The design guide for 24V Digital Input Modules for PLCs by using high-speed communication photocouplers

Overview

This document describes the designing of 24V Digital Input Modules for PLCs when using a high-speed communication photocoupler.

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

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Introduction

The Factory Automation (FA) is becoming an indispensable premise for today's advanced manufacturing. **PLC**s (Programmable Logic Controllers) play a central role in the realization of FA, and **Digital Input Modules** support its wide variety of input and output functions.

This application note introduces **how to design a Digital Input Module** compliant to the international standard **IEC 61131-2** for PLCs **by using** a high-speed communication photocoupler **TLP2363**.

1. 24V Digital Input Module for PLCs and IEC 61131-2

In a PLC, the Digital Input Module is used to receive external 24V digital inputs from sensors or switches and transmit signals to the host controller. Fig. 1 shows the basic configuration of the 24V Digital Input Module. Because the GND level on the host controller side and the GND level on the external input side are different, high-speed communication photocouplers is used for signal transmission. [Note 1]

[Note 1] Transistor output photocouplers are also used for low-speed signal transmission.

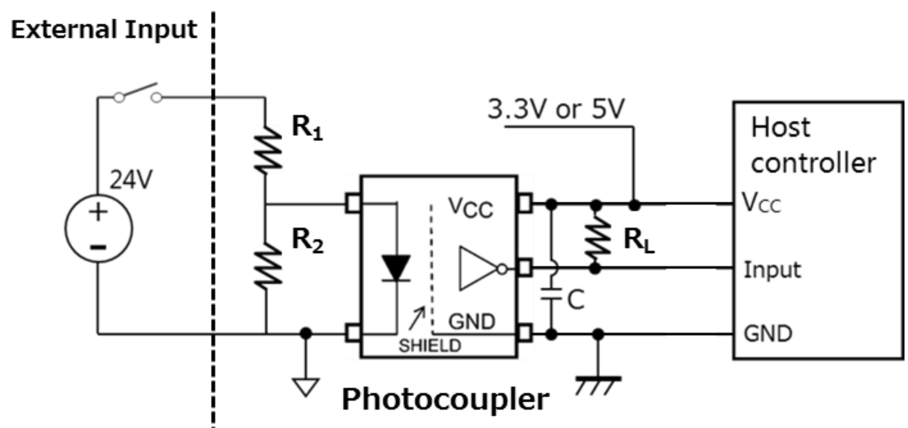


Fig. 1 Basic Configuration of 24V Digital Input Module

IEC 61131 is an international standard that aims to provide user-friendly PLCs by partially unifying concepts, for which different design concepts have been reflected by different manufacturers. **IEC 61131-2** describes **Equipment requirements and tests**, and specifies three kinds of digital input types (Type 1, 2, and 3) for each connected device to the Digital Input Module used in the PLC. (Table 1)

Table 1 Connected Devices for Each Digital Input Type

Digital Input Types	Connected Devices
Type 1	Device for sensing signals from mechanical contact switching devices, such as relay contacts, push-buttons, switches, etc.
Type 2	Device for sensing signals from solid-state switching devices such as 2-wire proximity switches.
Type 3	Device for sensing signals from solid-state switching devices such as 2-wire proximity switches. Type 3 digital inputs offer lower power characteristics than Type 2 digital inputs

In addition, the **operating ranges for input voltage and input current** is specified for each digital input type.

In the input-rated 24V_{dc}, the operating ranges specified for each of type 1, 2, and 3 are shown in Fig. 2. A characteristic of this requirement is that the range a module should be turned off is also specified.

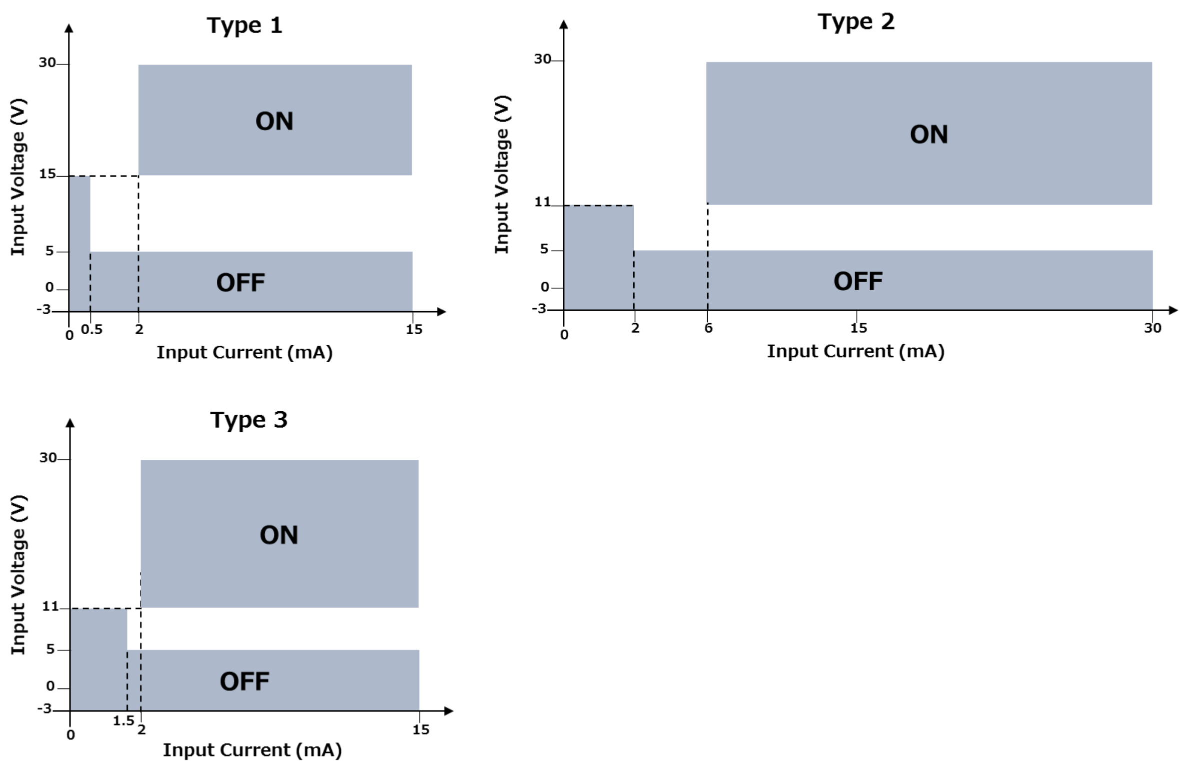


Fig. 2 IEC 61131-2 Input Voltage/Current Operating Range for Type 1, 2, and 3

To design the Digital Input Module shown in Fig. 1, the **optimum R_1 and R_2 must be selected** in accordance with the operating range shown in Fig. 2. With conventional high-speed communication photocouplers, the guaranteed value for the threshold input current that controls High/Low of the output is only the maximum value, making it difficult to design modules that follow the operating range shown in Fig. 2.

TLP2363 ensures not only the maximum value but also the minimum value of the threshold input current, which helps to simplify the designing of the Digital Input Module according to the operating range shown in Fig. 2.

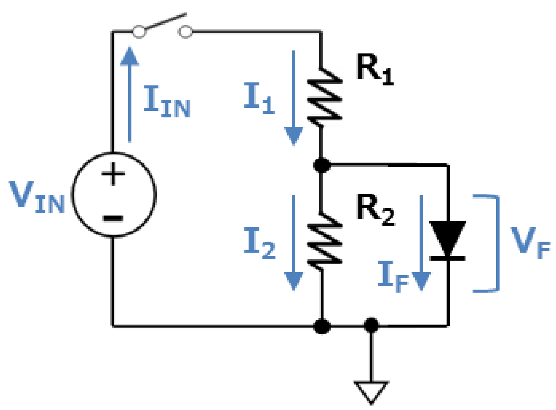
Refer to this (Link) for the detail of TLP2363.

2. Designing Input Circuitry for 24V Digital Input Modules Using TLP2363

2-1. Design Policy

This section describes **how to design a 24V Digital Input Module that complies with IEC 61131-2 Type 1** using TLP2363.

Fig. 1' shows the parameter names given by focusing on from the external input to the photocoupler input in Fig. 1.



V_{IN} : Input voltage (DC)

I_{IN} : Input current

I_1 : Current flows in R_1

I_2 : Current flows in R_2

I_F : Input forward current of TLP2363

V_F : Input forward voltage of TLP2363

Fig. 1' Input Circuit Configurations and Parameters for the Digital Input Module

From Fig. 2, it can be seen that TLP2363 needs to take the state of Table 2 for each V_{IN} and I_{IN} range.

Table 2 TLP2363 State Required for V_{IN}, I_{IN} Ranges Defined in IEC 61131-2 Type 1

TLP2363 State		I_{IN} (mA) 0 ~ 0.5	0.5 ~ 2	2 ~ 15
V_{IN} (V)	-3 ~ 5	OFF	OFF	OFF
	5 ~ 15	OFF	Transition	Transition
	15 ~ 30	Transition	Transition	ON

The following four points are **critical to R_1, R_2 selection**.

① When -3 V < V_{IN} < 5 V, limit the current I_F so as TLP2363 is always turned off.
② When 5V < V_{IN} < 15 V, limit the current to 0.5 mA < I_{IN} < 15 mA.
③ When 15V < V_{IN} < 30 V, limit the current to 2 mA < I_{IN} < 15 mA.
④ When 15V < V_{IN} < 30V, limit the current I_F so as TLP2363 is always turned on.

In this application note, **R_1 and R_2 that satisfies ① and ④ are calculated** first, and **I_{IN} is checked if ② and ③ are satisfied**.

2-2. Selection of Resistance R_1 and R_2 that Satisfy the Requirements

① and ④ are expressed as below (a) and (b) using minimum value of the threshold input current (**I_{FHL_min}**) and maximum value of the threshold input current (**I_{FHL_max}**) of TLP2363.

