Basic Electrical Characteristics and Application Designs of Low-I_F Photocouplers

Outline:

This application note discusses the electrical characteristics of low-I_F photocouplers as well as the considerations for application designs to obtain the best characteristics from these photocouplers.

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1. Candidates of photocouplers to be used

Typically, photocouplers consist of a light-emitting device optically coupled with a light-detecting device via a transparent galvanic insulator. They are commonly used to transfer electrical signals between two circuits with different ground potentials by means of light. Photocouplers have been commonly used because they help solve an impedance mismatch problem, increase the electrical isolation between input and output, suppress induced electromotive force, and simplify noise blocking. Use of photocouplers is also expanding to applications requiring a reduction in board mounting areas and an improvement in reliability to eliminate the need for maintenance.

Designers of industrial electronic systems sometimes face various issues concerning transmission lines. For example, if an offset voltage occurs because of a ground loop, unwanted ground loop current flows through different systems and can potentially damage them. To avoid this problem, system designers often use photocouplers to transfer electric signals across short distances.

There is growing demand for reducing the power consumption of electronic devices. In line with this trend, there is market demand for general-purpose transistor-output photocouplers with low input forward current (I_F) to realize low-power control. To meet this demand, Toshiba is expanding its portfolio of transistor-output photocouplers that are used to transfer data signals between two isolated circuits.

There are several considerations to take into account in order to obtain the best performance from these photocouplers. This application note describes the electrical characteristics of Toshiba's low-I_F transistor-output photocouplers as well as considerations for creating system designs.

1.1 Types of low-I_F transistor-output photocouplers

Figure 1.1 shows three typical photocouplers: the TLP185 general-purpose transistor-output photocoupler in the SO6 small, thin package, the TLP183 low-I_F transistor-output photocoupler, and the TLP2301 that is a high-speed version of the TLP183.

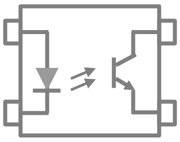
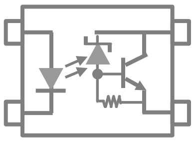
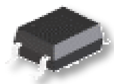
Item \ Part number		TLP185(SE	TLP183	TLP2301
Output type		Single Tr (General)	Single Tr (Low input)	Single Tr (Low input,High speed)
Pin assignment				
Package		 4pin SO6		
Current transfer ratio (CTR) I_C/I_F	Blank	50～600%	50～600%	50～600%
	Rank GB	100～600%	100～600%	100～600%
	Condition	@I_F=5mA,V_{CE}=5V	@I_F=0.5mA,V_{CE}=5V	@I_F=1mA,V_{CE}=5V
Propagation delay time [t_{OFF}]		40µs (typ.) @ I_F=16mA , R_L=1.9kΩ	30µs (typ.) @ I_F=1.6mA , R_L=4.7kΩ	t_{pLH} (max.) =30µs @ I_F=1mA , R_L=10kΩ
V_{CEO}		80V(min)	80V(min)	40V(min)
Operating temperature T_{opr}		-55～110℃	-55～125℃	-55～125℃
Isolation voltage BV_s		3750Vrms		

Figure 1.1 Overview for representative products of TLP185, TLP183, TLP2301

Current transfer ratio (CTR) is defined as the ratio of the collector current (I_C) from the output transistor to the forward current (I_F) applied to the input LED, i.e., I_C/I_F, expressed as a percentage. CTR varies with the test conditions for I_F. The CTR values of general-purpose photocouplers are specified at an I_F of 5 mA and a V_{CE} of 5 V whereas the CTR values of low-I_F photocouplers are specified at an I_F of 1 mA or 0.5 mA.

Low-I_F transistor-output photocouplers:
TLP185 : CTR = 50%-600% at I_F = 5 mA
TLP183 : CTR = 50%-600% at I_F = 0.5 mA
TLP2301 : CTR = 50%-600% at I_F = 1 mA

Figure 1.2 compares the dependence of CTR on I_F of the general-purpose TLP185 and the low-I_F TLP183.

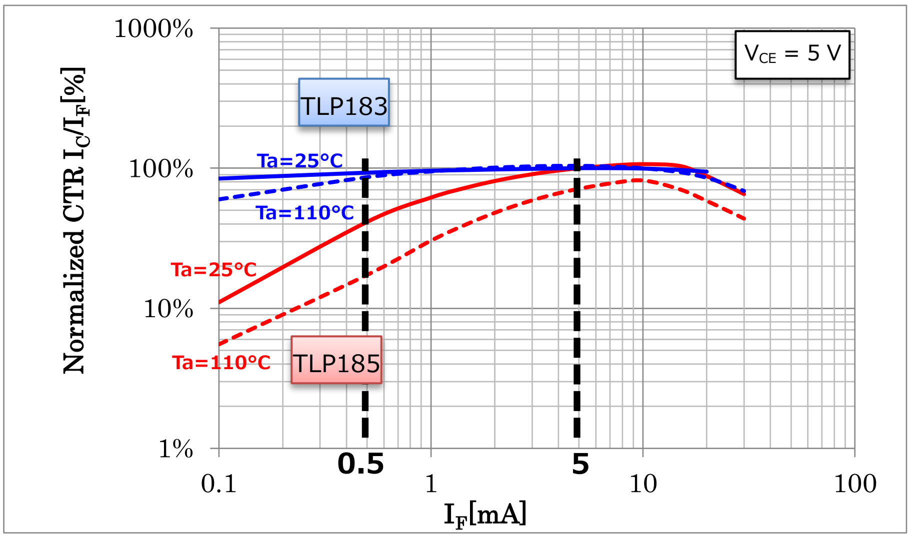


Figure 1.2 I_F dependency for CTR on representative products of TLP185, TLP183

As shown in Figure 1.2, the CTR curves of the TLP183 and TLP185 have a marked difference in the low-I_F region. Their CTR values change as follows over the I_F range between 5 mA and 0.5 mA:

$$I_F = 5\ \text{mA} \rightarrow I_F = 0.5\ \text{mA}$$

TLP185: The CTR value decreases roughly by half.

TLP183: The CTR value decreases by only a few percentage points.

The TLP183 exhibits a very low reduction in CTR in the low-I_F region. This is because the TLP183 incorporates a high-output, long-life LED of a new generation. The TLP2301 also incorporates a high-output, long-life LED and therefore exhibits an I_F-CTR curve similar to that of the TLP183. Such CTR characteristics of the TLP183 and TLP2301 help reduce the input current (I_F) and improve the performance of system designs.

2. Designing an interface circuit using a transistor-output photocoupler

In Figure 2.1, a 4-pin photocoupler interfaces between two logic ICs. This section discusses how to select R_{IN} and R_L to ensure that "on" and "off" signals are transferred properly across the photocoupler. First of all, you should tentatively decide on the input current (I_F). Then, calculate the minimum collector current that is drawn at the saturation voltage of the output transistor in order to determine the pull-up resistor value (R_L).

Example of design specifications

Operating temperature T_{opr}: 0 to 70°C
Data transmission rate: 5 kbit/s
Supply voltage: V_{CC} = 5 V ± 5%
Operating life: 10 years (88,000 hours)
System working duty: 50%

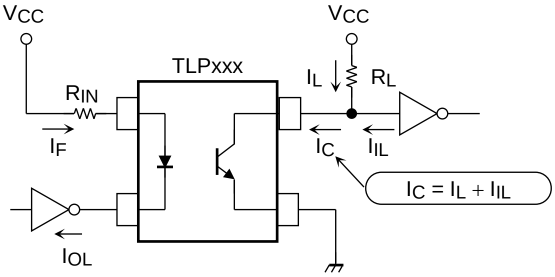


Figure 2.1 Interface circuit between TTLs using a 4pin transistor coupler

Let's select a photocoupler first.

Here, we will consider three choices: the general-purpose TLP185(SE, the low-I_F TLP183, and the TLP2301 that is an IC-output variant of the TLP183. Table 2.1 shows major electrical characteristics of these photocouplers necessary for circuit design.

