Automotive high-voltage photorelay’s applications and withstanding voltage

Overview

This document summarizes the dielectric voltage required for each application of a high-voltage photorelay.

This is for reference only. Do not design the final equipment in this document.

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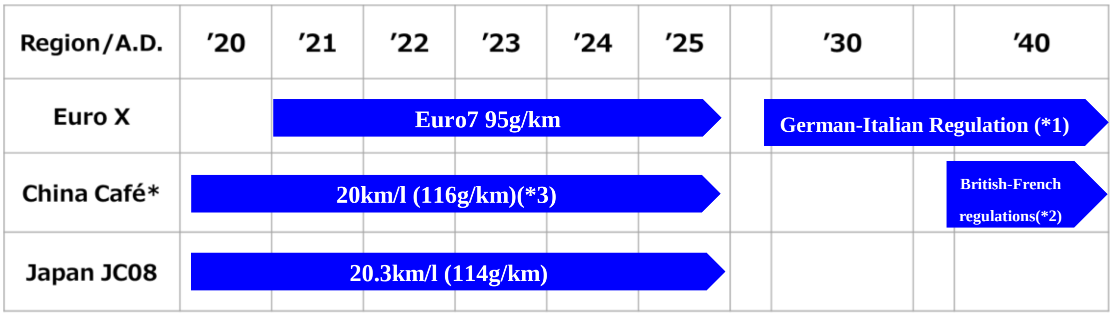
1. Introduction



*Café : Corporate Average Fuel Efficiency
1*) Prohibition of sales of new vehicles other than EVs and FCVs '30~ (2*) Prohibition of sales of new vehicles running only on engines '40~
(3*) Elimination of subsidy when purchasing NEVs

Figure 1 Trends in Carbon Dioxide Emission Regulations in Each Country

In the automotive market, as shown in Fig. 1, emission controls for carbon dioxide (CO_2) are progressing in various countries, and this trend is expected to continue in the future. For this reason, more and more environmentally friendly vehicles have been developed in recent years, including electric vehicles (EVs) and Plug-in hybrids (PHEV), which have superior fuel efficiency (low CO_2 emissions during driving). Recently, the battery voltage of this environmentally friendly vehicle has tended to increase from 400V to 800V for reasons such as extending the range per charge and shortening the charging time. Along with this trend, the use of semiconductor relays, which have no risk of contact wear or sticking, is increasing in the areas where mechanical relays have been used so far. This document describes the High Voltage Photorelay TLX9160T features and applications for environmentally friendly vehicles that are becoming increasingly high-voltage.

2. Features of High Voltage Photorelays

TLX9160T is an isolation voltage 5kVrms photorelay composed of an infrared light-emitting diode (LED) that emits a control signal, a photodiode array (PDA) that receives a control signal, and a high blocking voltage MOSFET of 1500V.

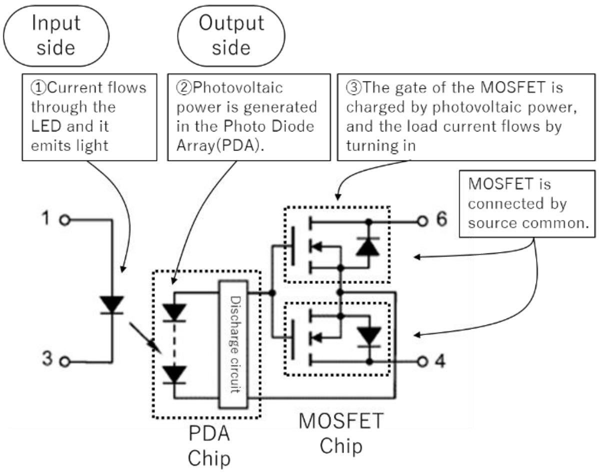
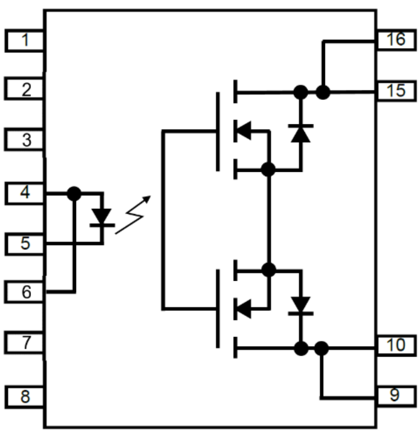


Fig. 2(a) Principles of Photorelay Operation



(b) TLX9160T Interior Structural Diagram

The LED emits light when the current flows through the LED. When the PDA receives the light, the PDA generates electric power (photovoltaic power). MOSFET is turned on by charging the gate of MOSFET to which this power is connected.