(a) : when V_{IN} = 5 V, I_F < **I_{FHL_min}**

(b) : when V_{IN} = 15 V, **I_{FHL_max}** < I_F

In addition, since I_F of TLP2363 has an absolute maximum rating, this is expressed as below (c).

(c) : when V_{IN} = 30 V, I_F < **I_F absolute maximum rating**

The goal of this chapter is **to calculate the R_1 and R_2 that satisfies all (a), (b), and (c)**.

First, **I_F** is represented as below using **R_1 and R_2** in Fig. 1'.

$V_{IN} = I_1 \times R_1 + V_F$

$I_1 = I_2 + I_F$

$I_2 = V_F / R_2$

So, $V_{IN} = (V_F / R_2 + I_F) \times R_1 + V_F$

Therefore, $\mathbf{I_F = V_{IN} / R_1 - (1 / R_1 + 1 / R_2) \times V_F}$ **・・・ (Equation 2.2.0)**

2-2-1. Expression when V_{IN} = 5 V

(a) : Set as $I_F = I_{F\_off}$ when V_{IN} = 5 V, and substitute them in Equation 2.2.0.

$I_{F\_off} = 5 / R_1 - (1 / R_1 + 1 / R_2) \times V_F < I_{FHL\_min}$ ・・・ (Equation 2.2.1)

In Equation 2.2.1, **I_{F_off}** is considered to **be the largest when $V_F = V_{F\_min1}$**.

* V_{F_min1} : the minimum V_F under all operating temperature conditions when $I_{F\_off} = I_{FHL\ min}$

2-2-1(a). Consideration of V_F Variation Range

In Equation 2.2.1, we first consider the variation in V_F.

TLP2363 datasheet shows the minimum and maximum V_F values with typical V_F value when I_F = 2.6 mA and Ta = 25 °C, as shown in Table 3.

Table 3 The Min, Typical and Max V_F Values of TLP2363 when I_F = 2.6 mA, Ta = 25 °C.

Characteristic	Symbol	Conditions	Min	Typ.	Max	Unit
Input forward voltage	V_F	I_F = 2.6 mA, T_a = 25 ℃	1.35	1.5	1.65	V

From this description, **the minimum and maximum variations for the standard values of V_F can be read as ±10%**. Using $I_F - V_F$ characteristic curve in TLP2363 datasheet (Fig. 3),

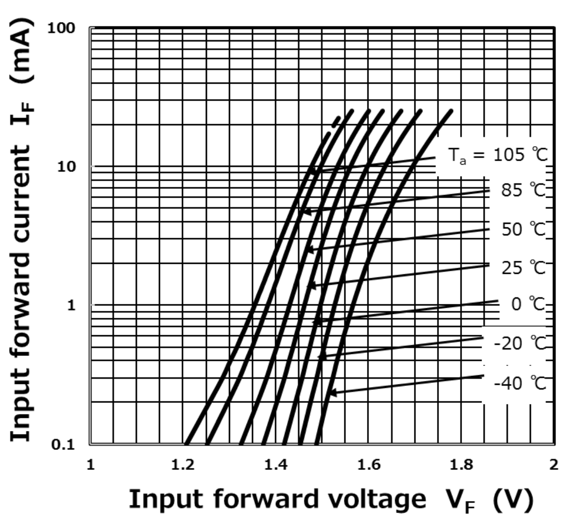


Fig. 3 $I_F - V_F$ Characteristic Curve of TLP2363 under **Ta = 25 °C**, **I_F – V_F characteristic curves considering ±10% variation to the typical curve** are shown in Fig. 4.

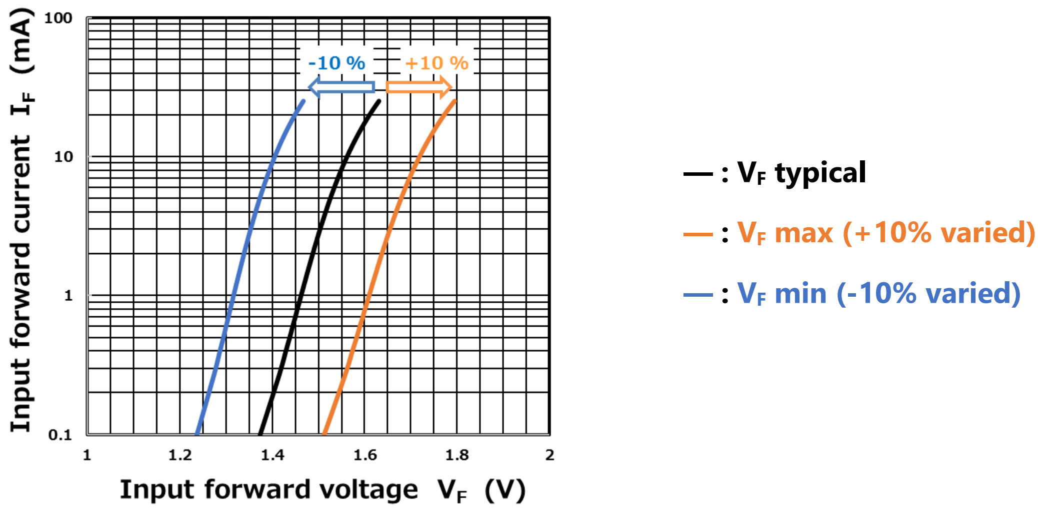


Fig. 4　I_F – V_F Characteristic Curve at Ta = 25 °C in TLP2363 (considered ±10 % variation)

Similarly, under the condition **Ta =-40 °C**, **I_F – V_F characteristic curves considering the ±10% variation to the typical curve** are shown in Fig. 5. Under the condition **Ta = 105 °C**, **I_F – V_F characteristic curves considering the ±10% variation to the typical curve** are shown in Fig. 6.

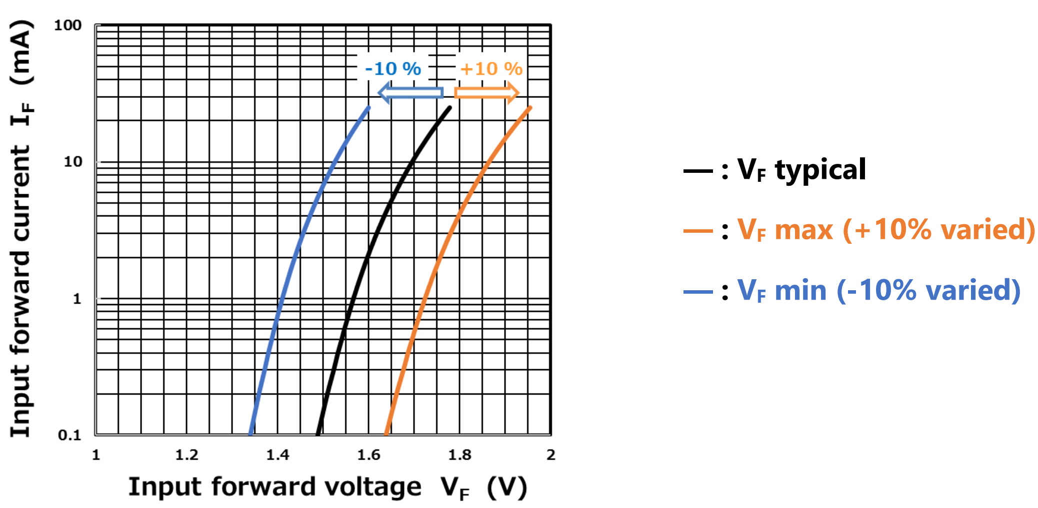


Fig. 5　I_F – V_F Characteristic Curve at Ta = -40 °C in TLP2363 (considered ±10 % variation)

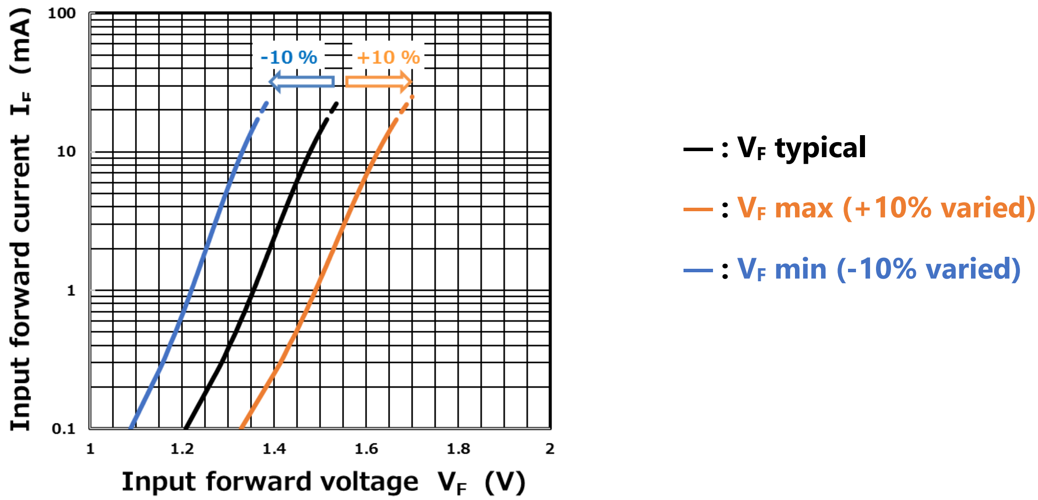


Fig. 6 I_F – V_F Characteristic Curve at Ta = 105 °C in TLP2363 (considered ±10 % variation)

Figs. 4, 5, and 6 show that under all TLP2363 operating temperatures (-40 to 105°C), **(1) the typical I_F-V_F characteristic curve**, **(2) V_F maximum-side worst I_F-V_F characteristic curve considering a variation range of +10% with respect to the typical**, and **(3) V_F minimum-side worst I_F-V_F characteristic curve considering a variation range of -10% with respect to the typical** can be represented in Fig. 7. (Note that (1) is assumed when Ta = 25 °C)

