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. PLCs (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](image)

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

<table>
<thead>
<tr>
<th>Digital Input Types</th>
<th>Connected Devices</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 1</td>
<td>Device for sensing signals from mechanical contact switching devices, such as relay contacts, push-buttons, switches, etc.</td>
</tr>
<tr>
<td>Type 2</td>
<td>Device for sensing signals from solid-state switching devices such as 2-wire proximity switches.</td>
</tr>
<tr>
<td>Type 3</td>
<td>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</td>
</tr>
</tbody>
</table>
In addition, the **operating ranges for input voltage and input current** is specified for each digital input type.

In the input-rated 24V<sub>dc</sub>, 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.

![Type 1, Type 2, Type 3](image)

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<sub>1</sub> and R<sub>2</sub> 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.

![Input Circuitry Diagram]

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

<table>
<thead>
<tr>
<th>$V_{IN}$ (V)</th>
<th>0 ~ 0.5</th>
<th>0.5 ~ 2</th>
<th>2 ~ 15</th>
</tr>
</thead>
<tbody>
<tr>
<td>-3 ~ 5</td>
<td>OFF</td>
<td>OFF</td>
<td>OFF</td>
</tr>
<tr>
<td>5 ~ 15</td>
<td>OFF</td>
<td>Transition</td>
<td>Transition</td>
</tr>
<tr>
<td>15 ~ 30</td>
<td>Transition</td>
<td>Transition</td>
<td>ON</td>
</tr>
</tbody>
</table>

$V_{IN}$ : 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
The following four points are critical to \( R_1 \), \( R_2 \) selection.

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

\[(a) : \text{ when } V_{IN} = 5 \text{ V}, I_F < I_{FHL\_min} \]
\[(b) : \text{ when } V_{IN} = 15 \text{ V}, I_{FHL\_max} < I_F \]

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

\[(c) : \text{ when } V_{IN} = 30 \text{ V}, I_F < I_F \text{ absolute maximum rating} \]

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, \[ I_F = V_{IN} / R_1 - (1 / R_1 + 1 / R_2) \times V_F \quad \cdots \quad \text{(Equation 2.2.0)} \]
2-2-1. Expression when $V_{IN} = 5 \text{ V}$

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

$$I_{F, off} = \frac{5}{R_1} - \left(\frac{1}{R_1 + 1/R_2}\right) \times V_F < I_{FHL_{min}} \cdots \text{ (Equation 2.2.1)}$$

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 $I_F = 2.6 \text{ mA}$ and $T_a = 25 \degree \text{C}$, as shown in Table 3.

**Table 3** The Min, Typical and Max $V_F$ Values of TLP2363 when $I_F = 2.6 \text{ mA}$, $T_a = 25 \degree \text{C}$.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Symbol</th>
<th>Conditions</th>
<th>Min</th>
<th>Typ.</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input forward voltage</td>
<td>$V_F$</td>
<td>$I_F = 2.6 \text{ mA}, T_a = 25 \degree \text{C}$</td>
<td>1.35</td>
<td>1.5</td>
<td>1.65</td>
<td>V</td>
</tr>
</tbody>
</table>

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 $\text{Ta} = 25 \, ^\circ\text{C}$, $I_F - V_F$ characteristic curves considering $\pm 10\%$ variation to the typical curve are shown in Fig. 4.

Similarly, under the condition $\text{Ta} = -40 \, ^\circ\text{C}$, $I_F - V_F$ characteristic curves considering the $\pm 10\%$ variation to the typical curve are shown in Fig. 5. Under the condition $\text{Ta} = 105 \, ^\circ\text{C}$, $I_F - V_F$ characteristic curves considering the $\pm 10\%$ variation to the typical curve are shown in Fig. 6.
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 \( T_a = 25 \) °C)

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**Fig. 6**  \( I_F - V_F \) Characteristic Curve at \( T_a = 105 \) °C in TLP2363 (considered ±10 % variation)

