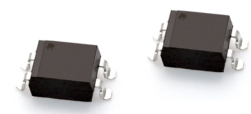
AN3010

Design Guideline for a Renesas/CEL Optocoupler with Transistor Output



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Introduction

A standard optocoupler provides signal transfer between an isolated input and output via an infrared Emitting Diode (IRED) and a silicon phototransistor. Electrical isolation is achieved by sending a beam of infrared energy to an optical receiver in a single package with a light-conducting medium between the emitter and detector. This mechanism provides complete electrical isolation of electronic circuits from input to output while transmitting information from one side to the other, and from one voltage potential to another.

This application note addresses the two common modes of operation: Linear mode and digital logic mode.

What is linear mode?

In linear mode, the optocoupler output produces a signal, which is a copy of the input signal; its amplitude is a product of the input signal and the Current Transfer Ratio (CTR). In an optocoupler the CTR is specified as a ratio of the collector current I_C at the output to the forward current, I_F, applied to the Infrared Emitting Diode (IRED) on the input side. A key condition for the Linear Mode is the collector - emitter voltage, V_{CE} is not in saturation.

What is digital logic mode?

In digital logic mode, the output signal is either logic high (~Vcc) or low (ground level, for example), and ideally the phototransistor on the receiver side goes into saturation when the transistor output switches to logic high so that the power consumption would be at the very low level. Typically, for a silicon-based phototransistor, the saturation voltage across the collector and emitter, V_{CE} would be at 0.3 V or less.

Parameter Definition

Current Transfer Ratio (CTR) is the gain of the optocoupler. It is the ratio of the phototransistor collector current to the IRED forward current.

$CTR = (I_C / I_F) * 100$

It is expressed as a percentage (%).

The CTR depends on the current gain (hfe) of the transistor, the supply voltage to the phototransistor, the forward current through the IRED and operating temperature.

Below is the CTR vs. Forward Current, I_F graph of the PS2501A-1-A.

Current Transfer Ratio vs. Forward Current

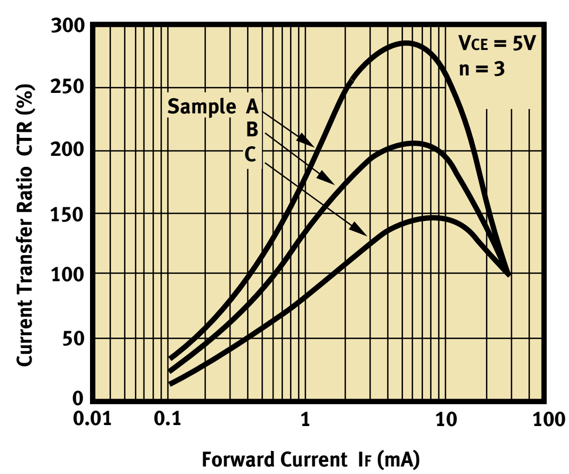
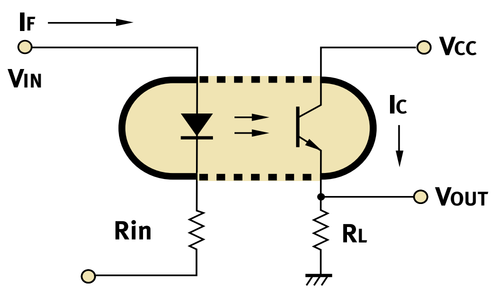


Fig 1: CTR vs. Forward Current, I_F.

This application note is written around Renesas phototransistor optocoupler PS2501A-1-A in DIP 4 package, the measurements were done at nominal room temperature, the common collector circuit configuration was used and was operating at 5 Volts, a common operating voltage for use with digital circuits, and in other situations where data or pulse-edge events communicate between units. Since the emitter current is approximately equal to collector current, $I_E =\sim I_C$, they will be used interchangeably in this application note.

Linear Mode Operation

In the common collector configuration (see figure 2.0), the collector is the common point of this transistor circuit, and the output is taken at the emitter. The output transitions from a low state to a high state when the optocoupler input transitions high.