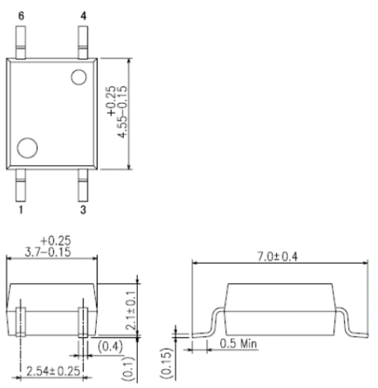
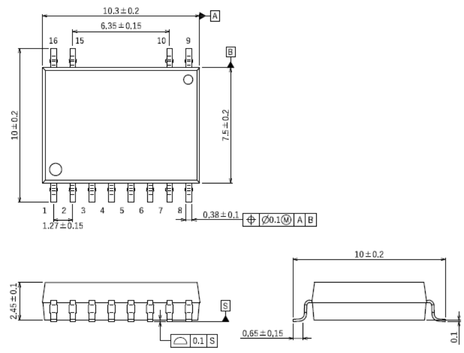
If the current to the LEDs falls below a certain level, the photovoltaic power of the PDAs will not be sufficient to charge the gates of MOSFET, resulting in an off-state. At this time, the gate charges of MOSFET are quickly pulled out through the control circuitry in the PDA-chip.

In addition, TLX9160T has been developed to accommodate higher voltages in environmentally friendly vehicles and assumes operating voltages of up to 1000V. For use at an operating voltage of 1000V, a creepage distance of at least 5mm is required (CTI>600, Pollution Degree 2 environmental). TLX9160T ensures a creepage of 5mm by eliminating the four terminals on the output side.

TLX9160T is also superior to TLX9175J in terms of rejection voltage enhancement and avalanche current performance addition. A comparison table of our in-vehicle photorelay products is shown below.

Table 1 Product Comparison Table2

***Ta=25°C unless otherwise specified**

Product name	**TLX9175J**	**TLX9160T**
AEC-Q101	✓	✓*1
Tstg (min to Max)	-55 to 125°C	~55 to 150°C
Topr (min to Max)	-55 to 105°C	-40 to 125°C
BVs (min)	3750Vrms	5000Vrms
I_{AV} (Max) *2	-	0.6mA
Recommended operating VDD (Max)	450V	1000V
V_{OFF}	600V Bi-directional	1500V Bi-directional
I_{FT} (Max)	3mA	3mA
R_{ON} (Max)	335Ω @ IF=10mA, ION=15mA	250Ω @ IF=10mA, ION=50mA
I_{ON} (peak)	15mA (80mA @ 1ms)	50mA (150mA @ 1ms)
CTI (Comparative tracking index)	≥500	>600
Pin to pin clearance Secondary side	2.14mm	> 5mm *3
Package		

*1 The reliability test of high voltage application was carried out at 1200V.
*2 As a lifetime accumulation, it can be applied up to 5 times at the longest consecutive 1min and Duty cycle=0.1%.
*3 For application of operating voltage of 1000V, creepage distance of 5mm or more is required. @Pollution Degree 2, Material Gr.I

3. Applications for high-voltage photorelays

High-voltage photo relays cannot control high loads like mechanical relays. On the other hand, the photorelay has no contact wear, contact welding, and contact opening/closing limitations, making it possible to provide better-set reliability than Mechanical relay for applications that control low currents. Especially for the Battery Management System (BMS) with Mechanical relay welding detection circuit (1), Battery Total Voltage Monitoring circuit (2), and Ground Fault Detection circuit (3)

It is widely used in circuit applications that frequently switch while retaining which, high battery voltage.

