	0 / 11

3-2 Lifetime Tests

Test	No. of Samples	168 hrs	500 hrs	1000 hrs	Remarks
Steady-state operation	30	0 / 30	0 / 30	0 / 30	
High-temperature reverse bias	30	0 / 30	0 / 30	0 / 30	
High-temperature storage	30	0 / 30	0 / 30	0 / 30	
High-temperature, high-humidity storage	30	0 / 30	0 / 30	0 / 30	

3-3 Other

Test	No. of Samples	24 hours
Autoclave test (PCT)	20	0 / 20

(2) Estimated lifetime of Toshiba photosensor and photocoupler LEDs

Broadly classified, Toshiba photosensor and photocouplers use three types of LED. Estimated lifetimes are calculated for each type. The type of LED used in each photosensor or photocoupler is shown on the next page. The table below and the diagrams on pages 5-80 to 5-82 show estimated lifetimes. These estimates are based on long-term data taken from small lots, however, and thus can only be used for reference purposes.

The following equations shows the correlation between LED radiant power degradation and the degradation of the optical coupling characteristics.

1) I_C/I_F fluctuation: One-to-one correlation with LED radiant power degradation

$I_C/I_F(t)$

$I_C/I_F(o)$

$$\frac{\text{CTR (t)}}{\text{CTR (o)}} = \frac{P_o(t)}{P_o(o)}$$

2) I_{FLH}/I_{FHL} fluctuation: One-to-one correlation with the reciprocal of LED radiant power degradation

$$\frac{I_{FT}(t)}{I_{FT}(o)} = \left[\frac{P_o(t)}{P_o(o)}\right]^{-1}$$

Table 5.3.3 LEDs used in photosensors

Photosensor	LED	Photosensor	LED	Photosensor	LED	Photosensor	LED
TLN101A	A	TLP814	A	TLP910	A	TLP1208 (C3)	A
TLN102	A	TLP818	A	TLP1000A	A	TLP1209 (C7)	A
TLN103A	A	TLP822	A	TLP1001A	A	TLP1211	A
TLN104	A	TLP824	A	TLP1002A	A	TLP1215 (C1)	A
TLN104(LB)	A	TLP825	A	TLP1003A	A	TLP1217 (C2)	A
TLN105B	A	TLP827	A	TLP1004A	A	TLP1221 (C7)	A
TLN107A	A	TLP828	A	TLP1005A	A	TLP1224	A
TLN108	A	TLP830	A	TLP1006A	A	TLP1224 (C1)	A
TLN110	A	TLP831	A	TLP1007A	A	TLP1230 (C4)	A
TLN113	A	TLP832	A	TLP1014	A	TLP1231 (C5)	A
TLN115A	A	TLP833	A	TLP1015	A	TLP1241 (C5)	A
TLN119	A	TLP836	A	TLP1016	A	TLP1242 (C6)	A
TLN201	B	TLP837	A	TLP1017	A	TLP1251 (C5)	A
TLN203	B	TLP853	A	TLP1018	A	TLP1252 (C6)	A
TLN205	B	TLP862	A	TLP1019	A	TLP1253 (C6)	A
TLN221	C	TLP863	A	TLP1020	A		
TLN223	C	TLP864	A	TLP1023	A		
TLN225	C	TLP865	A	TLP1024	A		
TLN226	C	TLP866	A	TLP1025	A		
TLN227	C	TLP867	A	TLP1029	A		
TLP507A	A	TLP869	A	TLP1034	A		
TLP800A	A	TLP871	A	TLP1201A	A		
TLP801A	A	TLP907	A	TLP1201A (C1)	A		
TLP803	A	TLP907(LB)	A	TLP1201A (C2)	A		
TLP810	A	TLP938	A	TLP1204 (C1)	A		
TLP812	A	TLP938(LB)	A	TLP1204 (C3)	A		
TLP813	A	TLP909	A	TLP1205	A		

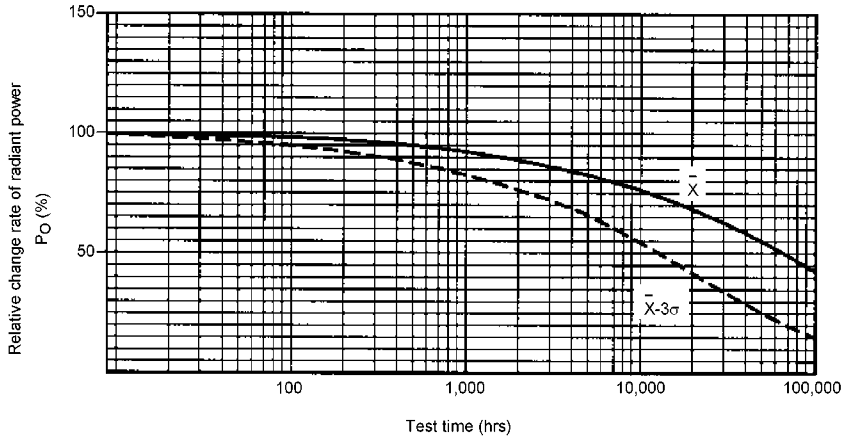
A: GaAs infrared LED, B: GaAlAs (SH) infrared LED, C: GaAlAs (DH) infrared LED

Table 5.3.4 LEDs used in photocouplers

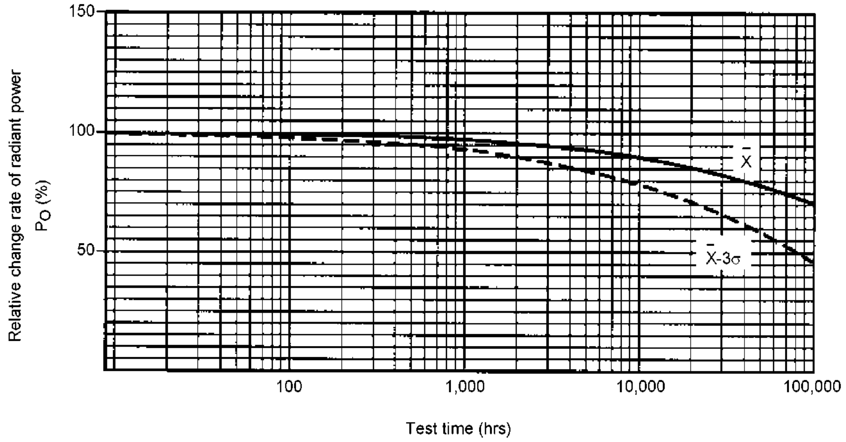
Coupler Name	LED Type	Coupler Name	LED Type	Coupler Name	LED Type	Coupler Name	LED Type	Coupler Name	LED Type
4N25 (short)	A	TLP160G	A	TLP523	A	TLP620	A	TLP666JF	A
4N25A (short)	A	TLP160J	A	TLP523-2	A	TLP620-2	A	TLP668J	C
4N26 (short)	A	TLP161G	A	TLP523-3	A	TLP620-3	A	TLP721	A
4N27 (short)	A	TLP161J	A	TLP523-4	A	TLP620-4	A	TLP721F	A
4N28 (short)	A	TLP168J	C	TLP525G	A	TLP621	A	TLP731	A
4N29 (short)	A	TLP180	A	TLP525G-2	A	TLP621-2	A	TLP732	A
4N29A (short)	A	TLP181	A	TLP525G-3	A	TLP621-3	A	TLP733	A
4N30 (short)	A	TLP190B	A	TLP525G-4	A	TLP621-4	A	TLP733F	A
4N31 (short)	A	TLP191B	C	TLP531	A	TLP624	A	TLP743	A
4N32 (short)	A	TLP215	B	TLP532	A	TLP624-2	A	TLP734F	A
4N32A (short)	A	TLP216	B	TLP541G	A	TLP624-3	A	TLP741G	A
4N33 (short)	A	TLP225A	A	TLP542G	A	TLP624-4	A	TLP741J	A
4N35 (short)	A	TLP250	C	TLP543J	A	TLP626	A	TLP747G	A
4N36 (short)	A	TLP251	B	TLP545J	A	TLP626-2	A	TLP747GF	A
4N37 (short)	A	TLP280	A	TLP550	B	TLP626-3	A	TLP747J	A
4N38 (short)	A	TLP280-4	A	TLP551	B	TLP626-4	A	TLP747JF	A
4N38A (short)	A	TLP281	A	TLP552	B	TLP627	A	TLP750	B
6N135	B	TLP281-4	A	TLP553	B	TLP627-2	A	TLP751	B
6N136	B	TLP296G	A	TLP554	B	TLP627-3	A	TLP759	B
6N137	B	TLP320	A	TLP555	B	TLP627-4	A	TLP795G	C
6N138	B	TLP320-2	A	TLP557	B	TLP628	A	TLP2200	B
6N139	B	TLP320-3	A	TLP558	B	TLP628-2	A	TLP2530	B
TLP112	B	TLP320-4	A	TLP559	B	TLP628-3	A	TLP2531	B
TLP112A	C	TLP321	B	TLP560G	A	TLP628-4	A	TLP2601	B
TLP113	B	TLP321-2	A	TLP560J	A	TLP629	A	TLP2630	B
TLP114A	C	TLP321-3	A	TLP561G	A	TLP629-2	A	TLP2631	B
TLP115	B	TLP321-4	A	TLP561J	A	TLP629-3	A	TLP3502	A
TLP115A	C	TLP330	A	TLP570	A	TLP629-4	A	TLP3502A	A
TLP120	A	TLP331	A	TLP571	A	TLP630	A	TLP3503	A
TLP120-4	A	TLP332	A	TLP572	A	TLP631	A	TLP3506	A
TLP121	A	TLP371	A	TLP582	C	TLP632	A	TLP3507	A
TLP121-4	A	TLP372	A	TLP590B	C	TLP641G	A	TLP3520	A
TLP124	A	TLP373	A	TLP591B	C	TLP641J	A	TLP3520A	A
TLP124-4	A	TLP504A	A	TLP595A	C	TLP651	B	TLP3521	A
TLP126	A	TLP511GA	A	TLP595B	C	TLP665G	A	TLP3526	A
TLP127	A	TLP512	B	TLP595G	C	TLP665GF	A	TLP3527	A
TLP127-4	A	TLP513	B	TLP596A	A	TLP665J	A	TLP3530	A
TLP130	A	TLP521-1	A	TLP596B	A	TLP665JF	A	TLP3560	A
TLP131	A	TLP521-2	A	TLP596G	A	TLP666G	A	TLP3661	A
TLP137	A	TLP521-3	A	TLP597G	A	TLP666GF	A		
TLP141G	A	TLP521-4	A	TLP611J	A	TLP666	A		