Common Collector Amplifier

Fig 2.0: Common Collector Amplifier

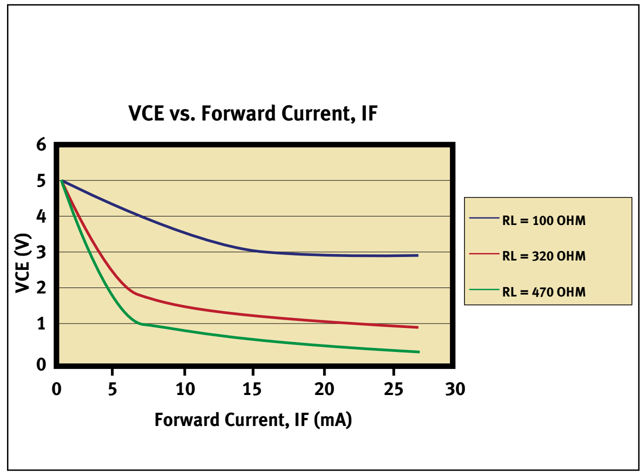


Fig 3.0: Collector-Emitter Voltage vs. Forward current at different load resistors

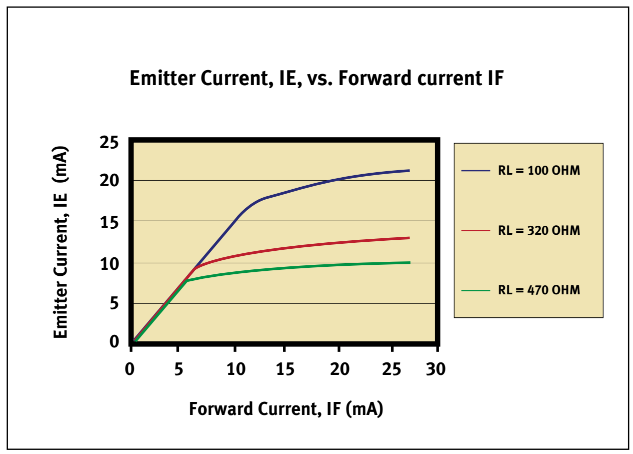


Fig 4.0: Emitter Current vs. Forward Current at different load resistors

The output voltage is at the load resistor between the emitter pin and ground.

In general, choose the load resistor R_L, to make sure that

$Vcc - (I_E * R_L) > 0.7V$

Where, I_E is the emitter current through load resistor R_L. To work effectively in the linear mode, R_L should be around 470Ω or less, depending on the drive current I_F and the design objective.

To show how the forward current, I_F, and load resistor, R_L, affect the collector-emitter voltage V_{CE}, and emitter current I_E, data was collected and is shown in figures 3.0 and 4.0 for reference.

From these graphs, we can see that the load resistor R_L at 470Ω would limit the linear operating region of the forward current, I_F to around 6mA or less.
In comparison, the load resistor value of 100Ω would extend the linear operating region up to 12mA. Note that the values for V_{CE} do not go below about 2.7V. A resistor value somewhere between 100Ω and 320Ω would provide a linear range of V_{CE} values with different slope.

Figure 4.0 shows a fairly linear range of collector current I_C with the 100Ω resistor value. Depending on the desired goal, various resistor values provide the desired results.

Digital Logic Mode

Option without using CTR

To operate in the digital logic mode, we plan for the optocoupler output transistor to operate in saturation mode. First, review the Renesas optocoupler datasheet for values useful in calculating circuit values at the input and output. Our example uses graphs and information from the PS2501A-1-A data sheet as shown in figure 5.0

Figure 5.0 shows the Collector Current vs. Collector Saturation Voltage. The collector current shown is developed from the input forward current I_F and CTR value for the selected optocoupler.

Collector Current vs. Collector Saturation Voltage

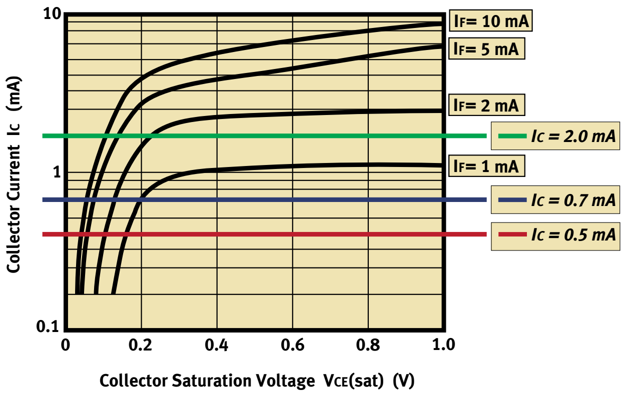


Fig 5.0: Collector Current vs. Collector Saturation Voltage

The simple approach to operating the phototransistor in saturation mode is by selecting the constant collector current at 0.5mA as shown in figure 5.0, so that V_{CE} is at 0.2V or less. Note that one could select Ic = 0.7mA and V_{CE} = 0.2V with an input current of I_F = 1mA. However, in the example, Ic = 0.5mA is selected as a demonstration.

Calculate the R_L :

R_L=(Vcc - V_{CE})/0.5mA = (5V-0.2V)/0.5mA =9.6kΩ.

In practice, R_L should be chosen with additional 30% tolerance or more, so by selecting R_L = 13.0kΩ as a standard value, it would be sufficient.

