Photorelay E-book
(Replacement for mechanical relay)

Toshiba Electronic Devices & Storage Corporation
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WHAT IS A PHOTORELAY ?

Classification of Relay

Group	Sub-Group	Notes
Mechanical Relay (Contact Relay)	Signal Relay	・Low current switching mechanical relays, often below 2 A, used for applications such as signal, circuit, high frequency control etc. ・Includes high frequency relays.
	Power Relay	・Mechanical relays whose switching current is above 2 A ・Includes general purpose relays for control panel, high DC current controlling power relays etc.
Semiconductor Relay (Contactless Relay)	Photorelay (MOSFET output)	・Uses MOSFET as output device. ・Mainly used to replace signal relays ・Able to control both AC and DC loads Product with I_{ON} > 1 A is referred to as high current photorelay, according to the standard of Toshiba.
	SSR (Solid State Relay)	・Uses phototriac, phototransistor or photothyristor as output device. ・Phototriac, photothyristor used devices are limited to use for AC loads.

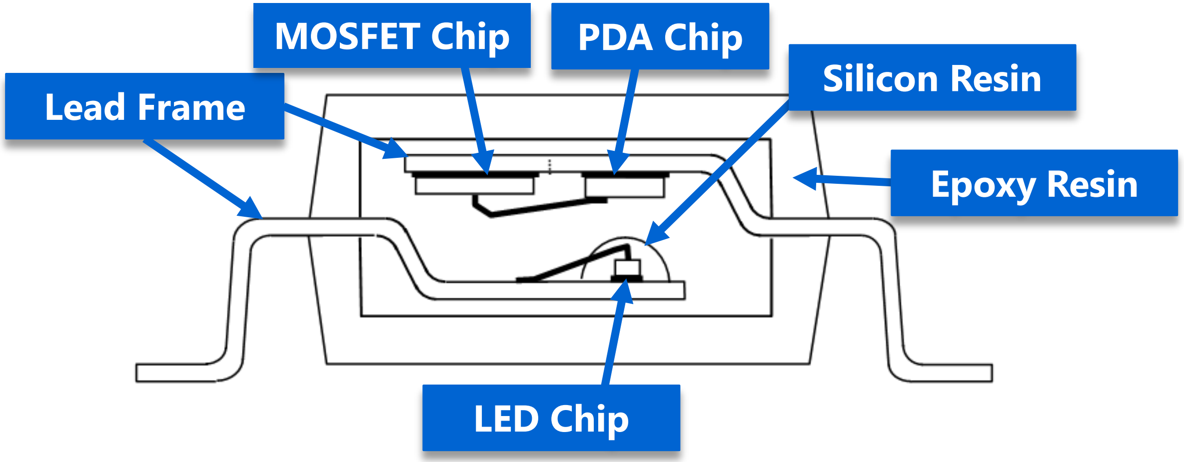
⚠ This classification may differ from actual classification in different catalog distributor (e.g. Digikey / Mouser etc.). We recommend searching with the product's name directly.

Structure of Photorelay

SO6 Package

3.7 × 7.0 × 2.1 mm

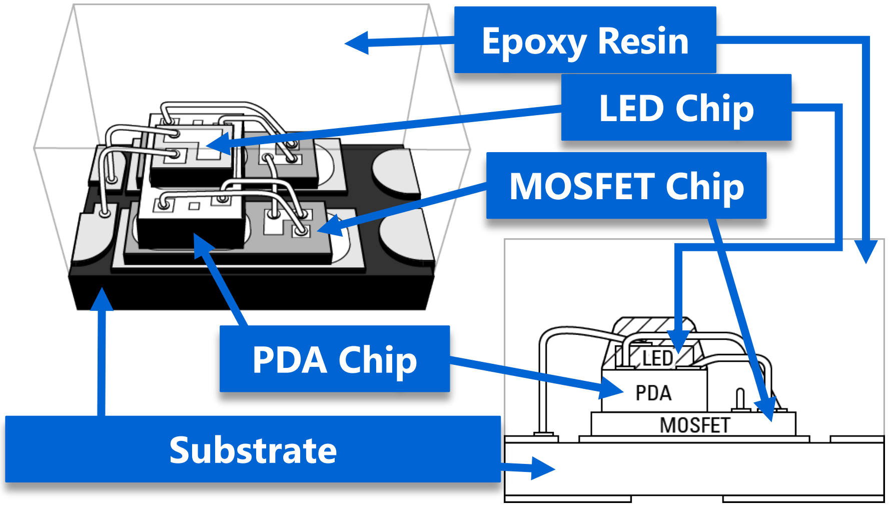
Frame Type



S-VSON Package

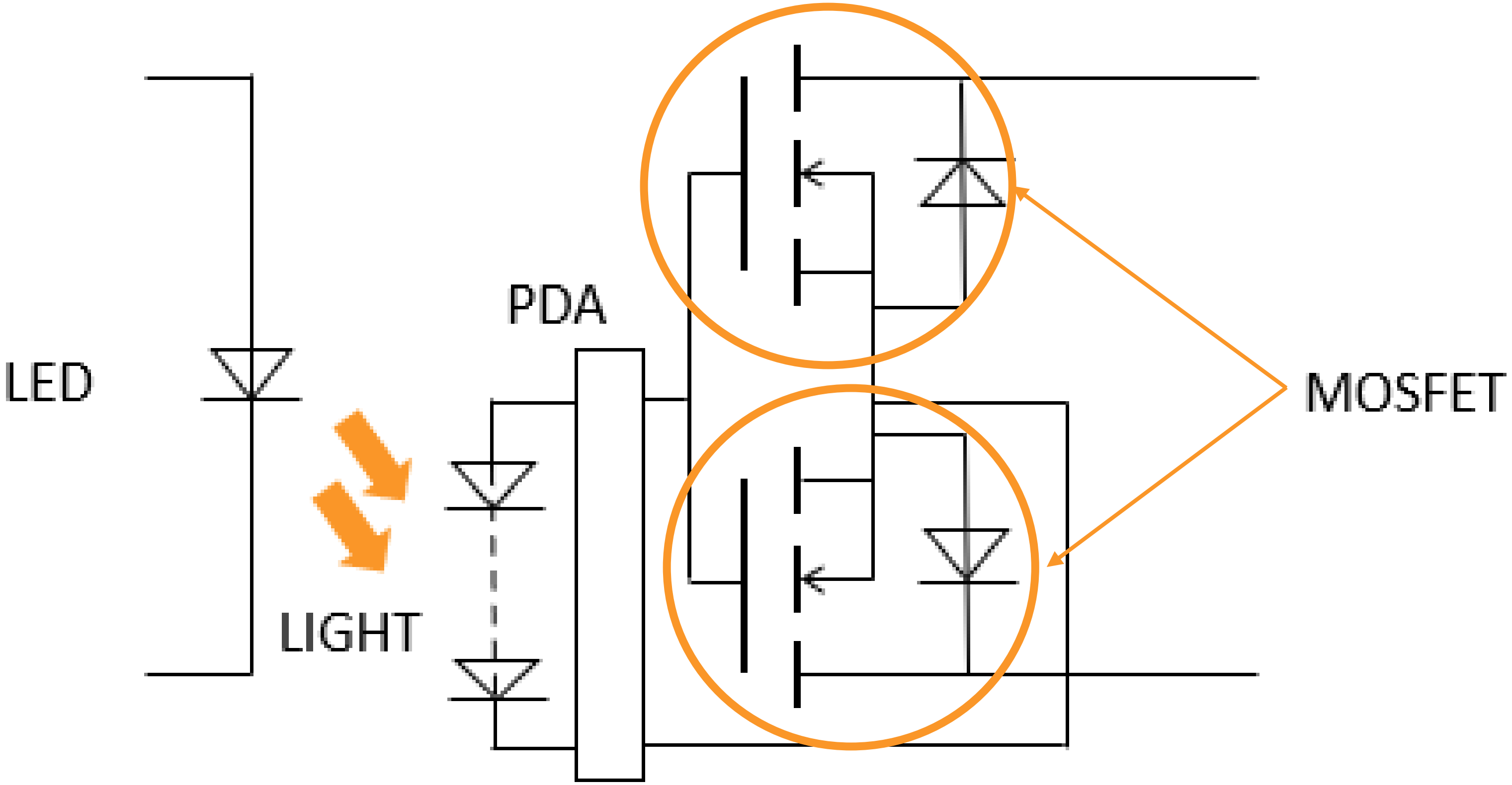
2.0 × 1.45 × 1.65 mm

Substrate Type



MOSFET: **M**etal **O**xide **S**emiconductor **F**ield **E**ffect **T**ransistor
PDA: **P**hoto **D**iode **A**rray

How a Photorelay Operates (in Case of 1 Form A Type)



[1]

Apply a current to the LED to emit light

[2]

The PDA that received light from the LED drives the gates of MOSFET.

[3]

MOSFETs turn on, thus the circuit on the output side turns on.

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ADVANTAGES OF PHOTORELAY

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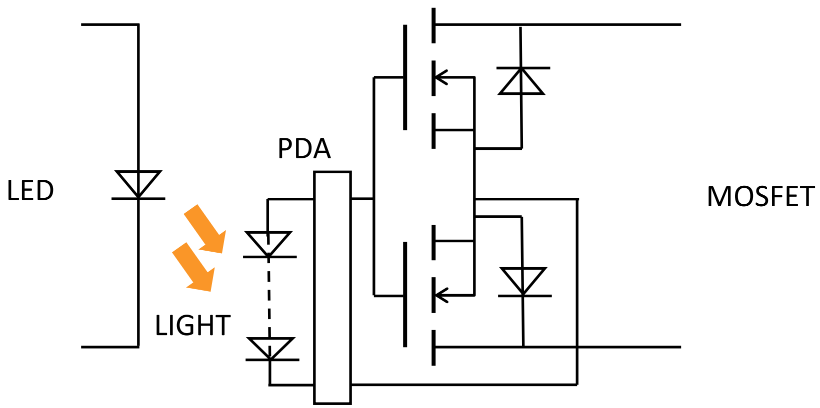
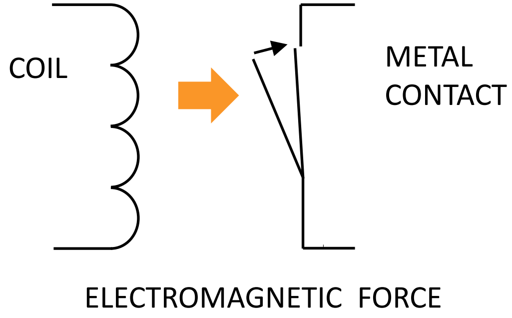
Photorelay VS Mechanical Relay

Photorelay
(MOSFET output photocoupler)



Mechanical Relay

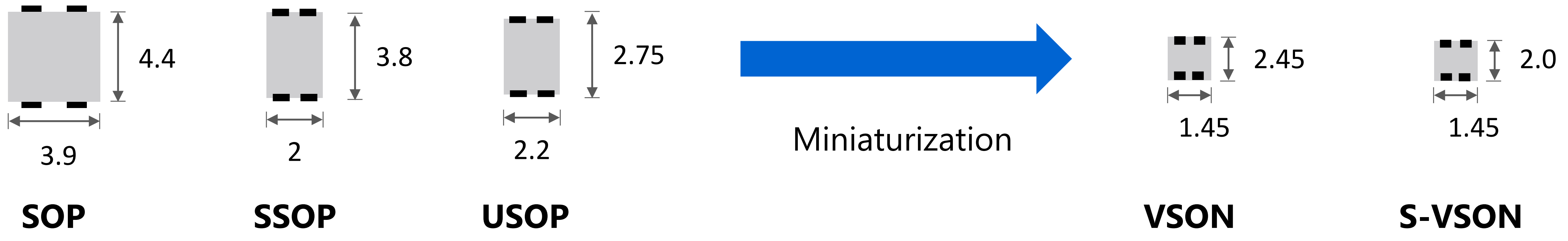


Comparison with Mechanical Relay

1． Miniaturization of mounting area
2． High reliability (long lifetime)
3． Low input current / driving voltage
4． Excellent switching characteristics (high speed, low noise)
5． Supporting hot switching

Toshiba Photorelay Package Trend

Package Trend (unit: mm)

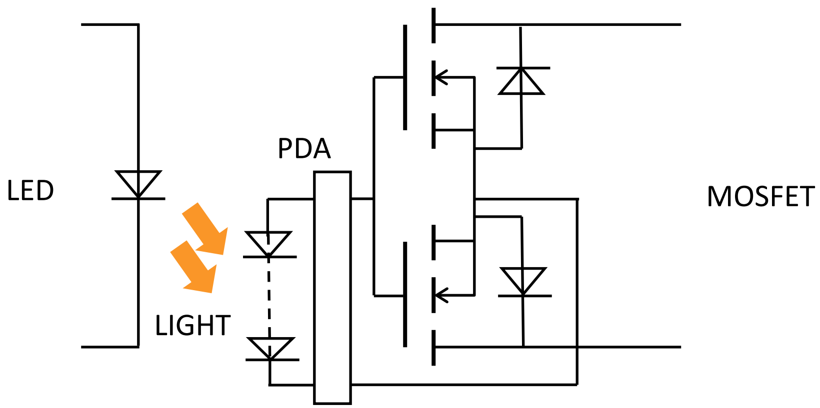


We have a line-up of products in small packages such as VSON and S-VSON.
Replacing with photorelays greatly contributes to the miniaturization of circuits.

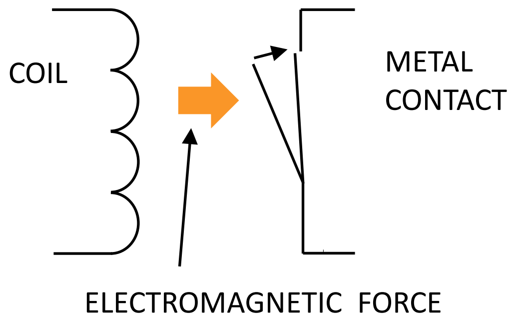
High Reliability (Long Lifetime)

Photorelay

(MOSFET output photocoupler)



Mechanical Relay



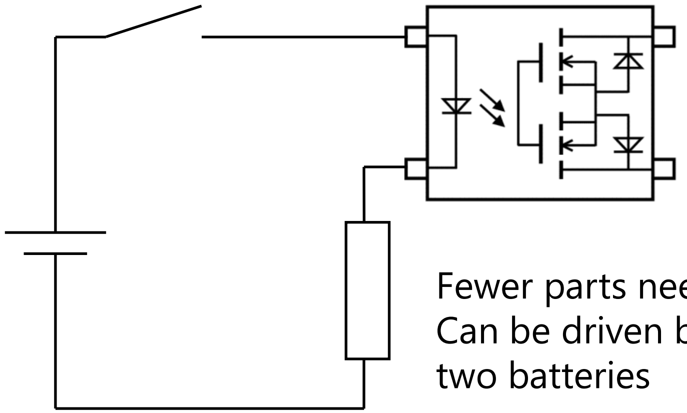
No wear or welding

Wear and welding, periodic maintenance is required

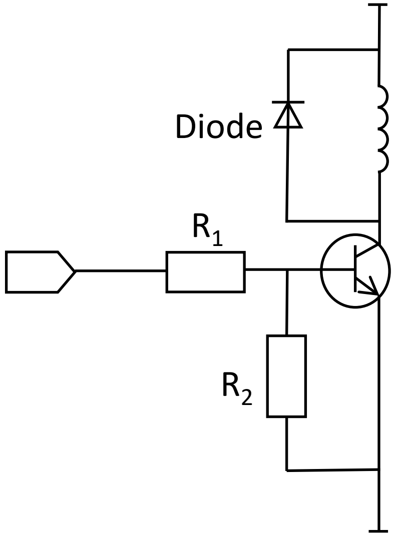
A photorelay operates by receiving LED light with photodiode array, converting it into voltage signal which drives MOSFETs. Since there are no mechanical contacts, **there is no wear and welding** like mechanical relay (no limit on the number of switching times, and it's maintenance free).

