CEL California Eastern Laboratories

APPLICATION NOTE

AN 3005

Modeling phototransistor optocouplers using PSPICE simulation software

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Introduction

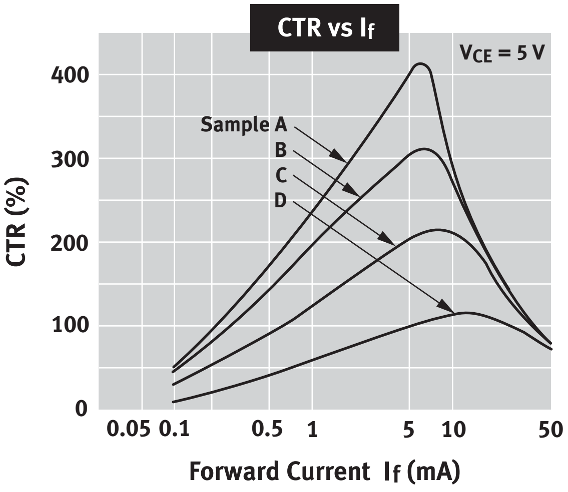
PSPICE is a circuit simulation program that's used to provide a reasonably detailed analysis of circuits containing active components such as bipolar transistors, field effect transistors, diodes, and op-amps. PSPICE can also help characterize lumped components like resistors, capacitors and inductors.

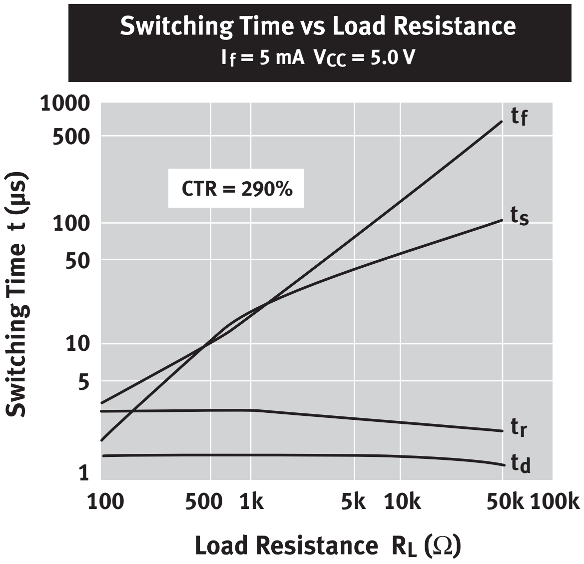
PSPICE programs are comfortable with measurement parameters like *Voltage* and *Current*. However, when it comes to modeling optoelectronic components the PSPICE program does not possess the capability to evaluate or simulate components with outputs measured in radiometric or photometric units like Watts (w) or Lumens (lm), or other variables like optical intensity, radiant power, irradiance with unit measurements in mW/sr, mW/m^2, lumens.

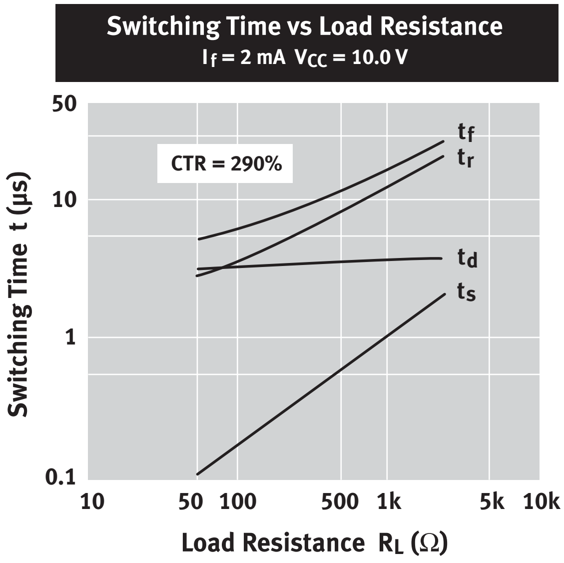
This application note provides a guideline to model phototransistor optocouplers with first order approximation using PSPICE models.

An Optocoupler Model

Typically, an optocoupler is an optically-coupled isolator that uses a GaAs LED as a light source and a bipolar NPN phototransistor as a receiver. In this note, the optocoupler will be modeled by a current-controlled current source. The forward current *If* through the LED emitter will act as current control and current source acts an output of the phototransistor. The output of the phototransistor will be a product of I_f and Current Transfer Ratio or *CTR*. The internal capacitance *Cint* of the optocoupler output will also be added across the output terminals of the current-controlled current source for transient analysis, the internal capacitance, Cint, is calculated based on the formula Tr = 2.2 x Cint x R_L where t_r and R_L are the rise time and load resistor provided in the data sheet, respectively. Please note that the CTR, t_r or the internal capacitance of the optocoupler will vary depending on the forward current I_f through the LED, power supply V_{CC}, and load resistance R_L on the detector side. As a result, any changes to the I_f, V_{CC} or R_L will lead to a change in CTR, t_r and capacitance Cint. To the right are some graphs from the PS2501 data sheet for reference.