Table 2.1 (1) Main specifications on TLP185(SE

Characteristics	Symbol	Test conditions (Ta = 25°C)		Min	Typ	Max	Unit
Input forward voltage	V_F	I_F = 10 mA		1.1	1.25	1.4	V
Collector-emitter breakdown voltage	$V_{(BR)\ CEO}$	I_C = 0.5 mA		80	—	—	V
Emitter-collector breakdown voltage	$V_{(BR)\ ECO}$	I_E = 0.1 mA		7	—	—	V
Dark current	I_{DARK}	I_F = 0 mA, V_{CE} = 48 V		—	0.01	0.08	μA
		I_F = 0 mA, V_{CE} = 48 V, Ta = 85°C		—	2	50	μA
Current transfer ratio	CTR (I_C/I_F)	I_F = 5 mA V_{CE} = 5 V	Blank	50	—	600	%
			Rank GB	100	—	600	
			Rank GR	100	—	300	
Collector-emitter saturation voltage	$V_{CE\ (sat)}$	I_F = 8 mA, I_C = 2.4 mA		—	—	0.3	V

Table 2.1 (2) Main specifications on TLP183

Characteristics	Symbol	Test conditions (Ta = 25°C)		Min	Typ	Max	Unit
Input forward voltage	V_F	I_F = 10 mA		1.1	1.25	1.4	V
Collector-emitter breakdown voltage	$V_{(BR)\ CEO}$	I_C = 0.5 mA		80	—	—	V
Emitter-collector breakdown voltage	$V_{(BR)\ ECO}$	I_E = 0.1 mA		7	—	—	V
Dark current	I_{DARK}	I_F = 0 mA, V_{CE} = 48 V		—	0.01	0.08	μA
		I_F = 0 mA, V_{CE} = 48 V, Ta = 85°C		—	2	50	μA
Current transfer ratio	CTR (I_C/I_F)	I_F = 0.5 mA V_{CE} = 5 V	Blank	50	—	600	%
			Rank GB	100	—	600	
			Rank GR	100	—	300	
Collector-emitter saturation voltage	$V_{CE\ (sat)}$	I_F = 8 mA, I_C = 2.4 mA		—	—	0.3	V

Table 2.1 (3) Main specifications on TLP2301

Characteristics	Symbol	Test conditions (Ta = 25°C)		Min	Typ	Max	Unit
Input forward voltage	V_F	I_F = 10 mA		1.1	1.25	1.4	V
Collector-emitter breakdown voltage	$V_{(BR)\ CEO}$	I_C = 0.1 mA		40	—	—	V
Emitter-collector breakdown voltage	$V_{(BR)\ ECO}$	I_E = 0.1 mA		7	—	—	V
Dark current	I_{DARK}	I_F = 0 mA, V_{CE} = 40 V		—	0.01	0.08	μA
		I_F = 0 mA, V_{CE} = 40 V, Ta = 85°C		—	2	50	μA
Current transfer ratio	CTR (I_C/I_F)	I_F = 1 mA V_{CE} = 5 V	Blank	50	—	600	%
			Rank GB	100	—	600	
Collector-emitter saturation voltage	$V_{CE\ (sat)}$	I_F = 8 mA, I_C = 2.4 mA		—	—	0.3	V

2.1 Setting the forward current (I_F)

First of all, you need to set the LED drive current (I_F) tentatively.

(1) In the case of the TLP185

The maximum I_F value must be lower than the maximum output low-level sink current (I_{OL}) of the logic IC connected to the input of the TLP185. Suppose that the I_{OL} value of a typical logic IC is 8 mA. Then, I_F must be equal to or less than 8 mA to satisfy $I_F \leq I_{OL}$. Figure 2.2 shows that the maximum permissible I_F value is 50 mA. However, I_F should be minimized since I_F affects the degradation of the current transfer ratio (CTR) due to aging. Figure 2.3 shows the light output degradation of the LED incorporated in the TLP185(SE. Suppose that the service life required for the TLP185(SE is 10 years (i.e., roughly 88,000 hours, which translates to 44,000 hours if the LED is active 50% of the time). So, CTR will decrease by roughly 30% (D_t = 0.7) over the period of the service life. In the TLP185 data sheet, CTR is specified at an I_F of 5 mA. Let's adopt this value for now. Then, the initial I_F value should be at least 5 mA / 0.7 = 7.2 mA. Therefore, let's tentatively set I_F to 8mA which is same value as the I_{OL} of the preceding logic IC.

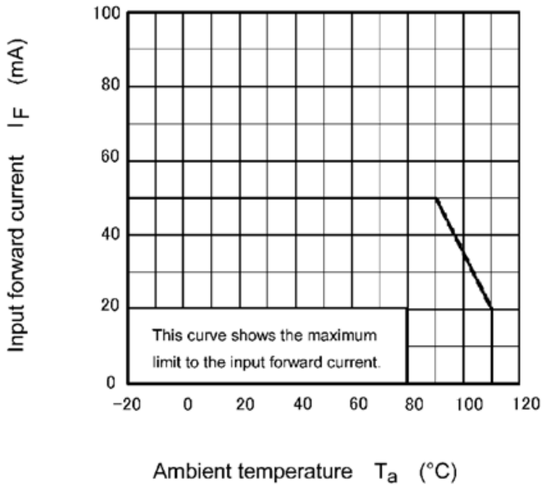


Figure 2.2 Allowable forward current – Ambient temperature (TLP185(SE)

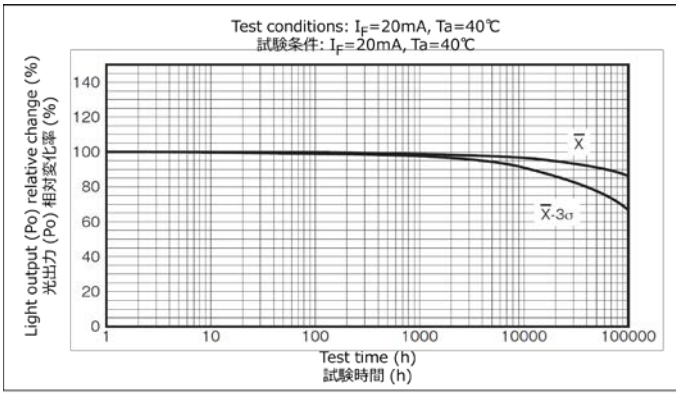


Figure 2.3 Example of LED light power degradation curve(*)

* The graph shows a typical LED light output degradation curve. When designing a circuit incorporating photocoupler components including the TLP185(SE, consult reliability data individually

(2) In the case of the TLP183

In the TLP183 data sheet, the current transfer ratio and turn-on and turn-off times are specified not only at I_F = 5 mA but also at I_F = 0.5 mA. Figure 2.4 shows the light output degradation of the LED incorporated in the TLP183 and TLP2301 due to aging. The lower the I_F value, the lower the CTR degradation. Suppose, however, that the service life required for the TLP183 is 10 years (i.e., roughly 88,000 hours, which translates to 44,000 hours if the LED is active 50% of the time). So, CTR will decrease by roughly 15% (D_t = 0.85) over the period of the service life. In the TLP183 data sheet, CTR is specified at an I_F of 0.5 mA. Let's adopt this value for now. Then, the initial I_F value should be at least 0.5 mA / 0.85 = 0.6 mA. Therefore, let's set I_F to 1 mA tentatively, allowing for some margin.

(3) In the case of the TLP2301

In the TLP2301 data sheet, the current transfer ratio and propagation delay times are specified at a low I_F value of 1 mA. As is the case with the TLP183, it is necessary to take 15% degradation in CTR into consideration. However, increasing current affects propagation delay times. The TLP2301 is a high-speed variant of the TLP183; its propagation delay times are specified at an I_F of 1 mA. It is therefore beneficial to set I_F at or close to 1 mA. Here, let's set design parameters tentatively so that I_F will be 1 mA under the worst-case conditions considering two conflicting factors.

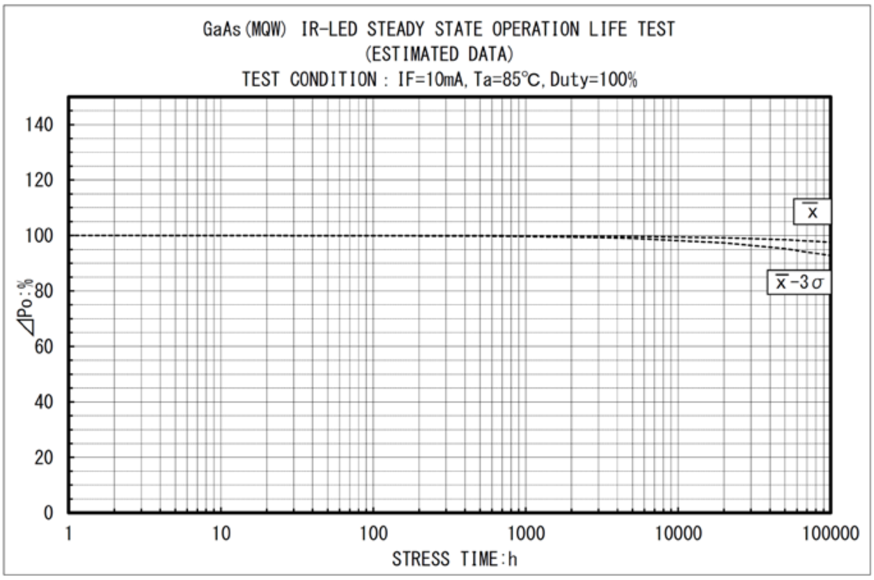


Figure 2.4 Example of LED light power degradation curve(*)

* The graph shows a typical LED light output degradation curve. When designing a circuit incorporating photocoupler components including the TLP183 and TLP2301, consult reliability data individually

2.2 Setting the value of the I_F-limiting resistor (R_{IN})

$I_{F(typ.)}$ is expressed as:

$$I_{F(typ.)} = \frac{V_{CC} - V_{F(typ.)} - V_{OL}}{R_{IN(typ.)}}$$

(1) In the case of the TLP185

The data sheet (Figure 2.5) shows that $V_{F\ (typ.)}$ is:

$V_{F\ (typ.)}$ = 1.25 V (I_F = 10 mA)

Hence, R_{IN} is calculated as:

$$R_{IN} = \frac{5V - 1.25V - 0.4V}{8mA}$$

$$= 419\ \Omega$$

Therefore, let’s select a resistor with a value of 430 Ω ± 5% for R_{IN}.

$I_{F\ (min)}$ and $I_{F\ (max)}$ are calculated as shown below.

V_{CC} is 5 V ± 5%. The data sheet also shows the minimum and maximum V_F values.