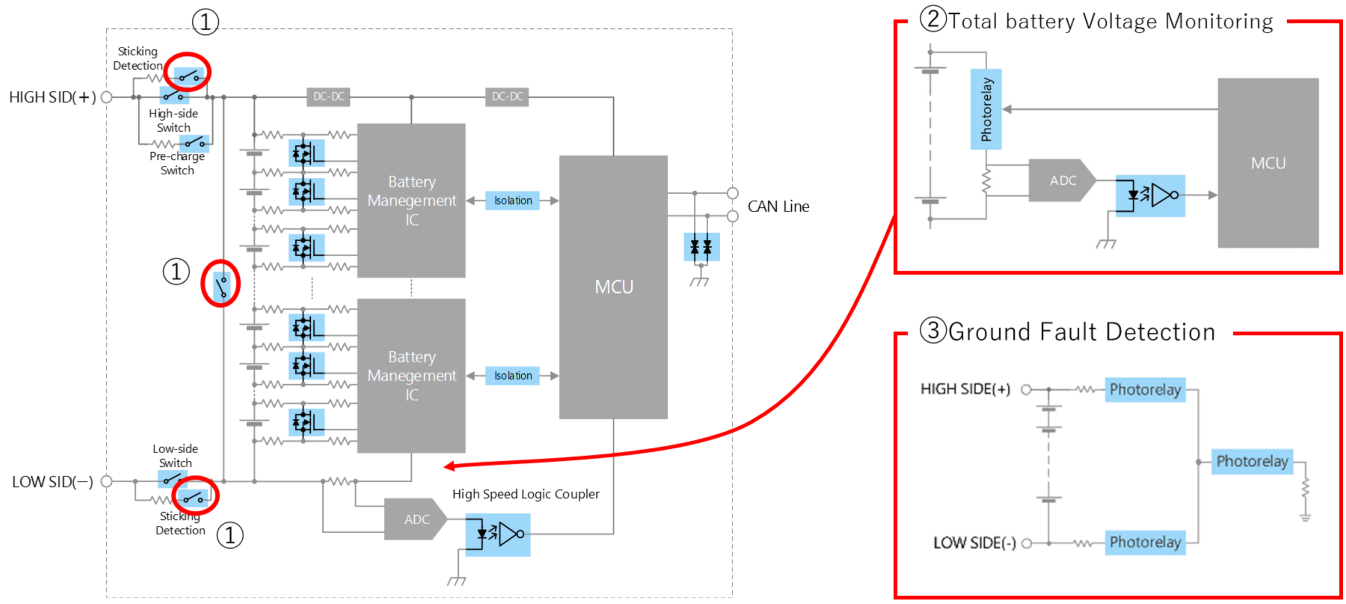


Figure 3 High Voltage Resistance Photorelay Application Block Diagram

3.1. Mechanical relay welding detection circuit

It is common to use mechanical relays with excellent characteristics because the main circuit for charging and discharging the battery is applied several hundred volts and several tens to several hundred amps. However, while the on characteristics are excellent, there is a risk of contact sticking and welding occurring in mechanical relays. If the mechanical relay welds, the charge/discharge circuit cannot be turned OFF, which is extremely dangerous. For this reason, it is necessary to check the presence or absence of welding of mechanical relays. Since the detection of welding does not require a huge current flow, it has been confirmed using a high withstand voltage photorelay with no sticking risk.