A: GaAs infrared LED, B: GaAlAs (SH) infrared LED, C: GaAlAs (DH) infrared LED

Test conditions: I_F = 50 mA, Ta = 40°C



Test conditions: I_F = 20 mA, Ta = 40°C



Test conditions: I_F = 10 mA, Ta = 40°C

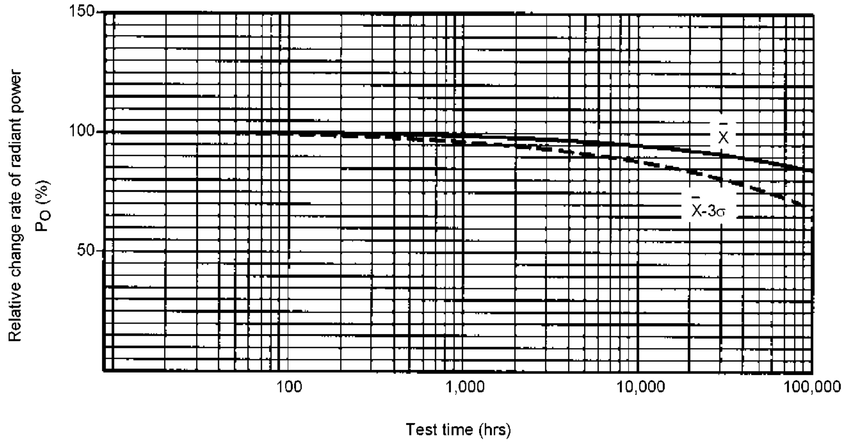
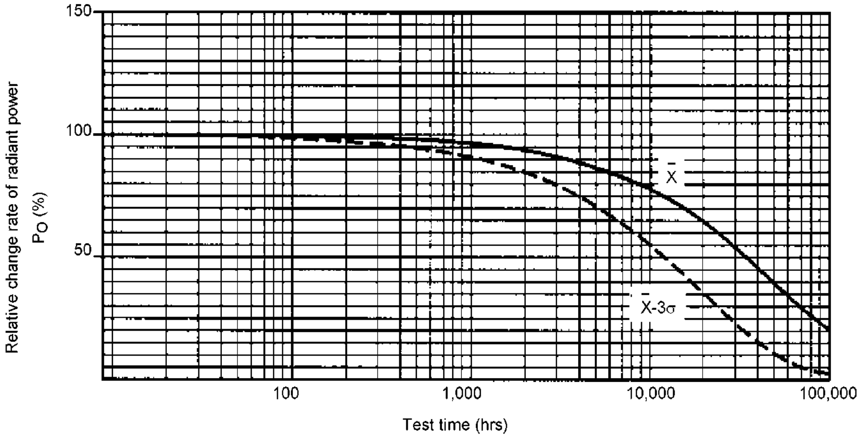
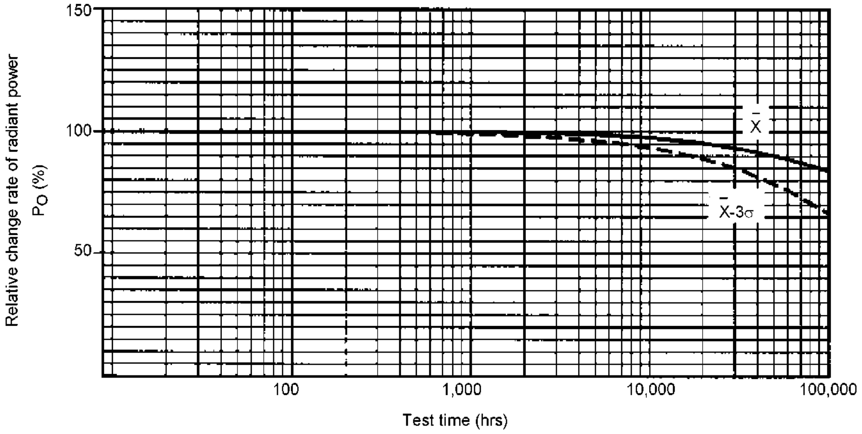