**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). $V_{F,\text{min1}}$ Considerations

On the other hand, TLP2363 datasheet shows the min and max values of $I_{\text{FHL}}$ 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 $T_a = -40$ to $105$ °C, and the typical value is at $T_a = 25$ °C.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Symbol</th>
<th>Conditions</th>
<th>Min</th>
<th>Typ.</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Threshold input current</td>
<td>$I_{\text{FHL}}$</td>
<td>$V_{CC} = 3.3$ V, $R_L = 1$ kΩ, $V_o &lt; 0.6$ V</td>
<td>0.3</td>
<td>0.9</td>
<td>2.4</td>
<td>mA</td>
</tr>
</tbody>
</table>

From Table 4, when $V_{CC} = 3.3$ V and $R_L = 1$ kΩ, since $I_{\text{FHL,min}} = 0.3$ mA, $V_{F,\text{min1}}$ can be set to the smallest $V_F$ under all temperature conditions when $I_F = I_{F,\text{off}} = 0.3$ mA. So, from Fig. 7', $V_{F,\text{min1}} = 1.16$ V.

![Fig. 7’](image)

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

$$I_{F,\text{off}} = 5 / R_1 - (1 / R_1 + 1 / R_2) \times 1.16 < 0.3 \times 10^{-3} \quad \cdots \text{(Equation 2.2.1’)}$$
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.

$$I_{F,on1} = \frac{15}{R_1} - \left(\frac{1}{R_1} + \frac{1}{R_2}\right) \times V_F > I_{FHL_{\text{max}}\cdots (\text{Equation 2.2.2})}$$

In Equation 2.2.2, $I_{F,on1}$ is considered to be the smallest when $V_F = V_{F_{\text{max}}}$.

* $V_{F_{\text{max}}}$: the maximum $V_F$ under all operating temperature conditions when $I_{F,on1} = I_{FHL_{\text{max}}}$

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). $V_{F_{\text{max}}}$ Considerations

Same as in (a), we would like to estimate $V_{F_{\text{max}}}$ 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)](image)
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, $2.4 \text{ mA} / (1-0.2) = 3.0 \text{ mA}$

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%)

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Symbol</th>
<th>Conditions</th>
<th>Min</th>
<th>Typ.</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Threshold input current</td>
<td>$I_{FHL}$</td>
<td>$V_{CC} = 3.3$ V, $R_L = 1$ kΩ, $V_O &lt; 0.6$ V</td>
<td>0.3</td>
<td>0.9</td>
<td>3.0</td>
<td>mA</td>
</tr>
</tbody>
</table>

From Table 4’, when $V_{CC} = 3.3$ V and $R_L = 1$ kΩ, since $I_{FHL\text{,max}} = 3.0$ mA, $V_{F,\text{max}}$ can be set to the largest $V_F$ under all temperature conditions when $I_F = I_{F,\text{on1}} = 3.0$ mA.

So, From Fig. 7”, $V_{F,\text{max}} = 1.78$ V.

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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'.

\[ I_{F,on1} = 15 / R_1 - (1 / R_1 + 1 / R_2) \times 1.78 > 3.0 \times 10^{-3} \quad \cdots \quad \text{(Equation 2.2.2')} \]

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.

\[ I_{F,on2} = 30 / R_1 - (1 / R_1 + 1 / R_2) \times V_F < I_F \text{ Absolute Maximum Rating} \quad \cdots \quad \text{(Equation 2.2.3)} \]

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 $Ta = 25 \degree C$ and the derating rate of $I_F$ to temperature, as shown in Table 5.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Symbol</th>
<th>Rating</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input forward current ( $Ta = 25 \degree C$ )</td>
<td>$I_F$</td>
<td>25</td>
<td>mA</td>
</tr>
<tr>
<td>Input forward current derating ( $Ta \geq 85 \degree C$ )</td>
<td>$\Delta I_F / \Delta T_a$</td>
<td>-0.5</td>
<td>mA/°C</td>
</tr>
<tr>
<td>Operating temperature</td>
<td>$T_{opr}$</td>
<td>-40 to 105</td>
<td>°C</td>
</tr>
</tbody>
</table>

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

\[ 25 - 0.5 \times (105 - 85) = 15 \text{ mA}. \]
\( V_{F_{\text{min2}}} \) can be set to the smallest \( V_F \) under all temperature conditions when \( I_F = I_{F_{\text{on2}}} = 15 \) mA. So, from Fig. 7”, \( V_{F_{\text{min2}}} = 1.35 \) V.