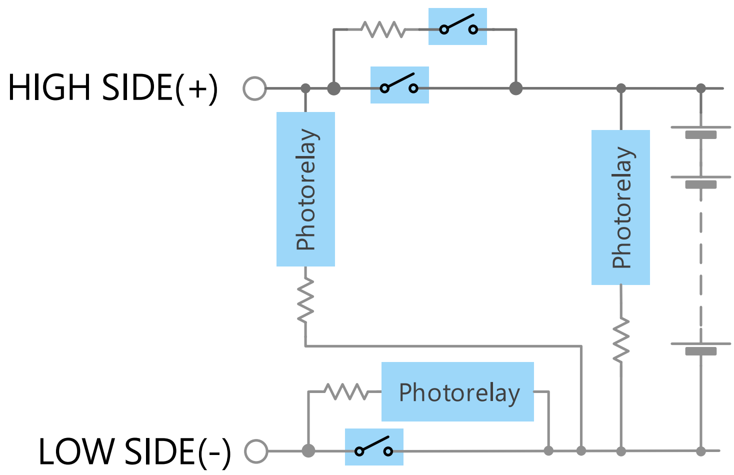


Fig. 4 Mechanical Relay Weld Detection Circuit (Example)

3.2. Total Battery Voltage Monitoring Circuit

Environmentally Friendly Vehicles (EVs, PHEV) run only at all times or often on motors. At that time, especially when starting, it is preferable to drive the motor with enormous electric power. For this reason, it is important to know the individual battery cells and the total voltage status of the entire in-vehicle battery, and it is desirable to monitor the total battery voltage.

Due to the need for total voltage monitoring, voltage monitoring is frequently required when a vehicle is running or stopped. For this reason, mechanical relays with contact open/close limitation and slow switching speed are unsuitable. In addition, for voltage monitoring, it is common to measure accurately through a shunt resistor or the like, and only a minimal current is applied. From these backgrounds, the photorelay, which is a non-contact relay, is used as an ON/OFF switch for this circuit.

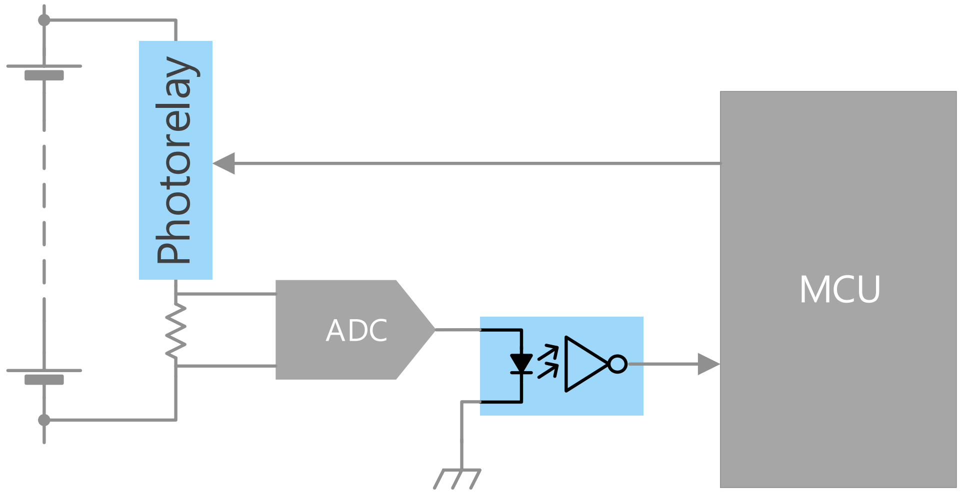


Figure 5 Battery Total Voltage Monitoring Circuit (Example)

3.3. Ground Fault Detection Circuit

As for the electrification of automobiles, vehicle drivability and in-vehicle comfort improve, while high voltages require passengers and peripheral equipment safety. It should avoid that the battery voltage flows into the chassis. In particular, there is a significant risk of electric shock to persons in the event of a ground fault or short circuit, which leads to continuity with the enclosure through a minimal resistance. For this reason, a ground fault detection circuit that confirms insulation is required for vehicles equipped with high-voltage batteries.

The presence or absence of this ground fault is checked at various events, such as when driving, stopping, charging, etc., and between events. Also, if the circuit switch remains in the ON state, normal detection cannot be performed. For this reason, the switch on the ground fault detection circuit employs a high withstand voltage photorelay that is free from contact wear and welding risk.