PS2501-1 Electrical Characteristics *($T_A = 25°C$)*

	PARAMETER	SYMBOL	CONDITION	MIN	TYP	MAX	UNIT
DIODE	Forward Voltage	V_F	$I_F = 10$ mA		1.17	1.4	V
	Reverse Current	I_R	$V_R = 5$ V			5	µA
	Terminal Capacitance	C_t	V = 0 V, f = 1.0 MHz		50		pF
TRANSISTOR	Collector to Emitter Dark Current	I_{CEO}	$V_{CE} = 80$ V, $I_F = 0$ mA			100	nA
COUPLED	Current Transfer Ratio (I_C/I_F) Note 1	CTR	$I_F = 5$ mA, $V_{CE} = 5$ V	80	300	600	%
	Collector Saturation Voltage	$V_{CE(sat)}$	$I_F = 10$ mA, $I_C = 2$ mA			0.3	V
	Isolation Resistance	$R_{I\text{-}O}$	$V_{I\text{-}O} = 1.0$ kV$_{DC}$	10^{11}			Ω
	Isolation Capacitance	$C_{I\text{-}O}$	V = 0 V, f = 1.0 MHz		0.5		pF
	Rise Time See Test Circuit Fall Time See Test Circuit	t_r t_f	$V_{CC} = 10$ V, $I_C = 2$ mA, $R_L = 100$ Ω		3 5		µs

NOTE 1. *PS2501-1 CTR Rank:*

K	300 to 600 (%)
L	200 to 400 (%)
M	80 to 240 (%)
D	100 to 300 (%)
H	80 to 160 (%)
W	130 to 260 (%)
Q	100 to 200 (%)

Modeling the PS2501-1 optocoupler for DC and transient analysis

The following is an example of a modeling of the PS2501 optocoupler with load resistance RL, in emitter follower configuration.

From the *Electrical Characteristics* in the table above, the CTR can vary from 80% to 600% at $I_f = 5$ mA and $V_{CC} = 5.0$ V.

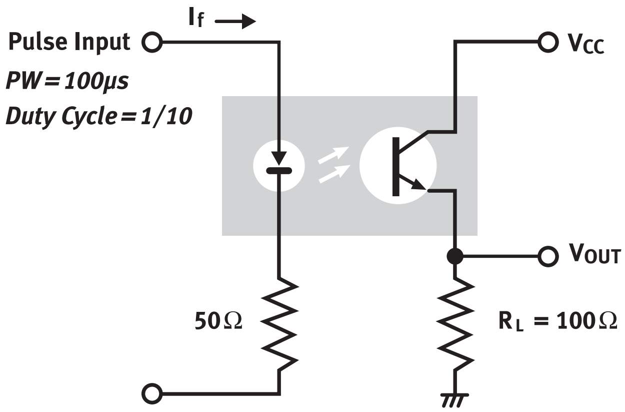


Figure 1. Test circuit for determining Switching Time

From this data, let's set the CTR = 300% at $I_f = 1$ mA, and Cint = 3 µs /2.2 x 100Ω = 14nF, $V_{CC} = 10$V, and model the PS2501-1 using the emitter follower configuration with $R_L = 100Ω$.

DC Analysis

The PSPICE model and Netlist for $I_f = 1$ mA, $I_C = 3$ mA and $R_L = 100Ω$ are shown in *Figure 2* below and on the next page.

Rise time t_r is 3µs, based on V_{CC} =10V, I_C = 3mA, and R_L =100Ω.

The test circuit is shown in *Figure 1*.

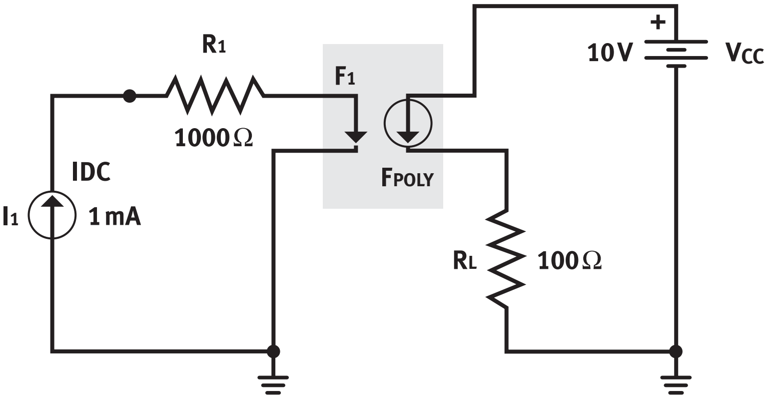


Figure 2. DC Analysis — Schematics Netlist

```
R_R1      $N_0002 $N_0001  1000
I_I1      0 $N_0002 DC 1mA
F_F1      $N_0003 $N_0004 POLY(1) VF_F1 3
VF_F1     $N_0001 0 DC 0V
R_RL      0 $N_0004  100
V_Vcc     $N_0003 0 10V
```

