Basic Characteristics and Application Circuit Design of IC Couplers

Overview

This document describes characteristics and application circuit design of IC output couplers used in communication applications.

Contents

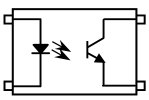
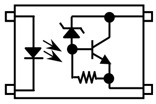
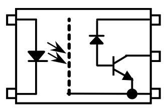
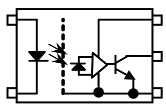
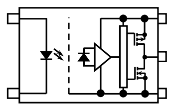
Toslink is a trademark of Toshiba Electronic Devices & Storage Corporation.

System design of industrial electronic equipment often throws up multiple challenges in relation to transmission lines. For example, ground loop offset voltage can generate loop current between systems and lead to equipment failure. These issues can often be addressed through the use of fiber couplers such as Toslink™ (over long distances) or photocouplers (over short distances). Standard phototransistor output couplers used in communications applications support transmission rates of up to several kbps, provided the design is good. However, given the increasing demand for shorter wait times for data transfer between devices and faster loop processing between circuits, timing issues due to photocoupler delays is now an important consideration. We offer a wide range of medium to high speed photocouplers for communications applications (optically coupled rapid-response light emitting device and light-detecting IC) that support standard transmission rates of 20 kbps through 50 Mbps. This document describes the characteristics and applied designs of our IC output coupler range.

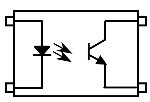
1. Photocouplers for communications applications

Table 1.1.1 shows the most common photocouplers and associated communication standards.

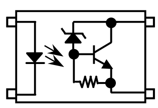
Table 1.1.1 Photocoupler Variety and Major Communication Standard

Class	Transistor Coupler	Middle Speed Range Coupler	High Spped Range Couplers		
Communication Rate	(1)few kbps	(2)around 20kbps	(3)100k to 1Mbps	(4)over 1Mbps	
Communication Standard		RS-232	RS-232C	I2C, SPI, RS-485, RS-422, FA network	
Internal Circuit				Open Collector 	Totempole 
Elements in Photodetector	Phototransistor	Phototransistor B-E Resistor Schottky Diode	Photodiode Transistor	Photodiode Amplifier IC	Photodiode Amplifier IC
Product Example	TLP293 TLP385	TLP2301	TLP2303 TLP2309	TLP2362 TLP2368	TLP2361 TLP2366

(1) Transistor output couplers such as the TLP293 are used for transmission speeds of up to several kbps. Normally the collector-base of the phototransistor on the light detecting side has a large bonding area for maximum light receptivity, with high collector-base capacity (C_{ob}). This results in longer propagation delay times due the Miller effect, particularly when the transistor status changes from ON to OFF. In non-saturated operation, output current varies in accordance with input current, which allows transistor output couplers to be used for analog signal.

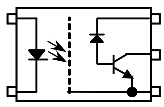


(2) Mid-range (20 kbps) couplers such as the TLP2301 have a shorter propagation delay when the phototransistor changes to off. This is due to the built-in base-emitter resistance that diverts the minority carriers remaining in

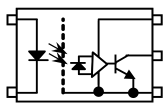


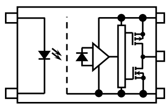
the transistor base domain as well as the collector-base capacity charging current over to the emitter side. Unlike standard transistor output couplers, the TLP2301 has a guaranteed maximum propagation delay at saturation (t_{pHL} = 30 μs (Max) @ Ta = 25°C) and is therefore suitable for transmission interfaces such as RS-232 operating at speeds of up to 20 kbps.

(3) High-speed IC output couplers (100 k to 1 Mbps) separate the photodiode and transistor on the light detector chip to enable high-speed switching and reduce C_{ob}, which has a direct bearing on propagation delay. High-speed IC output couplers are suitable for speeds up to 1 Mbps (e.g. RS-232C), and are also used in conjunction with transistor output couplers for switching power output differential feedback in analog signal transmission equipment.



(4) High-speed IC output couplers (1 Mbps or more) feature a high-gain, high-speed amplifier circuit after the photodiode for a further speed boost, and are designed for transmission speeds of up to 50 Mbps class. We offer a wide range of high-speed IC output couplers including open collector output and totem pole output configurations. IC output couplers with amplifier circuits have a threshold input current, which means that current in excess of the given LED input current threshold digitally switches the output on or off. This makes them unsuitable for linear transmission of analog signal. They are used for digital signal transmission only.





2. IC output couplers - electrical characteristics and applied designs

This section lists key electrical properties of mid-range (20 kbps) and high-speed (1 Mbps and more) couplers as well as applied designs.

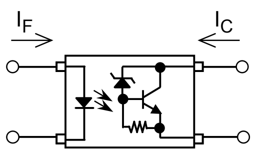
2.1 TLP2301 mid-range (20 kbps) coupler

2.1.1 Current transfer ratio (CTR) I_C/I_F

The TLP2301 has the current transfer ratio (CTR) like standard transistor output couplers. Current transfer ratio is defined as the ratio of output collector current I_C to input current I_F, expressed as a percentage. CTR is guaranteed under V_{CE} = 5 V non-saturation conditions. Saturated CTR $I_C/I_{F(sat)}$ refers to CTR under V_{CE} = 0.3 V saturated conditions.

Table 2.1.1 Current Transfer Ratio of TLP2301

Characteristics	Symbol	Note	Test Condition	Min	Typ.	Max	Unit
Current transfer ratio	I_C/I_F	(Note1)	I_F = 1 mA, V_{CE} = 5 V	50	—	600	%
			I_F = 1 mA, V_{CE} = 5 V, Rank GB	100	—	600	
Saturated current transfer ratio	$I_C/I_{F(sat)}$		I_F = 1 mA, V_{CE} = 0.3 V	—	100	—	
			I_F = 1 mA, V_{CE} = 0.3 V, Rank GB	50	—	—	



CTR =100 x I_C/I_F (%)

Figure 2.1.1 shows a digital signal transmission circuit example using TLP2301. Digital signal transmission requires output to be maintained at a low voltage consistently. Thus, when the output transistor is on, in the presence of LED input current, it must be pushed into the saturation region or maintained at a low voltage suitable for subsequent elements. If the low voltage for subsequent elements is assumed to be V_{IL} = 0.6 V (Max) then we find the corresponding minimum collector current when V_O = 0.6 V, and set the pull-up resistance so that the load current is lower than the minimum. Normally, the CTR for V_{CE} = 5 V is used as the basis for calculating the change rate D_{VCE} from the I_C - V_{CE} curve on the data sheet.

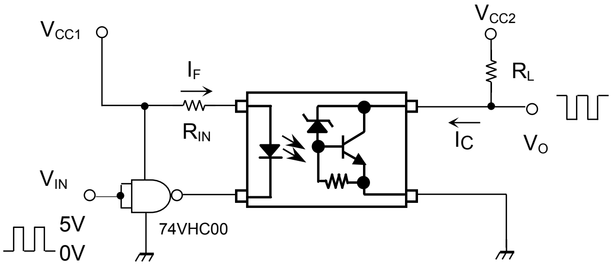


Figure 2.1.1 Example of Signal Transmission Interface using TLP2301

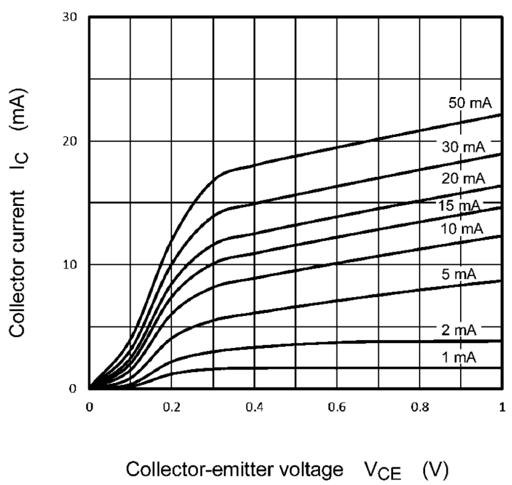


Figure 2.1.2 TLP2301 V_{CE} - I_C (to 1 V)

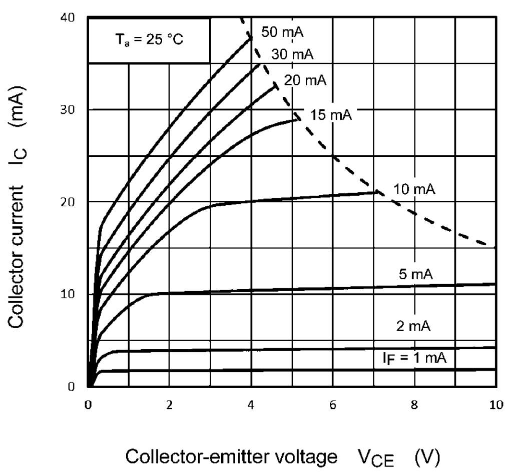


Figure 2.1.3 TLP2301 V_{CE} - I_C (to 10 V)

When TLP2301 is used at I_F = 1 mA, the change rate D_{VCE} for V_{CE}: 5 → 0.6 V is found from the I_C - V_{CE} characteristics on the data sheet.

$$D_{VCE} = \frac{I_C(V_{CE} = 0.6\ V)}{I_C(V_{CE} = 5\ V)} = \frac{1.9\ (mA)}{2.0\ (mA)} = 0.95$$

For GB rank, the minimum CTR is 100% for I_F = 1 mA and thus I_C = 1 mA:

$$I_C(@V_{CE} = 0.6\ V) = I_C \times D_{VCE} = 1\ (mA) \times 0.95$$

$$= 0.95\ (mA)$$

We then need to factor in the design margin. Here, for a design margin of 20 %, we have 0.95 mA × 0.8 = 0.76 mA; thus R_L should be designed to ensure that the load current does not exceed 0.76 mA, in order to maintain a low-level output voltage of no greater than 0.6 V. Note that the actual collector current will be slightly lower still, due to factors such as temperature characteristics and LED life expectancy, which also apply to transistor output couplers. Section 2-1-3 shows a typical calculation.