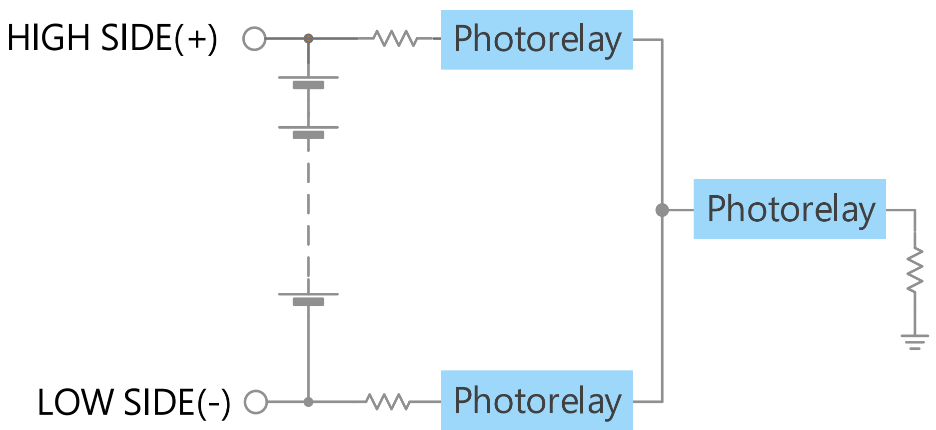


Figure 6 Ground Fault Detection Circuit (Example)

4. Withstanding Voltage Tests Required for Electric Vehicles

When adopting a battery system of 60V or higher, which requires insulation measures, it is necessary to confirm whether electric vehicles and in-vehicle equipment have appropriate insulation functions. This application note describes the following standards, which are specifically intended for protecting persons against electrical hazards.

International Standards ISO 6469-3, Japanese Industrial Standards JIS D5305-3, Chinese National Standards GB/T 18384-3, etc.

These standards are IEC 60664; Insulaiton coordination for equipment within low-voltage system, applied to equipment used at rated voltages of 1000 VAC or less, or 1500 VDC or less, and IEC 61140; Protection against electric shock. Taking JIS D5305-3 as an example here, one equipment is roughly classified into class II equipment which the dangerous charged part may come in contact with persons, and class I equipment which the dangerous charged part not come in contact with persons. And in each equipment, each insulation resistance is required. The procedure for checking this insulation resistance is a withstanding voltage test.

For Class I and Class II equipment, the withstanding voltage tests are defined below. However, this application note assumes that the equipment is Class I equipment.

Test voltage of withstanding voltage

Class I equipment:	Basic insulation	2U+1000Vrms (Note)
Class II equipment:	Auxiliary insulation	2U+2250Vrms
	Double insulation/reinforced insulation	2U+3250Vrms

U : Maximum operating voltage of the electrical circuit

(NOTE)This test requires that a test voltage obtained by adding 1000 to twice the battery voltage be applied at 50 to 60Hz AC for 1 minute. If this test is performed with DC, the test voltage must be 1.41 times the AC voltage.

When Class-I equipment *[1], battery voltage (U) =800V
(2U + 1000) = 2×800 + 1000 = 2600Vrms/ 1min. ⇔2600 × 1.41 = 3666Vdc/ 1min.

As shown in the example above, a voltage significantly higher than the battery voltage is applied to in-vehicle equipment in withstanding voltage testing. Naturally, this test is also applied to the insulation device. When using a photorelay, it is necessary to configure a circuit in which the photorelay is not destroyed even in a withstanding voltage test.