Figure 5.3.6 GaAs infrared LED estimated degradation data

Test conditions: I_F = 50 mA, Ta = 40°C



Test conditions: I_F = 20 mA, Ta = 40°C



Test conditions: I_F = 10 mA, Ta = 40°C

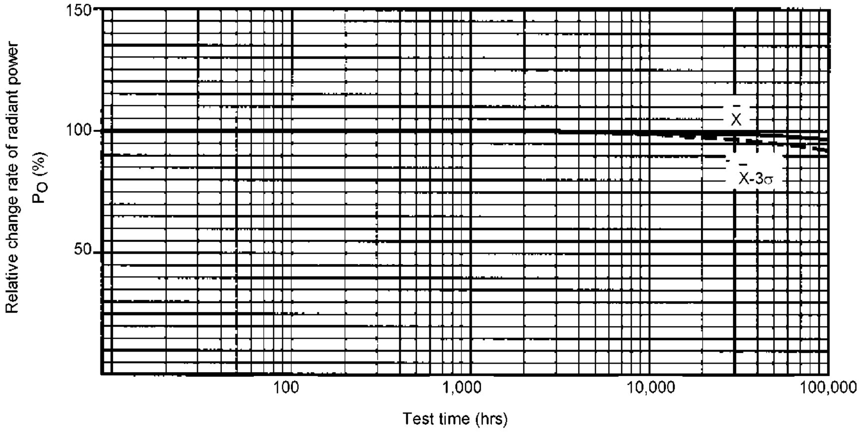


Figure 5.3.7 GaAlAs (SH) infrared LED estimated degradation data

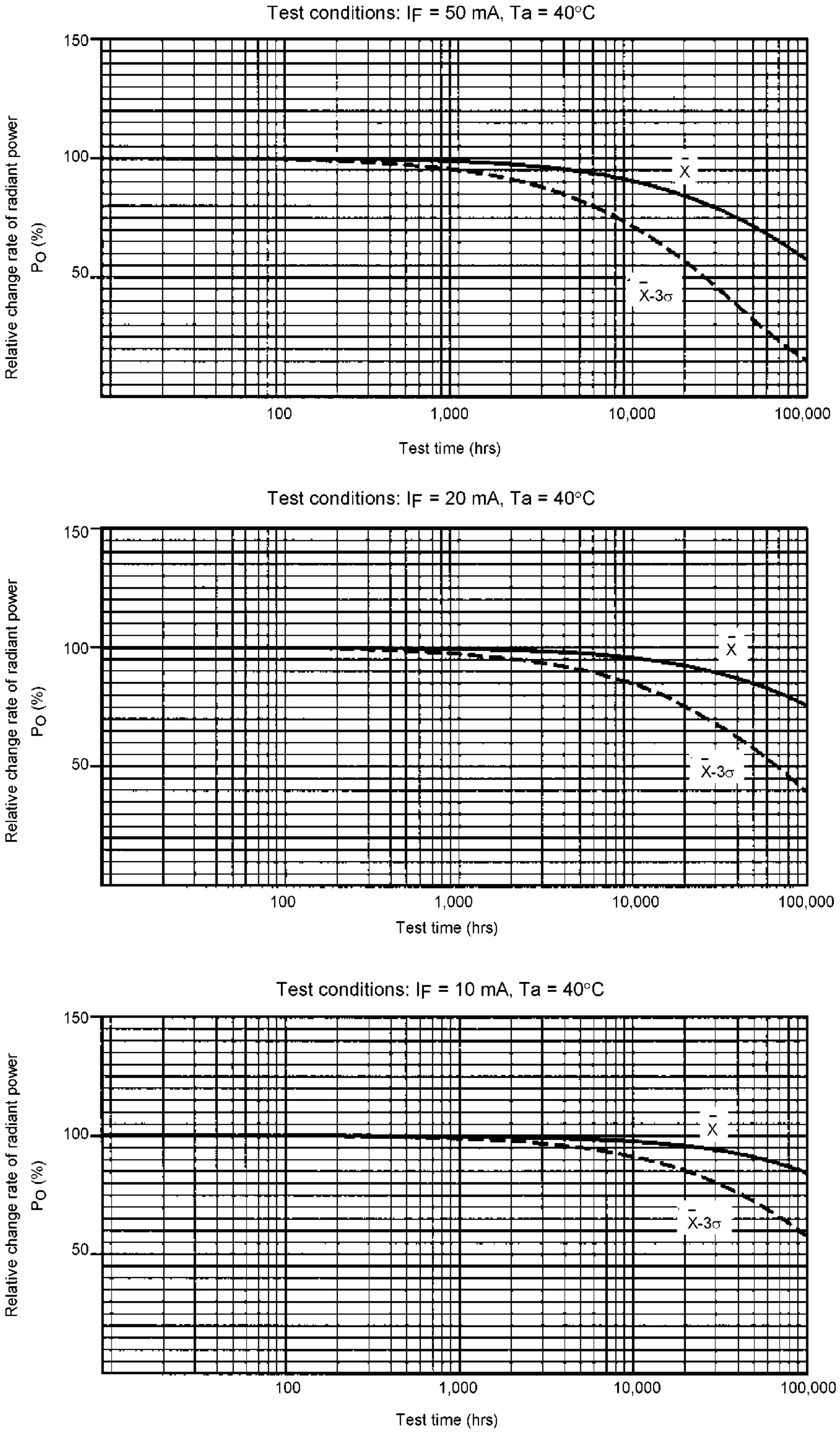


Figure 5.3.8 GaAlAs (DH) infrared LED estimated degradation data

5.4 TOSLINK® Reliability

5.4.1 Overview

TOSLINK converts data from electrical to optical form and transmits it. TOSLINK comprises the following devices:

(1) Fiber-optic transmitter module

This device converts electrical signals into optical signals. It contains a light-emitting diode (LED) and a transmission circuit to drive the LED. The LED is turned on and off by the digital input signal going high and low respectively.

(2) Fiber-optic receiver module

This device converts optical signals back into electrical signals. It consists of a photodiode (PD) and a receiver IC that can amplify and reshape the signal waveform. A digital electrical signal is output, its value (High or Low) whether or not a light signal is received.

(3) Optical-fiber

This is the transmission path medium for sending optical signals from the fiber-optic transmitter module to the fiber-optic receiver module. Different types of optical fiber are used, depending on the transmission distance.

(4) Optical connector

This device efficiently combines a fiber-optic transmitter module, a fiber-optic receiver module and optical fiber into an integrated system. Optical connectors are typically situated at each end of an optical fiber cable.

To transmit data optically, select the appropriate optical fiber for the transmission distance. Then, obtain fiber-optic modules with wavelength characteristics appropriate for the selected optical fiber.

Transmission Distance	Type of Optical Fiber	Emission Wavelength
Short-haul transmission (up to 50 m)	Plastic optical fiber	650 nm ~ 670 nm
Mid-range transmission (up to 1 km)	Plastic-clad quartz optical fiber	800 nm
Long-haul transmission (1 km and over)	Quartz optical fiber	850 nm, 1300 nm

5.4.2 Structure of Fiber-Optic Modules

TOSLINK fiber-optic transmitter/receiver modules are available in two types: a plastic package with a resin-molded internal unit that can be produced easily in large quantities, and a ceramic package which affords a high degree of protection from the environment to the internal unit.

(1) Plastic-package type

Figure 5.4.1 shows how an internal fiber-optic transmitter/receiver module is housed in a plastic package. There are three primary components: a transmitter unit encapsulated in transparent plastic comprised of an LED mounted on a lead frame, a single-chip transmitter IC with an LED driver circuit, and a chip capacitor; a receiver unit encapsulated in transparent plastic comprised of a photodiode (PD) mounted on a lead frame, a receiver IC capable of reshaping the waveform, and a chip capacitor; and the casing which provides the coupling with the optical connectors. The casing is made of a conductive plastic that provides shielding.

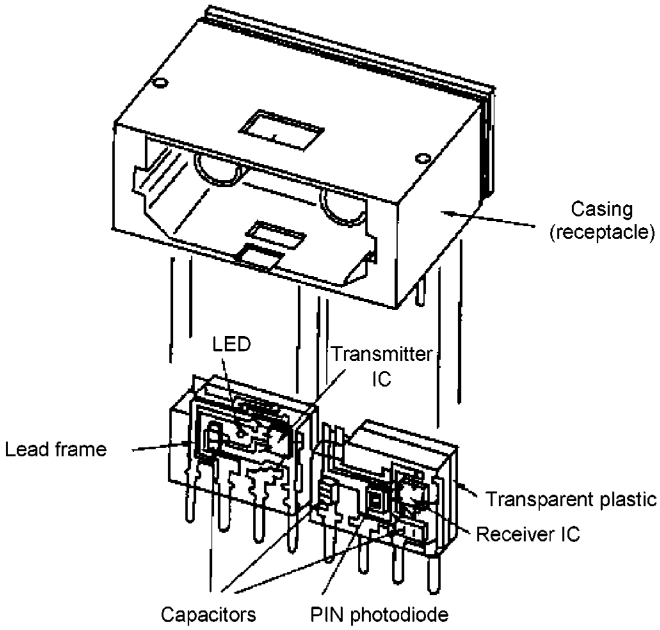


Figure 5.4.1 Structure of fiber-optic transmitter/receiver in plastic package

(2) Ceramic-package type

Figure 5.4.2 shows the structure of an internal fiber-optic transmitter/receiver module housed in a ceramic package. Mounted on a ceramic substrate are an LED, a transmitter IC for driving the LED, a photodiode, a receiver IC capable of reshaping the waveform, and a chip capacitor. The ceramic substrate is hermetically sealed with metal shells which include glass windows.

