How to Use Optocoupler Normalized Curves (Appnote 45)

An optocoupler provides insulation safety, electrical noise isolation, and signal transfer between its input and output. The insulation and noise rejection characteristics of the optocoupler are provided by the mechanical package design and insulating materials.

A phototransistor optocoupler provides signal transfer between an isolated input and output via an infrared LED and a silicon NPN phototransistor.

When current is forced through the LED diode, infrared light is generated that irradiates the photosensitive base-collector junction of the phototransistor. The base-collector junction converts the optical energy into a photocurrent which is amplified by the current gain (HFE) of the transistor.

The gain of the optocoupler is expressed as a Current Transfer Ratio (CTR), which is the ratio of the phototransistor collector current to the LED forward current. The current gain (HFE) of the transistor is dependent upon the voltage between its collector and emitter. Two separate CTRs are often needed to complete the interface design. The first CTR, the non-saturated or linear operation of the transistor, is the most common specification of a phototransistor optocoupler and has a V_{ce} of 10 V. The second is the saturated or switching CTR of the coupler with a Vce of 0.4 V. Figures 1 and 2 illustrate the Normalized CTR_{CE} for the linear and switching operation of the phototransistor. Figure 1 shows the Normalized Non-Saturated CTR_{CE} operation of the coupler as a function of LED current and ambient temperature when the transistor is operated in the linear mode. Normalized $CTR_{CE(SAT)}$ is illustrated in Figure 2. The saturated gain is lower with LED drive greater than 10 mA.
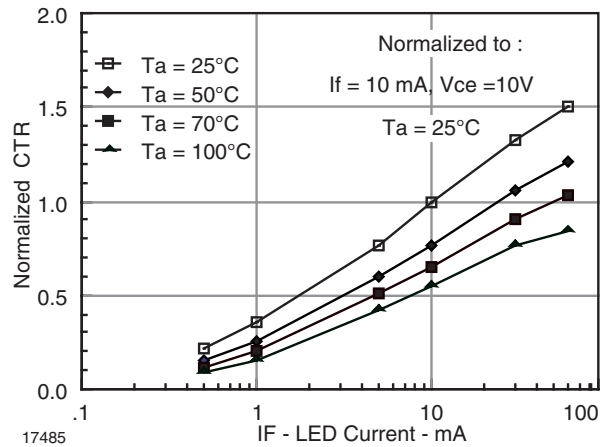

Figure 1. Normalized CTR versus I_F and T_{amb}
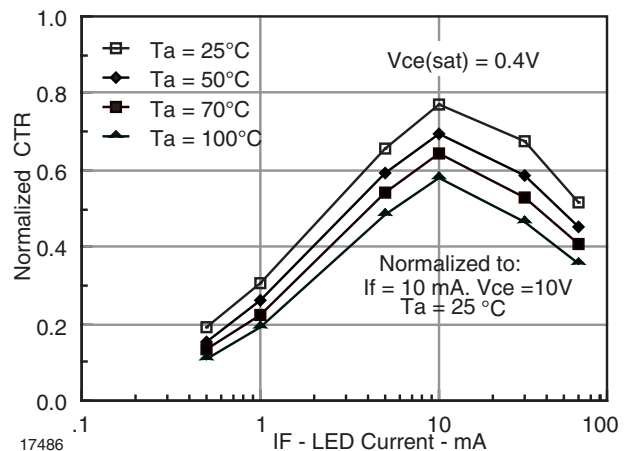

Figure 2. Normalized saturated CTR

The following design example illustrates how normalized curves can be used to calculate the appropriate load resistors.

Problem 1.

Using an IL1 optocoupler in a common emitter amplifier (Figure 3) determine the worst case load resistor under the following operation conditions:
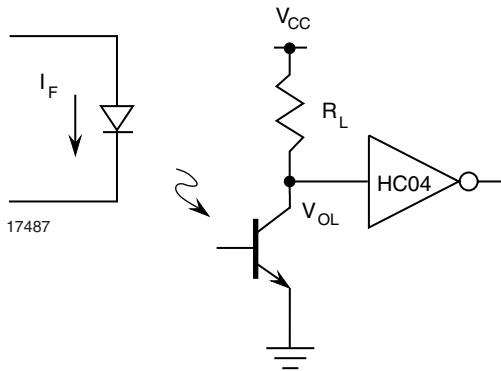