Low Input Current / Driving Voltage

Photorelay
(MOSFET output photocoupler)



Mechanical Relay



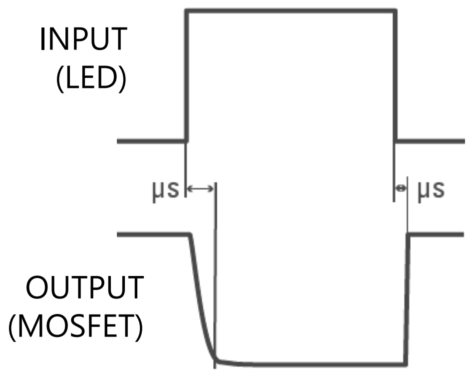
The driving circuit of the photorelay is simple. Low input power type can be driven directly by batteries or a microcomputer.

Since higher driving current is needed, buffer transistor is required to boost the output of microcomputer.

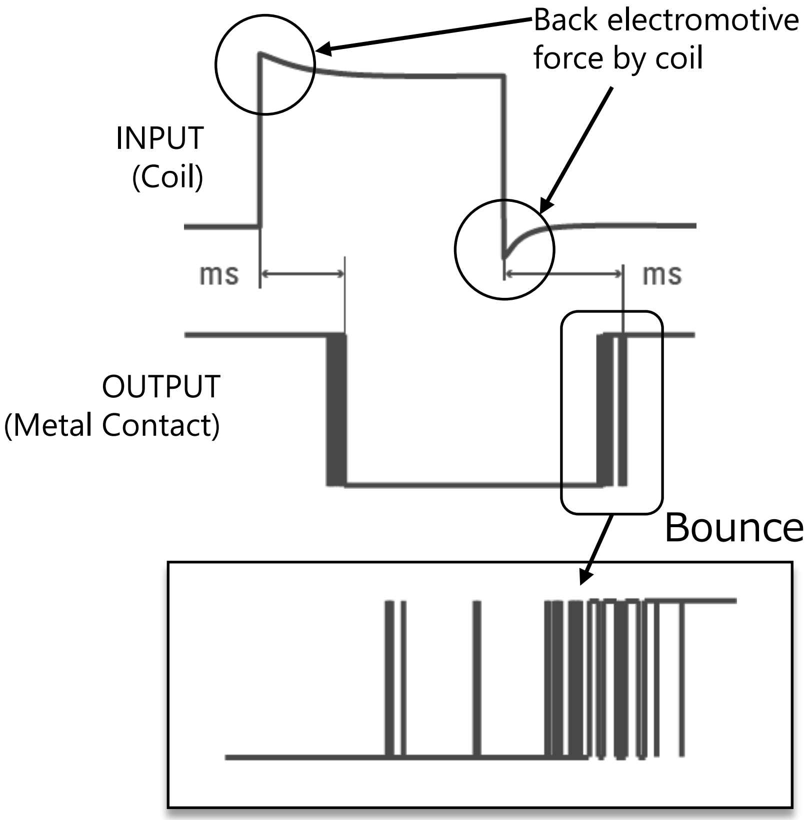
Since an LED is used on the input side which driven by current signal, and necessary input current (trigger LED current: I_{FT}) to turn on the output is as low as 3 to 5 mA (max), thus a photorelay **can be driven even by batteries**. But it is necessary to consider LED lifetime when designing I_F specification.

Excellent Switching Characteristics (High speed, Low noise)

Photorelay
(MOSFET output photocoupler)



Mechanical Relay

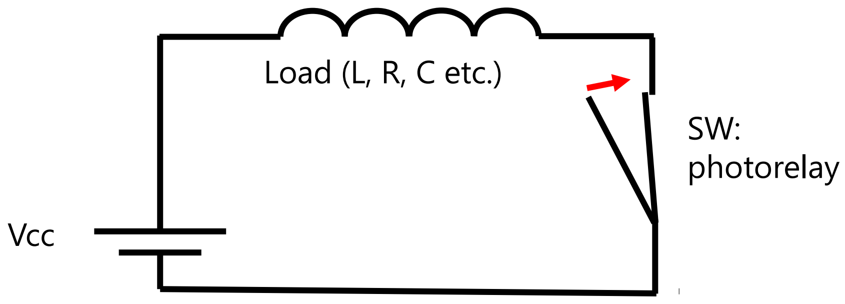


Benefits of replacing mechanical relay with photorelay

- **Reduction of noise**
  - input: no back electromotive force
  - output: no bounce
- **Switching speed is 1/10 to 1/100 of mechanical one**

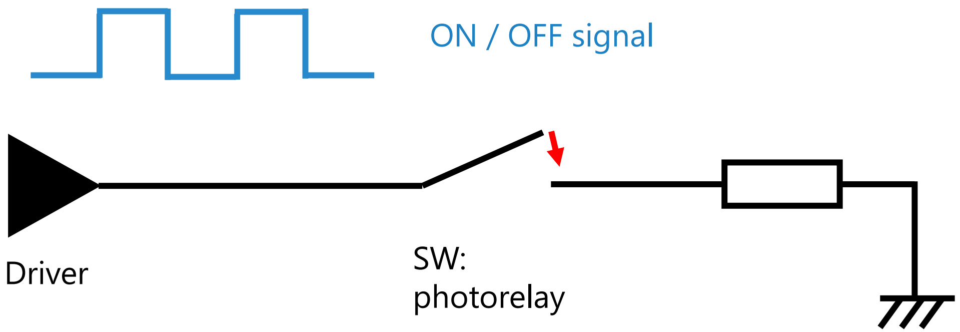
Since photorelay uses an LED on the input side and MOSFETs on the output side, noise caused by back electromotive force or bounce does not exist anymore. It also does not produce operation sound like mechanical relay (hitting of contacts).

Case of HOT Switching



This means that the switch (SW) operates with voltage applied on the output side.
Current flows through the load at the moment SW is closed.

Case of COLD Switching



This means that the switch (SW) operates without voltage applied on the output side.
Therefore no generated current when SW is closed, then output the signal from power supply.

Mechanical relays have shorter lifetime when used in HOT switching.
Photorelay can be used in both HOT switching or COLD switching cases as long as the maximum rating is maintained.
＊In the case of mechanical relays, since the voltage is being applied during HOT switching, current arises at the moment the contact is closed, as a result the contact is likely to be worn out. Also, when the switch opens, the current will be interrupted, which may generate an arc, shortening the lifetime of relay.

Comparison of Performance with Mechanical Relays

	Mechanical Relay (Signal Relay)	Photorelay	Remarks (Feature of Photorelay)
Lifetime	★★ (With contact limit)	★★★★ (No contact limit)	Long lifetime
Contact capacity (ON-state current)	★★★★(2 A) *T_a 85 °C / AC･DC applicable	★★★ (up to 5 A) *T_a 25 °C/V_{OFF} = 60 V basis	
Contact resistance (ON-state resistance)	About 0.1 Ω (Degraded by on / off)	About 0.02 to 25 Ω (Stable)	High reliability
Contact voltage (OFF-state output terminal voltage)	★★★★ (e.g. AC 250 V, DC 30 V)	★★★ (e.g. line up with 20 to 600 V)	
Isolation voltage	★★★ (e.g. 1 kV_{rms})	★★★★ (max: 5 kV_{rms})	
Operation / Release time (Turn-on time / Turn-off time)	★★ (about 5 ms)	★★★ (about 0.1 ms)	High speed
Operation sound	★★(exist)	★★★★ (No sound)	No noise
Miniaturization	★★★ (e.g. 60 mm^2)	★★★★ (S-VSON: 2.9 mm^2 - 1.45 × 2.0 mm)	Smaller size
Input power dissipation	★ (coil) (>100 mW)	★★★★ (LED) (e.g. 0.5 mW)	Reducing power consumption
Contact form	1c, 2c mainly	1a, 1b, 2a, 1a1b	
OFF-state current	★★★★ (not exist)	★★★ (>20 pA)	

In recent years, replacement of mechanical relays and reed relays is accelerating.

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TERMINOLOGY OF PHOTORELAY

Contents

Electrical Characteristics Comparison: Mechanical Relay vs. Photorelay

Mechanical Relay Characteristics	Explanation	Equivalent in Photorelay Characteristics
Rated coil voltage and (Coil) Nominal operating current	Voltage and current that applied to the coil by design to make relay function normally	Input forward current (I_F) , Input forward voltage (V_F), Recommended Input Current
Contact form	The type and the number of contacts in the circuit e.g. Normally Open × 1 Contact (1a) Normally Close × 1 Contact (1b) Change-over contacts × 1 Contact (1c)	Contact Form e.g. Normally ON × 1 Contact (1a) Normally OFF × 1 Contact (1b)
Contact resistance	Total resistance in the ON-state	ON-state resistance (R_{ON})
Contact capacity	The voltage and the current of load that contact can handle	OFF-state output terminal voltage (V_{OFF}), ON-state current (I_{ON}, I_{ONP})
Maximum allowable power	The upper limit of energy consumption of load that relay can function normally	Output power dissipation (P_O)
Maximum allowable voltage	The maximum open circuit voltage Requires derating according to driven load and current.	OFF-state output terminal voltage (V_{OFF})

Electrical Characteristics Comparison: Mechanical Relay vs. Photorelay (cont'd)

Mechanical Relay Characteristics		Explanation	Equivalent in Photorelay Characteristics
Maximum allowable current		The maximum current that the contact can handle Requires derating according to driven load and voltage	ON-state current (I_{ON} , I_{ONP})
Switching (time) characteristics	Operation time	The time interval from the power applied to the coil until the closure of the contact. (Bouncing time is not included)	Turn-on time (t_{ON})
	Release time	The time interval from the power removed from the coil until the return of the contact to it's initial position. (Bouncing time is not included)	Turn-off time (t_{OFF})
Lifetime	Mechanical life	The minimum number of operation cycles the relay can undergo without load on the contact.	Estimate the lifetime from the LED degradation data and trigger LED current maximum value
	Electrical life	The minimum number of operation cycles the relay can undergo with a specified load on the contact.	Estimate the lifetime from the LED degradation data and trigger LED current maximum value
Operating temperature		The temperature of the environment when the relay is operating.	Operating temperature (T_{opr})

Terminology of Photorelay 1

Term		Symbol	Description
Absolute maximum rating		---	The maximum value which can not be exceeded during operation, even for an instant When temperature condition is unspecified, T_a = 25 °C.
LED	Input forward current	I_F	The rated current which can flow continuously in the forward direction of the LED
	Input forward current (pulsed)	I_{FP}	The rated current which can flow momentarily in the forward direction of the LED
	Input forward current derating	$\Delta I_F/\Delta T_a$	The Rate of change of maximum of Input forward current to ambient temperature
	Input reverse voltage	V_R	The rated reverse voltage which can be applied between the cathode and anode of LED
	Junction temperature	T_j	The highest temperature of LED junction which can be allowed during operation
Detector	OFF-state output terminal voltage	V_{OFF}	The rated voltage that can be applied between the output terminals of MOSFETs in the OFF-state. In the case of AC, it means peak voltage.
	ON-state current	I_{ON}	The rated current which can flow between the MOSFETs' output pins in the ON-State In the case of AC, it means peak current.
	ON-state current derating	$\Delta I_{ON}/\Delta T_a$	The reduction ratio of on-current against ambient temperature increasing
	ON-state current (pulsed)	I_{ONP}	The rated current that can flow instantly between output terminals of MOSFETs in ON-state (100 ms, DUTY = 1/10)
	Junction Temperature	T_j	The highest temperature of the junction of detector side which can be allowed during operation

Absolute Maximum Rating : The maximum value that can not be exceeded during operating, even for an instant.

Terminology of Photorelay 1 (cont'd)

Term	Symbol	Description
Isolation voltage	BV_s	The isolation voltage between input and output at the specified voltage value (High POT)
Ambient temperature	T_a	The ambient temperature at which the photorelay can function normally
Storage temperature	T_{stg}	The ambient temperature range at which the device can be stored
Lead soldering temperature	T_{sol}	The rated temperature at which the pins of the device can be soldered without loss of functionality

Terminology of Photorelay 2
Electrical Characteristics

	Term	Symbol	Description
LED	Input forward Voltage	V_F	The voltage drop between the LED's anode and cathode at a certain forward current rating
LED	Input reverse current	I_R	The leakage current flowing at the LED's reverse direction (from cathode to anode) under a certain reverse voltage
LED	Input capacitance (LED)	C_t	The electrostatic capacitance between the anode and cathode pins of the LED
LED	Trigger LED current	---	The minimum value of input current required to transition the output state of the relay The relay must be used at a current higher than the maximum specified in this item to let it transition normally.
LED		I_{FT}	Form-A: The minimum input forward current I_F required to let the output MOSFETs transition into ON-state
LED		I_{FC}	Form-B: The minimum input forward current I_F required to let the output MOSFETs transition into OFF-state
LED	Return LED current	---	The maximum value of input current to restore the output state of the relay The current must be lower than or equal to the minimum specification in this item to ensure that the relay is restored.
LED		I_{FC}	Form-A: The maximum input forward current I_F required to let the output MOSFETs transition into OFF-state
LED		I_{FT}	Form-B: The maximum input forward current I_F required to let the output MOSFETs transition into ON-state
Detector	ON-state resistance	R_{ON}	The resistance between the MOSFETs' output pins at a specified ON-state rating
Detector	OFF-state current	I_{OFF}	The leakage current passing through the MOSFETs' output pins in OFF-state
Detector	Output capacitance	C_{OFF}	The electrostatic capacitance between the MOSFETs' output pins (between the two drains)

Terminology of Photorelay 2 (cont'd)
Electrical Characteristics

Term	Symbol	Description
Current Limit	I_{LIM}	The load current maintained when the current limit function kicks in
Total capacitance (input to output)	C_S	The electrostatic capacitance between the input and output pins
Isolation voltage	BV_S	The maximum allowable voltage between the input and output pins
Turn-on time	t_{ON}	The time taken for the output waveform to change upon input of a specified current into the LED
		Form-A: Time required for the output voltage waveform transition to 10 % upon turning on the LED
		Form-B: Time required for the output voltage waveform transition to 90 % upon turning off the LED
Turn-off time	t_{OFF}	The time taken for the output waveform to change upon turning off the specified current into the LED
		Form-A: Time required for the output voltage waveform transition to 90% upon turning off the LED
		Form-B: Time required for the output voltage waveform transition to 10% upon turning on the LED
Equivalent rise time	ERT	An indicator of the output transition characteristics for applications with high frequency or high speed signals ERT is expressed with the formula $ERT = \sqrt{t_{rout}^2 - t_{rin}^2}$, where t_{rin} is the input waveform rise time and t_{rout} is the output waveform rise time after transition within relay. The lower the ERT value, the closer the output signal is compared to the original input waveform.

Terminology of Photorelay 2 (cont'd)
Electrical Characteristics

Term		Symbol	Description
Reference data	MOSFET ON-state voltage drop	V_{ON}	The voltage drop between the output pins when the MOSFET is turned on
	Relative output capacitance	$C_{OFF}/C_{OFF}(0\ V)$	The capacitance between the output pins relative to the capacitance between the output pins at zero volts
Others	Current limit function	---	A function whereby the load current is maintained at a certain range according to specification when an overcurrent is detected This helps to protect the photorelay and related parts in the circuit from damage.
	Low product of C and R	---	An indicator of photorelay output characteristics in applications with high frequency or high speed signals C refers to C_{OFF} – Electrostatic capacitance between the MOSFETs' output pins R refers to R_{ON} - Resistance between the MOSFETs' output pins at a specified ON-state rating High C_{OFF} may cause following phenomena: ・Signal may pass through relay even if the relay is at OFF-state (signal leak or lower isolation level). ・Longer output signal rise time (waveform distortion) ・High R_{ON} leads to signal loss (voltage drop and insertion loss reduction). Therefore in such applications, low C_{OFF} and R_{ON}, thus low product of C and R characteristic, is important.