$V_{CC\ (min)}$ = 5 V - 5% = 4.75 V, $V_{CC\ (max)}$ = 5 V + 5% = 5.25 V

$V_{F\ (min)}$ = 1.1 V, $V_{F\ (max)}$ = 1.4 V

(Ta=25°C)

	Characteristics	Symbol	Note	Test Condition	Min	Typ.	Max	Unit
LED	Input forward voltage	V_F		I_F = 10 mA	1.1	1.25	1.4	V

Figure 2.5 Specification on TLP185(SE excerpted from data sheet

$$I_{F(min.)} = \frac{V_{CC(min.)} - V_{F(max.)} - V_{OL}}{R_{IN(max.)}}$$

$$= \frac{4.75V - 1.4V - 0.4V}{452\Omega}$$

= 6.5 mA

$$I_{F(max.)} = \frac{V_{CC(max.)} - V_{F(min.)} - V_{OL}}{R_{IN(min.)}}$$

$$= \frac{5.25V - 1.1V - 0.4V}{409\Omega}$$

= 9.2 mA

(2) In the case of the TLP183

The data sheet (Figure 2.6) shows that $V_{F\ (typ.)}$ is:

$V_{F\ (typ.)}$ = 1.25 V (I_F = 10 mA)

Here, let's estimate $V_{F\ (typ.)}$ at an I_F of 1 mA.

Figure 2.7 shows that V_F decreases by roughly 0.1 V when I_F = 1 mA.

(Ta=25°C)

	Characteristics	Symbol	Note	Test Condition	Min	Typ.	Max	Unit
LED	Input forward voltage	V_F		I_F = 10 mA	1.1	1.25	1.4	V

Figure 2.6 Specification on TLP183 excerpted from data sheet

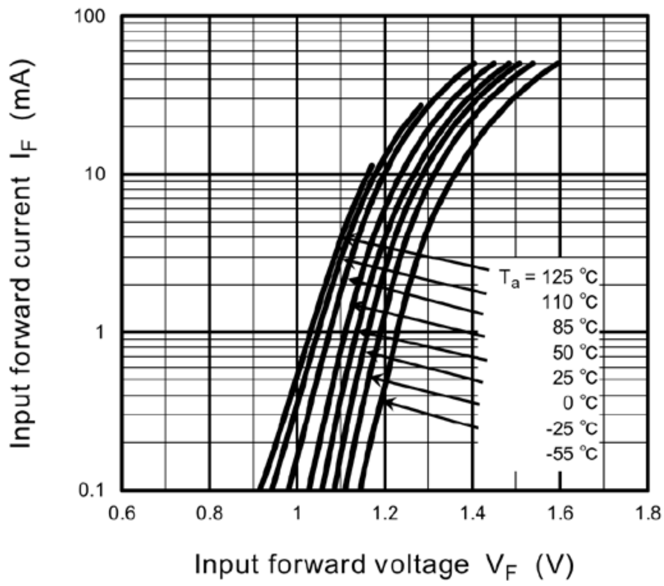


Figure 2.7 I_F - V_F characteristics on TLP183 excerpted from data sheet

$$R_{IN} = \frac{5V - 1.15V - 0.4V}{1mA}$$

$$= 3.45\ k\Omega$$

Therefore, let's select a resistor with a value of 3.3 kΩ ± 5% for R_{IN}.

$I_{F\ (min)}$ and $I_{F\ (max)}$ are calculated as shown below.

V_{CC} is 5 V ± 5%. From the data sheet values and I_F - V_F curves (Figure 2.7), the minimum and maximum V_F values are as follows:

$V_{CC\ (min)}$ = 5 V - 5% = 4.75 V, $V_{CC\ (max)}$ = 5 V + 5% = 5.25 V

$V_{F\ (min)}$ = 1.0 V, $V_{F\ (max)}$ = 1.3 V

$$I_{F(min.)} = \frac{V_{CC(min.)} - V_{F(max.)} - V_{OL}}{R_{IN(max.)}}$$

$$= \frac{4.75V - 1.3V - 0.4V}{3.47k\Omega}$$

$$= 0.88\ mA$$

$$I_{F(max.)} = \frac{V_{CC(max.)} - V_{F(min.)} - V_{OL}}{R_{IN(min.)}}$$

$$= \frac{5.25V - 1.0V - 0.4V}{3.14k\Omega}$$

$$= 1.23\ mA$$

(3) In the case of the TLP2301

The data sheet (Figure 2.8) shows that $V_{F\,(typ.)}$ is:

$V_{F\,(typ.)}$ = 1.25 V (I_F = 10 mA)

Here, let's estimate $V_{F\,(typ.)}$ at an I_F of 1 mA.

Figure 2.9 shows that V_F decreases by roughly 0.1 V when I_F = 1 mA.

(Ta=25℃)

	Characteristics	Symbol	Note	Test Condition	Min	Typ.	Max	Unit
LED	Input forward voltage	V_F		I_F = 10 mA	1.1	1.25	1.4	V

Figure 2.8 Specification on TLP2301 excerpted from data sheet

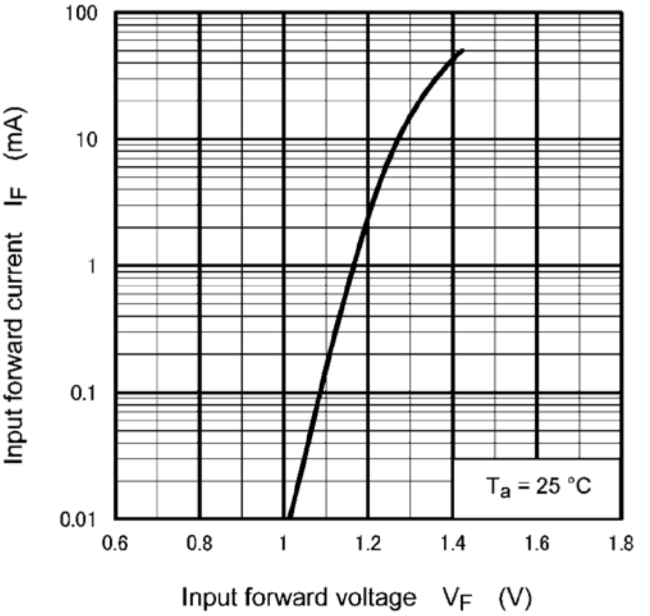


Figure 2.9 I_F - V_F characteristics on TLP2301 excerpted from data sheet

$$R_{IN} = \frac{5V - 1.15V - 0.4V}{1mA}$$

$$= 3.45\ k\Omega$$

Therefore, let's select a resistor with a value of 3.3 kΩ ± 5% for R_{IN}.

$I_{F\,(min)}$ and $I_{F\,(max)}$ are calculated as shown below.

V_{CC} is 5 V ± 5%. From the data sheet values and I_F - V_F curves (Figure 2.9), the minimum and maximum V_F values are as follows.

$V_{CC\,(min)}$ =5 V - 5% = 4.75 V, $V_{CC\,(max)}$ = 5 V + 5% = 5.25 V

$V_{F\,(min)}$ = 1.0 V, $V_{F\,(max)}$ = 1.3 V

$$I_{F(min.)} = \frac{V_{CC(min.)} - V_{F(max.)} - V_{OL}}{R_{IN(max.)}}$$

$$= \frac{4.75V - 1.3V - 0.4V}{3.47k\Omega}$$

$$= 0.88 \text{ mA}$$

$$I_{F(max.)} = \frac{V_{CC(max.)} - V_{F(min.)} - V_{OL}}{R_{IN(min.)}}$$

$$= \frac{5.25V - 1.0V - 0.4V}{3.14k\Omega}$$

$$= 1.23 \text{ mA}$$

2.3 Setting the value of the pull-up resistor (R_L)

Choose a pull-up resistor (R_L) so that the collector current will not exceed the specified I_C under the worst-case condition.

Let the worst-case I_C value be minI_C. Then, minI_C is calculated as follows:

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

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

where:

V_{IL} : Maximum low-level input voltage of the device driven by a photocoupler (or low-level output voltage required)

D_t : Rate of degradation in I_C after an elapse of a certain time

D_{IF} : Rate of change in I_C at the I_F setpoint corresponding to the data sheet-specified conditions

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

D_{Ta} : Rate of change in I_C in the operating temperature range

α : Design margin

Read performance curves in the data sheet to obtain these values.

(1) In the case of the TLP185

$I_{C(min)}$: Here, let's use the TLP185(SE of rank GB. The minimum current transfer ratio of rank GB is specified as 100% at I_F = 5 mA and V_{CE} = 5 V. Thus, $I_{C(min)}$ is calculated as 5 mA x 100% = 5 mA.

D_t: The decrease in I_C due to aging greatly depends on the degradation of the LED light output. Figure 2.10 shows an example of the light output degradation of the LED incorporated in the TLP185(SE. Suppose that the service life required for the TLP185(SE is 44,000 hours (i.e., 50% of an expected service life of 10 years or roughly 88,000 hours, assuming that the LED is active 50% of the time), and its light output is calculated as 80%. Allowing some design margin, let's assume that CTR will decrease by 30% and substitute 0.7 for D_t.

