

Optocoupler Applications

DESIGNING FOR OPTOCOUPPLERS WITH BASE PIN

GENERAL

Optocouplers (optical couplers) are designed to isolate electrical output from input for complete elimination of noise. They have been used conventionally as substitutes for relays and pulse transformers. Today's current technology in the area of microcomputers creates new applications for optocouplers.

This manual describes the characteristics of typical optocouplers. Also included are notes on designing application circuits for typical optocouplers (with a base pin) for better comprehension. NEC's typical optocouplers with or without base pins are listed on the following pages.

PS2600 Series Optocouplers (6-Pin Dual-in-Line Package)

Product name	Internal connection	Features	Absolute Maximum Ratings (T _A = 25°C)			Electric Characteristics (T _A = 25°C)		
			BV (Vr.m.s.)	I _F (mA)	I _C (mA)	CTR (%)	tr (μs) (TYP)	tr (μs) (TYP)
* PS2601 PS2601L		High isolation voltage High V _{CEO} (80 V MIN.) Single transistor	5 k	80	50	80 to 600	3	5
PS2602 PS2602L								
* PS2603 PS2603L		High isolation voltage High CTR Darlington-transistor	5 k	80	200	200 to 2500	100	100
PS2604 PS2604L								
* PS2605 PS2605L		High isolation voltage A.C. input High V _{CEO} (80 V MIN.) Single transistor	5 k	±80	50	80 to 600	3	5
PS2606 PS2606L								
* PS2607 PS2607L		High isolation voltage A.C. input High CTR Darlington-transistor	5 k	±80	200	200 to 3400	100	100
PS2608 PS2608L								
* PS2621 PS2621L		High isolation voltage Large input current Single transistor	5 k	150	50	20 to 50	3	5
PS2622 PS2622L								
* PS2625 PS2625L		High isolation voltage A.C. input Large input current Single transistor	5 k	±150	50	20 to 50	3	5
PS2626 PS2626L								
* PS2633 PS2633L		High isolation voltage High V _{CEO} (300 V MIN.) High CTR Darlington-transistor	5 k	80	150	1000 to 15000	100	100
PS2634 PS2634L								
* PS2651 PS2651L2		High isolation voltage High V _{CEO} (80 V MIN.) Single transistor	5 k	80	50	50 to 400	3	5
PS2652 PS2652L2								
* PS2653 PS2653L2		High isolation voltage High CTR Darlington-transistors	5 k	80	200	200 to 3400	100	100
PS2654 PS2654L2								

* (with a base pin)

Note: A product name followed by letter L indicates a product having leads formed for surface mount.

There are two kinds of optocouplers (a light emitting diode (LED) as an input and a phototransistor as an output) according to the type of output transistor: Single transistor type and Darlington-transistor type.

The single-transistor type optocouplers are used to perform high-speed switching (with high-speed response). The Darlington-transistor type optocouplers are used to obtain a large output current by utilizing a small input current (independently of switching speeds).

Designing the circuits properly will improve the PS2601 optocoupler (Single Transistor type) by having a base pin in terms of switching speed, elimination of noise in input signals, and output leakage current (collector dark current, and application to high-voltage circuits).

APPLICATIONS OF OPTOCOUPLER BASE PINS

INCREASING SWITCHING SPEED

The switching speed of an optocoupler with a base pin can be increased by inserting a resistor between the base and the emitter of its phototransistor even when the optocoupler is applied to a large load resistance.

Generally, the phototransistor of an optocoupler such as the PS2601 has a large photo-sensitive area on it. Accordingly, the junction capacitance (C_{C-B}) between the collector and the base of the phototransistor is great (up to 20 pF) and as a result its response speed (turn-off time t_{off}) is low. The relationship between turn-off time t_{off} and collector-base capacitance C_{C-B} is expressed by:

$$t_{off} \times C_{C-B} \times h_{FE} \times R_L \dots\dots\dots(1)$$

where

t_{off} : Turn-off time (See Fig. 2-2.)

C_{C-B} : Collector-base capacitance

h_{FE} : D.C. current amplification factor

R_L : Load resistance

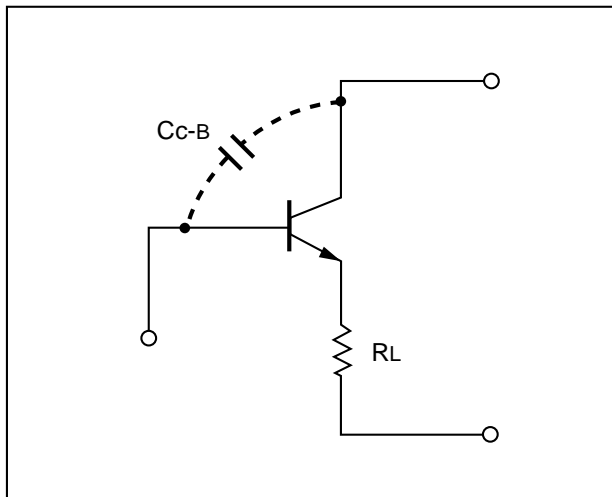


Figure 2-1. Collector-Base Capacitance C_{C-B} of Phototransistor

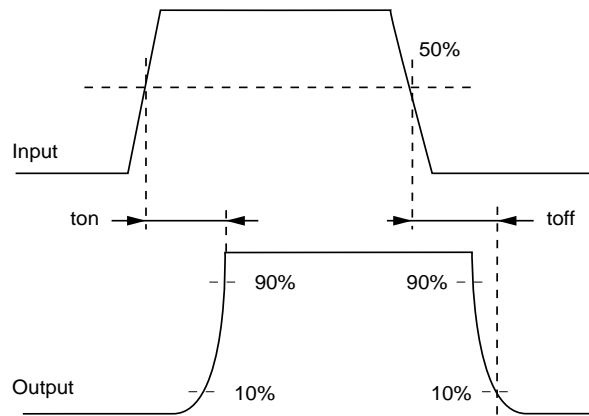
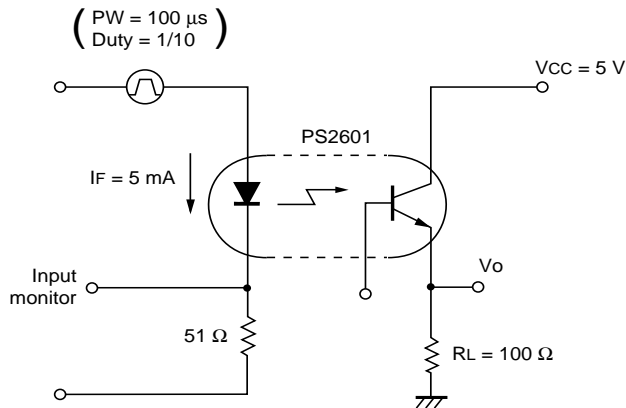


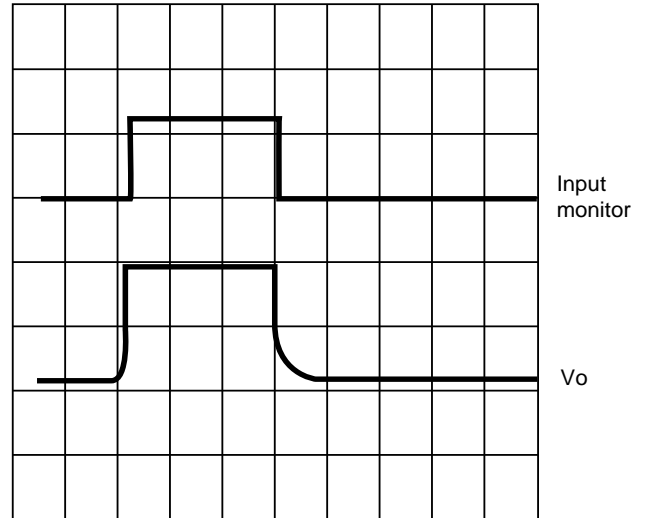
Figure 2-2. t_{on}/t_{off} Measuring Points

As judged from expression (1), the turn-off time t_{off} is affected by collector-base capacitance C_{c-b} , D.C. current amplification factor h_{FE} , and load resistance L_R . In actual circuit design, C_{c-b} and h_{FE} are fixed. Accordingly, the turn-off time is significantly affected by the resistance of load R_L .

Graph 1 shows the relationship between response speed (t_{on}, t_{off}) and load resistance (R_L) in typical emitter follower (test circuit 1) having a load resistance of 100Ω .



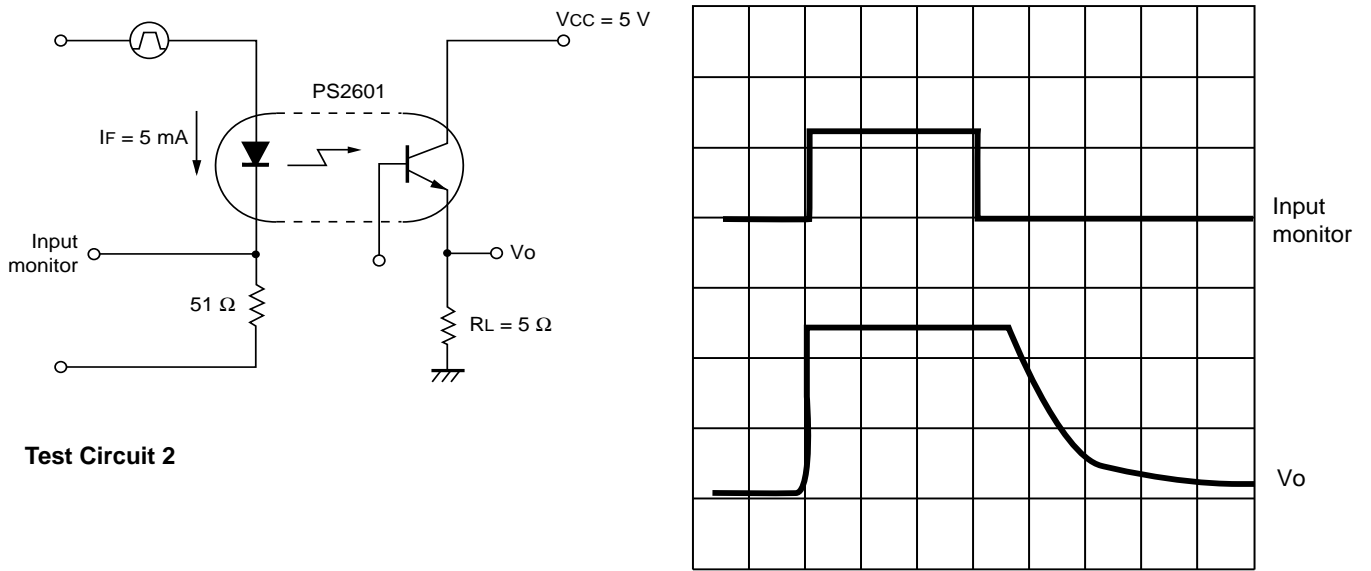
Test Circuit 1



Graph 1

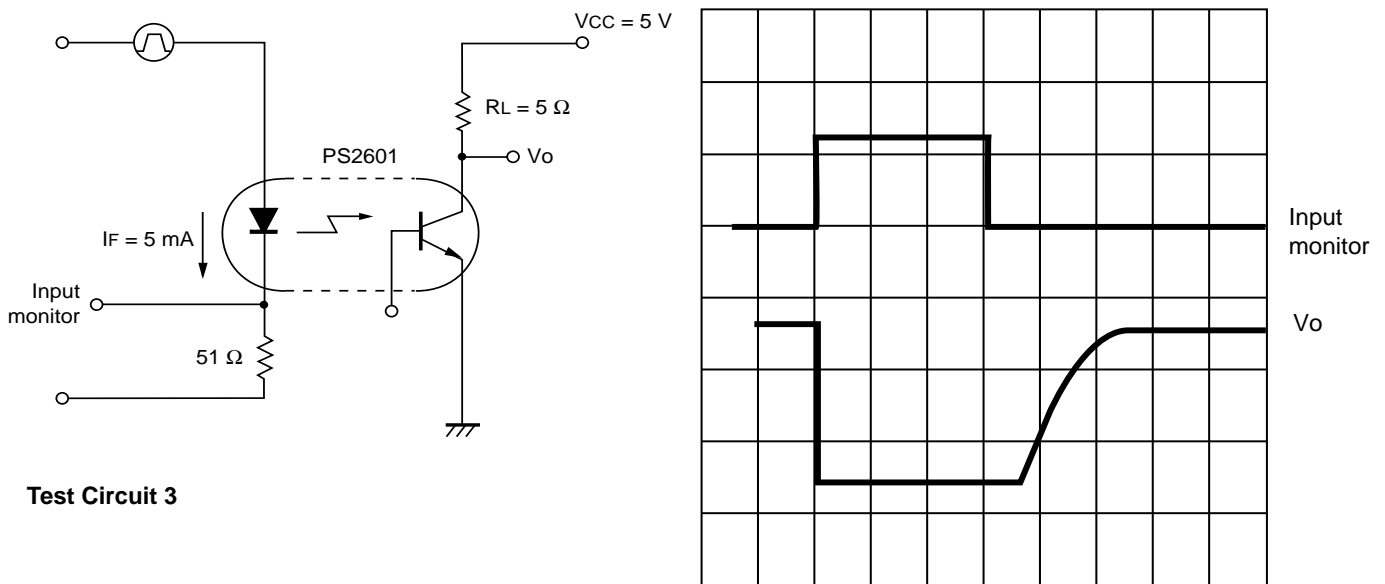
Up : Input 0.2 V/DIV
 DOWN : Output 0.5 V/DIV
 (50 μ s/DIV)

Graph 2 shows the relationship between response speed (t_{on} , t_{off}) and load resistance (R_L) in a typical emitter follower (Test circuit 2) having a greater load resistance ($5\text{ k}\Omega$).



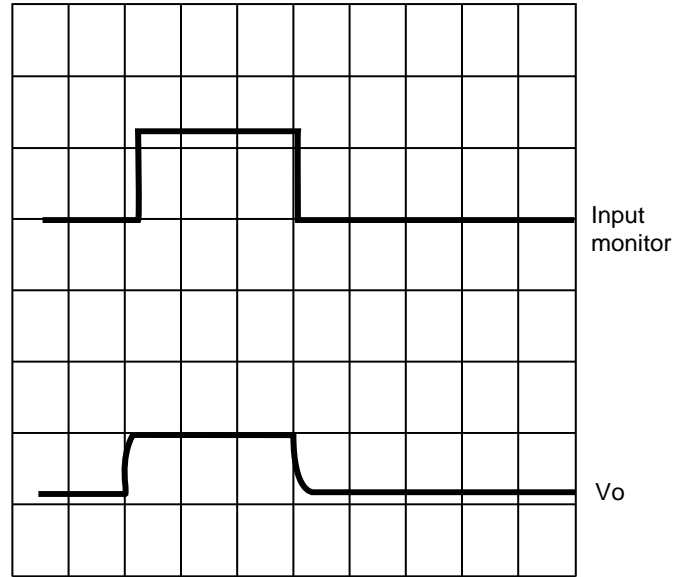
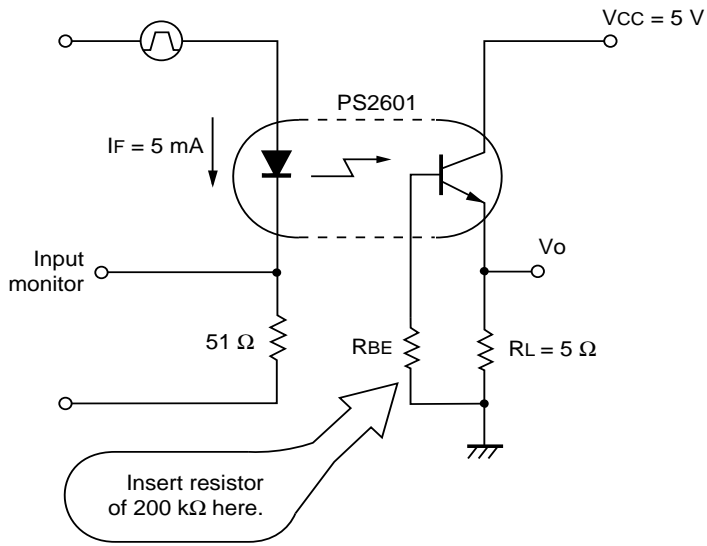
Graph 2
 Up : Input 0.2 V/DIV
 DOWN : Output 2 V/DIV
 (50 μs /DIV)

As shown in Graph 2, the turn-off time for load resistance of $5\text{ k}\Omega$ is about $100\text{ }\mu\text{s}$. Similarly, the turn-off time for load resistance of $100\text{ k}\Omega$ is 1 to 2 ms. This is also true when the load resistance is connected to the collector of the phototransistor. Graph 3 shows the relationship between response speed (t_{on} , t_{off}) and load resistance (R_L) in a typical circuit (Test circuit 3) having collector load resistance ($5\text{ k}\Omega$) with the emitter grounded.