Terminology of Photorelay 3

Term		Symbol	Description
Recommended operating conditions	Supply voltage	V_{DD}	Recommended supply voltage which has taken derating of maximum specifications into consideration In the case of alternating current, it means the peak voltage.
	Input forward current	I_F	Recommended LED input forward current which has taken derating of maximum specifications into consideration
	ON-state current	I_{ON}	Recommended load current which has taken derating of maximum specifications into consideration In the case of AC, it means the peak current.
	Operating temperature	T_{opr}	Recommended operating temperature which has taken derating of maximum specifications into consideration

Recommended operating conditions is only a reference to achieve the intended performance of the device, which has taken margin into consideration.
Also, it is necessary to design in detail according to the customers' actual usage conditions.

Key Characteristic : ON Resistance (R_{ON})

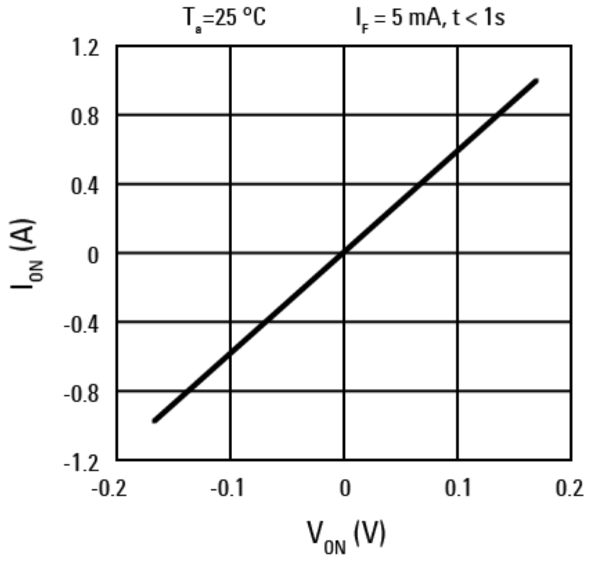


Fig. 1 $I_{ON} – V_{ON}$

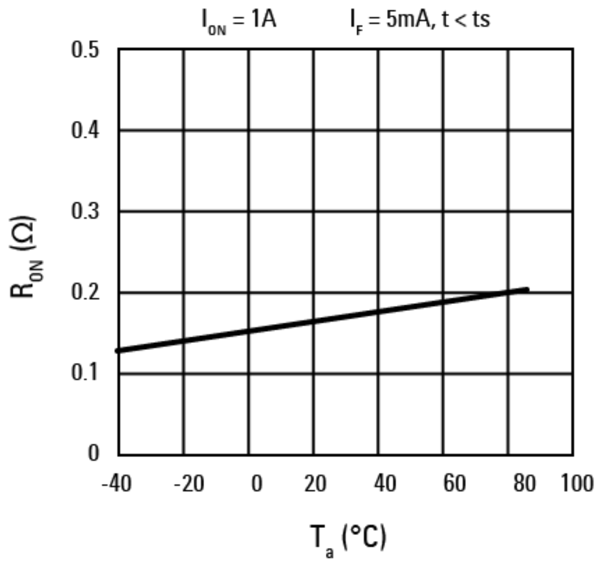
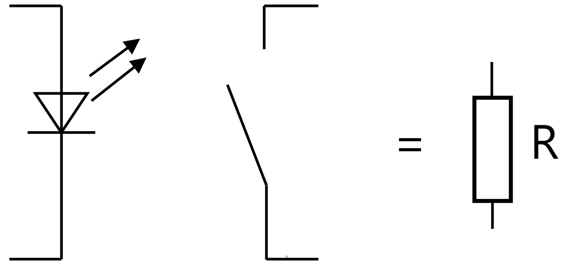


Fig. 2 $R_{ON} – T_a$



A resistance is seen during on state

Fig 3. Characteristics under a high temperature

ON Resistance (R_{ON})

・Fig. 1 shows a photorelay output current – voltage characteristic which is equivalent to contact resistance characteristics of mechanical relay The grater slope of this line means smaller R_{ON} value.

・The R_{ON} of output MOSFETs has a trade-off relationship with the off-state output voltage. Higher off-state voltage usually means higher R_{ON} and power consumption.

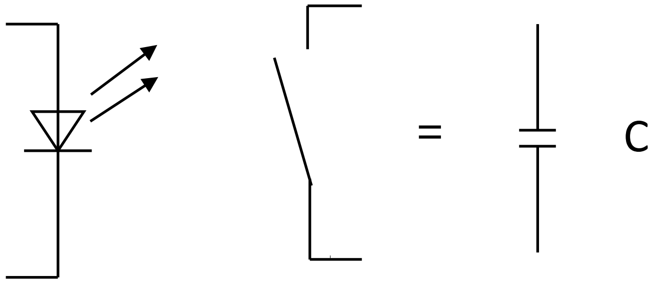
・Ambient temperature can influence R_{ON} (Fig. 2). R_{ON} and power consumption become higher when ambient temperature is higher.

・Please take sufficient V_{OFF} margin into account in your design. It is desirable to choose a photorelay with the smallest R_{ON} in this V_{OFF} range.

・To prevent breakdown of the device due to heat generated by increased power consumption, the ratings should be set to ensure that the load current does not exceed a certain level under high temperature.

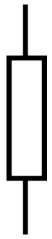
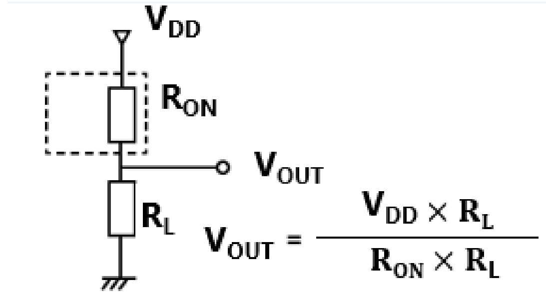
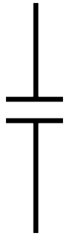
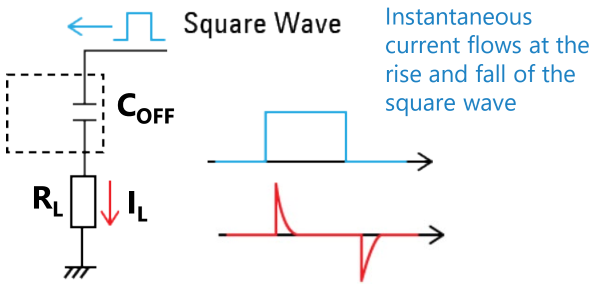
It is recommended the photorelay with the lowest RON be selected ensuring a sufficient off-state voltage margin for the load voltage to be used.

Key Characteristic : Output Capacitance (C_{OFF})



Unlike mechanical relays, ON-state resistance and output capacitance are inherent characteristics of photorelays (semiconductor relays), which requires consideration when replacing mechanical relay with photorelays.

The diagram on the right shows the operation example of the waveform due to ON-state resistance and output capacitance.

Mode	Equivalent Circuit	Operation Example
LED: ON	Resistor 	
LED: OFF	Capacitor 	

・Output capacitance is the electrostatic capacitance between the MOSFETs' output pins **when there is no input current (MOSFET is OFF)**. In a non conductive state, the AC signal leaks through this capacitance.
・The difficulty of flow of current in an AC circuit is known as **impedance**. In a DC circuit, this is known as resistance. The impedance of electrostatic capacitance becomes smaller with higher frequencies and larger with lower frequencies– also to say that current flows more easily.
・When the LED is OFF, it is desirable to have a smaller leak current on the output side. A smaller electrostatic capacitance helps limiting this leak current (especially at high frequencies).

Switching Time (t_{ON}/t_{OFF})

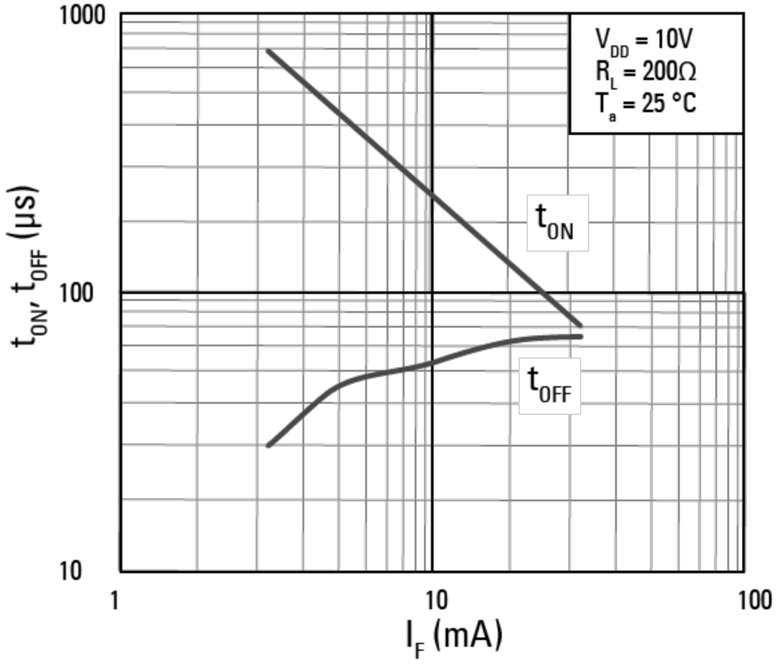


Fig. 1 t_{ON}, t_{OFF} - I_F

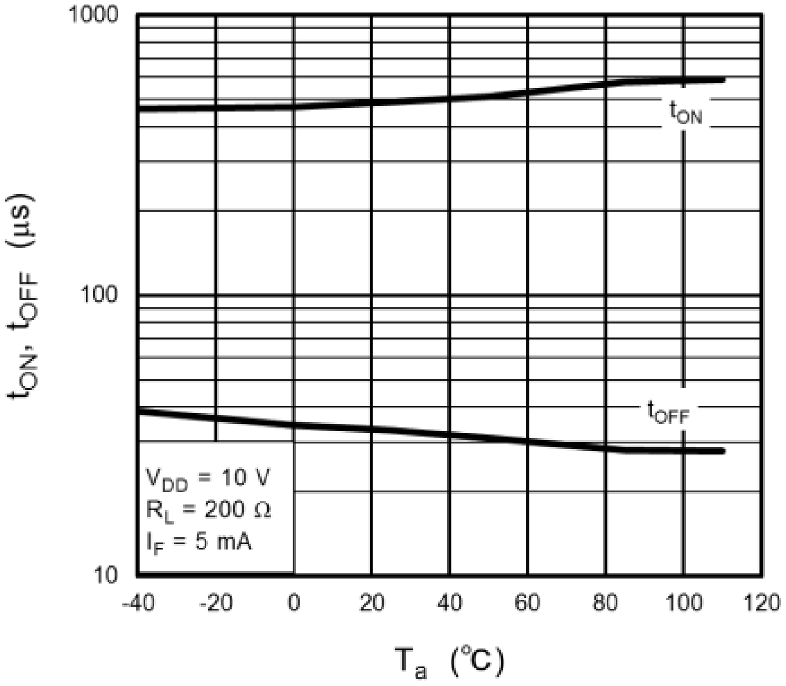


Fig. 2 t_{ON}, t_{OFF} - T_a

・Switching time for standard products ranges from 0.2 ms to 2.0 ms, differing with products.
・Higher input currents imply higher LED emission intensity, which brings about faster switching speed.
・With higher ambient temperatures, LED emission intensity drops together with PDA capabilities resulting in increasing of switching times.

C × R

When using a photorelay to control high speed (> several MHz) input square waves, distortion of the wave can be observed (Fig. 1). This leads to degradation of signal quality and signal strength after passing through the photorelay, and signal leakage when the photorelay is off state.

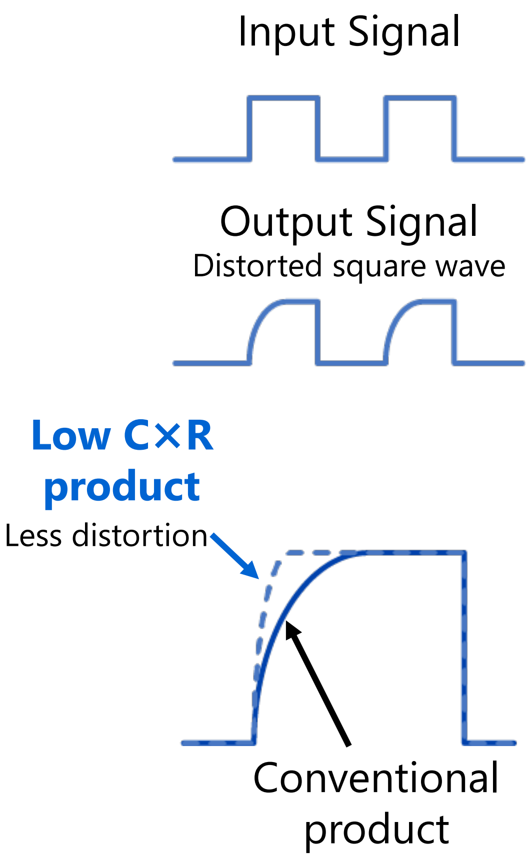
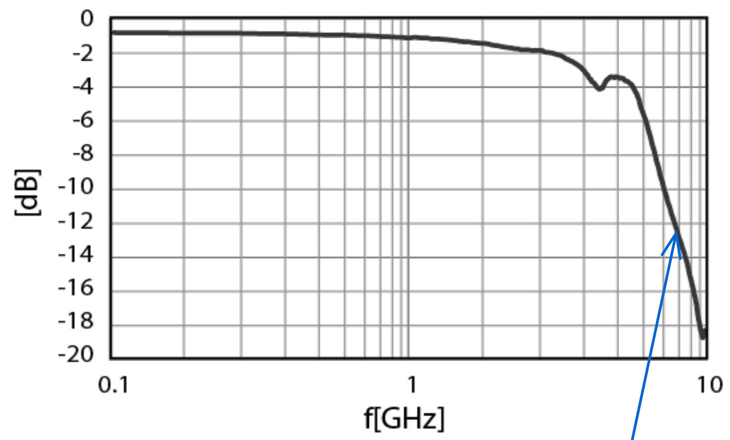
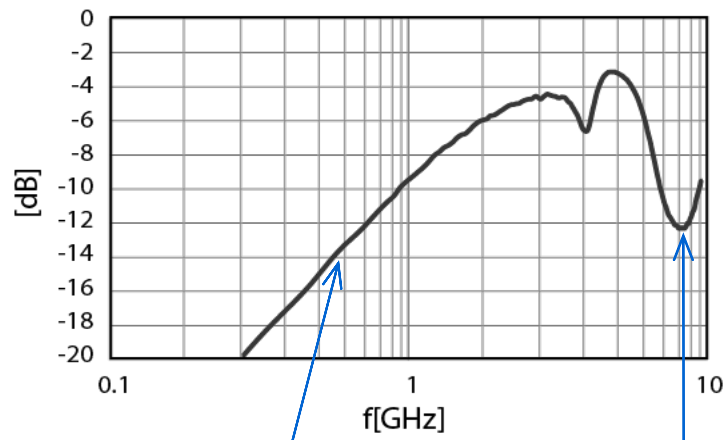


Fig. 1

Insertion Loss: **LED ON**



Insertion Loss: **LED OFF**



At high frequencies, impedance from the frame and wires become significant, making it difficult for the signal to pass.

At high frequencies, impedance due to the output capacitance is lowered. The signal can passed easily even in the OFF-state.

Also, C and L cause resonance.

The lower the product of C and R, the closer the output is to the original waveform (Better impedance matching characteristic).

➡ **Possible to replace reed relays**

LED Lifetime Estimation

The LED degradation rate changes with the input current and time.
The LED life estimation is based on LED long term data taken from one lot and thus can only be used for reference purposes.

F50% Lifetime: The projected lifetime for 50 % of cumulative failures. This is the time period up to where the projected long-term light output degradation curve of the average light output (AVG) reaches the failure criteria.
F0.1% Lifetime: The projected lifetime for 0.1 % of cumulative failures. This is the time period up to where the projected long-term light output degradation curve AVG-3σ reaches the failure criteria.