Figure 3. IL1 to 74HC04 interface

T_{amb} = 70 °C, I_F = 2 mA, V_{OL} = 0.4 V,
Logic load = 74 HC04

IL1 Characteristics:

$CTR_{CE(NON\ SAT)}$ = 20 % Min. at T_{amb} = 25 °C,
I_F = 10 mA, V_{CE} =1 0 V

Solution

Step 1. Determine $CTR_{CE(SAT)}$ using the normalization factor ($NF_{CE(SAT)}$) found in Figure 2.
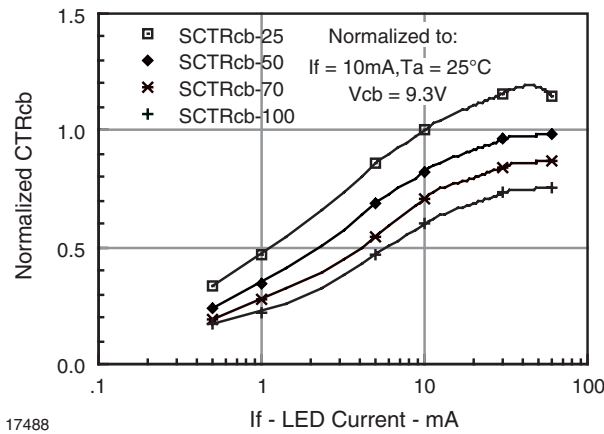

Figure 4. Normalized saturated CTR

$$CTR_{CE(SAT)} = CTR_{CE(NON\ SAT)}\ NF_{CE(SAT)} \quad (1)$$
$$CTR_{CE(SAT)} = 20\ \% * 0.36$$
$$CTR_{CE(SAT)} = 7.2\ \%$$

Step 2. Select the minimum load resistor using the following equation:

$$R_{L(MIN)} = \frac{V_{CC} - V_{OL}}{\dfrac{CTR_{CE(SAT)}I_F}{100\%} - I_L} \quad (2)$$

$$R_{L(MIN)} = \frac{5\,V - 0{,}4\,V}{\dfrac{(0{,}072)2\,mA}{100\%} - 50\mu A}$$

$R_{L(MIN)}$ = 48.94 KΩ, select 51 KΩ ± 5 %

The switching speed of the optocoupler can be greatly improved through the use of a resistor between the base and emitter of the output transistor. This is shown in Figure 5. This resistor assists in discharging the charge stored in the base to emitter and collector to base junction capacitances. When such a speed-up technique is used the selection of the collector load resistor and the base-emitter resistor requires the determination of the photocurrent and the HFE of the optocoupler.

The photocurrent generated by the LED is described by the CTR_{CB} of the coupler. This relationship is shown in Equations 3 and 4. Equation 5 shows that CTR_{CE} is the product of the CTR_{CB} and the HFE. The HFE of the transistor is easily determined by evaluating Equation 4, once the $CTR_{CE(SAT)}$ and CTR_{CB} are known. The Normalized CTR_{CB} is shown in Figure 6. Equations 5, 6, and 7 describe the solution for determining the R_{BE} that will permit reliable operation.
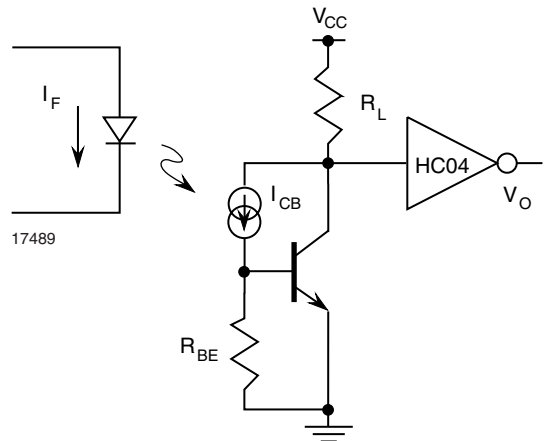