This structure affords the internal unit a high degree of protection from moisture and from the external environment.

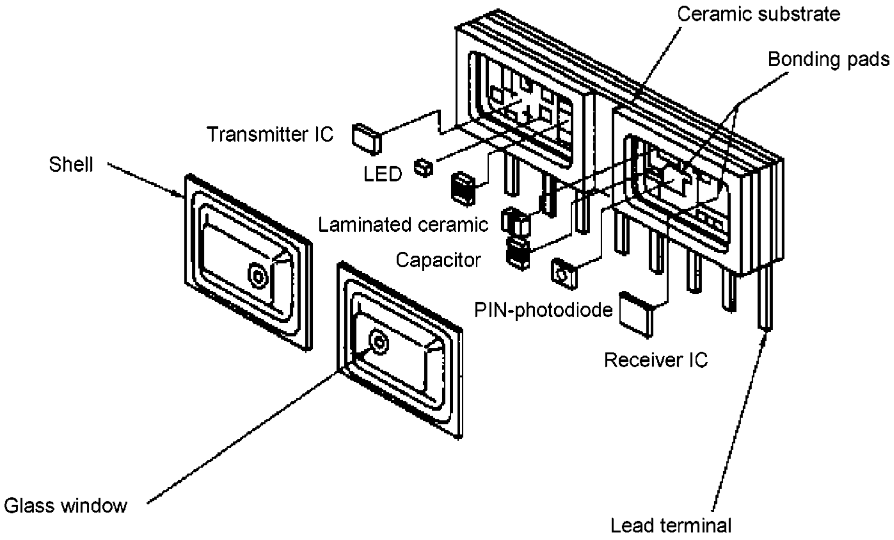


Figure 5.4.2 Structure of fiber-optic transmitter/receiver module in a ceramic package

5.4.3 Usage Precautions

(1) Reliability

In an optical module that has been in use for some time, nearly all of the deterioration in characteristics is due to a reduction in the fiber-coupled output power (P_f). This is due to deterioration over time in the level of optical output of the LED used as the light source.

The drop in the LED's optical output is thought to be caused by crystal flaws in the wafer or stress in the mold resin, although the detailed causes are not clear.

Although LEDs used for optical communications are generally considered to have an almost indefinite lifetime, their optical output does fall over time.

The lifetime of light-emitting devices is greatly affected by the operating conditions and operating environment as well as by the lifespan characteristics of the particular device.

Before you select a device and set the operating conditions, Toshiba recommend that you first check the device's lifetime characteristics.

For information on product reliability, contact a Toshiba sales office. In stringent environmental conditions, frequent maintenance, such as checking the amount of light emitted, is recommended.

In the case of the red LEDs used in the TOTX195 and TODX297, for example, a light-absorbing layer may form on the surface of the LED as the aluminum in the liquid crystal oxidizes, causing the optical output to fall. As this tendency is more pronounced in high-humidity environments, it is recommended that products containing red LEDs not be used in such environments.

For high-humidity environments or applications requiring a long lifespan, Toshiba recommend the use of a TOSLINK ceramic-package optical module.

(2) Soldering

Optical modules include semiconductor devices but are essentially optical components. When soldering, be careful that flux does not adhere to the light-emitting or light-receiving surfaces.

Take the same care when cleaning off flux after soldering.

Some optical modules include a protective cap. This cap is intended to prevent accidental operation when the module is not in use. It is not dust- or water-proof. Because the optical module is an optical component, Toshiba do not recommend soldering methods or post-solder flux cleaning methods in which flux could affect the module. Toshiba recommend first soldering without mounting the module, then cleaning the PCB. Finally, hand-solder the module and refrain from cleaning thereafter.

If it is not possible to hand-solder the module, one way of avoiding the effects of flux is to use non-halogen (chlorine-free) flux, taking care not to leave behind chlorine or any other residue, and omotting the post-solder cleaning. In this case, too, be sure to check the reliability of the device.

(3) Noise Resistance

The case for the TOSLINK (simplex) optical receiving module and (duplex) optical transceiving module is made of conductive plastic.

The case is designed to provide shielding when the reinforced pin at the front of the module is grounded. When using the module, connect this pin to SIGNAL-GND.

Since the case for the optical receiving module and optical transceiving module has a resistance of several tens of ohms, take care that the case does not touch the power line or any other circuits.

Generally, the use of optical transmission devices is considered to improve noise resistance.

While optical fibers are certainly not affected by noise, optical modules, particularly receiver modules, are comparatively sensitive to noise because they handle such minute current signals.

To improve noise resistance, the TOSLINK case is treated to make it conductive. However, since the signal output from the optical receiving module photodiode is a minute current signal, in some environments the shielding from the case alone is insufficient to protect against noise. When using a TOSLINK device, conduct live tests to check noise resistance.

A simple noise filter is compulsory for the power lines for the TOSLINK optical receiving module and optical transceiving module.

If there are significant power supply ripples, further filter reinforcement is necessary. Also, if the optical module is to be placed in a location susceptible to emission noise, Toshiba recommend covering the optical module and power supply filter with a metal cover to enhance the shielding.

(4) Protective Cap

When the optical module is not in use, cover it with the protective cap. Take particular care with the optical receiving module since, depending on the circuit used, extraneous light may be input to the module when the TOSLINK device is not in use and may adversely affect other circuits.

(5) Vibration, Shock and Stress

Plastic-molded optical modules are plastic-sealed devices whose wires are fixed with resin. While this structure makes them comparatively resistant to vibration and shock, wire breakage has been observed in equipment in which the module is used when the soldering and connections are exposed to vibration, shock or stress. Therefore, when using a plastic-molded optical module in equipment with high vibration levels, ensure that the structure is designed to withstand vibration, shock and stress.

Ceramic-package optical modules are ceramic-sealed, with a hollow interior. Since the wires in the module are not fixed, the module is susceptible to vibration and shock. Therefore, when using a ceramic-package optical module in equipment subject to high levels of vibration and shock, ensure that the structure of the equipment is designed to withstand vibration, shock and stress.

(6) Supply Voltage

The modules should be used with a supply voltage that is within the standard operating conditions ($V_{CC} = 5$ V ± 0.25 V). Ensure that the supply voltage does not exceed the absolute maximum rating of 7 V, even momentarily.

(7) Input Voltage

If a voltage exceeding the absolute maximum rating (V_{CC} + 0.5 V) is applied to the transmitter input, the internal IC may be adversely affected or even destroyed. If there is a possibility of excessive input voltage due to a surge, for example, add a protector circuit to the input.

(8) Output

Note that internal ICs can be damaged when the receiver output is low and the output is shorted to the power supply, or when the output is high and is shorted to GND.

(9) Handling Optical Fiber Cables

Do not drop heavy or sharp metal objects onto the optical fiber cable. If the fiber cable breaks, data cannot be transmitted.

Also, transmission loss increases if there are sharp bends in the fiber cable. Toshiba recommend that, if the cable must be bent during installation, the bent section should have as large a radius as possible (six to 10 times the minimum bending radius).

Some fiber optic connectors are vertical connectors. When inserting a fiber-optic connector, note the orientation of the connection.

When coupling or decoupling a fiber-optic connector, be sure to grip the connector itself. Do not decouple a fiber-optic connector by pulling on the optical fiber cable.

(10) Assembling Fiber-Optic Connectors

Since specialized assembly tools are available for the fiber-optic connectors used with TOSLINK devices, people without specialist knowledge can assemble the connectors. However, the person who assembled the product must be responsible for its characteristics and quality.

When using a connector in an application where reliability is essential, Toshiba recommend purchasing a pre-assembled product or contacting a specialist with the necessary expertise.