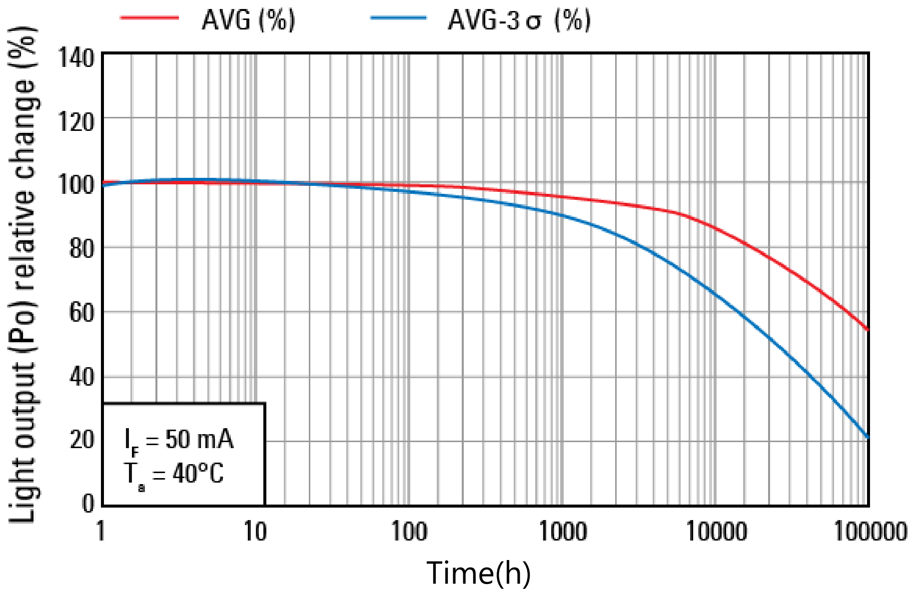


Fig. 1 GaAs LED projected light output degradation data

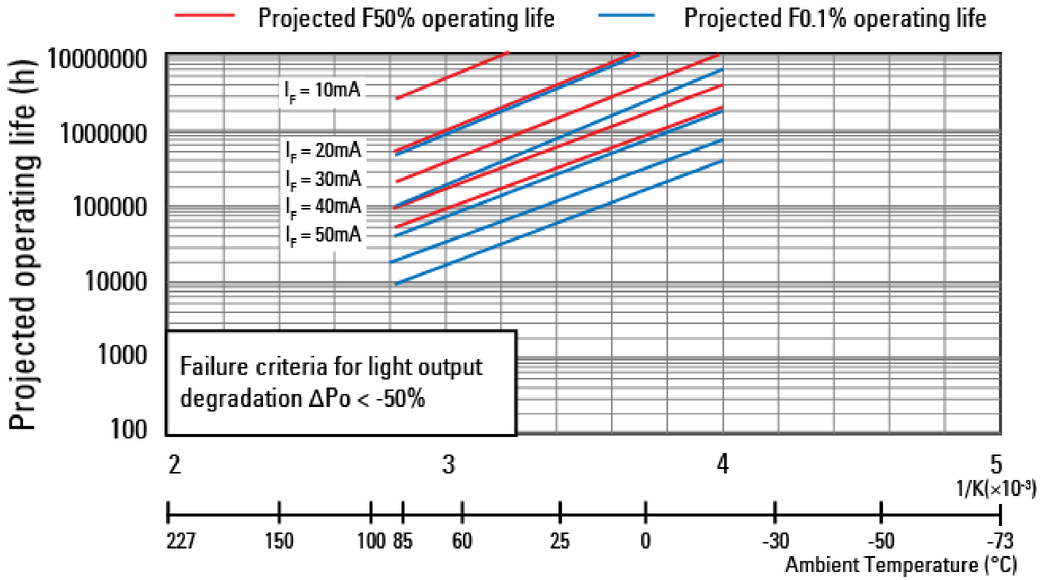


Fig. 2 GaAs LED projected operating life data

Toshiba Photorelay Datasheet Example

Input (LED) forward current

The maximum allowable forward current that can be input into the LED without damaging it.
Please design input forward current within this specification.

OFF-state output terminal voltage

The maximum voltage which can be applied between the MOSFETs' output pins in the OFF-state. It provides an indication of the power source to use.

ON-state current

The maximum current which can flow between the MOSFETs' output pins in the ON-state
Design of both DC and AC currents should be kept within this value.
I_{ON}(max) changes with ambient temperature.

Isolation voltage

The resistance between the input and output pins with specified voltage applied.
The limit within which isolation breakdown does not occur.

Absolute Maximum Ratings (Note) (Unless otherwise specified, T_a = 25 ℃)

	Characteristics		Symbol	Note	Rating	Unit
LED	Input forward current		I_F		30	mA
	Input forward current derating	($T_a \geq$ 25 ℃)	$\Delta I_F/\Delta T_a$		-0.3	mA/℃
	Input reverse voltage		V_R		5	V
	Input power dissipation		P_D		50	mW
	Input power dissipation derating	($T_a \geq$ 25 ℃)	$\Delta P_D/\Delta T_a$		-0.5	mW/℃
	Junction temperature		T_j		125	℃
Detector	OFF-state output terminal voltage		V_{OFF}		20	V
	ON-state current		I_{ON}		1	A
	ON-state current derating	($T_a \geq$ 25 ℃)	$\Delta I_{ON}/\Delta T_a$		-10	mA/℃
	ON-state current (pulsed)	(t = 100 ms, Duty = 1/10)	I_{ONP}		3	A
	Output power dissipation		P_O		240	mW
	Output power dissipation derating	($T_a \geq$ 25 ℃)	$\Delta P_O/\Delta T_a$		-2.4	mW/℃
	Junction temperature		T_j		125	℃
Common	Storage temperature		T_{stg}		-40 to 125	℃
	Operating temperature		T_{opr}		-40 to 110	
	Lead soldering temperature	(10 s)	T_{sol}		260	
	Isolation voltage	AC, 60 s, R.H. ≤ 60 %	BV_S	(Note 1)	500	Vrms

*Extracted from TLP3403 datasheet

Toshiba Photorelay Datasheet Example

Electrical Characteristics (Unless otherwise specified, T_a = 25 °C)

	Characteristics	Symbol	Note	Test Condition	Min	Typ.	Max	Unit
LED	Input forward voltage	V_F		I_F = 10 mA	1.1	1.27	1.4	V
	Input reverse current	I_R		V_R = 5 V	—	—	10	μA
	Input capacitance	C_t		V = 0 V, f = 1 MHz	—	30	—	pF
Detector	OFF-state current	I_{OFF}		V_{OFF} = 20 V	—	—	1	nA
	Output capacitance	C_{OFF}		V = 0 V, f = 100 MHz, t < 1 s	—	40	—	pF

Coupled Electrical Characteristics (Unless otherwise specified, T_a = 25 °C)

Characteristics	Symbol	Note	Test Condition	Min	Typ.	Max	Unit
Trigger LED current	I_{FT}		I_{ON} = 100 mA, t < 1 s	—	—	3	mA
Return LED current	I_{FC}		I_{OFF} = 10 μA	0.1	—	—	
ON-state resistance	R_{ON}		I_{ON} = 1 A, I_F = 5 mA, t < 1 s	—	0.18	0.22	Ω

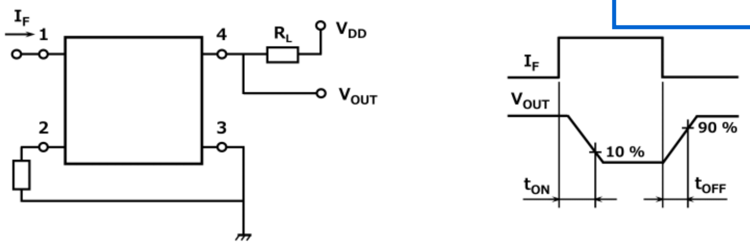
Isolation Characteristics (Unless otherwise specified, T_a = 25 °C)

Characteristics	Symbol	Note	Test Condition	Min	Typ.	Max	Unit
Total capacitance (input to output)	C_S	(Note 1)	V_S = 0 V, f = 1 MHz	—	1.0	—	pF
Isolation resistance	R_S	(Note 1)	V_S = 500 V, R.H. ≤ 60 %	—	10^{14}	—	Ω
Isolation voltage	BV_S	(Note 1)	AC, 60 s	500	—	—	Vrms

Note 1: This device is considered as a two-terminal device: Pins 1 and 2 are shorted together, and pins 3 and 4 are shorted together.

Switching Characteristics (Unless otherwise specified, T_a = 25 °C)

Characteristics	Symbol	Note	Test Condition	Min	Typ.	Max	Unit
Turn-on time	t_{ON}		See Fig. 11.1. R_L = 200 Ω, V_{DD} = 10 V, I_F = 5 mA	—	—	2.0	ms
Turn-off time	t_{OFF}			—	—	1.0	



*Extracted from TLP3403 datasheet

Output capacitance

The electrostatic capacitance between the MOSFETs' output pins (capacitance of the PN junction between the two drains)
This leads to signal leakage through this "capacitor" in the OFF-state when using AC power source.

Trigger LED current

The minimum value of the input current I_F necessary to turn the output MOSFETs into the ON-state

ON-state resistance

The resistance between the MOSFET output pins when the MOSFETs turns on at a specified input LED current

Turn-on time

Time required for output waveform to drop to 10% upon turning on the LED

Turn-off time

Time required for output waveform to return to 90% upon turning off the LED

04

SELECTION GUIDE

Photorelay Selection Guide and Points to Note (1/3)

1 Voltage and current maximum ratings

Unlike mechanical relays where exceeding the maximum ratings may not cause circuit to break down immediately, photorelays are susceptible to excess voltage and current. Care needs to be taken for design within the specified maximum ratings.

2 Lifetime (Reliability)

Cycle lifetime is specified for mechanical relays due to contact wear and welding.
Conversely, since photorelays turn on and off with respective MOSFET operation, there is no mechanical contact and therefore no need for maintenance like mechanical relays. When used within the specified ratings, photorelays provide long lifetime.

3 ON-state resistance

Mechanical relays hardly have any ON-state resistance, while photorelays have a range of high to low R_{ON} products. High current photorelay with a R_{ON} lower than that of mechanical relays also exists.

Photorelay Selection Guide and Points to Note (2/3)

4 Output OFF-state

OFF-state output terminal voltage

Complete isolation is achieved in mechanical relays when the contact is open. On the other hand, photorelays are not completely isolated due to the existence of PN junction. Compared to mechanical relays, the OFF-state terminal voltage is lower, and therefore we recommend a protection diode added to the circuit.

OFF-state current (leakage)

There is hardly any leakage current in mechanical relays. In photorelays, leakage current flows when voltage is applied on the output side. For applications where leakage is a concern, please consider Toshiba's low leakage (pA order) products.

5 Switching time

Toshiba has photorelays with typical switching times less than 1 ms even about 0.01 ms, unlike mechanical relays, which takes a few milliseconds even for signal relay.

Photorelay Selection Guide and Points to Note (3/3)

6 Input power consumption

Mechanical relay power consumption, even for low power consumption signal relays, are typically from 100 mW onwards. For photorelays, trigger currents of about 3 mA can operate the MOSFETs. Typically I_F around 5 mA (below 10 mW) is sufficient. There are also products with I_{FT} = 0.2 mA (max), further lowering the power consumption.

7 Driving current

Mechanical relays can be driven by both DC and AC. However, most of the photorelays are DC driven.

8 Contact form

Mechanical relays have a range of contact forms (Form-A, Form-B, Form-C) to choose from. Photorelays are typically Form-A. (Some products also support Form b)

9 Size

Small sized mechanical signal relays takes up 60 mm^2 area.
However, the area photorelays taken is considerably smaller, such as 2.9 mm^2（2.0 mm × 1.45 mm）, making it possible to mount more parts in a limited area.

05

DESIGN CONSIDERATION

Contents

Photorelay Failure Modes

Below are the causes of photorelay failures when used beyond specified voltage and current limits.
To reduce the risk of such failures, the section [Design Considerations] is provided for your reference.

	Factor	Cause	Area of defect	Phenomena	Cause of defect	Countermeasure
Detection of defect	Electrical stress	Overvoltage or over current on the input side	Melted wire	Open: Does not turn on by I_{FT}	1. Load-included noise in the circuit 2. Surge in the circuit	1. Re-design the protection circuit 2. Countermeasure against surge
			LED chip burnout	Short: Does not turn on by I_{FT}	1. Load-included noise in the circuit 2. Surge in the circuit 3. ESD damage	1. Re-design the protection circuit 2. Countermeasure against surge 3. Countermeasure against ESD
			LED chip junction destruction	Short / Leak: Does not turn on by I_{FT}	1. Load-included noise in the circuit 2. Surge in the circuit 3. ESD damage	1. Re-design the protection circuit 2. Countermeasure against surge 3. Countermeasure against ESD
			Package discoloration (caused by heat)	Short / Leak: Does not turn on by I_{FT}	1. Over current (higher than maximu ratings) 2. Overvoltage	Re-design the circuit (resistance / voltage)
		Overvoltage or over current on the output side	Melted wire	Open: Does not turn on by I_{FT}	1. Load-included noise in the circuit 2. Surge in the circuit	1. Re-design the protection circuit 2. Countermeasure against surge
			MOSFET chip burnout	Short: Does not turn on by I_{FT}	1. Load-included noise in the circuit 2. Surge in the circuit 3. ESD damage	1. Re-design the protection circuit 2. Countermeasure against surge 3. Countermeasure against ESD
			MOSFET chip junction destruction	Short / Leak: Does not turn on by I_{FT}	1. Load-included noise in the circuit 2. Surge in the circuit 3. ESD damage	1. Re-design the protection circuit 2. Countermeasure against surge 3. Countermeasure against ESD
			Package discoloration (caused by heat)	Short / Leak: Does not turn on by I_{FT}	1. Over current (higher than maximu ratings) 2. Overvoltage	Re-design the circuit (resistance / voltage)

I_F Design Consideration

To turn the photorelay ON, the input current (I_F) should be designed higher than trigger LED current (I_{FT}).
Based on the maximum of trigger LED current, I_F should be taken into consideration like the equation below.