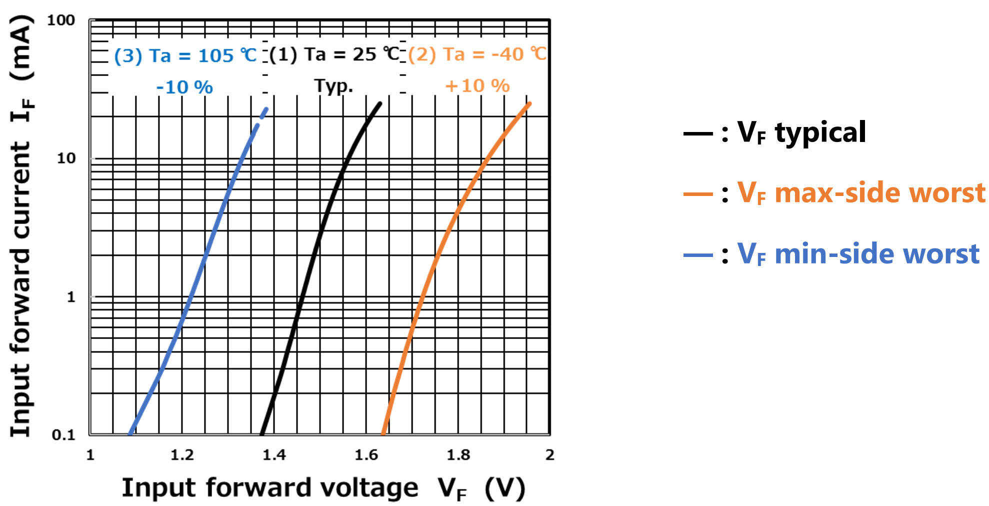


Fig. 7 The Typical I_F-V_F Characteristic Curve and V_F Max-Side Worst and Min-Side Worst I_F-V_F Characteristic Curves under All Operating Temperatures of TLP2363

2-2-1(b). V_{F_min1} Considerations

On the other hand, TLP2363 datasheet shows **the min and max values of I_{FHL} along with the typical value** when V_{CC} = 3.3 V, R_L = 1 kΩ, as shown in Table 4. Note that the minimum and maximum values are guaranteed at Ta = -40 to 105 °C, and the typical value is at Ta = 25 °C.

Table 4 TLP2363 I_{FHL} Characteristics Table

Characteristic	Symbol	Conditions	Min	Typ.	Max	Unit
Threshold input current	I_{FHL}	V_{CC} = 3.3 V, R_L = 1 kΩ, V_O < 0.6 V	0.3	0.9	2.4	mA

From Table 4, when V_{CC} = 3.3 V and R_L = 1 kΩ, since I_{FHL_min} = 0.3 mA ,
V_{F_min1} can be set to the smallest V_F under all temperature conditions when I_F = I_{F_off} = 0.3 mA.
So, from Fig. 7', V_{F_min1} = 1.16 V.

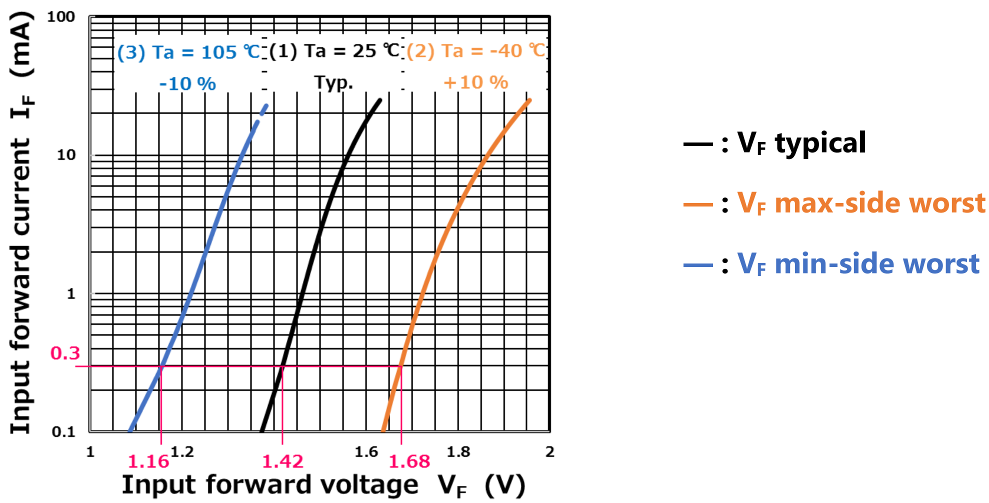


Fig. 7' The Typical I_F-V_F Characteristic Curve and V_F Max-Side Worst and Min-Side Worst I_F-V_F Characteristic Curves under All Operating Temperatures of TLP2363 (with V_F values when I_F = 0.3 mA)

By substituting it into Equation 2.2.1, we can see that **R_1 and R_2 must satisfy Equation 2.2.1'**.

$I_{F\_off} = 5 / R_1 - (1 / R_1 + 1 / R_2) \times 1.16 < 0.3 \times 10^{-3}$ ･･･ (Equation 2.2.1')

2-2-2. Expression when V_{IN} = 15 V

(b) : Set as $I_F = I_{F\_on1}$ when V_{IN} = 15 V, and substitute them in Equation 2.2.0.

$$I_{F\_on1} = 15 / R_1 - (1 / R_1 + 1 / R_2) \times V_F > I_{FHL\_max} \quad \cdots \text{(Equation 2.2.2)}$$

In Equation 2.2.2, I_{F_on1} is considered to **be the smallest when $V_F = V_{F\_max}$**.

* V_{F_max} : the maximum V_F under all operating temperature conditions when $I_{F\_on1} = I_{FHL\_max}$

2-2-2(a). Consideration of V_F Variation Range

In Equation 2.2.2, the variation of V_F is shown in Fig. 7.

2-2-2(b). V_{F_max} Considerations

Same as in (a), we would like to estimate V_{F_max} from Fig. 7 and Table 4, but we have to pay attention to a point. Since the light output of the LED mounted on photocouplers changes over time, **when used for a long period of time**, it is **necessary to secure margins for the aging** at the initial design stage.
Fig. 8 shows the light output degradation curve when the LED on TLP2363 is continuously used under the maximum ratings.

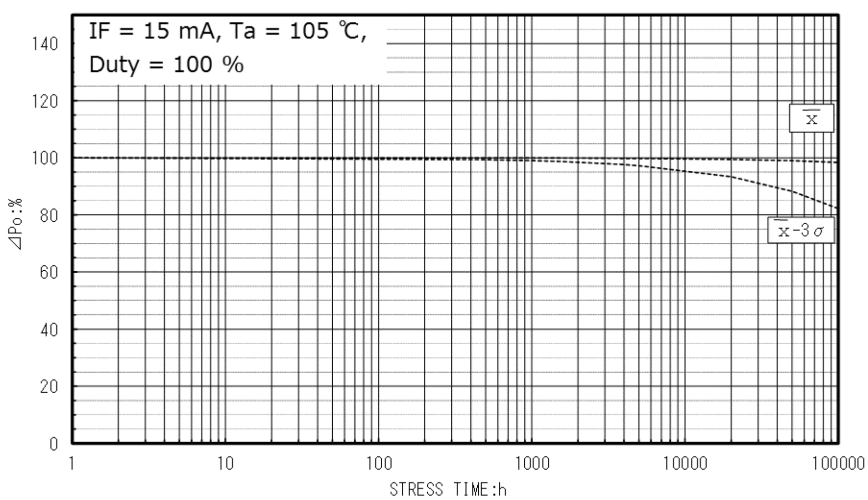


Fig. 8 Light Output Degradation Curve for the LED on TLP2363 (worst case)

Fig. 8 shows that even in the worst case, the degradation in light output after 0.1 million hours is 20 % or less. If I_F is designed to be close to the maximum value shown in Table 4 under the input condition in which the photocoupler is to be turned on (here, V_{IN} = 15 V) without considering the degradation, the photocoupler may not be turned on appropriately when the product is used for a long period of time.

For this reason, we recommend designing input circuit with consideration of **the max value of I_{FHL} as 3.0 mA**[Note 3] at the initial design stage.

[Note 3] From Table 4, I_{FHL} max value is 2.4 mA under V_{CC} = 3.3 V and R_L = 1 kΩ, and the worst degradation after 0.1 million hours is about 20%.
So, 2.4 mA / (1-0.2) = 3.0 mA

For I_{FHL} minimum value, the light output of the LEDs mounted on the photocoupler is reduced over time. Therefore, if I_F is designed to be smaller than I_{FHL} min value in the initial stage of the input condition for which the photocoupler is to be turned off (here, V_{IN} = 5 V), TLP2363 is securely turned off even if the product is used for a long period of time.

Based on the above, considering the degradation of the light output by 20 % in Table 4, it is considered as Table 4'.

Table 4' TLP2363 I_{FHL} Characteristics Table (including light output degradation of 20 %)

Characteristic	Symbol	Conditions	Min	Typ.	Max	Unit
Threshold input current	I_{FHL}	V_{CC} = 3.3 V, R_L = 1 kΩ, V_O < 0.6 V	0.3	0.9	3.0	mA

From Table 4', when V_{CC} = 3.3 V and R_L = 1 kΩ, since I_{FHL_max} = 3.0 mA ,
V_{F_max} can be set to the largest V_F under all temperature conditions when I_F = I_{F_on1} = 3.0 mA.
So, From Fig. 7'', V_{F_max} = 1.78 V.