Saturated CTR $I_C/I_{F(sat)}$ is used to determine the collector current when V_O = 0.3 V. For GB rank, minimum collector current is $I_C/I_{F(sat)}$ = 50 %@I_F = 1 mA, so by adjusting the load current such that I_C = 0.5 mA (Max), we can maintain a saturated state at V_{CE}: 0.3 V (Max). And as we saw earlier, we can use CTR V_{CE} = 5 V as the basis for change rate D_{VCE} for V_{CE}: 5 → 0.3 V and the design margin. In the case of $I_C/I_{F(sat)}$ likewise, we must take into consideration the impact on collector current of other variables such as temperature characteristics.

2.1.2 Switching characteristics

Propagation delays in standard transistor output couplers can vary substantially, and there is no guaranteed maximum value under saturation conditions. Instead, we have to use a standard value to estimate the switching time, taking into account variation due to CTR, temperature characteristics and pull-up resistance. The TLP2301, by way of contrast, is able to offer a guaranteed maximum value thanks to shorter propagation delays at transistor turn-off and less variation. Irrespective of the CTR of the product there is a guaranteed maximm of 30 μs, which means that potential variation in switching time associated with CTR does not need to be factored in, like it does with transistor couplers. This makes it easier to design the delay time.

Table 2.1.2 Switching Time Characteristics of General PurposeTransistor Coupler TLP185

Characteristic	Symbol	Test Condition	Min	Typ.	Max	Unit
Turn-on time	t_{on}	R_L = 1.9 kΩ (Fig.1) V_{CC} = 5 V, I_F = 16 mA	—	2	—	μs
Storage time	t_s		—	30	—	
Turn-off time	t_{off}		—	70	—	

Table 2.1.3. Switching Time Characteristics of 20kbps IC Coupler TLP2301

Characteristics	Symbol	Note	Test Condition	Min	Typ.	Max	Unit
Propagation delay time (H/L)	t_{pHL}		See figure 10.1 V_{CC} = 5 V, I_F = 1 mA, R_L = 10 kΩ	—	15	30	μs
Propagation delay time (L/H)	t_{pLH}		See figure 10.1 V_{CC} = 5 V, I_F = 1 mA, R_L = 10 kΩ	—	8	30	μs

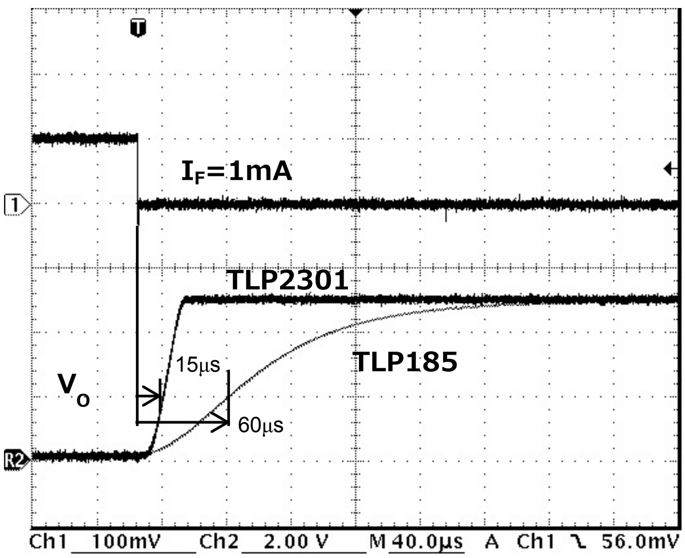


Figure 2.1.4 Switching waveform comparison of TLP185 and TLP2301

Conditions: I_F = 1 mA, R_L = 10 kΩ, Ta = 25 °C

CTR TLP2301: 250 %, TLP185: 100 % @ I_F = 1 mA

t_{pLH} measuring point: I_F = 0.5 mA, V_O = 2 V

2.1.3 Applied design example

Figure 2.1.5 shows the R_{IN} and R_L design process for a signal transmission circuit with TLP2301. R_L is determined such that the output never exceeds the saturation voltage relative to the LED input current. Provisional input current and R_{IN} values are used to calculate the Min collector current when the transistor is at saturation voltage and thus determine R_L.

Example of Design Specifications

- Operating temperature T_{opr}: 0 to 60 °C
- Data transmission rate : 10 kbps
- Supply voltage : V_{CC} = 5 V ± 5%
- Operating life : 10 years (88 kh)
- Signal Duty : 50 %

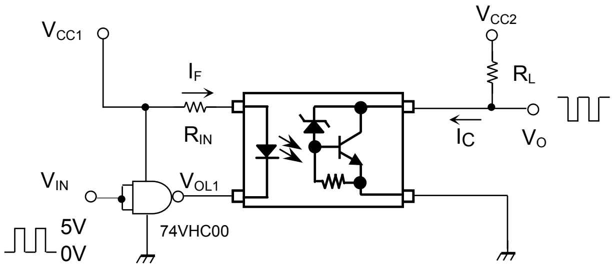


Figure 2.1.5 Example of Signal Transmission Interface using TLP2301

(1) R_{IN}

First we determine the LED input current. For TLP2301 we stipulate the CTR and propagation delay under low current conditions (I_F = 1 mA). For larger current the propagation delay will be longer and there are other impacts too, so it is better to stipulate the current at conditions close to I_F = 1 mA. Here, we have used a provisional value designed to produce I_F = 1 mA even in the worst-case scenario. R_{IN} is calculated as follows.

$$R_{IN(min)} = \frac{V_{CC1} - V_F - V_{OL1}}{I_F}$$

The Min R_{IN} values occur at $V_{CC1(min)}$, $V_{F(max)}$ and $V_{OL1(max)}$, so we must calculate these.
Since V_{CC1} is 5 V±5 %, we have:

$$V_{CC1(min)} = 5\ (V) \times 0.95 = 4.75\ (V)$$

V_F is the maximum value 1.4 V at I_F = 10 mA and T_a = 25 °C, as per Table 2.1.4. We use this value to find the maximum value of V_F for I_F = 1 mA and in the temperature range 0 to 60 °C. From the I_F - V_F curve on the data sheet, we know that V_F falls by approximately 0.1 V when I_F drops from 10 to 1 mA. V_F also increases in inverse proportion to temperature. The V_F temperature coefficient curve gives a value of -1.1 mV/°C when I_F = 1 mA. Thus when T_a drops from 25 to 0 °C, the change in V_F is given by:

$$\Delta V_F = \Delta V_F/\Delta T_a \times \Delta T_a = -1.1\ (mV/°C) \times (0 - 25)\ (°C) = 27.5\ (mV) \approx 0.03\ (V)$$

And therefore:

$$V_{F(max)} = 1.4\ (V) - 0.1\ (V) + 0.03\ (V) = 1.33\ (V)$$

$V_{OL1(max)}$ is the maximum value of V_{OL} for the relevant logic IC. Here, it is 0.4 V.

Table 2.1.4 Input Forward Voltage of TLP2301

Characteristic	Symbol	Test Condition	Min	Typ.	Max	Unit
Forward voltage	V_F	I_F = 10 mA	1.1	1.25	1.4	V

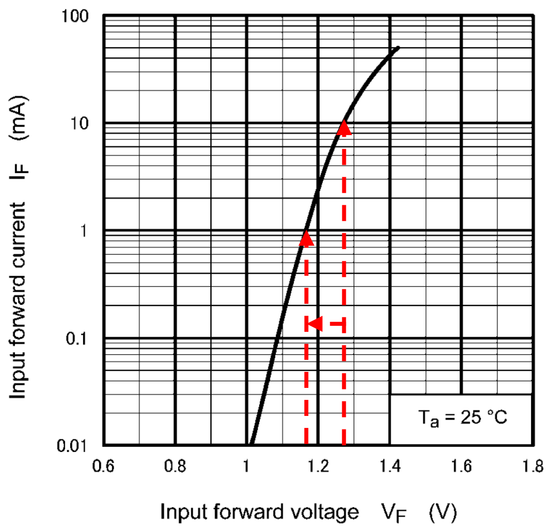


Figure 2.1.6 TLP2301 I_F - V_F

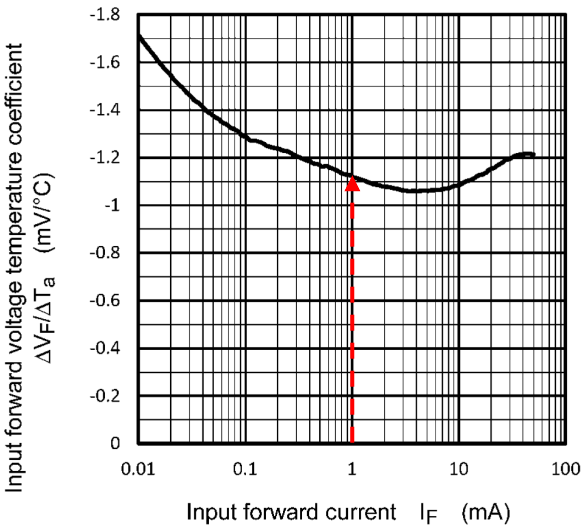


Figure 2.1.7 TLP2301 I_F - $\Delta V_F/\Delta T_a$

We calculate $R_{IN(min)}$ under these conditions as follows:

$$R_{IN(min)} = \frac{V_{CC1} - V_F - V_{OL1}}{I_F}$$

$$= \frac{4.75\ (V) - 1.33\ (V) - 0.4\ (V)}{1\ (mA)}$$

$$= 3.02\ (k\Omega)$$

So an R_{IN} value of 3 kΩ should produce LED input current of 1 mA even in the worst-case scenario. We also calculate for typical and maximum current values as follows.

Typical current:

$V_{CC1(typ.)}$ = 5 V, $V_{F(typ.)}$ = 1.25 V - 0.1 V = 1.15 V, $V_{OL1(typ.)}$ = 0.2 V

so

$$I_{F(typ.)} = \frac{5\ (V) - 1.15\ (V) - 0.2\ (V)}{3\ (k\Omega)} \approx 1.22\ (mA)$$

Maximum current:

$V_{CC1(max)}$ = 5.25 V, $V_{F(min)}$ = 1.1 V - 0.1 V - 0.04 V = 0.96 V, $V_{OL1(min)}$ = 0.1 V

so

$$I_{F(max)} = \frac{5.25\ (V) - 0.96\ (V) - 0.1\ (V)}{3\ (k\Omega)} \approx 1.4\ (mA)$$

We can see how the Min V_F value changes in accordance with temperature characteristics. Change in V_F when Ta increases from 25 to 60 °C is given by:

$$\Delta V_F = \Delta V_F/\Delta T_a \times \Delta T_a = -1.1\ (mV/℃) \times (60 - 25)\ (℃) = -38.5\ (mV) \approx -0.04\ (V)$$

(2) Pull-up resistance R_L

Output voltage V_O should not exceed V_{IL} in the worst-case scenario for I_C.