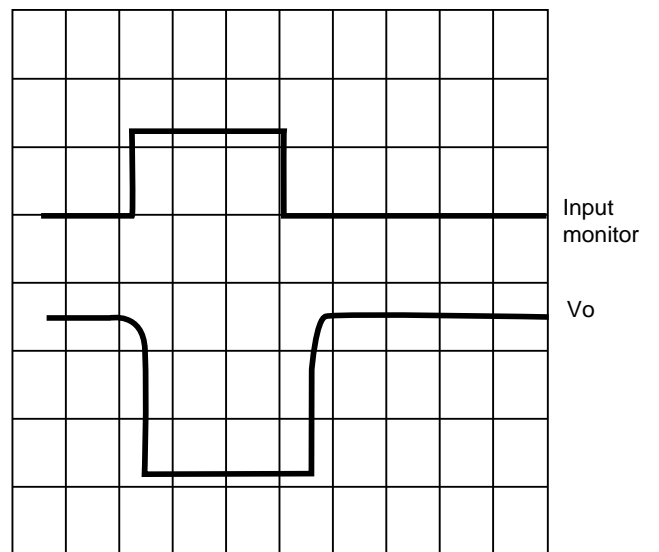
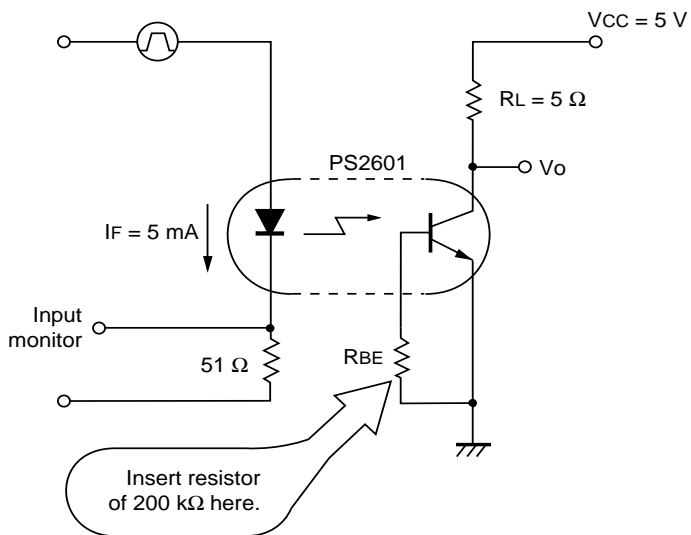
Graph 3
 Up : Input 0.2 V/DIV
 DOWN : Output 2 V/DIV
 (50 μs /DIV)

To reduce the turn-off time t_{off} of a test circuit having a greater resistance, insert a resistor R_{BE} between the emitter and the base of the phototransistor. See Test circuit 4 and Test circuit 5. Graph 4 and 5 show their input and output waveforms.



Test Circuit 4
(Emitter Follower)

Graph 4
Up : Input 0.2 V/DIV
DOWN : Output 2 V/DIV
(50 μs/DIV)



Test Circuit 5
(Emitter Grounded)

Graph 5
Up : Input 0.2 V/DIV
DOWN : Output 2 V/DIV
(50 μs/DIV)

The turn-off time can be greatly reduced by the base-emitter resistance (R_L). In Test circuit 4, the turn-off time of the test circuit having resistance R_L is about 1/30 of that of the test circuit without the resistance. This is because the carrier (photocurrent) stored in the collector-base capacitor (C_{C-B}) is quickly released through the base-emitter resistor (RBE). However, note that part of a photocurrent generating on the base of the phototransistor flows through the RBE resistor and reduces the current transfer ratio (CTR). Compare the voltage level of the output waveform in Photo 4 with that of the output waveform in Photo 2. The current transfer ratio of the test circuit having a base-emitter resistor of 200 k Ω is half or less of that of the test circuit without the resistance. (See 3.3 for reduction of the current transfer ratio CTR.)

For reference, Fig. 2-3 shows the switching-time vs. R_L characteristics and Fig. 2-4 shows the switching-time vs. RBE characteristics.

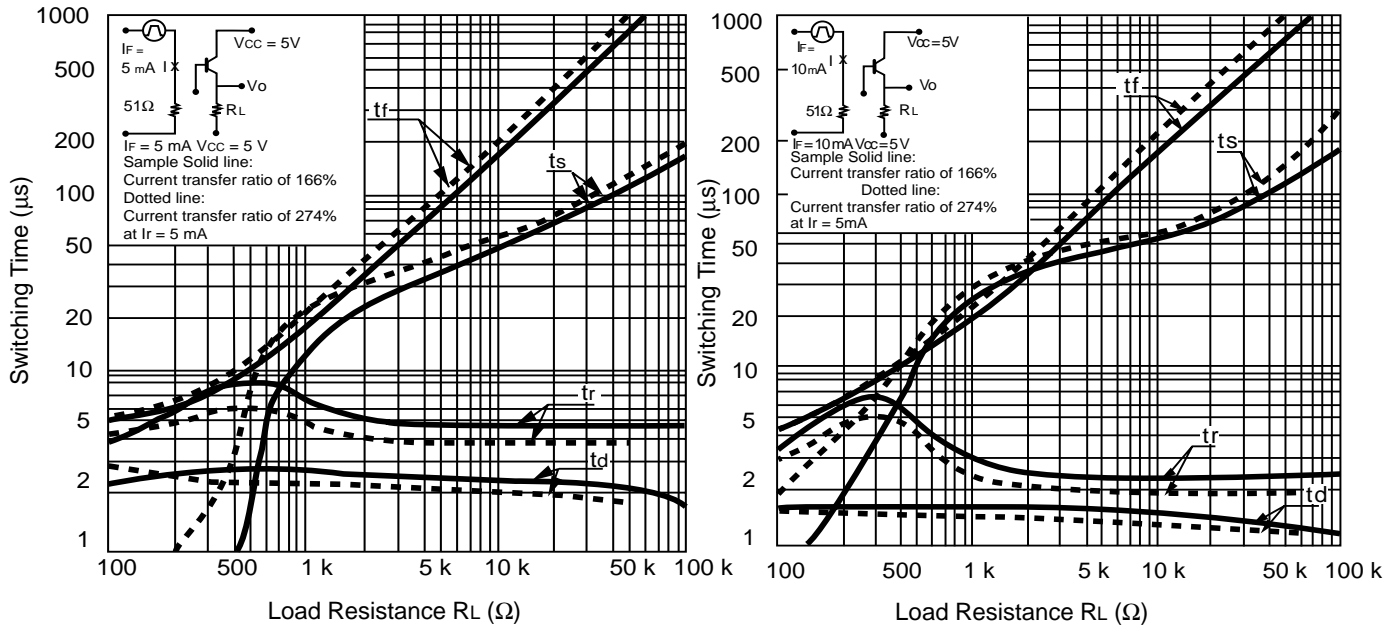


Fig. 2-3 Switching-Time vs. R_L Characteristics

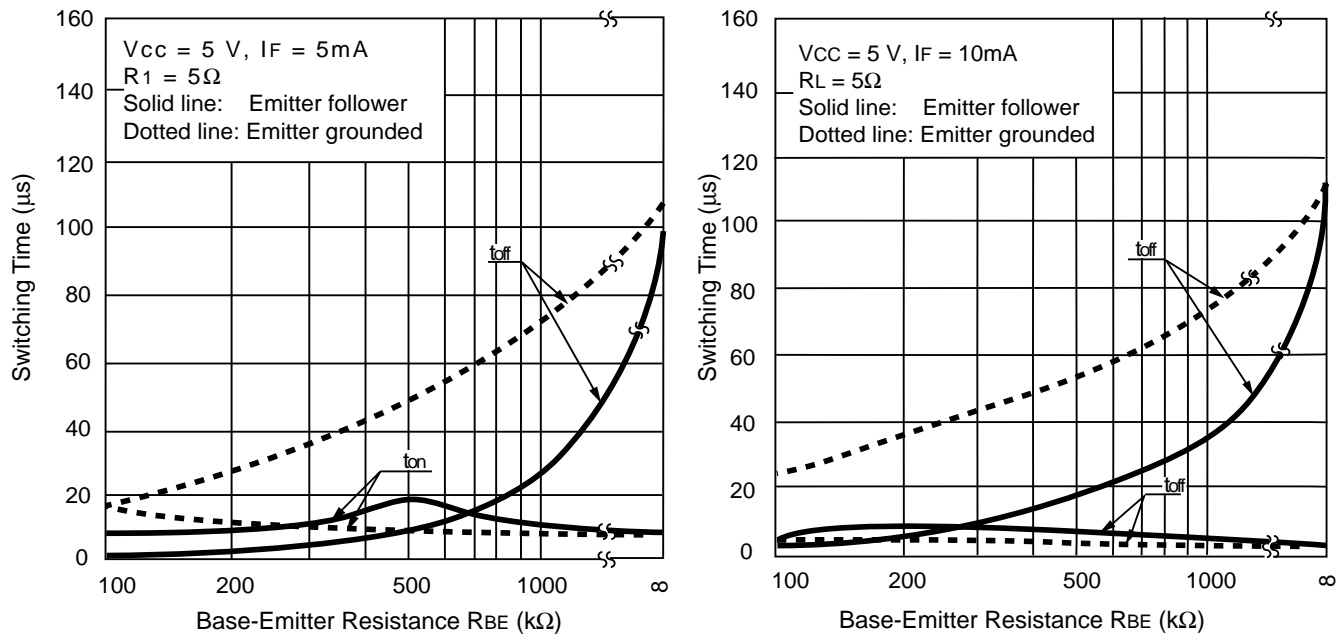


Fig. 2-4 Switching-Time vs. RBE Characteristics

STABILIZING OUTPUT LEVELS

When an optocoupler is used with the base pin of its phototransistor open, the collector dark current (I_{CEO}) flows as a base current. The current is amplified as a collector current and could make the output level of the phototransistor unstable. To eliminate this unwanted base current and make the output level stable, flow the collector dark current (I_{CEO}) through the base-emitter resistor (R_{BE}).

Fig 2-5 shows the I_{CEO} vs. T_A characteristics of a PS2601 optocoupler.

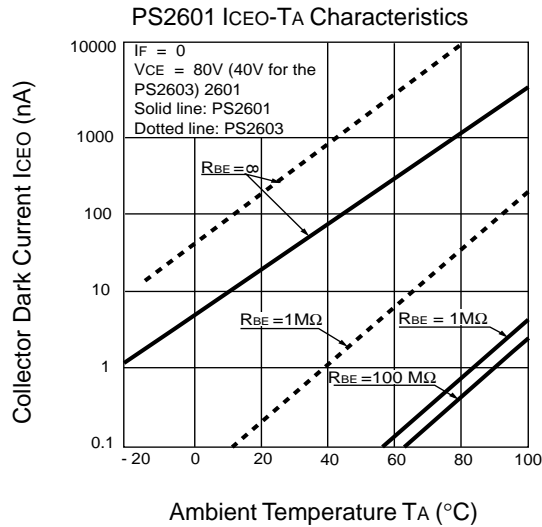


Figure 2-5. I_{CEO} vs. T_A Characteristics

ELIMINATION OF INDUCED NOISE

Generally, machine-controlling equipment generates induced noise which may cause malfunctions. This unwanted noise in input signals can be isolated by means of optocouplers. However, if the noise is too strong, it may be switched to the output through the input-output capacitance C_{1-2} of the optocoupler. This unwanted noise in the output can be removed in the following manner. Insert a capacitor (preferably 100 pF) between the base and the emitter of the phototransistor of the optocoupler. This capacitor delays response and suppresses malfunctions.

Graph 6-(a) to 6-(d) show how an external noise (surge voltage of 1000 V/ μ s at rise time) is eliminated as the capacitance of the base-emitter capacitor.

A fluctuation in the collector-emitter voltage caused by the on/off operation of a power switch at the output of the optocoupler causes a base current to flow through the collector-base capacitor (C_{CB}), which causes a malfunction.

In Fig. 2-7, for example, an instantaneous base current flows through the collector-base capacitor (C_{CB}) of the optocoupler. The current is multiplied by h_{FE} (as a collector current) and causes an output voltage on both ends of the load resistance. It seems as if an input signal was applied to the optocoupler. Graph 7-(a) shows the waveforms. This unwanted instantaneous induction current can be eliminated by inserting a capacitor C_{BE} between the emitter and the base of the phototransistor. Graph 7-(b) shows the waveforms. Fig. 2-8 shows the output-voltage vs. C_{BE} characteristics.

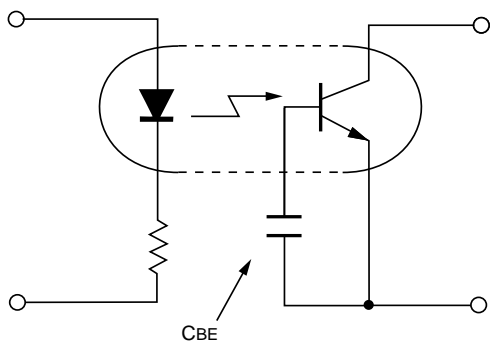


Figure 2-6.

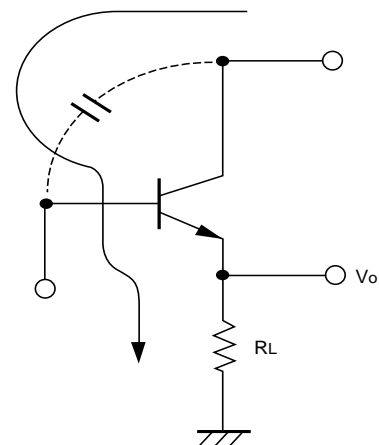
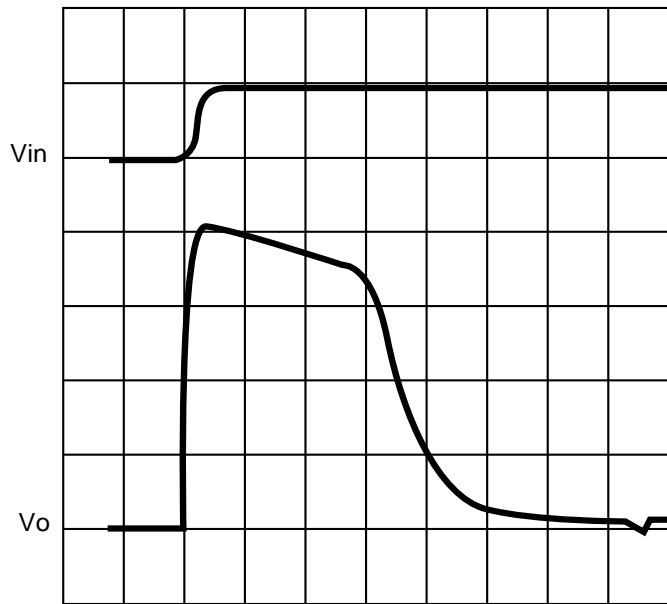
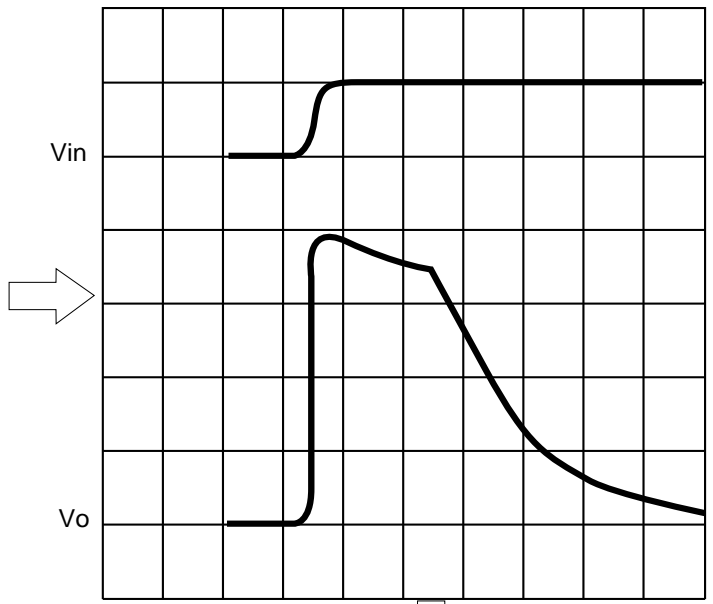


Figure 2-7.

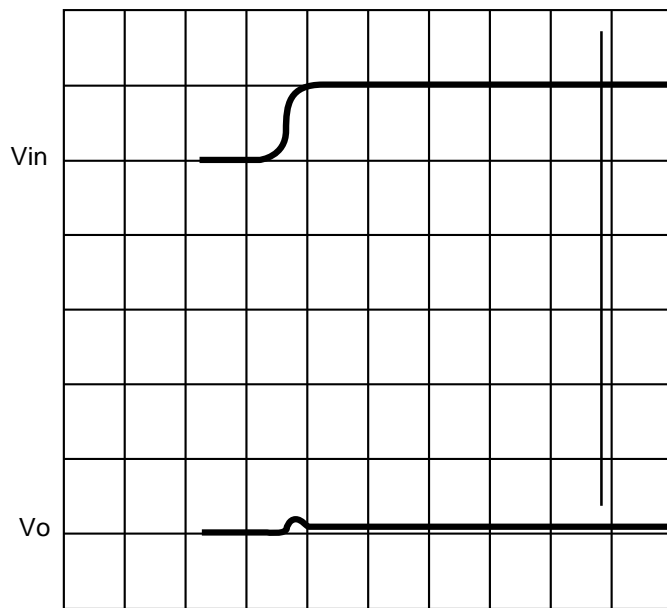
6a) C_{BE} = No capacitance



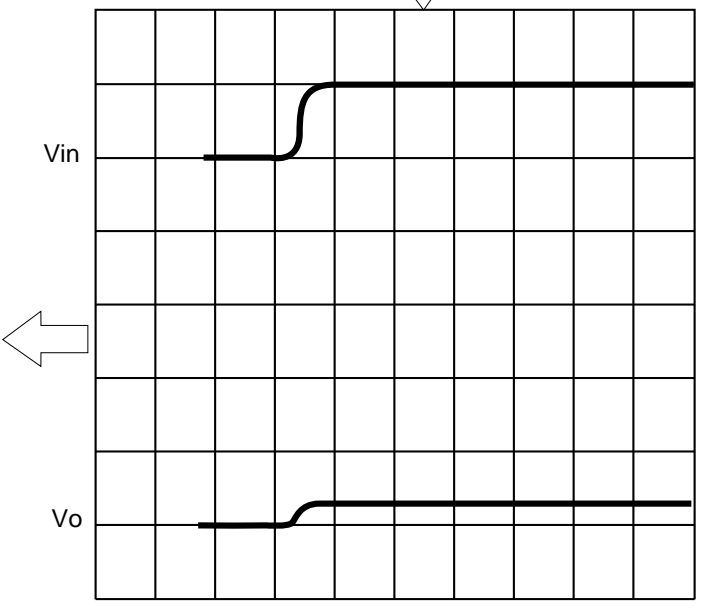
6b) C_{BE} = 10 pF



6d) C_{BE} = 1000 pF

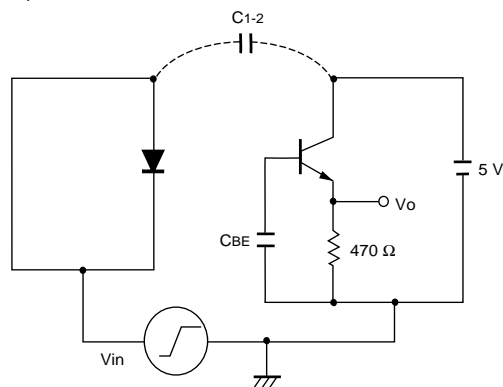


6c) C_{BE} = 100 pF

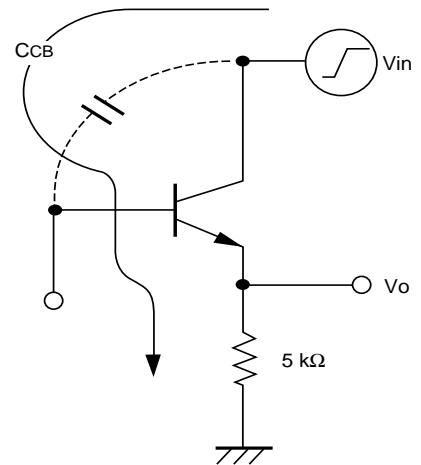
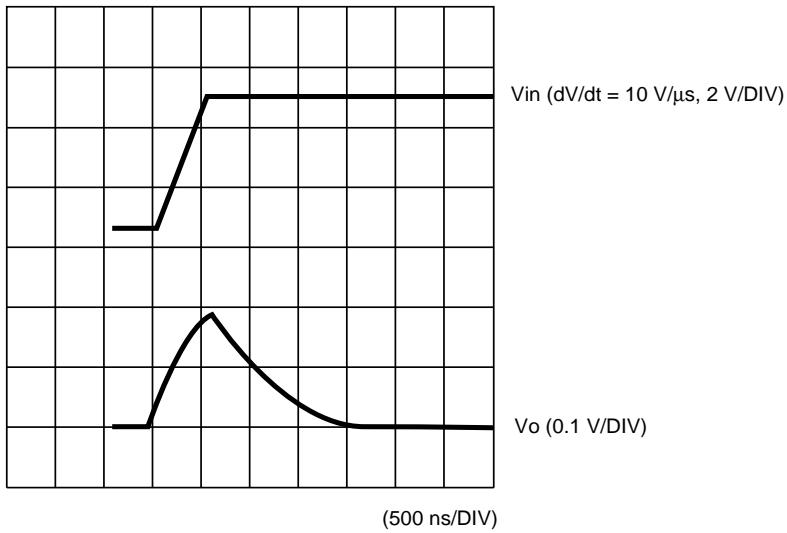