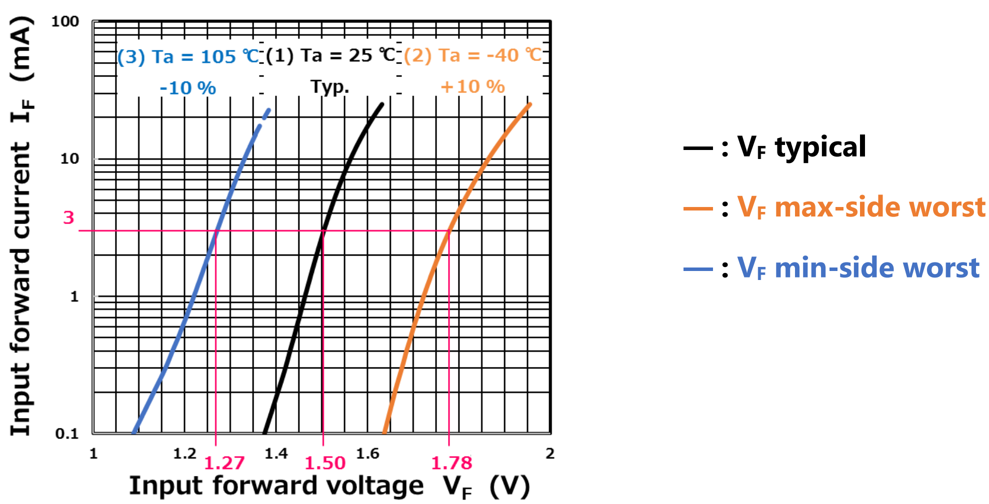


Fig. 7" The Typical I_F-V_F Characteristic Curve and V_F Max-Side Worst and Min-Side Worst I_F-V_F Characteristic Curves under All Operating Temperatures of TLP2363 (with V_F value when I_F = 3.0 mA)

By substituting it into Equation 2.2.2, we can see that **R_1 and R_2 must satisfy Equation 2.2.2'**.

$I_{F\_on1} = 15 / R_1 - (1 / R_1 + 1 / R_2) \times 1.78 > 3.0 \times 10^{-3}$ ・・・ (Equation 2.2.2')

2-2-3. Expression when V_{IN} = 30 V

(c) : Set as $I_F = I_{F\_on2}$ when V_{IN} = 30 V, and substitute them in Equation 2.2.0.

$I_{F\_on2} = 30 / R_1 - (1 / R_1 + 1 / R_2) \times V_F < I_F$ Absolute Maximum Rating ・・・ (Equation 2.2.3)

In Equation 2.2.3, **I_{F_on2}** is considered to **be the largest when $V_F = V_{F\_min2}$**.

* V_{F_min2} : the min V_F under all operating temperature conditions
when $I_{F\_on2} = I_F$ absolute max rating

2-2-3(a). Consideration of V_F Variation Range

In Equation 2.2.3, the variation of V_F is shown in Fig. 7.

2-2-3(b). V_{F_min2} Considerations

TLP2363 datasheet shows **the absolute maximum rating of I_F** at Ta = 25 °C and **the derating rate of I_F** to temperature, as shown in Table 5.

Table. 5 TLP2363 I_F Absolute Max Rating, I_F Derating Rate to Temperature and Operating Temperature Range

Characteristics		Symbol	Rating	Unit
Input forward current	(Ta = 25 ℃)	I_F	25	mA
Input forward current derating	(Ta ≧ 85 ℃)	$\Delta I_F/\Delta T_a$	-0.5	mA/℃
Operating temperature		T_{opr}	-40 to 105	℃

From Table 5, I_F absolute max rating will be the smallest when Ta = 105 °C, and I_F absolute max rating at that condition is :

25 - 0.5 x (105 - 85) = 15 mA.

V_{F_min2} can be set to the smallest V_F under all temperature conditions when $I_F = I_{F\_on2}$ = 15 mA. So, from Fig. 7''', V_{F_min2} = 1.35 V.

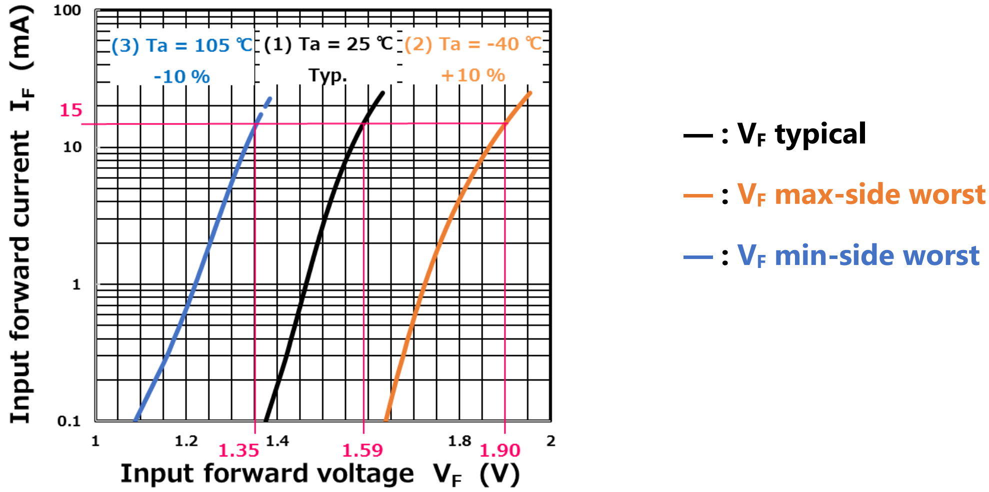


Fig. 7 ''' The Typical I_F-V_F Characteristic Curve and V_F Max-Side Worst and Min-Side Worst I_F-V_F Characteristic Curves under All Operating Temperatures of TLP2363 (with V_F value when I_F = 15 mA)

By substituting it into Equation 2.2.3, we can see that **R_1 and R_2 must satisfy Equation 2.2.3'**.

$$I_{F\_on2} = 15 / R_1 - (1 / R_1 + 1 / R_2) \times 1.35 < 15 \times 10^{-3} \quad \cdots \quad \text{(Equation 2.2.3')}$$

2-2-4. Integration of each Requirement

By 2-2-1 to 2-2-3, (a), (b) and (c) each are represented as below.

(a) : when V_{IN} = 5 V, I_F < $\mathbf{I_{FHL\_min}}$ is:

$5 / R_1 - (1 / R_1 + 1 / R_2) \times 1.16 < 0.3 \times 10^{-3}$ ・・・ (Equation 2.2.1')

(b) : when V_{IN} = 15 V, $\mathbf{I_{FHL\_max}}$ < I_F is:

$15 / R_1 - (1 / R_1 + 1 / R_2) \times 1.78 > 3.0 \times 10^{-3}$ ・・・ (Equation 2.2.2')

(c) : when V_{IN} = 30 V, I_F < **$\mathbf{I_F}$ absolute maximum rating** is:

$30 / R_1 - (1 / R_1 + 1 / R_2) \times 1.35 < 15 \times 10^{-3}$ ・・・ (Equation 2.2.3')

R_1 and R_2 that satisfies all (a), (b), and (c) can be found to be a combination within the striped area in Fig. 9.

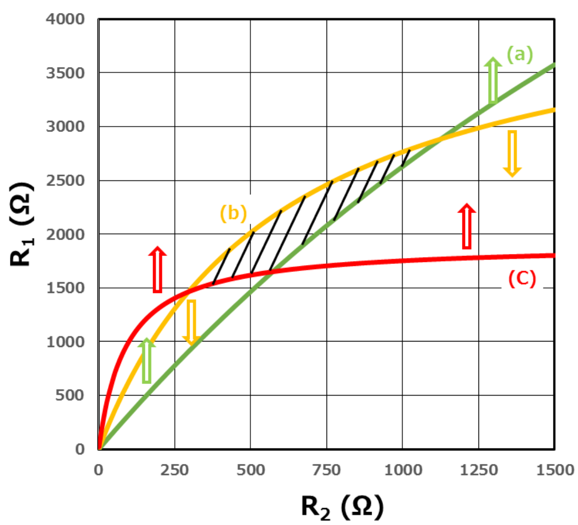


Fig. 9 R_1 and R_2 Combination Area for Complying with IEC 61131-2 Type 1

2-2-5. Selection of R_1 and R_2, and I_F Calculation

Here, we estimate I_F when **R_1 = 2200 Ω** and **R_2 = 750 Ω** are selected from the combination area of **R_1** and **R_2** in Fig. 9 and the resistance of the E24 series.
(Note that the resistance tolerance is within ±5 % considering temperature change and aging.)

2-2-5(a). I_F Calculation when V_{IN} = 5 V

First, from (a), we estimate I_{F_off} when V_{IN} = 5 V.
From Equation 2.2.1, we can see that the larger V_F, the smaller I_{F_off}.
And Equation 2.2.1 can be deformed as:

$$I_{F\_off} = (5 - V_F) / R_1 - V_F / R_2$$

We can see that the larger R_1 and the smaller R_2, the smaller I_{F_off}.

From Fig. 7' and Equation 2.2.1, **the minimum, typical, and maximum values of I_{F_off} can be calculated by using each variation condition of V_F, R_1 and R_2** as Table 6.

Table 6 I_{F_off} Min, Typical and Max Values under each Condition

V_{in} = 5 V	Min	Typ.	Max	Unit
I_{F_off}	-0.91	-0.27	0.37	mA
Conditions				
T_a	-40	25	105	℃
V_F	1.68	1.42	1.16	V
R_1	2200 + 5 %	2200	2200 – 5 %	Ω
R_2	750 – 5 %	750	750 + 5 %	Ω

Now, when **Ta = 105 °C**, which is the worst condition, confirm that **TLP2363 can be turned off reliably at the largest I_{F_off} of 0.37 mA**.

TLP2363 I_{FHL}-Ta characteristic curves in the datasheet are shown in Fig. 10.