Assuming that the I_C value in the worst-case scenario is given by minI_C we have:

$$R_L \geqq \frac{V_{CC(max)} - V_{IL}}{minI_C}$$

$$minI_C = I_{C(min)} \times D_{IF} \times D_t \times D_{VCE} \times D_{Ta} \times \alpha$$

where,

V_{IL}: Maximum value of the low level input voltage to subsequent elements (or the required low-level output voltage)

D_{IF}: Rate of change in I_C at the I_F set value corresponding to the data sheet conditions

D_t: Rate of degradation in I_C after a given time

D_{VCE}: Rate of change in I_C under $V_{CE(sat)}$ conditions

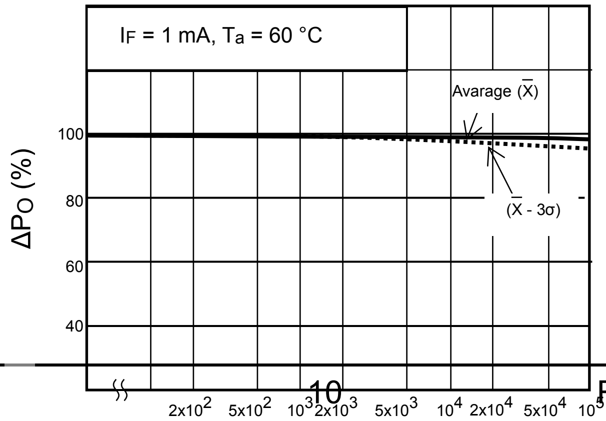
D_{Ta}: Amount of variation in I_C within the operating temperature range

α: Design margin

These values can be found in the data sheet and elsewhere.

$I_{C(min)}$: Choose the TLP2301 GB rank. Since the GB rank produces a minimum CTR of 100 % when I_F = 1 mA and V_{CE} = 5 V, we have $I_{C(min)}$ = 1 mA × 100 % = 1 mA when I_F = 1 mA.

D_t: The rate of change in I_C is directly proportional (1:1) to degradation of LED light output. From the LED light output degradation curve shown in Figure 2.1.8, we see that light output after 44,000 hours (based on a utilization rate of 50 % over 88,000 hours assuming a 10-year service life) is approximately 95 %. With a small margin this becomes 90 %, which yields D_t = 0.9 for the equation.



Test time (h)

Figure 2.1.8 Example of LED Light Power Degradation Curve*

* The graph shows a typical LED light output degradation curve, and should not be construed as actual data for the TLP2301. When designing a circuit incorporating photocoupler components including the TLP2301, consult reliability data individually.

D_{IF}: the rate of change in I_C for the value of I_F based on the conditions specified on the data sheet can be found on the I_C - I_F curve for TLP2301. In this case I_F = 1 mA, so D_{IF} = 1. If I_F = 3 mA, for instance, then from the curve in Figure 2.1.9 we have $I_C(@I_F$ = 1 mA) = 1.8 mA and $I_C(@I_F$ = 3 mA) = 5 mA, so the rate of change is D_{IF} = 5 mA / 1.8 mA ≈ 2.7.

D_{VCE}: the rate of change in I_C for $V_{CE(sat)}$ state is taken from the I_C - V_{CE} curve as per 2.1.1. Here, we use D_{VCE} = 0.95 from 2.1.1.

D_{Ta}: the rate of change of I_C within T_{opr} is found on the I_C-T_a curve. Since I_C is smallest at 0 °C, we have $I_C(@T_a$ = 25 °C) = 1.8 mA and $I_C(@T_a$ = 0 °C) = 1.6 mA, so the rate of change is

$$D_{Ta} = 1.6/1.8 \fallingdotseq 0.88$$

α: the design margin is 20 % here, so α = 0.8.

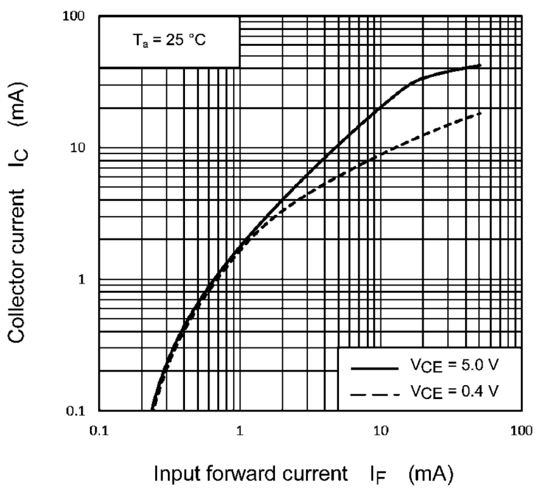


Figure 2.1.9 TLP2301 I_C - I_F

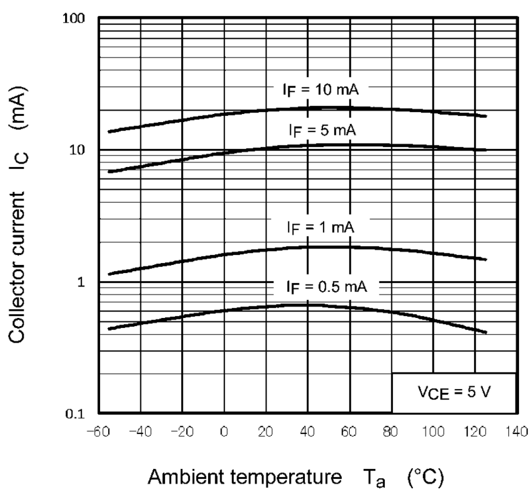


Figure 2.1.10 TLP2301 I_C - T_a

Thus:

$$minI_C = I_{C(min)} \times D_{IF} \times D_t \times D_{VCE} \times D_{Ta} \times \alpha$$

$$= 1\ (mA) \times 1 \times 0.9 \times 0.95 \times 0.88 \times 0.8$$

$$\fallingdotseq 0.6\ (mA)$$

$$R_L \geqq \frac{V_{CC2(max)} - V_{IL}}{minI_C} = \frac{5.25\ (V) - 0.6\ (V)}{0.6\ (mA)}$$

$$\geqq 7.75\ (k\Omega)$$

If R_L is too large this can lead to unacceptable propagation delay t_{pLH} so we use 10 kΩ here.

The final step is to estimate the propagation delay. Based on 10 kbps signal transfer speed, total switching time must satisfy the following expression:

$$T = t_{pHL} + t_{pLH} \leqq 100 \ (\mu s)$$

TLP2301 guarantees a propagation delay of 30 μs (Max). I_F, R_L and V_{CC} are 1 mA, 10 kΩ, and 5 V respectively (the same as the conditions stipulated for the guarantee) so we confirm T_a dependency. The delay is longest when T_a = 60 ˚C.
The graph yields t_{pLH}(@T_a = 25 ˚C) = 16 μs and t_{pLH}(@T_a = 60 ˚C) = 19 μs, so the rate of change is

$$D_{Ta} = \frac{19 \ (\mu s)}{16 \ (\mu s)} \approx 1.19$$

Also we have t_{pHL}(@T_a = 25 ˚C) = 8 μs and t_{pHL}(@T_a = 60 ˚C) = 9 μs, in which case the rate of change is

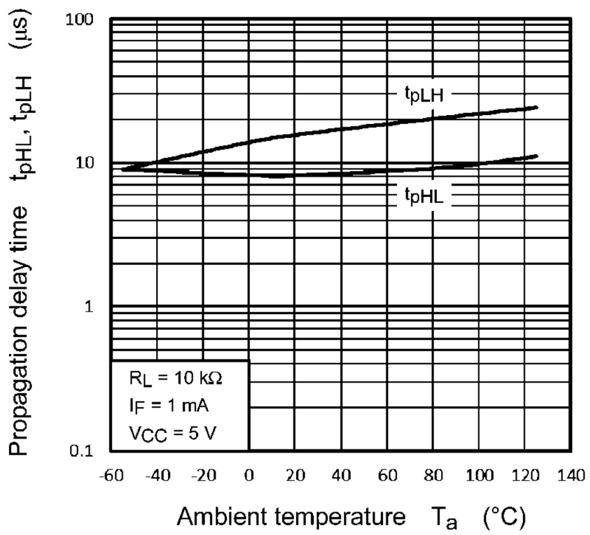
$$D_{Ta} = \frac{9 \ (\mu s)}{8 \ (\mu s)} \approx 1.13$$

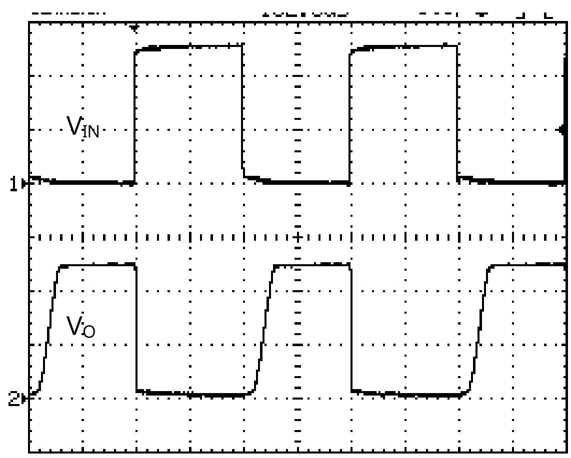
Thus:

$$T = 30 \times 1.19 + 30 \times 1.13 \approx 70 \leq 100 \ (\mu s)$$

This suggests that data transfer is still viable when temperature characteristics are taken into account. Waveform checking indicates successful signal transfer at 10 kbps, as per Figure 2.1.12.

The drive used input power with a logic IC 74VHC00 circuit. Since the TLP2301 drive current was just 1 mA, it should be possible to drive the LED directly from the microcomputer that generates the signal without need for a logic IC, provided that the microcomputer output current rating has sufficient margin to accommodate this.