By substituting it into Equation 2.2.3, we can see that \( R_1 \) and \( R_2 \) must satisfy Equation 2.2.3’.

\[
I_{F_{\text{on2}}} = \frac{15}{R_1} - \left( \frac{1}{R_1} + \frac{1}{R_2} \right) \times 1.35 < 15 \times 10^{-3} \quad \cdots \quad \text{(Equation 2.2.3’)}
\]
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, \( I_F < I_{FHL \text{ min}} \) is:

\[
5 / R_1 - (1 / R_1 + 1 / R_2) x 1.16 < 0.3 \times 10^{-3} \quad \cdots \quad \text{(Equation 2.2.1')}
\]

(b) : when \( V_{IN} = 15 \) V, \( I_{FHL \text{ max}} < I_F \) is:

\[
15 / R_1 - (1 / R_1 + 1 / R_2) x 1.78 > 3.0 \times 10^{-3} \quad \cdots \quad \text{(Equation 2.2.2')}
\]

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

\[
30 / R_1 - (1 / R_1 + 1 / R_2) x 1.35 < 15 \times 10^{-3} \quad \cdots \quad \text{(Equation 2.2.3')}
\]

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

![Graph showing \( R_1 \) and \( R_2 \) combinations](image)

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 \( R_1 = 2200 \, \Omega \) and \( R_2 = 750 \, \Omega \) 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 \( \pm 5 \% \) considering temperature change and aging.)

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

First, from (a), we estimate \( I_{F_{\text{off}}} \) when \( V_{IN} = 5 \, V \).

From Equation 2.2.1, we can see that the larger \( V_F \), the smaller \( I_{F_{\text{off}}} \).

And Equation 2.2.1 can be deformed as:

\[
I_{F_{\text{off}}} = \frac{(5 - V_F)}{R_1} - \frac{V_F}{R_2}
\]

We can see that the larger \( R_1 \) and the smaller \( R_2 \), the smaller \( I_{F_{\text{off}}} \).

From Fig. 7’ and Equation 2.2.1, the minimum, typical, and maximum values of \( I_{F_{\text{off}}} \) can be calculated by using each variation condition of \( V_F, R_1 \) and \( R_2 \) as Table 6.

<table>
<thead>
<tr>
<th>( V_{IN} = 5 , V )</th>
<th>Min</th>
<th>Typ.</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>( I_{F_{\text{off}}} )</td>
<td>-0.91</td>
<td>-0.27</td>
<td>0.37</td>
<td>mA</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>( T_a )</td>
</tr>
<tr>
<td>( V_F )</td>
</tr>
<tr>
<td>( R_1 )</td>
</tr>
<tr>
<td>( R_2 )</td>
</tr>
</tbody>
</table>

Now, when \( T_a = 105 \, ^\circ \text{C} \), which is the worst condition, confirm that TLP2363 can be turned off reliably at the largest \( I_{F_{\text{off}}} \) of 0.37 mA.

TLP2363 \( I_{FHL-Ta} \) characteristic curves in the datasheet are shown in Fig. 10.
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 $T_a = 0$ °C, and will be the maximum at $T_a = 105$ °C.

By combining what $I_{FHL,\text{min}} = 0.3$ 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.
We can estimate that the minimum $I_{FHL}$ when $T_a = 105 \, ^\circ C$ is $0.59 \, mA$ from the $I_{FHL\text{-}min}$-$T_a$ curve (the blue line in Fig. 11) which is parallel translated from $I_{FHL}$-$T_a$ curve when $V_{CC} = 3.3 \, V$, $R_L = 1 \, k\Omega$ so that the min value of $I_{FHL}$ indicates $0.3 \, mA$ at $T_a = 0 \, ^\circ C$.

Therefore, even when the worst condition $T_a = 105 \, ^\circ C$ and $I_{F\text{-}off\text{ max}} = 0.37 \, mA$ 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 $I_{F\text{-}on1}$ when $V_{IN} = 15 \, V$.

From Equation 2.2.2, we can see that the larger $V_F$, the smaller $I_{F\text{-}on1}$.