(11) Absolute Maximum Ratings

The absolute maximum ratings must never be exceeded, even momentarily. Even a single rating must never be exceeded. The parameters which feature in of the absolute maximum ratings depend on the product, but they generally include such parameters as the input and output currents, input voltage, storage temperature, operating temperature and lead temperature.

If the input current or input voltage exceeds its absolute maximum rating value, over current or overvoltage could occur, adversely affecting the internal circuitry of the device. If the rating is grossly exceeded, the wiring may fuse due to heating in the internal circuits, or the circuitry in the semiconductor chips may be destroyed.

If the absolute maximum operating temperature, storage temperature or soldering temperature rating is exceeded, the differences in the coefficients of thermal expansion of the various materials which make up the device can result damage to cause the sealing or bonded parts to open up. When using TOSLINK devices, never exceed any of the absolute maximum ratings.

(12) Recommended Operating Conditions

The recommended operating conditions are conditions recommended to ensure the level of operation described in the corresponding product datasheet.

To improve the reliability of a device even further, derate the maximum voltage, current, temperature or any other parameter.

Note that the recommended operating conditions are intended to guarantee operation and do not always guarantee characteristic values.

(13) Smoke and Fire

Since optical modules, connectors and fiber-optic cables are flammable, scorching or burning them may cause them to emit smoke or burst into flames, which can in turn cause gas emissions. Therefore, do not use these devices in the vicinity of flames, smoke or any flammable materials.

(14) Disposal Precautions

TOSLINK devices and packaging materials must be disposed of by the user as industrial waste products in an environmentally appropriate way and in accordance with the law.

5.4.4 Reliability Characteristics

Table 5.4.1 and 5.4.2 show the results of a fiber-optic module reliability test using the TODX296 fiber-optic transmitter/receiver module as an example.

Table 5.4.1

Thermal Environment Tests

Test	Applicable Standard	Test Condition	Remarks
Soldering heat	JIS C7021 A-1	T_{sol} = 260°C, 10 secs, once	Immersed 1.5 mm from base of device
Temperature cycling	JIS C7021 A-4	−40°C to 25°C to 85°C to 25°C 30 mins 5 mins 30 mins 5 mins	100 cycles
Moisture resistance	JIS C7021 A-5	25°C to 65°C to −10°C, 90% to 98% 24 hrs/cycle	10 cycles

Mechanical Environment Tests

Test	Applicable Standard	Test Condition	Remarks
Vibration	JIS C7021 A-10	100 to 2000 to 100 Hz 196 m/s^2 (20 g) 4 times each in 3 directions	
Mechanical shock	JIS C7021 A-7	14,700 m/s^2 (1,500 g), 0.5 ms 3 times each in 4 directions	
Constant acceleration	JIS C7021 A-9	196,000 m/s^2 (20,000 g), 1 minute once each in 6 directions	
Solderability	JIS C7021 A-2	230°C, 5 secs, once	95% or more (using flux)
Lead integrity	JIS C7021 A-11	Load 2.5 N (0.25 kgf) 0 to 90° to 0, bent 3 times	No separation or breakage allowed

Lifetime Tests

Test	Applicable Standard	Test Condition	Remarks
Steady-state operation	—	V_{CC} = 5 V, Ta = 85°C	1,000 hours
High-temperature storage	JIS C7021 B-10	Ta = 85°C	1,000 hours
High-temperature, high-humidity storage	JIS C7021 B-11	Ta = 60°C, RH = 90%	1,000 hours

Failure Criteria (Ta = 25°C, V_{CC} = 5 V)

Parameter	Symbol	Measuement Condition	Criteria	
			minimum	maximum
Fiber-coupled optical output	P_f	PCF 2 m, R = 1.2 kΩ	Initial value − 1.5 dB	Initial value + 1.5 dB
Current consumption	I_{CC}	R = 1.2 kΩ	—	USL × 1.2
Maximum power of received light	P_{max}	PCF 2 m, 6 Mb/s, NRZ code	Initial value − 1.5 dB	Initial value + 1.5 dB
Minimum power of received light	P_{min}	PCF 2 m, 6 Mb/s, NRZ code	Initial value − 1.5 dB	Initial value + 1.5 dB

LSL: Lower specification limit; USL: Upper specification limit

Test Results
Environment Tests

Test	No. Of Samples	No. Of Failures	Test Item	No. Of Samples	No. Of Failures
Soldering heat	32	0 / 32	Vibration	11	0 / 11
Temperature cycling	50	0 / 50	Mechanical shock	11	0 / 11
Moisture resistance	32	0 / 32	Constant acceleration	11	0 / 11
			Solderability	11	0 / 11
			Lead integrity	11	0 / 11

The GaAlAs red-emitting LED with a double-hetero structure used in some TOSLINK modules is prone to the formation of a light-absorbing surface layer on the LED due to Al oxidation in the mixed crystal. This occurs as the LED conducts current, reducing the LED's radiant power. This phenomenon is especially noticeable in systems operating in high-humidity environments. Users are therefore encouraged not to use red-emitting LEDs in fiber-optic systems in this type of environment. (See Figure 5.4.3.)

For TOSLINK systems which must operate in high humidity, or for applications requiring a long service life, Toshiba recommend the use of ceramic package-type fiber-optic modules.

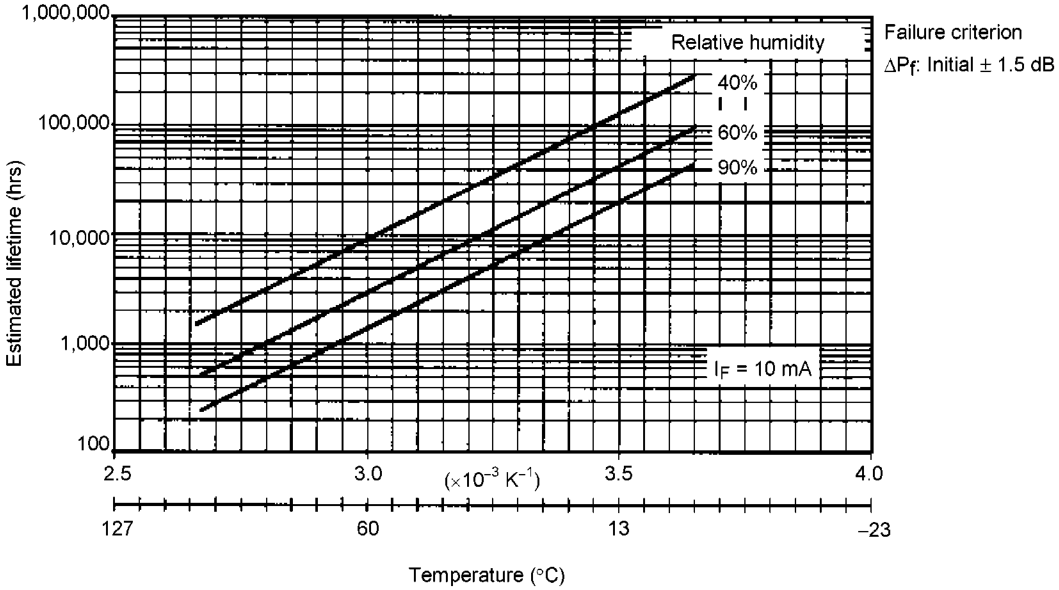


Figure 5.4.3 **Relationship between moisture degradation, temperature and relative humidity in a GaAlAs double-hetero red LED**

5.5 Red Semiconductor Laser Reliability

5.5.1 Overview

The TOLD9000 Series of semiconductor lasers is manufactured from InGaAlP crystal. They exhibit a lasing wavelength in the 635 nm ~ 690 nm red region, and combine the excellent visibility of He-Ne gas lasers with the compact size and easy-to-use features of semiconductor lasers.

5.5.2 Structure

Red semiconductor lasers are available in two chip structures: gain waveguide and refractive index waveguide. These are shown in Figure 5.5.1. The internal structure consists of a laser chip and a monitor photodiode housed together in a single package (of MC type) as shown in Figure 5.5.2.

