

# APPLICATION NOTE

## VCSEL SPICE Model

### INTRODUCTION

This application note describes a quasi-dc model of a Vertical Cavity Surface Emitting Laser (VCSEL) for use in a circuit analysis tool such as SPICE. The model contains the electrical and optical characteristics of the VCSEL. The designer can call this model as a subcircuit to an existing design, and determine the optical output as a function of the VCSEL device parameters and the ambient temperature. Typical low frequency applications of a VCSEL include encoders, reflective/transmissive sensing, and scatterometry. For a more complete description of several applications, and the VCSEL itself, see the application note titled VCSELs: An Enabling Technology. This note is organized into two major sections. The first describes the model used in SPICE, and the second gives a design example using the model to predict power variation over temperature.

The electrical and optical properties of VCSELs have been described previously in the application note Modulating VCSELs. The reader is referred to that paper for physical descriptions of the VCSEL threshold current, slope efficiency, series resistance, and emitted power.

As with any laser system, there are classes of safety depending on the emitted optical power and the laser wavelength. There are several standards, with different test methods and requirements, but there is always a maximum allowable average power for each classification. For purposes of this application note, we will describe mostly class IIIb lasers, and we do not (and cannot) provide specific guidance for achieving any particular eye safety classification.

The VCSEL behavior defined here is based on testing and analysis, but it must be considered typical, not assured. Some data is shown here for instruction and may not be representative of VCSELs available for sale; refer to data sheets for actual limits. Finally, while described behaviors may fit many VCSELs, they are specifically applicable to ~850-nm, protonimplanted devices.

Some simplifying assumptions are built into the model, and it should be used with some caution. In particular, when extrapolating results over large temperature ranges.

## THE SPICE MODEL

The model described here is intended only for low frequency, quasi-dc applications. The model does not include temperature effects that can lead to changes in the VCSEL output over time. The thermal relaxation time constant for the VCSEL and submount is on the order of 10μs, and, depending on current, application and assembly, may lead to slight output power variations during the first millisecond of operation. The optical rise and fall time of the VCSEL is much less than 10ns, and this model is appropriate for signals having time bandwidth less than 200MHz. Typical packaging used for VCSELS, including TO type headers, surface mount products, and most leadframes have intrinsic bandwidth greater than one gigahertz. For a detailed description of the VCSEL and package high frequency characteristics, the reader is referred to the application note titled Modulating VCSELS.

Figure 1 is a schematic of the circuit used to describe the low frequency characteristics of VCSELS. There are two input nodes, Anode and Cathode, and two output nodes, OP and ON. The low frequency electrical properties of the VCSEL are modeled as a temperature dependent resistor in series with a temperature dependent voltage source. The optical output of the VCSEL is modeled as a current dependent current source. The light output is defined as the current flowing from ON to OP (1mA=1mW). The VCSEL threshold current and slope efficiency are included in the model through the transfer function of the current dependent current source.