Graph 6

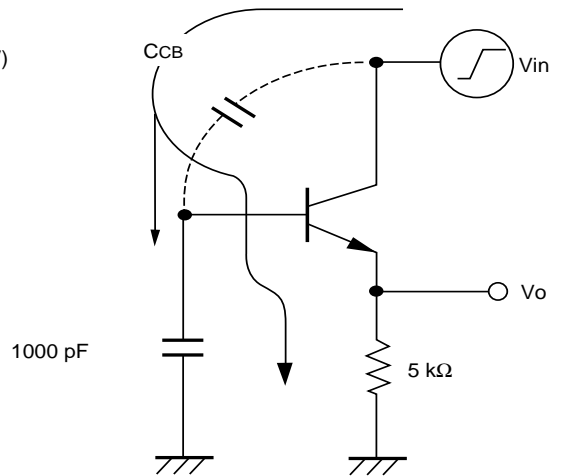
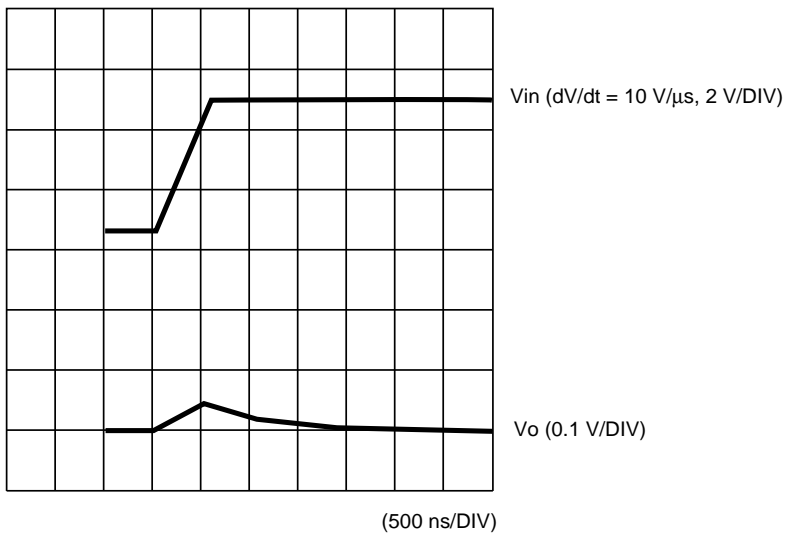
Up : Input Surge Voltage (Vin :1000 V/DIV)
 DOWN : PS2601 output (VO: 1 V/DIV)



Test Circuit



Graph 7-(a)
Input Voltage Fluctuation and Output



Graph 7-(b)
Effect of Collector-Base Capacitance on
Voltage Fluctuation

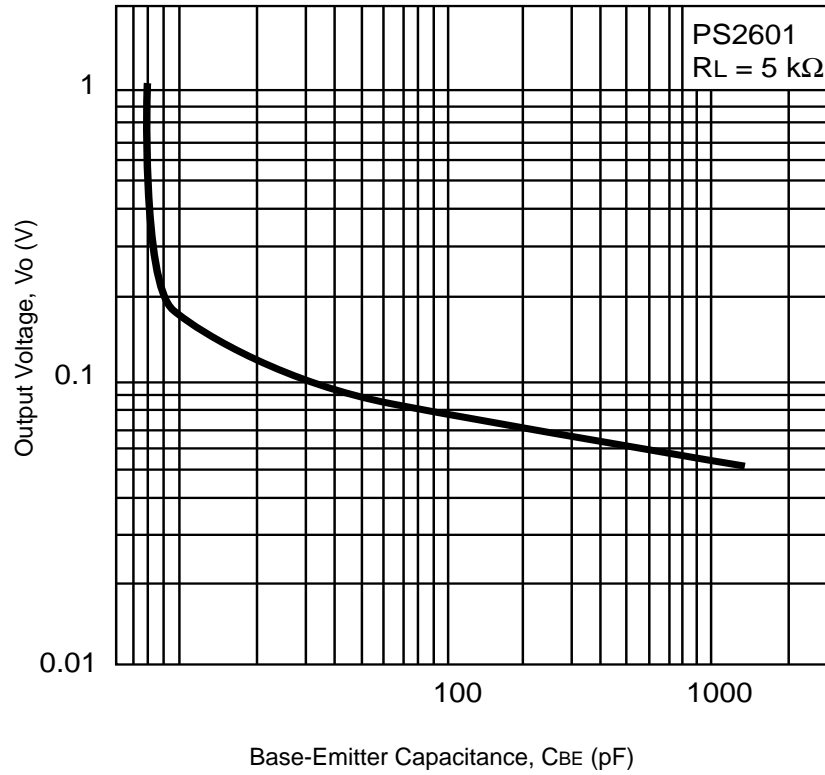
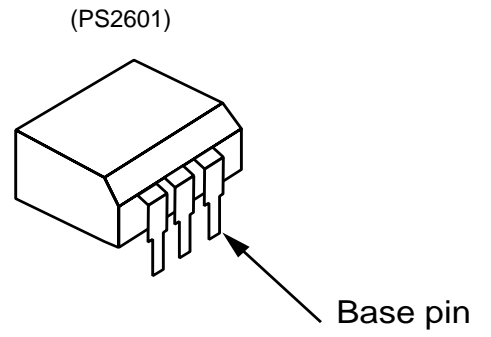
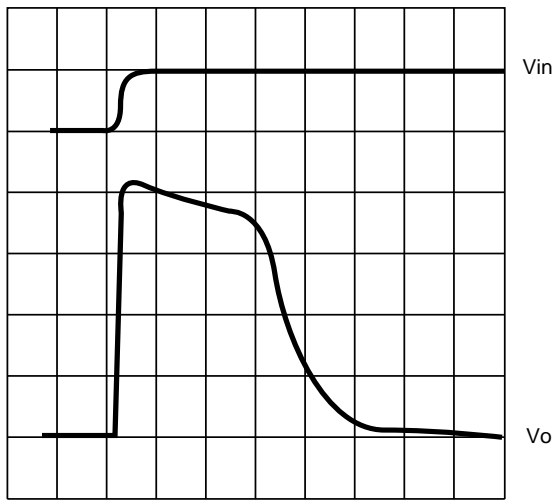


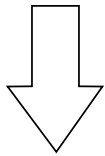
Figure 2-8. Vo vs. CBE Characteristics

As mentioned above, noise induced by the fluctuation of supply voltage can be removed by proper treatment of the base pin. For switching of input free from induced noise at normal switching speed, optocouplers with a base pin such as the PS2602 series are available. If the base pin of an optocoupler is left unused or opened, it typically will pick up external noise. Cutting off the base pin is also effective in order to prevent it from picking up external noise. See Graph 8-(b).

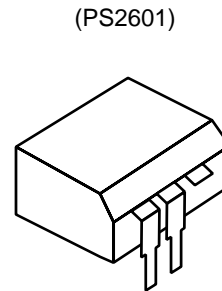
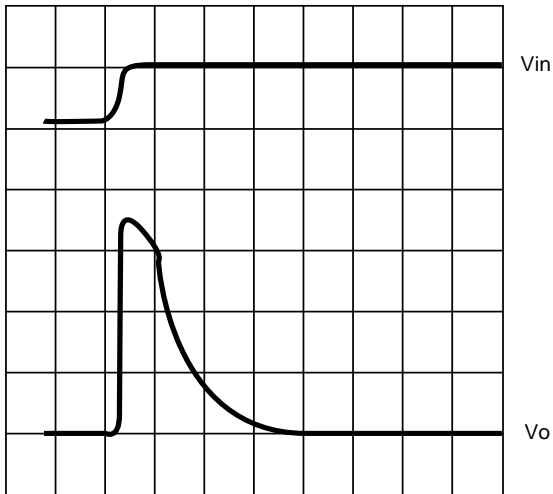


Graph 8-(a)

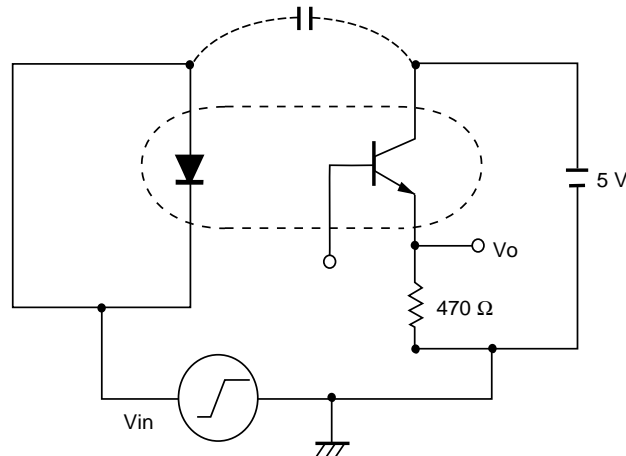
Up : Input Surge Voltage (Vin: 1000 V/DIV)
 DOWN : PS2601 Output (Vo: 1 V/DIV)



Cut the base pin (pin 6)



Graph 8-(b)



Test Circuit

ELIMINATION OF INPUT SURGES

Unwanted external noise and output leakage currents (e.g., collector current I_C) of a preceding transistor may cause the light-emitting diode (LED) of an optocoupler to light involuntarily. Usually, a circuit (connecting a resistor in parallel to the LED) is provided to absorb such input surges. To prevent malfunction of an optocoupler, it is also effective to insert a resistor (R_{BE}) that increases the input threshold current (by the use of the input-output characteristics) between the base and the emitter of the phototransistor. In this case, the current transfer ratio (CTR) must be low. (See 3.3 for Reduction of CTR.)

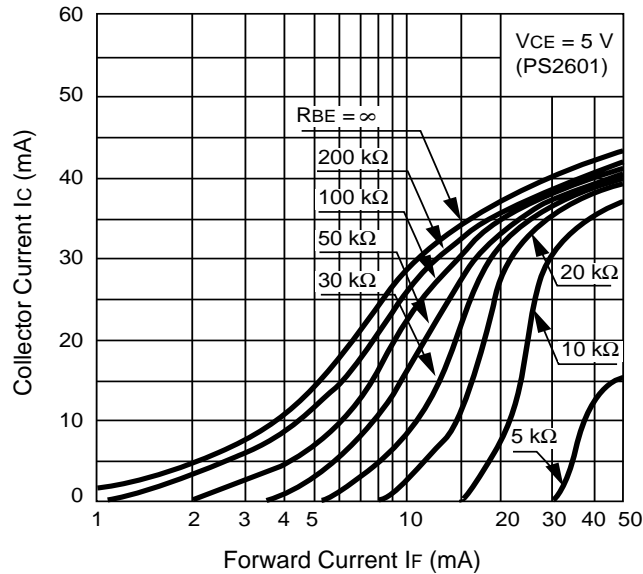


Figure 2-9. I_C vs. I_F Characteristics (Example)

APPLICATION TO HIGH POTENTIAL CIRCUIT

The withstanding voltage between the collector and the emitter of the PS2601 optocoupler is 80 V (MAX). To make the optocoupler available to higher withstanding voltages, use the collector-base junction photodiode as a light-sensitive element and connect a high-voltage circuit to the output of the optocoupler. In this case, the output of the photodiode must be amplified because it is smaller than the usual output.

Fig. 2-10 shows an example of an optocoupler applied to a high-voltage circuit. In this sample circuit, the photocurrent (I_{CBL}) of the optocoupler is fed to the base of the high-voltage transistor and a current (I_F) passes forward through the light-emitting diode (LED). Fig. 2-11 shows the I_{CBL} vs. I_F characteristics. Before working on applications outside the rated values of the optocouplers, evaluate the practical circuits fully by contacting CEL.

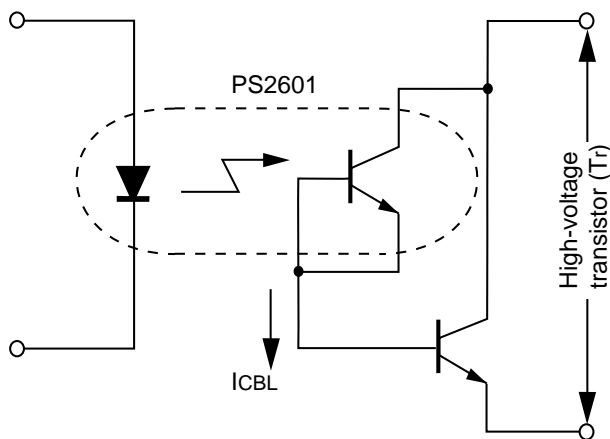


Figure 2-10. Application to a High Voltage Circuit

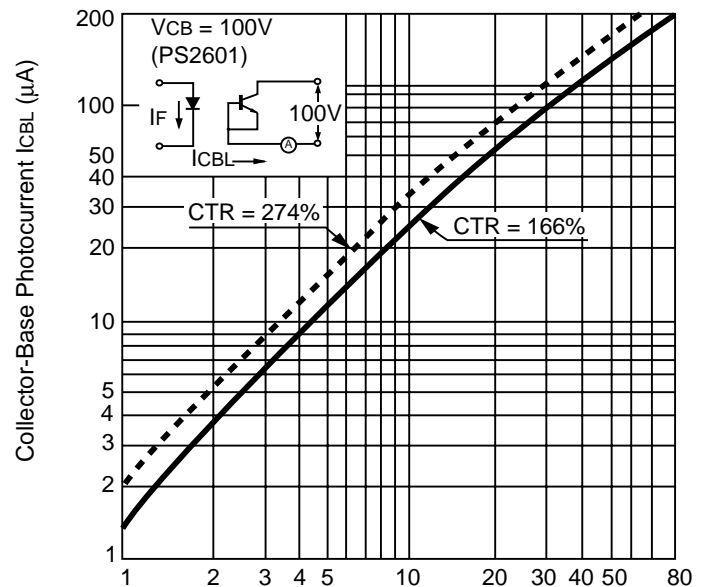


Figure 2-11. I_{CBL} vs. I_F Characteristic

NOTES ON USE OF OPTOCOUPLER BASE PIN

This chapter explains the reduction of a current transfer ratio of an optocoupler whose base and emitter are connected by a resistor (RBE) and other optocouplers that seem to be significant in the treatment of the base pin of an optocoupler.

EQUIVALENT CIRCUIT (FOR PS2601 OPTOCOUPLER)

Fig. 3-1 shows an equivalent circuit of a single-transistor optocoupler such as the PS2601.