T_a = 25˚C, V_{IN}: 2V/div, V_O: 2V/div, 50 μs/div

Figure 2.1.11 TLP2301 t_{pHL}, t_{pLH} - T_a

Figure 2.1.12 TLP2301 Switching Waveform

2.2 TLP2309 1 Mbps high-speed coupler

2.2.1 Current Transfer Ratio (CTR) I_O/I_F

The TLP2309 type IC output coupler has an independent photodiode and transistor. Power is connected to the V_{CC} terminal and reverse voltage is applied to the photodiode. Like the transistor output coupler and the mid-range coupler TLP2301, the TLP2309 has a CTR value: this is the ratio between output current I_O and input current I_F (see Table 2.2.1).

Table 2.2.1 Current Transfer Ratio of TLP2309

Characteristics	Symbol	Test Condition	Min	Typ.	Max	Unit
Current transfer ratio	I_O/I_F	I_F = 10 mA, V_O = 0.4 V, V_{CC} = 3.3 V	15	—	—	%
		I_F = 16 mA, V_O = 0.4 V, V_{CC} = 4.5 V	15	—	—	

For a signal transmission circuit as shown in Figure 2.2.1, the R_L design involves calculating the worst-case I_O (min I_O) value, as for the transistor output coupler. Normally, the rate of change in a TLP2309 type IC photocoupler would be guaranteed at a saturation voltage of V_O = 0.4 V, so min I_O is given by the following expression with no D_{VCE} term:

$$minI_O = I_{O(min)} \times D_{IF} \times D_t \times D_{Ta} \times \alpha$$

$$R_L \geqq \frac{V_{CC2(max)} - V_{IL}}{minI_O}$$

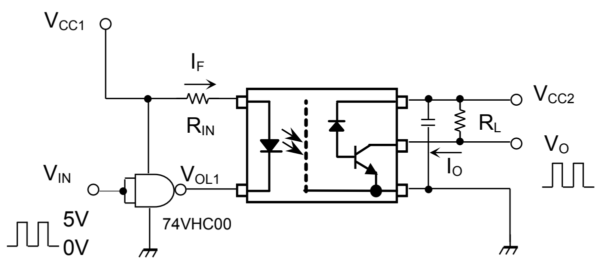


Figure 2.2.1 Example of Signal Transmission Interface using TLP2309

V_{IL}: Maximum value of the low level input voltage to subsequent elements (or the required low-level output voltage)

D_t: Rate of degradation in I_C after a given time

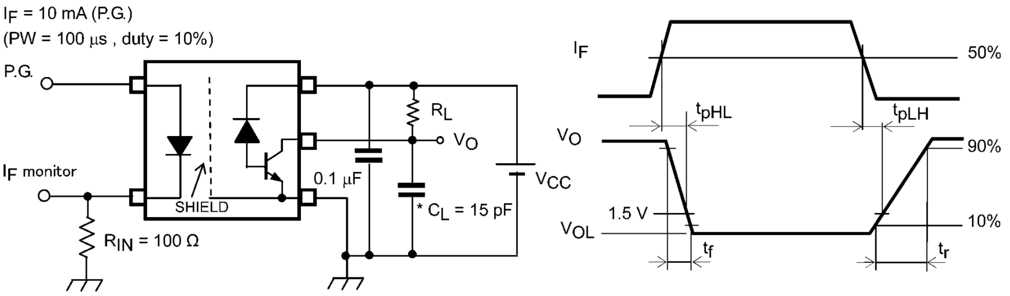
D_{IF}: Rate of change in I_C at the I_F set value corresponding to the data sheet conditions

D_{VCE}: Rate of change in I_C under $V_{CE(sat)}$ conditions

D_{Ta}: Amount of variation in I_C within the operating temperature range
α: Design margin

2.2.2 Switching characteristics

The propagation delay time t_{pHL} (or t_{pLH}) is the time from when the input signal is detected to when the output logic is reversed. "HL" indicates the direction of change in output voltage. Figure 2.2.2 shows the measuring circuit used to evaluate switching characteristics. Normally this is used in the common emitter configuration, so the output signal is reversed relative to the input current. An 0.1 μF bypass capacitor is fitted between V_{CC} and GND to eliminate power supply noise.



P.G. : Pulse generator *C_L includes probe and stray capacitance

Figure 2.2.2 Switching Time Test Circuit of TLP2309

The switching time design needs to take into account the variable conditions I_F, R_L, V_{CC} and T_a. Given that TLP2309 has a guaranteed maximum switching time for ambient temperatures in the range -40°C to 110°C, T_a can be excluded from consideration. And V_{CC} is also guaranteed at the commonly used voltages 3.3 V and 5 V, so one of these should be used, depending on the nature of the application. Figure 2.2.3 shows only a relatively small difference in delay time t_{pLH} between I_F = 10 mA and I_F = 16 mA; however t_{pLH} rises significantly as R_L increases. The design of R_L and maximum delay time should take into consideration the degree of fluctuation in delay time under the set conditions and the conditions stipulateed in the data sheet (R_L = 1.9 kΩ), similar to the R_L setting process described in Section 2.1.3.

Table 2.2.2 Switching Time Characteristics of TLP2309

(Unless otherwise specified, T_a = -40 to 110 °C)

Characteristics	Symbol	Note	Test Circuit	Test Condition	Min	Typ.	Max	Unit
Propagation delay time (H/L)	t_{pHL}		Fig. 12.1.1	I_F = 0→10 mA, R_L = 1.9 kΩ, V_{CC} = 3.3 V, C_L = 15 pF	—	—	1	μs
Propagation delay time (L/H)	t_{pLH}			I_F = 10→0 mA, R_L = 1.9 kΩ, V_{CC} = 3.3 V, C_L = 15 pF	—	—	1	
Propagation delay time (H/L)	t_{pHL}		Fig. 12.1.1	I_F = 0→16 mA, R_L = 1.9 kΩ, V_{CC} = 5 V, C_L = 15 pF	—	—	0.8	
Propagation delay time (L/H)	t_{pLH}			I_F = 16→0 mA, R_L = 1.9 kΩ, V_{CC} = 5 V, C_L = 15 pF	—	—	0.8	

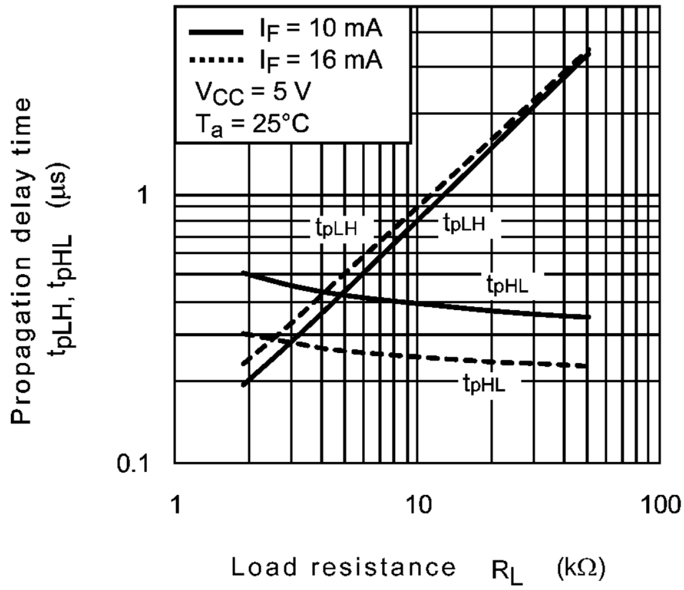


Figure 2.2.3 TLP2309 t_{pHL}, t_{pLH} - R_L

2.2.3 Applied design

The TLP2309 circuit in Figure 2.2.1 is similar to the TLP2301 circuit in Figure 2.1.5 in that the R_{IN} and R_L design uses the same process, as outlined in Section 2.1.3.

2.3 High-speed IC output couplers

This section describes the key electrical characteristics and applied designs for speed-boosted IC output couplers with a high-gain high-speed amplifier circuit after the photodiode.

2.3.1 Threshold input current I_{FLH} and I_{FHL}

An IC output coupler with amplifier circuit inverts the output with a logical action once the input current I_F exceeds a given value. The threshold input current is the value at which the output is inverted, usually denoted I_{FHL} or I_{FLH}. "HL" refers to the direction of change of output voltage in the presence of LED input current. For inverter output products such as the TLP2366, we use I_{FHL}, as shown in Table 2.3.1, since the output voltage changes from high level to low level in the presence of LED input current. Most IC output couplers guarantee the threshold input current within the operating temperature range; for the TLP2366 this is T_a = -40 °C – 125 °C.

Figure 2.3.1 shows the V_O - I_F curve for the TLP2366. The TLP2366 in standard configuration inverts output at I_F = 0.9 mA, with a maximum value of I_{FHL} = 3.5 mA. In other words, I_{FHL} may vary according to the product and temperature but will not exceed 3.5 mA, so in actual usage, I_F must be capable of operating at 3.5 mA or more.

Figure 2.3.2 shows how pull-up resistance affects the threshold input current for the open collector output product TLP2368. Pull-up resistance is used on open collector output products as a means of controlling the propagation delay and load current. A high pull-up resistance will reduce the threshold input current, albeit only very slightly, but can extend the propagation delay substantially, so in applications where speed is important, the resistance should be as small as possible.