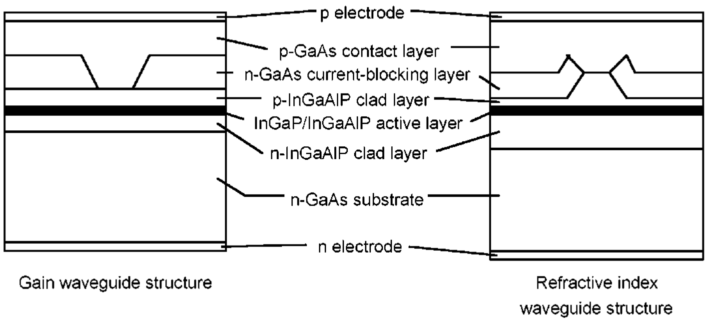


Figure 5.5.1 Chip structure

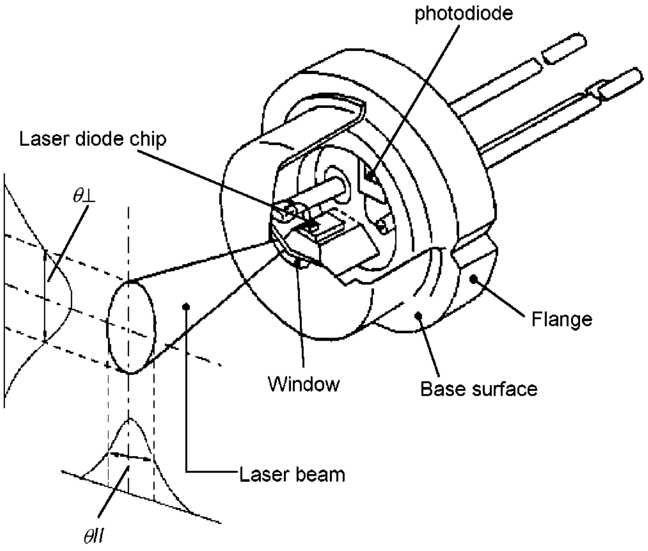


Figure 5.5.2 Internal structure (MC type)

5.5.3 Usage Precautions

(1) Do not exceed absolute maximum ratings, even momentarily. Check spike currents generated when the drive circuit is powered on or off to ensure that they will not cause absolute maximum rating values to be exceeded. Excessive spike currents applied to a laser can cause deterioration in the laser optical output and other characteristics or, in the worst case, cause the laser to fail.

(2) Radiant output power decreases as the temperature increases, imposing limits on the operating temperature range. This should be taken into account when designing circuits. Use a copper or aluminum heat sink of sufficient size to disperse the heat.

(3) Take precautions against electrostatic device breakdown during handling. Take preventive measures such as grounding the workbench, your body and the soldering iron to earth. Also, avoid electrostatic pulses caused by turning fluorescent lamps and similar devices on and off.

(4) To keep the hermetically sealed package airtight, do not apply excessive stress between the leads and the case, or on the glass surface. When forming the leads, bend them at a point 2 mm or more from the base of the device. Do not solder leads before they have been formed. Adhere to the following conditions:

Soldering temperature ≤ 260°C; soldering time ≤ 5 seconds (2 mm or more from the device package)

(5) Damaging or staining the glass surface can reduce the radiant output power or deform the far field pattern. Do not contaminate the window.

(6) Do not look directly into the laser beam or lens during laser emission. Because of its high concentration of power, the laser beam can be very harmful to the eye.

5.5.4 Reliability Characteristics

The tables below list reliability test conditions, failure criteria and results for the TOLD9421(S) red semiconductor laser.

1. Table of Test Conditions

1-1 Thermal Environment Tests

Test	Applicable Standard	Test Conditions	Remarks
Soldering heat	JIS C7021 A-1	T_{sol} = 260°C, 10 secs, once	
Temperature cycling	JIS C7021 A-4	–40°C to 25°C to 100°C to 25°C 30 mins 5 mins 30 mins 5 mins	100 cycles
Hermetic seal	JIS C7021 A-6	Minute leaks detected by tracer gas; large leaks detected by bubbles	

1-2 Mechanical Environment Tests

Test	Applicable Standard	Test Conditions	Remarks
Vibration	JIS C7021 A-10	100 Hz to 2000 Hz to 100 Hz 20 g, 4 times each in 3 directions	
Mechanical shock	JIS C7021 A-7	1,500 g, 0.5 ms 3 times each in 4 directions	
Constant acceleration	JIS C7021 A-9	20,000 g, 1 minute once each in 6 directions	
Solderability	JIS C7021 A-2	230°C, 5 secs, once	95% or more (using flux)
Lead integrity (bending)	JIS C7021 A-11	Load 250 g, bent 3 times 0 to 90° to 0	No separation or breakage allowed
Lead integrity (tensile)	JIS C7021 A-11	Axial load 500 g, applied once for 30 seconds	No separation or breakage allowed

1-3 Lifetime Test

Test	Applicable Standard	Test Conditions	Remarks
Steady-state operation	—	P_O = 5 mW (autmatic power control) Ta = 70°C	1,000 hours
High temperature storage	JIS C7021 B-10	Ta = 85°C	1,000 hours
Low-temperature storage	JIS C7021 B-12	Ta = –40°C	1,000 hours

2. Failure Criteria (Ta = 25°C)

Parameter	Symbol	Measurement Conditions	Criteria	
			minimum	maximum
Operating current	I_{OP}	P_O = 5 mW (CW)	—	USL × 1.2
P_D monitor current	Im	P_O = 5 mW (CW)	Initial × 80%	Initial × 120%
P_D dark current	I_D	V_R = 5 V	—	USL × 1.2

USL: Upper specification limit; LSL: Lower specification limit

3. Test Results

3-1 Environment Tests

Test	No Of Samples	No Of Failures	Test	No Of Samples	No Of Failures
Soldering heat	32	0 / 32	Vibration	11	0 / 11
Temperature cycling	50	0 / 50	Mechanical shock	11	0 / 11
Hermetic seal	11	0 / 11	Constant acceleration	11	0 / 11
			Solderability	11	0 / 11
			Lead integrity (bending)	11	0 / 11
			Lead integrity (tensile)	11	0 / 11

3-2 Lifetime Tests

Test	No Of Samples	168 hrs	500 hrs	1,000 hrs
Steady-state operation	30	0 / 30	0 / 30	0 / 30
High-temperature storage	30	0 / 30	0 / 30	0 / 30
Low-temperature storage	30	0 / 30	0 / 30	0 / 30

The degradation in characteristics of a device which is in operation for a long period time can be explained by increased junction temperature due to increased operating current. The degradation results in damage to the end surfaces or internal structure of the laser chip. Figure 5.5.3 shows test data for APC drive operation and shows a change in operating current over time.

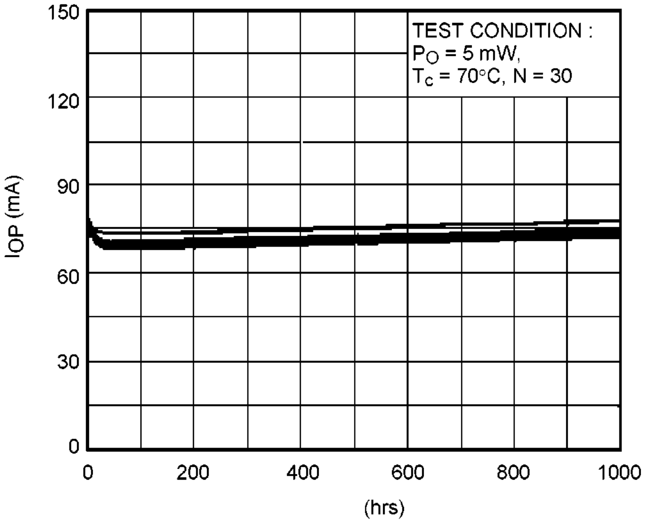


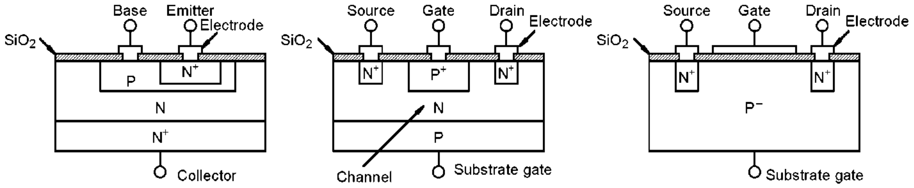
Figure 5.5.3

5.6 Small-Signal Transistor Reliability

5.6.1 Overview

(1) Structure

Typical small-signal transistor products include bipolar transistors, junction-type FETs, and MOSFETs. Figure 5.6.1 shows the structure of these devices. Almost all small-signal bipolar transistors now manufactured are of the epitaxial planar structure shown in the diagram. This structure has the important advantage of being protected with a silicon oxide film, giving high reliability.