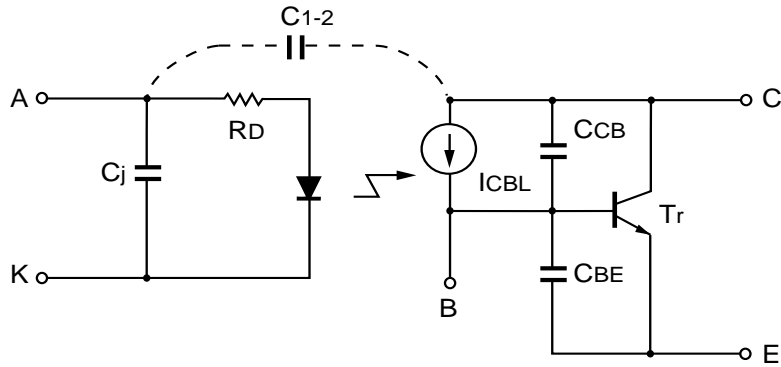


Figure 3-1. Equivalent Circuit (for PS2601 Optocoupler)

- C_j : Junction capacity of LED
- C_{BE} : Base-emitter capacitance
- R_D : Resistor serially connected to LED
- I_{CBL} : Collector-base photocurrent generated by the light of the LED
- C₁₋₂ : Input-output capacitance
- T_r : Amplifying transistor

DEFINITION OF CURRENT TRANSFER RATIO (CTR)

A current transfer ratio (CTR) of an optocoupler indicates the rate of an output current I_c of its phototransistor to a forward input current (I_F) flowing through its light-emitting diode (LED). The CTR is expressed by:

$$\text{CTR} = \frac{I_c}{I_F} \times 100 (\%) \dots\dots\dots(2)$$

where $I_c = I_{CBL} \cdot h_{FE} \dots\dots\dots(3)$

(h_{FE}: D.C. current amplification factor of the phototransistor)

REDUCTION OF CURRENT TRANSFER RATIO (CTR) BY INSERTION OF BASE-EMITTER RESISTOR

A resistor (R_{BE}) connected to the base and emitter pins of an optocoupler causes the reduction of the output current (reduction of current transfer ratio). This is because a part (I_1) of the base current flows through the base-emitter resistor and causes a voltage equivalent to the emitter-base voltage (V_{BE}). The base current is reduced by this current component (I_1) and, as the result, the current transfer ratio (CTR) goes down. The output current I_C' is expressed as follows:

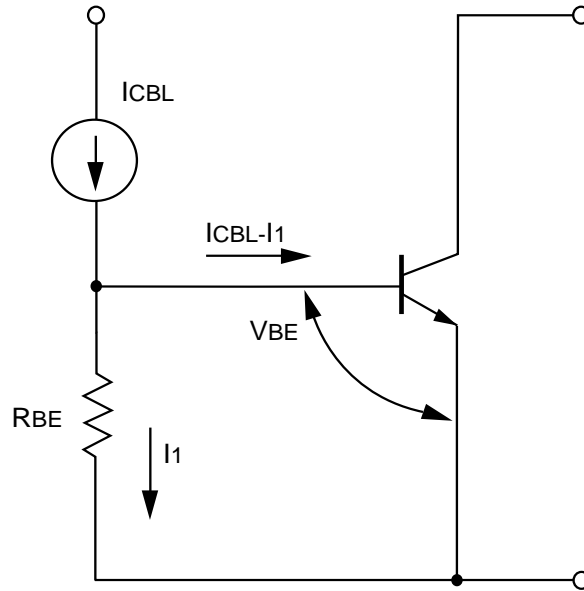


Figure 3-2.

$$I_C' = h_{FE}' (I_{CBL} - I_1) = h_{FE}' \left(I_{CBL} - \frac{V_{BE}}{R_{BE}} \right)$$

$$\therefore I_C' = h_{FE}' \cdot I_{CBL} \left(1 - \frac{V_{BE}}{I_{CBL} \cdot R_{BE}} \right) \dots\dots\dots (4)$$

Note I_C' : Output current of an optocoupler having R_{BE}
 h_{FE}' : Amplification factor of an optocoupler having R_{BE}

Accordingly, the ratio of output current I_C' (of the optocoupler having R_{BE}) to output current I_C (of the optocoupler with the base open) is expressed by:

$$\frac{I_C'}{I_C} \frac{h_{FE}'}{h_{FE}} = \left(1 - \frac{V_{BE}}{I_{CBL} \cdot R_{BE}} \right) \dots\dots\dots (5)$$

As h_{FE}' is equal to h_{FE} if $I_F = \text{approx. } 5 \text{ mA}$, $I_C = \text{approx. } 15 \text{ mA}$, and $R_{BC} > 100 \text{ k}\Omega$, expression (5) is simplified as follows:

$$\frac{I_C'}{I_C} = 1 - \frac{V_{BE}}{I_{CBL} \cdot R_{BE}} \dots\dots\dots (6)$$

Expression (6) indicates that the current transfer ratio (CTR) is significantly affected by the value of $I_{CBL} \cdot R_{BE}$. For example, if the forward current I_F of the light-emitting diode is smaller (that is, I_{CBL} is smaller) or if the base-emitter resistance R_{BE} is smaller, the reduction rate (rate of I_C) becomes greater.

The above CTR reduction must be considered when inserting a resistor between the emitter and the base of the phototransistor of the optocoupler to increase the switching speed. The performance of the optocoupler might become unstable because the CTR will be affected by time elapse or temperature change (even if it is initially stable).

Fig. 3-3 shows the ΔCTR - R_{BE} characteristics.

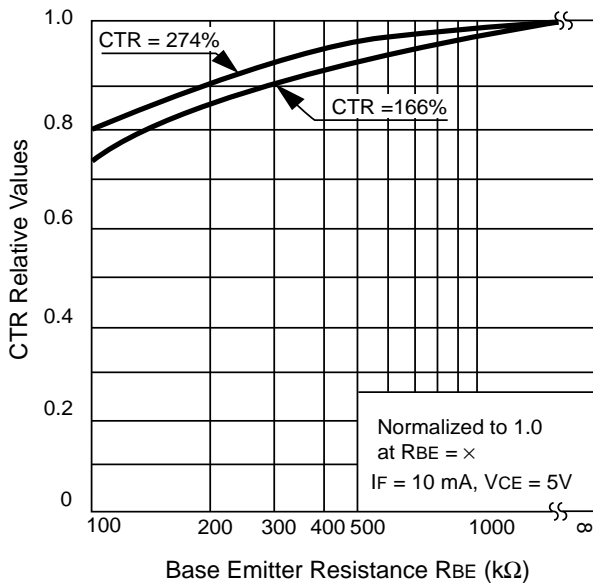
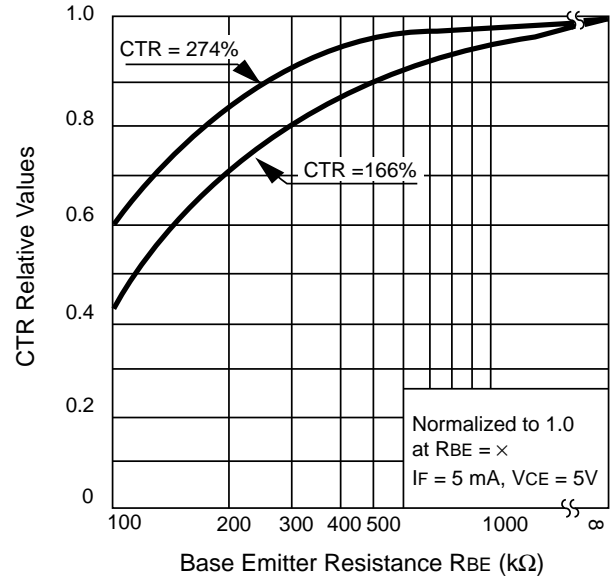
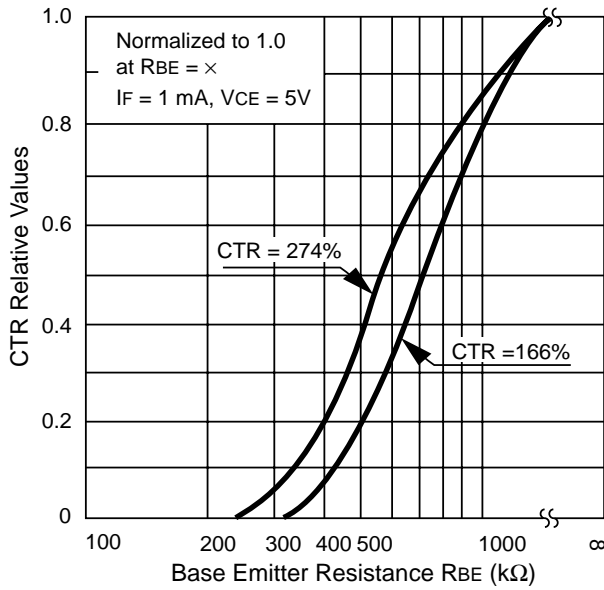
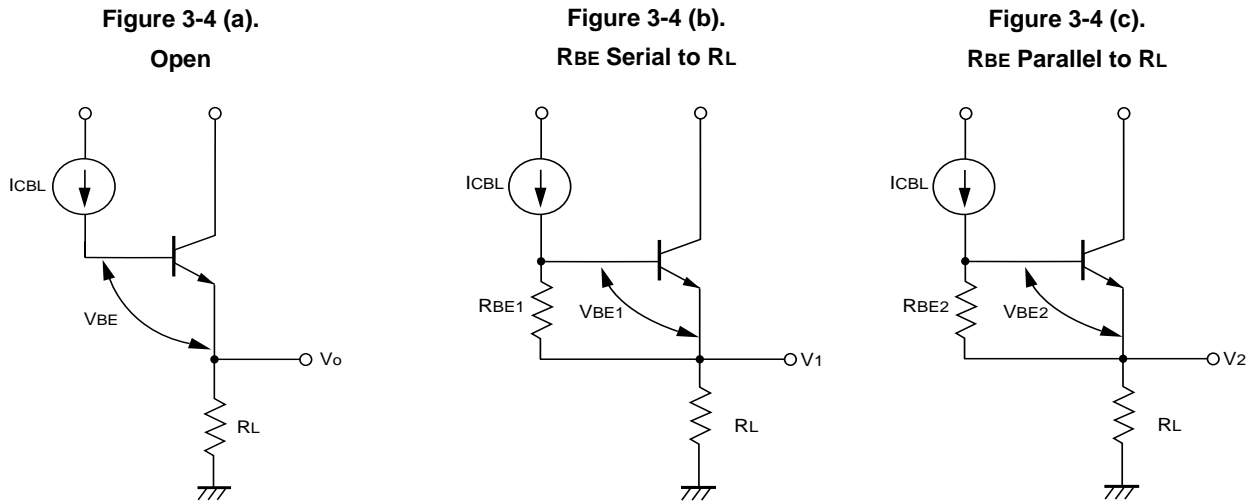


Figure 3-3. ΔCTR - R_{BE} Characteristics

The reduction of a CTR is greatly affected by the positional relationship between load resistor R_L and base-emitter resistor R_{BE} , as shown in Fig. 3-4 (b) and 3-4 (c).



The output voltage V_0 , V_1 , and V_2 of the above circuits (a), (b), and (c) are related as follows:

$$\frac{V_1}{V_2} = \frac{hFE1}{hFE0} \left(1 - \frac{V_{BE}}{I_{CBL} \cdot R_{BE1}} \right) \dots\dots\dots (7)$$

$$\frac{V_2}{V_0} = \frac{hFE2}{hFE0} \left(\frac{1 - \frac{V_{BE2}}{I_{CBL} \cdot R_{BE1}}}{1 + \frac{R_L \cdot hFE2}{R_{BE2}}} \right) \dots\dots\dots (8)$$

When resistor R_{BE} is serially connected to resistor R_L (see Fig. 3-4 (c)), the reduction of a CTR becomes greater even if $hFE2$ is approximately equal to $hFE0$ in expression (8) as the expression includes R_L as a parameter. Fig. 3-5 shows typical V_o vs. I_F characteristics of the above circuits (a), (b), and (c).

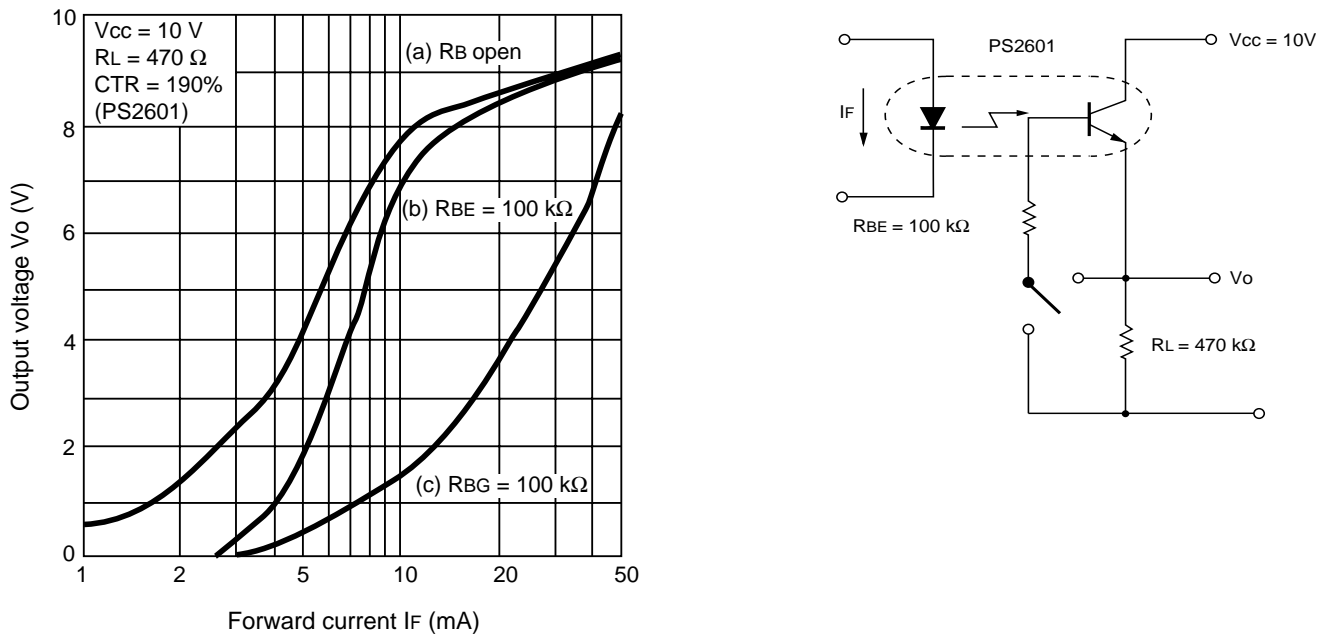


Figure 3-5. V_o vs. I_F Characteristics

CIRCUIT DESIGN EXAMPLE (USING THE PS2601)

Fig. 4-1 shows a design example of an optocoupler circuit having a base-emitter resistor for improvement of response ability.

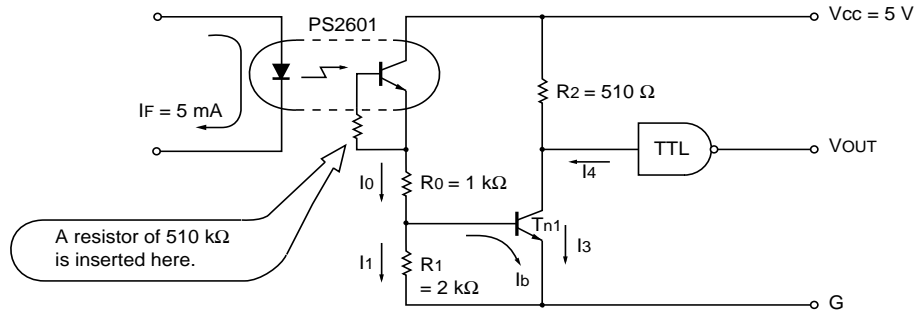


Figure 4-1. Circuit Design Example

The minimum current transfer ratio (CTR) required for TTL operation is calculated as follows:

Current I_4 must be 1.6 mA to drive the TTL and the collector-emitter voltage of transistor T_{r1} must be 0.8 V or less. Accordingly, I_2 must be as follows:

$$I_2 \oplus \frac{V_{CC} - V_{CE}}{R_2} = \frac{5 - 0.8}{0.51 \text{ (k}\Omega\text{)}} = 8.2 \text{ (mA)} \dots\dots\dots(9)$$

Therefore $I_3 = I_2 + I_4 = 8.2 + 1.6 = 9.8 \text{ (mA)} \dots\dots\dots(10)$

Let's assume that h_{FE} of transistor T_{r1} is 40 (worst). I_b must be as follows:

$$I_b \oplus \frac{I_3}{h_{FE}} = \frac{9.9 \text{ (mA)}}{40} = 0.247 \text{ (mA)} \dots\dots\dots(11)$$

Similarly, let's assume that V_{BE} of transistor T_{r1} is 0.8 V (worst), I_1 must be as follows:

$$I_1 = \frac{V_{BE}}{R_1} = \frac{0.8}{2 \text{ (k}\Omega\text{)}} = 0.4 \text{ (mA)} \dots\dots\dots(12)$$

Therefore, the output current I_o of the optocoupler is

$$I_o \oplus I_1 + I_b = 0.647 \text{ (mA)} \dots\dots\dots(13)$$

If forward current I_F is 3 mA (worst) (normally $I_F = 5 \text{ mA}$), the CTR is calculated as follows:

$$CTR = \frac{I_o}{I_F} \times 100 = \frac{0.647 \text{ (mA)}}{3 \text{ (mA)}} \times 100 = 21.6\% \dots\dots\dots(14)$$

Accordingly, the CTR value including reduction of CTR by time elapse, temperature change, and insertion of RBE must be 21.6 % or more.

A design example of an optocoupler circuit that operates for at least ten years is shown below (using Fig. 3-3, 4-2 and 4-3). The major causes of CTR reduction area as follows:

- (From Fig. 3-3) CTR-relative-value vs. RBE characteristics
15% down (with respect to initial value, RBE = ×)
- (From Fig. 4-2) CTR change with time (10 years, Ta = 60 °C)
40% down (with respect to initial value, 0 year)
- (From Fig. 4-3) CTR-relative-value vs. ambient-temperature characteristics
(Ta = 60 °C)
15% down (with respect to initial value ta = 25 °C)

Considering the above characteristics and safety factor = 2 (twice margin), the recommended CTR is:

$$21.6 \times 1.4 \times 1.15 \times 1.15 \times 2 = 80\% \dots \dots \dots (15)$$

(Reference)

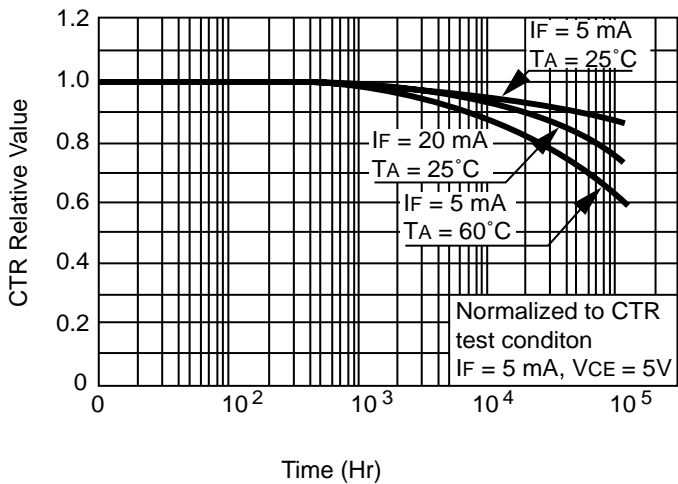


Figure 4-2. Change of CTR with Time (PS2601)

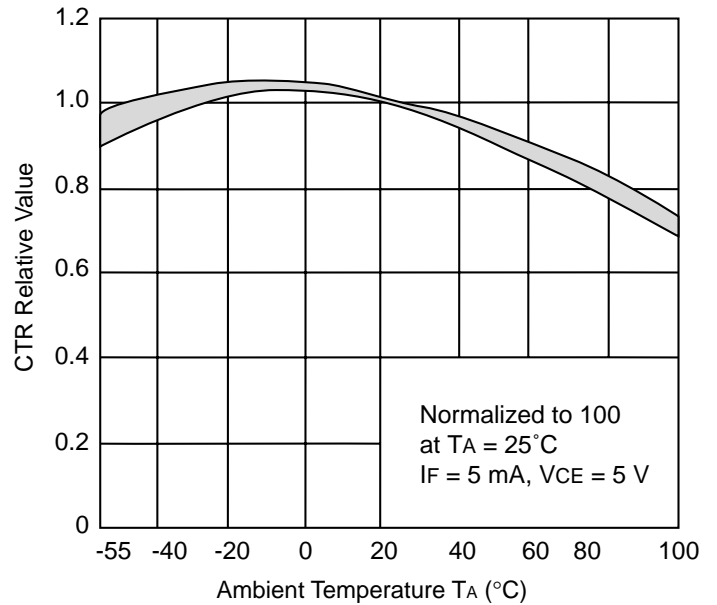


Figure 4-3. CTR-Relative-Value vs. TA Characteristics

PS2500-SERIES MULTI-CHANNEL OPTOCOUPLEDERS

GENERAL

Recently, optocouplers have been supplanting relays and pulse transformers for complete noise elimination, level conversion, and high-potential isolation. Microprocessor systems are requiring more and more optocouplers on the limited area of PC boards for I/O interface and other purposes. For these requirements, NEC has manufactured multi-channel optocouplers having 4 pins (for one channel) to 16 pins (for four channels). These multi-channel optocouplers are called the PS2500 series optocouplers. The PS2500 series optocouplers are divided into PS2501, PS2502, PS2505, and PS2506 according to their functions. (PS2501L, PS2502L, PS2505L, and PS2506L have leads formed for surface installation.)