Table 2.3.1 Threshold Input Current of Inverter Logic Type TLP2366

(Unless otherwise specified, T_a = -40 to 125 °C, V_{CC} = 2.7 to 5.5 V)

Characteristics	Symbol	Test Circuit	Test Condition	Min	Typ.	Max	Unit
Low-level supply current	I_{CCL}	Fig. 12.1.3	I_F = 14 mA	—	1.6	3	mA
High-level supply current	I_{CCH}	Fig. 12.1.4	I_F = 0 mA	—	1.5	3	
Threshold input current (H/L)	I_{FHL}	—	I_O = 1.6 mA, V_O < 0.4 V	—	0.9	3.5	

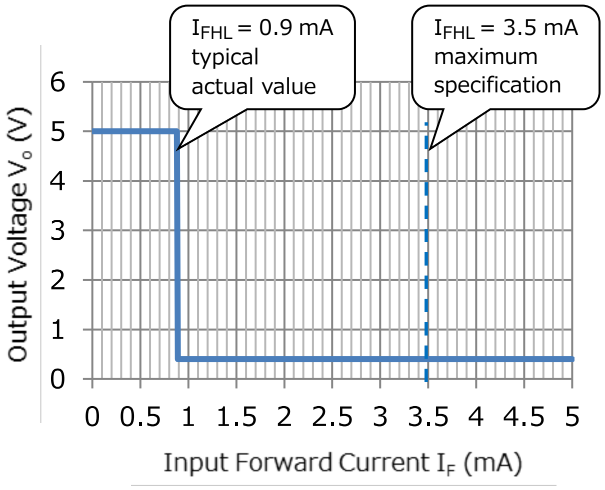


Figure 2.3.1 TLP2366 V_O - I_F Waveform and I_{FHL} specification

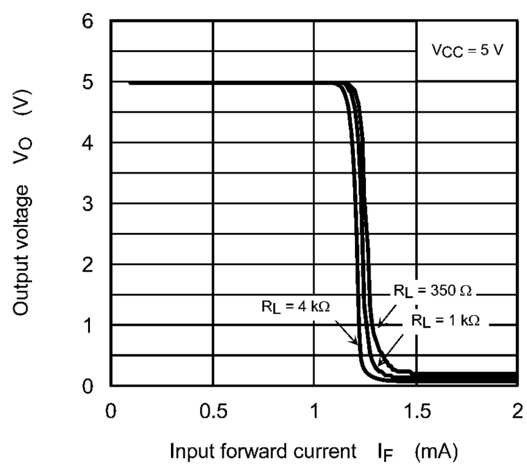


Figure 2.3.2 TLP2368 V_O - I_F Waveform R_L Dependency

2.3.2 Threshold input voltage V_{FLH}, V_{FHL} and $V_{F(OFF)}$

The TLP2366 output drops from high level to low level when the input current exceeds 3.5 mA. The current limit resistance on the LED side I_{FHL} is used to design the optimum current, taking into account LED output degradation and the design margin. To restore output from low to high level again, the LED input current must be at low level corresponding to the threshold input voltage V_{FLH}, V_{FHL} or input off-state voltage $V_{F(OFF)}$.The input off-state voltage $V_{F(OFF)}$ for the TLP2366 is 0.8 V (Max). Thus, if the voltages at both ends of the LED are 0.8 V or less, the LED input current will be at low level while the output will flip from low to high level.

2.3.3 Switching characteristics

The propagation delay times t_{pHL} and t_{pLH} represent the time from when the input signal is detected to when the output logic is reversed. "HL" indicates the direction of change of output voltage.

Pulse width distortion $|t_{pHL} - t_{pLH}|$ is an absolute value that represents the differential between t_{pHL} and t_{pLH} for a given product. This is a useful indicator of the level of distortion in the transmission waveform. The TLP2366 guarantees maximum pulse width distortion of 30 ns. If there were no such guarantee, then in an extreme case you could have t_{pHL} = 55 ns and t_{pLH} = 5 ns, in which case the output pulse width would be 150 ns for an input pulse width of 200 ns, resulting in distortion of 50 ns. Since the TLP2366 guarantees maximum pulse width distortion of 30 ns, the output pulse width will never be shorter than 170 ns, as shown in Figure 2.3.3. For more accurate pulse signal transmission, choose a product that guarantees the maximum variance in propagation delay time.

Table 2.3.2 Switching Time Characteristics of TLP2366

(Unless otherwise specified, T_a = -40 to 125 °C, V_{CC} = 2.7 to 5.5 V)

Characteristics	Symbol	Note	Test Circuit	Test Condition	Min	Typ.	Max	Unit
Propagation delay time (H/L)	t_{pHL}	(Note 1)	Fig. 12.1.5	I_F = 0→6 mA, R_{IN} = 100 Ω, C_L = 15 pF	—	36	55	ns
Propagation delay time (L/H)	t_{pLH}	(Note 1)		I_F = 6→0 mA, R_{IN} = 100 Ω, C_L = 15 pF	—	27	55	
Pulse width distortion	$\|t_{pHL}-t_{pLH}\|$	(Note 1)		I_F = 6 mA, R_{IN} = 100 Ω, C_L = 15 pF	—	9	30	
Propagation delay skew (device to device)	t_{psk}	(Note 1), (Note 2)			-30	—	30	

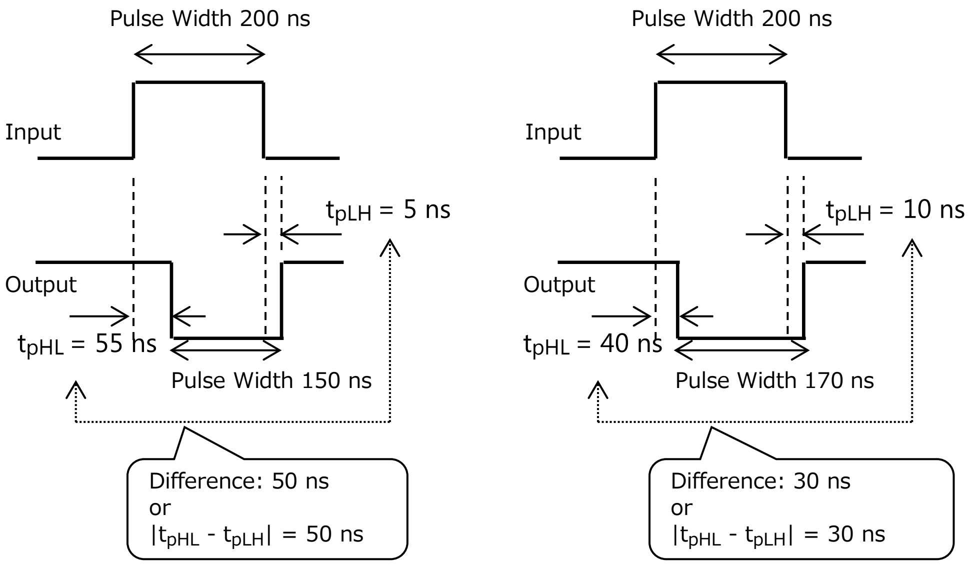


Table 2.3.3 Propagation Delay Time Distortion

Propagation delay skew is the maximum difference between t_{pHL} or t_{pLH} values for differing products. Figure 2.3.4 shows waveforms for multiple products ;t_{pHL} in the upper half and t_{pLH} in the lower half. The difference between the Min value of t_{pHL} and the maximum value of t_{pLH} in Figure 2.3.4 is the propagation delay skew, denoted t_{psk}. For parallel data transmission, data signal must be switched on or off in conjunction with clock signal when reading the clock signal, so the transmission rate should allow a margin for variation in photocoupler delay times for multiple products. In addition to pulse width distortion, t_{psk} should be as low as possible to maximize the speed of parallel transmission.

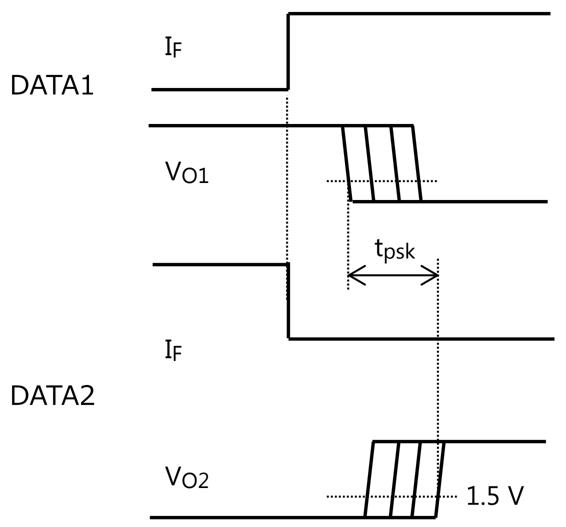


Figure 2.3.4 Propagation Delay Skew, t_{psk}

2.3.4 Typical applied design

Figure 2.3.5 is the circuit diagram used for R_{IN} and R_L design for signal transmission using TLP2368. If the product has a threshold input current, I_F and R_{IN} should be designed to ensure that the LED input current is greater than or equal to the maximum threshold input current. An 0.1 μF bypass capacitor is also required between the V_{CC} and GND terminals on the photocoupler output side. IC output couplers with built-in amplifier circuit are particularly susceptible to internal oscillation phenomena such as V_{CC} voltage transient due to load switching as well as power supply noise. For best results, the bypass capacitor should be placed within 1 cm of the pins.

Example of Design Specifications

Operating temperature T_{opr} : 0 to 85 °C
Data transmission rate : 10 Mbps
Supply voltage : V_{CC} = 5 V±5 %
Operating life : 10 years (88 kh)
Signal Duty : 50 %

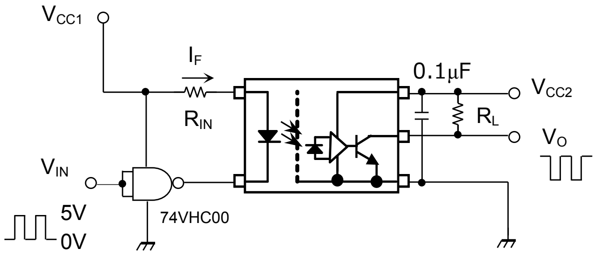


Figure 2.3.5 Example of Signal Transmission Interface using TLP2368

(1) $I_{FHL(max)}$

First, we calculate the maximum value of the threshold input current of the product as follows.

$$I_{FHL(max)} = I_{FHL} \times D_{ta} \times D_t \times \alpha$$

Where,

I_{FHL}: Guaranteed maximum value of threshold input current as per data sheet

D_{ta}: Rate of temperature dependency increase for threshold input current
(not relevant if I_{FHL} is guaranteed for the entire operating temperature range)

D_t: Rate of degradation in I_{FHL} after a given time

α: design margin

For TLP2368, the maximum value of I_{FHL} within the ambient temperature range T_a = -40 to 125 °C is 5 mA. This means that there is no need to include D_{ta} (temperature dependency) in the calculation. So we calculate Dt (rate of degradation after a given time). I_{FHL} is inversely proportion to LED light output degradation in a 1:1 ratio. From the light output degradation curve in Figure 2.3.6, we know that light output after 44,000 hours (based on a utilization rate of 50 % over 88,000 hours and assuming a 10-year service life) is approximately 85 %. With the design margin, this becomes 80 %, the inverse of which gives us D_t = 1.25.