Design $I_F(ON) = I_{FT}(max) \times \alpha 1 \times \alpha 2 \; (\times \alpha 3)$

α1: LED Degradation Rate (Multiplication factor)	Derive α1 from the related (X)−3σ curve (e.g. Fig. 1). The higher the ambient temperature or I_F value, the greater the degradation rate. Also, LED used changes with product. If required, please contact us for more information.
α2: IFT-Ta Characteristic (Multiplication factor)	Refer to the datasheet for I_{FT} - T_a, and derive α2 (e.g. Fig. 2).
α3: Drive Factor	Power supply fluctuations, tolerance levels

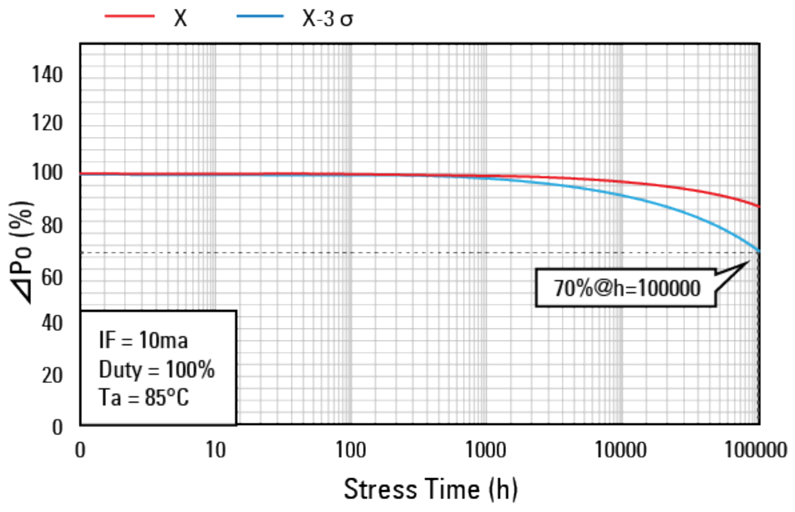


Fig. 1 GaAs LED projected light output degradation data

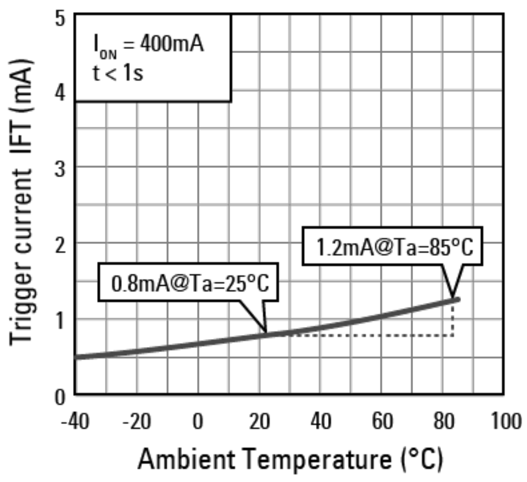


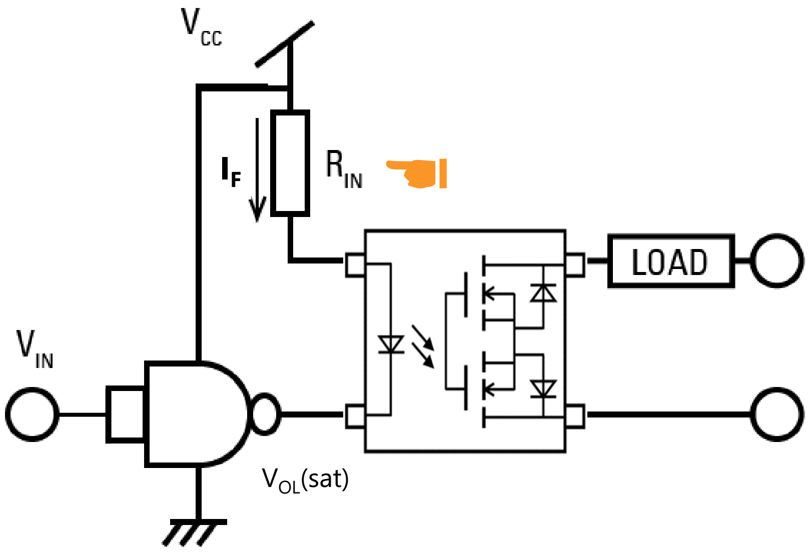
Fig. 2 I_{FT}-T_a

e.g. $I_{FT}(max)$ = 3 mA. When designing for use in T_a = 85 °C, with lifetime of 100khrs: Design $I_F(ON)$ = 3 mA × 1.43 × 1.5 = 6.53 mA ← Set I_F above 6.53 mA.

I_F Design Consideration

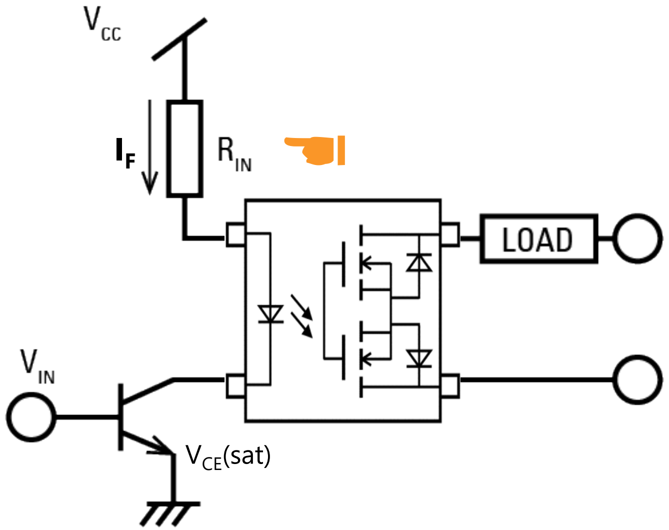
Points to note for Voltage driven design (Determining LED limiting resistor value)

- The voltage drop due to LED input current, temperature dependency (lower temperature with higher V_F) and voltage drop of input signal are some of the factors to take into consideration.
- Please refer to respective maximum values in the datasheet, and make sure to design within the specified absolute maximum I_F value.
- Also, check that the power supply (V_{CC}) used is able to support input current larger than designed I_F(ON) value.



$$R_{IN} \leqq \frac{V_{CC}(min) - V_F(max) - V_{OL}(max)}{Design\ I_F(ON)}$$

$$*R_{IN} > \frac{V_{CC}(max) - V_F(min) - V_{OL}}{I_F(max)}$$



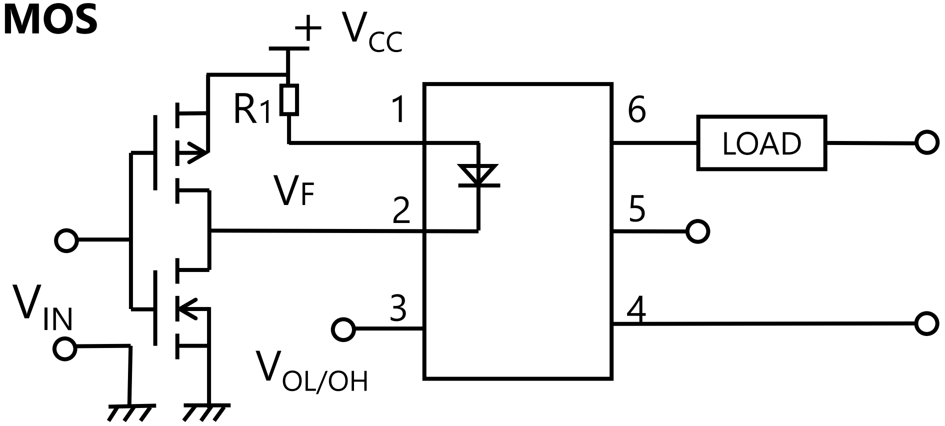
$$R_{IN} \leqq \frac{V_{CC}(min) - V_F(max) - V_{CE}(sat)(max)}{Design\ I_F(ON)}$$

$$*R_{IN} > \frac{V_{CC}(max) - V_F(min) - V_{CE}(sat)}{I_F(max)}$$

Recommended LED Driving Circuit Example

Representative photorelay drive circuit

C-MOS



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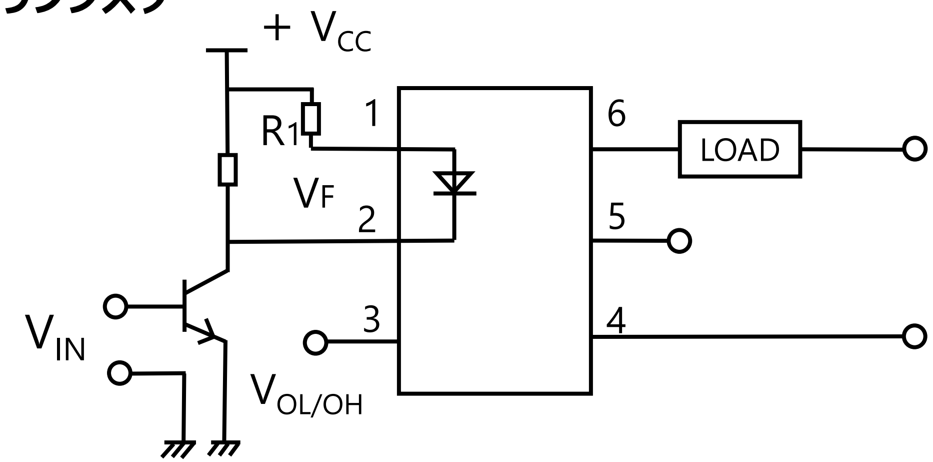


Calculation of LED current limiting resistor required for proper operation of photorelay

$$R_1 = \frac{V_{CC} - V_{OL} - V_F(ON)}{5 - 20\ \text{mA}}$$

Calculation of LED forward voltage V_F required for proper return operation of photorelay

$$V_F(OFF) = V_{CC} - I_F R_1 - V_{OH} < 0.8\ \text{V}$$

The above C-MOS driving circuit has excellent noise tolerance (when LED is OFF, the top MOS is ON (shorted)).
If noise occurs in the transistor driving circuit, connect in parallel to the LED a resistor in the order of several tens of kΩ.

Overvoltage / Overcurrent on Input Side

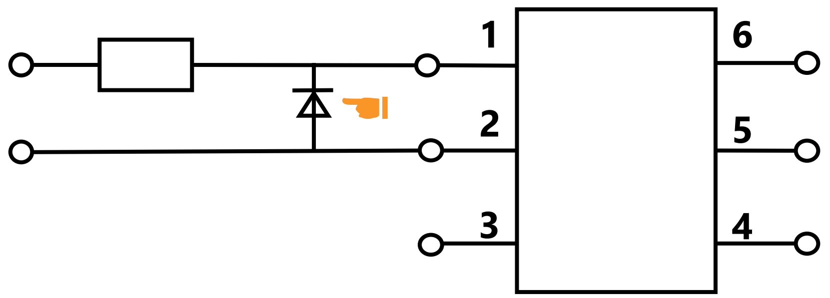
Causes of output failure due to external surges

When a reverse voltage greater than that of the rated maximum is applied to the LED

- Shorted input terminals ⇒ LED does not turn on
- Open input terminals ⇒ LED does not turn on

Countermeasures against output failure due to external surges

For applications that may have reverse voltage surges on the input side, connect a reverse diode to the input terminals to prevent excess reverse voltages on the LED diode. The representative circuit is shown below.



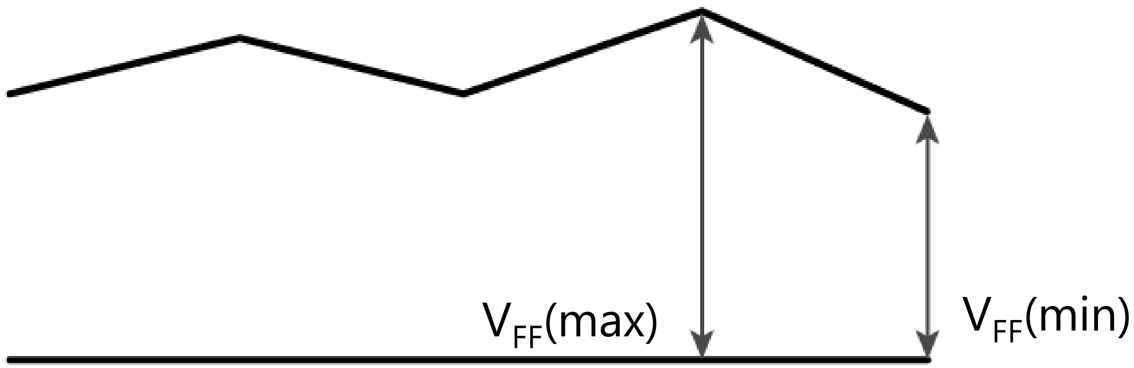
Surge voltage protection circuit example for input side

Overvoltage / Overcurrent on Input Side

Input power supply ripple-induced defects

When a current greater than that of the rated maximum is applied to the LED

- Shorted input terminals ⇒ LED does not turn on
- Open input terminals ⇒ LED does not turn on



Countermeasure for input power supply ripple

When there is a ripple in the input side power source, please note the following.

- Check and confirm the LED trigger input corresponding to V_{FF}(min) of LED.
- Do not exceed the max rated current for input current at V_{FF}(max).

Input Side Design Consideration

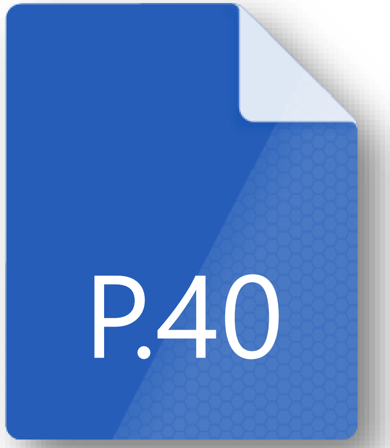
If not turned on due to insufficient input side current

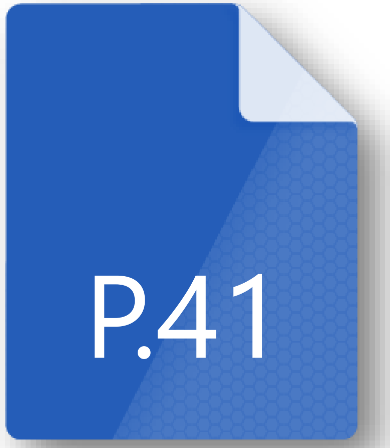
The design input current did not take into sufficient consideration changes to the $I_{FT,}$ therefore the photorelay ceased to turn on after a period of operation time.

It is important to take into consideration **changes to I_{FT} with ambient temperature and also the LED degradation over time** in your design.

If not turned on due to insufficient input side current

Please set the appropriate design I_{FT} according to the below recommendation (p. 40-41) at the early stages of circuit design.





Design failure example

Typical value of the trigger LED in the datasheet is 1 mA (ambient temperature is T_a = 25 °C)

⇒ Mr. A sets the I_F design value at 1 mA.

The set was successfully tested on a prototype circuit in the laboratory
(the air conditioning in the laboratory was set at 25 °C).

However, the set did not work in mass production.

Coupled Electrical Characteristics (Unless otherwise specified, T_a = 25 ℃)

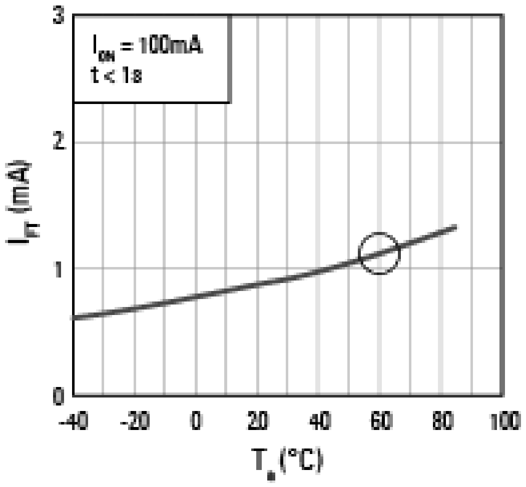
Characteristics	Symbol		Test Condition	Min	Typ.	Max	Unit
Trigger LED current	I_{FT}		I_{ON} = 500 mA	—	1	3	mA
Return LED current	I_{FC}		I_{OFF} = 100 μA	0.1	0.5	—	mA
ON-state resistance	R_{ON}		I_{ON} = 500 mA, I_F = 5 mA	—	1	2	Ω

* Extracted from TLP172AM datasheet

Input Side Design Consideration

Causes

The ambient temperature of a photorelay in a mass-produced set had risen to 60 °C.
However, they were designed to be used under 25 °C conditions.



I_{FT} rises with ambient temperatures.
As shown in the left figure, the design I_F = 1 mA < I_{FT}.
When 1 mA is applied, the photorelay does not operate even if I_F is turned on.

When determining the I_F, design the I_{FT}(max) plus a margin.

Coupled Electrical Characteristics (Unless otherwise specified, T_a = 25 ℃)

Characteristics	Symbol		Test Condition	Min	Typ.	Max	Unit
Trigger LED current	I_{FT}		I_{ON} = 500 mA	—	1	3	mA
Return LED current	I_{FC}		I_{OFF} = 100 μA	0.1	0.5	—	mA
ON-state resistance	R_{ON}		I_{ON} = 500 mA, I_F = 5 mA	—	1	2	Ω

* Extracted from TLP172AM datasheet

Design failure example

The maximum value of the trigger LED current in the datasheet is 3 mA (ambient temperature T_a = 25 °C).

⇒ Mr. A set the I_F design value at 3 mA. The prototype circuit in the laboratory operated successfully.

However the set did not turn on at the outgoing test after 1000 h.