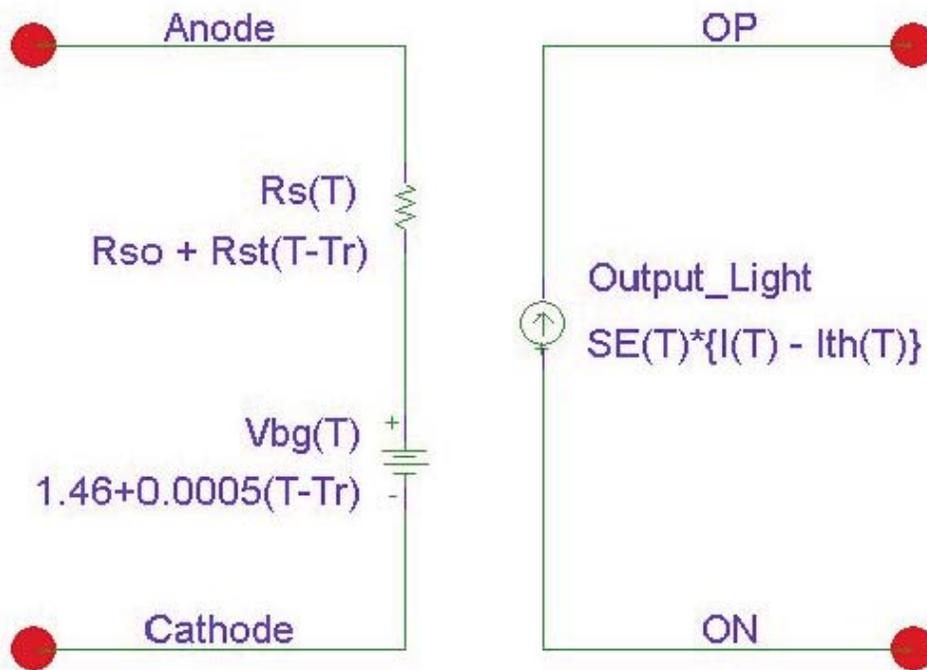


Figure 1. Schematic of the circuit used to describe the electrical properties of a VCSEL

The adjustable parameters in the model are the series resistance, threshold current and slope efficiency. The bandgap voltage variation is hard coded into the model. The equations that govern the electrical and optical properties of the VCSEL are given below.

$$R_s(T) = R_{SO} + R_{ST}(T - T_r)$$

$$V_{BG}(T) = 1.46 + 0.0005(T - T_r)$$

$$I_{TH}(T) = I_0 \left[ 1 + 1.1 \times 10^4 (T - T_0)^2 \right]$$

$$SE(T) = SE_O + SE_T(T - T_r)$$

In the above equations the series resistance (RS) and slope efficiency (SE) are assumed to be linear; RSO is the room temperature series resistance, RST is the temperature coefficient of S, SE0 is the room temperature slope efficiency, and SET is the temperature coefficient of SE. The threshold current is parabolic with temperature, reaching a minimum value of I0 at the temperature T0. For purposes of simulation, the minimum, typical, and maximum values of each of the six adjustable parameters are summarized in table one. Refer to data sheets for actual limits.

Spice Parameter	MIN	TYP	MAX
$R_{SO}$ ( $\Omega$ )	20	30	40
$R_{ST}$ (ppm/ $^{\circ}$ C)	-1000	-2500	-5000
$I_0$ (mA)	2.5	3	5
$T_0$ ( $^{\circ}$ C)	-30	40	70
$SE_0$ (mW/mA)	0.1	0.25	0.4
$SE_T$ (ppm/ $^{\circ}$ C)	-2000	-6000	-10000

Table 1. Values used in SPICE simulations

## SUB-CIRCUIT LISTING

In order to model temperature effectively in SPICE, we used the internal variable TEMP. In SPICE, passive components do not have temperature models, therefore to get a temperature dependent resistance, it is necessary to model a resistor as a

voltage controlled current source. An additional high value resistor is placed in parallel with the modeled resistor in order to prevent a shunt current. The actual subcircuit used to model the VCSEL is listed below.

```

* A is the anode lead; K is the cathode lead.
* Current from ON to OP is representative of light
*
.SUBCKT VCSEL_DC A K OP ON PARAMS:
+ SE=0.22
+ SET=-6500u
+ RS0=20
+ RST=-2700u
+ T0=45
+ I0=2mA
*
G_RS A A1 VALUE {V(A,A1)/(RS0*(1+RST*(TEMP-25)))}
*
ED A2 K VALUE = {1.46-0.5mV*(TEMP-25)}
*
VD A1 A2 DC 0
*
R1 A A1 10MEG
*
GLIGHT ON OP VALUE = {IF(I(VD) < (I0*(1+0.11m*(TEMP-T0)**2)),0,
+ ((SE*(1+SET*(TEMP-25)))*(I(VD)-(I0*(1+0.11m*(TEMP-T0)**2))))}
*
.ENDS