And Equation 2.2.2 can be deformed as:

$$I_{F\text{-}on1} = \frac{(15 - V_F)}{R_1} - \frac{V_F}{R_2}$$

We can see that the larger $R_1$ and the smaller $R_2$, the smaller $I_{F\text{-}on1}$.

From Fig. 7" and Equation 2.2.2, the minimum, typical, and maximum values of $I_{F\text{-}on1}$ can be calculated by using each variation condition of $V_F$, $R_1$, and $R_2$ as Table 7.

Table 7  $I_{F\text{-}on1}$ Min, Typical and Max Values under each Condition

<table>
<thead>
<tr>
<th>$V_{IN} = 15 , V$</th>
<th>Min</th>
<th>Typ.</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>$I_{F\text{-}on1}$</td>
<td>3.23</td>
<td>4.13</td>
<td>4.96</td>
<td>mA</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Conditions</th>
<th>$T_a$</th>
<th>$V_F$</th>
<th>$R_1$</th>
<th>$R_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-40</td>
<td>1.78</td>
<td>2200</td>
<td>750</td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>1.50</td>
<td>2200</td>
<td>750</td>
</tr>
<tr>
<td></td>
<td>105</td>
<td>1.27</td>
<td>2200</td>
<td>750</td>
</tr>
</tbody>
</table>

From Table 4', $I_{FHL\text{ max}}$ is $3.0 \, mA$. Therefore, even when the worst condition $T_a = -40 \, ^\circ C$ and $I_{F\text{-}on1\text{ min}} = 3.23 \, mA$ 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 $I_{F\text{on2}}$ when $V_{IN} = 30$ V.

From Equation 2.2.3, we can see that the larger $V_F$, the smaller $I_{F\text{on2}}$. And Equation 2.2.3 can be deformed as:

$$I_{F\text{on2}} = \frac{(30 - V_F)}{R_1} - \frac{V_F}{R_2}$$

We can see that the larger $R_1$ and the smaller $R_2$, the smaller $I_{F\text{on2}}$.

From Fig. 7 and Equation 2.2.3, the minimum, typical, and maximum values of $I_{F\text{on2}}$ can be calculated by using each variation condition of $V_F, R_1$ and $R_2$ as Table 8.

<table>
<thead>
<tr>
<th>$V_{in} = 30$ V</th>
<th>Min</th>
<th>Typ.</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>$I_{F\text{on2}}$</td>
<td>9.49</td>
<td>10.8</td>
<td>12.0</td>
<td>mA</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_a$</td>
</tr>
<tr>
<td>$V_F$</td>
</tr>
<tr>
<td>$R_1$</td>
</tr>
<tr>
<td>$R_2$</td>
</tr>
</tbody>
</table>

From Table 5, the $I_F$ absolute max ratings of TLP2363 are 25 mA at $T_a = -40$, 25 °C, and 15 mA at $T_a = 105$ °C. This means that even in the worst condition $T_a = 105$ °C and $I_{F\text{on2}}$ 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 $R_1 = 2200 \ \Omega$ and $R_2 = 750 \ \Omega$ 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 $R_1 = 2200 \ \Omega$ and $R_2 = 750 \ \Omega$

<table>
<thead>
<tr>
<th>$V_{IN}$ (V)</th>
<th>$I_F$ Min (mA)</th>
<th>$I_F$ Typ. (mA)</th>
<th>$I_F$ Max (mA)</th>
<th>TLP2363 Output Logic</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>-0.91</td>
<td>-0.27</td>
<td>0.37</td>
<td>High</td>
</tr>
<tr>
<td>15</td>
<td>3.23</td>
<td>4.13</td>
<td>4.96</td>
<td>Low</td>
</tr>
<tr>
<td>30</td>
<td>9.49</td>
<td>10.8</td>
<td>12.0</td>
<td>Low</td>
</tr>
</tbody>
</table>
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 $-3 \, \text{V} < V_{IN} < 5 \, \text{V}$, limit the current $I_F$ so as TLP2363 is always turned off.
② When $5 \, \text{V} < V_{IN} < 15 \, \text{V}$, limit the current to $0.5 \, \text{mA} < I_{IN} < 15 \, \text{mA}$.
③ When $15 \, \text{V} < V_{IN} < 30 \, \text{V}$, limit the current to $2 \, \text{mA} < I_{IN} < 15 \, \text{mA}$.
④ When $15 \, \text{V} < V_{IN} < 30 \, \text{V}$, limit the current $I_F$ so as TLP2363 is always turned on.