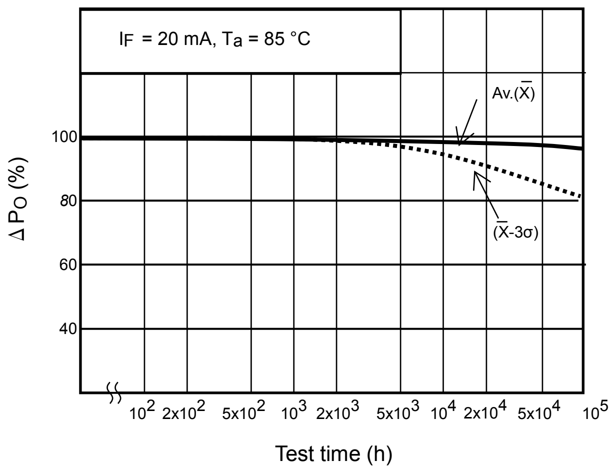


Figure 2.3.6 Example of LED Light Power Degradation Curve*

* The graph shows a typical LED light output degradation curve, and should not be construed as actual data for the TLP2368. When designing a circuit incorporating photocoupler components including the TLP2368, consult reliability data individually.

Adding in the 20 % design margin α, we find $I_{FHL(max)}$ as follows:

$$I_{FHL(max)} = I_{FHL} \times D_{ta} \times D_t \times \alpha$$
$$= 5 \ (mA) \times 1 \times 1.25 \times 1.2$$
$$= 7.5 \ (mA)$$

(2) R_{IN}

Now we calculate R_{IN}. R_{IN} using the following expression.

$$R_{IN(min)} = \frac{V_{CC1} - V_F - V_{OL1}}{I_{FHL(max)}}$$

R_{IN} is lowest at $V_{CC1(min)}$, $V_{F(max)}$ and $V_{OL1(max)}$, so we must find these values.
V_{CC1} is 5V±5 %, so

$$V_{CC1(min)} = 5 \ (V) \times 0.95 = 4.75 \ (V)$$

V_F has a maximum value of 1.7 V when I_F = 10 mA and T_a = 25 °C, as shown in Table 2.3.3. Based on the temperature dependence characteristics shown on the I_F - V_F curve on the data sheet, we can see that a drop in ambient temperature T_a from 25 to 0 °C would cause a voltage increase of around 0.05 V. Thus:

$$V_{F(max)} = 1.7 \ (V) + 0.05 \ (V) = 1.75 \ (V)$$

$V_{OL1(max)}$ is the maximum value of V_{OL} for the relevant logic IC; in this case, 0.4 V.

Table 2.3.3 V_F characteristics for TLP2368

Characteristics	Symbol	Note	Test Circuit	Test Condition	Min	Typ.	Max	Unit
Input forward voltage	V_F		—	I_F = 10 mA, T_a = 25 °C	1.45	1.55	1.7	V

We calculate $R_{IN(min)}$ under these conditions as follows:

$$R_{IN(min)} = \frac{V_{CC1} - V_F - V_{OL1}}{I_{FHL(max)}}$$
$$= \frac{4.75 \ (V) - 1.75 \ (V) - 0.4 \ (V)}{7.5 \ (mA)}$$
$$\approx 0.346 \ (k\Omega) \approx 330 \ (\Omega)$$

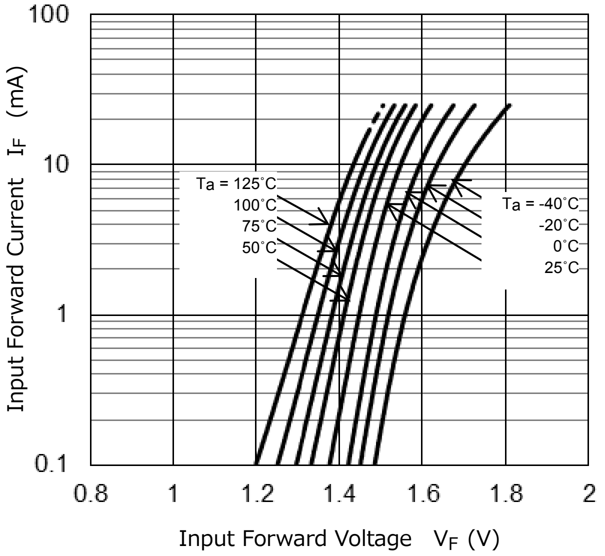


Figure 2.3.7 TLP2368 I_F - V_F

When R_{IN} = 330 Ω, the current will be 7.5 mA even at the minimum LED input current. Now we check the standard and maximum current values. For the standard current, when $V_{CC1(typ.)}$ = 5 V, $V_{F(typ.)}$ = 1.55 V and $V_{OL(typ.)}$ = 0.2 V, we have:

$$I_{F(typ.)} = \frac{5\ (V) - 1.55\ (V) - 0.2\ (V)}{330\ (\Omega)} \approx 9.85\ (mA)$$

For the maximum current, when $V_{CC1(max)}$ = 5.25 V, $V_{F(min)}$ = 1.45 V - 0.1 V = 1.35 V and $V_{OL(min)}$ = 0.1 V, we have:

$$I_{F(max)} = \frac{5.25\ (V) - 1.35\ (V) - 0.1\ (V)}{330\ (\Omega)} \approx 11.5\ (mA)$$

For the minimum value of V_F, the I_F - V_F curve tells us the amount of variation due to temperature dependence. When the ambient temperature increases from 25 °C to 85 °C there is a drop of approximately 0.1 V. Thus:

$$V_{F(min)} = 1.45\ (V) - 0.1\ (V) = 1.35\ (V)$$

(3) Pull-up resistance R_L

Pull-up resistance R_L should not exceed the maximum rated value of the output current I_O. Normal practice is to keep R_L to less than or equal to the maximum value of the low-level input voltage of subsequent elements V_{IL}, or alternatively below the required low-level voltage. R_L is given by the following expression. For TLP2368, where I_O = 13 mA, R_L must be less than I_O. Thus:

$$R_L > \frac{V_{CC2} - V_{IL}}{I_O} = \frac{5\ (V) - 0.6\ (V)}{13\ (mA)}$$

$$> 338\ (\Omega)$$

Thus, an R_L value of at least 338 Ω is required. A larger R_L reduces power consumption but also tends to exacerbate propagation delays. Figure 2.3.8 shows the correlation between R_L and propagation delay time (t_{pHL} and t_{pLH}). In light of the signal transmission speed (10 Mbps), it is best to avoid an excessively large resistance value. R_L = 510 Ω is considered appropriate. To finish up, we investigate the switching waveform under the given conditions. Figure 2.3.9 demonstrates that 10 Mbps signal transmission is indeed viable.

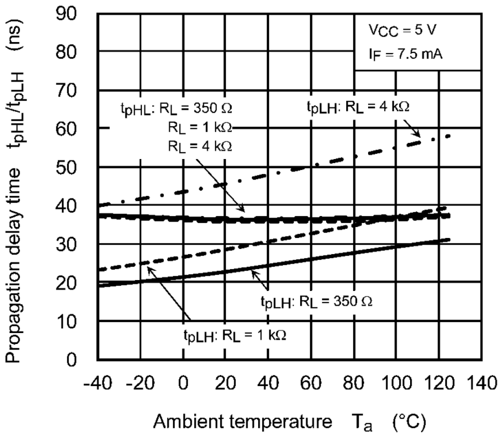
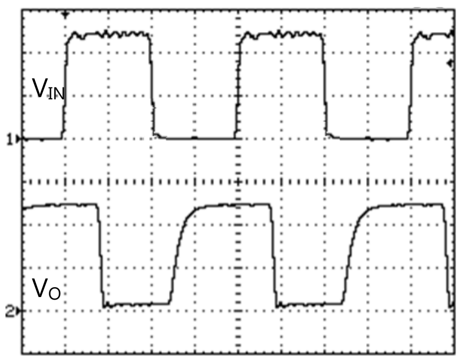


Figure 2.3.8 TLP2368 t_{pHL}, t_{pLH} - T_a



T_a = 25 ˚C, V_{IN}: 2V/div, V_O: 2V/div, 50 ns/div
R_{IN} = 330 Ω, R_L = 510 Ω

Figure 2.3.9 Switching Waveform

Note: The graphs show statistics for a representative sample of the devices discussed in this document and should not be construed as a guarantee of performance.

2.3.5 Sample application: programmable logic controller (PLC)

The PLC is a sequence controller that is normally isolated by means of a photocoupler on the signal input or output side. The PLC input circuit typically receives sensor signal or encoder pulse signal. A transistor output coupler is normally used for low-speed signal transmission, and a high-speed coupler is used for high-speed signal transmission. Sink devices and/or source devices are connected to the input circuit as per Figure 2.3.10. A bridge diode or AC input type (sink/source input type) photocoupler will be used in cases where compatibility with both forms of input signal is required. Figure 2.3.11 shows typical circuits using a bridge diode and using the TLP2391 high-speed (10 Mbps) coupler designed for both high-speed sink and source devices. The TLP2391 does not need a bridge diode and since it has totem pole output, does not require pull-up resistance R_L either. This helps to reduce the number of components in the circuit.