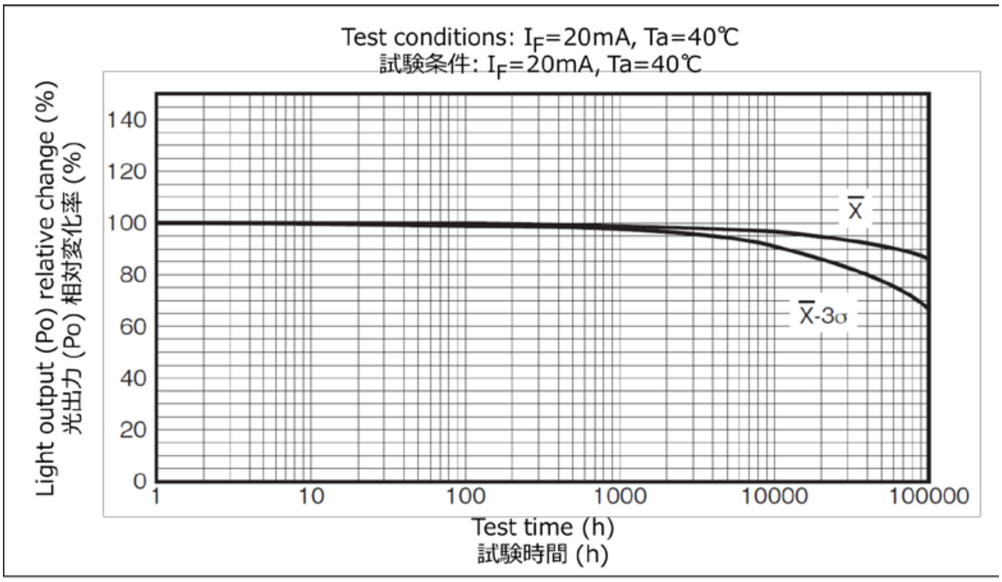


Figure 2.10 Example of LED light power degradation curve(*)

* The graph shows a typical LED light output degradation curve. When designing a circuit incorporating photocoupler components including the TLP185(SE, consult reliability data individually

D_{IF}: The rate of change in I_C at the I_F setpoint corresponding to the data sheet-specified conditions can be calculated from the I_C-I_F curves of the TLP185(SE. Here, we have assumed that I_F = 8 mA. From Figure 2.11, I_C can be read as 9.5 mA at I_F= 5 mA and as 16 mA at I_F = 8 mA. Hence, D_{IF} is calculated as 16 mA / 9.5 mA ≈ 1.7.

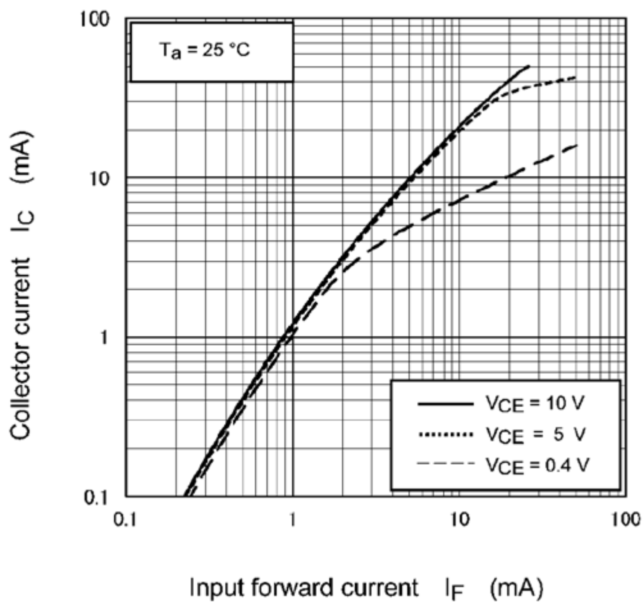


Figure 2.11 I_C - I_F characteristics on TLP185(SE excerpted from data sheet

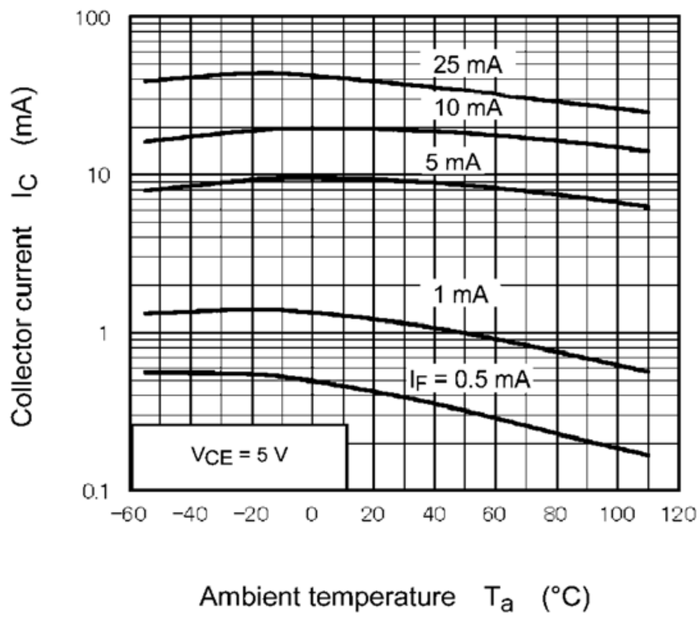


Figure 2.12 I_C - Ta characteristics on TLP185(SE excerpted from data sheet

D_{VCE}: A rate of change in I_C under $V_{CE\ (sat)}$ ($\approx$ 0.4 V) condition can be calculated from the I_C-I_F curves shown in Figure 2.11. When I_F = 8 mA, I_C can be read as 16 mA at V_{CE} = 5V and 6.5 mA at V_{CE} = 0.4 V. Hence, the rate of change in I_C (D_{VCE}) can be calculated as 6.5 mA / 16 mA ≈ 0.4.

D_{Ta}: The rate of change in I_C over the T_{opr} range can be calculated from the I_C-Ta curves shown in Figure 2.12. Read the curve for I_F = 10 mA that is close to our condition of I_F = 8 mA. Since I_C is the lowest at 70°C, we get I_C = 20 mA at Ta = 25°C and I_C = 16 mA at Ta = 70°C. Hence, the rate of change in I_C (D_{Ta}) is calculated as 16 mA / 20mA ≈ 0.8.

α: Here, let's assume a design margin of 20%. Hence, α = 0.8.

Hence, $minI_C$ can be calculated as follows:

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

$minI_C$ = 5 mA × 0.7 × 1.7 × 0.4 × 0.8 × 0.8

$minI_C$ =1.5 mA

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

$$R_L \geq \frac{5.25V - 0.6V}{1.5mA}$$

$$R_L \geq 3.1k\Omega$$

Increasing the R_L value provides a greater margin, but at the expense of an increase in the turn-off time (t_{OFF}). So, let's use a 4.7-kΩ resistor here, roughly 1.5 times as large as the above calculation result.

(2) In the case of the TLP183

$I_{C(min)}$: Here, let's use the TLP183 of rank GB. The minimum current transfer ratio of rank GB is specified as 100% at I_F = 0.5 mA and V_{CE} = 5 V. Thus, $I_{C(min)}$ is calculated as 0.5 mA x 100% = 0.5 mA.

D_t: The decrease in I_C due to aging greatly depends on the degradation of the LED light output. Figure 2.13 shows an example of the light output degradation of the LED incorporated in the TLP183 and TLP2301. Suppose that the service life required for the TLP183 is 44,000 hours (i.e., 50% of an expected service life of 10 years or roughly 88,000 hours, assuming that the LED is active 50% of the time). So, CTR will decrease by roughly 10% (D_t = 0.9) over the period of the service life. Allowing some design margin, let's assume that CTR will decrease by 15% and substitute 0.85 for D_t.

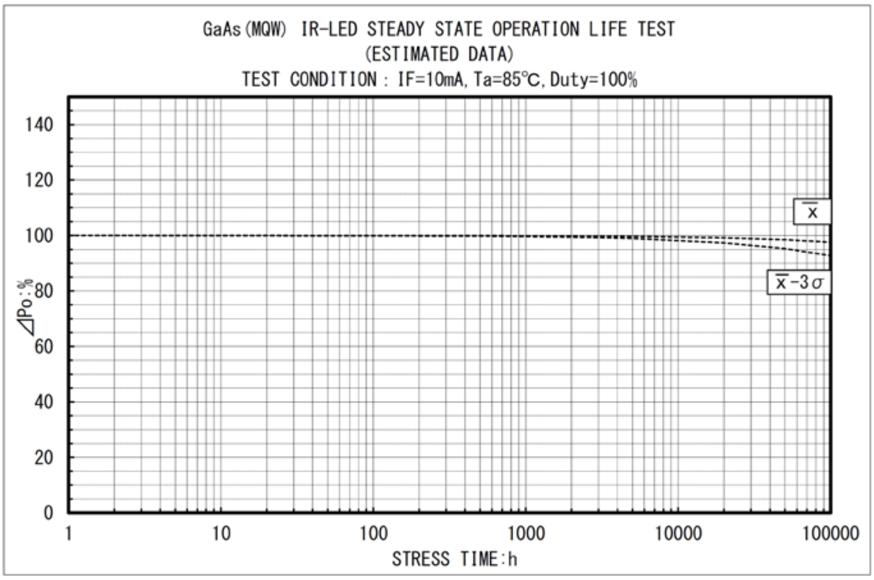


Figure 2.13 Example of LED light power degradation curve(*)

* The graph shows a typical LED light output degradation curve. When designing a circuit incorporating photocoupler components including the TLP183 and TLP2301, consult reliability data individually.

