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/m², 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 $I_f$ 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 $C_{int}$ of the optocoupler output will also be added across the output terminals of the current-controlled current source for transient analysis, the internal capacitance, $C_{int}$, is calculated based on the formula $Tr = 2.2 \times C_{int} \times R_L$ where $I_f$ and $R_L$ are the rise time and load resistor provided in the data sheet, respectively. Please note that the $CTR$, $tr$ 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 $CTR$, $tr$ and capacitance $C_{int}$. To the right are some graphs from the PS2501 data sheet for reference.
PS2501-1 Electrical Characteristics \((TA = 25°C)\)

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>SYMBOL</th>
<th>CONDITION</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DIODE</strong></td>
<td>Forward Voltage</td>
<td>(V_F)</td>
<td>(I_F = 10\ mA)</td>
<td>1.17</td>
<td>1.4</td>
<td>V</td>
</tr>
<tr>
<td>Reverse Current</td>
<td>(I_R)</td>
<td>(V_R = 5\ V)</td>
<td>5</td>
<td>(\mu A)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Terminal Capacitance</td>
<td>(C_t)</td>
<td>(V = 0\ V, f = 1.0\ MHz)</td>
<td>50</td>
<td>pF</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>TRANSISTOR</strong></td>
<td>Collector to Emitter Dark Current</td>
<td>(I_{CEO})</td>
<td>(V_{CE} = 80\ V, I_F = 0\ mA)</td>
<td>100</td>
<td>nA</td>
<td></td>
</tr>
<tr>
<td><strong>COUPLED</strong></td>
<td>Current Transfer Ratio ((I_C/I_F)_{DC})</td>
<td>CTR</td>
<td>(I_F = 5\ mA, V_{CE} = 5\ V)</td>
<td>80</td>
<td>300</td>
<td>600</td>
</tr>
<tr>
<td>Collector Saturation Voltage</td>
<td>(V_{C(SAT)})</td>
<td>(I_F = 10\ mA, I_C = 2\ mA)</td>
<td>0.3</td>
<td>V</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Isolation Resistance</td>
<td>(R_{I-O})</td>
<td>(V_{I-O} = 1.0\ kV)</td>
<td>(10^{11})</td>
<td>(\Omega)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Isolation Capacitance</td>
<td>(C_{I-O})</td>
<td>(V = 0\ V, f = 1.0\ MHz)</td>
<td>0.5</td>
<td>pF</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rise Time</td>
<td>(t_r)</td>
<td>(V_{CC} = 10\ V, I_C = 2\ mA, R_L = 100\ \Omega)</td>
<td>3</td>
<td>(\mu s)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fall Time</td>
<td>(t_f)</td>
<td>(V_{OUT} = 10\ V, I_C = 2\ mA, R_L = 100\ \Omega)</td>
<td>5</td>
<td>(\mu s)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**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 (%)

From this data, let’s set the CTR = 300% at \(I_F = 1\ mA\), and \(C_{int} = 3\ \mu s / 2.2 \times 100\ \Omega = 14\ nF\), \(V_{CC} = 10\ V\), and model the PS2501-1 using the emitter follower configuration with \(R_L = 100\ \Omega\).

**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 \(R_L\), 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 \(V_{CC} = 5.0\ V\).
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 2.** PSPICE model for DC Analysis; current across R1 and RL.

**Figure 3.** PSPICE model of PS2501-1 for transient analysis.
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, \( I_r \) and \( V_{CC} \) data shown on the data sheet. The capacitance \( C_{int} \) has to be recalculated from the equation \( t_r = 2.2 \times C \times R \) based on different switching times for different load resistance, \( I_r \) 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, \( I_C \times R_L \geq V_{CC} \), 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.