This manual describes features, structures, and basic characteristics of the PS2500 series optocouplers.

FEATURES, STRUCTURES, AND PACKAGE DIMENSIONS

Features

The major feature of PS2500 is very high isolation voltage between input and output (substantially two to three times that of the conventional PS2400 series optocouplers). This can be proved because none of the 1300 test optocouplers were destroyed in a strict product test (applying 10 kVac to each optocoupler for one minute). The improvement in dielectric strength of the PS2500 optocouplers has been accomplished by the double molding package structure.

In addition to high isolation voltage, the PS2500 optocouplers boast high heat resistance and high moisture resistance. Table 1 lists the major features of the PS2500 series optocouplers.

Features	High isolation Voltage	Abundant I/O functions	High CTR (TYP)	High V _{CEO} (MIN)	Response (TYP)
Product name					
PS2501 PS2501L (*)	5 kVac	D.C. input, Single transistor output	300%	80V	tr = 3 μs tr = 5 μs
PS2502 PS2502L (*)		D.C. input, Darlington pair transistor output	2000%	40V	tr, tf = 100 μs
PS2505 PS2505L (*)		A.C. input, single transistor output	300%	80V	tr = 3 μs tr = 5 μs
PS2506 PS2506L (*)		A.C. input, Darlington pair transistor output	2000%	40V	tr, tf = 100 μs

Table 1. Features of PS2500 Optocouplers

Note: Tested in oil (In the air, unwanted arc discharging will occur at 6 to 7 kVac.)

* The product name followed by letter L is for a product having leads for surface mount.

Optocoupler Structure

Figure 1 shows the internal perspective view of a PS2500 optocoupler and Figure 2 shows the sectional view of the optocoupler. Figure 2 below shows the optocoupler in a light-tight epoxy resin housing, and a light-sensitive element (phototransistor or photo Darlington transistor) with light-transmittable epoxy resin medium between them. A light signal emitted by the LED is transferred to the photosensitive transistor via the internal resin medium.

Both the housing resin and the internal resin have the same expansion coefficient. Namely, the optocoupler elements are molded twice with epoxy resin. (This structure is referred to as a double molding structure.)

The high isolation voltage is obtained by the long adjacent area of the inner and outer resins (inner boundary) and identical expansion coefficient of the inner and outer resins (eliminating arc discharges on the inner boundary).

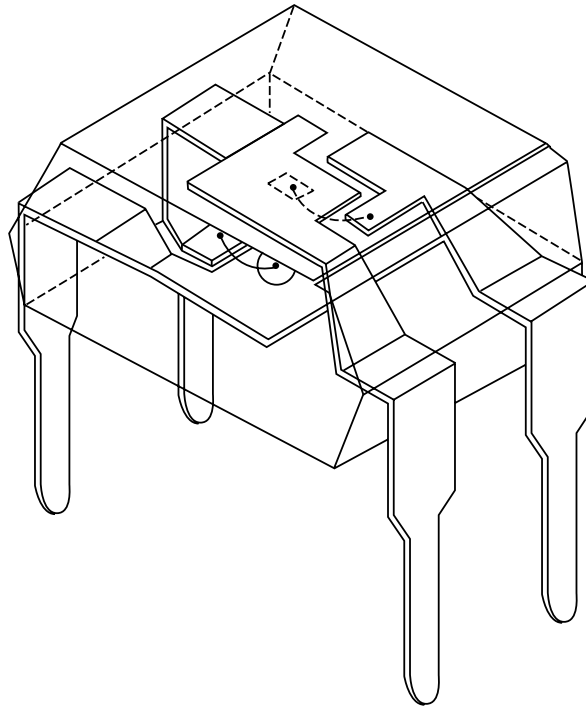


Figure 1. Internal perspective view of optocoupler

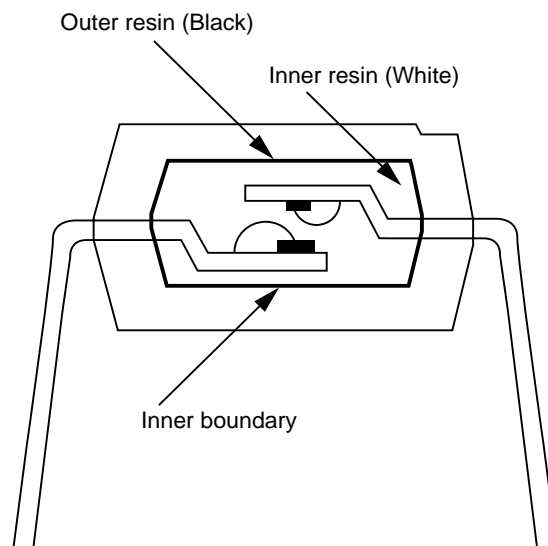


Figure 2. Sectional view of optocoupler

Dimensions

Figures 3 and 4 show the dimensions of the PS2500 series optocouplers. The PS2500 series optocouplers are very compact and fit for high-density installation on PC boards. For example, the package area occupied by a single channel of the PS2500 series is half that of the PS2600 series (6-pin Dual in-line package).

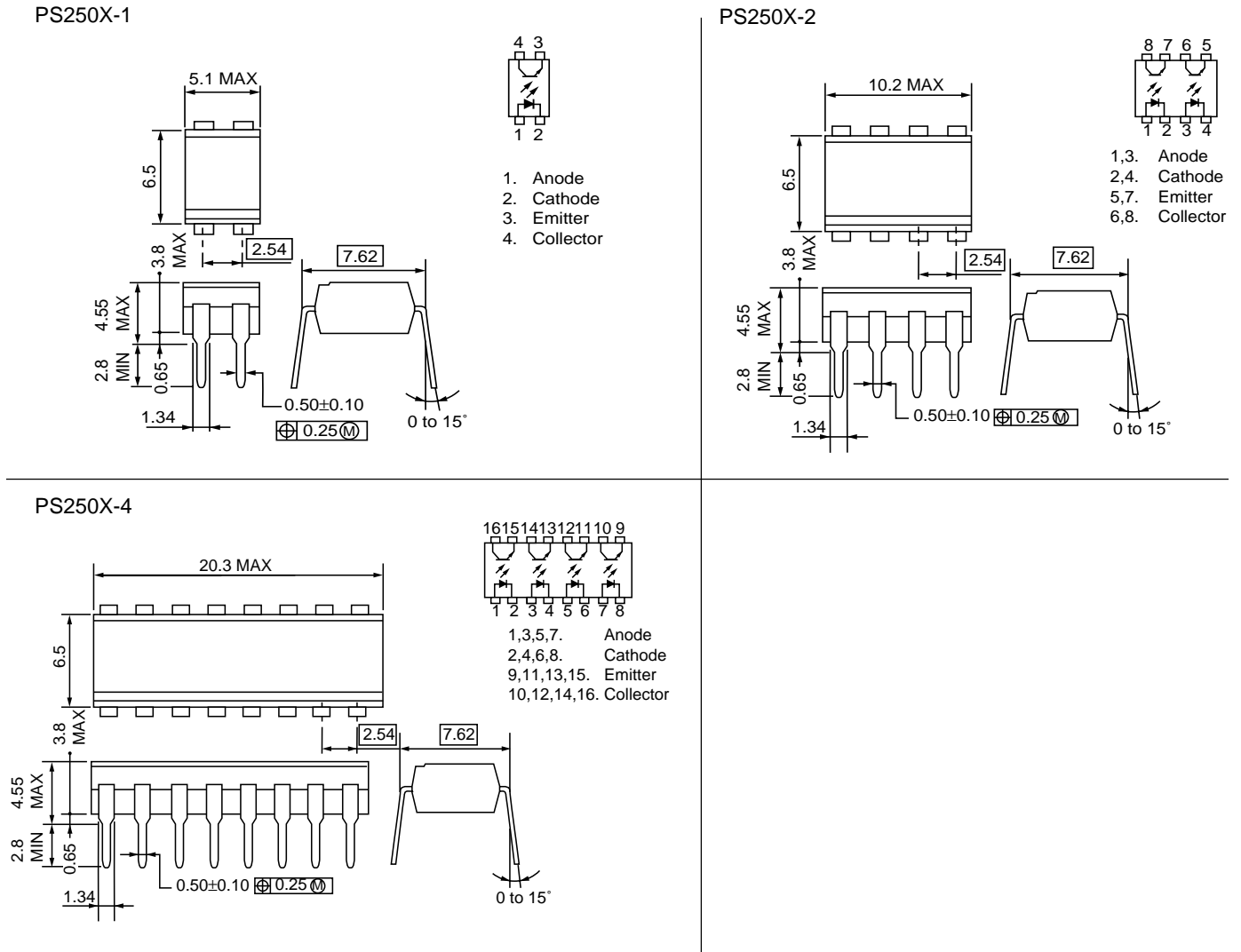
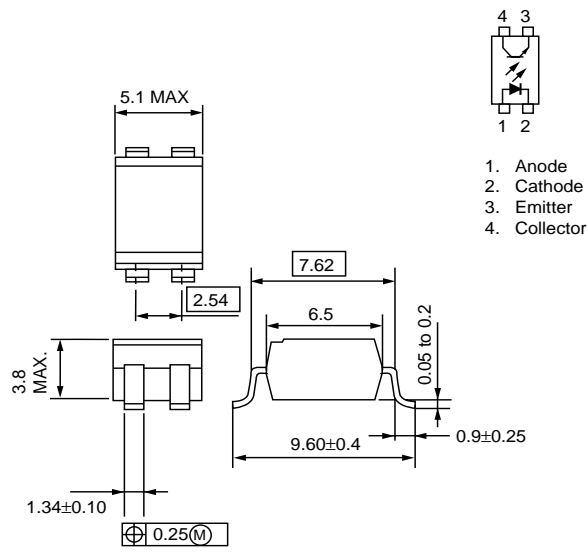


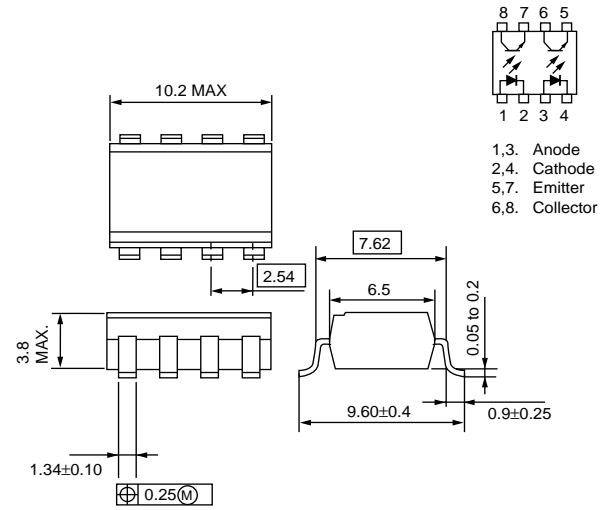
Figure 3. Package Dimensions (Units in mm) (PS2501, PS2502, PS2505, and PS2506)

Lead Bending type (Gull-wing)

PS250XL-1



PS250XL-2



PS250XL-4

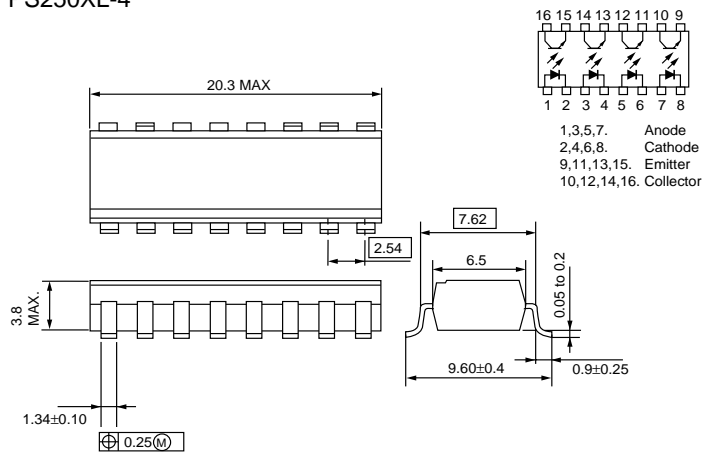


Fig. 4 Package Dimensions (Units in mm) (PS2501L, PS2502L, PS2505L, and PS2506L)

CHARACTERISTICS OF PS2501 AND PS2505 OPTOCOUPLERS

Current Transfer Ratio (CTR)

The current transfer ratio (CTR) of an optocoupler is the ratio of the value of output current I_C to the value of input forward current I_F ($I_C/I_F \times 100\%$). The CTR is a parameter equivalent to the D.C. current amplification factor h_{FE} of a transistor. The CTR is one of the most significant characteristics of optocouplers, as well as isolation voltage. In circuit designing, CTR must be considered first of all because the CTR:

- ① varies as time goes by,
- ② is affected by ambient temperature, and
- ③ is dependent upon forward current I_F flowing through the LED.

Both PS2505 and PS2506 optocouplers (bidirectional input type) have two current transfer ratios (CTRs) because they have two LEDs in the input. For further information, refer to Applications of Optocouplers for A.C. input.

Change of CTR over time

The current transfer ratio (CTR) of an optocoupler is determined by the light-emission efficiency of the LED (emitting infrared light), efficiency of light transmission between the LED and the phototransistor, light sensitivity of the phototransistor, and h_{FE} of the transistor.

The change of a CTR over time is mainly caused by reduction of the light-emission efficiency of the LED. Generally, the CTR is reduced to a greater extent as the forward current I_F increases or as the operating temperature increases. Figure 5 and 6 respectively show estimated changes of CTRs of PS2501 and PS2505 optocouplers over time.

Estimated change of CTRs with time lapse (Standard values)

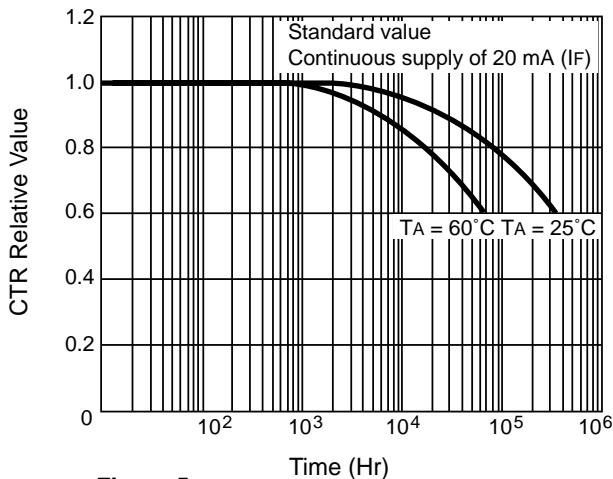


Figure 5.

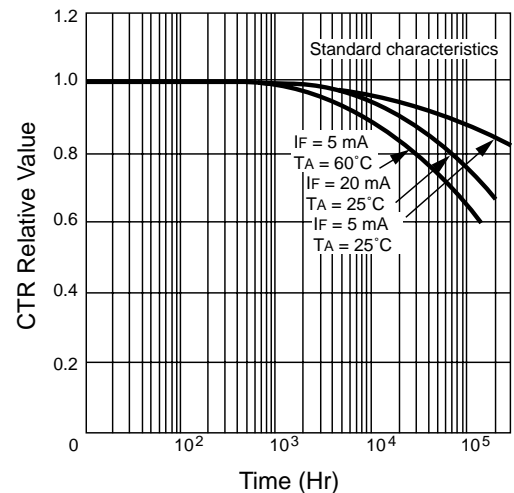


Figure 6.

CTR vs. TA Characteristics (TA: Ambient Temperature)

The CTR-Temperature characteristic is greatly affected by the total characteristics of light-emission efficiency of the LED and h_{FE} of the phototransistor as the light-emission efficiency has a negative temperature coefficient and h_{FE} has a positive temperature coefficient. See Figure 7.