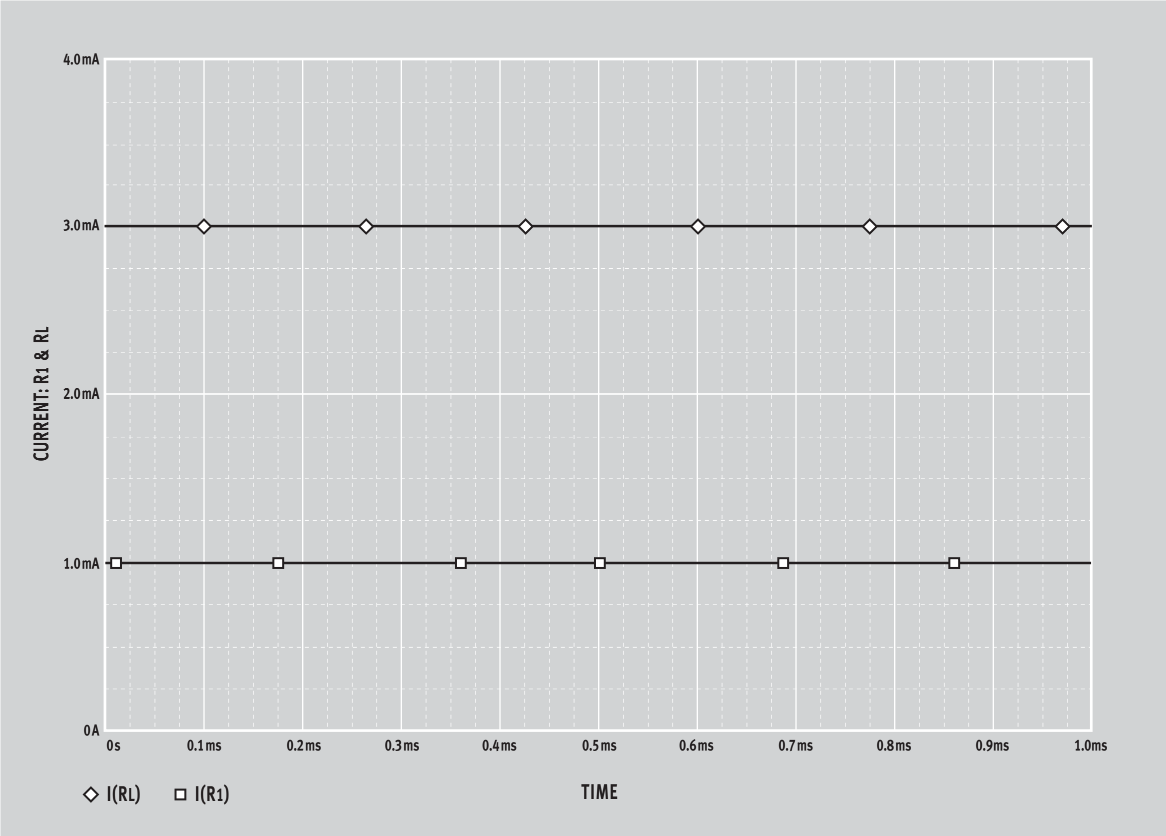


Figure 2. PSPICE model for DC Analysis; current across R1 and RL.

Transient Analysis

The pulse input with pulse width = 100 µs, duty cycle = 50% and peak current of the 1mA will be used. Its Netlist is shown below and PSPICE model in *Figure 3*.

Input Current $I(R_1)$ and Output Current $I(R_L)$ are shown in *Figures 4* and *5*.