(a) Bipolar transistor (b) Junction-type FET (c) MOSFET

Figure 5.6.1 Structure of small-signal transistors

(2) Features

Table 5.6.1 summarizes the features of small-signal transistors.

Table 5.6.1 Features of small-signal transistors

Type	Features	Uses
Epitaxial planar transistor	Low saturation voltage. Low IF noise. Can be easily fabricated with finer pattern width than FET and has excellent high-frequency response.	Low- and high-frequency amplification; High-speed switching
Junction FET	High input impedance. Low IF noise (in particular, lower high-signal source impedance than bipolar transistor).	Low- and high-frequency amplification; Switching
MOSFET	Input impedance is very high. Good cross modulation and intermodulation characteristics.	High-frequency amplification

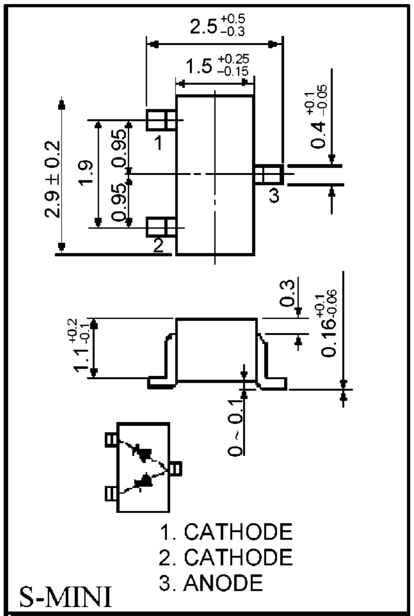
In addition to the above, there are several other device types, including the GaAs-based MESFET and HEMT. These devices are used in applications where low-noise characteristics at high frequencies are important.

(3) Packages

Small-signal transistors come in lead-type (insertion) and surface-mount packages. Surface-mount packages have become the standard. A noticeable trend in surface mount packaging is increased mounting density which is achieved by reducing size and by increasing the number of pins. Accordingly, the requirements for package reliability are becoming more stringent every year.

Figure 5.6.2 shows the external profile and an internal structural view of the super-mini (SM) package, a typical surface-mount package type.

Unit: mm



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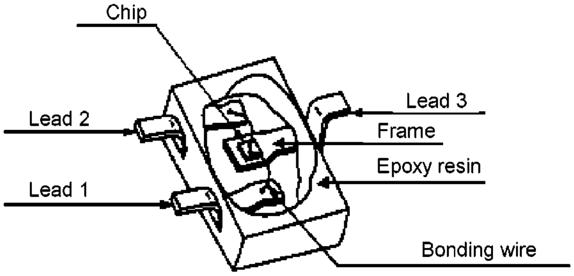
EIAJ	SC-59
TOSHIBA	1-3G1E



(a) External profile (b) Internal structure

Figure 5.6.2 Super-mini (SM) package

5.6.2 Usage Precautions

The following lists specific precautions that should be observed when using small-signal transistors. General precautions for semiconductor devices are not discussed here.

(1) Degradation of h_{FE}

When a bipolar transistor breaks down from the application of a reverse voltage across the emitter-to-base junction, h_{FE} deteriorates causing reduced gain or increased noise.

When the current I_{EBO} is applied to a 2SC3429 VHF/UHF-band low-noise amplification transistor, causing it to breakdown, h_{FE} deteriorates over time as shown in Figure 5.6.3 and 5.6.4. The greater the applied current I_{EBO}, the greater the degradation of h_{FE}. Figure 5.6.3 shows degradation of h_{FE} at I_C = 0.1 mA and Figure 5.6.4 shows degradation of h_{FE} at I_C = 20 mA, indicating that the reduction in h_{FE} is large when I_C is small, and small when I_C is large.

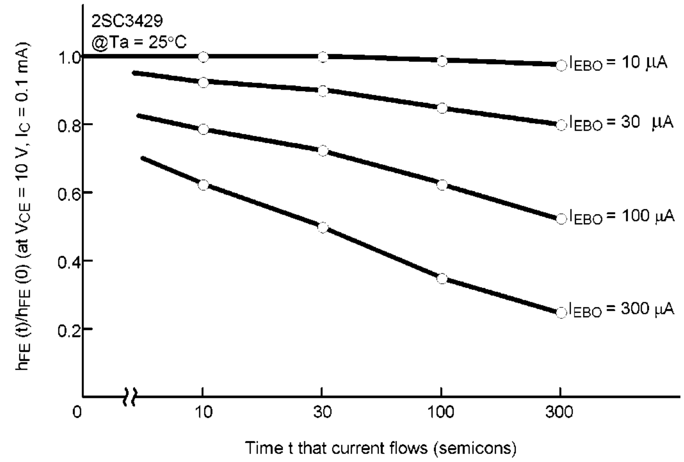


Figure 5.6.3 Degradation of h_{FE} (at I_C = 0.1 mA)

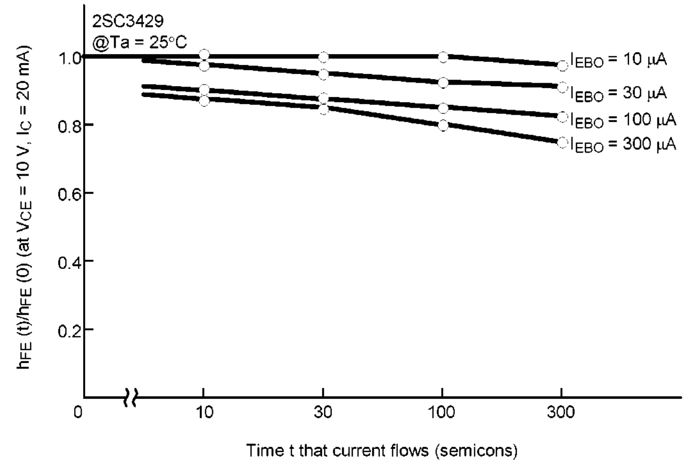


Figure 5.6.4 Degradation of h_{FE} (at I_C = 20 mA)

The greater the current I_{EBO} with which the emitter-to-base junction is made to break down, and the lower the temperature, the greater the h_{FE} degradation. From this observation it appears that hot carriers are the cause of the problem and that the degradation is brought about by an increased energy level at the Si-SiO_2 interface. This problem has become more noticeable as transistors are manufactured with increasingly finer dimensions and the emitter junction depth becomes shallower.

In recent years, transistors have become increasingly susceptible to the effects of reduced h_{FE} because they are designed to operate at small currents to meet the requirements of low-power equipment. When designing circuits, therefore, be careful to avoid emitter-base reverse-voltage breakdown. Also, avoid measuring V_{EBO} during incoming product inspections.

In summary, particular care must be taken with high-frequency transistors. This is because they have been fabricated with very fine dimensions and very shallow junctions to improve performance characteristics.

5.6.3 Reliability Characteristics

(1) Reliability test results

As an example, Table 5.6.2 lists the results of reliability tests conducted for a plastic-encapsulated low-noise amplification transistor. Table 5.6.3 lists the failure criteria applied during the test.

A basic method frequently used to evaluate reliability is to have a device in operation and to perform a detailed analysis of the changes that occur in its characteristics over time. As an example, Figure 5.6.5 to 5.6.7 show changes in characteristics that occurred during the lifetime test described in Table 5.6.2.