```

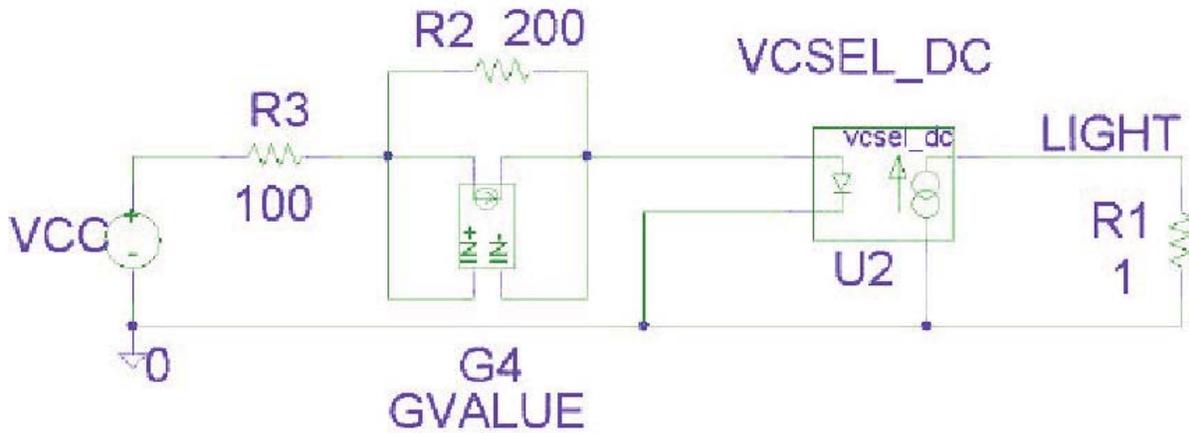


Figure 2. Schematic of circuit used to flatten the power variation over temperature

## DESIGN EXAMPLE

In this section, we describe a simple design case where a negative temperature coefficient (NTC) resistor is used to flatten the power over temperature for a VCSEL. We will look at the nominal cases, as well as a few of the corner cases. NTC resistors do not have linear temperature coefficients, and a series parallel combination of resistors will greatly reduce the non-linearity. The circuit we chose is shown in figure 2. The circuit has a single 5 volt power supply, two resistors, R2 and R3 used to flatten the temperature coefficient, and the NTC resistor. The subcircuit is included as the VCSEL\_DC model.

The parameter space simulated is summarized in table 1. (NOTE: Values given are for reference only, refer to the data sheets for the actual limits) Figure 3a is a plot of the output power variation as a function of temperature without and with the NTC resistor, respectively, for the worst cases of increasing and decreasing power described in Table 1. The output power variation is dramatically decreased with the addition of the NTC resistor. In this case, we used a NTC resistor with  $R_0=1000\ \Omega$ , and  $\beta=4100$ . This is representative of a NTC resistor TBPS1x102x410H5Q from Taiyoyuden products.