In 2-2, if $R_1 = 2200 \, \Omega$ and $R_2 = 750 \, \Omega$ 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.

$$I_{IN} = I_2 + I_F$$
$$I_{IN} = \frac{V_F}{R_2} + I_F \quad \text{(Equation 2.3.1)}$$

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 $T_a = -40 \, ^\circ\text{C}$, where $I_{IN}$ will be the smallest, $R_2$ varies by +5% in the worst case, and when $T_a = 105 \, ^\circ\text{C}$, where $I_{IN}$ will be the largest, $R_2$ varies by -5% in the worst case.
2-3-2. $V_{IN}$ Calculation

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

By $I_{1} = I_{IN}$,

$$V_{IN} = I_{IN} \times R_{1} + V_{F} \quad \cdots \quad \text{(Equation 2.3.2)}$$

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 $R_{1} = 2200 \ \Omega$ and $R_{2} = 750 \ \Omega$ are selected can be calculated as shown in Fig. 13.
Fig. 13  $V_{IN} - I_{IN}$ Characteristic Curves when Using TLP2363 and Selected $R_1 = 2200 \, \Omega$, $R_2 = 750 \, \Omega$
(with $I_{IN}$ values when $V_{IN} = 5 \, \text{V}, 15 \, \text{V}$ and $30 \, \text{V}$)

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

Table 10  Conditions for Fig. 13 Drawing

<table>
<thead>
<tr>
<th>Conditions</th>
<th>$I_{IN}$ Min</th>
<th>$I_{IN}$ Typ.</th>
<th>$I_{IN}$ Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_a$ (°C)</td>
<td>-40</td>
<td>25</td>
<td>105</td>
</tr>
<tr>
<td>$I_F$-$V_F$ Curve</td>
<td>+10 %</td>
<td>標準</td>
<td>-10 %</td>
</tr>
<tr>
<td>$R_1$ (Ω)</td>
<td>2200 + 5 %</td>
<td>2200</td>
<td>2200 - 5 %</td>
</tr>
<tr>
<td>$R_2$ (Ω)</td>
<td>750 + 5 %</td>
<td>750</td>
<td>750 - 5 %</td>
</tr>
</tbody>
</table>
### 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’.

![Characteristics curve](image)

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

From Fig. 13’, when **using TLP2363** and selecting $R_1 = 2200 \, \Omega$ and $R_2 = 750 \, \Omega$ 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 $R_1 = 2200 \, \Omega$, $R_2 = 750 \, \Omega$

<table>
<thead>
<tr>
<th>$V_{IN}$ (V)</th>
<th>TLP2363 Output Logic</th>
<th>$I_{IN}$ Min (mA)</th>
<th>$I_{IN}$ Typ. (mA)</th>
<th>$I_{IN}$ Max (mA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>High</td>
<td>1.41</td>
<td>1.60</td>
<td>1.79</td>
</tr>
<tr>
<td>15</td>
<td>Low</td>
<td>5.72</td>
<td>6.13</td>
<td>6.56</td>
</tr>
<tr>
<td>30</td>
<td>Low</td>
<td>12.18</td>
<td>12.92</td>
<td>13.71</td>
</tr>
</tbody>
</table>

From Table 11, **when $R_1 = 2200 \, \Omega$ and $R_2 = 750 \, \Omega$ 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.

![Photocoupler Output Voltage Measurement Circuit for Slow Rise and Fall of Power Supply](image-url)
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.

**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.

As shown in Fig. 16, **TLP2363 does not chatter the output when the power supply voltage (Vcc) 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.

![Photocoupler Output Voltage Measurement Circuit for Slow Rise and Fall of Input Signals](image)
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](image)

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.

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**Revision History**

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<thead>
<tr>
<th>Revision</th>
<th>Date</th>
<th>Description</th>
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</thead>
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<tr>
<td>Rev. 1.0</td>
<td>2021-03-25</td>
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