Transient Analysis — Schematics Netlist

```
R_R1     $N_0002 $N_0001  1000
F_F1     $N_0003 $N_0004 POLY(1) VF_F1 3
VF_F1    $N_0001 0 DC 0V
V_V6     $N_0002 0
+PULSE 0 1 0 5ns 5ns 1ms 10ms
V_Vcc    $N_0003 0 10V
C_CINT   $N_0004 $N_0003  14nF
R_RL     0 $N_0004  100
```

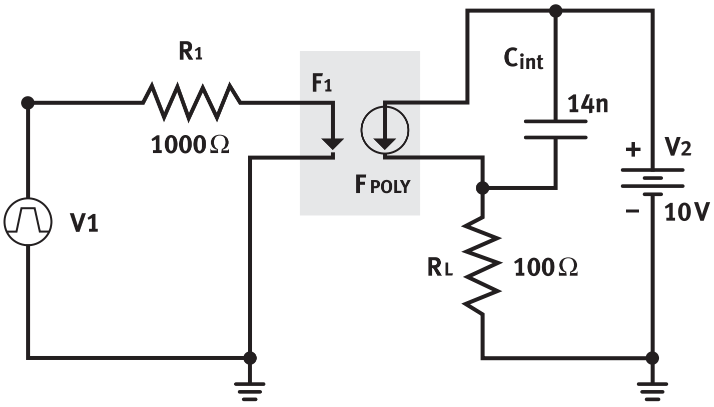


Figure 3. PSPICE model of PS2501-1 for transient analysis.

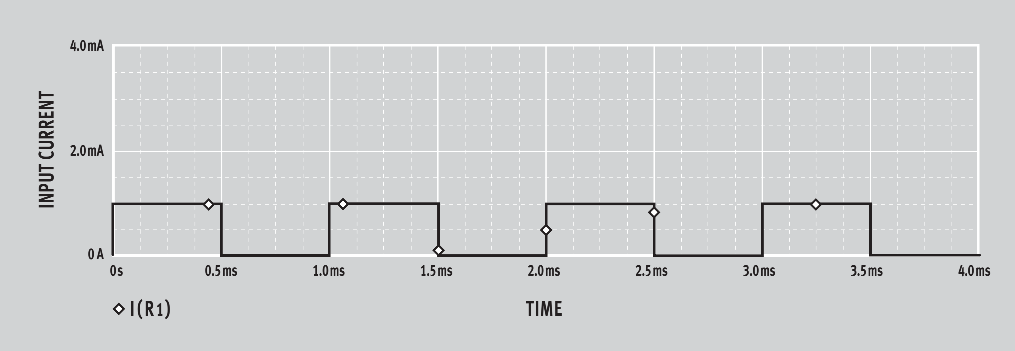


Figure 4. Input Current I(R1)

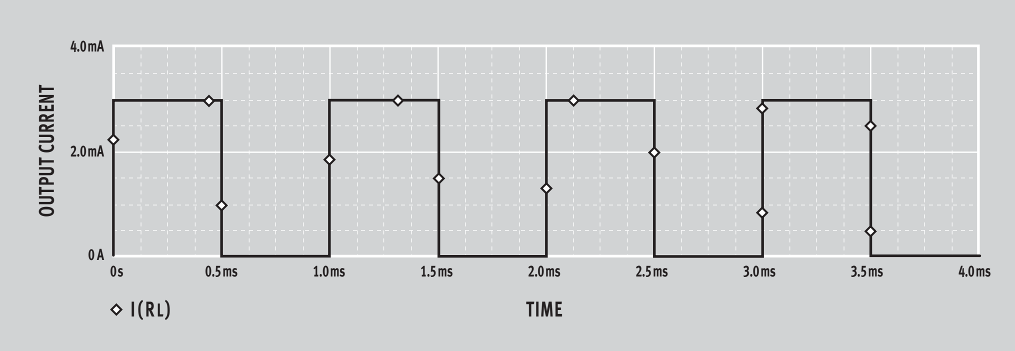


Figure 5. Output Current I(RL)

Comments

To study the dynamic behavior of the model, one must manually change the gain setting of the current-controlled current source based on the CTR, If and V_{CC} data shown on the data sheet. The capacitance Cint has to be recalculated from the equation $t_r = 2.2 \times C \times R$ based on different switching times for different load resistance, If and V_{CC} shown on the data sheet.

The load resistance should be carefully selected for the study and application since PSPICE programs have limitations that may provide a voltage across the load resistance that exceeds the power supply V_{CC} which does not happen in real life. For example, if R_L is chosen to be 15K, the PSPICE program would provide you a $V(R_L)$ of 30V given $V_{CC} = 10V$!!!!

The CTR or gain may become irrelevant if the load resistance becomes too big. For instance, if R_L is chosen to be 20K in the above example, the $I_C \times R_L \geq V_{CC}$, it means that the output of the optocoupler will act as a switch or operate between the saturation and cutoff regions, and CTR is no longer accounted for.

Be cautious about the polarities of the elements as well when reviewing the data or graphs, due to the limitations of the PSPICE program.

For optocouplers with AC input, the same model can be used. However, the DC input or forward current through the LED is applied with the frequency equal to two times the frequency of the AC signal, and the optocoupler will produce the same output as the AC signal.

Conclusion

PSPICE modeling can be a helpful tool for simulating optocouplers in circuits that incorporate these devices. However, care must be taken to ensure that the results are valid as outlined above.

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