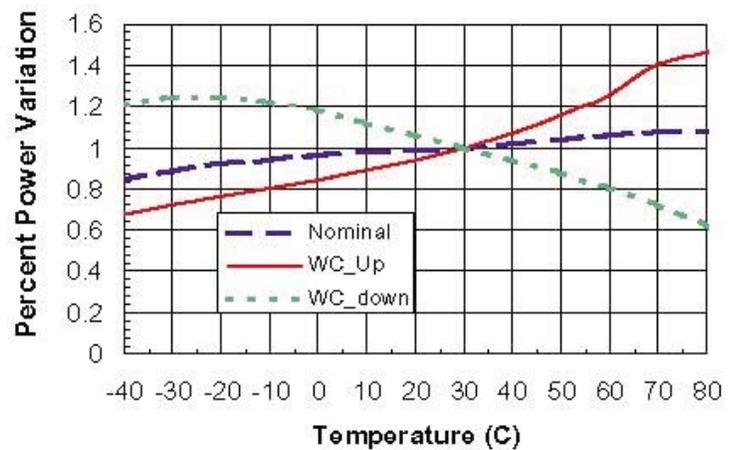
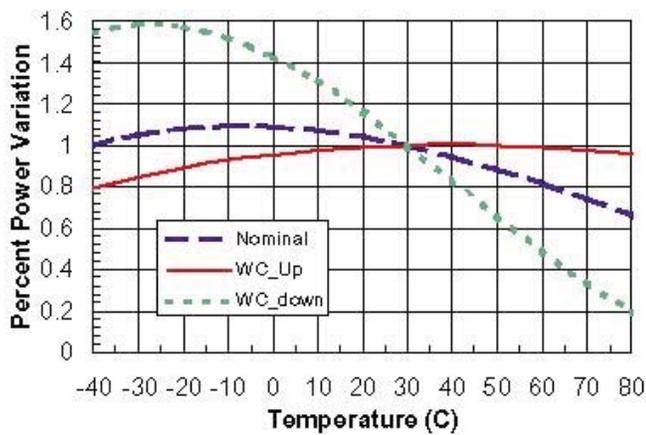


Figure 3. Worst case power variation without thermistor (left) and with thermistor (right)

## ADVANCED OPTICAL COMPONENTS

Finisar's ADVANCED OPTICAL COMPONENTS division was formed through strategic acquisition of key optical component suppliers. The company has led the industry in high volume Vertical Cavity Surface Emitting Laser (VCSEL) and associated detector technology since 1996. VCSELS have become the primary laser source for optical data communication, and are rapidly expanding into a wide variety of sensor applications. VCSELS' superior reliability, low drive current, high coupled power, narrow and circularly symmetric beam and versatile packaging options (including arrays) are enabling solutions not possible with other optical technologies. ADVANCED OPTICAL COMPONENTS is also a key supplier of Fabrey-Perot (FP) and Distributed Feedback (DFB) Lasers, and Optical Isolators (OI) for use in single mode fiber data and telecommunications networks

## LOCATION

- Allen, TX - Business unit headquarters, VCSEL wafer growth, wafer fabrication and TO package assembly.
- Fremont, CA – Wafer growth and fabrication of 1310 to 1550nm FP and DFB lasers.
- Shanghai, PRC – Optical passives assembly, including optical isolators and splitters.

## SALES AND SERVICE

Finisar's ADVANCED OPTICAL COMPONENTS division serves its customers through a worldwide network of sales offices and distributors. For application assistance, current specifications, pricing or name of the nearest Authorized Distributor, contact a nearby sales office or call the number listed below.

***Finisar***<sup>®</sup>  
Advanced Optical Components Division

**Phone:** 1-866-MY-VCSEL USA (toll free)  
1-972-792-1800 USA (Direct dial)  
44 (0) 174 336 5533 Europe  
886-935-409898 China & Taiwan  
81-90-4437-1130 Japan  
82-11-220-6153 Asia Pacific & Korea

**Fax:** 1-214-509-3709 USA

Email: [support@adopco.com](mailto:support@adopco.com)  
WEB: [www.finisar.com/aoc.php](http://www.finisar.com/aoc.php)

## AOC CAPABILITIES

ADVANCED OPTICAL COMPONENTS' advanced capabilities include:

- 1, 2, 4, 8, and 10Gbps serial VCSEL solutions
- 1, 2, 4, 8, and 10Gbps serial SW DETECTOR solutions
- VCSEL and detector arrays
- 1, 2, 4, 8, and 10Gbps FP and DFB solutions at 1310 and 1550nm
- 1, 2, 4, 8, and 10Gbps serial LW DETECTOR solutions
- Optical Isolators from 1260 to 1600nm range
- Laser packaging in TO46, TO56, and Optical subassemblies with SC, LC, and MU interfaces for communication networks
- VCSELS operating at 670nm, 780nm, 980nm, and 1310nm in development
- Sensor packages include surface mount, various plastics, chip on board, chip scale packages, etc.
- Custom packaging options