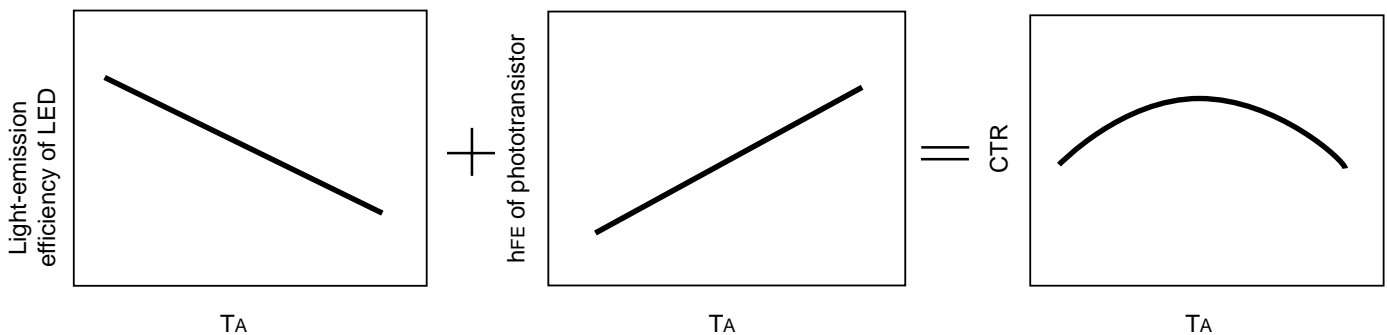
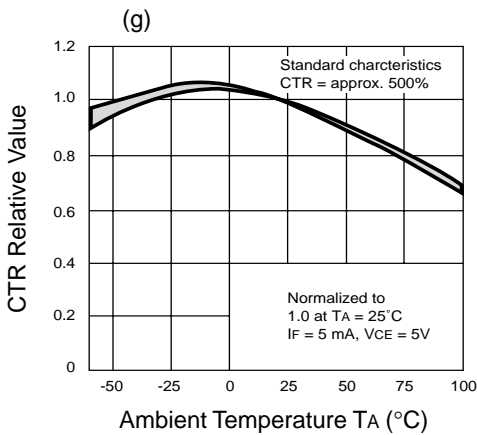
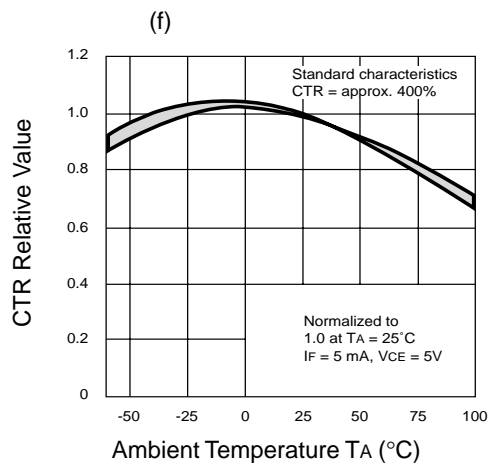
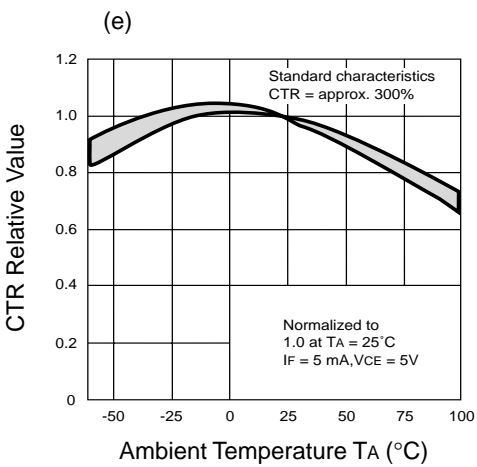
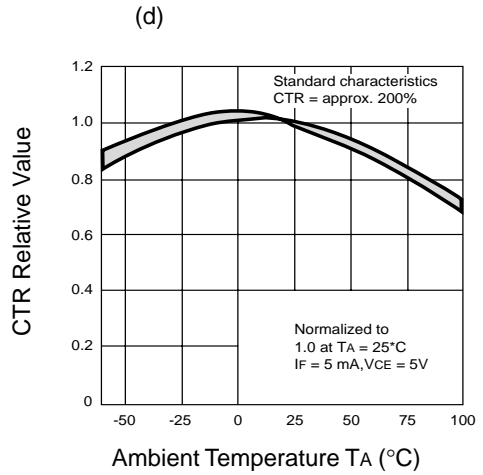
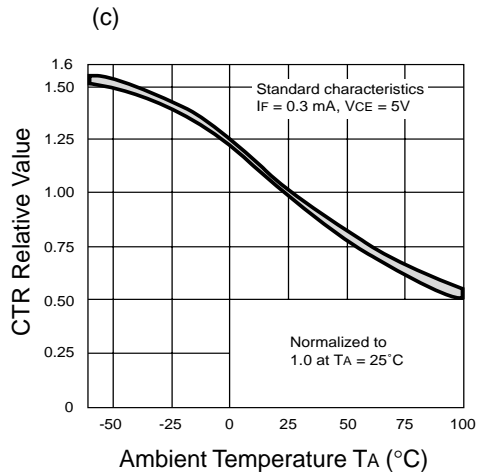
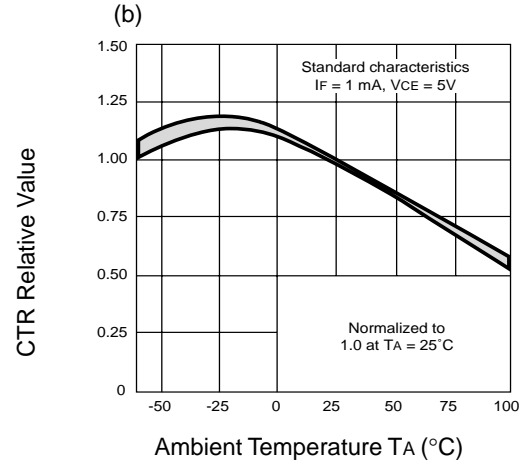
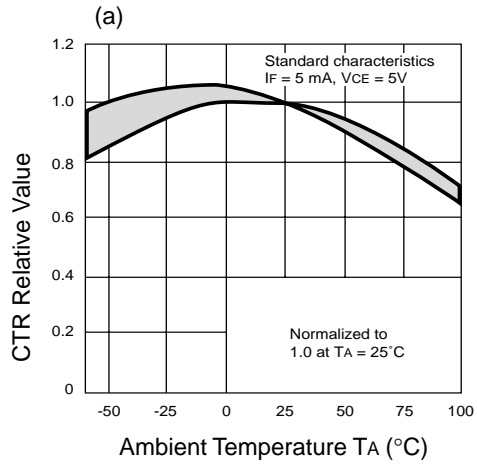


Figure 7. CTR vs. TA Characteristics

Figure 8-(a) to Figure 8-(g) show CTR vs. TA characteristics under various conditions.



CTR vs. I_F Characteristics (I_F: Forward Current Flowing Through the LED)

The current transfer ratio (CTR) depends upon the magnitude of a forward current (I_F). When I_F goes lower or higher than a proper magnitude, the CTR becomes smaller. Figure 9 shows the CTR vs. I_F characteristics. Note that rate changes of CTRs are very different at low I_F magnitude (approx. 5 mA), middle I_F magnitude (approx. 5 mA), and high I_F magnitude (approx. 20 mA). Namely, the CTR depends heavily upon the magnitude of forward current I_F in lower and higher current ranges. For low-input and high-output switching, see Chapter 4.

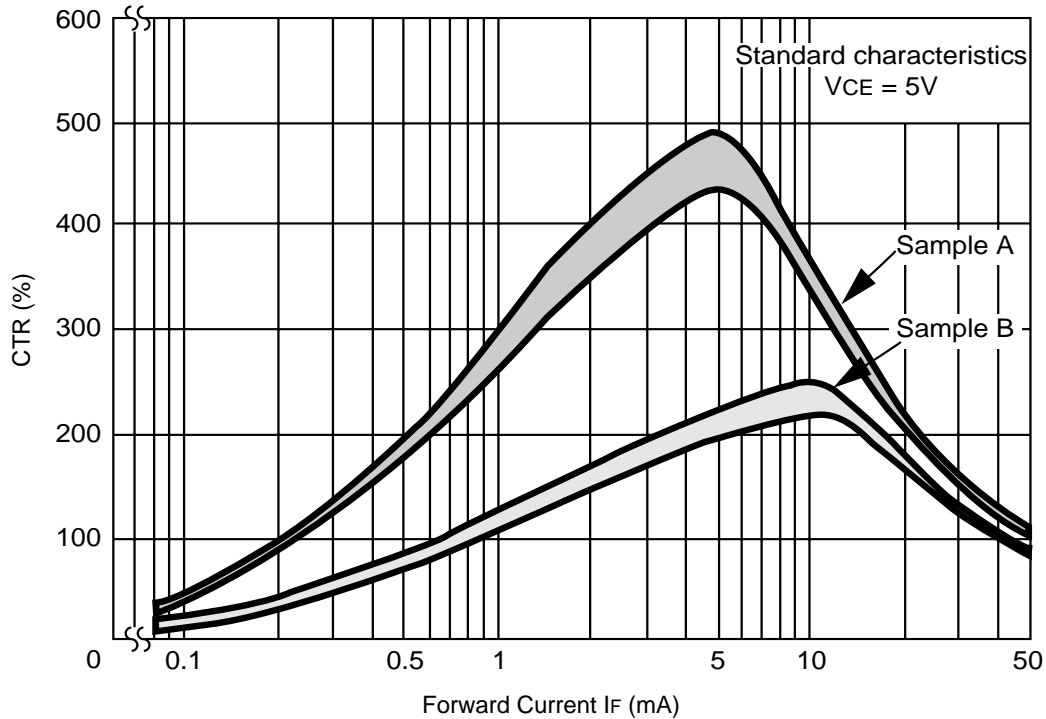


Figure 9. CTR vs. I_F Characteristics (Standard Value)

Response Characteristics

The response characteristics of optocouplers are the same as those phototransistors. The fall time t_f is expressed by:

$$t_f \propto R_L \cdot h_{FE} \cdot C_{CB}$$

- RL: Load resistance
- h_{FE}: Amplification factor
- C_{CB}: Collector-base capacitance

If R_L is too high, t_f becomes too high to be fit for high-speed signal transmission. Select the proper load resistance for the desired signal rate. Similarly, the collector current must fully satisfy the minimum value of the CTR, CTR vs. T_A characteristics, and CTR vs. time characteristics. Otherwise, the phototransistor will operate unsaturated, causing lower response characteristics and malfunction.

Figures 10 to 13 show the response-time vs. forward current characteristics and response-time vs. V_{CC} characteristics, using load resistance and ambient temperature as parameters.

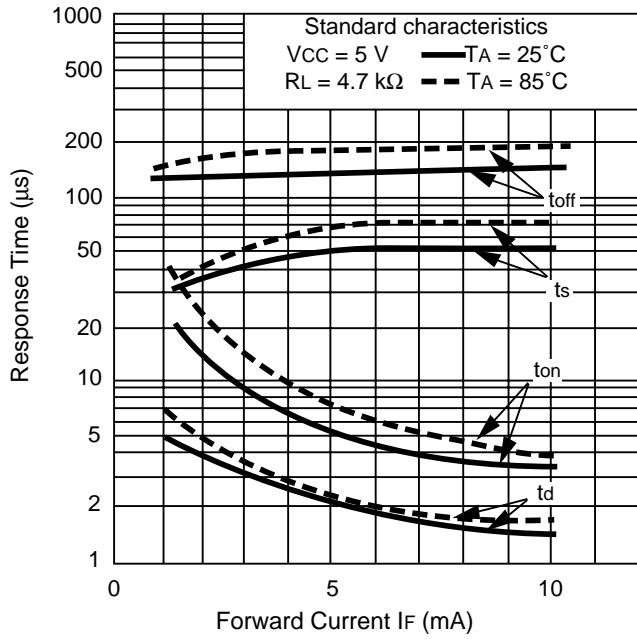


Figure 10. Response-Time vs. I_F Characteristics

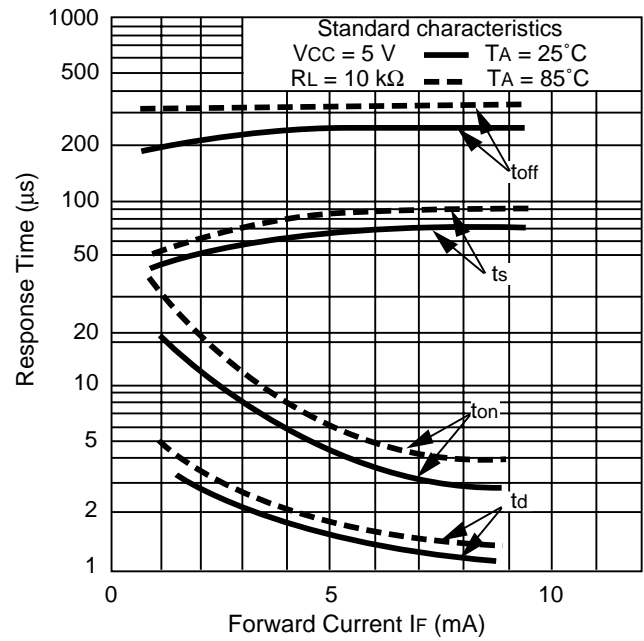


Figure 11. Response-Time vs. I_F Characteristics

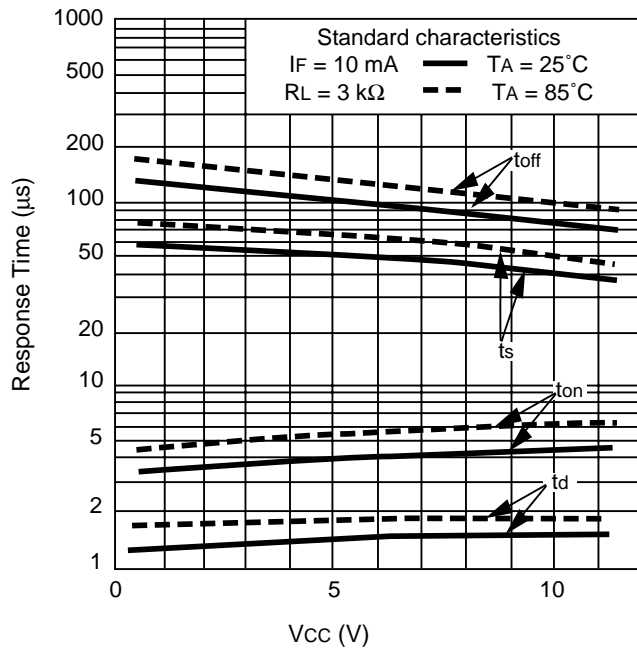


Figure 12. Response-Time vs. V_{CC} Characteristics

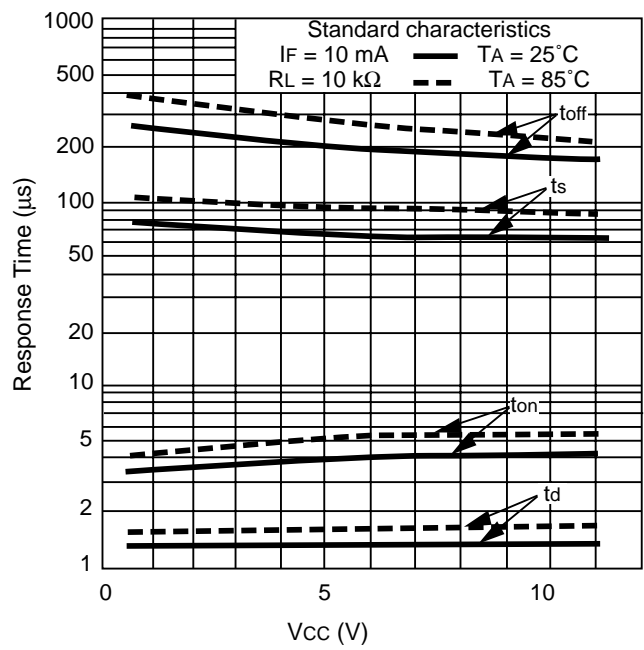


Figure 13. Response-Time vs. V_{CC} Characteristics

For reference, a voltage-gain vs. frequency characteristic using CTR as a parameter is shown below.

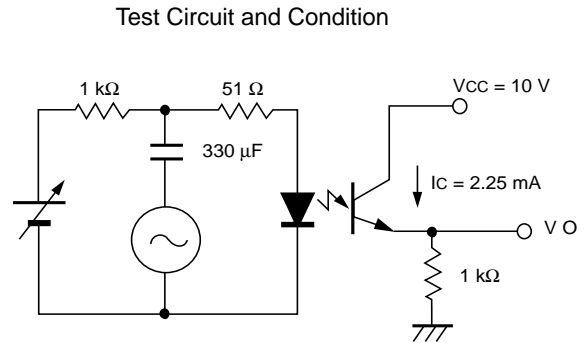
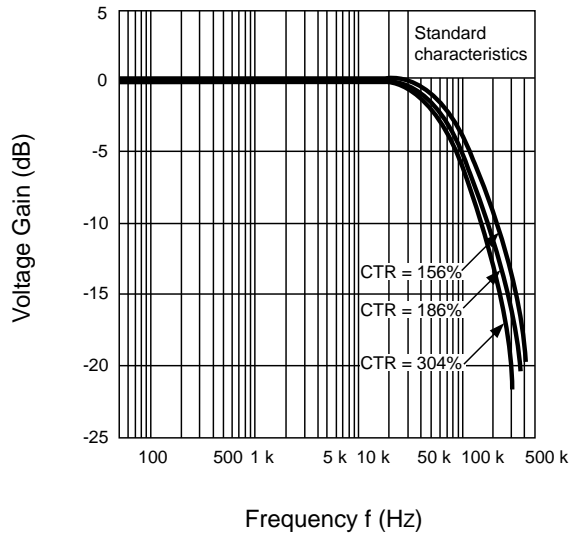


Figure 14. Voltage-Gain vs. Frequency Characteristics (Standard Value) (PS2501, PS2505).

Other Temperature Characteristics

Almost all characteristics of optocouplers are apt to be affected by ambient temperature (see 3.1.2). Figures 15 to 21 show how V_F (Forward Voltage), I_{CEO} (Collector Cut-Off Current), and $V_{CE(sat)}$ (Collector Saturation Voltage) are affected by ambient temperature.