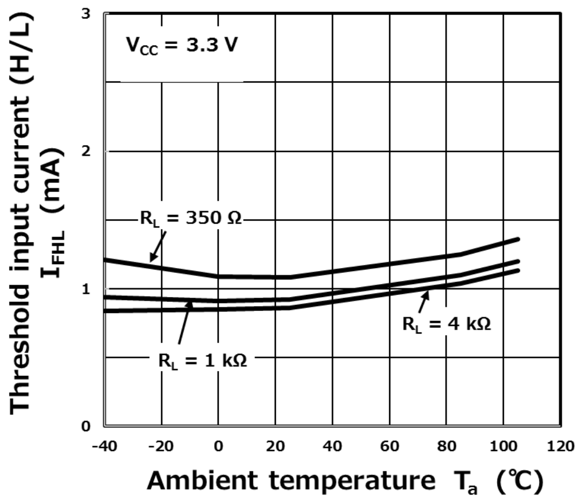


Fig. 10 TLP2363 I_{FHL}-Ta Characteristic Curves at V_{CC} = 3.3 V

From Fig. 10, when V_{CC} = 3.3 V, R_L = 1 kΩ and under all operating temperature conditions, **I_{FHL} will be the minimum at Ta = 0 °C**, and **will be the maximum at Ta = 105 °C**.

By combining what I_{FHL_min} = 0.3 mA in Table 4 and Fig. 10, when V_{CC} = 3.3 V and R_L = 1 kΩ, the relation between the min value of I_{FHL} and the temperature drift of I_{FHL} can be expressed as Fig. 11.

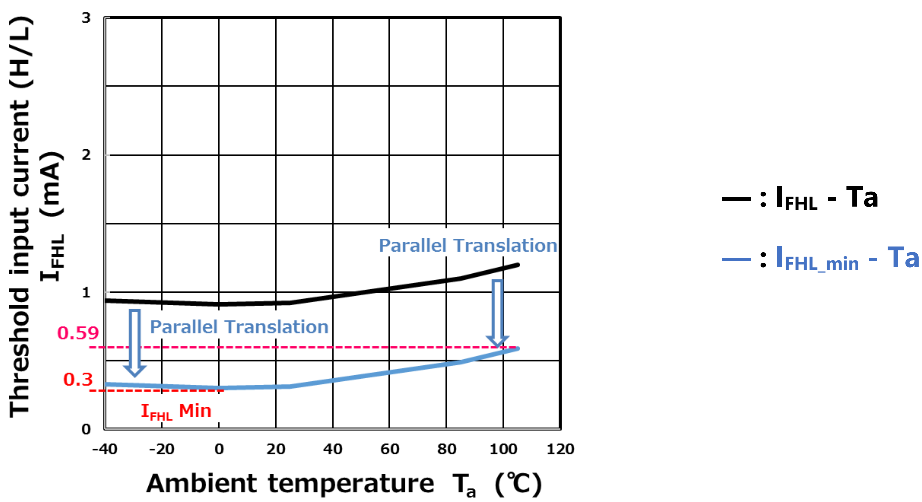


Fig. 11 Relation between the I_{FHL} Min and the I_{FHL} Temperature Drift at V_{CC} = 3.3 V, R_L = 1 kΩ in TLP2363

We can estimate that **the minimum I_{FHL} when Ta = 105 °C** is 0.59 mA from the I_{FHL_min}-Ta curve (the blue line in Fig. 11) which is parallel translated from I_{FHL}-Ta curve when V_{CC} = 3.3 V, R_L = 1 kΩ so that the min value of I_{FHL} indicates 0.3 mA at Ta = 0 °C.

Therefore, even when the worst condition **Ta = 105 °C** and **I_{F_off} max 0.37 mA** in Table 6, **TLP2363 can be certainly turned off**.

2-2-5(b). I_F Calculation when V_{IN} = 15 V

Next, from **(b)**, we estimate I_{F_on1} when V_{IN} = 15 V.
From Equation 2.2.2, we can see that the larger V_F, the smaller I_{F_on1}.
And Equation 2.2.2 can be deformed as:

$$I_{F\_on1} = (15 - V_F) / R_1 - V_F / R_2$$

We can see that the larger R_1 and the smaller R_2, the smaller I_{F_on1}.

From Fig. 7" and Equation 2.2.2, **the minimum, typical, and maximum values of I_{F_on1} can be calculated by using each variation condition of V_F, R_1 and R_2** as Table 7.

Table 7 I_{F_on1} Min, Typical and Max Values under each Condition

V_{in} = 15 V	Min	Typ.	Max	Unit
I_{F_on1}	3.23	4.13	4.96	mA
Conditions				
T_a	-40	25	105	℃
V_F	1.78	1.50	1.27	V
R_1	2200 + 5 %	2200	2200 − 5 %	Ω
R_2	750 − 5 %	750	750 + 5 %	Ω

From Table 4', I_{FHL} max is 3.0 mA. Therefore, even when the worst condition **Ta =-40 °C** and **I_{F_on1} min = 3.23 mA** in Table 7, **TLP2363 can be certainly turned on**.

2-2-5(c). I_F Calculation when V_{IN} = 30 V

Finally, from **(c)**, we estimate I_{F_on2} when V_{IN} = 30 V.
From Equation 2.2.3, we can see that the larger V_F, the smaller I_{F_on2}.
And Equation 2.2.3 can be deformed as:

$$I_{F\_on2} = (30 - V_F) / R_1 - V_F / R_2$$

We can see that the larger R_1 and the smaller R_2, the smaller I_{F_on2}.

From Fig. 7"' and Equation 2.2.3, **the minimum, typical, and maximum values of I_{F_on2} can be calculated by using each variation condition of V_F, R_1 and R_2** as Table 8.

Table 8　I_{F_on2} Min, Typical and Max Values under each Condition

V_{in} = 30 V	Min	Typ.	Max	Unit
I_{F_on2}	9.49	10.8	12.0	mA
Conditions				
T_a	-40	25	105	℃
V_F	1.90	1.59	1.35	V
R_1	2200 + 5 %	2200	2200 − 5 %	Ω
R_2	750 − 5 %	750	750 + 5 %	Ω

From Table 5, the I_F absolute max ratings of TLP2363 are 25 mA at Ta =-40, 25 °C, and 15 mA at Ta = 105 °C. This means that even in the worst condition **Ta = 105 °C** and **I_{F_on2} max 12.0 mA** in Table 8, **I_F absolute maximum rating of TLP2363 is certainly not exceeded**.

2-2-5(d). Summary of I_F Calculations

To summarize, when **R_1 = 2200 Ω** and **R_2 = 750 Ω are selected** from the E24 series, I_F values are calculated as in Table 9 under each of V_{IN} conditions, and **TLP2363 is capable of ON/OFF transitions according to the requirements of IEC 61131-2 Type 1**.

Here, because TLP2363 has an open-collector type of output, when V_{CC} is given a voltage equal to or higher than the min operating voltage,
V_O : High when $I_F < I_{FHL\_min}$, V_O : Low when $I_F > I_{FHL\_max}$.

Table 9 I_F and TLP2363 Output Logic for each V_{IN} Condition when R1 = 2200 Ω and R2 = 750 Ω

V_{IN} (V)	I_F Min (mA)	I_F Typ. (mA)	I_F Max (mA)	TLP2363 Output Logic
5	-0.91	-0.27	0.37	High
15	3.23	4.13	4.96	Low
30	9.49	10.8	12.0	Low

2-3. Considerations for Input-Conditions I_{IN} and V_{IN}

Now we will take a look at R_1 and R_2 selection process again. As described in 2.1, in this application note, we are designing in the order of **determining R_1 and R_2 that satisfies ① and ④**, **calculating I_{IN}**, and **confirming that ② and ③ are satisfied**.

① **When -3 V < V_{IN} < 5 V, limit the current I_F so as TLP2363 is always turned off.**
② **When 5V < V_{IN} < 15 V, limit the current to 0.5 mA < I_{IN} < 15 mA.**
③ **When 15V < V_{IN} < 30 V, limit the current to 2 mA < I_{IN} < 15 mA.**
④ **When 15V < V_{IN} < 30V, limit the current I_F so as TLP2363 is always turned on.**

In 2-2, **if R_1 = 2200 Ω and R_2 = 750 Ω are selected** from the E24 series, it was confirmed that **TLP2363 can operate as required by IEC 61131-2 Type 1**. Then, check that ② and ③ can be satisfied under these resistance conditions.

2-3-1. I_{IN} Calculation

In Fig. 1', I_{IN} is represented using I_F, V_F as below.

$I_{IN} = I_2 + I_F$

$= V_F / R_2 + I_F$ ・・・ (Equation 2.3.1)

From Equation 2.3.1, we can see that I_{IN} can be expressed by TLP2363's I_F and V_F, and the larger R_2, the smaller the value.

From I_F – V_F curve in Fig. 7 and Equation 2.3.1, **the minimum, typical, and maximum I_{IN} for I_F and V_F of TLP2363** can be represented as shown in Fig. 12. Here, it is regarded that when Ta = -40 °C, where I_{IN} will be the smallest, R_2 varies by +5% in the worst case, and when Ta = 105 °C, where I_{IN} will be the largest, R_2 varies by -5% in the worst case.