D_{IF}: The rate of change in I_C at the I_F setpoint corresponding to the data sheet-specified conditions can be calculated from the I_C-I_F curves of the TLP183. Here, we have assumed that I_F = 1 mA. From Figure 2.14, I_C can be read as 0.95 mA at I_F = 0.5 mA and as 2 mA at I_F = 1 mA. Hence, D_{IF} is calculated as 2 mA / 0.95 mA ≈ 2.1.

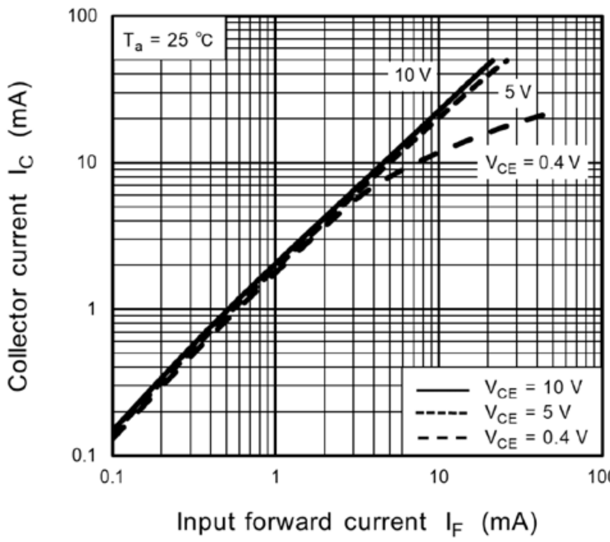


Figure 2.14 I_C - I_F characteristics on TLP183 excerpted from data sheet

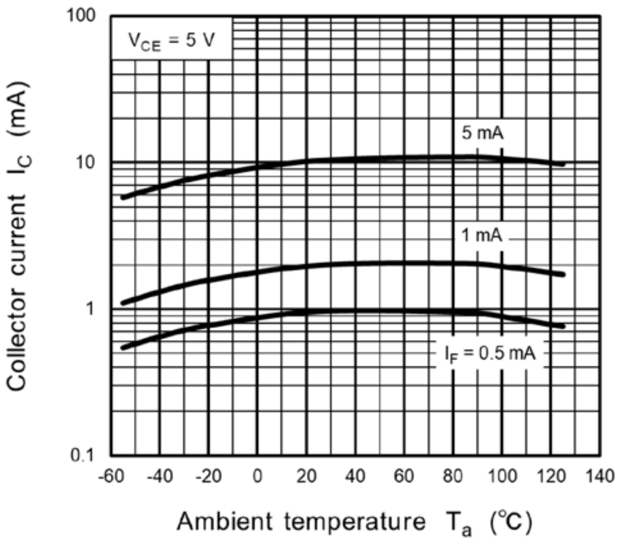


Figure 2.15 I_C - Ta characteristics on TLP183 excerpted from data sheet

D_{VCE}: A rate of change in I_C under $V_{CE\,(sat)}$ (≈ 0.4 V) condition can be calculated from the I_C-I_F curves shown in Figure 2.14. When I_F = 1 mA, I_C can be read as 2 mA at V_{CE} =5V and 1.9 mA at V_{CE} = 0.4 V. Hence, the rate of change in I_C (D_{VCE}) can be calculated as 1.9 mA / 2 mA ≈ 0.95.

D_{Ta}: The rate of change in I_C over the T_{opr} range can be calculated from the I_C-Ta curves shown in Figure 2.15. Read the curve for I_F =1 mA. Since I_C is the lowest at 0°C, we get I_C = 2 mA at Ta = 25°C and I_C = 1.8 mA at Ta = 0°C. Hence, the rate of change in I_C (D_{Ta}) is calculated as 1.8 mA / 2 mA ≈ 0.9.

α: Here, let's assume a design margin of 20%. Hence, α = 0.8.

Hence, $minI_C$ can be calculated as follows:

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

$minI_C$ = 0.5 mA × 0.85 × 2.1 × 0.95 × 0.9 × 0.8

$minI_C$ = 0.61 mA

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

$$R_L \geq \frac{5.25V - 0.6V}{0.61mA}$$

$$R_L \geq 7.6k\Omega$$

Increasing the R_L value provides a greater margin, but at the expense of an increase in the turn-off time (t_{OFF}). So, let's use a 10-kΩ resistor here.

(3) In the case of the TLP2301

$I_{C(min)}$: Here, let's use the TLP2301 of rank GB. The minimum current transfer ratio of rank GB is specified as 100% at I_F = 1 mA and V_{CE} = 5 V. Thus, $I_{C(min)}$ is calculated as 1 mA x 100% = 1 mA.

D_t: The decrease in I_C due to aging greatly depends on the degradation of the LED light output. Figure 2.13 shows an example of the light output degradation of the LED incorporated in the TLP2301. Suppose that the service life required for the TLP2301 is 44,000 hours (i.e., 50% of an expected service life of 10 years or roughly 88,000 hours, assuming that the LED is active 50% of the time), and its light output is calculated as 90%. Allowing some design margin, let's assume that CTR will decrease by 15% and substitute 0.85 for D_t.

D_{IF}: The rate of change in I_C at the I_F setpoint corresponding to the data sheet-specified conditions can be calculated from the I_C-I_F curves of the TLP2301. Here, we have assumed that I_F = 1 mA; hence, D_{IF} = 1. When I_F = 3 mA, from Figure 2.16, we get I_C = 1.8 mA at I_F = 1 mA and I_C = 6.2 mA at I_F = 3 mA. Hence, D_{IF} is calculated as 6.2 mA / 1.8 mA ≈ 3.4.

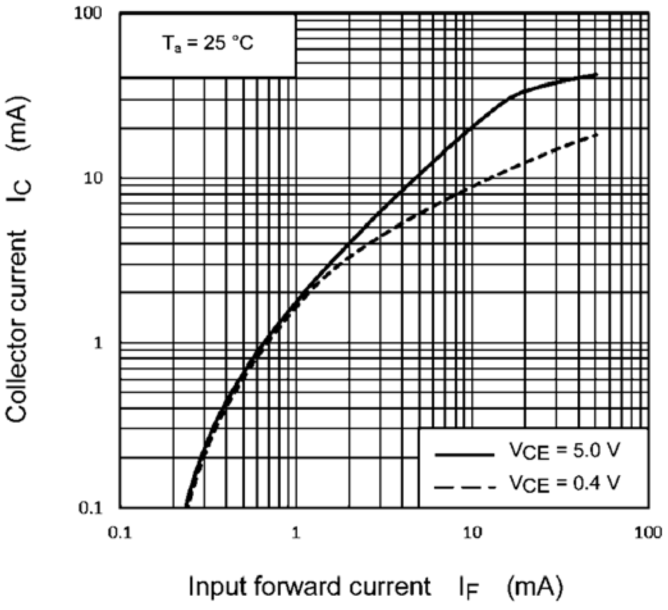


Figure 2.16 I_C - I_F characteristics on TLP2301 excerpted from data sheet

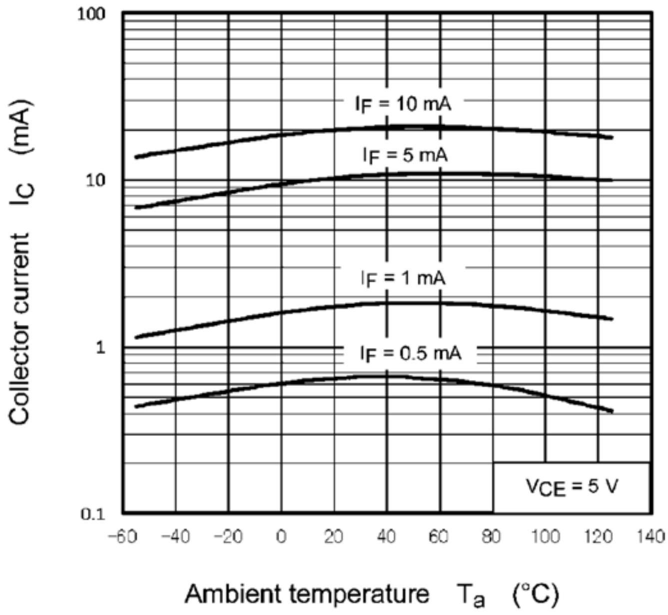


Figure 2.17 I_C - Ta characteristics on TLP2301 excerpted from data sheet

D_{VCE}: A rate of change in I_C under $V_{CE\,(sat)}$ (≈ 0.4 V) condition can be calculated from the I_C-I_F curve shown in Figure 2.16. When I_F = 1 mA, I_C can be read as 1.8 mA at V_{CE} = 5 V and 1.7 mA at V_{CE} = 0.4 V. The rate of change in I_C (D_{VCE}) can be calculated as 1.7 mA / 1.8 mA ≈ 0.95.

D_{Ta}: The rate of change in I_C over the T_{opr} range can be calculated from the I_C-Ta curves shown in Figure 2.17. Read the curve for I_F =1 mA. Since I_C is the lowest at 0°C, we get I_C = 1.8 mA at Ta = 25°C and I_C = 1.6 mA at Ta = 0°C. Hence, the rate of change in I_C (D_{Ta}) is calculated as 1.6 mA / 1.8 mA ≈ 0.88.