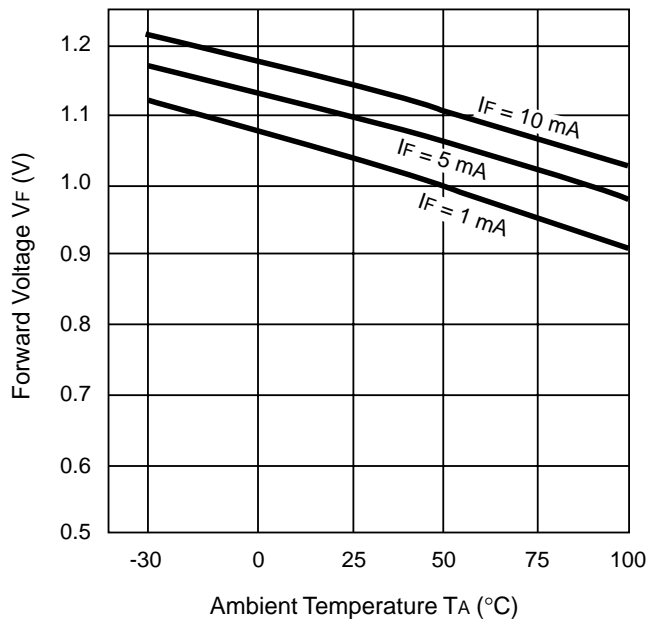


Figure 15. V_F vs. T_A Characteristics

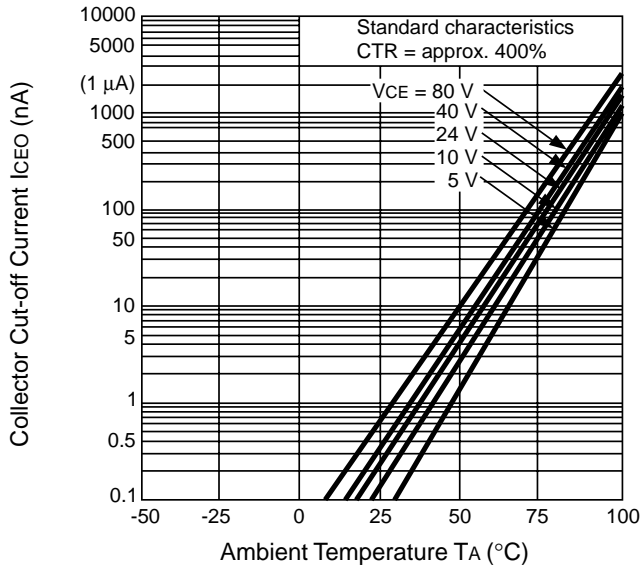


Figure 16. I_{CEO} vs. T_A Characteristics

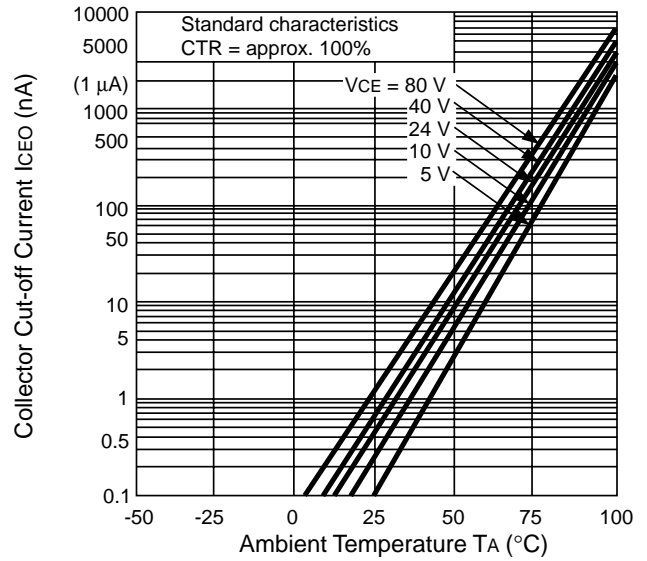


Figure 17. I_{CEO} vs. T_A Characteristics

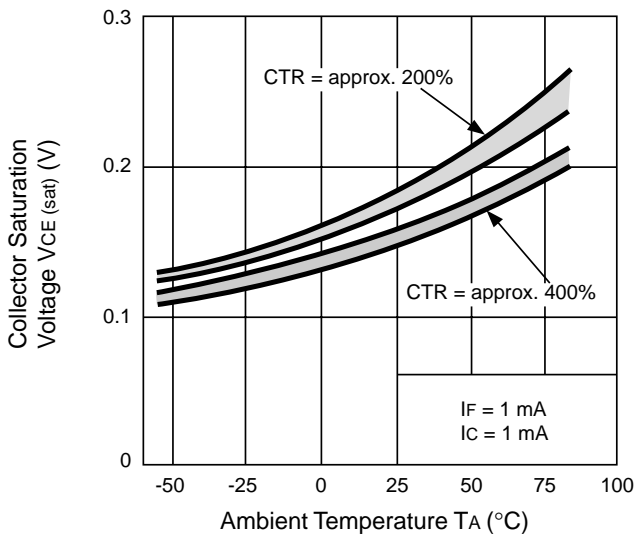


Figure 18. $V_{CE(sat)}$ vs. T_A Characteristics

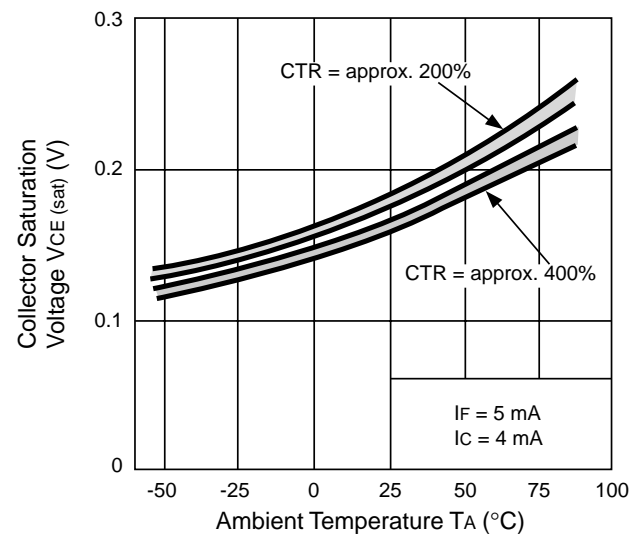


Figure 19. $V_{CE(sat)}$ vs. T_A Characteristics

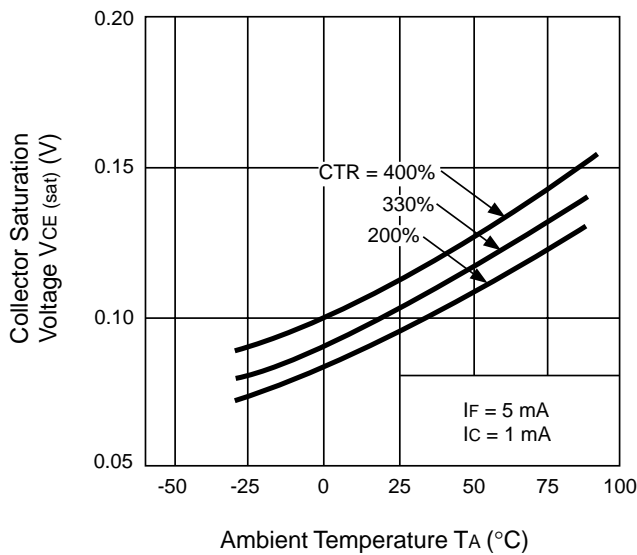


Figure 20. $V_{CE(sat)}$ vs. T_A Characteristics

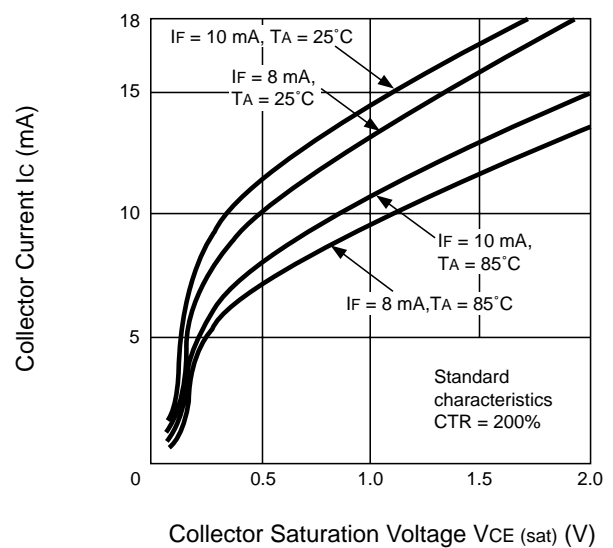


Figure 21. I_C vs. $V_{CE(sat)}$ Characteristics

At normal temperature ($T_A = 25^\circ\text{C}$), the collector cut-off current I_{CEO} is very little (about 1 nA (at $V_{CE} = 80\text{ V}$ and $CTR =$ about 400%)), but it will be multiplied by about 10 at an increment of 25°C . This needs to be kept in mind when using a small output current (I_C) of an optocoupler with a high load.

The rate change of $V_{CE(sat)}$ (Collector Saturation Voltage) is about 0.7% per $^\circ\text{C}$ at ambient temperature of 0°C to 70°C . In circuit design, the collector output current I_C should be determined under the condition of half or less of the CTR rated values. Otherwise, the saturation voltage $V_{CE(sat)}$ will become greater.

CHARACTERISTICS OF PS2502 AND PS2506 OPTOCOUPERS

The PS2502 and PS2506 optocouplers are higher in sensitivity than the PS2501 and PS2505 optocouplers and can be driven by low currents.

CTR-Related Characteristics

The PS2502 and PS2506 optocouplers assure $CTR \pm 200\%$ at $I_F = 1\text{ mA}$ and can be directly driven by CMOS output signals. See 3.1 for CTR definition and characteristics.

Change of CTR Over time

Figure 22 shows the CTR vs. time characteristics of the PS2502 and PS2506 optocouplers.

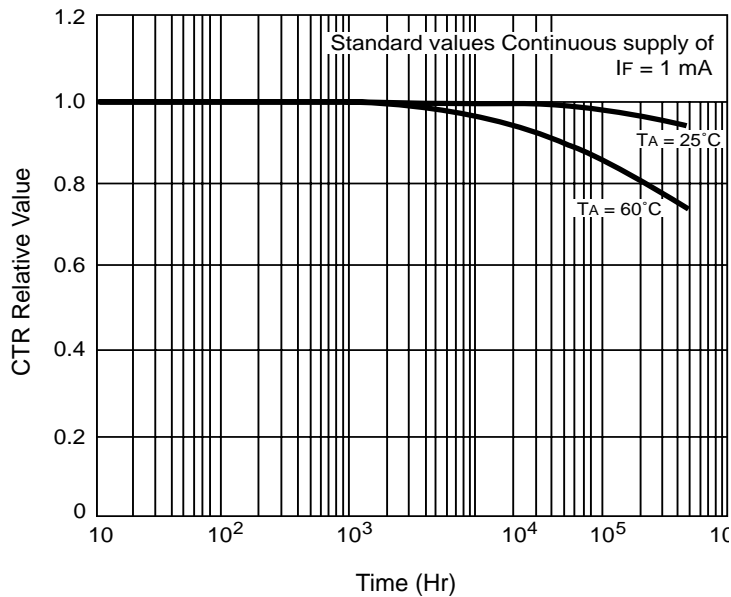
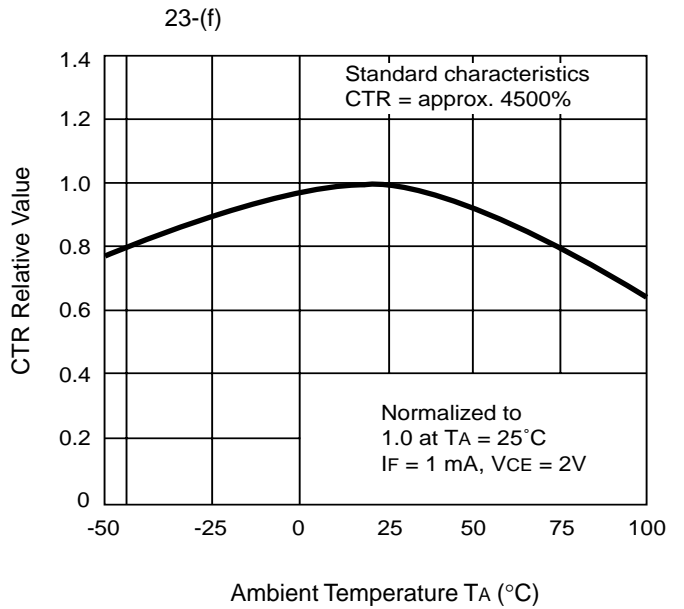
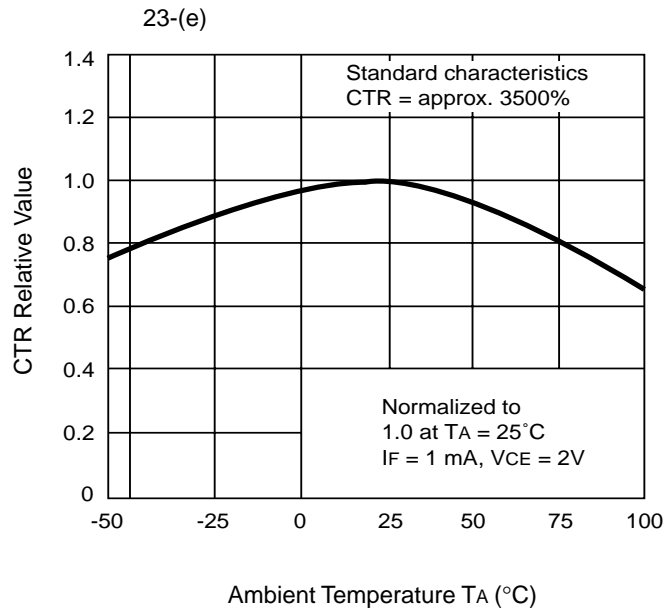
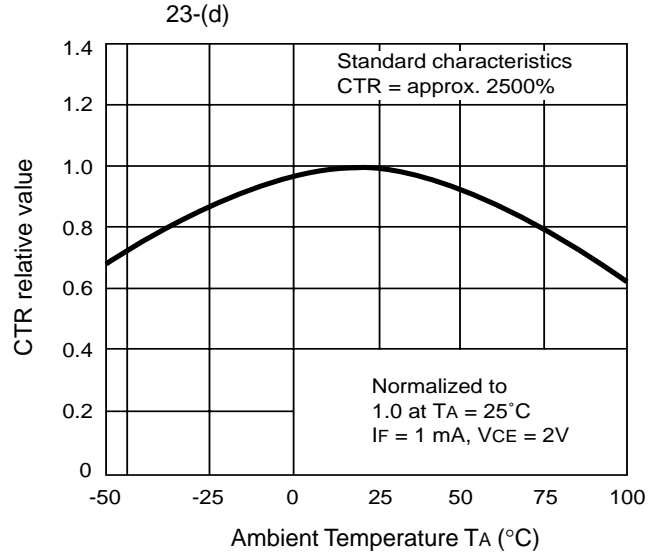
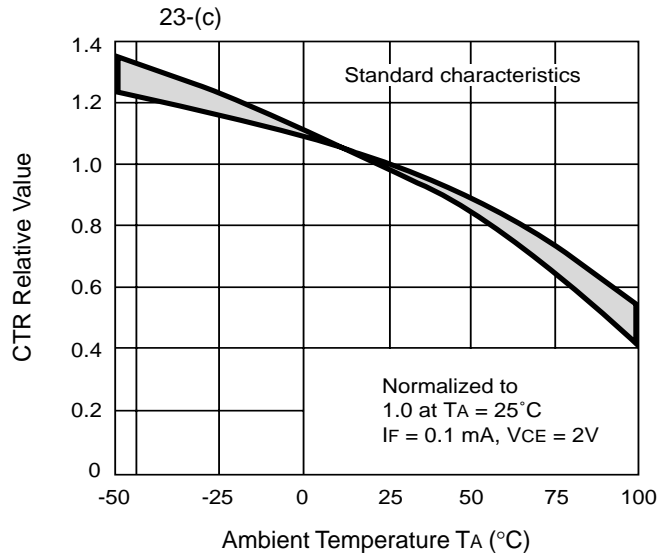
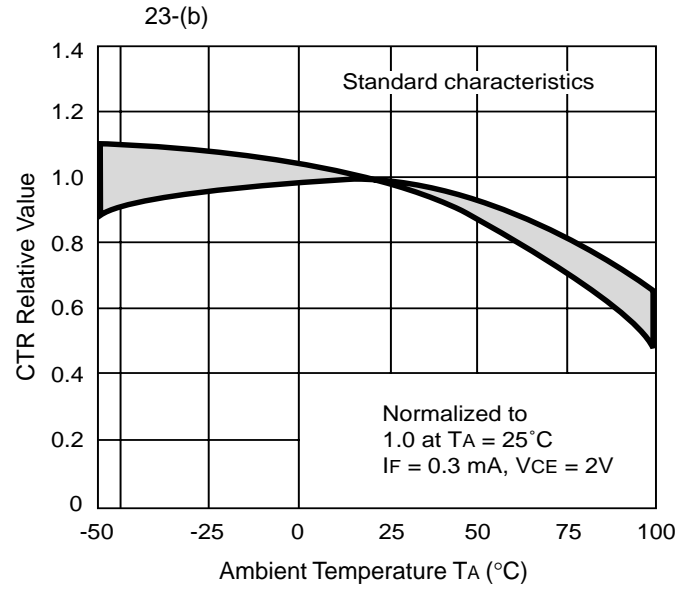
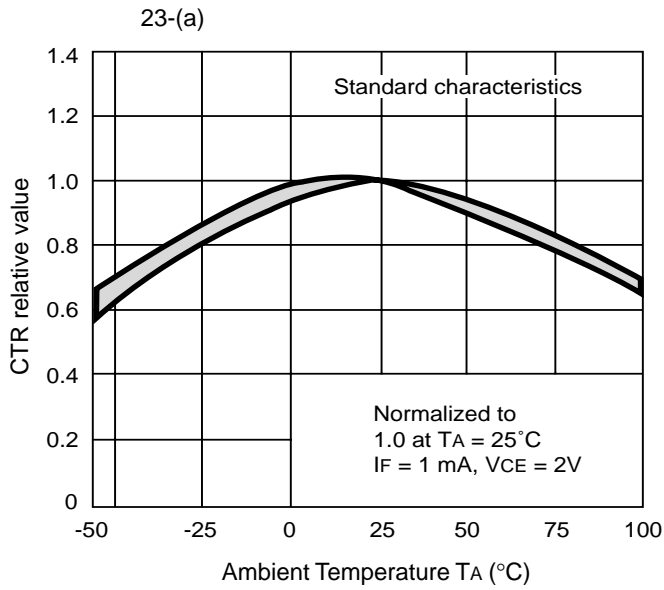


Figure 22. CTR vs. Time Characteristics (Standard Value)

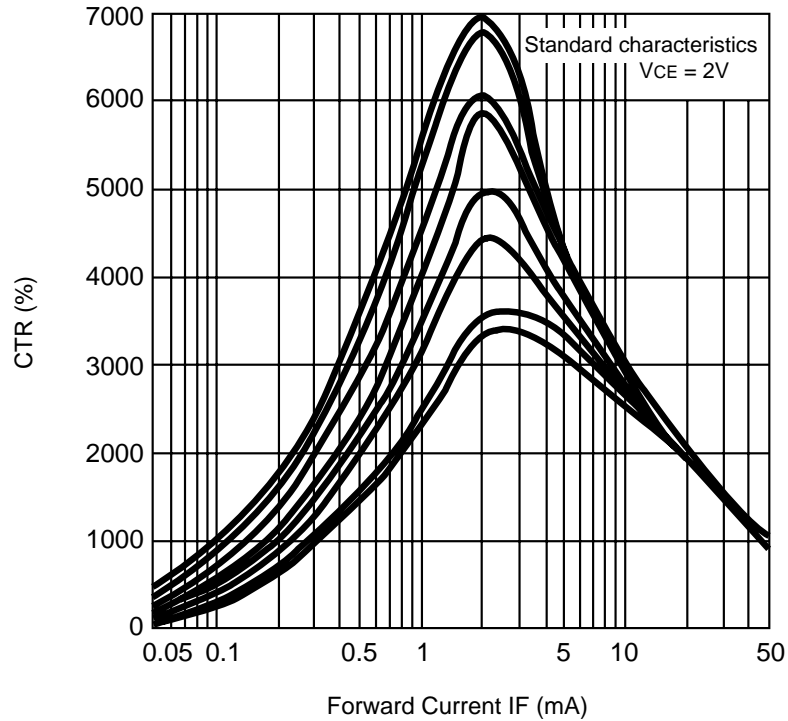
CTR vs. Temperature Characteristics

Figure 23-(a) to 23-(f) show CTR vs. Temperature Characteristics under various conditions.