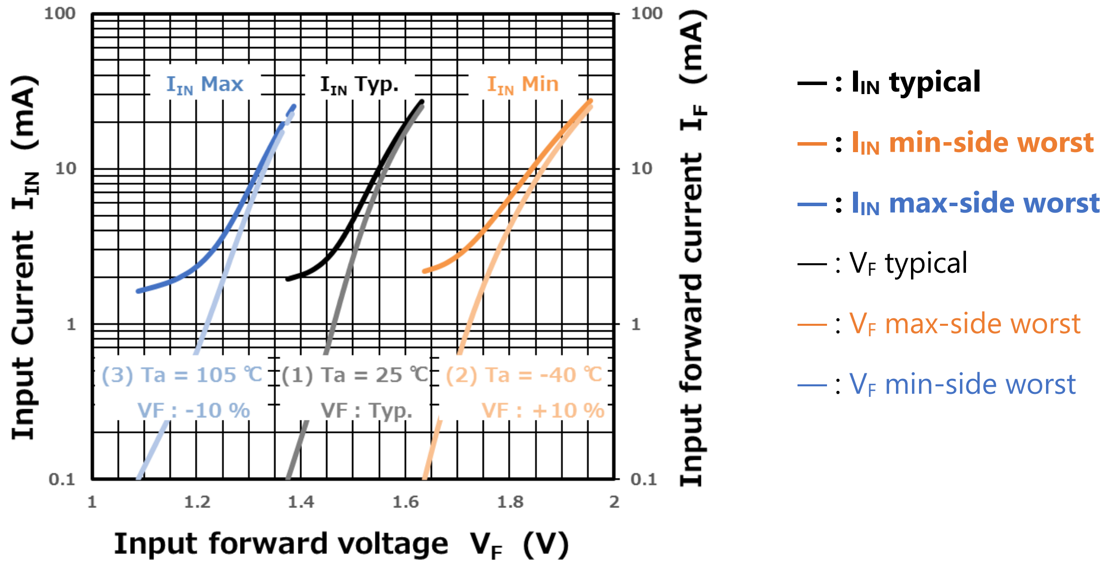


Fig. 12 Min, Typical and Max of I_{IN} for TLP2363's I_F and V_F

2-3-2. V_{IN} Calculation

In Fig. 1', V_{IN} is represented using I_{IN}.

By $I_1 = I_{IN}$,

$V_{IN} = I_{IN} \times R_1 + V_F$ ・・・ (Equation 2.3.2)

From Equation 2.3.2, we can see that V_{IN} can be expressed by the linear function of I_{IN}. We can also see that for the same V_{IN}, the larger R_1, the smaller I_{IN}.

From Fig. 12 and Equation 2.3.2, **the relation between V_{IN} and I_{IN} when R_1 = 2200 Ω and R_2 = 750 Ω are selected** can be calculated as shown in Fig. 13.

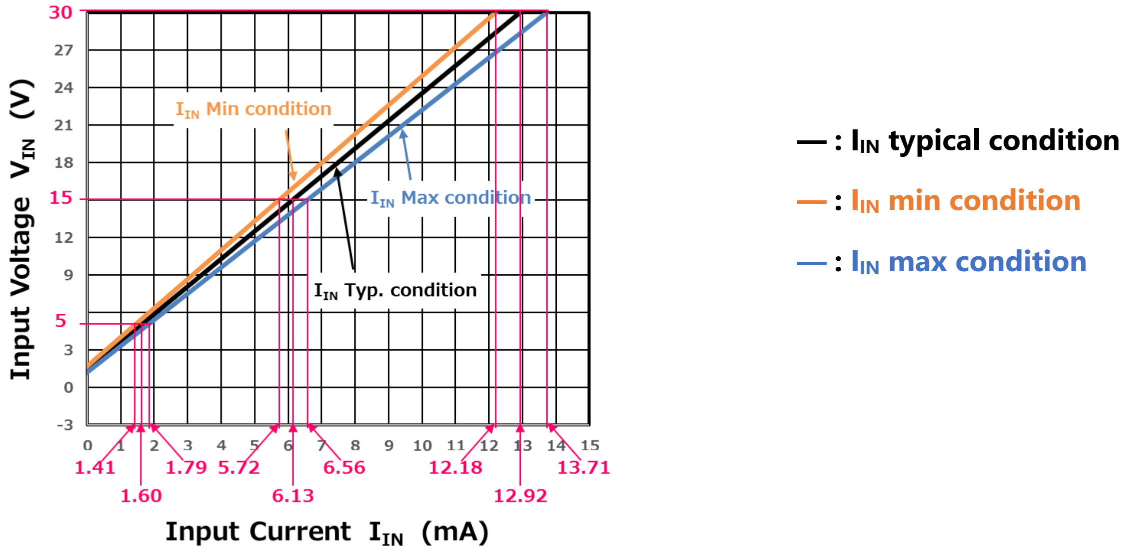


Fig. 13 V_{IN} – I_{IN} Characteristic Curves when Using TLP2363 and Selected R_1 = 2200 Ω, R_2 = 750 Ω (with I_{IN} values when V_{IN} = 5 V, 15 V and 30 V)

The conditions used to calculate each line in Fig. 13 are shown in Table 10.

Table 10 Conditions for Fig. 13 Drawing

Conditions	I_{IN} Min	I_{IN} Typ.	I_{IN} Max
T_a (℃)	-40	25	105
I_F-V_F Characteristic Curve	+10 %	標準	-10 %
R_1 (Ω)	2200 + 5 %	2200	2200 – 5 %
R_2 (Ω)	750 + 5 %	750	750 - 5 %

2-3-3. Summary of I_{IN}, V_{IN} Calculations

Writing ON/OFF area of IEC 61131-2 Type 1 in Fig. 13 can be expressed as Fig. 13'**.**

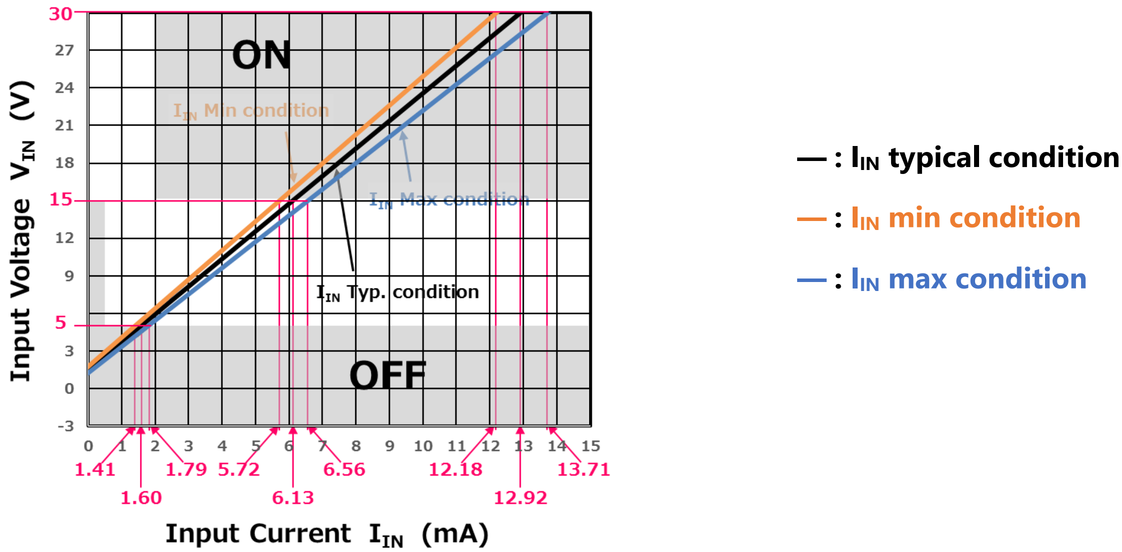


Fig. 13' V_{IN} – I_{IN} Characteristic Curves when Using TLP2363 and Selected R_1 = 2200 Ω, R_2 = 750 Ω, and IEC 61131-2 Type 1 ON/OFF Range

From Fig. 13', when **using TLP2363** and **selecting R_1 = 2200 Ω and R_2 = 750 Ω** from the E24 series, **the input module can be ON/OFF transitioned according to IEC 61131-2 Type 1**.
Each of I_{IN} values at each V_{IN} condition are shown in Table 11.

Table 11 TLP2363 Output Logic and I_{IN} for each V_{IN} Condition when R_1 = 2200 Ω, R_2 = 750 Ω

V_{IN} (V)	TLP2363 Output Logic	I_{IN} Min (mA)	I_{IN} Typ. (mA)	I_{IN} Max (mA)
5	High	1.41	1.60	1.79
15	Low	5.72	6.13	6.56
30	Low	12.18	12.92	13.71

From Table 11, **when R_1 = 2200 Ω and R_2 = 750 Ω** are selected using **TLP2363**:

1.41 mA < I_{IN} < 6.56 mA, when 5V < V_{IN} < 15 V,

6.56 mA < I_{IN} < 13.71 mA when 15V < V_{IN} < 30 V

Then, we can see that ② **and** ③ **are satisfied**.

From the above, we have been able **to design a 24V Digital Input Module that complies with IEC 61131-2 Type1 using TLP2363**.

3. TLP2363 Tolerance to Gradual Rise and Fall of the Power Supply

In addition to the requirements for the operating range of the input circuit, IEC 61131-2 specifies the tests to be performed on the behavior of the PLC system against variations in the external power supply. In the **Gradual shut-down/start-up test** of the external power supply in it, it is specified that **when the power supply is turned on or off with 60 seconds, the PLC system** should be confirmed that it **shows the predefined behavior**.

Depending on the product, **the output may chatter** when the power supply voltage (V_{CC}) of the high-speed communication photocoupler is slowly turned on or off.

Fig. 14 shows a measuring circuit for evaluating the output voltage (V_O) of the photocoupler when the power supply voltage (V_{CC}) is gently ramped up by the slope of 3.3V/75s or gently ramped down by the slope of the -3.3V/75s.