α: Here, let's assume a design margin of 20%. Hence, α = 0.8.

Hence, $minI_C$ can be calculated as follows:

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

$minI_C$ = 1 mA × 0.9 × 1 × 0.95 × 0.88 × 0.8

$minI_C$ = 0.6 mA

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

$$R_L \geq \frac{5.25V - 0.6V}{0.6mA}$$

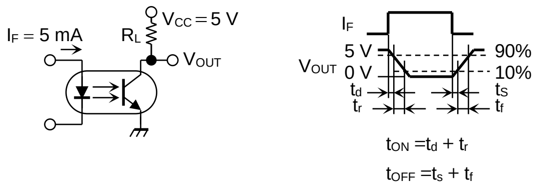
$$R_L \geq 7.8k\Omega$$

Increasing the R_L value provides a greater margin, but at the expense of an increase in the propagation delay time (t_{pLH}). So, let's use a 10-kΩ resistor here.

2.4 Estimating turn-on and turn-off times obtained with the selected pull-up resistor (R_L)

To achieve a signal transfer rate of 5 kbits/s, the sum of the turn-on and turn-off times must satisfy the following equation:

$$T = t_{ON} + t_{OFF} \leq 200\ \mu s$$



Switching times are affected by various factors, including the current transfer ratio (CTR), load resistance (R_L), and the ambient temperature (Ta).

First of all, let's check the relationship between switching times and CTR. Figure 2.18 shows that t_{OFF} (= t_s + t_f) tends to increase with CTR. This is because photocouplers with a high CTR tend to incorporate a phototransistor with a high h_{FE}. It is therefore advisable to use photocouplers with a low CTR if your design has any switching time constraints. Different photocouplers have different switching times. For example, Figure 2.18 shows that there is a roughly 10-μs difference in t_{OFF} among photocouplers with a CTR of roughly 200%. It is necessary to take account of t_{OFF} variations among different photocouplers as well as the effects of Ta, R_L, and other factors.

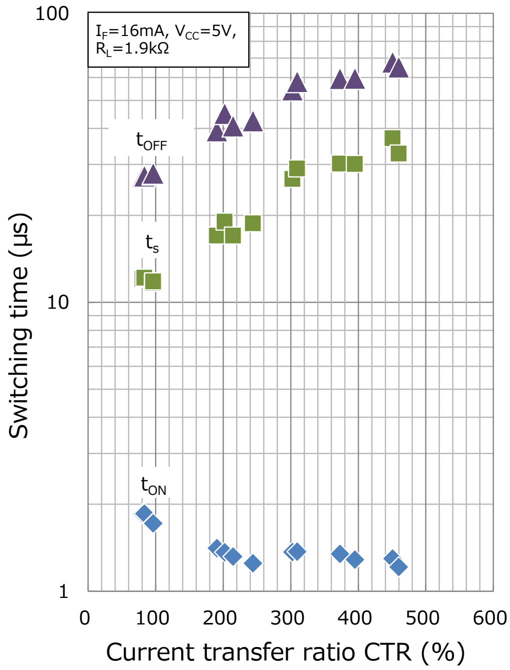


Figure 2.18 Example for switching time vs. CTR

(1) In the case of the TLP185

From the switching time-R_L curves shown in Figure 2.20, t_{off} can be read as roughly 75 μs at R_L = 4.7 kΩ and I_F = 16 mA. The switching time-I_F curves of Figure 2.21 also show that:

t_{off} ≈ 70μs at R_L = 4.7 kΩ and I_F = 8 mA

Figure 2.19 gives the switching time-Ta curves of the TPL185(SE with a CTR of roughly 200%. It shows that the switching time increases by roughly 30% when the ambient temperature (Ta) rises from 25°C to 70°C. Taking a temperature rise into account, T should be considered to be T= 70 μs x 1.3 ≈ 90 μs. In addition, CTR varies between 100% and 600%. Assuming that there is a twofold variation in T over this CTR range, T becomes roughly 180 μs at the maximum.

When creating an actual design, be sure to take these effects into consideration, referring to a data sheet. Although the TLP185(SE satisfies the switching time requirement of 200 μs, it is necessary to examine whether there is a sufficient margin.

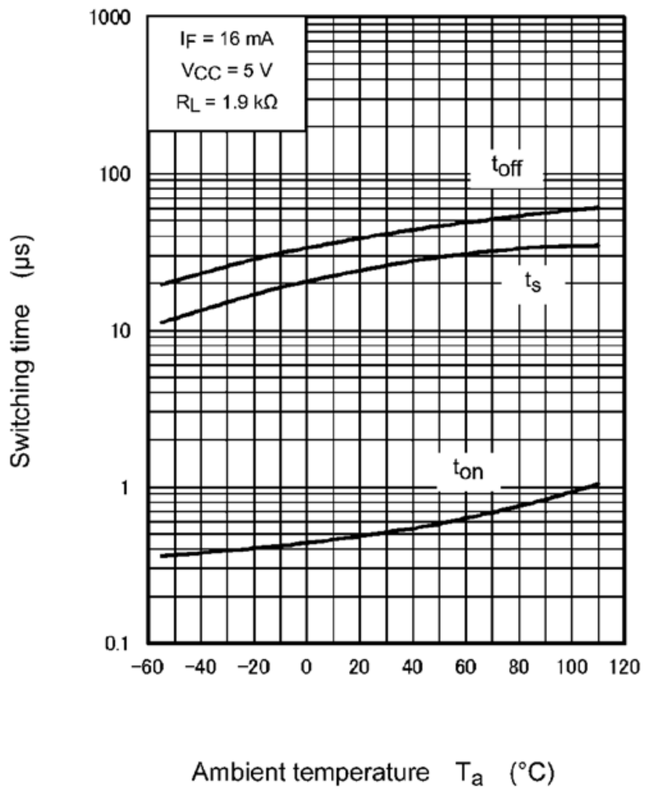


Figure 2.19 Switching time - Ta characteristics on TLP185(SE excerpted from data sheet

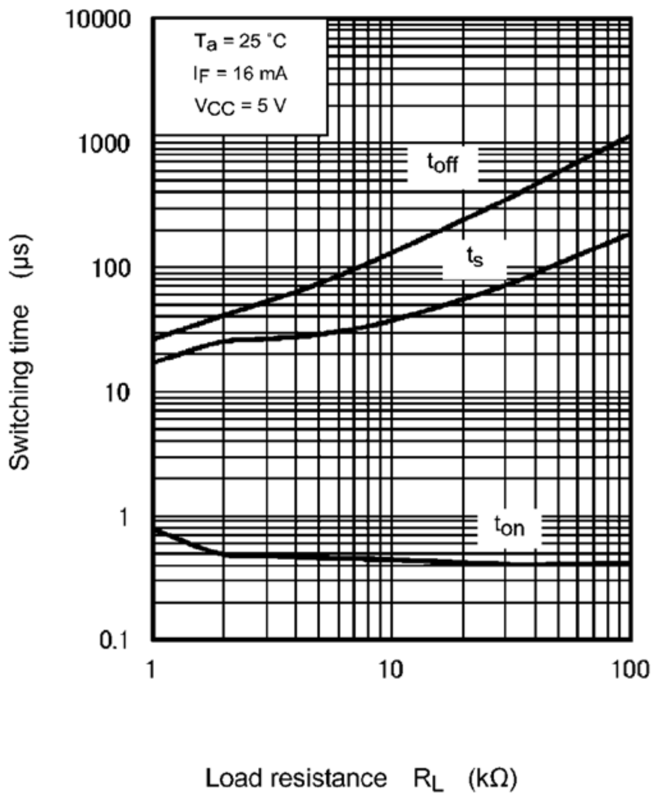


Figure 2.20 Switching time - R_L characteristics on TLP185(SE excerpted from data sheet

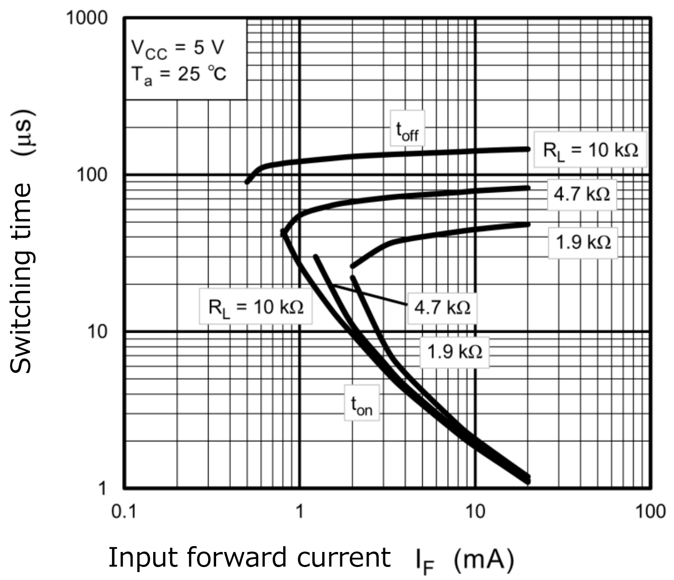


Figure 2.21 Switching time - I_F characteristics on TLP185(SE

(2) In the case of the TLP183

From the switching time-R_L curves shown in Figure 2.23, t_{off} can be read as roughly 90 μs at R_L = 10 kΩ and I_F = 1.6 mA. The switching time-I_F curves of Figure 2.24 also show that:

t_{off} ≈ 90 μs at R_L = 10 kΩ and I_F = 1 mA

Figure 2.22 gives the switching time-Ta curves of the TPL183 with a CTR of roughly 200%. It shows that the switching time increases by roughly 30% when the ambient temperature (Ta) rises from 25°C to 70°C. Taking a temperature rise into account, T should be considered to be T= 90 μs x 1.3 ≈ 120 μs. In addition, CTR varies between 100% and 600%. Assuming that there is a twofold variation in T over this CTR range, T becomes roughly 240 μs at the maximum.