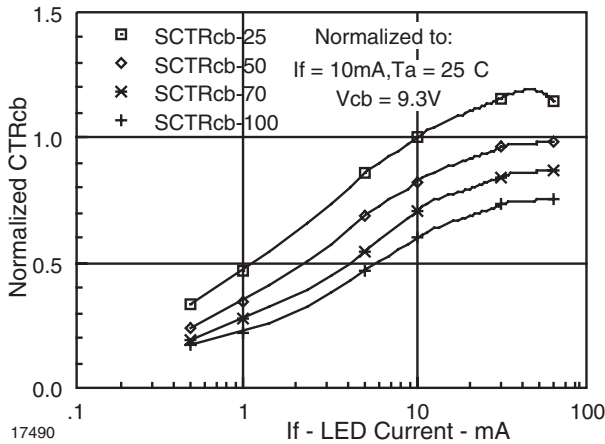Figure 5. Optocoupler/logic interface with R_{BE} resistor

Figure 6. Normalized CTR$_{CB}$ versus LED current

$$CT_{CB} = \frac{I_{CB}}{I_F}100\% \quad (3)$$

$$I_{CB} = I_F\frac{CTR_{CB}}{100\%} \quad (4)$$

$$CTR_{CE(SAT)} = CTR_{CB}HFE_{(SAT)} \quad (5)$$

$$HFE_{(SAT)} = \frac{CTR_{CE(SAT)}}{CTR_{CB}} \quad (6)$$

$$R_{BE} = \frac{V_{be}}{I_{CB} - I_{BE}} \quad (7)$$

$$R_{BE} = \frac{V_{BE}HFE_{(SAT)}R_L}{I_{CB}HFE_{(SAT)}R_L - [V_{CC} - V_{CE(SAT)}]} \quad (8)$$

$$(9)$$

$$R_{BE} = \frac{V_{BE}\dfrac{CTR_{CE}NF_{CE(SAT)}}{CTR_{CB}NF_{CB}}R_L}{\dfrac{I_F CTR_{CE}NF_{CE(SAT)}R_L}{100\%} - [V_{CC} - V_{CE(SAT)}]}$$

Problem 2.

Using an IL2 optocoupler in the circuit shown in Figure 6, determine the value of the collector load and base-emitter resistor, given the following operational conditions:

T_{amb} = 70 °C, I_F = 5 mA, V_{OL} = 0.4 V,
Logic load = 74HC04

IL2 Characteristics:

CTR_{CE} = 100 % at T_{amb} = 25 °C, V_{CE} = 10 V,
I_F = 10 mA

CTR_{CB} = 0.24 % at T_{amb} = 25 °C, V_{CB} = 9.3 V,
I_F = 10 mA

Solution

Step 1. Determine $CTR_{CE(SAT)}$, and CTR_{CB}.
From Figure 2 the $CTR_{CE(SAT)}$ = 55 %,
[$NF_{CE(SAT)}$ = 0.55]
From Figure 6 the CTR_{CB} = 0.132 %, [NF_{CB} = 0.55]

Step 2. Determine R_L.
From Equation 2 R_L = 1.7 KΩ
Select R_L = 3.3 KΩ

Step 3. Determine R_{BE}, using Equation 9.

$$R_{BE} = \frac{0,65\,V\dfrac{(100\%)(0,55)}{(0.24\%)(0,55)}3,3K\Omega}{\dfrac{(5mA)(100\%)(0,55)(3,3K\Omega)}{100\%} - [5\,V - 0,4\,V]} \quad (10)$$

R_{BE} = 199 KΩ, select 220 KΩ

Using a 3.3 kΩ collector and a 220 KΩ base-emitter resistor greatly minimize the turn-off propagation delay time and pulse distortion. The following table illustrates the effect the R_{BE} has on the circuit performance.

	I_F = 5 mA, V_{CC} = 5 V	
	R_L = 3.3 KΩ R_{BE} = ∞ Ω	R_L = 3.3 KΩ R_{BE} = 220
t_{delay}	1 µs	2 µs
t_{rise}	4 µs	5 µs
$t_{storage}$	17 µs	10 µs
t_{fall}	5 µs	12 µs
t_{phl}	3.5 µs	7 µs
t_{plh}	22 µs	12 µs
Pulse Distortion 50 µs	37 %	10 %

Not only does this circuit offer less pulse distortion, but it also improves high temperature switching and lower static DC power dissipation and improved common mode transient rejection.