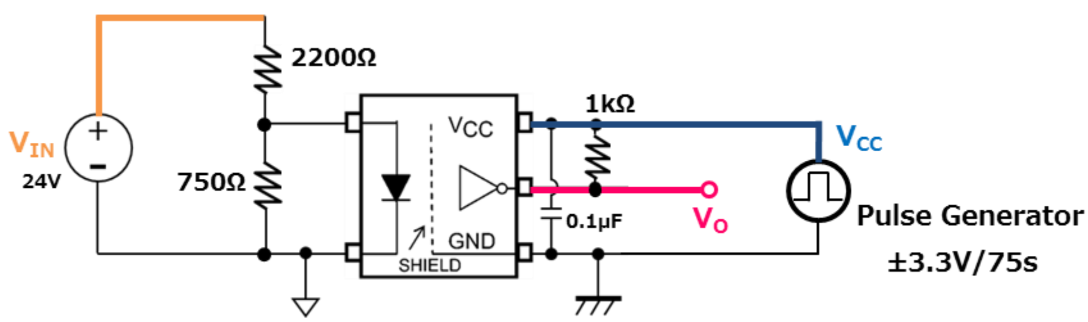
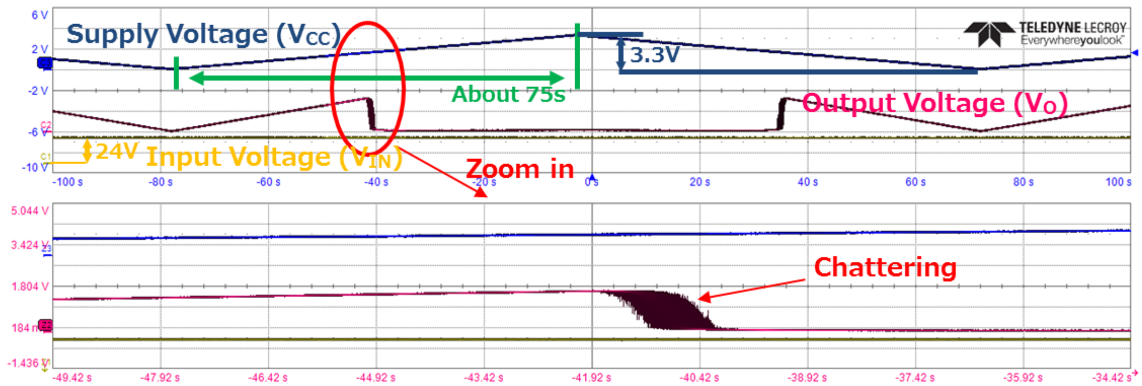


Fig. 14 Photocoupler Output Voltage Measurement Circuit for Slow Rise and Fall of Power Supply

Fig. 15 shows an **example of chattering occurring in the output voltage (V_O)** when a photocoupler is measured by the measuring circuit of Fig. 14.



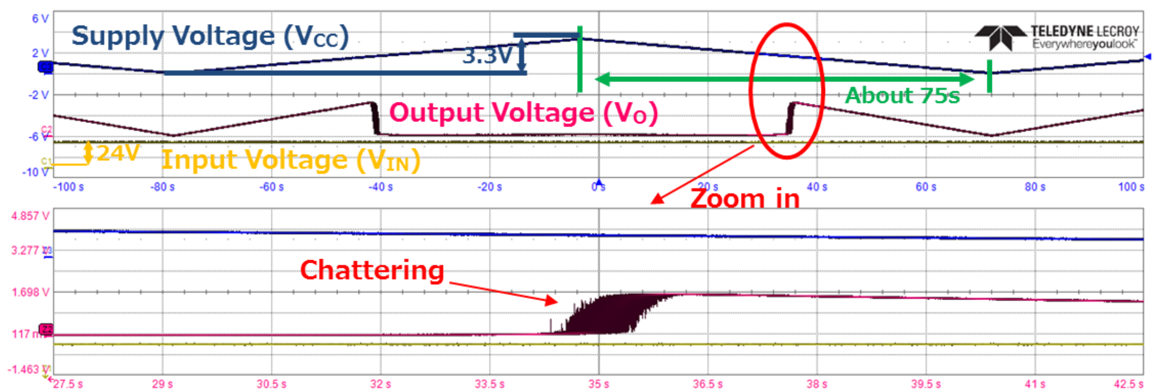


Fig. 15 Above: Example of Chattering Occurring in the Output Voltage (V_O) of the Photocoupler when the Power Supply Voltage (V_{CC}) is Slowly Risen up with the Slope of 3.3V/75s.

Below: Example of Chattering Occurring in the Output Voltage (V_O) of the Photocoupler when the Power Supply Voltage (V_{CC}) is Slowly Fallen down with the Slope of -3.3V/75s.

Next, Fig. 16 shows **the behavior when TLP2363 is used** as a high-speed communication photocoupler.

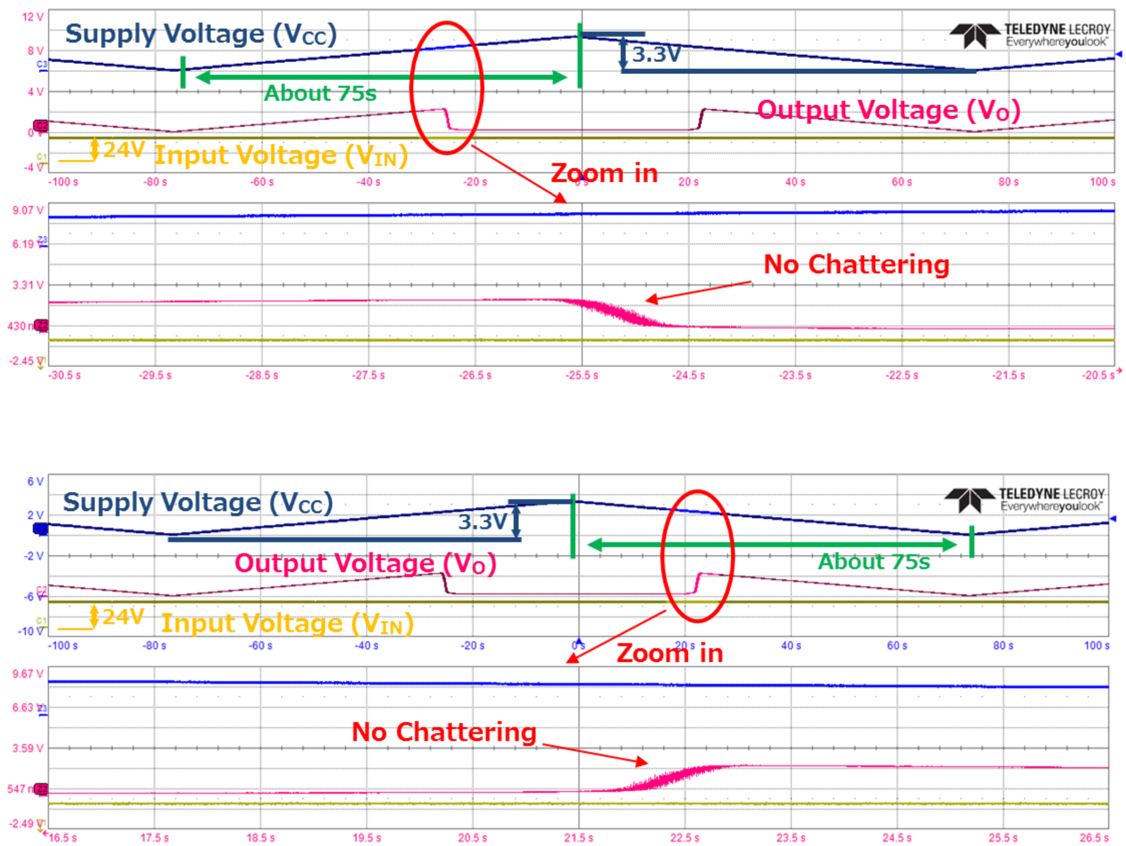


Fig. 16 Above: Output Voltage (V_O) of TLP2363
when the Power Supply Voltage (V_{CC}) is Slowly Risen up with the Slope of 3.3V/75s.

Below: Output Voltage (V_O) of TLP2363
when the Power Supply Voltage (V_{CC}) is Slowly Fallen down with the Slope of -3.3V/75s.

As shown in Fig. 16, **TLP2363 does not chatter the output when the power supply voltage (V_{CC}) is turned on or off very slowly**.

With TLP2363, the **Gradual shut-down/start-up test** of the external power supply specified in IEC 61131-2 can be cleared without any troubles.

4. TLP2363 Tolerance to Gradual Rise and Fall of the Input Signal

In section 3, we focused on the behavior of the photocoupler when the power supply voltage (V_{CC}) is gently turned on or off. This chapter introduces the behavior of the photocoupler when **the input signal to the PLC has gentle rising and falling edges**.

Using the measuring circuitry shown in Fig. 17, measure the output voltage (V_O) of the photocoupler when a signal with a gradual rise and fall by the slope of ±24V/75s is input.

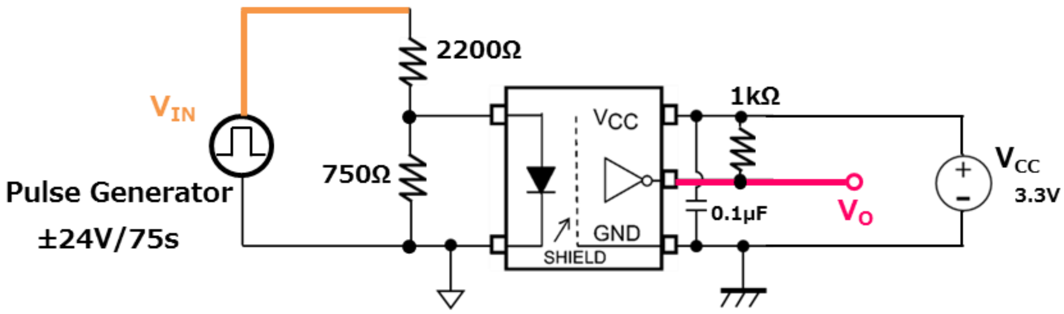


Fig. 17 Photocoupler Output Voltage Measurement Circuit for Slow Rise and Fall of Input Signals

Using the measurement circuit shown in Fig. 17 to measure the behavior of a photocoupler that does not withstand input signals with gradual rising and falling edges, **the output** of the photocoupler will **chatter** as shown in Fig. 18.