Coupled Electrical Characteristics (Unless otherwise specified, T_a = 25 ℃)

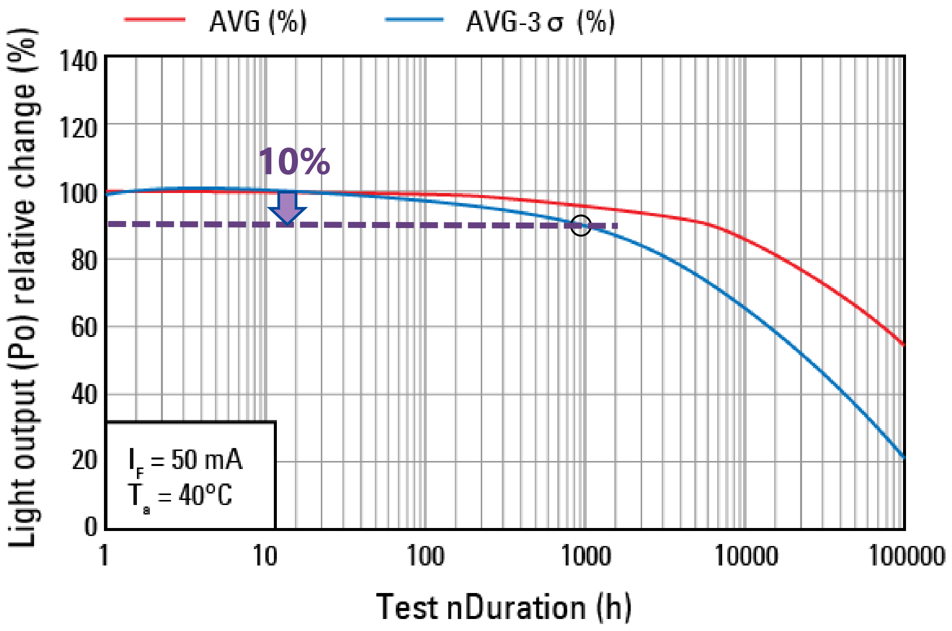
Characteristics	Symbol		Test Condition	Min	Typ.	Max	Unit
Trigger LED current	I_{FT}		I_{ON} = 500 mA	—	1	3	mA
Return LED current	I_{FC}		I_{OFF} = 100 μA	0.1	0.5	—	mA
ON-state resistance	R_{ON}		I_{ON} = 500 mA, I_F = 5 mA	—	1	2	Ω

* Extracted from TLP172AM datasheet

Input Side Design Consideration

Cause

The light output of the input LEDs had deteriorated over time.



As shown in the figure on the left, the light output of LEDs deteriorates with the energization time because defects in the crystal increase as the LEDs are energized.
In this case, the optical output has degraded by 10 % from the initial state, so I_{FT} has actually increased by 10 % (I_{FT} = 3.3 mA).

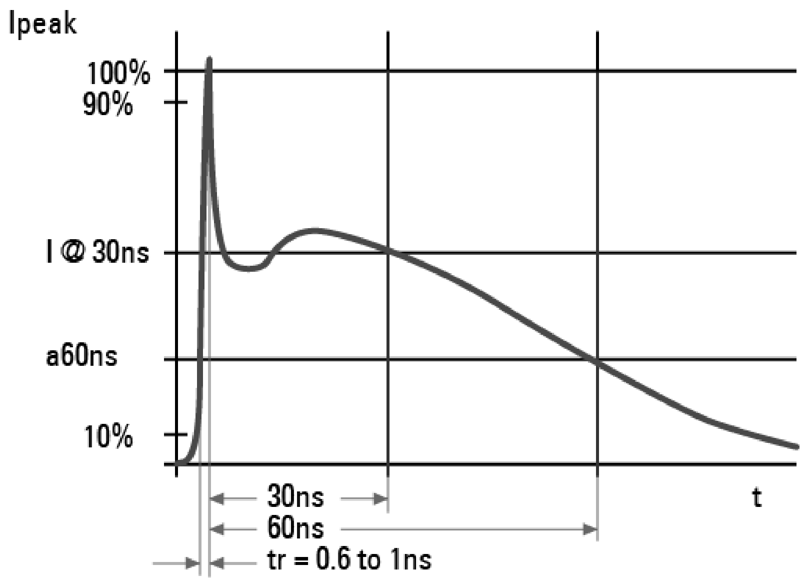
This results in I_F 3 mA < I_{FT} 3.3 mA,
This is because the I_F value is below the value required for the MOSFET to turn on, so it no longer works.

The I_F design is recommended to be based on I_{FT} (max), taking into account the degradation of optical output according to the operating time of the set.

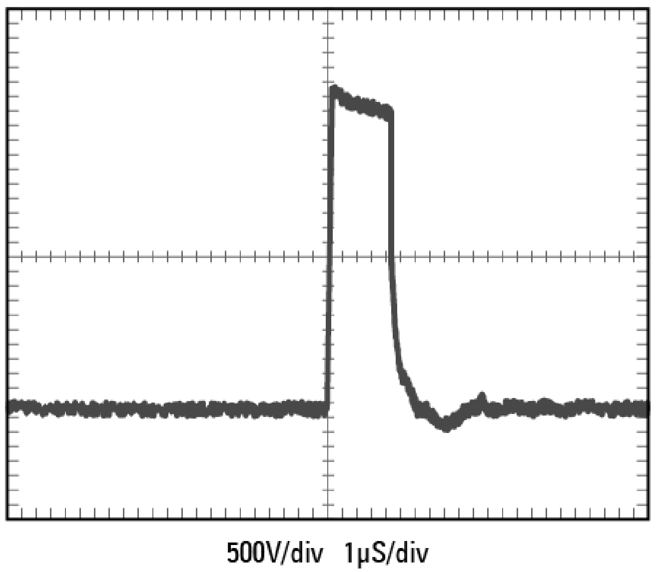
Output failure due to external surge

There are cases in the load power supply whereby the induced impulse noise of the power line overlaps with ESD surge etc., causing damage to the photorelay output chip(short or open).

- Output terminal is short ⇒ Photorelay is on even when input LED is not.
- Output terminal is open ⇒ Photorelay does not turn on.



ESD noise waveform example : ns order



Impulse noise waveform example : μs order

Overvoltage / Overcurrent on Output Side

Countermeasures against output failure due to external surges

■ Add a varistor (variable resistor)

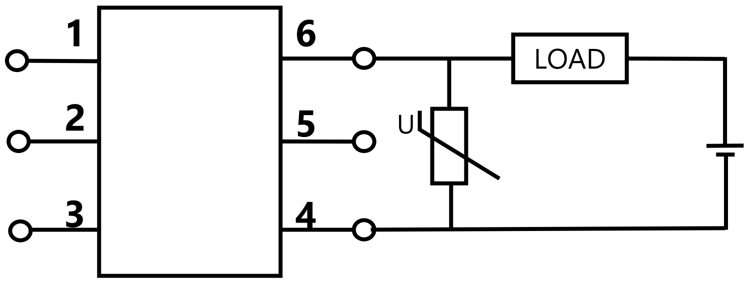
Varistor: Typically (small currents) acts like a condenser, but with high currents from overvoltage acts like a resistor to draw away the short circuit current, thereby protecting the circuit

■ Selection method

Choose a varistor with limit voltage not more than that of the OFF-state terminal voltage of the photorelay. (Guideline: $V_{OFF} \times 0.7$).

- In case of ESD: Stacked type varistor for ESD protection is typically used.
- In case of used with commercial AC power supply: Please refer to the table below.

Power supply voltage	Recommended varistor rated voltage	Photorelay V_{OFF}	Surge current tolerance
AC 100 V line	220 to 270 V	400 to 600 V	Above 1000 A
AC 200 V line	430 to 470 V	600 V	Above 1000 A

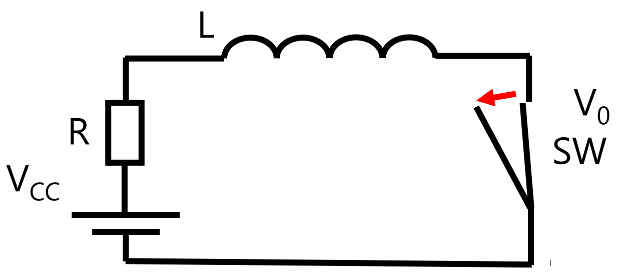


Overvoltage / Overcurrent on Output Side

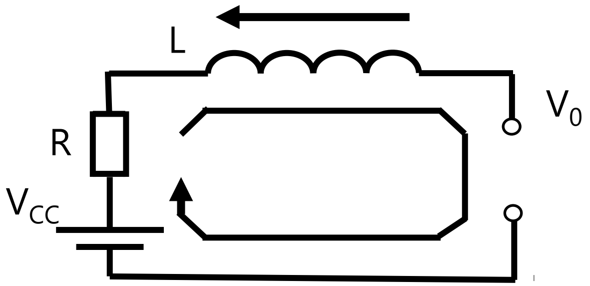
Output device failure due to reverse voltage

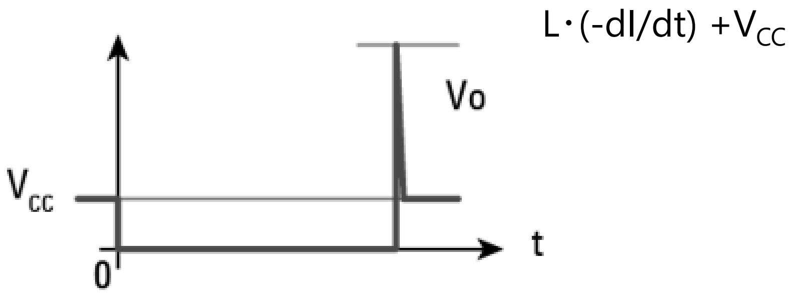
When controlling an inductive load and turning the photorelay from on to off, the inductance current suddenly changes from (V_{CC} /R) to zero, which has a large current change (dI/dt).
As a result, high counter voltage is induced according to the relationship E=L・(-dI/dt). When this voltage exceeds the OFF-state terminal voltage of the photorelay, it may become a cause of output chip damage.

Photorelay OFF



Reverse voltage: E=L・(-dI/dt)

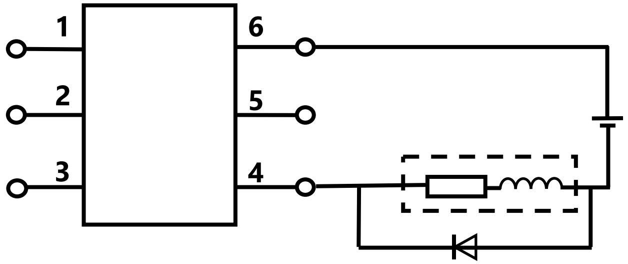




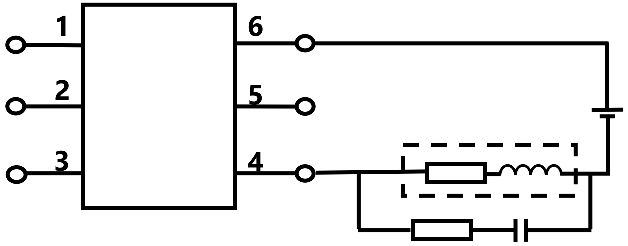
Overvoltage / Overcurrent on Output Side

Countermeasures against output device failure due to reverse voltage

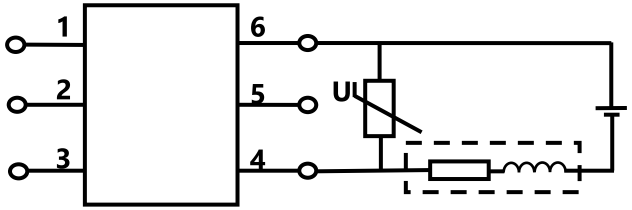
It is recommended to include a protective element to prevent overvoltage from inductive loads.
The point is to keep overvoltage values within the rated V_{OFF}.



Provide path for excess energy through the diode.



Absorb the energy with a snubber circuit.



Prevent overvoltage with a varistor.

Note : When using protection elements such as diodes, snubbers (C-R), varistors etc., it is necessary to place them close to the load and/or photorelay or the effect will diminish.

Overvoltage / Overcurrent on Output Side

Output device failure due to inrush current

In-rush current occurs when power is supplied to the load controlled by the photorelay.
Depending on the type of load, the magnitude of the in-rush current changes. The below explains the characteristics of the various types of loads.

1. Heater Loads (resistive load)

Typically no in-rush current.
However, there are some heaters with changing resistance as temperature changes. For such heaters, in-rush current occurs due to the low resistance at room temperature.
When this in-rush current exceeds the rated current for photorelay pulse ON, it may cause output chip damage.

<Heater types with in-rush currents>

- Pure metal type heater (3 to 5 times of rated current)
- Ceramic type heater (3 to 5 times of rated current)
- Lamp heater (10 to 15 times of rated current)

2. Lamp Loads

Incandescent light bulb・halogen lamp (including lamp heater etc.) produce in-rush current of around 10 to 15 times that of rated current.
It is a cause of output chip damage when this in-rush current exceeds the photorelay rated pulse current repeatedly.

Overvoltage / Overcurrent on Output Side

Output device failure due to inrush current

3. Motor Loads

When inductive loads from the motor starts, in-rush current of around 5 to 10 times of the rated current flows. It may cause output chip damage when this in-rush current exceeds the photorelay rated pulse current repeatedly.

4. Transformer Loads

When power is supplied on the input side of a transformer, excitation current about 10 to 20 times that of the photorelay rated current flows within a short duration of 10 to 500 ms. When excitation current exceeds the photorelay rated ON current repeatedly, it may cause chip damage.

Overvoltage / Overcurrent on Output Side

Countermeasure against breakdown of output elements due to inrush current

When selecting a photorelay, please check the inrush current of the load and select a product that is less than paused ON-state current rating of the photorelay.

Detector	OFF-state output terminal voltage		V_{OFF}		60	V
	ON-state current		I_{ON}		500	mA
	ON-state current derating	($T_a \geq 25$ °C)	$\Delta I_{ON}/\Delta T_a$		-5.0	mA/°C
	ON-state current (pulsed)	(t = 100 ms, duty = 1/10)	I_{ONP}		1.5	A
	Output power dissipation		P_O		300	mW
	Output power dissipation derating	($T_a \geq 25$ °C)	$\Delta P_O/\Delta T_a$		-3.0	mW/°C
	Junction temperature		T_j		125	°C

* Extracted from TLP172AM datasheet

Output Side Design Consideration

Design failure example

From the datasheet, absolute maximum rating of ON-state current is 500 mA.
⇒Mr. A took a margin and configured the circuit with I_{ON} = 400 mA, 80 % of the rating.

Although the set was successfully tested in a prototype circuit in the laboratory, **the set did not work during mass production**. (The air conditioning in the laboratory was set to 25 °C.)