When creating an actual design, be sure to take these effects into consideration, referring to a data sheet. The above estimation indicates that the TLP183 is unlikely to satisfy the switching time requirement of 200 μs. Therefore, we need to take countermeasures to reduce the switching time.

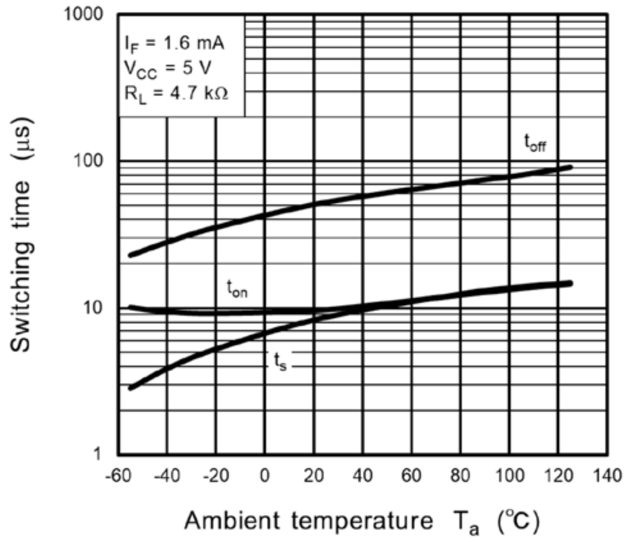


Figure 2.22 Switching time - Ta characteristics on TLP183 excerpted from data sheet

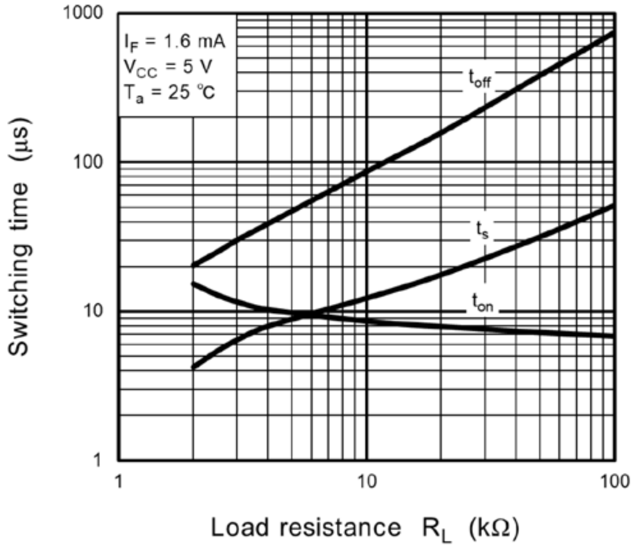


Figure 2.23 Switching time - R_L characteristics on TLP183 excerpted from data sheet

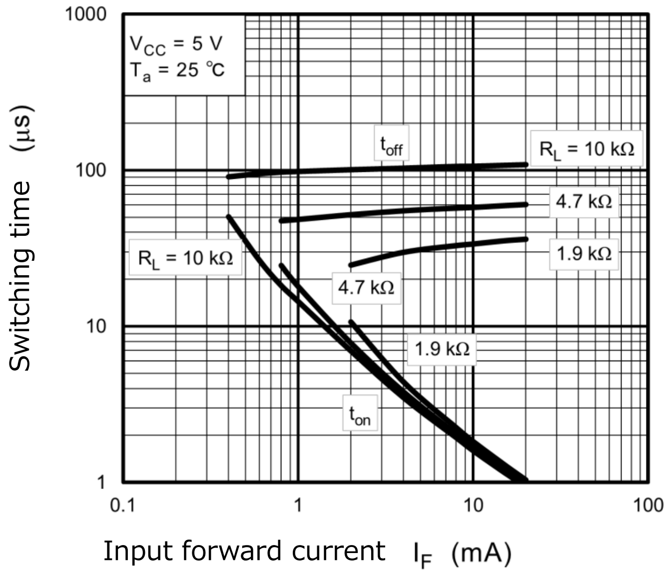


Figure 2.24 Switching time - I_F characteristics on TLP183

The switching time can be reduced by reducing R_L as indicated by the switching time-R_L curves of Figure 2.23. It is also necessary to search for conditions that satisfy the relationship between R_L and I_F discussed in (1), "In the case of the TLP185," of Section 2.3, "Setting the value of the pull-up resistor (R_L)"

There are two options to reduce the R_L value:

1. Increasing the setting of I_F from 1 mA to 2 mA and thereby changing R_L from 10 kΩ to 4.7 kΩ
2. Changing the CTR rank of the TLP183 (I_F = 0.5 mA, V_{CE} = 5 V) from GB (100% to 600%) to BL (200 to 600%) and thereby changing R_L from 10 kΩ to 4.7 kΩ

Then, we can assume that T = 50 μs x 1.3 ≈ 65 μs. With a twofold variation in T over the CTR range, T ≈ 130 μs, which satisfies the switching time requirement of 200 μs.

(3) In the case of the TLP2301

The TLP2301 guarantees that its propagation delay is 30 μs at the maximum.

Table 2.2 TLP2301 t_{pHL}, t_{pLH} specification (excerpted from data sheet*)

(Ta=25℃)

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	—	8	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	—	15	30	μs

* For test circuits, see the data sheets of respective photocouplers.

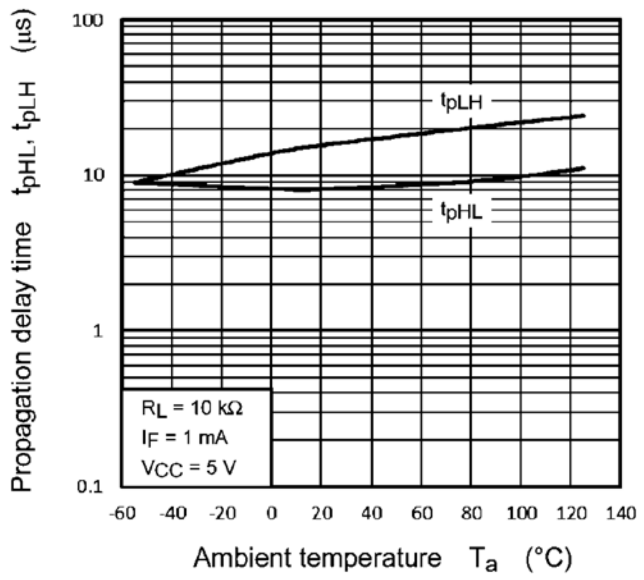


Figure 2.25 t_{pHL}, t_{pLH} - Ta characteristics on TLP2301

Since the maximum propagation delay is specified at I_F = 1 mA, R_L = 10 kΩ and V_{CC} = 5 V, which are same as the selected values, we need to check its dependency on Ta under these conditions. The propagation delay time of the TLP2301 is the longest at Ta = 70°C.

By reading the propagation delay time curves, we get t_{pLH} = 16 μs at Ta = 25°C and t_{pLH} = 20 μs at Ta = 70°C. Hence, D_{Ta} is calculated as 20 μs / 16 μs ≈ 1.25.

By reading the propagation delay time curves, we also get t_{pHL} = 8 μs at Ta = 25°C and t_{pHL} = 9 μs at Ta = 70°C. Hence, D_{Ta} is calculated as 9 μs / 8 μs ≈ 1.13.

Hence:

$$T = 30 \times 1.25 + 30 \times 1.13 \approx 72\ \mu s \leq 100\ \mu s$$

Therefore, we can achieve a 5-kbps data transfer rate with a switching time of 200 μs, even when the temperature characteristics are taken into consideration. Furthermore, because T ≤ 100 μs, 10-kbps data transfer may be possible.

2.5 Considerations for obtaining the best performance from low-I_F photocouplers

The TLP185 is a photocoupler with general-purpose performance. To ensure reliable transfer of "on" and "off" signals, it is necessary to drive the TLP185 with an I_F of 10 to ten-plus milliamperes. In contrast, the TLP183 and TLP2301 are designed to operate at a low I_F of 1 mA or so.

General-purpose transistor-output photocouplers usually have significant variations in propagation delay times and thus provide no guarantee for maximum switching times in the saturated state. It is therefore necessary to estimate switching times based on typical values, taking the effects of a current transfer ratio, temperature, and a pull-up resistor value into consideration. On the other hand, the TLP2301 is designed to provide faster propagation delay times (especially transistor turn-off time) and less delay time variations, thereby guaranteeing maximum propagation delay times. The TLP2301 guarantees a maximum propagation delay time of 30 μs irrespective of the CTR rank, making it easier to adjust its delay times by means of design because, unlike transistor-output photocouplers, it is unnecessary to take the effect of a current transfer ratio on switching times into account.