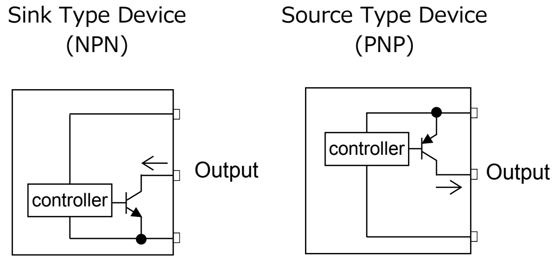
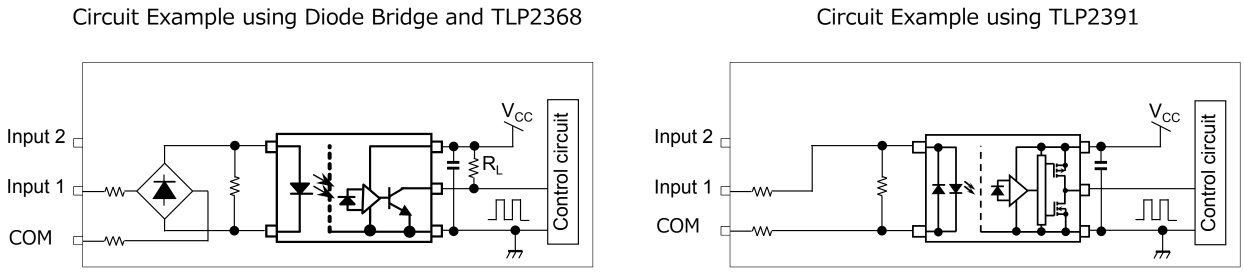


Figure 2.3.10 Sink Type Device and Source Type Device



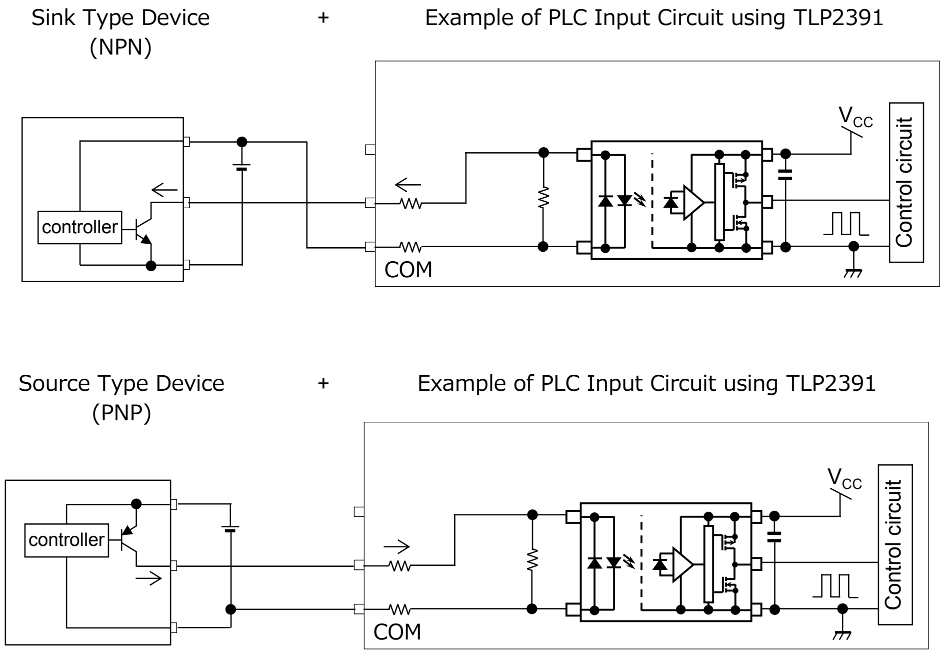


Figure 2.3.11 Connection Example for PLC and Sink Type Device, or Source Type Device

< Column> Power consumption and magnetic coupling isolator

Power consumption of communication photocouplers is the sum of power consumption on both the LED side and the light detecting side. Power consumption with no output load is given by the following expression:

$$P_{TTL} = P_I + P_O$$

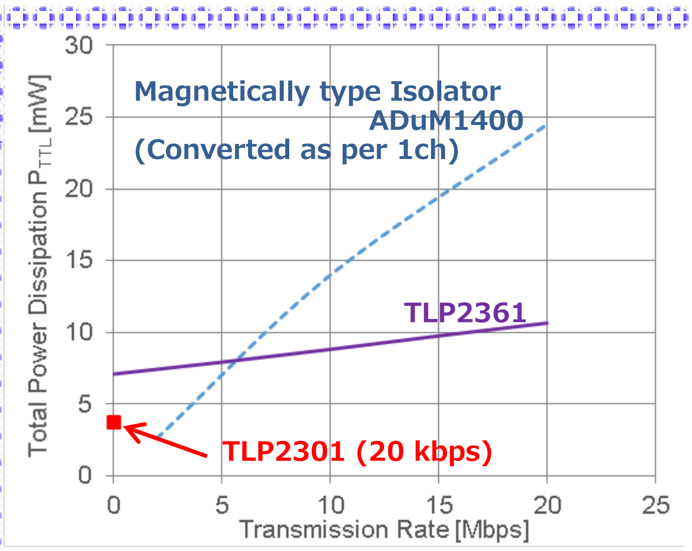
$$P_I = V_F \times I_F \times duty$$

$$P_O = I_{CC} \times V_{CC} + f_{IN} \times C_{PD} \times {V_{CC}}^2$$

where,
P_I: Power consumption on input side
P_O: Power consumption on output side
f_{IN}: Input frequency
C_{PD}: Equivalent internal capacity within IC

$I_{CC} \times V_{CC}$ denotes static power consumption, with output fixed at a high or low level. $f_{IN} \times C_{PD} \times {V_{CC}}^2$ denotes dynamic power consumption, which extends to charging the capacity of MOSFET and Tr elements in the light detecting IC circuit.

In recent years, optically coupled isolators have been joined by magnetically coupled isolators and capacity coupled isolators. However, these newer types tend to have higher power consumption needs, particularly for high-speed transmission. Figure 2.3.12 compares power consumption figures (P_{TTL}) for the TLP2361 totem pole output high-speed coupler and a magnetically coupled isolator. Above 5 Mbps, the magnetically coupled isolator uses more power than a photocoupler; at 20 Mbps it is using double the power of the TLP2361. In applications with multiple communication interfaces (such as PLC) this is a substantial difference. In terms of photocouplers, the TLP2301 and TLP2303 use minimal power at mid-range speeds (20 kbps and 100 kbps respectively). So it is important to choose a product with the lowest possible power consumption relative to the transmission speed.



Conditions

f_{IN} = 0 to 20 Mbps (0 to 10 MHz), T_a = 25 ˚C

TLP2361:

Input: V_{DD1} = 5 V, I_F = 1.6 mA, duty = 50 %

Output: V_{DD2} = 5 V , no output load

Magnetically coupled isolator ADuM1400

(Converted to 1ch equivalent)

Input: V_{DD1} = 5 V

Output: V_{DD2} = 5 V, no output load

Figure 2.3.12 Transmission Rate and Total Power Dissipation

From the above, input power consumption for a standard photocoupler is given by:

$P_I = V_F \times I_F \times duty$

For this calculation, we are comparing the input circuit power consumption of a standard photocoupler and a magnetically coupled isolator under identical conditions. Thus:

$P_I = V_{CC} \times I_F \times duty$

For TLP2301
Input power V_{CC1} = 5 V, I_F = 1.0 mA
Output power V_{CC2} = 5 V, I_C = 0.5 mA (current consumption for high level; at high level we can safely ignore I_{DARK} = 0.01 μA (typ.))

$$P_I = V_F \times I_F \times duty = 5\ (V) \times 1.0\ (mA) \times 0.5 = 2.5\ (mW)$$

$$P_O = V_{CC} \times I_C \times duty = 5\ (V) \times 0.5\ (mA) \times 0.5 = 1.25\ (mW)$$

$$P_{TTL} = 2.5 + 1.25 = 3.75\ (mW)$$

3. Terms

(General terms)

Term	Symbol	Description
Absolute Maximum Rating		Maximum value that must not be exceeded even for an instant during operation
Isolation Voltage	BV_S	Isolating voltage between input and output under the specified conditions
Capacitance (Input to Output), Total Capacitance (Input to Output)	C_S	Electrostatic capacitance between the input and output pins
Capacitance (Input), Input Capacitance	C_T C_t	Electrostatic capacitance between the anode and cathode pins of the LED
Forward Current, Input Forward Current	I_F	Rated current that can flow continuously in the forward direction of the LED
Pulse Forward Current, Input Forward Current (Pulsed)	I_{FP}	Rated current that can flow momentarily in the forward direction of the LED
Peak Transient Forward Current	I_{FPT}	Rated current that can flow momentarily in the forward direction of the LED
Reverse Voltage, Input Reverse Voltage	V_R	Rated reverse voltage that can be applied across the LED's cathode and anode
Reverse Current, Input Reverse Current	I_R	Leakage current flowing in the reverse direction of the LED (from cathode to anode)
Forward Voltage, Input Forward Voltage	V_F	Voltage drop across the anode and cathode pins of the LED under the specified forward-current condition
LED Power Dissipaiton, Input Power Dissipaiton	P_D	Rated power that can be dissipated in the LED
Total Power Dissipaiton	P_T	Total rated power that can be dissipated in both the input and output devices
Isolation Resistance	R_S	Resistance between the input and output pins at the specified voltage
Junction Temperature	T_j	Permissible temperature of the junction of the photodetector or LED
Operating Temperature	T_{opr}	Ambient temperature range in which the device can operate without loss of functionality
Lead Soldering Temperature	T_{sol}	Rated temperature at which the device pins can be soldered without loss of functionality
Storage Temperature	T_{stg}	Ambient temperature range in which the device can be stored without operation
Creepage Distance		Shortest distance along the surface of insulation between the path of two conductive parts (input and output)
Clearance(Clearance Distance)		Shortest distance through air between the path of two conductive parts (input and output)
Internal Isolation Thickness, Insulation Thickness		Distance through insulation. Shortest thickness through internal insulation between the path of two conductive parts (input and output)

(Transistor output)