Absolute Maximum Ratings (Unless otherwise specified, T_a = 25 ℃)

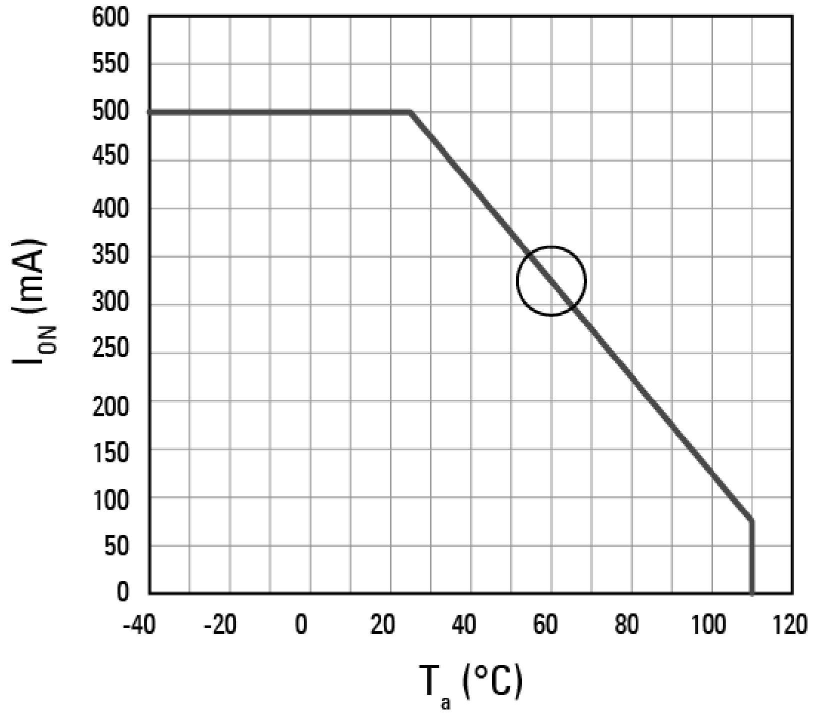
	Characteristics		Symbol	Note	Rating	Unit
LED	Input forward current		I_F		30	mA
	Input forward current derating	($T_a \geq$ 25 °C)	$\Delta I_F/\Delta T_a$		-0.3	mA/°C
	Input forward current (pulsed)	(100 μs pulse, 100 pps)	I_{FP}		1	A
	Input reverse voltage		V_R		6	V
	Input power dissipation		P_D		50	mW
	Input power dissipation derating	($T_a \geq$ 25 °C)	$\Delta P_D/\Delta T_a$		-0.5	mW/°C
	Junction temperature		T_j		125	°C
Detector	OFF-state output terminal voltage		V_{OFF}		60	V
	ON-state current		I_{ON}		500	mA
	ON-state current derating	($T_a \geq$ 25 °C)	$\Delta I_{ON}/\Delta T_a$		-5.0	mA/°C
	ON-state current (pulsed)	(t = 100 ms, duty = 1/10)	I_{ONP}		1.5	A
	Output power dissipation		P_O		300	mW
	Output power dissipation derating	($T_a \geq$ 25 °C)	$\Delta P_O/\Delta T_a$		-3.0	mW/°C
	Junction temperature		T_j		125	°C

* Extracted from TLP172AM datasheet

Output Side Design Consideration

Design failure example (Cause)

The ambient temperature of the photorelay components in the mass-produced was up to 60 °C.



* Extracted from TLP172AM datasheet

The ON-state current of photorelays, which are semiconductor devices, must be derated according to the ambient temperature.

As shown in the left figure, the rated on-current at an ambient temperature of 60 °C is 500 mA – {5 mA/°C × (60 °C - 25 °C)} = 325 mA, which is lower than the ON-state current at 25 °C.

As a result, MOSFETs damaged due to thermal runaway caused by the 400 mA over-rated current flow.

On-current should be designed considering temperature derating.

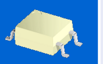
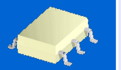
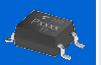
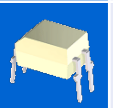
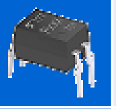
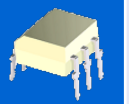
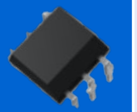
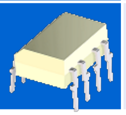
06

LINE-UP FOR HIGH-CURRENT CONTROL

High Current Photorelay Line-up

For the full line up of photorelays, please refer to the photorelay webpage of Toshiba.
Searching by parameters function is also available on the website.

New Product

Package	20 V	30 V	40 V	60 V	80 V	100 V	200 V	400 V	600 V
2.54 SOP4 		**TLP3146** (3.3 A)		**TLP3147** (2.5 A)		**TLP3149** (1.5 A)	**TLP3145** (0.4 A)		
2.54 SOP6 	**TLP3100** (2.5 A)	**TLP3106A** (4.5 A)	**TLP3102** (2.5 A)	**TLP3103** (2.3 A) **TLP3107A** (4 A)		**TLP3105** (1.4 A) **TLP3109A** (3 A)			
4pin SO6 				**TLP3122A** (1.4 A)					
DIP4  	**TLP3553** (3 A)		**TLP3553A** (3.5 A) **TLP241A** (2 A)	**TLP3555A** (3 A)	**TLP241BP** (1.4 A)	**TLP3556A** (2 A) **TLP241B** (2 A)	**TLP3558A** (0.7 A)	**TLP223GA** (0.12 A)	**TLP223J** (0.09 A)
DIP6  	**TLP3543** (4 A)	**TLP3543A** (5 A)	**TLP3544** (3.5 A)	**TLP3545A** (4 A) **TLP4590A** **1-Form-B** (1.2 A)		**TLP3546A** (3.5 A)			
DIP8 				**TLP3547** (5 A)		**TLP3823** (3 A)	**TLP3825** (1.5 A)	**TLP3548** (0.4 A)	**TLP3549** (0.6 A)

*Line up is as of Dec./2023. You can find the latest line-up from Toshiba website.

07

APPLICATION EXAMPLES

Contents

HVAC (Including Thermostat)

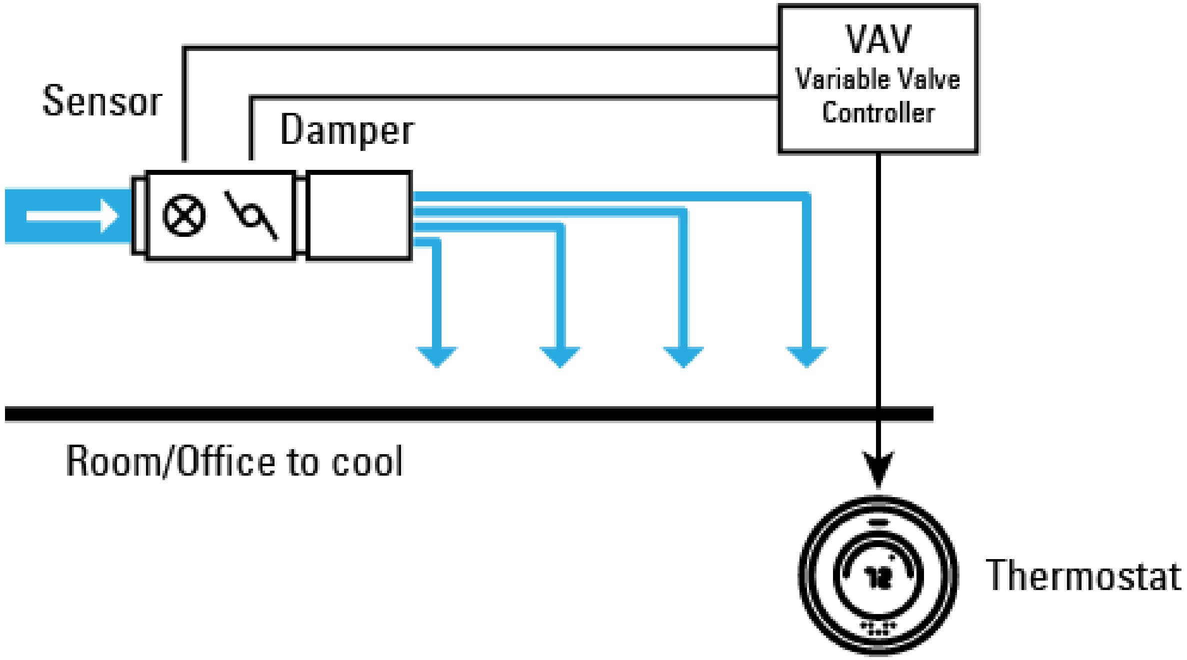
Function of relay

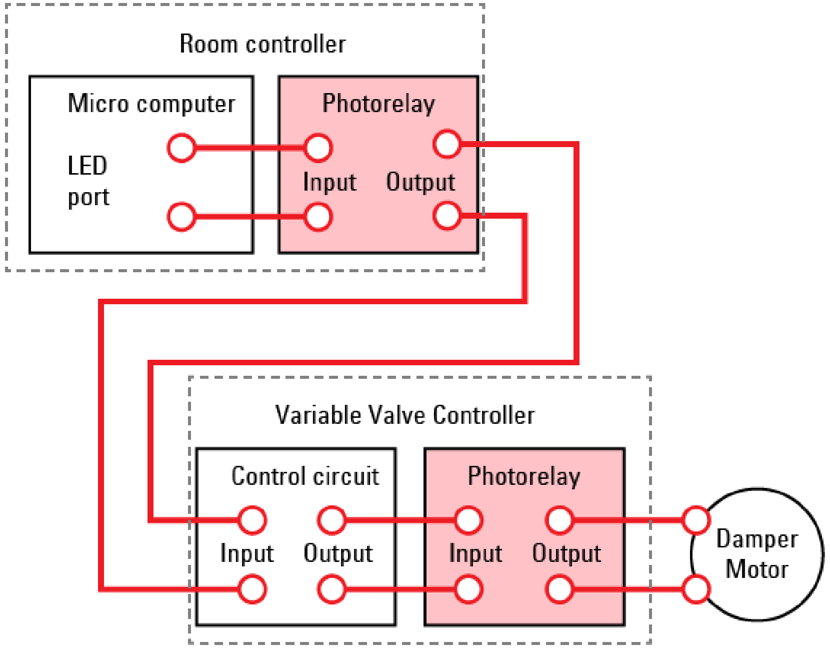
Photorelays are used for signal transmission in thermostats for heating, ventilation, and air conditioning control in building automation and for damper motor control in valve controls.

Traditionally, mechanical relays have been used, but with the increasing current rating of photo relays, photorelays are increasingly being used.

Merits of photorelay

- No noise
- Long lifetime
- High capacity





HVAC: Heating, Ventilation and Air Conditioning

Surveillance Camera

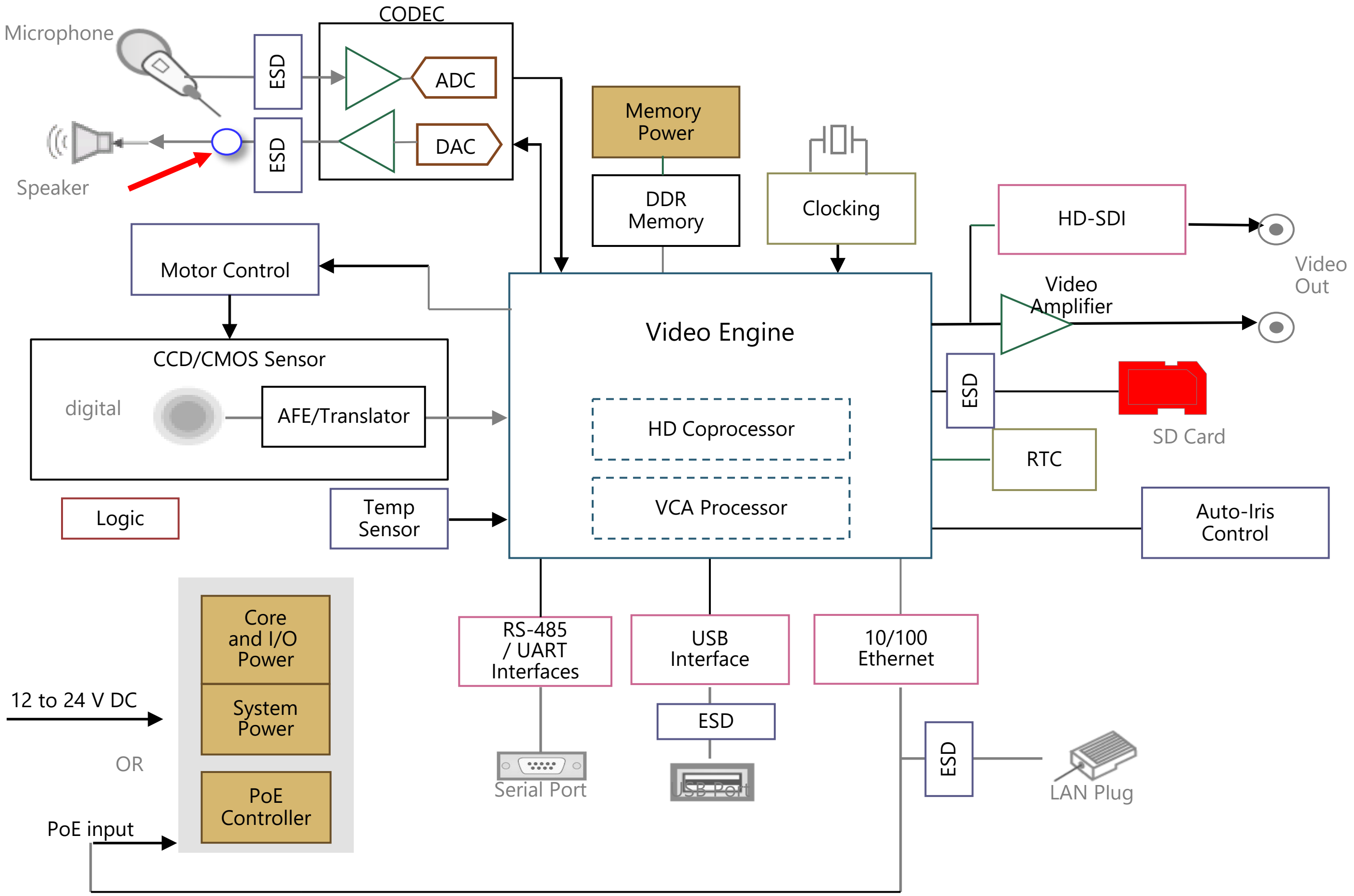
Function of relay

Photorelays are used as switches for the light and sound output of the camera set.

Merits of photorelay

- No noise
- Long life
- Small size

Example: Isolation>2 kV
60 V/2 A switch
2pieces for alarm



FA with STO Function

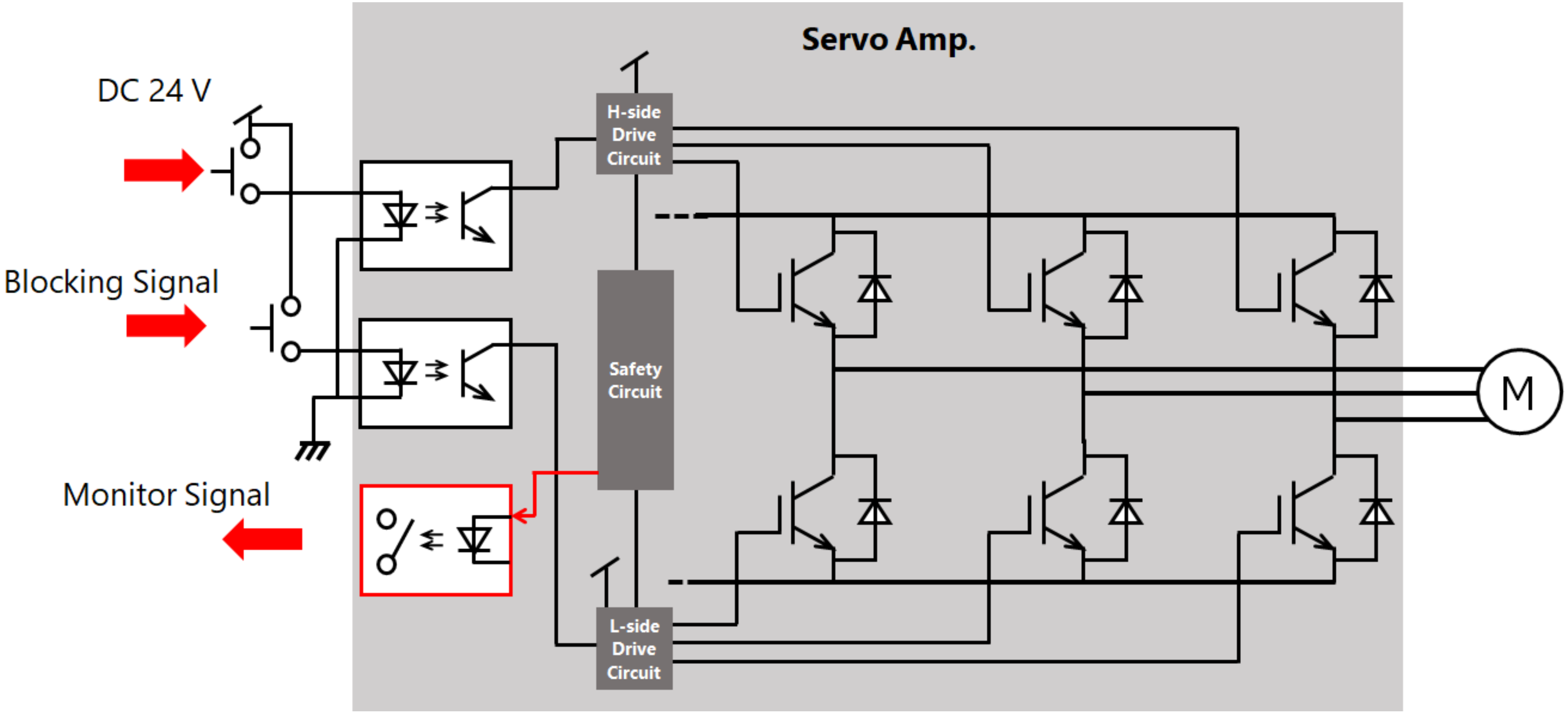
Function of relay

Safe torque-off function is a safety function that turns off the motor output torque by forcibly turning off the driving signal of the servo amplifier, etc. on the circuit from the safety input signal, thereby cutting off the motor current.