Table 2.3(1) General use Tr coupler TLP185(SE propagation delay time(Ta=25℃) (excerpted from data sheet*)

Characteristics	Symbol	Note	Test Condition	Min	Typ.	Max	Unit
Turn-on time	t_{on}		See Fig. 10.1 V_{CC} = 5 V, I_F = 16 mA, R_L = 1.9 kΩ	—	0.5	—	μs
Storage time	t_s			—	25	—	
Turn-off time	t_{off}			—	40	—	

Table 2.3(2) 20kbps IC coupler TLP2301 propagation delay time(Ta=25℃) (excerpted from data sheet*)

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	—	8	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	—	15	30	μs

* For test circuits, see the data sheets of respective photocouplers.

However, in order to obtain the best performance from the low-I_F TLP183 and TLP2301, appropriate forward current (I_F) and pull-up resistor (R_L) values should be selected.

Table 2.4 summarizes the parameters discussed in the previous subsections.

Table 2.4 Design information sumarry for example of interface circuit using Tr coupler

Type	TLP185(SE	TLP183			TLP2301
Setting conditions	I_F=8mA	I_F=1mA	I_F=1mA	I_F=2mA	I_F=1mA
	R_L=4.7kΩ	R_L=10kΩ	R_L=4.7kΩ	R_L=4.7kΩ	R_L=10kΩ
	CTR:rank GB	CTR:rank GB	CTR:rank BL	CTR:rank GB	CTR:rank GB
Response performance	T≈around 180μs	T≈around 240μs	T≈around 130μs	T≈around 130μs	T≈around 75μs

(rank GB : 100 to 600%、 rank BL : 200 to 600%)

(1) In the example of the TLP183 discussed in Section 2.4,
T was calculated to be roughly 130 μs at I_F = 2 mA, R_L = 4.7 kΩ, and V_{CC} = 5 V, i.e., the same conditions for the R_L of the TLP185(SE. However, if the TLP183 is used under the same I_F condition as for the TLP185(SE (= 8mA), T is estimated to be roughly 160 μs from Figure 2.27. This does not differ much from the performance of the TLP185(SE. Under this I_F condition, the TLP183 does not exhibit its advantage.
Table 2.4 also indicates that, even at low I_F, the switching time of the TLP183 differs greatly between the following two combinations. Therefore, careful consideration is necessary.

- Combination with I_F = 1 mA, R_L = 10 kΩ, V_{CC} = 5 V, CTR: GB rank
- Combination with I_F = 1 mA, R_L = 4.7 kΩ, V_{CC} = 5 V, CTR: BL rank, or
  I_F = 2 mA, R_L = 4.7 kΩ, V_{CC} = 5 V, CTR: GB rank

(2) In the case of the TLP2301,
T (= t_{OFF}＋t_{ON}) was calculated to be roughly 75 μs at I_F = 1 mA, R_L = 10 kΩ, and V_{CC} = 5 V in Subsections 2.1 to 2.4. Now, let's see how the switching time changes if it is used under the same conditions as for the TLP185(SE, i.e., at I_F = 8 mA, R_L = 4.7 kΩ, and V_{CC} = 5 V. This can be considered from the following two viewpoints.

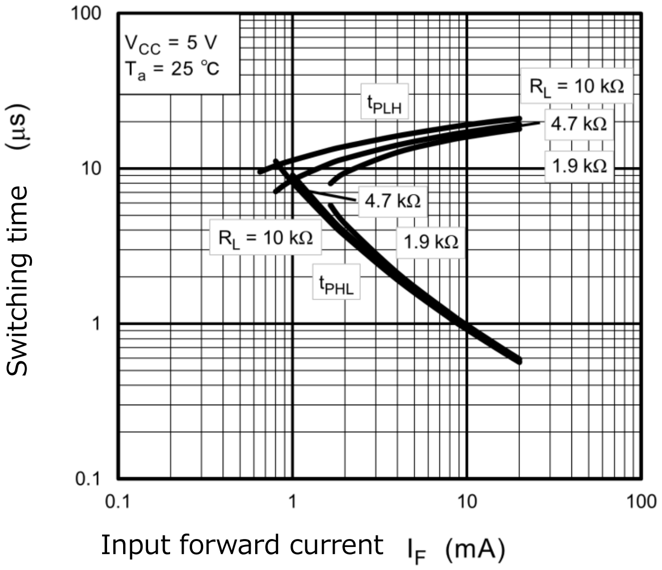


Figure 2.26 Switching time - I_F characteristics on TLP2301

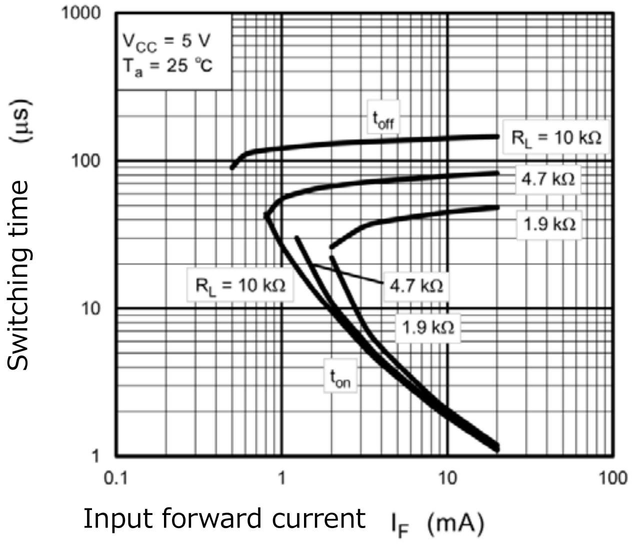


Figure 2.27 Switching time - I_F characteristics on TLP185(SE

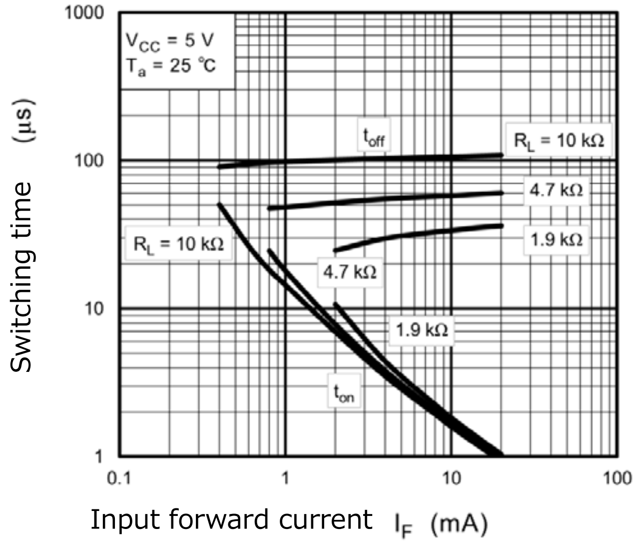


Figure 2.28 Switching time - I_F characteristics on TLP183

1. R_L: 10 kΩ ⇔ 4.7 kΩ

Figures 2.26 to 2.28 indicate that the switching time of the TLP2301 does not exhibit as much dependence on R_L as those of the TLP185(SE and TLP183.

2. I_F: 1 mA ⇔ 8 mA

Figure 2.26 indicates that, in the case of the TLP2301, t_{OFF} (t_{pLH}) and t_{ON} (t_{pHL}) become increasingly asymmetrical as I_F increases. At a low I_F of around 1 mA, t_{OFF} (t_{pLH}) and t_{ON} (t_{pHL}) are almost equal. Therefore, care should be taken as to the symmetry of turn-on and turn-off times.

(3) Figure 2.29 compares the switching waveforms of the TLP2301 and TLP185(SE. It indicates that there is a difference in the V_O rise time when they turn off.

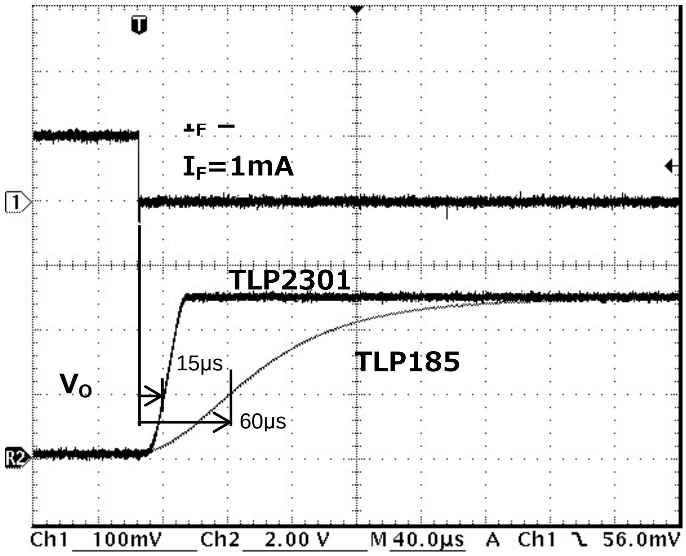


Figure 2.29 Switching waveform comparison between TLP185 and TLP2301

Conditions : I_F = 1mA, R_L = 10kΩ, 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

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 Dissipation, Input Power Dissipation	P_D	Rated power that can be dissipated in the LED
Total Power Dissipation	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 Current	$I_{C(off)}$	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

Revision history

Version	Date	Page reference	Details
Rev. 1.0	2019-05-17	-	Created

RESTRICTIONS ON PRODUCT USE

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