Term	Symbol	Description
Collector Current	I_C	Rated current allowed to flow to collector
Current Transfer Ratio	I_C/I_F (CTR)	Ratio of output current, I_C, to input current, I_F: $I_C/I_F \times 100$ (unit: %)
Collector Dark Current, Dark Current	I_{CEO} I_{DARK}	Leakage current flowing between collector and emitter
OFF-state Collector Curreent	$I_{C(off)}$	Leakage current flowing between collector and emitter when Low voltage is applied to input
Current Gain Factor	h_{FE}	h_{FE} for phototransistor
Base Photo-Current	I_{PB}	Photo-current generated by the specified input current, I_F, in the phototransistor base block
Collector Power Dissipation	P_C	Rated power that can be dissipated in collector
Turn-On Time	t_{ON} t_{on}	Time required for the output waveform to change from 100% (0%) to 10% (90%) when the input is turned off and back on under the specified conditions
Turn-Off Time	t_{OFF} t_{off}	Time required for the output waveform to change from 0% (100%) to 90% (10%) when the input is turned on and back off under the specified conditions
Storage Time	t_S	Time required for the output waveform to change from 0% (100%) to 10% (90%) when input is turned on and back off under the specified conditions
Fall Time	t_f	Time required for the output waveform to change from 90% to 10%
Rise Time	t_r	Time required for the output waveform to change from 10% to 90%
Collector-Emitter Saturation Voltage	$V_{CE(sat)}$	Voltage between collector and emitter under the specified saturation conditions
Collector-Base Breakdown Voltage	$V_{(BR)CBO}$	Breakdown voltage between collector and base when emitter is open
Collector-Emitter Breakdown Voltage	$V_{(BR)CEO}$	Breakdown voltage between collector and emitter (when base is open)
Emitter-Base Breakdown Voltage	$V_{(BR)EBO}$	Breakdown voltage between emitter and base when collector is open
Emitter-Collector Breakdown Voltage	$V_{(BR)ECO}$	Breakdown voltage between emitter and collector (when base is open)
Collector-Base Voltage	V_{CBO}	Rated voltage that can be applied across collector and base
Collector-Emitter Voltage	V_{CEO}	Rated voltage that can be applied across collector and emitter
Emitter-Base Voltage	V_{EBO}	Rated voltage that can be applied across emitter and base
Emitter-Collector Voltage	V_{ECO}	Rated voltage which can be applied across emitter and collector
Capacitance (Collector to Emitter), Collector-Emitter Capacitance	C_{CE}	Electrostatic capacitance between the collector and emitter pins

(IC output)

Term	Symbol	Description
Common-Mode Transient Immunity at Output High	CM_H	Maximum tolerable rate of rise (fall) of input/output common-mode voltage at which the specified High level can be maintained
Common-Mode Transient Immunity at Output Low	CM_L	Maximum tolerable rate of rise (fall) of input/output common-mode voltage at which the specified Low level can be maintained
High-Level Supply Current	I_{CCH} I_{DDH}	Current supply to the circuit that flows to power supply pins when the output is at the High level
Low-Level Supply Current	I_{CCL} I_{DDL}	Current supply to the circuit that flows to power supply pins when the output is at the Low level
Threshold Input Current	I_{FHL} (I_{FLH})	Minimum input current, I_F, necessary to change the output from High (Low) to Low (High) (*1)
Input Current Hysteresis	I_{HYS}	Difference between I_{FLH} and I_{FHL} for a given device
Threshold Input Voltage	V_{FLH} (V_{FHL})	Maximum input voltage, V_F, necessary to hold the initial output High (Low), or to return the output from Low (High) to High (Low) after the initial output changes from High (Low) to Low (High)
Current Transfer Ratio	I_O/I_F	Ratio of output current, I_O, to input current, I_F: $I_O/I_F \times 100$ (unit: %)
High-Level Output Current	I_{OH}	Output current under the specified High-level output voltage
Peak High-Level Output Current	I_{OPH}	Peak output current under the specified High-level output voltage
Low-Level Output Current	I_{OL}	Output current under the specified Low-level output voltage
Peak Low-Level Output Current	I_{OPL}	Peak output current under the specified Low-level output voltage
High-Level ShortCircuit Output Current	I_{OSH}	Output current under the specified High-level output and short-circuit conditions
Low-Level Short-Circuit Output Current	I_{OSL}	Output current under the specified Low-level output and short-circuit conditions
High-Level Output Voltage	V_{OH}	Output voltage under the specified High-level output current condition
Low-Level Output Voltage	V_{OL}	Output voltage under the specified Low-level output current condition
Output Power Dissipation	P_O	Rated power that can be dissipated in the output stage
Propagation Delay Time (H → L)	t_{PHL}	Time required from when the input changes from the OFF (ON) stateto the ON (OFF) state to when the output waveform changes fromthe High level to specified Low level
Propagation Delay Time (L → H)	t_{PLH}	Time required from when the input changes from the ON (OFF) stateto the OFF (ON) state to when the output waveform changes fromthe Low level to the specified High level
Output Current	I_O	Rated current that can flow to output pins
Peak Output Current	I_{OP}	Rated peak current that can be applied between output pins
Supply Voltage	V_{CC} V_{DD}	Rated voltage that can be applied to power supply pins
Output Voltage	V_O	Rated voltage that can be applied to output pins
UVLO Threshold Voltage	V_{UVLO}	Threshold voltage at which the undervoltage lockout (UVLO) function is tripped
Three-State Enable Voltage	V_E	Rated voltage that can be applied to the enable pin
High-Level Enable Voltage	V_{EH}	Voltage at which the enable pin functions as the High level
Low-Level Enable Voltage	V_{EL}	Voltage at which the enable pin functions as the Low level

(*1) I_F greater than the maximum I_{FHL} (I_{FLH}) is required to ensure that the IC output transitions from High (Low) to Low (High).

Revision history

Version	Date	Page reference	Details
Rev. 1.0	2018-04-06	-	Created
Rev. 2.0	2019-11-14	-	Revised

RESTRICTIONS ON PRODUCT USE

Toshiba Corporation and its subsidiaries and affiliates are collectively referred to as "TOSHIBA".
Hardware, software and systems described in this document are collectively referred to as "Product".

- TOSHIBA reserves the right to make changes to the information in this document and related Product without notice.
- This document and any information herein may not be reproduced without prior written permission from TOSHIBA. Even with TOSHIBA's written permission, reproduction is permissible only if reproduction is without alteration/omission.
- Though TOSHIBA works continually to improve Product's quality and reliability, Product can malfunction or fail. Customers are responsible for complying with safety standards and for providing adequate designs and safeguards for their hardware, software and systems which minimize risk and avoid situations in which a malfunction or failure of Product could cause loss of human life, bodily injury or damage to property, including data loss or corruption. Before customers use the Product, create designs including the Product, or incorporate the Product into their own applications, customers must also refer to and comply with (a) the latest versions of all relevant TOSHIBA information, including without limitation, this document, the specifications, the data sheets and application notes for Product and the precautions and conditions set forth in the "TOSHIBA Semiconductor Reliability Handbook" and (b) the instructions for the application with which the Product will be used with or for. Customers are solely responsible for all aspects of their own product design or applications, including but not limited to (a) determining the appropriateness of the use of this Product in such design or applications; (b) evaluating and determining the applicability of any information contained in this document, or in charts, diagrams, programs, algorithms, sample application circuits, or any other referenced documents; and (c) validating all operating parameters for such designs and applications. **TOSHIBA ASSUMES NO LIABILITY FOR CUSTOMERS' PRODUCT DESIGN OR APPLICATIONS.**
- PRODUCT IS NEITHER INTENDED NOR WARRANTED FOR USE IN EQUIPMENTS OR SYSTEMS THAT REQUIRE EXTRAORDINARILY HIGH LEVELS OF QUALITY AND/OR RELIABILITY, AND/OR A MALFUNCTION OR FAILURE OF WHICH MAY CAUSE LOSS OF HUMAN LIFE, BODILY INJURY, SERIOUS PROPERTY DAMAGE AND/OR SERIOUS PUBLIC IMPACT ("UNINTENDED USE"). Except for specific applications as expressly stated in this document, Unintended Use includes, without limitation, equipment used in nuclear facilities, equipment used in the aerospace industry, lifesaving and/or life supporting medical equipment, equipment used for automobiles, trains, ships and other transportation, traffic signaling equipment, equipment used to control combustions or explosions, safety devices, elevators and escalators, and devices related to power plant. IF YOU USE PRODUCT FOR UNINTENDED USE, TOSHIBA ASSUMES NO LIABILITY FOR PRODUCT. For details, please contact your TOSHIBA sales representative or contact us via our website.
- Do not disassemble, analyze, reverse-engineer, alter, modify, translate or copy Product, whether in whole or in part.
- Product shall not be used for or incorporated into any products or systems whose manufacture, use, or sale is prohibited under any applicable laws or regulations.
- The information contained herein is presented only as guidance for Product use. No responsibility is assumed by TOSHIBA for any infringement of patents or any other intellectual property rights of third parties that may result from the use of Product. No license to any intellectual property right is granted by this document, whether express or implied, by estoppel or otherwise.
- **ABSENT A WRITTEN SIGNED AGREEMENT, EXCEPT AS PROVIDED IN THE RELEVANT TERMS AND CONDITIONS OF SALE FOR PRODUCT, AND TO THE MAXIMUM EXTENT ALLOWABLE BY LAW, TOSHIBA (1) ASSUMES NO LIABILITY WHATSOEVER, INCLUDING WITHOUT LIMITATION, INDIRECT, CONSEQUENTIAL, SPECIAL, OR INCIDENTAL DAMAGES OR LOSS, INCLUDING WITHOUT LIMITATION, LOSS OF PROFITS, LOSS OF OPPORTUNITIES, BUSINESS INTERRUPTION AND LOSS OF DATA, AND (2) DISCLAIMS ANY AND ALL EXPRESS OR IMPLIED WARRANTIES AND CONDITIONS RELATED TO SALE, USE OF PRODUCT, OR INFORMATION, INCLUDING WARRANTIES OR CONDITIONS OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE, ACCURACY OF INFORMATION, OR NONINFRINGEMENT.**
- GaAs (Gallium Arsenide) is used in Product. GaAs is harmful to humans if consumed or absorbed, whether in the form of dust or vapor. Handle with care and do not break, cut, crush, grind, dissolve chemically or otherwise expose GaAs in Product.
- Do not use or otherwise make available Product or related software or technology for any military purposes, including without limitation, for the design, development, use, stockpiling or manufacturing of nuclear, chemical, or biological weapons or missile technology products (mass destruction weapons). Product and related software and technology may be controlled under the applicable export laws and regulations including, without limitation, the Japanese Foreign Exchange and Foreign Trade Law and the U.S. Export Administration Regulations. Export and re-export of Product or related software or technology are strictly prohibited except in compliance with all applicable export laws and regulations.
- Please contact your TOSHIBA sales representative for details as to environmental matters such as the RoHS compatibility of Product. Please use Product in compliance with all applicable laws and regulations that regulate the inclusion or use of controlled substances, including without limitation, the EU RoHS Directive. **TOSHIBA ASSUMES NO LIABILITY FOR DAMAGES OR LOSSES OCCURRING AS A RESULT OF NONCOMPLIANCE WITH APPLICABLE LAWS AND REGULATIONS.**

Toshiba Electronic Devices & Storage Corporation

https://toshiba.semicon-storage.com/