Photorelays are used to transmit monitor signals to PLCs and other devices.

Merits of photorelay

- Small Size
- High Speed



Use servo amplifier, CNC, Robot etc.

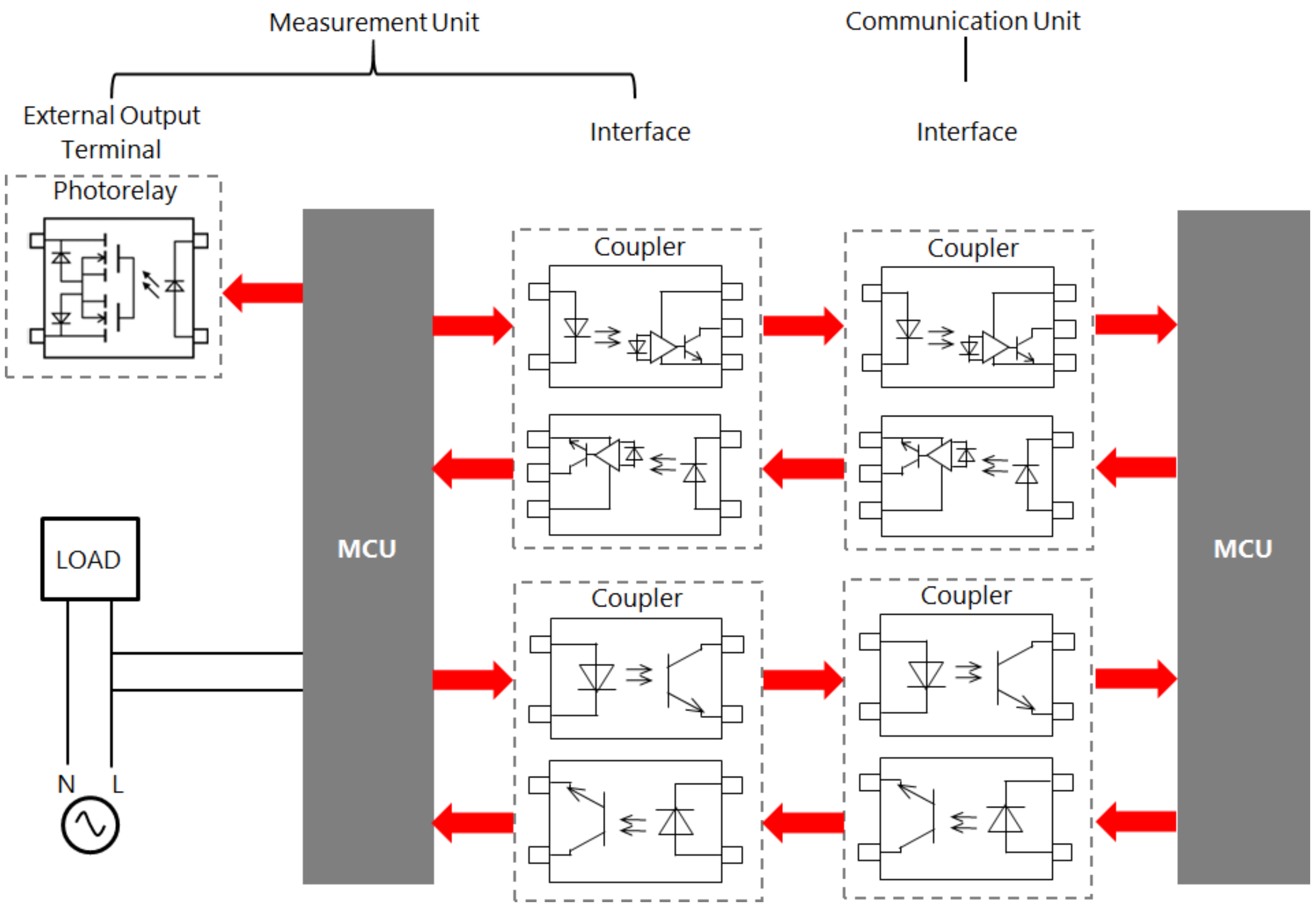
E-meter, Smart Meter

Function of relay

Photorelay is used as a contact output for external communication.

Merits of photorelay

- High withstand voltage
- Reinforced insulation
- Long life



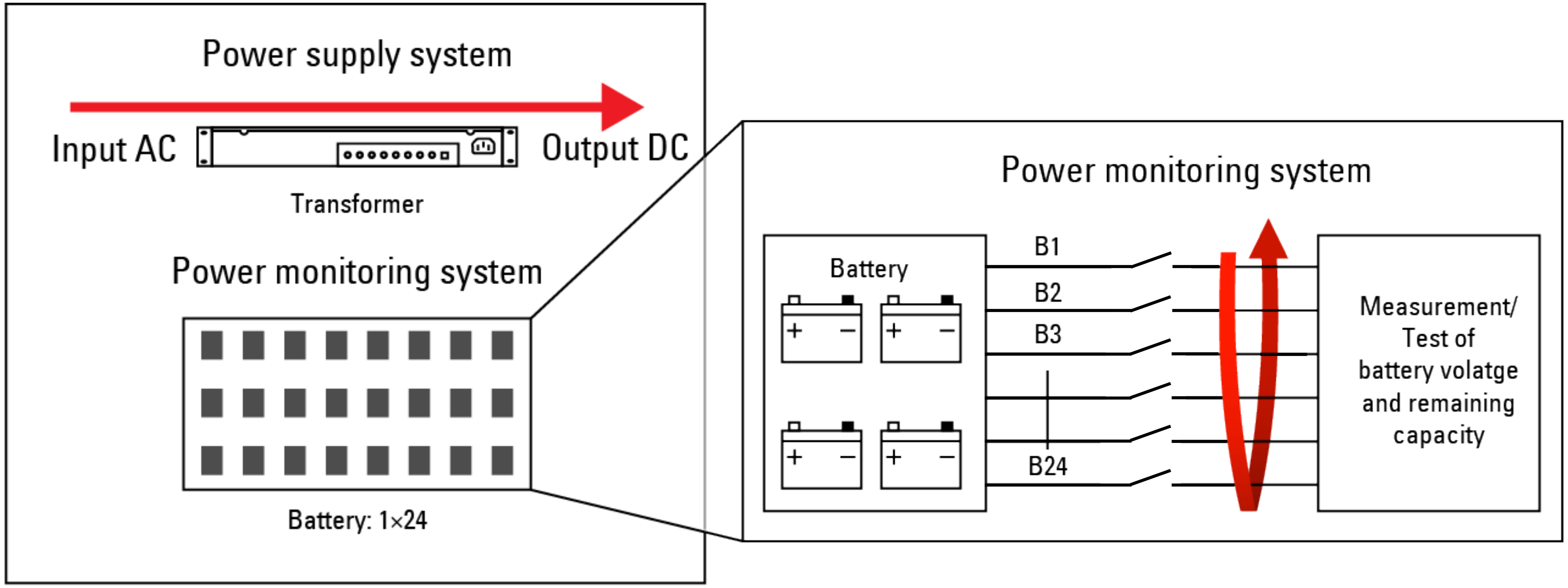
Power Monitoring System (BMS etc.)

Function of relay

Photorelays are used in circuits for monitoring the charge voltage of battery cells. The relay is expected to make many contacts and photorelays are highly recommended as they have no such a concept as contact lifetime(long lifetime).

Merits of photorelay

- Small size
- Long life
- High withstand voltage



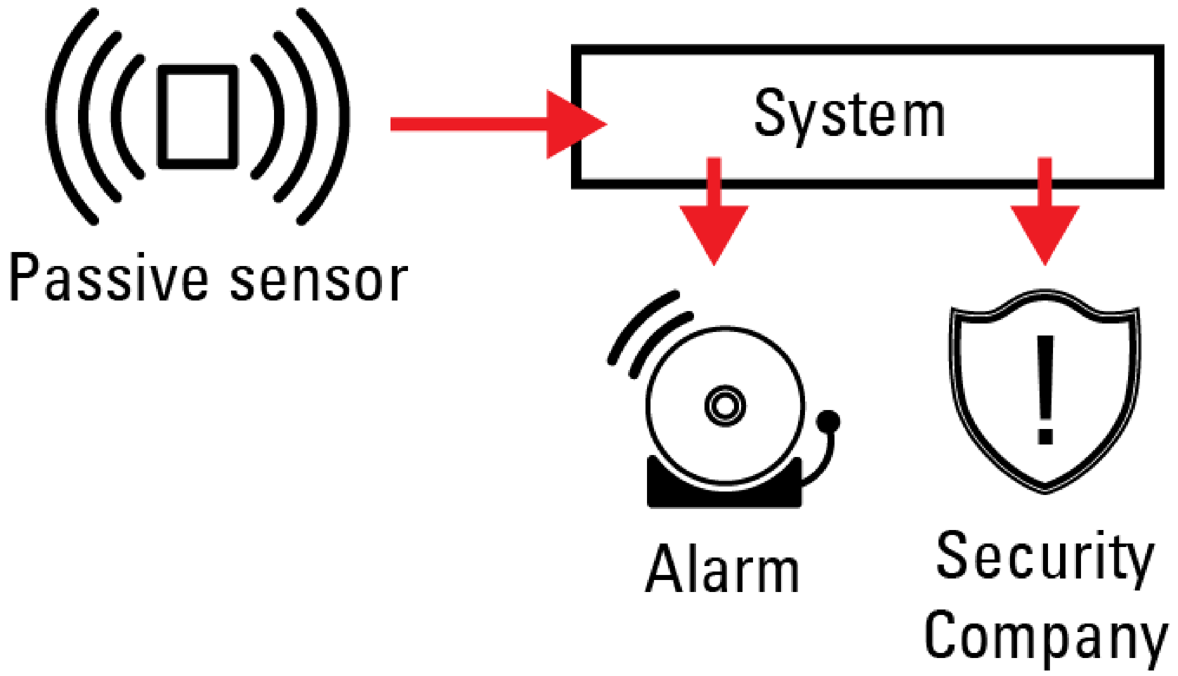
Security (e.g. Passive Sensors)

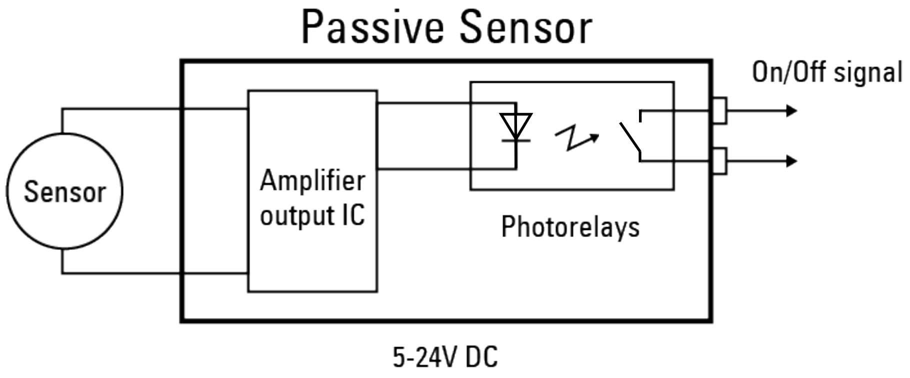
Function of relay

When a suspicious activity is detected by the passive security sensor, it is detected by a motion sensor and the information is transmitted to an assembly terminal or other devices by turning ON/OFF a photorelay.

Merits of photorelay

- Small size
- Low power consumption
- High capacity





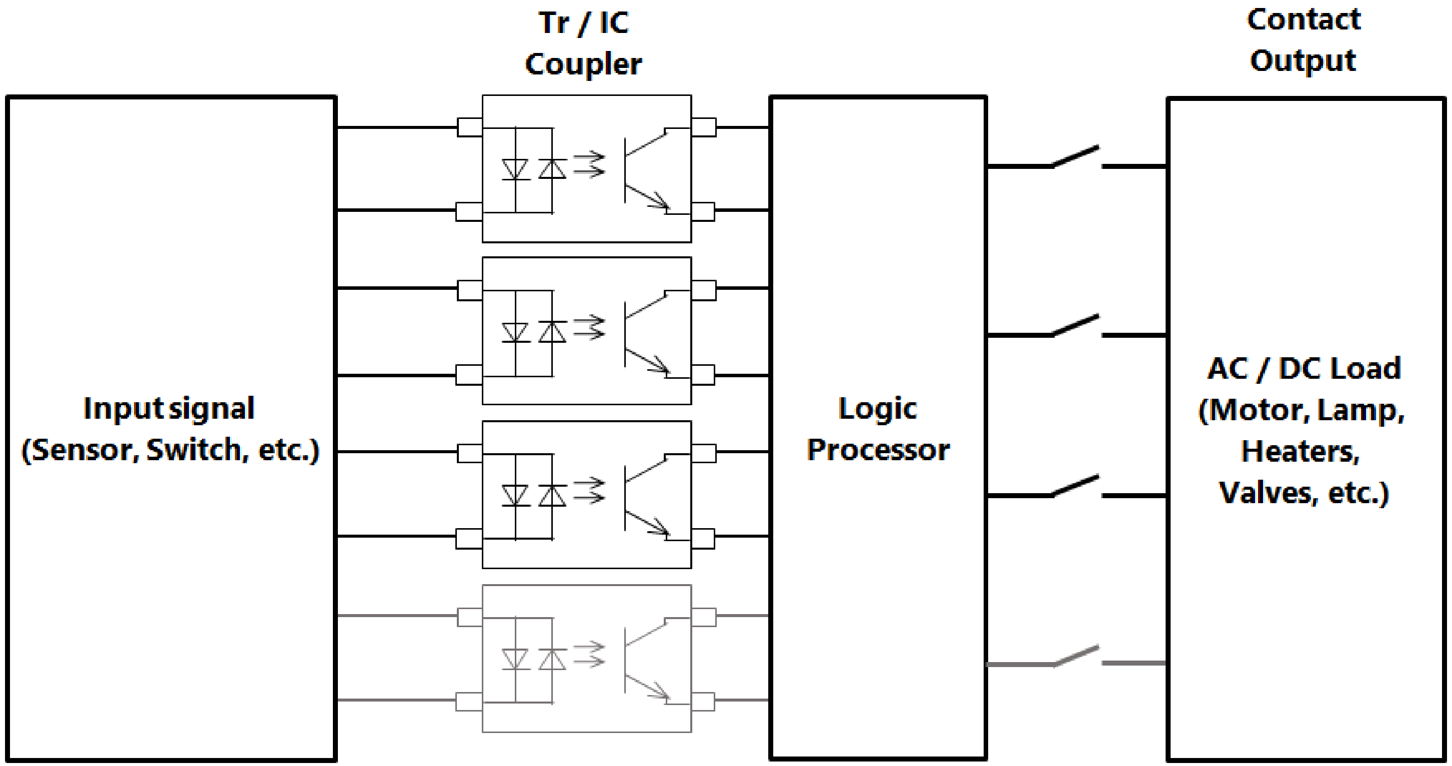
PLC (Programmable Logic Controller)

Function of relay

A mechanical relay is traditionally used as the contact output of the PLC output stage. However, semiconductor relays (photorelays, PDA couplers + MOSFETs) have become the common choice due to their superior reliability.

Merits of photorelay

- High reliability
- Small size
- High capacity



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