Next, what is the forward current needed to achieve the desired result?

Key goals of the design are to achieve a long service lifetime for the device and to operate at low power consumption.

Choose the forward current I_F between 1.0 to 3.0 mA as shown in figure 5.0 since further increase of I_F will not make any significant difference in the output, Vout, and higher input drive does not drive the saturation voltage lower. Data is collected in table 1.0 for reference.

	RL = 11.0 KΩ		
Forward Current, IF (mA)	**VOUT (V)**	**VCE (V)**	**IE (mA)**
1	4.88	0.12	0.452
2	4.89	0.11	0.453
3	4.89	0.11	0.453
4	4.91	0.09	0.455
5	4.95	0.05	0.458
6	4.96	0.04	0.459

Table 1.0: Forward Current, I_F vs. V_{out}

Some applications may be required to tolerate higher forward current, I_F, such as, 10 mA, for example.

The option is either to keep the same load resistor, R_L, at 13kΩ or choose the Ic = 2.0 mA as shown in figure 5.0, then select the R_L, so the product of (R_L * IC) > 5V. In this example, select any resistance value of 2.5kΩ *1.3 or greater. In this example, 3.3kΩ would be sufficient.

Note that a load resistor change from R_L = 13kΩ to 3.3kΩ would improve the switching time, such as, rise and fall time as shown in table 2.2 below.

CTR = 140% @ VCC = 5V, IF = 5mA			
IF (mA)	**RL (KΩ)**	**tr (us)**	**tf (us)**
1	13.0	22.5	82.5
10	3.3	8.5	28.0

However, there is a trade-off between high input current and the degradation of an optocoupler over the lifetime.

Option with CTR

In some instances, when the designers prefer to use opto device with a specific rank for the digital mode to switch it ON or OFF.

There are two things must be observed:

Design based on the worst-case scenario

In other words, design it based on the low end of the CTR rank. For example, if the PS2501A-1-Q-A is used. From the data sheet, the "Q" rank shows that the CTR = 100% to 200% at LED forward current, I_F = 5mA, then use the CTR = 100% at I_F = 5mA as the reference point for the design and the same forward current, I_F = 5.0mA must be used. Other forward currents that are different from I_F = 5mA would produce different sets of CTR graphs as shown in figure 1.0.

Calculate Load Resistance, R_L

By using the same configuration as shown in figure 2.0 as an example, calculate R_L as follows:

R_L_calculated = (Vcc – 0.2V) / (5mA * Lower limit of CTR rank)

And select R_L_actual > = 2 * R_L_calculated

For example, assume Vcc=5V, I_F = 5mA and PS2501A-1-Q is used, then

R_L_calculated = (5V - 0.2V)/5mA)=960Ω

And R_L_actual = 2.0kΩ

To set the forward current, I_F of the IRED

The input resistor to set the forward current, I_F is calculated:
$Rin = (Vin - V_F) / I_F$ (Refer to Figure 2.0)

Find the value for V_F from the graph in figure 6.0. This will not be exact, and a nominal value will work.

For the $I_F = 5.0mA$, we can select $V_F = 1.15V$ and $Vin = 5V$ at a temperature of 25°C from figure 6.0 as a reference:

Rin = (5.0V – 1.15V) / 5mA = 770Ω, so choose the standard value of 750Ω or less.

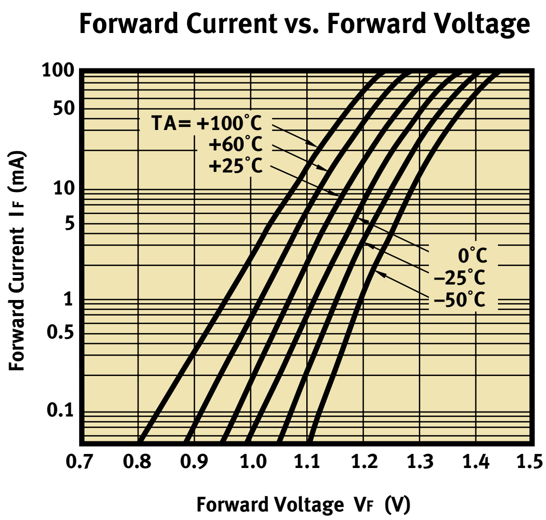


Figure 6. Forward Voltage vs. Forward Current

Conclusion

This application note uses the PS2501A-1-A as an example to provide a general design guideline or a general reference that applies to other Renesas/CEL optocoupler products to meet a specific design need in either the linear mode or digital logic mode.

However, take note on the dynamic relationship between I_F, CTR, Vcc, R_L, operating temperature and lifetime that interact with one another.

Also, refer to AN 3009 Phototransistor Switching Time Analysis for more information on improving switching time for an optocoupler.

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