Test results indicate that, although the device was operated at its absolute maximum ratings, the initial characteristics remained stable over a long period of time. Consequently, this device can be expected to offer high reliability in an application.

Table 5.6.2 Reliability test results for 2SC3606 low-noise amplification transistor

	Test	Applicable Standard JIS C7021	Test Conditions	No. Of Devices Tested	No. Of Failures	Remarks
Life Test	Steady-state operation	B-4	Pc = 150 mW, Ta = 25°C, 1,000 hrs	30	0	
	High-temperature reverse bias	B-8	Ta = 125°C, V_{CB} = 8 V, 1,000 hrs	30	0	
	High-temperature storage	B-10	Ta = 125°C, 1,000 hrs	30	0	
	High-temperature, high-humidity storage	B-11	Ta = 60°C, RH = 90% 1,000 hrs	30	0	
Environment Tests	Soldering heat	A-1	260°C, 10 secs, once (immersed entirely)	32	0	
	Temperature cycling	A-4	–55°C to 25°C to 125°C to 25°C 100 cycles	50	0	
	Thermal shock	A-3	100°C to 0°C, 50 cycles	32	0	
	Moisture resistance	A-5	Ta = to 65°C, RH = 90% to 98% 10 cycles	32	0	
Mechanical Tests	Vibration	A-10	100 to 2,000 Hz 196 m/s^2 (20 g) 4 times each in 3 directions	11	0	
	Mechanical shock	A-7	14,700 m/s^2 (1,500 g), 0.5 ms 3 times each in 4 directions	11	0	
	Constant acceleration	A-9	196,000 m/s^2 (20,000 g) Fo1 minute each in 6 directions	11	0	
	Dropping	A-8	75 cm, on maple board, 3 times	11	0	
	Solderability	A-2	230°C, 5 secs (using designated flux)	11	0	

Table 5.6.3 Failure criteria for 2SC3606

Parameter	Symbol	Measurement Conditions (Ta = 25°C)	Criteria		Remarks
			Minmimum	Maximum	
Collector cut-off current	I_{CBO}	V_{CB} = 10 V, I_E = 0	—	2 μA	USL × 2
Emitter cut-off current	I_{EBO}	V_{EB} = 1 V, I_C = 0	—	2 μA	USL × 2
DC amplification rate	h_{FE}	V_{CE} = 10 V, I_C = 0 mA	24	300	USL × 1.2 LSL × 0.8

USL: Upper specification limit; LSL: Lower specification limit

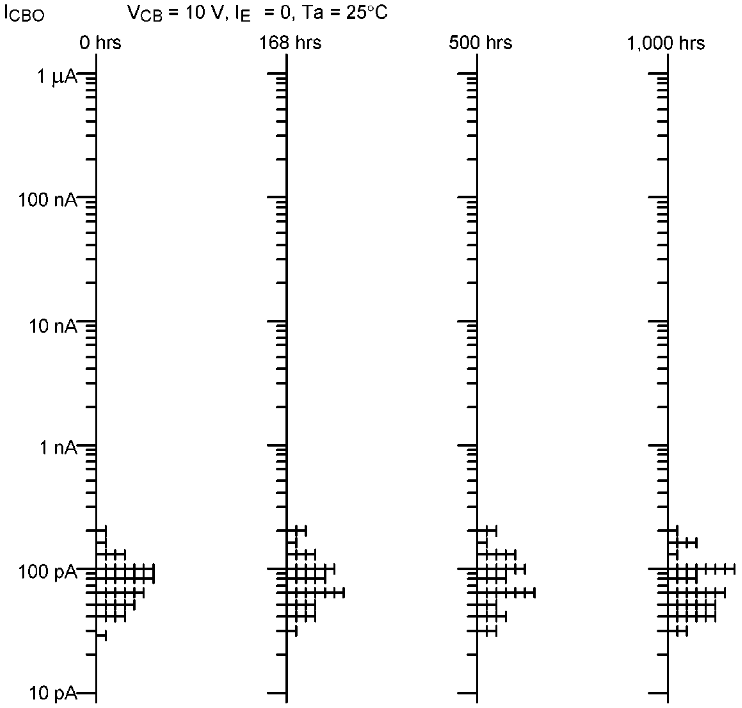


Figure 5.6.5 I_{CBO} results from steady-state operation lifetime test for the 2SC3606 low-noise amplification transistor

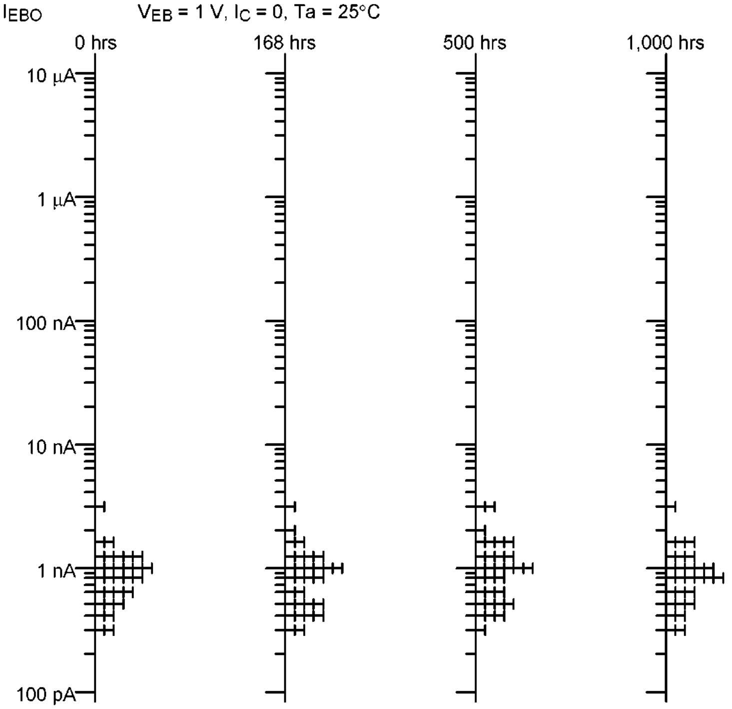


Figure 5.6.6 I_{EBO} results from steady-state operation lifetime test for the 2SC3606 low-noise amplification transistor

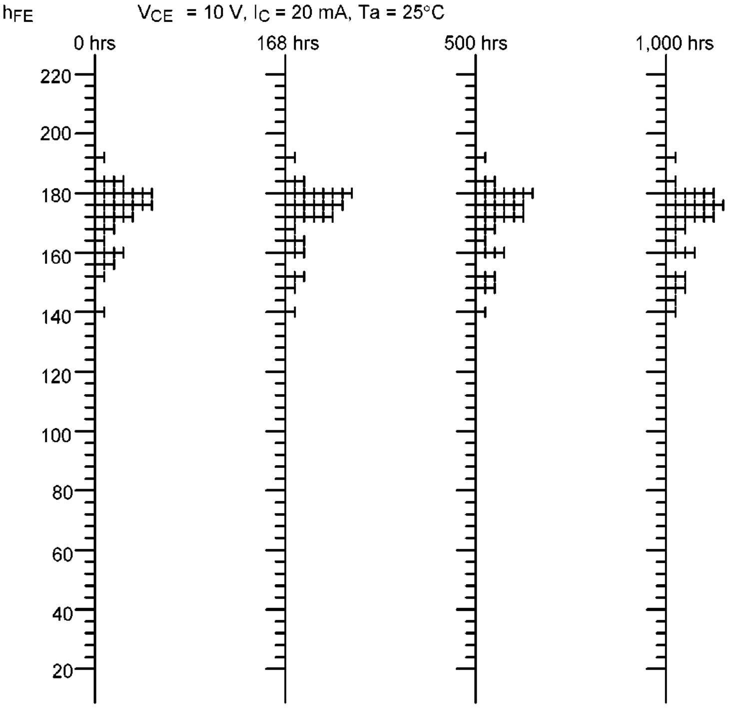


Figure 5.6.7 Transistor h_{FE} results from steady-state operation life test for 2SC3606 low-noise amplification transistor