4.1. Mechanical relay welding detection circuit and Battery total voltage monitoring circuit

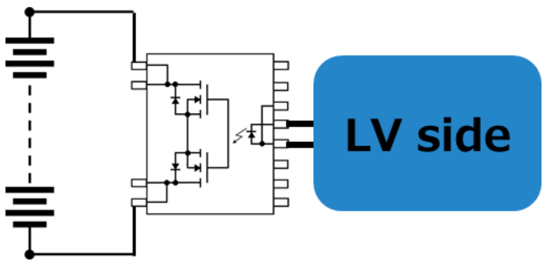
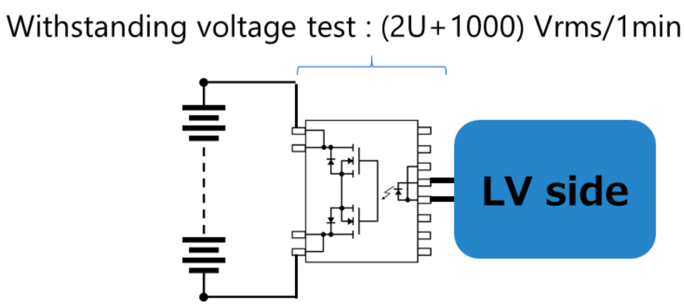
Only the battery voltage is applied between MOSFET during normal operation, so use below the recommended operating voltage will not destroy the photorelay.

Also, when the withstanding voltage test voltage is calculated based on the battery system of 400V or less and 800V or less, which is common in the market,

Battery voltage = 400V : 2×400 + 1000 = 1800 Vrms/1min. ⇔Approximately 2538Vdc/ 1min.
Battery voltage = 800V : 2×800 + 1000 = 2600 Vrms/1min. ⇔Approximately 3666Vdc/ 1min.

The test voltage is equal to or lower than the respective isolation voltage (BVs) 3750Vrms, 5000Vrms. For this reason, the photorelay can be used without a special circuit configuration in the mechanical relay welding detection circuit and the battery total voltage monitoring circuit.

Table 2 Normal Operation/Withstanding Voltage Testing (Mechanical relay Weld Detection Circuit, Battery Total Voltage Monitoring Circuit)

Normal operation	During withstanding voltage test
	

4.2. Ground fault sensing circuit

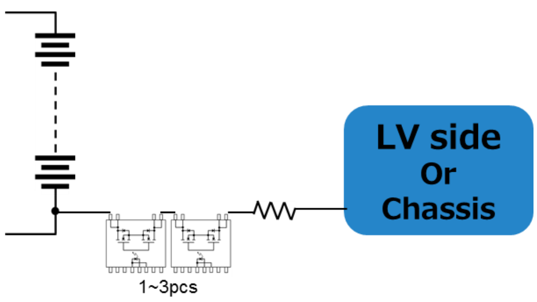
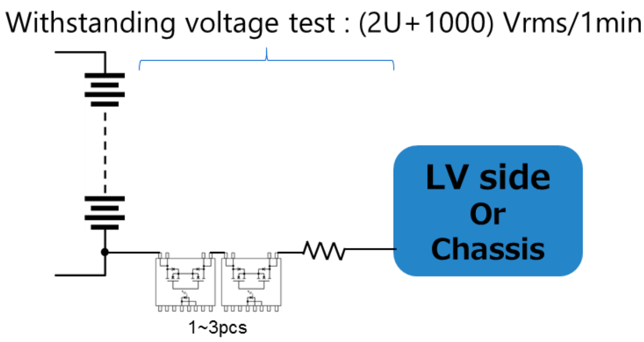
In the same way, the earth fault detector applies only battery voltage between MOSFET during normal operation. Therefore, if it is used below the recommended operating voltage, the photorelay will not be damaged.

On the other hand, during withstanding voltage testing,

Battery voltage = 400V : 1800 Vrms/1min. ⇔Approximately 2538Vdc/ 1min.
Battery voltage = 800V : 2600 Vrms/1min. ⇔Approximately 3666Vdc/ 1min.

The above voltages are applied between MOSFET. These voltages significantly exceed the blocking voltage of TLX9175J, TLX9160T. For this reason, it is necessary to configure a circuit using either dividing the test voltage by connecting multiple units in series or inserting a huge resistance, or both, so that the photorelays are not destroyed in a withstanding voltage test.

Table 3 Normal Operation/Withstanding Voltage Test (Ground Fault Detection Circuit)

Normal operation	During withstanding voltage test
	

4.2.1. Applications of TLX9160T

In general, the photorelay's blocking voltage is guaranteed by the DC voltage. In withstanding voltage testing, it is necessary to check whether the photorelay can maintain the peak voltage of the AC test voltage or the DC test voltage. As described above, ground fault detection circuits often consist of a few photorelay, connected in series. For this reason, the following assumes that TLX9160T is connected in series for 2pcs in an 800V battery system.