CTR vs. IF Characteristics

As shown in Figure 8, the CTR of a single-transistor output optocoupler (such as the PS2501 and PS2505 optocouplers) is at most 20% in a low-current area (e.g. $I_F = 0.1$ mA). However, the CTR of a Darlington-transistor output optocoupler (such as the PS2502 and PS2506 optocouplers) can be greater than 200% in a low-current area (e.g. $I_F = 0.1$ mA). Figure 24 shows the CTR vs. I_F characteristics of the PS2502 and PS2506 optocouplers.



**Figure 24. CTR vs. I_F Characteristics (Standard Value)
(PS2502, PS2506)**

CONCLUSION

Demand for optocouplers featuring higher insulation and noise elimination is steadily increasing. At the same time, various problems (change of characteristics by ambient temperature and time elapse) will occur in their circuit design. We hope this manual will be helpful in solving such problems.

APPLICATION OF AC INPUT COMPATIBLE OPTOCOUPLER

INTRODUCTION

With the rapid penetration and diversification of electronic systems, demand for optocouplers is strengthening. Most popular are products featuring compact design, low cost, and high added value.

To meet the market needs, NEC is expanding the optocoupler. This manual focuses on optocouplers compatible with AC input, and covers configuration, principles of operation, and application examples.

CONFIGURATION (INTERNAL PIN CONNECTION DIAGRAM)

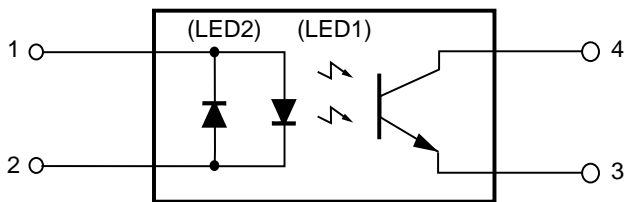


Figure 1. PS2505-1

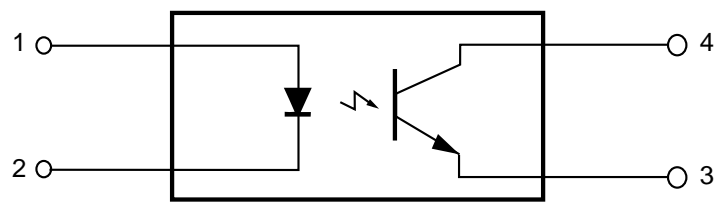


Figure 2. PS2501-1

Figure 1 shows the internal pin connection of the AC input compatible optocoupler PS2505-1, and Figure 2, of the optocoupler PS2501-1. The most significant difference from the optocoupler (PS2501-1) is that the PS2505-1 incorporates an input circuit with two LEDs connected in reverse parallel. In the optocoupler (PS2501-1), one LED is connected in the input circuit so that the LED emits light to provide a signal when a current flows in one direction (1-2 in Figure 2) (one-direction input type).

However, in the configuration shown in Figure 1, when a current flows in direction 1 to 2, LED1 emits light to send a signal, and when it flows from 2 to 1, LED2 emits light to send a signal (bidirectional input type). Namely, even if the voltage level between 1 and 2 varies, and the positive and negative polarities are changed, either of two LEDs emits light to send a signal. This means that the one direction input optocoupler permits DC input only, while the bidirectional input type permits AC input as well. Therefore, the PS2505-1 is described as an AC input compatible optocoupler.

The next section describes the status of output signals when 100 Vac power is directly input to an AC input compatible optocoupler (PS2505-1) via a current limit resistor.

DIRECT INPUT OF 100 Vac

Figure 3 shows the circuit diagram when 100 Vac power is directly input to an AC input compatible optocoupler via a current limit resistor. The relationship between input and output signals is as shown in Figure 4.

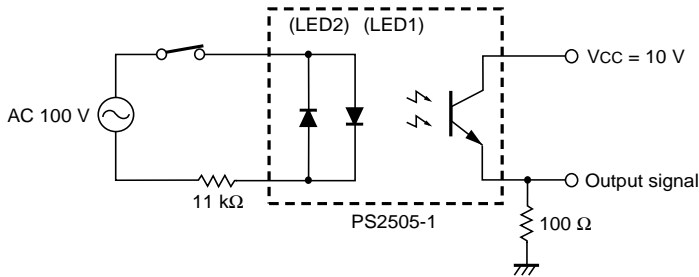


Figure 3. 100 Vac Direct Input Circuit

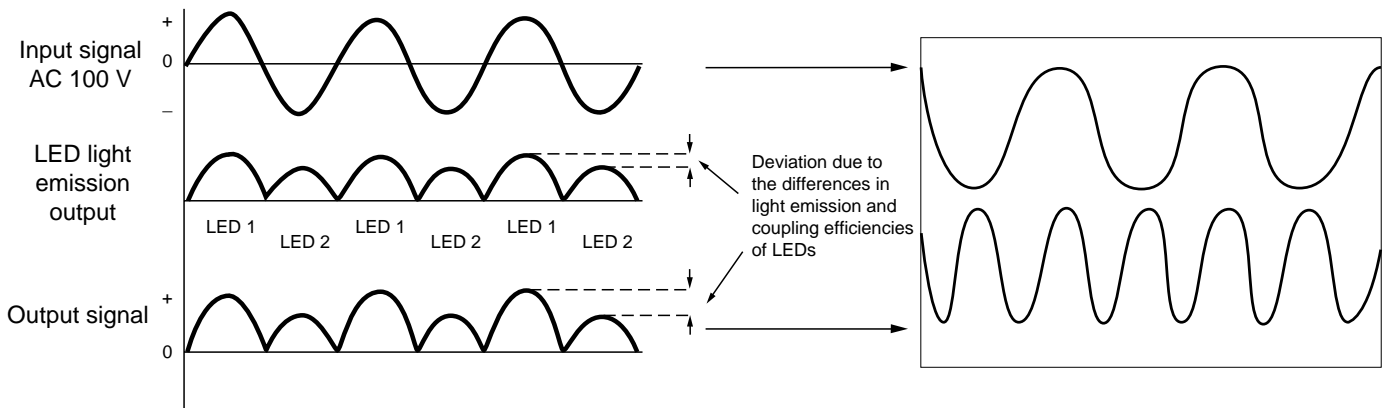


Figure 4. Input/Output Signal

**Graph 1 Upper: 100 Vac Input Signal 100 V/DIV
Lower: Output Signal 1 V/DIV**

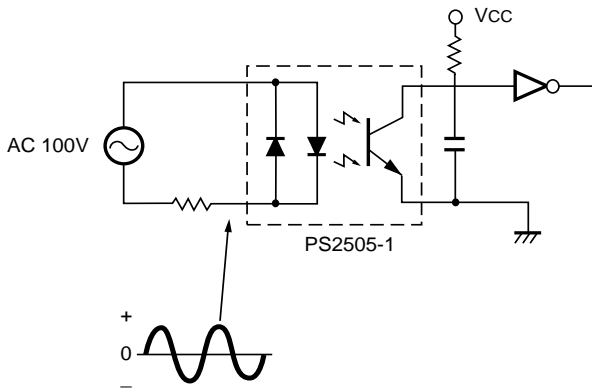
As described above, when an AC input compatible optocoupler is used, an AC input signal can be extracted as a full-wave rectified output signal. The output signal is smoothed by inserting a capacitor in the last stage of the circuit of a phototransistor if necessary.

In the one-direction input optocoupler (PS2501 series), when an AC signal is to be input, it must be full-or half-wave rectified by a diode bridge or CR circuit. On the other hand, the AC input compatible optocoupler permits direct input of an AC signal. This enables simpler configuration, space saving, and reduced design cost.

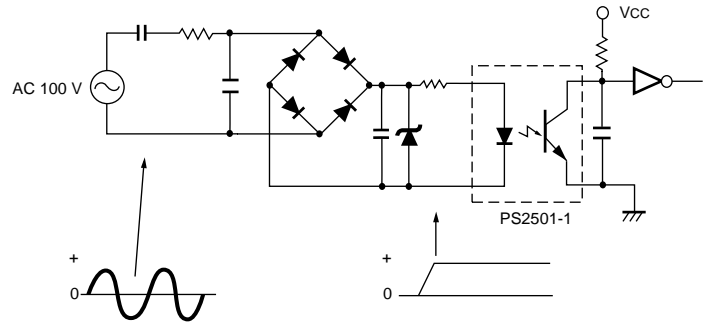
The next section demonstrates three examples of applications.

APPLICATION EXAMPLES

Example 1: AC-DC converter



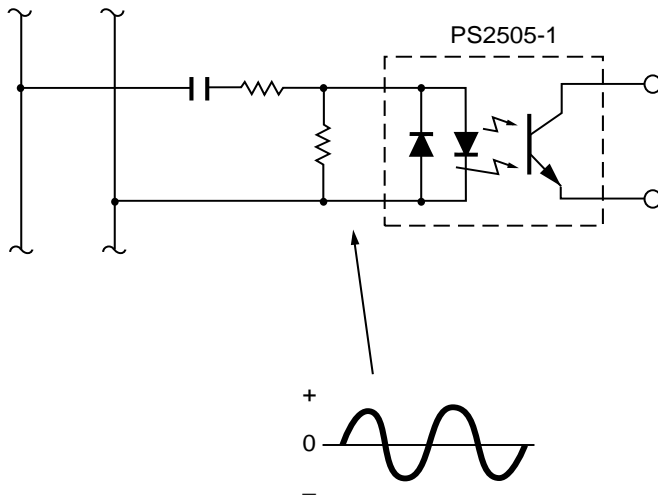
(a) AC input compatible optocoupler (bidirectional input)



(b) Conventional optocoupler (one-direction input) (Full-wave rectification by means of diode bridge)

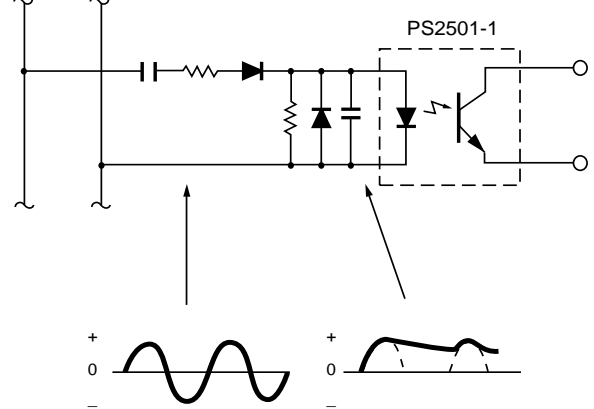
Example 2: Detection of a telephone bell signal

Station line
(75 Vr.m.s., 16 Hz)



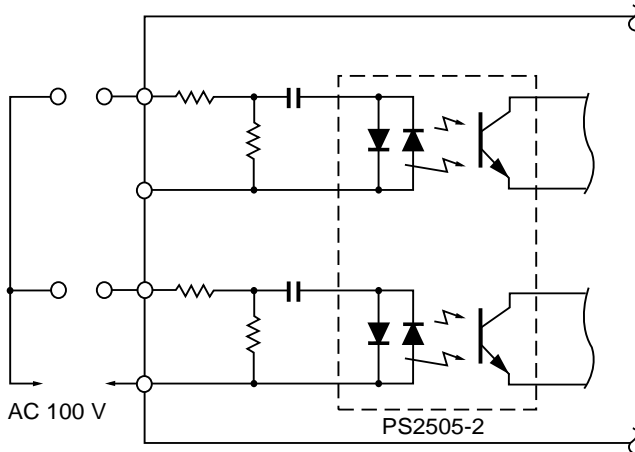
(a) AC input compatible optocoupler (bidirectional input)

Station line
(75 Vr.m.s., 16 Hz)

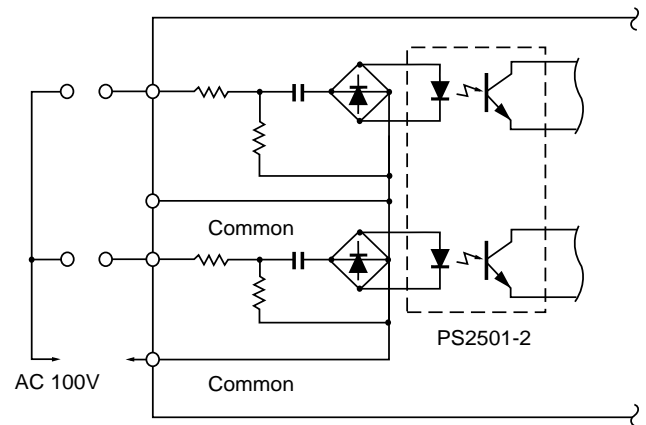


(b) Conventional optocoupler (one-direction input) (rectification by CR circuit)

Example 3: Sequencer circuit input section



(a) AC input compatible optocoupler
(bidirectional input)



(b) Conventional optocoupler
(one-direction input)
(Full-wave rectified by diode bridge)

PRECAUTIONS FOR DESIGN

The AC input compatible optocoupler is identical to the conventional optocoupler except for the presence of two LEDs connected in reverse parallel in the input circuit. Therefore, the circuit configuration can be designed as conventionally. The difference is that there are two types of current transfer ratios (CTR) because two LEDs are connected in the input circuit. The two CTRs are not necessarily the same, owing to the differences in light emission and coupling efficiencies of LEDs. Consequently, this causes deviation in output signal level. The differences are rated under the item of the current efficiency ratio (CTR₁/CTR₂) for electric characteristics.

Current transfer ratio (CTR₁/CTR₂)

$$CTR_1 = \frac{I_{C1}}{I_{F1} \times (\text{current flowing in LED1})}$$

$$CTR_2 = \frac{I_{C2}}{I_{F2} \times (\text{current flowing in LED2})}$$

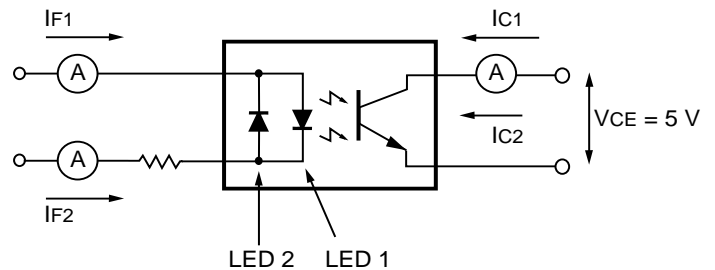


Figure 5. CTR Measuring Circuit

The transfer efficiency ratio (CTR₁/CTR₂) is rated as 0.3 (MIN.), 1.0 (TYP.), and 3.0 (MAX.). Assuming that CTR₁ is 200%, CTR₂ is in the range of 66 to 600%. Therefore, an AC input compatible optocoupler should be designed to operate with CTR 66 to 600%. For reference, the electric characteristics of the AC input compatible optocoupler (PS2505 series) are as follows:

Electric Characteristics (T_A = 25°C)

ITEM		CODE	CONDITIONS	MIN.	TYP.	MAX.	UNIT
Diode	Forward voltage	V _F	I _F = ±10 mA		1.1	1.4	V
	Pin-to-pin capacitance	C _t	V = 0, f = 1.0 MHz		50		pF
Transistor	Collector cutoff current	I _{CEO}	V _{CE} = 80 V, I _F = 0			100	nA
	Current transfer ratio	CTR(I _C /I _F)	I _F = ± 5 mA V _{CE} = 5.0 V	80	300	600	%
	Collector saturation voltage	V _{CE(sat)}	I _F = ±10 mA I _C = 2.0 mA			0.3	V
	Insulation resistance	R ₁₋₂	V _{in-out} = 1.0 kV	10 ¹¹			Ω
	Input-to-output capacitance	C ₁₋₂	V = 0, f = 1.0 MHz		0.5		pF
Coupled	Rise time	t _r	V _{CC} = 10 V, I _C = 2 mA, R _L = 100Ω		3		μs
	Fall time	t _f	V _{CC} = 10 V, I _C = 2 mA, R _L = 100Ω		5		μs
	Transfer efficiency ratio	CTR ₁ /CTR ₂	I _F = 5 mA, V _{CE} = 5.0 V	0.3	1.0	3.0	

For the external drawing, absolute maximum ratings, and characteristics curves, refer to the specific documents (AC input compatible multi-optocoupler series).

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