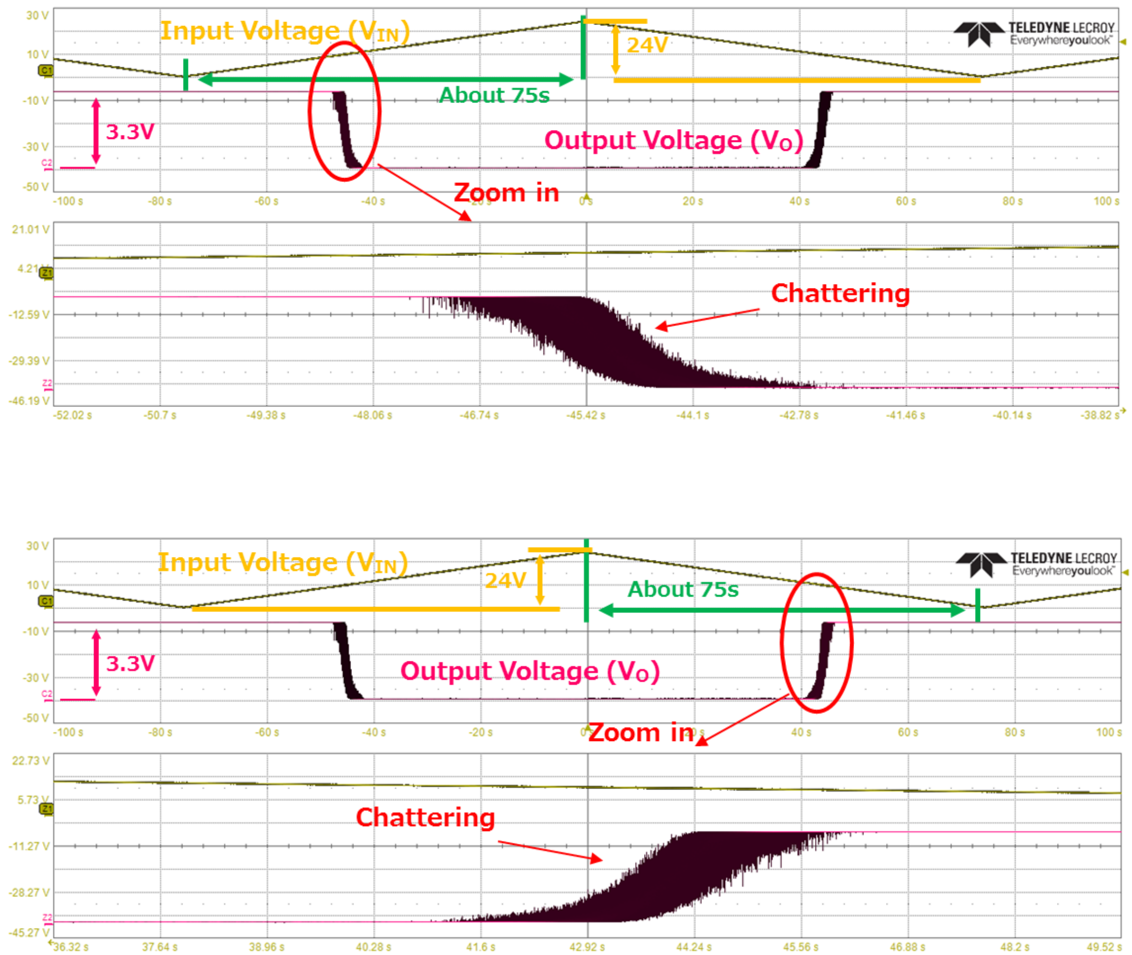


Fig. 18 Above: Example of Chattering Occurring in the Output Voltage (V_O) of the Photocoupler when the Input Voltage (V_{IN}) is Slowly Risen up with the Slope of 24V/75s.

Below: Example of Chattering Occurring in the Output Voltage (V_O) of the Photocoupler when the Input Voltage (V_{IN}) is Slowly Fallen down with the Slope of -24V/75s.

To suppress the chattering shown in Fig. 18, for example, an RC filter and a Schmitt trigger IC can be connected to the output of the photocoupler as shown in Fig. 19. However, **the number of components increases** and **the delay time of the signal increases**.

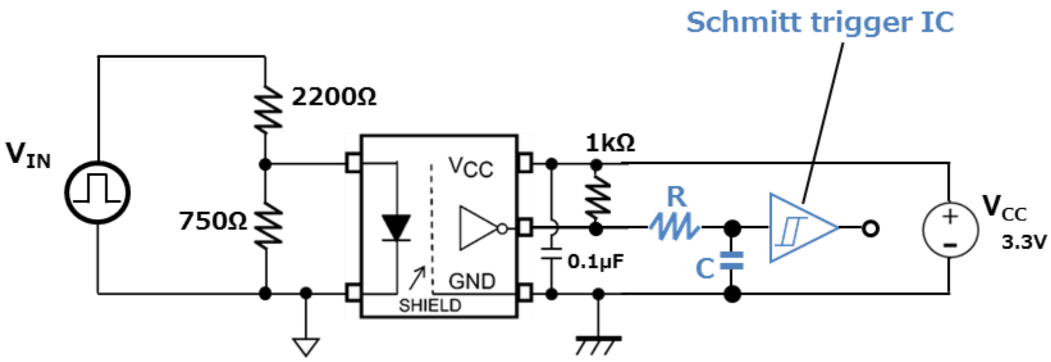
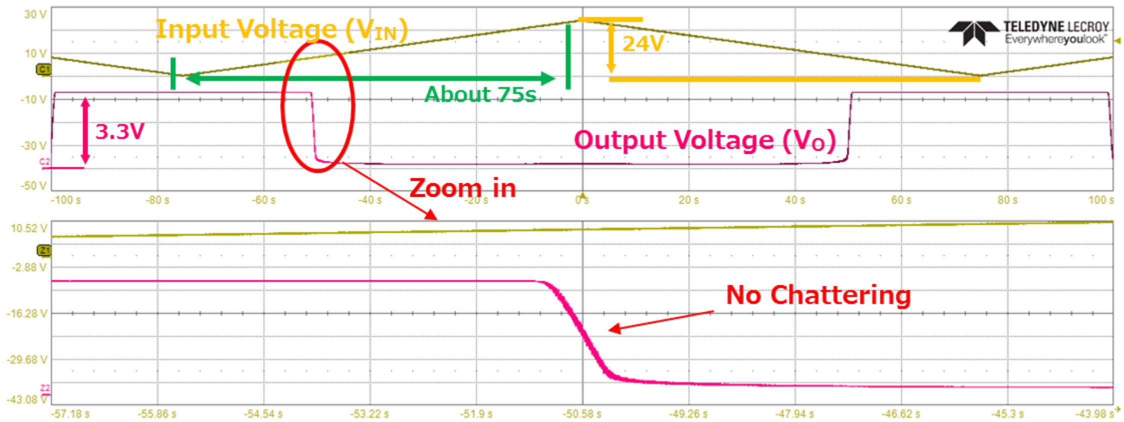


Fig. 19 Example of a Suppression Circuit for Photocoupler Output Chattering
by Adding an RC Filter and a Schmitt Trigger IC

TLP2363 has a high tolerance to input signals with gentle rising and falling edges, and can maintain a clean output even for input signals with the slope of ±24V/75s, as shown in Fig. 20.



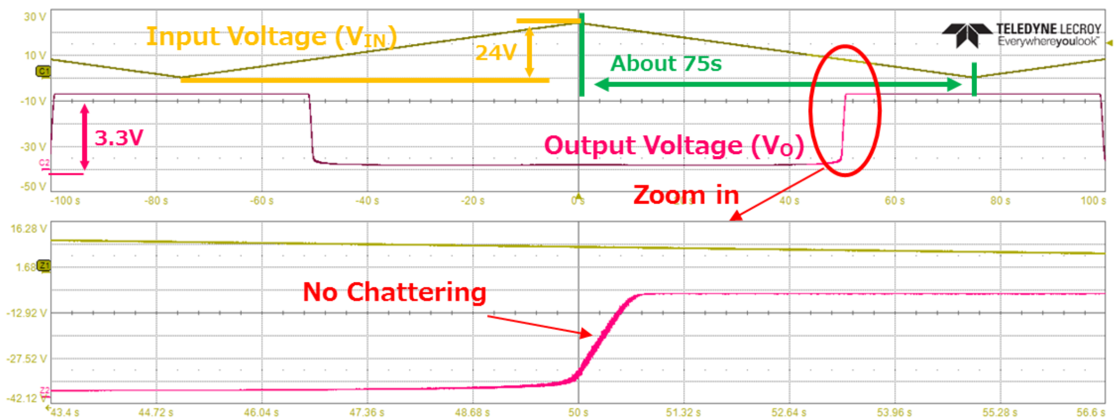


Fig. 20 Above: Output Voltage (V_O) of TLP2363
when the Input Voltage (V_{IN}) is Slowly Risen up with the Slope of 24V/75s.

Below: Output Voltage (V_O) of TLP2363
when the Input Voltage (V_{IN}) is Slowly Fallen down with the Slope of -24V/75s.

5. Summary

This application note introduced the designs of PLC 24V Digital Input Modules using a high-speed communication photocoupler. **TLP2363 makes it easy to design a 24V Digital Input Module compliant with IEC 61131-2 Type 1** and **has a high withstand capability for power supply voltages and input signals with gentle rising and falling edges**, eliminating the need for external components and reducing the number of components.

Refer to this (Link) for the detail of TLP2363.

Revision History

Revision	Date	Description
Rev. 1.0	2021-03-25	1st edition

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