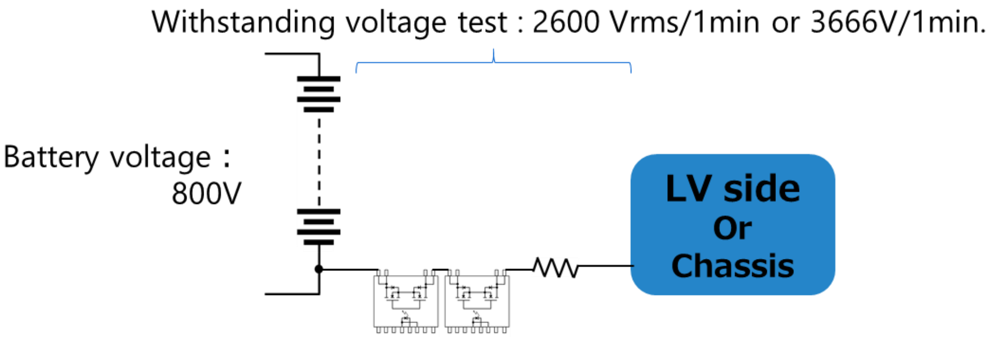


Fig. 7 Ground Fault Detection Circuit (Battery Voltage: 800V)

Since the battery voltage is 800V, the withstanding voltage test is 2600Vrms/1min or 3666Vdc/1min. This voltage must be held at TLX9160T 2 pieces.

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

	Characteristics	Symbol	Test Condition	Min	Typ.	Max	Unit
LED	Forward voltage	V_F	I_F = 10 mA	1.5	1.65	1.8	V
			I_F = 10 mA , Ta = -40 to 125 °C	1.4	—	1.95	
	Reverse current	I_R	V_R = 5 V	—	—	10	µA
	Capacitance	C_T	V = 0 V, f = 1 MHz	—	45	—	pF
Detector	Output withstand voltage	V_{OFF}	IOFF=10uA, Ta=25 °C (Note1)	1500	—	—	V
	Off-state current	I_{OFF}	V_{OFF} = 1000 V , Ta = 25 °C	—	—	100	nA
			V_{OFF} = 1000 V , Ta = 105 °C	—	—	1000	
			V_{OFF} = 1000 V , Ta = 125 °C	—	—	5000	
	Capacitance	C_{OFF}	V_{OFF} = 0 V, f = 1 MHz	—	100	—	pF

Note 1: Reliability test of applying high voltage is demonstrated at 1200V.

As shown in the data sheet, the blocking voltage of TLX9160T is 1500V (min),
3666V – 1500V×2 = 666V

Even when two units are connected in series, 666V cannot be maintained for the withstanding voltage test voltage. At this time, if the limiting resistor that protects the photorelay is not on the circuit, an excessive current is applied to the photorelay and destroyed. The voltage that could not be retained must be divided into the limiting resistor. The setting of the limit resistance is calculated based on the avalanche current described in the datasheet.

Absolute Maximum Rating (Unless otherwise specified, Ta = 25°C) (Note)

Characteristics		Symbol	Rating	Unit
	Forward current	I_F	30	mA
	Avalanche current (Note 1)	IAV	0.6	mA
	Output power dissipation	P_O	600	mW
	Output power dissipation derating (Ta ≥ 47 °C)	ΔP_O/°C	-7	mW/°C
	Junction temperature	T_j	135	°C
Storage temperature		T_{stg}	-55 to 150	°C
Operating temperature		T_{opr}	-40 to 125	°C
Lead soldering temperature (10 s)		T_{sol}	260	°C
Isolation voltage (AC, 60 s, R.H. ≤ 60%) (Note 2)		BV_S	5000	Vrms

Note: Using continuously under heavy loads (e.g. the application of high temperature/current/voltage and the significant change in temperature, etc.) may cause this product to decrease in the reliability significantly even if the operating conditions (i.e. operating temperature/current/voltage, etc.) are within the absolute maximum ratings. Please design the appropriate reliability upon reviewing the Toshiba Semiconductor Reliability Handbook ("Handling Precautions"/"Derating Concept and Methods") and individual reliability data (i.e. reliability test report and estimated failure rate, etc).

Note: This product is more sensitive than conventional products to electrostatic discharge (ESD). It is therefore all the more necessary to observe general precautions regarding ESD when handling this component.

Note 1: 1min (max. continuous), Duty cycle=0.1%, 5 time over lifetime.

Note 2: LED pins are shorted together. Detector pins are also shorted together.

Note 3: Exponential curve, pulse width < 1ms, f ≤150Hz

TLX9160T datasheet guarantees avalanche current. Unlike the avalanche currents that are sometimes guaranteed under typical MOSFET, if the current is limited to less than this current even if MOSFET breaks over, the devices will not be damaged in one-minute continuous energization (lifetime: up to five times).

Since the avalanche current assurance of TLX9160T is 0.6mA,

666V / 0.6mA = 1.11MΩ

By connecting a limiting resistor of 1.11MΩ or more in series with the product, TLX9160T can be used without being destroyed even in withstanding voltage testing.

4.2.2. Applications of TLX9175J

Since TLX9175J is used in a system of 400V or less, it is assumed that it is also used in a ground fault detector.

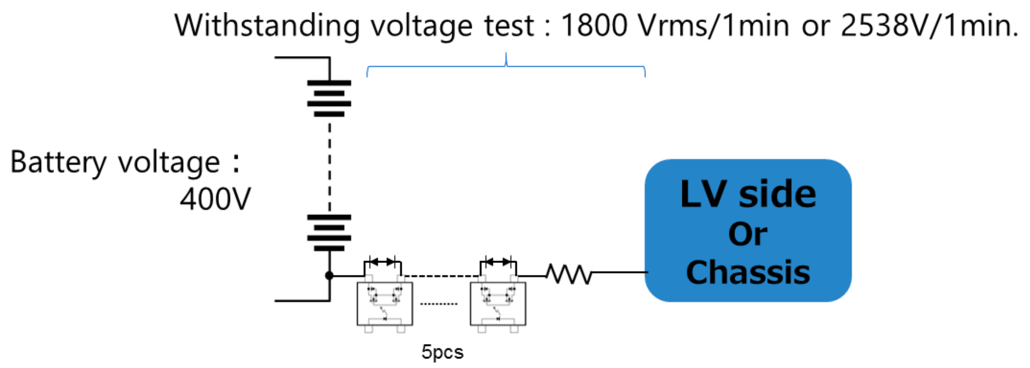


Fig. 8 Ground Fault Detection Circuit (Battery Voltage: 400V)

For 400V battery systems, the withstand voltage test is 1800Vrms/1min. or around 2538V/1min. This voltage must be held at TLX9175J.

Absolute Maximum Rating (Unless otherwise specified, Ta = 25°C) (Note)

Characteristics		Symbol	Rating	Unit
	Forward current	I_F	25	mA
	Off-state output terminal voltage	V_{OFF}	600	V

As per the absolute maximum ratings in the datasheet, TLX9175J has a blocking voltage of 600V. At least five TLX9175J must be connected in series to hold 2538 V. No voltage higher than 600V should be applied across MOSFET at any instant in TLX9175J. For this reason, protective devices such as zener diodes must be connected in parallel to the respective photorelays to protect TLX9175J.

4.2.3. Precautions for use above the blocking voltage

Do not operate the product ON/OFF when the voltage is higher than the blocking voltage. Since the withstanding voltage test is simply a test in which the photorelay is always in the OFF state, even if a voltage higher than the blockiing voltage of the photorelay is applied, it can be divided into other products and resistors for use. However, switching operation of ON/OFF in an environment where a voltage higher than the blocking voltage is applied may cause an instant in which a single photorelay carries an excessive voltage due to switching misalignment between tests, which may lead to a failure of the photorelay or the protective device, or shortening of the photorelay life.

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